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SURVEY OF SELECTED GEOTHERMAL SPRINGS AND WELLS IN SOUTHWESTERN MONTANA

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Cover image: The travertine mound at Warm Springs Montana State Hospital.

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INTRODUCTION

Geothermal springs and wells of southwestern Montana have been identified and studied by previous investigators (e.g., Sonderegger, 1984; Metesh, 2000). Many of these geothermal resources were evaluated during the late 1970s and early 1980s by the Montana Bureau of Mines and Geology (MBMG) and others when the country was reacting to the energy crisis of the late 1970s. One goal of these projects was to inventory geothermal resources that could be utilized to produce energy via steam-driven turbines. At the time, a steam-driven turbine was the primary way to generate power from geothermal resources. Steam-driven power plants are typically large facilities and are still the most cost-effective way to generate power when water temperatures exceed 175°C.

The ability to generate power from hot water has progressed greatly since the 1980s, with the development of binary cycle power plants. Binary plants use hot water to boil a secondary fluid, the pressurized vapor drives turbines to produce electricity, and then cold air or water is used to condense the vapor back into a fluid, completing the cycle (Organic Rankine Cycle; Brasz and others, 2005). Binary systems are much more applicable to small-scale plants because they can generate power at much lower temperatures and with less water flow. Similar to steam-driven plants, the economic potential for binary power production depends on reservoir depths, discharge rates, water temperatures, the chemical composition of fluids, prevailing electrical rates, and a variety of operational and maintenance considerations. The economics of binary power production can be improved through the co-production of other goods and/or services from the high-temperature waters, such as direct use (e.g., space heating, pools, aquaculture), using co-produced fluids from petroleum wells or excess industrial heat.

Small-scale, binary power plants may be well suited for use with the localized, moderate-temperature geothermal systems that are common in Montana. Binary power plants can generate power from water with temperatures well below 175°C (one of the lowest is 74°C in Chena, Alaska), and they are small enough to locate near urban or recreational areas with little public disturbance (Bill Olson, Electrotherm Inc., personal communication, 2010). Binary plants can be designed in modular units to allow for future expansion, and it is also relatively easy to design the plants to operate automatically, thus reducing operational costs.

With these recent advances in power plant technology, some of the geothermal resources in Montana may now be exploitable for power generation. Even sites that have little potential for power generation may be developed for other uses with new technology (e.g., building heat-pumps, greenhouses). However, water chemistry had not been sampled at most of these geothermal sources in 30 years, and the current condition of each resource was unknown. The goal of this work was to reevaluate a select number of geothermal sites, with an emphasis on providing information on the water chemistry, surface temperatures, reservoir temperatures, discharge rates, and the potential for economical power generation.

METHODS

PHYSICAL EVALUATION AND FIELD PARAMETERS

Nine geothermal sources were sampled at seven different locations for this project. The sites were chosen, in consultation with personnel from the Montana Department of Environmental Quality (DEQ), from a list of 14 possible sites based primarily on water temperature, with an emphasis placed on the hottest waters. Other sites were not included in the study due to accessibility problems; some owners denied access to their resource, while others could not be contacted. For every site visited in this investigation, geographic coordinates were obtained using a hand-held navigational GPS unit (using NAD83 datum). Each site was visually inspected, noting the conditions and current usage of the spring/well, and at developed sites, the owner/custodian was interviewed about its history and usage.

For springs and flowing wells, water temperatures were measured as close as possible to the source using a handheld digital thermometer. For sites with accessible discharge points, flow was estimated using the bucket-stop watch method. In other cases, the owner provided an estimate of the discharge into the system's storage reservoir (e.g., Silver Star and Broadwater).

Upon sampling each site, other physical and chemical parameters [pH, oxidation/reduction potential (Eh), specific conductivity (SC), and dissolved oxygen concentrations (DO)] were measured using a Hach Hydrolab® Minisonde-5 (multi-probe datasonde). Each probe within the Hydrolab® instrument was calibrated before each site visit using the following reference standards: pH—4, 7, and 10 pH buffered solutions; Eh—"Zobell's Solution" (reference to 428 millivolts or mV); SC—1,470 microSiemens per centimeter (µS/cm); DO—100% oxygen-saturated water barometric correction applied, in milligrams per liter (mg/L).

To ensure the accuracy of field measurements and to prevent damage to the datasonde, waters with temperatures greater than 50°C were cooled inside of a clean container placed within an ice-bath. The temperature was monitored until it was less than 50°C before recording field parameters. The cooled water was also used to perform an alkalinity titration, and colorimetric analysis of sulfide and ferric iron concentrations (based upon manufacturer's temperature specifications). An alkalinity titration was performed in the field using a 100-mL aliquot of water and 1.6 N H_2SO_4, to a colorimetric endpoint of pH = 4.5 (results in mg/L of $CaCO_3$). Sulfide (S^{2-}) and ferric iron (Fe^{2+}) concentrations were measured in the field using CHEMetrics Vacuvials on a cooled aliquot, following the procedures provided with the portable photometer.

WATER SAMPLING

Spring samples were collected as close as possible to the source. In cases where the springs were enclosed or inaccessible (e.g., Broadwater), samples were collected from the nearest drainage point from the spring source (i.e., pipe going to storage tank). All of the sampled wells were flowing during each site visit, so special considerations for water sampling were not needed (e.g., measuring static water levels, purging 3 well volumes, etc.). In each case, a clean container was used to collect a bulk water sample, so that a peristaltic pump and tubing could be used to filter the appropriate samples into smaller bottles. Samples for water-quality and isotope analyses were filtered through a 0.45-µm filter and collected in accordance with the following analysis regime:

- 500 mL unfiltered/unpreserved
- 500 mL filtered and preserved with 1% HNO_3
- 250 mL filtered/untreated
- 250 mL filtered and preserved with 0.5% H_2SO_4 (for nutrients)
- 10 mL of filtered sample, put into 90 mL of 1% HNO_3 (for silica)
- 1,000 mL filtered (for isotopes)

General water-quality analyses of these samples were conducted in the MBMG Laboratory using methods approved by the U.S. Environmental Protection Agency for the following species (EPA Methods 200.7 & 200.8, 150.1, SM2510B, 2302B, & 300.0):

1. Cations and trace metals—Ca, Mg, Na, K, SiO_2, Al, As, Co, Cd, Cr, Cu, Fe, Mn, Mo, Ni, U, Zn, Ce, Cs, Ga, La, Nb, Nd, Pb, Pr, Rb, Tl, Th, Sn, Ti, and W (acidified below pH 2 with nitric acid); and
2. Anions—SO_4, HCO_3, CO_3, Cl, F, Br, and NO_3.

