CALIFORNIA ENERGY COMMISSION

California Energy Commission

CONSULTANT REPORT

Golden Haven Spa GHS-3 Injection Well Final Report

Prepared for: **California Energy Commission**
Prepared by: **Golden Haven Hot Springs Spa and Resort**

Gavin Newsom, Governor
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California Energy Commission

Primary Authors:

Gene Suemnicht, EGS Consulting, Inc.
Paul Brophy, EGS Consulting, Inc.

on behalf of:
Golden Haven Hot Springs Spa and Resort
1713 Lake Street
Calistoga, CA 94515
(707) 942-8000
http://www.goldenhaven.com/

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Prepared for:

California Energy Commission

Elisabeth de Jong
Commission Agreement Manager

Armand Angulo
Assistant Deputy Director
RENEWABLE ENERGY OFFICE

Natalie Lee
Deputy Director
RENEWABLE ENERGY DIVISION

Drew Bohan
Executive Director

PREFACE

The California Energy Commission's Geothermal Grant and Loan Program is funded by the Geothermal Resources Development Account and provides funding to local jurisdictions and private entities for a variety of geothermal projects.

Golden Haven Spa GHS-3 Injection Well Final Report is the final report for the Geothermal Grant and Loan Program Agreement Number GEO-16-003, conducted by consultants for the Golden Haven Hot Springs Spa and Resort. The information from this project contributes to the Geothermal Grant and Loan Program's overall goals to:

- Promote the use and development of California's vast geothermal energy resources.
- Reduce any adverse impacts caused by geothermal development.
- Help local jurisdictions offset the costs of providing public services necessitated by geothermal development.

For more information about the Geothermal Grant and Loan Program, please visit the Energy Commission's website on the Geothermal Grant and Loan Program webpage (http://www.energy.ca.gov/geothermal/grda.html), or contact the Energy Commission's Renewable Energy Division toll-free in California at 844-454-2906 and outside California at 916-653-0237.

ABSTRACT

Golden Haven Hot Spring Spa and Resort is one of several geothermal spas in Calistoga, California, in the northern Napa Valley. Geothermal fluids with low to moderate temperatures of 60°F to 275°F (15 °C to 135°C) occur in the shallow subsurface over a 5.97-square-mile area around Calistoga and have been used in local spas since the early 1860s. The City of Calistoga has been trying to reduce the existing practice of spas, like Golden Haven, discharging spent geothermal fluids to the municipal sewer system because dissolved geothermal solids exceed the regulatory limits of a sanitary system release into the Napa River.

The Golden Haven Spa project sought to drill and successfully complete Golden Haven Spa #3 (GHS-3) as an injection well capable of disposing geothermal fluids used by the spa with no impact on production from the existing supply wells and adjacent direct-use wells in the Calistoga area. Based on test results, that goal has been accomplished with funding and support from the California Energy Commission. The location, depth, and casing program for GHS-3 were specifically chosen to minimize detrimental interference with the existing production well of the spa and adjacent shallow direct-use wells. The GHS-3 well has been permitted as a geothermal injection well by California Geologic Energy Management Division (CalGEM). Because of GHS-3, instead of being extracted and wasted, outflow from the Golden Haven Spa facilities will be returned to the deeper underlying geothermal system, effectively conserving geothermal fluids while reducing the levels of trace contaminants in discharged wastewater.

Keywords: California Energy Commission, geothermal, Sonoma Volcanics, resource fluid chemistry

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Introduction

Golden Haven Hot Spring Spa and Resort (Golden Haven) is one of several resorts and spas in Calistoga, California at the northern end of the Napa Valley that use geothermal fluids for space heating, swimming pools, and bathing, in some cases since the early 1860s. Geothermal fluids with low to moderate temperatures of 60°F to 275°F (15 °C to 135°C) occur in the shallow subsurface over a 5.79-square-mile area around Calistoga. The majority of wells in the area are completed at depths less than 300 feet. Golden Haven pumps geothermal fluids from a 338-foot-deep well for direct use as a heat source for swimming pool water or for mineral and mud baths. Spas like Golden Haven have historically discharged spent geothermal fluids to the Calistoga municipal sewer system. The municipal sewer plant commonly discharges water to the Napa River at high-flow periods during the winter rainy season or, in the summer months, during dry weather, the discharges are used for agricultural irrigation. The City of Calistoga has been operating under a cease and desist order from the State of California to reduce the practice of allowing spas to discharge geothermal effluent because those fluids contribute dissolved constituents that exceed regulatory limits for the sewer water discharge.

Objectives

The Golden Haven Spa project was funded to drill Golden Haven Spa #3 (GHS-3) as an injection well to return spent geothermal fluids to the underlying geothermal reservoir to eliminate the spa's contribution of dissolved solids to the sanitary sewer system of the City of Calistoga. Successful injection operations would not impact production from the existing supply wells and other adjacent direct-use wells in the Calistoga area.

Conclusions

Golden Haven successfully drilled and completed the GHS-3 injection well at 608 ft. The location, casing program, and completion depth of the well were specifically chosen to minimize potential detrimental interference with the spa's production well or surrounding adjacent shallow direct-use wells. The cased upper portion of the well effectively constrains injection to the deeper geothermal resource. Fluid chemistry and injection pressures are compatible with known reservoir conditions, and the only anticipated change with injection is the progressive heating of the injected fluids with minimal effects on adjacent wells.

Benefits to California

Estimates of the longevity of the Calistoga geothermal reservoir assumed that the shallow alluvium represented the only sequence that could produce geothermal fluids. The assumptions were based on the interpretation that the underlying Sonoma Volcanics units were impermeable and that sufficient volumes of geothermal fluids could only be extracted from shallow alluvium. Deeper wells like GHS-3 establish that permeability exists and that significant volumes of geothermal fluid can be produced from deeper volcanic sequences separated and isolated from shallower alluvial units. Deeper productive wells indicate that there is additional, useable (and hotter) geothermal fluids in the lower Sonoma Volcanics sections, and the extraction or injection would not affect the available fluids being extracted by existing users.

Developed geothermal systems use wells to extract fluids and benefit from injecting those fluids back into the subsurface. In the Calistoga area, many operating spas use relatively shallow (100 ft.) wells to produce low to moderate-temperature geothermal water to the surface. Water is the working fluid in a geothermal system, but the majority of the heat remains in the geothermal reservoir rocks. Returning fluid to the geothermal reservoir sustains the system because the water will regain heat from the reservoir rocks and flow toward a producing well to be used again. Injection also maintains reservoir pressures allowing easier flow to a wellbore and eventually back to the surface. Furthermore, reinjection reduces risk of subsidence and surface deformation. The net effect of injection at Golden Haven Spa is to conserve rather than deplete the geothermal resource by reinjecting the produced fluid into the injection well. In addition, Golden Haven Spa is sending monthly production and injection reports to California Geologic Energy Management Division (CalGEM) and receiving annual inspections from CalGEM.

CHAPTER 1:
Golden Haven Spa Project

The Golden Haven Hot Springs Spa and Resort (Golden Haven Spa) is at 1713 Lake Street in Calistoga (Napa County), California (Figure 1). The Calistoga area is noted for geothermal spas and bathing facilities that have operated since the early 1860s. Golden Haven Spa is one of several businesses in the Calistoga basin that use the geothermal fluids for baths and spa treatments. The economy of Calistoga relies heavily on spa tourism for local employment and revenue.

Figure 1: Golden Haven Hot Springs Spa and Resort

Inset map shows facility location in Calistoga. Location notes existing production wells (GHS-1 and GHS-2) and the completed Golden Haven Spa #3 (GHS-3) injection well.

Source: Google map adapted by EGS Consulting Inc.

Geologic Background

Calistoga is at the northern end of the Napa Valley, one of a series of northwest-trending fault-bounded valleys in the Mayacamas Mountains of the Coast Range The oldest rocks in the area are a chaotic mix of 150 to 66 million-year old (Jurassic – Cretaceous) metamorphosed and deformed marine sandstone, ocean floor basalts and occasional pieces of the mantle known collectively as the Franciscan Complex. These rocks are found throughout the northern