In addition to water-quality parameters, samples were collected to measure deuterium (δ^2H) and oxygen ($\delta^{18}O$) isotope ratios in the water molecule. These samples were submitted to IsoTech Laboratories of Champaign, Illinois for analysis, and the collection method followed the procedures outlined on the laboratory's website: (http://www.isotechlabs.com/). Deuterium/oxygen isotopic analyses can offer insight into the temperatures, geologic environments, and residence times of the waters in the reservoirs.

GENERAL PHYSICAL AND CHEMICAL OBSERVATIONS

GEOLOGIC SETTING

Seven geothermal sites around southwest Montana were sampled for this project; multiple samples were collected at two sites, Fairmont and Geyser Gulch (fig. 1). Southwest Montana's block-faulted valleys and mountain ranges are the product of Tertiary Basin and Range extension, which is superimposed on complex compressional and extensional features formed by earlier tectonic stresses

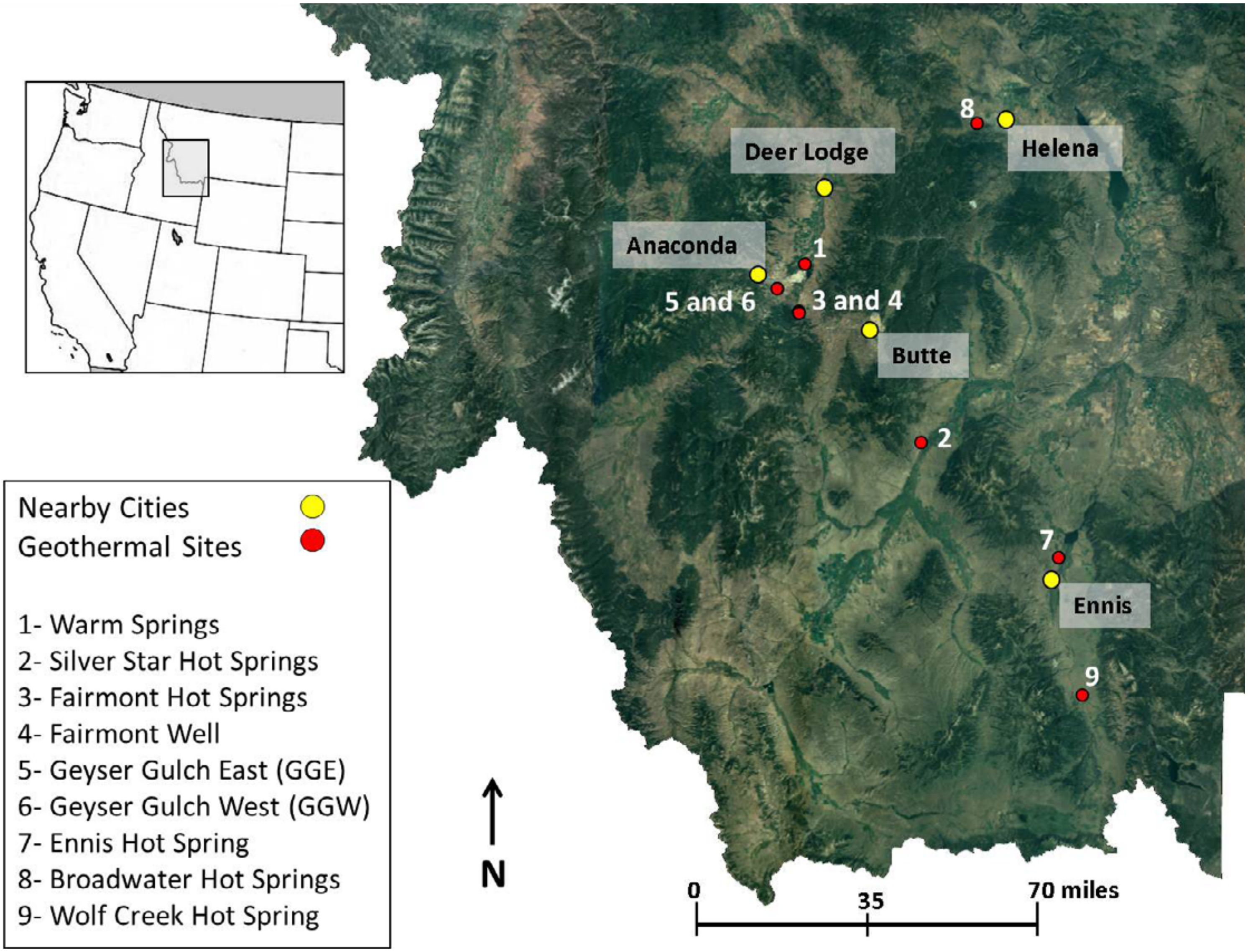

Figure 1. Map of southwest Montana, with geothermal sites plotted and numbered in order of visitation.

(Sonderegger, 1984; Lonn and Elliott, 2011). This part of the state contains the greatest variability of geothermal systems, which can be split into three main types (Sonderegger, 1984):

1. Fracture-controlled systems with a circulation depth of 2.5 km or less, and characterized by calculated reservoir temperatures of 80°C or less and an assumed regional gradient of 30°C/km.
2. Fracture-controlled systems with a circulation depth greater than 2.5 km and characterized by calculated reservoir temperatures greater than 80°C.
3. Carbonate-related flow systems (i.e., permeable limestone) with varying depth and temperature, although most of these spring systems are relatively shallow, large volume, and less than 80°C.

WATER CHEMISTRY

To avoid repetition within each site description, some physical characteristics (e.g., location, discharge) and abbreviated water chemistry results from each site are presented in table 1. Complete water chemistry analyses and field remarks for each site are found in appendix A.

The water chemistry analyses indicate that varying types of geothermal waters exist in southwest Montana (table 1; fig. 2; appendix A). Sodium-sulfate type waters are present at Silver Star, Fairmont, and Broadwater Hot Springs. The springs at Silver Star and Broadwater have relatively high SiO_2 concentrations, and Silver Star has the highest measured total nitrogen concentration in this study. The spring and well samples from Fairmont both exhibit relatively high pH values, high lithium concentrations, and some of the lowest calcium and magnesium concentrations measured. These similarities suggest that the Fairmont spring and well waters are coming from the same source. The low dissolved solute load (total dissolved solids less than 620 mg/L) of these waters suggests that they are circulating through rock dominated by silicate minerals, which dissolve less readily than other mineral types.

The second water type, sodium-bicarbonate-sulfate water type, was encountered at Ennis and Wolf Creek Hot Springs, which are both located in the Madison Valley (about 45 km apart). Water from the flowing well at Ennis has the highest surface temperature and sodium concentration measured in this study, as well as relatively high alkalinity and total dissolved solids (TDS). In contrast to Ennis, Wolf Creek Hot Spring has a relatively high pH, but dissolved constituents are present in very low concentrations (lowest measured TDS at 340 mg/L).