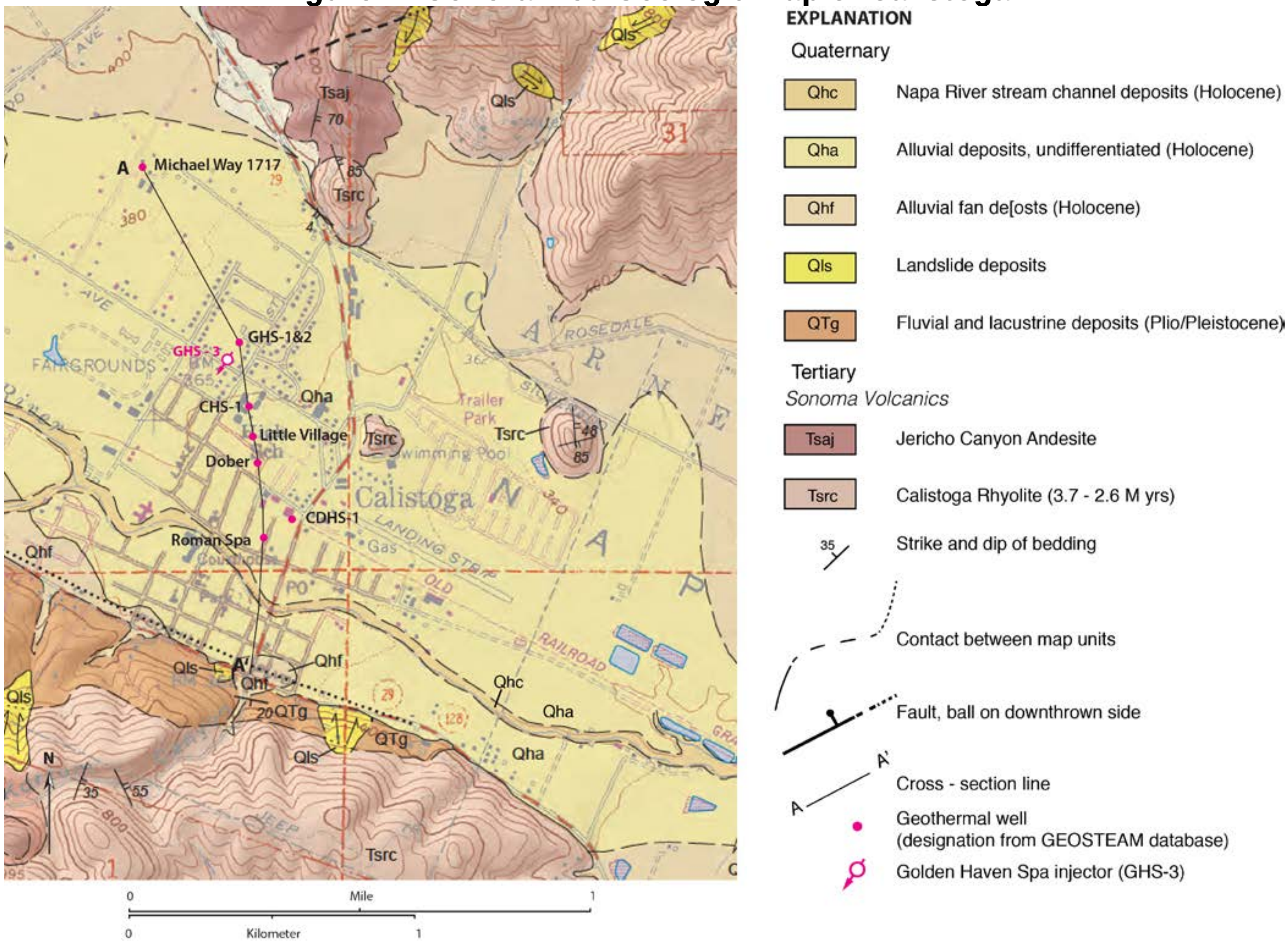
Coast Range and are the basement rocks of the Napa Valley (Figure 2). An overlapping series of volcanic rocks that are less than 4 million years old (Pliocene) comprise units of the Sonoma Volcanics that predominate on the valley margins around Mount St. Helena and fill much of the Napa Valley at depth. A series of young (less than 2 million years; Late Pliocene to Quaternary) lake sediments, stream deposits (alluvium), and slope failure deposits (colluvium) predominate on the flat valley floor interlayered with or unconformably overlying the Sonoma Volcanics.

Geothermal Setting

Low to moderate-temperature geothermal fluids occur in the shallow subsurface over a 5.79-square-mile (mi^2) area around Calistoga. Regional geothermal fluid temperatures range from relatively low 50–60 degrees Fahrenheit (°F) (10-15 degrees Celsius [°C]) waters to the hottest known subsurface temperature of approximately 275°F (135°C) at 1890 ft. The majority of direct-use wells in Calistoga are completed at depths of less than 300 ft. in shallow alluvial units.

Compiled temperature logs (Murray 1986) related the northwest (NW) trend of temperatures in the Calistoga area to a fault-controlled upflow zone along the axis of the valley extending from Indian Springs (previously Patcheteau's Spa) in the central part of Calistoga to the Calistoga Geyser on the NW (Figure 3). Wells in Calistoga reach maximum temperatures in porous permeable alluvium around 200 ft. below the surface. Wells deeper than 200 ft. outside the upflow region generally produce water at cooler temperatures, characteristic of a lateral outflow zone and conductive heat losses to the confining sedimentary layers (Bodvarsson 1982).

Figure 2: Generalized Geologic Map of Calistoga

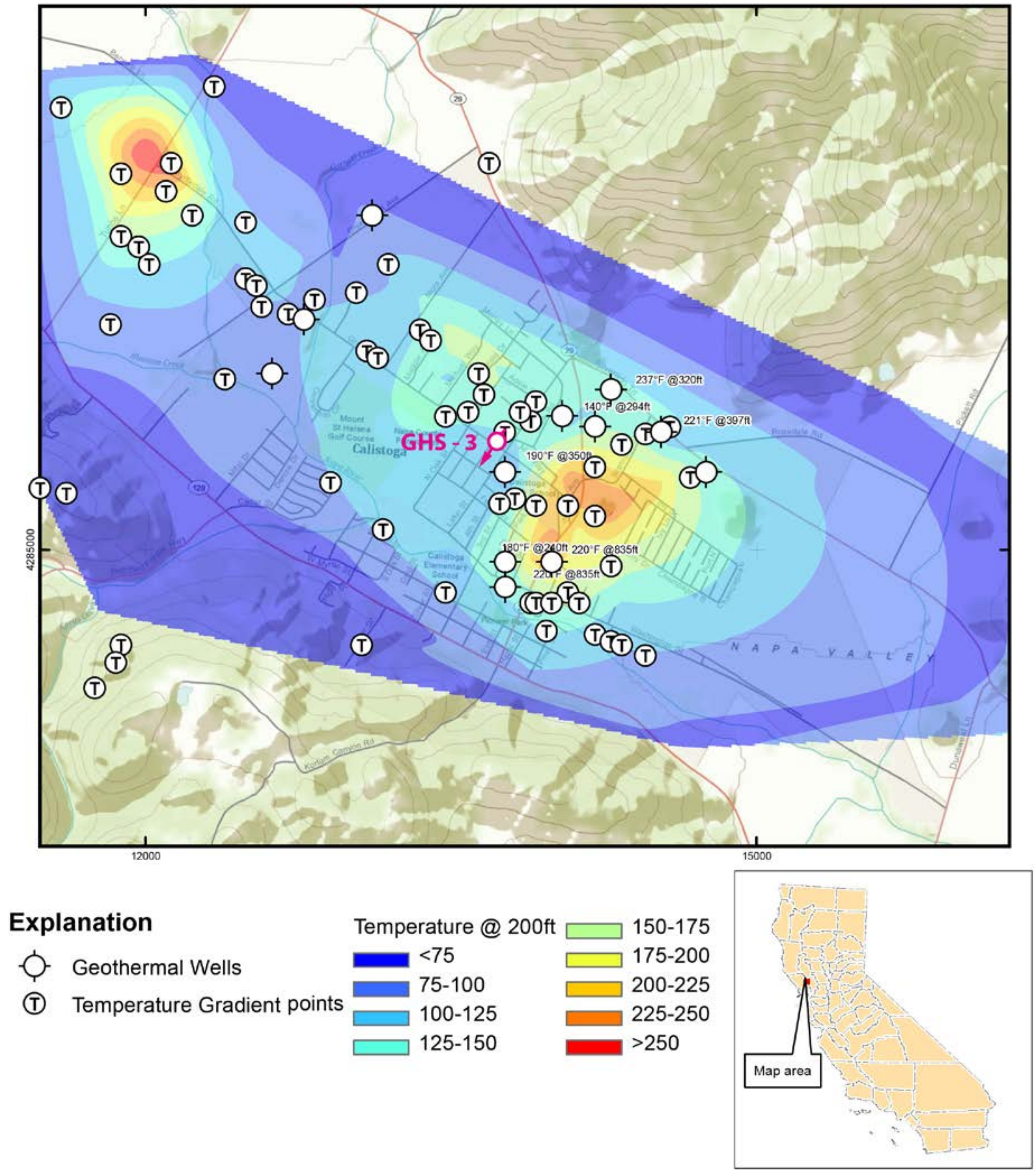


Source: Adapted by EGS Consulting, Inc. from (Delattre 2013)

Line A – A’ is the orientation of the cross-section. Wells for correlation and subsurface geology are from the California Geologic Energy Management Division (CalGEM) [GeoSteam](https://secure.conservation.ca.gov/GeoSteam/) (https://secure.conservation.ca.gov/GeoSteam/), database of geothermal wells in Calistoga.

A north-south cross section through peripheral wells is oriented oblique to the NW-oriented upflow zone that roughly parallels Grant Street on the south side of the Golden Haven Spa property (Figure 2). There are no coherent marker beds in the mixed alluvium, lacustrine sediments, and colluvial fill in the Napa Valley. There are no specific marker beds in the Sonoma Volcanics.

Figure 3: Temperature Distribution at 200 Feet in the Shallow Calistoga Geothermal System



Source: EGS Consulting Inc.

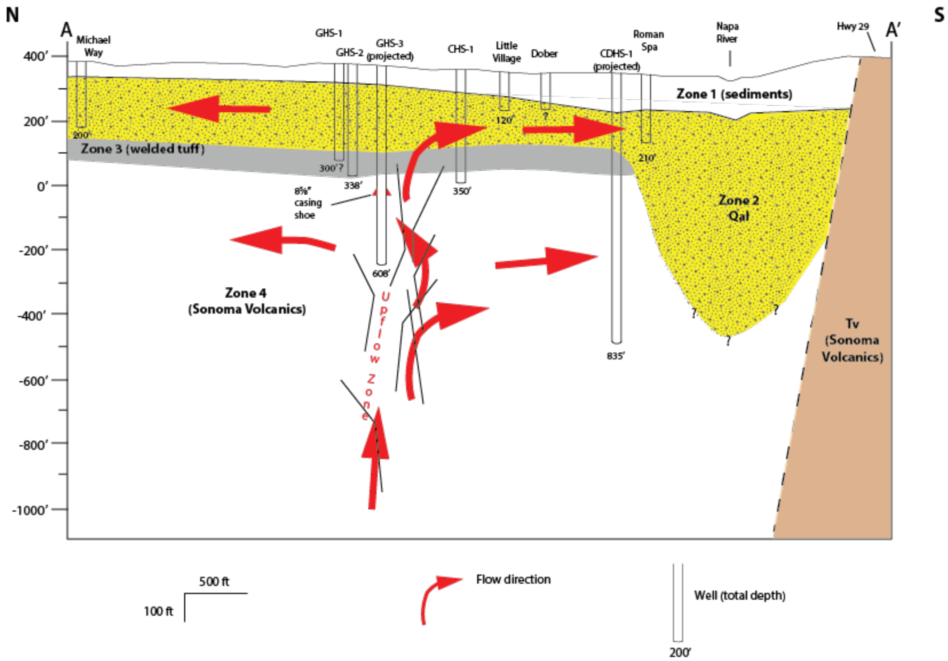
The Calistoga geothermal system has been divided into four stratigraphic zones based on existing shallow well data and exploratory drilling in the 1980s (Youngs 1980) (Murray 1986):

- **Zone 1** – Saturated alluvial sediments extending from the surface to about 120 ft. deep. Low water temperature (higher than 77°F [27°C]) with a few isolated higher-temperature wells.

- **Zone 2** – Main alluvium sequence, average thickness: 640 ft. maximum inferred thickness: 1,400 ft. Interpreted as the primary Calistoga geothermal aquifer.
- **Zone 3** – Impermeable sequence of variably welded ash flow tuffs with little or no interstitial water.
- **Zone 4** – Sonoma Volcanics – welded ash flows, ash fall, tuff, scoria, and intercalated sedimentary deposits.

Lacking deep wells in many zones, it was assumed that the alluvial sequence of Zone 2 was the only producing geothermal section in the upper Napa Valley (Youngs 1980) (Murray 1986). Based on more recent deep drilling of the Palisades-2, CDHS-1, and GHS-3 wells, permeable fractured sections of welded ashflow tuff with intercalated sedimentary units within the Sonoma Volcanics of Zone 4 indicate significant volumes of deeper hotter geothermal fluids.

Figure 4: Schematic Cross-Section A-A' of the Calistoga Geothermal System



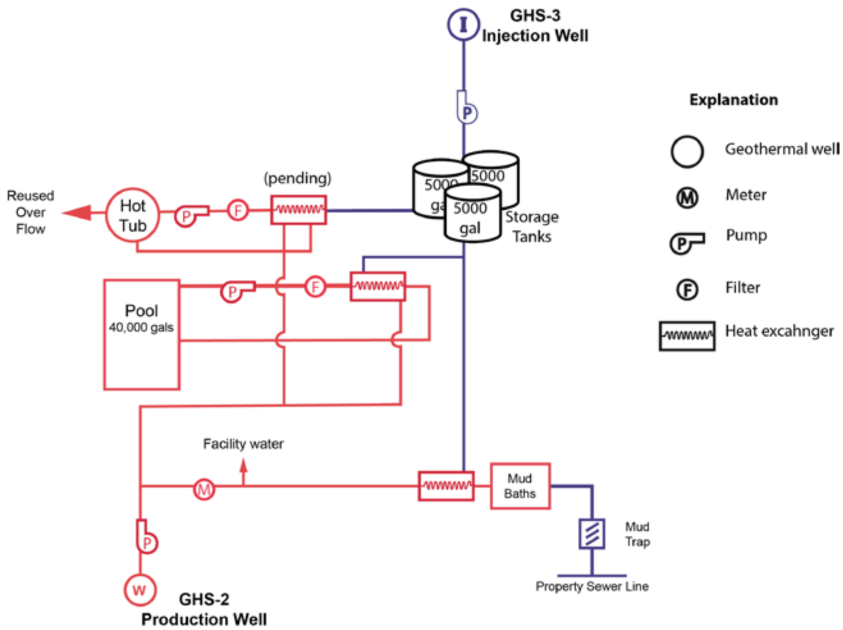
Source: EGS Consulting Inc.

Golden Haven Spa Utilization

Supply wells for the Golden Haven Spa (Figure 1) include Golden Haven Spa #1 (GHS-1), a suspended well drilled with cable tools to a depth of approximately 300 ft. around 1963. The current primary production well, Golden Haven Spa #2 (GHS-2), was drilled in 1978 to 338 ft. and produces fluids at a temperature of 158°F (53°C) with a 659 milligrams -per-liter (mg/L) total dissolved solids (TDS) content as the source water for the spa. The existing production wells are approximately 26 ft. apart within a shed. Attempts in the 1990s to convert the GHS-1 well to an injector were unsuccessful.

Geothermal fluids at Golden Haven Spa are used to heat fresh water (via a heat exchanger) or provide mineral directly for pools, tubs, or other spa treatments such as mud baths that use geothermal fluids directly. Figure 5 presents a schematic flow diagram of the existing spa system and completed Golden Haven Spa #3 (GHS-3) injector. Temperatures are moderated in 5,000-gallon storage tanks. Part of the geothermal fluid is used directly in a mineral pool, while the remaining fluid is sent through a heat exchanger for pool water heating or facility processes. Mixed geothermal water is also used to fill bathtubs for use by spa clients. A small amount is also used for mud baths that are a featured part of the spa treatments.

Figure 5: Flow Schematic of Golden Haven Spa Flow System



Source: EGS Consulting Inc.

Project Purpose

Golden Haven Spa has been disposing of its spent geothermal fluids in the municipal sewer system. The City of Calistoga is operating under a cease and desist order (R22016-0019) from the San Francisco Bay Area Regional Water Quality Control Board relating to the discharge of waters from its water treatment plant at 1100 Dunaweal Lane on the east side of Calistoga. Discharges from the plant into the Napa River occur at high-flow periods during the winter rainy season. In the summer months, during dry weather, treatment plant discharges are used for agricultural irrigation. Discharge constituents above regulatory levels include antimony (Sb) and boron (B) that are directly linked to the shallow geothermal system at Calistoga. Continuing to discharge spent geothermal fluids from Golden Haven Spa contributes to the persistence of these undesirable constituents in the municipal sewer system.

All developed geothermal systems that extract fluids from wells benefit from injection of those fluids back into the subsurface. In very high-temperature geothermal systems, fluids will flow up through wells without pumping. In Calistoga, the relatively moderate temperature geothermal system occurs at comparatively shallow depths requiring fluids to be pumped from wells. Water is the working fluid in a geothermal system but the majority of the heat remains in the geothermal reservoir rocks. Returning fluid to a geothermal reservoir sustains the system because the water will regain heat from the reservoir rocks, flow toward a producing well, and be used again. Injection also maintains reservoir pressures, allowing easier flow to a wellbore and eventually to the surface. The net effect of injection at Golden Haven Spa is to conserve rather than deplete the geothermal resource by discarding the produced fluid.

Project Goal

The Golden Haven Spa project sought to drill and successfully complete GHS-3 as an injection well capable of disposing of the geothermal fluids used by the spa with no impact on production from the existing supply wells or on adjacent direct-use wells in the Calistoga area.

Injection Well Site Selection

The GHS-3 injection well was sited and designed specifically to avoid any detrimental interference with the existing GHS-1 and 2 production wells and other direct-use wells adjacent to the spa property. The GHS-3 surface location was chosen 300 ft. away from the existing production wells at the farthest southern end of the Golden Haven Spa property (Figure 1). The cased interval in the GHS-3 well is 100 ft. deeper than production intervals in the supply wells of the spa and cemented behind casing to assure that those zones would not be affected by injection. At a planned depth of 600 ft., based on the known stratigraphy, the GHS-3 well would be in fractured Sonoma Volcanics (Zone 4) below an impermeable welded tuff (Zone 3)(Figure 4) to avoid detrimental interference with spa supply wells or surrounding peripheral direct use wells in the Calistoga area.