Warm Springs and the two springs located in Geyser Gulch on Smelter Hill (GGE and GGW) produce very similar waters. Although these sites are located within 16 km of the Fairmont sites, the samples collected from Warm Springs and Geyser Gulch are distinctly different from the water samples collected from Fairmont. Water from the Warm Springs and Geyser Gulch sites are the only calcium-sulfate type waters encountered in this study (fig. 2). These samples also had the highest specific conductivity, alkalinity, and TDS, as well as the highest measured calcium, magnesium, strontium, and sulfate concentrations. It has been previously hypothesized by Sonderegger (1984) that the travertine deposits in the Geyser Gulch area and the travertine mound at Warm Springs could be related and connected by a large-scale structure at depth, and these data support that hypothesis. These data also suggest that the Warm Springs and Geyser Gulch Springs are part of a carbonate-related flow system, as described by Sonderegger (1984).

Table 1. Abbreviated list of the physical and chemical data for each of the geothermal waters sampled during this investigation.

Spring Name	Warm Springs	Silver Star	Fairmont Spring	Fairmont Well	Geyser Gulch East	Geyer Gulch West	Ennis	Broadwater	Wolf Creek
GWIC ID	5375	8987	5116	5118	252930	252931	9025	258694	8876
Latitude	46.1782	45.6856	46.0429	46.0385	46.1052	46.1047	45.3711	46.5949	44.9841
Longitude	-112.7954	-112.2961	-112.8126	-112.8109	-112.9036	-112.9038	-111.7258	-112.1126	-111.6164
Township/Range/Section	T05N R10W 24	T02S R06W 01	T03N R10W 02	T03N R10W 02	T04N R11W 13	T04N R11W 13	T05S R01W 28	T10N R04W 28	T10S R01E 09
Discharge (Lpm)	NM	150	NF	680	NF	NF	230	320	55
Surface Temp (°C)	78.6	67.5	49.4	64.6	18.7	12.6	88.0	64.0	59.8
pH	6.45	8.12	8.61	8.51	6.76	6.68	7.83	7.91	8.53
SC (µS/cm)	1,628	915.9	824.7	771.2	2,739	2,733	1,495	882.6	535.8
Alkalinity (mg/L $CaCO_3$)	199	130	126	112	330	343	323	151	131
Eh (mV)	247	338	300	269	407	363	131	288	241
DO (mg/L)	2.21	2.61	3.73	2.11	5.86	4.66	1.85	2.95	3.50
TDS (mg/L)	1,240	608.7	550.9	522.1	2,296	2,351	1,016	616.9	340.1
Ca (mg/L)	236	8.11	4.27	3.97	464	472	5.59	9.30	4.02
Mg (mg/L)	18.7	0.247	0.070	0.017	36.7	65.8	0.335	0.295	0.841
Na (mg/L)	109	180	180	168	164	166	352	186	120
K (mg/L)	18.4	5.23	3.90	3.64	16.9	17.2	14.3	5.40	1.71
SiO_2 (mg/L)	44.5	99.9	71.7	69.2	20.8	19.6	91.6	86.7	48.5
Fe (mg/L)	1.16	0.007	<0.002	0.016	0.101	0.113	0.200	<0.002	<0.002
SO_4^{2-} (mg/L)	675.9	195.7	181.7	167.8	1,381	1,393	216.7	189.8	49.32
Cl (mg/L)	4.92	29.9	17.5	16.2	8.18	8.14	114	36.0	20.1
F (mg/L)	3.43	8.14	16.9	15.4	2.40	2.51	9.47	9.00	17.4
Li (µg/L)	334	213	695	619	215	213	198	540	53.7
Sr (µg/L)	2,920	392	108	134	5,860	5,980	151	201	25.8
Total N (mg/L N)	<1.00	5.94	2.81	2.15	<1.00	<1.00	1.93	<1.00	<1.00
Sulfide (mg/L)	-	0.213	0.222	0.131	0.154	-	0.179	0.197	0.205
$\delta^{18}O$-H_2O (‰)	-20.05	-	-18.31	-18.82	-19.87	-19.87	-18.81	-18.42	-20.00
δD-H2O (‰)	-157.9	-	-148.6	-149.7	-153.8	-153.1	-154.0	-147.9	-152.6
Water Type	Ca-SO_4	Na-SO_4	Na-SO_4	Na-SO_4	Ca-SO_4	Ca-SO_4	Na-HCO_3-SO_4	Na-SO_4	Na-HCO_3-SO_4

Note. Hyphens denote data not collected, and locations are given in decimal degrees (NAD83 datum). A complete water-chemistry analysis report is found for each site in appendix A. GWIC, Ground Water Information Center at http://mbmggwic.mtech.edu/; SC, specific conductance; ORP, oxidation-reduction potential; TDS, total dissolved solids; DO, Dissolved oxygen; Lpm, liters per minute; µS/cm, microSiemens per centimeter; mV, millivolts; mg/L, milligrams per liter; µg/L, micrograms per liter; ‰ ,per mil or parts per thousand; asterisk "*" denotes a flow reading taken from Sonderegger and others, 1981; NM, total flow at Warm Springs was not measurable due to the disperse nature of the discharge; NF, no flowing outlet.