CHAPTER 3:
Golden Haven Spa Contracting Process

EGS Consulting, Inc. (EGS Inc.) issued a request for proposals (RFP) targeting six drilling contractors with specific experience in drilling direct use wells in the Calistoga area.

Contractor selection criteria included:

- Price.
- Contractor familiarity with the area.
- Demonstrated experience in drilling and completing low-temperature geothermal wells.
- Capacity to drill to specified depth(s).
- Capacity to handle appropriate casing and completion material for geothermal wells.
- Past client recommendations.
- Availability.

The RFP specified that the drilling contractor would provide the drilling rig, materials, and labor for drilling and completing the well and field labor to support development and testing once the well was completed. Capuano Engineering Company provided drilling operations management and engineering for the well. EGS Inc. provided geologic logging, well testing, and data evaluations.

Drilling Specifications

The initial planned depth for the GHS-3 injection well was 600 ft. A series of short-term tests at that depth would determine whether the well could accept the output of spent spa fluids or whether the well needed to be drilled deeper. Injection and production wells drilled elsewhere in Calistoga occasionally penetrate less permeable sections within shallow volcaniclastics and require deepening to penetrate permeable zones that either produce enough fluid volumes or accept the required volumes of injected fluids.

Subcontractor Responses

Weeks Drilling and Pump Co. (Weeks Drilling) of Sebastopol (Sonoma County) was the only subcontractor who responded to the RFP and the only contractor to visit the site during a walkthrough.

Qualified contractors who did not respond gave the following reasons for not submitting bids:

- **Availability** — All local and regional drilling, pump, and supply system contractors were heavily involved in mitigating the effects of the 2017 wildfires that destroyed or severely compromised many of the wells and water delivery systems in burned-out sections of Sonoma and Napa Counties. Projected work commitments exceeded their existing availability.
- **Labor supply** — Increased demand for services required additional employees, and few contractors could compete with increased demand for craft labor to rebuild in

affected counties. The lack of qualified workers limited the drilling contractors' ability to expand their operations to accommodate the increased demand.

- **Project scope** – Many new groundwater wells were being drilled to supply existing agricultural needs, replace declining supply after a protracted drought, develop more supply for anticipated dry years, or to supply new agricultural development related to a very lucrative and newly legal cash crop. Groundwater supply wells are comparatively simple projects, and contractors were less motivated to take on more complicated and comparatively risky geothermal direct-use projects.

EGS Inc. awarded the drilling subcontract to Weeks Drilling and Pump because they are an established and experienced drilling contractor with a demonstrated history of performing the work required to drill, complete, and test a low to moderate temperature direct use geothermal well comparable to GHS-3 well in the Calistoga basin. EGS Inc. and Capuano Engineering also had experience with Weeks Drilling from drilling the Palisades wells to supply Auberge Resorts Solage property in the northern part of Calistoga. The casing sizes, drilling program, cementing operations, and testing program for the Palisades wells were all comparable to the work required for GHS-3 well. Weeks demonstrated that they were capable of executing direct-use drilling programs in Calistoga and adapting to changing conditions, including drilling deeper if required.

CHAPTER 4:
GHS-3 Well Drilling

On February 4, 2019, Weeks Drilling moved an Atlas Copco TH60 rotary drilling rig, mud system, and storage tanks to the site and spud the GHS-3 well on the southwest side of the Golden Haven Spa property (Figure 1). Drilling operations were conducted in a residential area. Work was restricted to normal business hours (8 a.m. – 5 p.m.) on weekdays to accommodate the potential concerns of surrounding residents. A timeline of drilling operations is included in Table 1 with gaps for weekends and national holidays.

Table 1: Drilling Summary for the GHS-3 Injection Well

Date	Operations
2/5/19	Drilled 8½-inch pilot hole to 30 ft.
2/6/19	Opening hole to 12¼ inches and 22½ inches in stages
2/7/19	Opening hole to 12¼ inches and 22½ inches in stages
2/8/19	Run and cement 14-inch casing. Witnessed by Napa Co. Wait on cement
2/11//19	Clean out cement
2/12/19	Drilled 7⅞-inch pilot hole to 400 ft. plus 18 ft. of extra hole to assure an adequate cemented section at the bottom of the casing.
2/13/19	Suspended operations due to extreme weather
2/14/19	Opening hole to 12¼ inches in stages
2/15/19	Opened hole to 300 ft.
2/19/19	Opened hole to 380 ft.
2/20/19	Opened hole to 418 ft. (includes rat hole to assure adequate shoe job)
2/21/19	Run wiper trips and condition hole for casing
2/22/19	Run and cement 8⅝-in. casing. Wait on cement.
2/25/19	Install wellhead, valves, and surface mud flowlines
2/26/19	Clean out cement and prep for wellhead test
2/27/19	Test wellhead to 300 pounds per square inch, gauge psig. Witnessed by Colin Lawson, Engineering geologist with CalGEM
2/28/19	Cleaned out cement and began drilling 7⅞-inch hole below 408 ft.
3/1/19	Drilled 7⅞-inch hole to 500 ft.

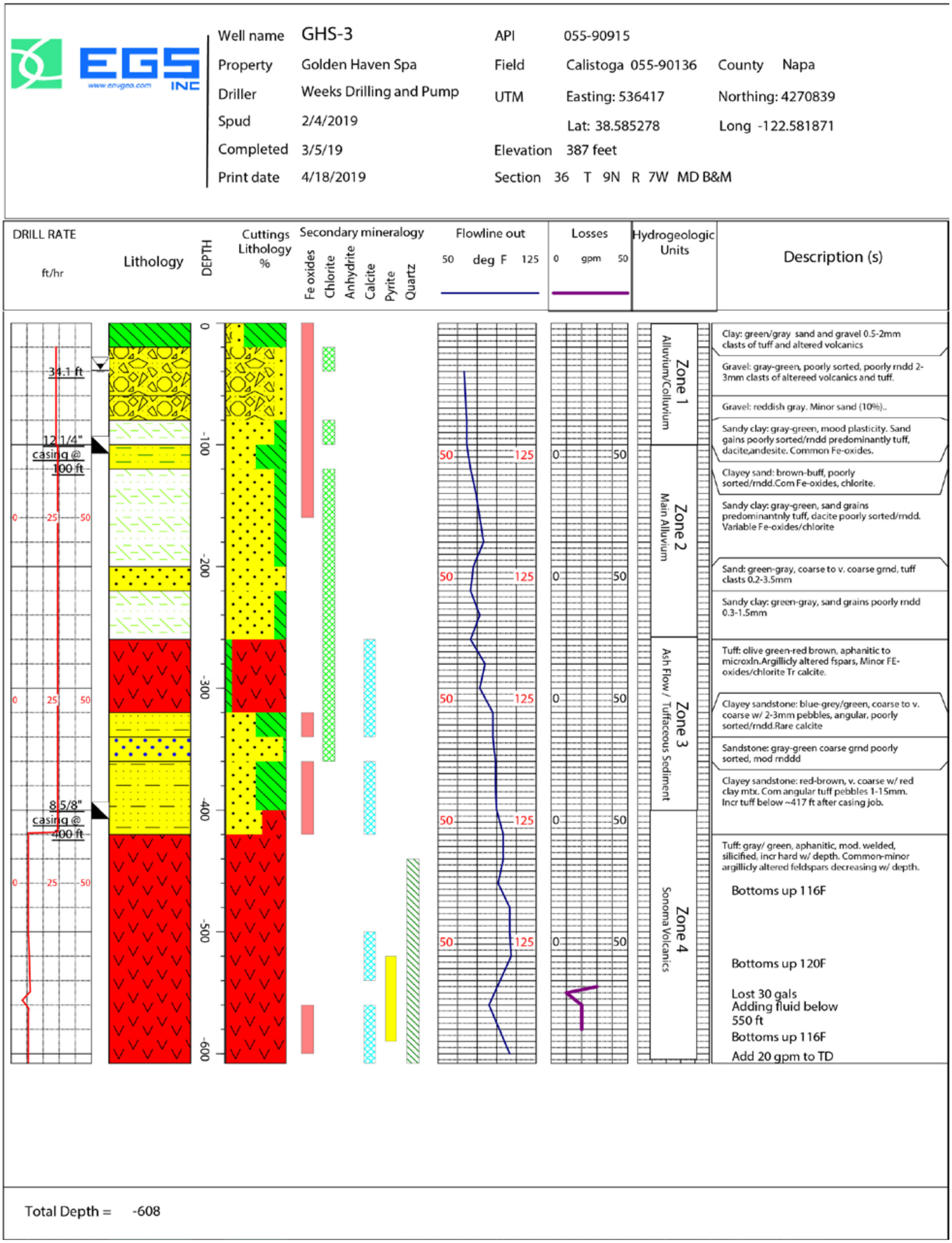
Date	Operations
3/4/19	Drilled 7⅞-inch hole to 580 ft.
3/5/19	Drilled 7⅞-inch hole to 600 ft. plus 8 ft. of rat hole. Circulate to condition hole and rig up to develop
3/6/19	Developed well with 190 – 195-psig-air assist. Well produced an average of 77 gpm at temperatures between 140°F and 170°F
3/7/19	Conducted short-term injection tests of 25, 35 gpm in 2-hour increments and 45 gpm to storage limit without running dry.
3/8/19	Test demonstrated adequate injectivity. Rig up for long-term testing.
3/11/19	Rig up Nor Cal Geophysics and run geophysical logs. Max temperature 231.38°F (110.76°C) at 584.6 ft.
3/12/19	Conducted long-term injection tests of 25, 38 gpm in 4-hour increments. Refill water supply tanks overnight.
3/13/19	Conducted long-term injection tests of 47 gpm for 4 hours. Increase rates to 57 gpm and 70 gpm in 1-hour increments until tanks were nearly dry.
3/14/19	Rig down, clean location, and move off.