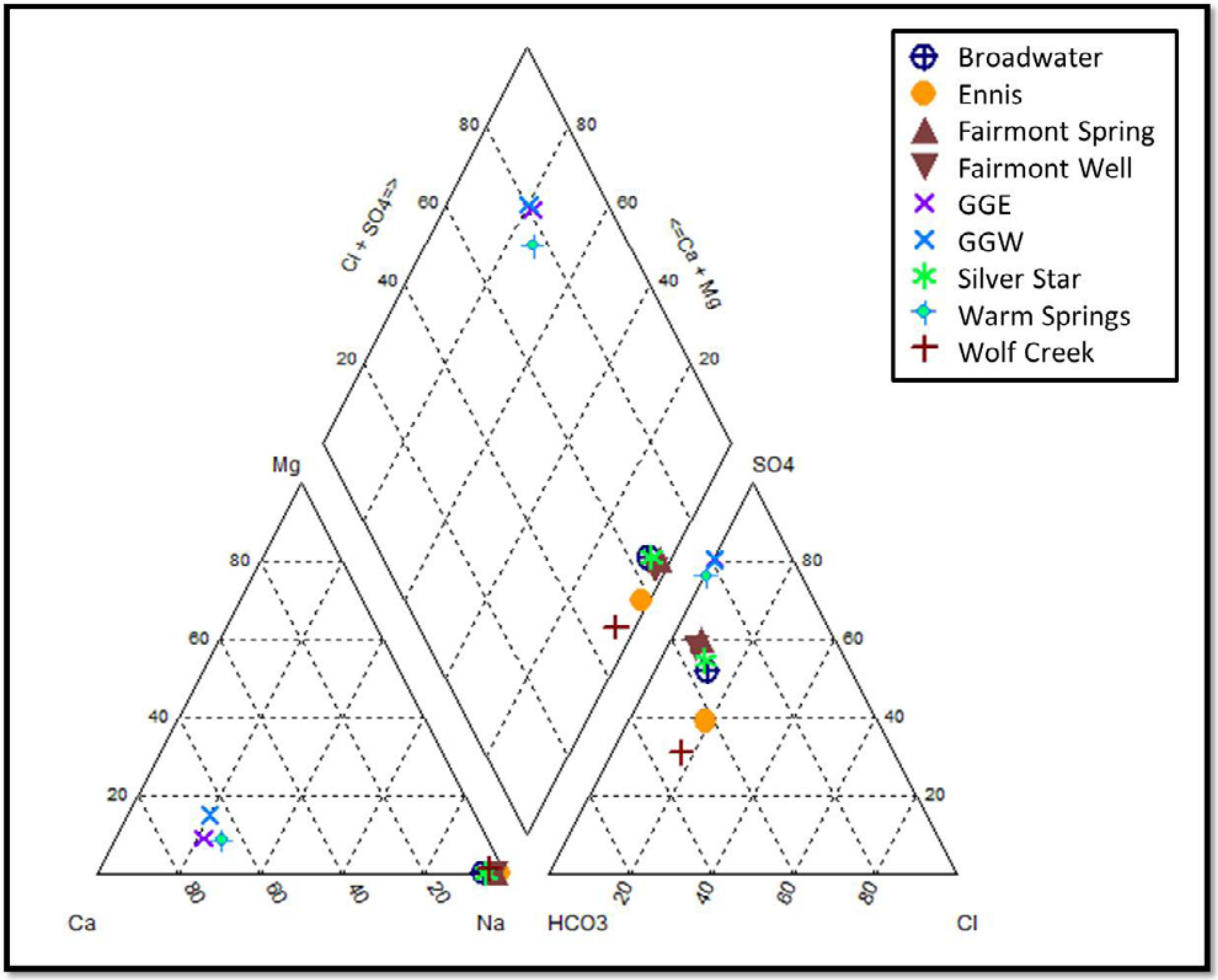

Figure 2. Piper Diagram, showing cation and anion concentration percentages (left and right triangles, respectively), with combined ionic contributions shown in the diamond. A discussion of these water types is found in the *Water Chemistry* section above.

WATER ISOTOPES

The isotopic ratios of oxygen and hydrogen in water ($\delta^{18}O-H_2O$ and δ^2H-H_2O) can be useful tools to determine the origin of a particular water, or understand some of the processes/reactions that may occur during the hydrologic cycle. When $\delta^{18}O$ and δ^2H values from precipitation are plotted against one another for a geographic area, the resulting line is known as the local meteoric water line. Deviations from this line can shed light on processes that may have acted on that water since precipitation occurred. Because most geothermal waters are meteoric in origin, the deuterium (^2H) content in geothermal waters is typically very similar to that of local precipitation, but in some cases the oxygen values are generally displaced toward higher $\delta^{18}O$ content, away from the meteoric trend (Clark and Fritz, 1997). This “oxygen isotope shift” is usually attributed to isotopic exchange between oxygen in the host-rock minerals and oxygen in the water (Truesdell and Hulston, 1980). The isotopic shift is usually greatest in the warmest waters with the deepest circulation, but it is also dependent on the isotopic composition of the minerals reacting with the water (Faure, 1977).

There are two notable observations with respect to the isotopic data (fig. 3); the waters from Wolf Creek Hot Spring and Geyser Gulch plot close to the Global Meteoric Water Line (GWML; Craig, 1961) and the Butte Meteoric Water Line (BMWL; Gammons and others, 2006), while waters from the other sites are shifted to the right, with higher $\delta^{18}O$ values. It is possible that these $\delta^{18}O$-shifted points

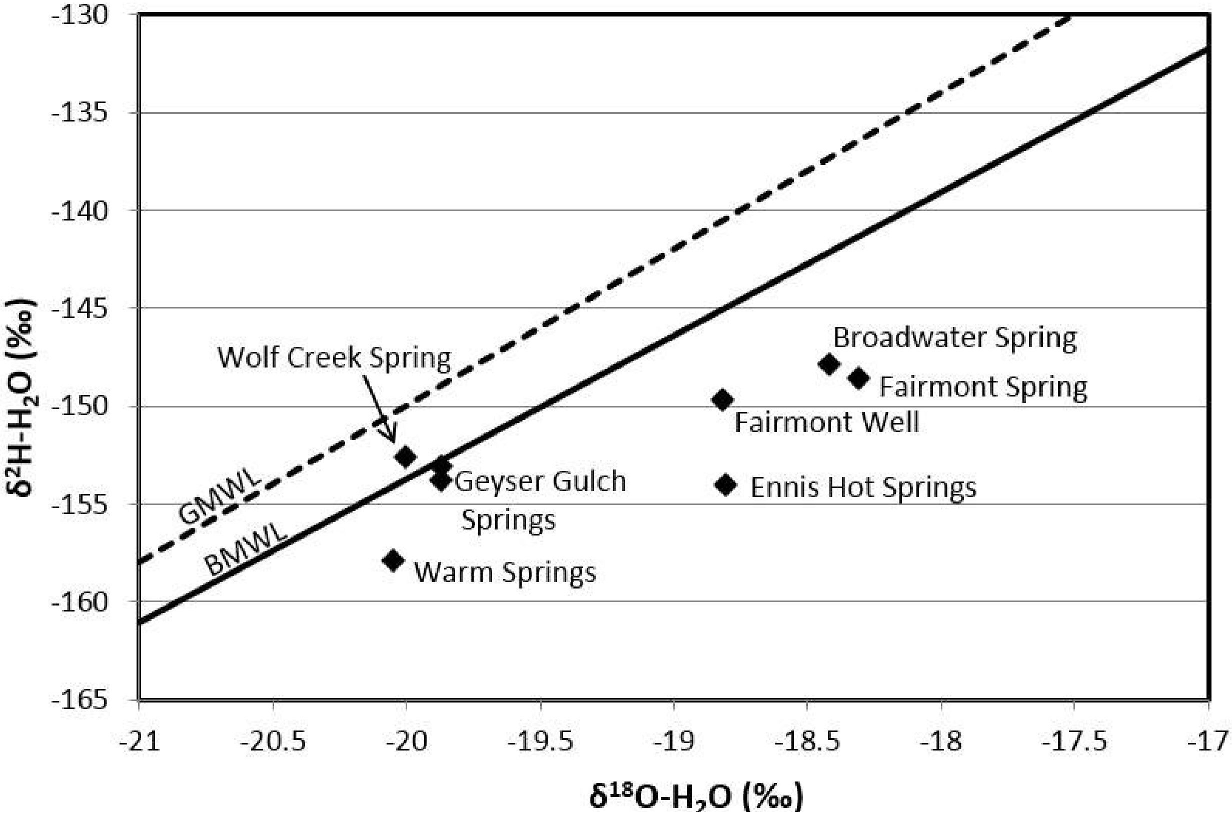

Figure 3. A graph showing the distribution of oxygen and hydrogen isotope ratios in water ($\delta^{18}O-H_2O$ and $\delta^{18}O-H_2O$) for geothermal sites. The Butte (BMWL; Gammons and others, 2006) and global meteoric water lines (GMWL; Craig, 1961) are shown for reference.

reflect other hydrologic cycle processes (e.g., evaporation), especially for sites with exposed pools (Broadwater and Fairmont). However, deuterium values are not significantly shifted in every sample as one might expect from evaporation. Also, the effects from evaporation are negligible in the well water samples, which also plot away from the BMWL. Therefore, the increase in $\delta^{18}O$ values in those waters (although only on the order of ~1 to 1.5 per mil - ‰) may be due to isotopic exchange with minerals in the subsurface as a result of elevated temperatures.

This isotopic shift was most pronounced in samples from the Broadwater, Fairmont, and Ennis Springs, which may indicate they are deeply circulating systems. The Geyser Gulch and Wolf Creek isotopic values are very close to the GWML and BMWL, which indicates that these springs may experience relatively shallow circulation. Generally speaking, all of the sites plot relatively closely to the meteoric water line. If any of these geothermal waters originated from a deeper, magmatic source, or experienced greater oxygen exchange with minerals, the $\delta^{18}O$ values would be much larger, shifted farther from the meteoric water line.

RESERVOIR TEMPERATURE ESTIMATES

Although many factors are involved in determining whether a site is suitable for geothermal power generation, the temperature of the deep geothermal reservoir is an important parameter, because it provides an upper-end estimate of temperatures that exist at the site. Several methods have been proposed to estimate geothermal reservoir temperatures; the most widely used are those including dissolved concentrations of silica (as SiO_2), Na-K-Ca (possible Mg correction), Na-K, and Mg-Li. These methods represent empirical, equilibrium equations for which the water temperature in the reservoir can be calculated (table 2). As noted by the authors of the methods, these calculations should be interpreted with consideration to the geologic and hydrogeologic setting of each site.

Table 2. Geothermometer equations commonly used to estimate reservoir temperatures.

Method	Equation	Reference
Quartz (No Steam)	$T = \frac{1309}{5.19 - logC_{Si}} - 273.15$	Fournier (1977)
Quartz (Steam Loss)	$T = \frac{1522}{5.75 - logC_{Si}} - 273.15$	Fournier (1977)
Chalcedony	$T = \frac{1032}{4.69 - logC_{Si}} - 273.15$	Fournier (1977)
Na-K-Ca	$T = (\frac{1647}{\log\left(\frac{C_{Na}}{C_K}\right) + \beta\left(\log\frac{(\sqrt{C_{Ca}})}{C_{Na}} + 2.06\right) + 2.47}) - 273.15$	Fournier and Truesdell (1973)
	Note: $\text{If} \log\frac{(\sqrt{C_{Ca}})}{C_{Na}} < 0, use\ \beta = \frac{1}{3}$	
	Note: $\text{If} \log\frac{(\sqrt{C_{Ca}})}{C_{Na}} > 0, use\ \beta = \frac{4}{3}$	
Na-K-Ca with Mg Correction	See reference for derivations	Fournier and Potter (1979)
Mg-Li	$T = \frac{1900}{4.67 + \log(\frac{\sqrt{C_{Mg}}}{C_{Li}})} - 273.15$	Kharaka and Specht (1985)

Note. Concentration variables are expressed in mg/L unless otherwise noted. Exceptional circumstances and other considerations for the use of these equations may be found within the respective references (including the lengthy Mg-correction equations).

The average reservoir temperature estimates, based on different methods, range from 49.4 to 124°C (table 3) and are generally similar to previously reported reservoir temperatures for these systems (Metesh, 2000). An estimate of the circulation depth can be obtained by dividing the reservoir temperature estimate by the geothermal gradient for a given area. Although using only one geothermal gradient may provide misleading results, the average gradient used in these calculations (30°C/km) was established as a rough estimate for southwest Montana (Sonderegger, 1984). Measuring and establishing new, site-specific geothermal gradients exceeds the scope of this project.

The lowest estimated reservoir temperature is for the Geyser Gulch Springs, at around 50°C, which supports the conclusion that these springs are part of a low-temperature flow system with a shallow circulation depth of about 1.5 km. The Warm Springs and Wolf Creek Spring sites had average reservoir temperatures of 76.4 and 87.5°C, respectively, which also indicate relatively shallow circulation depths for these systems. For Wolf Creek Spring, a shallow circulation depth supports the un-shifted $\delta^{18}O$ isotopic data, indicating little or no isotopic exchange with subsurface minerals. The Warm Springs reservoir temperature estimates are less strongly supported by the isotope data, but the Warm Springs water could also interact with more reactive mineral phases, which could facilitate complex isotopic exchange.

Table 3. Estimated reservoir temperatures for each site, from different chemical geothermometers (three significant figures, all expressed in °C).

Site	Surface Temp (°C)	Quartz (no steam)	Quartz (steam loss)	Chalcedony	Na-K-Ca	Mg-Li	Average Estimate
Warm Springs	78.6	96.5	97.9	66.1	66.1	55.6	76.4
Silver Star	67.5	137	132	110	129	104	122
Fairmont Spring	49.4	119	117	90.9	121	*174*	112
Fairmont Well	64.6	117	116	89.0	121	*203*	110
Geyser Gulch East	18.7	64.9	70.3	32.9	54.4	37.5	52.0
Geyser Gulch West	12.6	62.7	68.3	30.6	54.7	31.0	49.4
Ennis	88.0	132	128	105	154*	96.9	123
Broadwater	64.0	129	126	102	129	133	124
Wolf Creek	59.8	100	101	70.4	77.8	*48.9*	87.5

The italicized values are considered unreliable, due to reasons which are explained in the text. The asterisk "*" denotes a Mg-corrected value for the Na-K-Ca calculation.