Source: EGS Consulting Inc. summary

The GHS-3 injection well for the Golden Haven Spa reached the planned depth of 600 ft. on March 5, 2019 and was drilled an additional 8ft. was drilled to accommodate potential fill during the use of the well. The total depth was 608 ft.

The stratigraphic units penetrated by the GHS-3 well (Figure 6) included 80 ft of alluvium and colluvium (Unit 1;Figure 4) and 180 feet of mixed sand and clay that constitute the main alluvium unit (Unit 2) of the Calistoga geothermal system. The deeper parts of the well below 260 feet drilled into welded tuff and mixed tuffaceous sediments (Unit 3) that separate the shallow alluvial section from the deeper fractured tuff and of the Sonoma Volcanics below 380-400 feet. The sequence of lithologies in the GHS-3 well conforms to the anticipated stratigraphic sequence of the northern Napa Valley around Calistoga (Figure 4). Alluvial units are relatively thin in the Calistoga area and the deeper underlying Sonoma Volcanic rocks in the lower section of the well are variably fractured resulting in the loss of drilling fluids in permeable fractured sections starting at 560 feet (Figure 6).

Figure 6: Geologic Log of GHS-3 Injection Well



Source: EGS Consulting Inc.

CHAPTER 5: Development and Testing

At a total depth of 608 ft., Weeks Drilling rigged up surface flow lines to connect the on-site water storage tanks to pumps on the drilling rig and then to the wellhead to initially store the water produced during development and, eventually, to supply fluid for injection testing.

Well Development

The GHS-3 injection well was developed by pumping air through drill pipe within the cased section of the well. The air reduces hydraulic head of the standing column of fluid within the wellbore. The reduced pressure caued fluid in the well to flow to the surface and induces the flow of clean aquifer water into the well at depth. The flowing aquifer fluid cleans out drilling mud and any residual rock cuttings allowing the well to produce clean representative aquifer water. A total of 221 barrels (9,300 gallons) of water were circulated out of the hole and stored in temporary storage tanks. The produced amount represents 7.5 times the 29.5 barrel (1239 gallon) capacity of the wellbore fluid, more than the 88 barrels (3696 gallons) or 3 wellbore volumes commonly accepted to assure that the well is producing in-situ aquifer water. rather than near-wellbore waters potentially affected by residual drilling fluids. Based on flow rates measured during testing, the well can produce an average of 77 gpm while air lifted or pumped. Maximum temperatures of the produced water varied from 140°F to 178°F (60-81°C), reflecting flow surges induced by airlift or potential contribution from multiple feed zones. The maximum recorded temperatures exceed the 150°F (65°C) of water produced by the existing spa supply wells.

Geochemistry

Water samples were collected at 2,000-gallon increments of production during development of the GHS-3 well. Field parameters of pH, temperature, and electrical conductivity were measured to establish the stability of the fluid chemistry and assure the collection of a representative sample of aquifer water (Table 2). The field geochemical parameters of GHS-3 varied less than 10 percent after production of an initial 2,000 gallons, indicating that the GHS-3 well was producing aquifer water rather than near-wellbore fluid that might be affected by drilling operations. A geochemical sample was collected at the end of well development after producing 204 barrels (8,550 gallons. A sample of Golden Haven Spa effluent water was also collected as a background sample to compare the chemistry of the water that will be injected into the GHS-3 well.

The sampled waters were preserved, delivered to Alpha Analytical, a California-certified analytical laboratory, under standard chain-of-custody procedures, and analyzed for dissolved constituents. Table 3 shows comparative analytical results.

Table 2: Field Geochemical Screening Data for GHS-3 Waters Produced During Development

Cumulative Volume (Barrels)	Wellbore Volumes Produced	Temperature (°F/°C)	pH	Conductivity (Micro Siemens, µS)	TDS (calculated mg/L)
48	1.78	140/60	9.2	1046	523
96	3.56	140/60	9.01	1077	535
155	5.74	140/60	8.93	1064	530
203	7.5	140/60	8.94	1082	542

Source: EGS Consulting Inc.

Geochemical analyses establish how the chemistry of the water that will be injected into GHS-3 compares with the established chemistry of the Calistoga geothermal resource. The chemistry of the Golden Haven Spa water has changed little over time based on the geochemical baseline data from earlier analyses (Table 3) The total dissolved solids (TDS) content of 620 milligrams per liter (mg/L) and the chloride (Cl-) content of 200 mg/L for GHS-3 are comparable to the produced (GHS-2) and expended or cooled effluent waters (GHS-1) from the spa.

Table 3: Comparative Geochemistry of Golden Haven Spa Waters

Constituent	GHS-2 (Murray, 1980)	GHS-2 (ELAP, 2003)	USGS (2007)	GHS-1 Spa Effluent	GHS-3 Well Sample	Units
Sample Date	**3/1/80**	**6/19/03**	**11/13/0**	**3/6/19**	**3/6/19**	
Temperature	45 /113	NM*	65/149	42/107	60/140	°C/°F
Specific Conductance	600	NM*	1000	1082	1016	μS/cm
pH	7	NM*	7.2	7.71	8.94	
Calcium (Ca)	5	NA*	4.3	4.8	8.5	mg/L
Lithium (Li)	1.56	1.4	0.14	NA*	NA*	mg/L
Potassium (K)	8	NA*	7.45	8.1	11	mg/L
Sodium (Na)	198	NA*	168	180	190	mg/L
Silica (SiO2)	55	NA*	164	170	120	mg/L
Antimony (Sb)	NA	0.027	0.0348	0.038	0.55	mg/L
Arsenic (As)	ND	0.0085	0.037	0.08	0.510	mg/L
Barium (Ba)	NA	ND*	NM*	0.017	0.0079	mg/L
Beryllium (Be)	NA	ND*	0.0008	ND*	ND*	mg/L
Cadmium (Cd)	NA	ND*	NA*	ND*	ND*	mg/L
Chromium (Cr)	NA	ND*	NA*	ND*	ND*	mg/L
Cobalt (Co)	NA	NA*	NA*	ND*	ND*	mg/L
Copper (Cu)	NA	NA*	NA*	ND*	ND*	mg/L
Iron (Fe)	0.07	0.2	0.265	0.22	3.7	mg/L
Manganese (Mn)	ND	NA*	0.0401	0.1	0.089	mg/L
Magnesium (Mg)	NA	0.9	0.898	1	ND*	mg/L
Lead (Pb)	NA	ND*	NA	ND*	ND*	mg/L
Molybdenum (Mo)	NA	NA*	0.0039	0.0036	1.2	mg/L
Nickel (Ni)	NA	ND*	NA*	ND*	ND*	mg/L
Selenium (Se)	NA	ND*	NA*	ND*	ND*	mg/L
Silver (Ag)	NA	ND*	NA*	ND*	ND*	mg/L
Thallium (Tl)	NA	ND*	NA*	ND*	0.0009	mg/L
Vanadium (V)	NA	NA*	NA*	ND*	ND*	mg/L
Zinc (Zn)	ND	NA*	NA*	ND*	ND*	mg/L
Boron (B)	9.7	NA*	10.3	11	10	mg/L
Mercury (Hg)	NA*	ND*	NM	ND*	ND*	ug/L
Fluoride (F)	10.5	11	9.8	10	11	mg/L
Chloride (Cl)	202	NA*	197	200	200	mg/L
Sulfate (SO4)	ND	NA*	1.28	1.2	40	mg/L
Bicarbonate (HCO3)	147.9	NM*	NM*	110	61	mg $CaCO_3$
Total Alkalinity	NA*	NA*	118	110	100	mg $CaCO_3$
TDS	659	NA*	667	590	620	mg/L
Total Depth	300	300	300	Surface	608	ft.