Fairmont (well and spring), Broadwater, Ennis, and Silver Star appear to have average reservoir temperatures greater than 110°C, which implies a circulation depth of greater than 3 km. The estimated reservoir temperatures for these sites are supported by shifted $\delta^{18}O$ data that indicate a greater isotopic exchange with minerals in the subsurface, which in turn indicates higher temperatures. Ennis Hot Spring, with a surface temperature of 88.0°C, is near the lower limit of being economically viable for power generation.

POTENTIAL FOR BINARY POWER PRODUCTION

Theoretically, a binary power plant can be designed to produce power as long as there is at least a 40°C difference between the temperature of the heating water and the temperature of the coolant (air or water; Brasz and others, 2005). However, the efficiency of binary power plants decreases with decreasing water temperatures, which typically limits their usefulness to waters with temperatures of 90 to 150°C (Lund and Boyd, 1999; Rafferty, 2000; Risch and Eastham, 2012). Also, the volume of hot water required to produce the same amount of power increases with decreasing temperature. The binary power plant at Chena, Alaska is one notable exception to the general temperature restriction for binary power generation. The Chena plant produces power with 74°C water at 2,000 liters per minute (Lpm) and 4°C cooling water at 6,110 Lpm; however, the Chena binary power plant replaced a diesel-powered plant with very high operating costs (Holdmann, 2007). While binary power generation from water less than 90°C is possible, it's likely to be economically advantageous only in limited areas where other power sources are unusually expensive.

There are currently commercially available binary power generators that come pre-built and ready to install. One of these systems, called the Green Machine, manufactured by Electrotherm Inc., was evaluated as part of this investigation. The minimum requirements for the Green Machine are 90°C water with a flow rate of 760 Lpm (see appendix B for Green Machine evaluation form). None of the springs or wells investigated for this project met the minimum temperature or discharge requirements necessary to utilize the Green Machine for power production. The well at Ennis had a temperature near the required temperature but only approximately 30 percent of the required flow. The total flow at Warm Springs may meet the Green Machine flow requirements, but the water is not warm enough. Also, the water quality at Warm Springs is very poor, which has limited its usefulness for direct heating in the past due to corrosion and scaling issues. Reservoir temperatures at all of the sites, except for the Geyser Gulch Springs, were sufficient for binary power production. If high-production wells could be completed at depth, there is the potential for binary power production at these sites, but the added cost of drilling and pumping (if necessary) would increase the cost associated with developing this power.

SITE DESCRIPTIONS

SILVER STAR HOT SPRINGS

The hot springs in Silver Star (formerly “Barkell’s Hot Springs”) are privately owned and located west of the owners’ residence, less than 1 km off of MT Highway 41 (exact locations found in table 1). Five different springs occur at the site, all within 30 m of each other (fig. 4). Hot water from each spring is collected into one main outlet pipe that discharges into a storage tank near the residence.

The combined flow rate from the springs is about 150 Lpm, and historically the flow has not shown major seasonal fluctuations (oral commun. with owners). During this investigation, the surface temperatures of all five springs (66.5–67.5°C) were very similar; the small temperature difference and the close grouping of the springs suggest they issue from the same source. Although the current flow rate is consistent with historical flow estimates, current temperatures are slightly lower than the measurement of 71.5°C reported by Sonderegger and others (1981).

Carbonate-dominant outcrops (likely travertine–calcium carbonate) are visible to the north and west of the hot springs, which indicates a history of geothermal spring activity around Silver Star. Though of little economic importance, metal-rich mineralized zones have also been identified in these shallow carbonates by small, local mines (oral commun. with J. Sotendahl at Silver Star Mine). The location of the springs appears to be controlled by the intersection of the western valley-margin fault and the Cherry Creek and Green Campbell faults (Sonderegger, 1984), which apparently provide easy routes for hot-water movement in the region. Other springs along the western margin of the valley, perhaps related to this fault zone, are documented in the GWIC database. However, temperature and chemical data were not available at the time of this study, and those sites could not be accessed.

Water samples were collected from the western-most spring, which had the highest surface temperature of the group. Reservoir temperature estimates for Silver Star from the various geothermometers range from ~104 to 137°C, with a mean estimate of ~122°C. These relatively high temperature estimates are slightly lower than historic geothermometer estimates (quartz- 143°C; Na-K-Ca- 139°C), but they still indicate that the water circulates to a considerable depth (Type Two; Sonderegger, 1984). Assuming a geothermal gradient of 30°C/km (Sonderegger, 1984), the new temperature estimates indicate a circulation depth of approximately 4 km.

The estimated reservoir temperatures at Silver Star (~122°C) might be sufficient to produce electricity using a binary power plant. However, prior to power plant development, test wells should be installed to find cold-water sources and to determine the maximum potential hot-water discharge. A well might provide volumes of hot water suitable for this purpose (greater than 380 Lpm; from Sonderegger, 1984), although it may affect spring flow.

Currently, the geothermal water is being used for direct heat in the owners’ residence and a commercial greenhouse. The owners have expressed interest in further developing their geothermal resource, perhaps to heat more greenhouses. Another possibility for space heating might be to use a ground-source heat pump, which would not require additional water withdrawals.

Figure 4. A few of the hot spring vents in Silver Star (note: one spring is covered with a lid, while others are open to the air). Boxes were built around each spring to stabilize the holes. The combined discharge point is located near the trees.

DEER LODGE VALLEY

Two hot spring areas have been identified in the southern part of Deer Lodge Valley. The first is located at Warm Springs on the campus of the Montana State Hospital. The second is located in Gregson at the Fairmont Hot Springs Resort, about 6.5 km south of Opportunity. In addition, two geysers/springs on Smelter Hill (near Anaconda) discharge relatively low-temperature water, but have chemical signatures that indicate geothermal influence and possible connection to the nearby Warm Springs system. Sonderegger (1984) reported that Warm Springs has the characteristics of a large volume, low-temperature system (Type Three, page 7), and the springs at Fairmont discharge from a limited extent, higher-temperature system with moderately deep circulation (Type Two, page 7). These sites are described in more detail in the following sections.

Warm Springs

The geothermal spring at Warm Springs State Hospital discharges from a large mound of travertine that has a diameter of 21 to 24 m and rises approximately 23 m above the valley floor (figs. 1 and 5; table 1). Geothermal water discharges at about 70 Lpm from the top of the mound (Hills, 1998); however, geothermal water also discharges in all directions around the mound's base, so the overall discharge is currently unknown. The water temperature is consistently between 75 and 80°C (Hills, 1998; GWIC data from 1974 and 1980; 78.6°C in this study). Historically, there have been plans to use this geothermal resource for heating buildings and commercial greenhouses, but use of this water for heating has been limited due to corrosion and scaling. The remnants of a collection system installed to provide heat for greenhouses can still be seen near the mound's base (fig. 6). Production from a geothermal well at Warm Springs is used to heat some of the facility's domestic supply water via a heat exchanger.