Definitions:

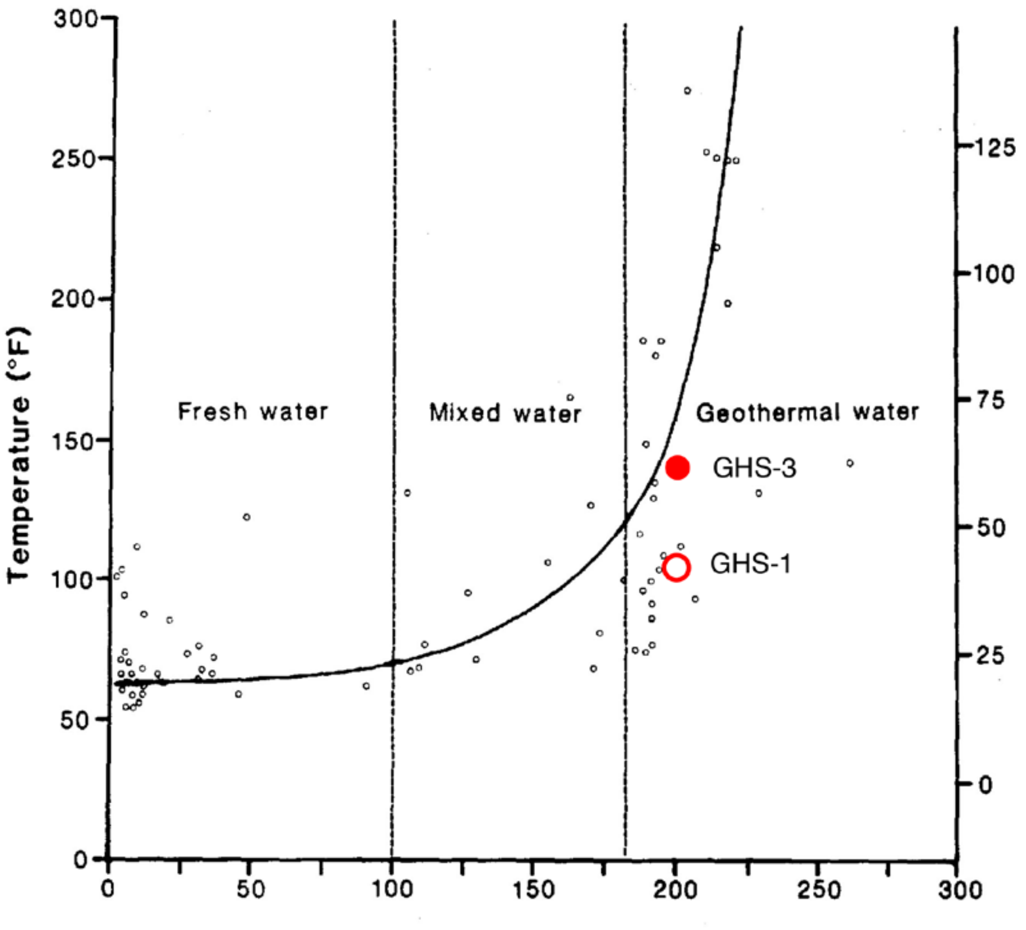
NA – not analyzed

NM – not measured

ND – not detected

The chloride content of 200 mg/L for GHS-3 development waters is within the range of other geothermal waters produced within the Calistoga basin (Figure 6). Production conditions were turbulent during development and, based on variances in production temperatures, the produced GHS-3 fluid could represent a mix of contributions from different permeable fracture zones in the welded tuffs in the lower section of the well.

Figure 7: Temperature vs. Chloride for Springs and Wells in the Calistoga Basin



Source: Adapted by EGS Consulting, Inc. from (Murray 1986)

Short-Term Testing

The GHS-3 well was specifically planned to penetrate the mixed volcaniclastic rocks and flows of the Sonoma Volcanics (Zone 4 in Figure 4) beneath an impermeable welded tuff unit (Zone 3) to avoid detrimental interference with Golden Haven Spa production wells completed in shallow alluvial units (Zones 1 and 2 in Figure 4). A short injection test on the GHS-3 well at the planned depth of 600 ft. demonstrated that the well could accept the volumes of fluid produced by Golden Haven Spa. An initial stable pumping rate of 25 gallons per minute (gpm) was maintained for two hours with the GHS-3 well accepting all the injected fluid at wellhead pressures of 40-50 pounds per square inch (gauge) (psig). The estimated volume of fluid injected at 25 gpm was 71 barrels (3,000 gallons). The pumping rate was increased to 35 gpm and maintained at a stable rate for another two hours. The well continued to accept fluid at wellhead pressures of 60-70 psig and an injection volume of 100 barrels (4,200 gallons). The pumping rate was increased to 45 gpm, within the range of the maximum anticipated output required for the spa, with the well continuing to accept fluid at wellhead pressures of 70-80 psig for approximately 30 minutes for a total volume of 32 barrels (1,320 gallons). Over the short 4.5-hour test period, the injected volume totaled 204 barrels (8550 gallons).

Geophysical Logging

A suite of geophysical logs were run in the GHS-3 wellbore on March 11, 2019 to compile temperature data, evaluate lithologic changes with depth, and corroborate interpreted fracture or permeability zones in the 200 ft of open wellbore penetrated by the well. The logs included the following measurements:

- Temperature
- Natural gamma
- Resistivity
    - Single-point
    - 16-normal
    - 64-normal
- Self-potential (SP)
- Caliper

Logs and accompanying data are on file and available through the CalGEM GeoSteam (https://secure.conservation.ca.gov/GeoSteam/) website.

The maximum log temperature was 231.38°F (110.76°C) at 504.6 ft., confirmed by a backup maximum reading thermometer temperature of 232°F (111°C). Caliper logs (Figure 7) show distinct hole enlargements at 460 and 538 ft., typical of fractured zones affected by repeated continual wear from drilling tools. Resistivity logs show distinct changes in resistivity over the same depth ranges. The zones identified in the logs confirm that fracture permeability occurs in the deeper siliceous tuffs penetrated by the well. The 140-178°F (60-81°C) fluids produced during development likely represent a mix of fluid from either of these permeable fractured portions of the wellbore.

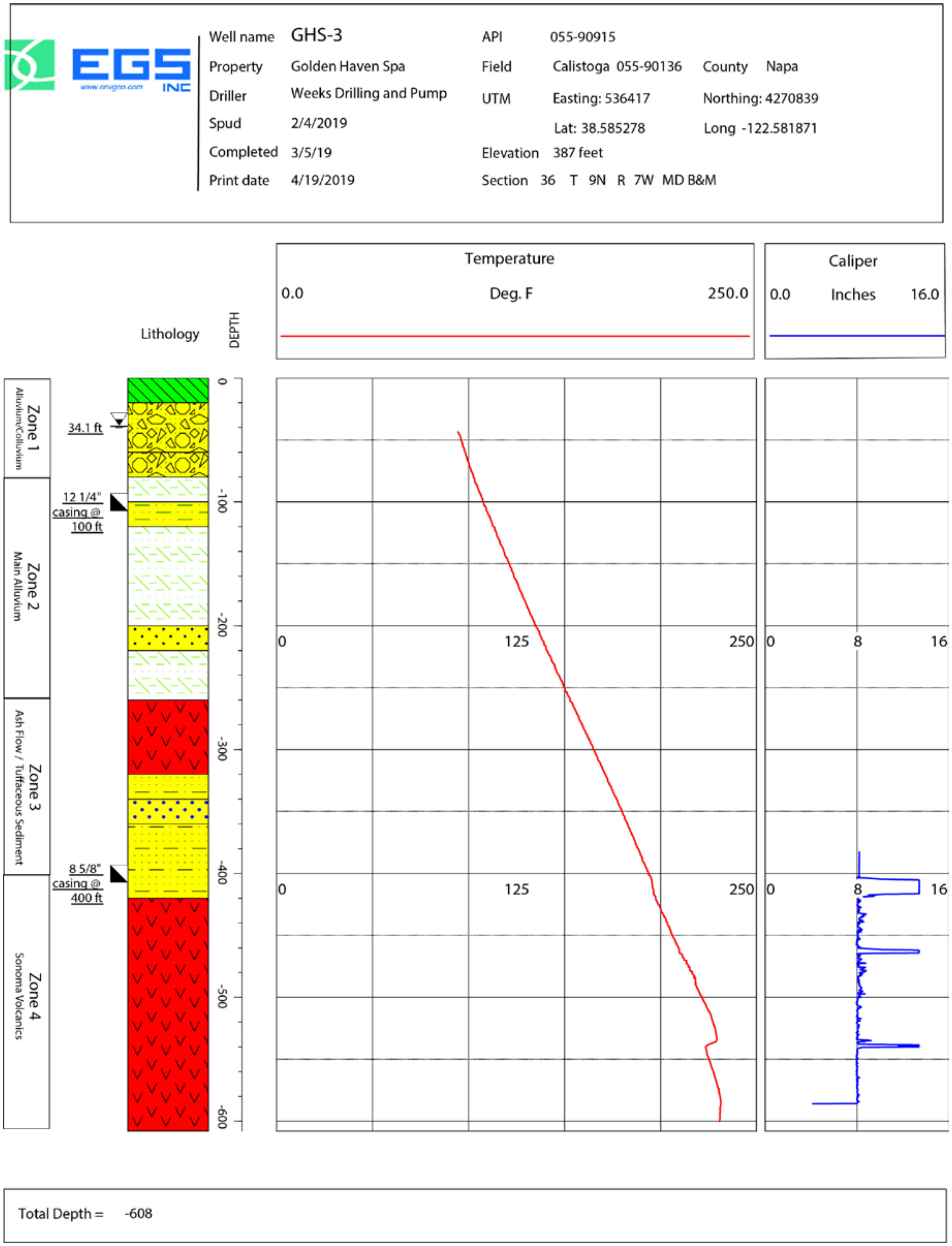
Long-Term Testing

Long-term injection tests of the GHS-3 well were run on March 12 and 13, 2019, after short-term testing established acceptable permeability in the well. Initial plans were for two 8-hour step-rate tests; however, water supplies were limited to the initial water produced from well development (9,330 gallons), and water produced by the Golden Haven Spa could replenish only a limited volume overnight between test periods.