In 1979 a geothermal exploration well (GWIC ID 5363) drilled northeast of the geothermal spring penetrated 457 m of unconsolidated sand, gravel, silt, and clay before encountering granitic basement rock. At the time of drilling, the well yielded high-temperature water (77–79°C) under flowing-artesian pressure (Stoker, 1980). The chemistry of the well water was nearly identical to that of water from the geothermal spring. After performing a shut-in pressure test in 1980, it was concluded that the well has

Figure 5. The travertine mound at the Warm Springs Montana State Hospital.

Figure 6. The remnants of a water collection system as seen from the top of the travertine mound at Warm Springs.

a maximum safe yield of 265 Lpm of 78 to 80°C water (Sonderegger, 1984).

In 1982 another well (GWIC ID 5374) was completed at a depth of 93 m by the MBMG. “Copious amounts of luke-warm water” were encountered in a shallow gravel zone, at a depth of 4.6 to 5.5 m (Sonderegger, 1984). The presence of warm water at these shallow depths indicates that the geothermal system feeding the springs at Warm Springs may also discharge into shallow groundwater.

Reservoir temperature estimates for Warm Springs vary from ~55 to 98°C (mean of 76°C), as seen in table 3. The new estimates from geothermometers are within range of the historic estimates (46 to 81°C). Assuming a regional geothermal gradient of 30°C/km, waters at Warm Springs are estimated to circulate to approximately 2.5 km (Sonderegger, 1984). These results are also consistent with the assessment that Warm Springs has the characteristics of a large volume, low-temperature, carbonate system (Type Three; Sonderegger, 1984).

With these relatively low temperature estimates, Warm Springs is not an ideal location for geothermal power generation. Additionally, this resource historically provided water for space heating, but the collection system was eventually abandoned due to the corrosive, scaling nature of the water (i.e., high iron and TDS). This resource may be useful in the future for similar space heating projects, but pretreating the water could add significant cost to development.

Gregson (Fairmont Hot Springs)

Geothermal water issues from three springs located at the Fairmont Hot Springs Resort near Gregson (fig. 1; table 1). This geothermal water was used to heat concrete-lined swimming pools at the resort until 1984. The springs still discharge water, but they are now enclosed by wooden, pyramidal “huts” which limit public access to the shallow spring pools (fig. 7). There was no visible source or direction of flow in any of the huts, but water must be slowly filling the spring pools, as the excess was collected and piped to a decorative fountain at the resort. Inside each hut, the water level is greater than 2 m below the entry platform, which makes it difficult to reach. The large- and mid-sized springs have similar water temperatures (45.7 and 45.4°C), but the small spring’s water temperature was 49.4°C. Water temperatures have decreased with time. Mariner and others (1976) reported a temperature of 70°C and Sonderegger and others (1981) reported a temperature of 61.5°C. When the hot springs were sampled by the USGS in 1974, discharge was recorded at 151 Lpm, but it was not possible to

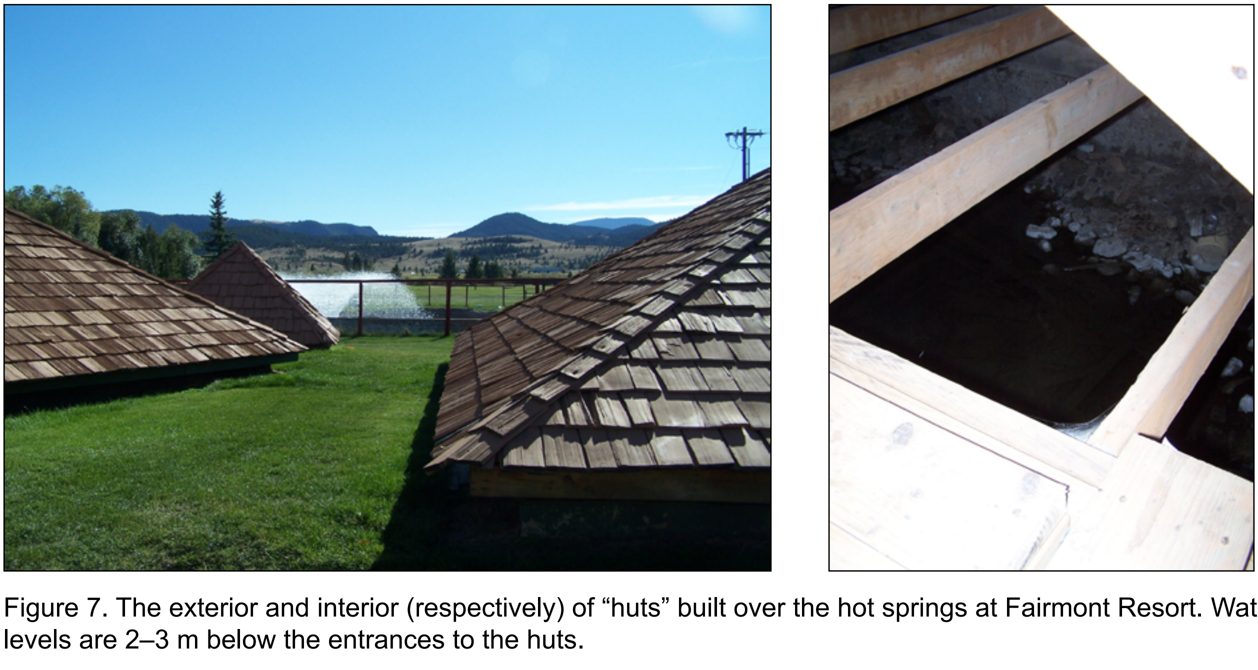

Figure 7. The exterior and interior (respectively) of “huts” built over the hot springs at Fairmont Resort. Water levels are 2–3 m below the entrances to the huts.

measure discharge for this investigation due to the structures around the springs, low flow, and the depth to water in the huts.

Since 1984, hot water (64.6°C) has been pumped from a 183-m-deep well located approximately 0.5 km southeast of Fairmont Hot Springs Resort. The well ("Fairmont #6," GWIC ID 5118) was installed by the MBMG in 1983 for geothermal exploration, and at the end of the study was left to the resort for geothermal water production (fig. 8). Currently, water from this well is pumped to a storage tank at 560–680 Lpm, from which it is then used to provide forced-air heat for the hotel or mixed with cool water to regulate the temperature of the swimming pools. According to Fairmont maintenance chief Vern Cook, the spring discharge has decreased significantly since the well production began. The well may also be responsible for the gradual decrease in spring discharge temperatures, by withdrawing hot water before it reaches the springs, thus allowing only a fraction of the original spring flow to discharge. There may also be cooler water mixing at shallow depths with this smaller fraction of geothermal water. For this study, water samples were gathered from both the hot-water well and the smallest, hottest spring.