The initial long-term step-rate test pumped stored water at a rate of 20 gpm for 4 hours. At the end of the period, the pump rate was increased to 30 gpm and maintained at a stable rate for another 4 hours. The well accepted fluid at both rates at pressures between 36 and 45 psig, more than the anticipated maximum operating conditions of 17 gpm for the spent geothermal fluid from the Golden Haven Spa. This initial step-rate test injected approximately 13,755 gallons (327.5 barrels) of water over the 8-hour test period. Data logging equipment collected pressure fall-off data at 10-minute intervals through the night.

A second higher-rate step test initially pumped stored water at a stable rate of 47 gpm at 68-76 psig for 4 hours. The pump rate was increased to 57 gpm at 145 psig for 1 hour and increased again to 70 gpm at 180 psig until the water stored on location ran out. An injection rate of 47 gpm assures that GHS-3 can accept more than the maximum operating conditions of 17 gpm of the Golden Haven Spa anticipated for potential future operations. The final step rates of 57 and 70 gpm were intended to stress the receiving formation and establish that enough injection capacity in the range of the average production rate of 77gpm maintained during well development. The second step-rate test injected approximately 19,660 gallons (468.1 barrels.) of water over a 6-hour test period. Data logging equipment collected pressure fall-off data at 10-minute intervals through the night.

Figure 8: Temperature-Depth-Caliper Logs for GHS-3 Well



Lithologic units as described in Figure 6

Source: EGS Consulting Inc.

Reservoir Characterization

Based on injection test data, the following hydrogeologic characteristics were determined:

Static water level:	10.39 m below ground surface (BGS)
Average thickness:	61 m (bottom hole section of GHS-3) (244 feet assumed for unknown base of Sonoma Volcanics in western Calistoga)
Areal extent:	15 km^2
Temperature:	231.3°F (110.76°C) at 153.8m
Pressure:	0.433 psi/ft.
Fracture gradient:	0.75 psi/ft.
Specific Capacity:	0.3342 gpm/psi
	Step-rate test #1
Hydraulic conductivity:	0.0133 ft^2/min
Storativity:	0.003015
Porosity:	0.0262
	Step-rate test #2
Hydraulic conductivity:	0.0123 ft^2/min
Storativity:	0.002423
Porosity:	0.0326

The GHS-3 well has been approved as an injection well by permitting authorities and documentation is included in Appendix A. All the waters in the Calistoga basin including geothermal waters are less than 3,000 mg/L TDS and are therefore classed as “drinking waters of the United States” by the U.S. Environmental Protection Agency (U.S. EPA). The depth to the base of fresh water is unknown in the valley. All the wells within a mandated quarter-mile radius of the Golden Haven Spa are direct-use geothermal wells and are not used for drinking water because of elevated levels of trace constituents such as antimony (Sb) and boron (B). These elements are the same constituents that necessitate returning the spent spa fluids to the underlying geothermal system rather than continuing to discharge the effluent to the sanitary sewer system. An older adjacent well (Fox-2; American Petroleum Institute (API)# 05590053) was originally designated as a water supply well in records from 1969, but there are no other filings with CalGEM, and the status of the well is unknown. Other water supply wells outside quarter-mile radius of the review area include the Calistoga Mineral Water facility northeast of Golden Haven Spa. Calistoga Mineral Water is no longer bottled and sold, and the wells are supposedly idle.

Injection conditions for the GHS-3 well are compatible with known reservoir conditions. Spent fluids will be injected intermittently through the existing 8⅝-inch cemented casing string into the open hole section below the casing shoe at 400 ft. A calculated hydraulic conductivity of 0.0133 – 0,0123 square feet per minute (ft^2/min) for GHS-3 is comparatively low for volcanic rocks; however, step-rate injection tests proved that fractured sections of the deeper wellbore could accept the injection volumes required by current spa operation.

The Golden Haven Spa injection fluid temperatures average 125°F (51.7°C) but may range from 115°F to 140°F (46-60°C), depending on spa operations. The maximum measured static reservoir temperature in the GHS-3 well was 231.3°F (110.7°C) at 584 ft. The only anticipated change with injection is the progressive heating of the injected spa water in the deeper sections of the Calistoga geothermal resource.

CHAPTER 6: Well Completion and Use

Golden Haven Spa successfully drilled and completed GHS-3 as an injection well capable of returning the geothermal fluids used by the spa to the underlying geothermal reservoir. Based on injection test results and function testing the spa effluent piping system connected to GHS-3, there is no detrimental impact on the GHS-2 supply well related to injecting the spa effluent into the GHS-3 wellbore.

Golden Haven Spa System

Geothermal fluid from GHS-2 production well is routed through heat exchangers and eventually into storage tanks that are also used to moderate temperatures within the system for direct mineral water use, as depicted in Figure 5. Current spa operations require approximately 17 gpm but only intermittently depending on spa usage and heating requirements. A float valve in the injection system storage tank activates a pump to send water to GHS-3 when water levels in the tank reach a predetermined level. Spa records indicate that, under normal operating conditions, the total daily injection rate averages 7,200 gallons/day as a Class V geothermal injection well approved by the CalGEM and the U.S. EPA (Appendix A).

Benefits

This California Energy Commission grant funding enabled Golden Haven Spa to finance the drilling and completion of the GHS-3 injection well that would not have been possible without funding assistance. The local community will benefit from this project because outflow from the Golden Haven facilities will not be directed to the wastewater treatment plant, thus reducing the levels of antinomy and boron in wastewater being either discharged to the Napa River or used for local agricultural irrigation. The City of Calistoga passed a resolution supporting this effort, citing this project as an example for other geothermal well operators in Calistoga. Instead of being extracted and wasted, outflow from Golden Haven Spa will be returned to the deeper underlying geothermal system, effectively conserving geothermal fluids while reducing the levels of trace contaminants in discharged wastewater.

Estimates of reservoir longevity made by (Youngs 1980) and (Murray 1986) assumed that the alluvial sequences (Zone 2 in Figure 4) represented the only sequence that could produce geothermal fluids. Their assumption was based on the interpretation that the underlying welded ash of Zone 3 was impermeable and geothermal fluids could only be extracted from the shallower alluvial sequences. Deeper wells such as Palisades-2, CDHS-1, and GHS-3 established that permeability existed and significant production was possible from deeper Zone 3 and Zone 4 volcanic sequences separated and isolated from shallower alluvial units.

Deeper productive wells indicate that there is additional, useable, and hotter geothermal fluids in the lower Sonoma Volcanics sections, and the extraction or injection of should not affect the available fluids being extracted by existing users from Zone 2. Geothermal fluids in deeper volcanic units significantly increases the total size of the geothermal reservoir in the Calistoga area, which suggests there are more available geothermal fluids than were initially estimated by (Murray 1986). Zone 2 alluvial sequences are 260 ft. thick in the GHS-3 well and are cemented behind casing. As a result, injection of geothermal fluids into the very large volume of fractured Zone 4 welded tuffs would not affect the current geothermal production at Golden Haven Spa or in surrounding wells. In addition, Golden Haven Spa is reporting monthly production and injection reports to California Geologic Energy Management Division (CalGEM) and is receiving annual inspections from CalGEM.

REFERENCES

Bodvarsson, G. S., P. A. Benson, and P. Witherspoon. "Theory of the Development of Geothermal Systems Charged by Vertical Faults." *Journal of Geophysical Research*, Vol. 87, n B11, 1982.

Delattre, M. P. and C. J. Gutierrez. "Preliminary Geologic Map of the Calistoga 7.5' Quadrangle, Napa and Sonoma Counties, California: A Digital Database Version 1.0." (California Geologic Survey http://www.conservation.ca.gov/cgs/rghm/rgm/preliminary_geologic_maps.ht) 2013.

Murray, A. *Calistoga Geothermal Resource Assessment.* California Energy Commission, 1986.

Youngs, L., C. Bacon, R. Chapman, C. Higgins, H. Majmunder, and G. Taylor. *Resource Assessment of Low and Moderate Temperature Geothermal Waters in Calistoga, Napa County, California.* California Division of Mines and Geology, 1980, 168.

GLOSSARY

Abbreviation, Acronym, or Term	Definition
Alluvial/alluvium	river sediment deposits
API	American Petroleum Institute
ARB	California Air Resources Board
Bbl.	barrels
bgs	Below-ground surface
CA	California
Ca	Calcium
Cal/EPA	California Environmental Protection Agency responsible for oversight of state environmental regulations and research.
CalGEM	California Geologic Energy Management Division responsible for protecting public health, safety, and the environment in its oversight of the oil, natural gas, and geothermal industries.
Caliper	A logging tool that measures the precise diameter of a wellbore.
Casing Program	Procedures and processes needed to successfully case a geothermal well
Colluvial/colluvium	rock detritus and soils accumulated at the foot of slopes
Cretaceous	Geologic Period from 145 to 66 million years
°C	degrees Celsius
EGS Inc.	EGS Consulting Inc.
Energy Commission	California Energy Commission
°F	degrees Fahrenheit
ft.	foot, feet
$ft.^2/min$	Square feet per minute
ft./s	feet per second
GHS	Golden Haven Hot Springs Spa and Resort

Abbreviation, Acronym, or Term	Definition
GHS-1	Golden Haven Spa well 1
GHS-3	Golden Haven Spa well 3
Gal	Gallons
gpm	Gallons per minute
gpm/psi	Gallons per minute per pound per square inch
hr.	hour
Jurassic	Geologic Period from 201 to 145 million years
mi2	Square miles
µS/cm	Micro Siemens per centimeter
mg/L	Milligrams per liter
NA	Not analyzed
Natural gamma	A measurement of naturally occurring gamma radiation to characterize the rock or sediment in a borehole or drill hole.
NM	Not measured
ND	Not detected
Pliocene	Geologic Epoch from 5.33 to 2.58 million years.
psig	Pounds per square inch (gauge)
psi/ft.	Pounds per square inch per foot
Quaternary	Geologic Period from 2.58 million years to the present.
RFP	Request for proposal
Siemens	A unit of electrical conductance
SP	Self-potential. A measurement of electrical potentials or voltages developed between borehole fluid and the surrounding rock and fluids.
spud	To start the well drilling process by removing rock, dirt and other sedimentary material with the drill bit.
stratigraphy	Layering in a sequence of rocks
TDS	Total dissolved solids
tuffaceous	Sediment derived predominantly from volcaniclastic rocks

Abbreviation, Acronym, or Term	Definition
U.S. DOE	United States Department of Energy
U.S. EPA	United States Environmental Protection Agency
volcaniclastic	Volcanic rock composed entirely of volcanic ash or broken volcanic fragments of varying sizes.

ATTACHMENTS I:
Injection Permits

September 23, 2019

Mr. Bruce Kendall, Agent
bbkendall1@aol.com
spa@goldenhaven.com
Golden Haven Spa
1713 Lake Street
Calistoga, CA 94515

Geothermal Underground Injection Project, Golden Haven Spa, Calistoga, California

Dear Mr. Kendall:

The initiation of the project designated above is approved provided that all field operations pertaining to this project shall conform to the Division of Oil, Gas, and Geothermal Resources' (DOGGR) geothermal statutes and regulations referenced in the California Public Resources Code and the California Code of Regulations, including any subsequent additions or amendments to those statutes and regulations. DOGGR's determination is based on the information and current representations provided in the project application. In addition, DOGGR's approval is strictly limited to injection operations consisting of "return flow" fluid produced from well GHS-2 (API No. 055-90139) and injected into well GHS-3 (API No. 055-90195). This operation shall also be conducted in accordance with the conditions specified by DOGGR and the U.S. Environmental Protection Agency (EPA). The conditions of approval for this injection project as specified below may be subsequently modified by DOGGR or EPA in response to surface and/or well conditions.

1. The injection permit issued to Golden Haven Hot Springs on February 19, 1998 and subsequently modified on August 17, 1999 for well GHS 1 (API 055-90061) or GHS 2 (API 055-90135) is hereby rescinded and superseded by this injection permit.

2. DOGGR forms OGG105 or OGG107 shall be used whenever a new injection well is intended to be drilled or whenever an existing well is intended for conversion to an injection well. This condition holds even if even if no well work is required for the conversion. Specific requirements will be outlined in DOGGR's response to the notice.

3. Submit monthly production and injection reports on Forms OGG110-W and OGG110-I, listing the amount of fluid produced and injected by weight and the surface pressure required for injection well (GHS-3). These are due by the 30th of the

following month. Please submit these reports in pdf and excel format to the Northern District email address at DOGGRNorthern@conservation.ca.gov .

4. An operating pressure gauge or chart with at least 1-psi precision is to be maintained on the well at all times.

5. Except for temperature, return flow fluids shall not be altered or treated in any way, nor shall wastes of any kind be introduced into the return flow fluid.

6. The injection fluid for each injection facility shall be sampled annually and a California Code of Regulations Title 22, Division 4.5 chemical analysis performed by a laboratory certified by the State Water Resources Control Board environmental laboratory accreditation program and submitted to the DOGGR. Additional water sampling and testing shall be performed whenever the source of injection fluid is changed, or as requested.

7. All injection piping, valves and facilities shall be maintained in a safe and leak-free condition.

8. Within 30 days after injection is started, surveys shall be run to demonstrate that the injection well has mechanical integrity and the injected fluid is confined to the intended zone of injection. Thereafter, such surveys shall be made at least every two years, or more often if ordered by the Supervisor or his or her representative. All such surveys shall be witnessed by a DOGGR engineer. The survey method shall be notified to the DOGGR and approved prior to implementation.

9. The injection gradient shall not exceed the fracture gradient (0.7 psi/ft.) in this injection well. Application may be made on an individual well basis for higher injection pressures but only following rate/pressure tests to maximum anticipated pressure.

10. Upon commencement of injection into a new zone or well bore, the injection pressure should be gradually increased over a 24-hour period from static pressure to the desired pressure.

11. Data shall be maintained to show performance of the project and to establish that no damage to life, health, property, or natural resources is occurring by reason of the project. Injection shall cease if any evidence of damage is observed or upon written notice from DOGGR.

12. This data shall be available for periodic inspection by DOGGR personnel.

13. Injection must not violate the terms and requirements of the Code of Federal Regulations (40 CFR Section 144.12), Prohibition of movement of fluid into underground sources of drinking water.

14. The injection program shall be reviewed yearly at a meeting between representatives of Golden Haven Spa and DOGGR.

The issuance of this injection project approval letter does not relieve you of your obligation to obtain necessary permits and approvals from local, state, and federal agencies and to satisfy their permit and approval requirements.

Sincerely,

DocuSigned by:
Charlene L Wardlow

Charlene L Wardlow
District Deputy
Northern District

cc: San Francisco Bay Regional Water Quality Control Board
Richard.Looker@waterboards.ca.gov
Napa County Planning Department
David.Morrison@countyofnapa.org
Emily Reader, UIC Program CA DOGGR Sacramento
Emily.Reader@conservation.ca.gov
Project file

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
REGION IX
75 Hawthorne Street
San Francisco, CA 94105-3901

August 15, 2019

Charlene L Wardlow
Northern District Deputy – CA DOGGR
801 K Street, MS 18-05
Sacramento, CA 95814

SUBJECT: Proposed Geothermal Injection Project, Golden Haven Hot Spring Spa and Resort, Calistoga, California.

Dear Ms. Wardlow:

US EPA Region 9 (EPA) received your letter of August 2, 2019 pertaining to the Proposed Geothermal Injection Project for the Golden Haven Hot Spring Spa and Resort in Calistoga, California. We also reviewed the related technical documents sent by Jerry Salera of your staff. The California Division of Oil, Gas and Geothermal Resources (DOGGR) is proposing that the low-temperature reservoir be protected by a permit that is protective of underground sources of drinking water (USDWs) rather than requesting an aquifer exemption for the aquifer. As your letter stated, this request is similar to one regarding a project in the City of Alturas, California we approved in 2018.

Based on the information you provided to the EPA, and additional information provided by EGS Consulting Inc., we understand that the geothermal reservoir is a USDW, that the two wells described in your letter (production well GHS-2 and injection well GHS-3) are completed at different depth intervals and zones separated by a welded tuff zone of lower permeability. The production well (GHS-2) is completed at depths from 225' to 270' below ground surface (bgs) and injection well GHS-3 located 300 feet away is completed at depths from 400' to 608' bgs. The proposed injection project would pump low-temperature geothermal fluid from production well GHS-2 through a series of heat-exchangers that supply heat to the spa facilities and inject the fluid into well GHS-3 back into the geothermal reservoir. In this instance, the proposed injection well GHS-3 will operate as a "return flow" well for this system and will not be used to dispose of wastes.

With these understandings, we have determined that an Aquifer Exemption, as defined in 40 CFR §§ 144.7 and 146.4, is not required. However, the aquifer must be protected by a permit such that injection does not violate 40 CFR § 144.12 "Prohibition of movement of fluid into underground sources of drinking water." In addition, our determination is based on the information and current representations provided. Should there be any change to the proposed activities or circumstances, please notify EPA.

If you have any questions, or wish to discuss this letter, please call me at 415-972-3971, or contact Joel Coffman of my staff at 415-972-3530.

Sincerely,

David Albright
Manager, Drinking Water Protection Section

cc: Jerry Salera, UIC Program Manager, CA DOGGR

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