A previous study by Chadwick and Leonard (1979) concluded that geothermal discharge at Fairmont Hot Springs is most likely controlled by fractures within the granitic rocks south, west, and potentially east of Gregson, in areas where normal regional heat is sufficient to maintain the geothermal systems without enhancement from cooling igneous bodies. Earlier quartz and Na-K-Ca geothermometer calculations yielded reservoir temperature estimates of 128 and 124°C, respectively, while chalcedony calculations yielded 101°C (Sonderegger, 1984). Current reservoir temperature estimates between

Figure 8. The Fairmont well is located 0.53 km southeast of the resort and springs.

the well and the springs range from 89 to 121°C, as seen in table 3. The Mg-Li temperature estimates for the Fairmont sites are considered unreliable due to very low magnesium concentrations, which can produce unusually high estimates (greater than 50°C more than others).

The difference between the surface water and estimated reservoir temperatures suggests that the water rises to the surface slowly. Using 30°C/km as a gradient for the area, the circulation system at Fairmont should be about 4 km deep based upon Na-K-Ca geothermometer estimates, while the much lower temperature chalcedony geothermometer estimates indicate a depth of only about 2.9 km. With these circulation depth and reservoir temperature estimates, the Fairmont system may have the potential for power generation through a binary power plant. Of the exploration wells installed in the early 1980s, only one produced hot water (the Fairmont #6 well), indicating that it may be relatively difficult to find sufficient hot-water flow for a power plant at this site. Even a second hot-water extraction well may not provide enough flow to produce electricity in addition to maintaining Fairmont's current space heating and swimming pool operations.

Smelter Hill

Although this study's primary focus was to document hot-water sites, the spring mounds in "Geyser Gulch" near Smelter Hill (fig. 1; table 1) were sampled, because they are only about 10 km northwest of the Fairmont site and 11 km southwest of Warm Springs. While locally known as geysers, there is no known evidence of eruptive activity from these mounds. This site was historically known as Anaconda Hot Springs, and the associated travertine benches were said to be as extensive as those found at Mammoth Hot Springs in Yellowstone National Park (Weed, 1904). Much of this travertine was mined as the main source of flux for the Washoe copper smelter, so very little of the deposit remains. A previous study measured these springs discharging moderately warm water (22°C) at a slow rate (about 11 Lpm; Sonderegger and others, 1981). Despite the relatively cool water temperatures, intersecting faults interpreted to exist beneath Warm Springs and Smelter Hill are thought to facilitate the upward migration of geothermal waters (Hills, 1998). If this connection does exist, then studying these 'geysers' may offer insight into a valley-scale geothermal system.

Currently, the springs discharge through small travertine cones on the upthrown (west) side of the valley-margin fault that cross-cuts Smelter Hill (Hills, 1998; figs. 9 and 10). The surface expression of the fault is concealed beneath a travertine deposit related to historic geothermal activity. The 'geysers' are near the center of the travertine deposit and discharge from Tertiary volcanic rock of the Lowland

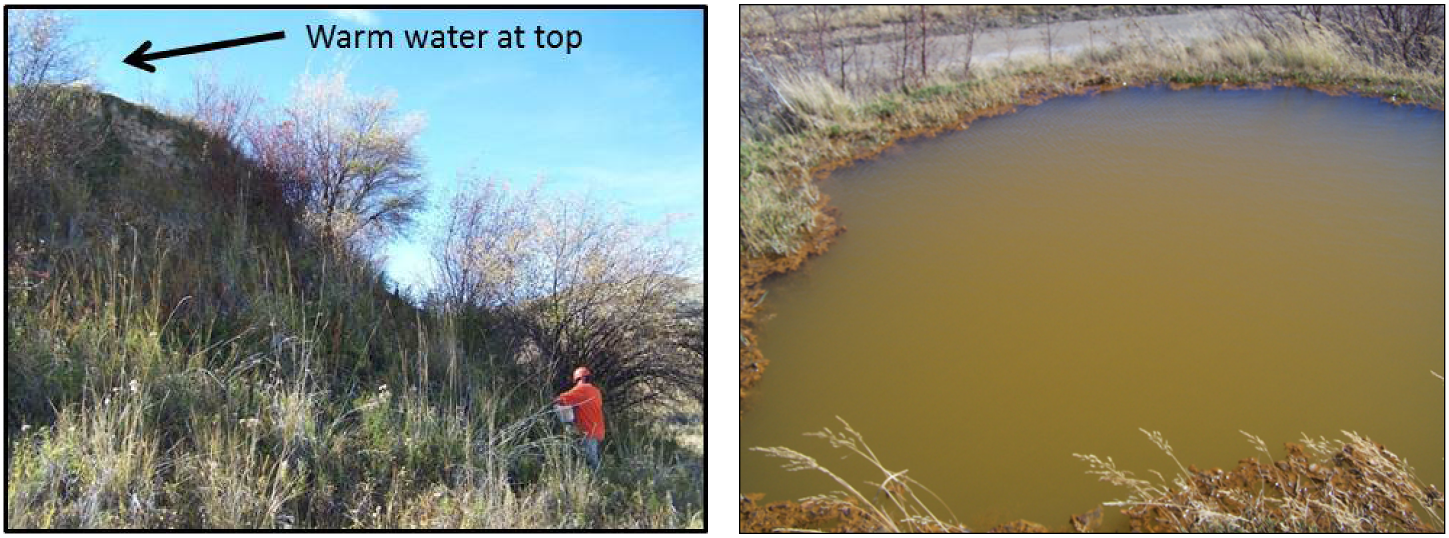

Figure 9. Side-view of GGE with a person shown for scale (left). The water level at the top of GGE (right).

Figure 10. The side/top of the collapsed geyser mound (GGW); the water level is hidden by shadows.

Creek Formation (Hills, 1998). The Geyser Gulch East (GGE) and Geyser Gulch West (GGW) sites are less than 30 m apart. The GGE cone is quite steep and vegetated and discharges slightly warmer water than GGW (18.7°C), and the water level is at the top of the ~6-m-tall cone. The cone at GGW is partially collapsed near ground level and contains a pool of relatively cool water (12.6°C), and the water surface is about 3 m below the inner edge of the cone. Neither spring had measurable discharge emanating from the mounds.

The hydraulic head for GGE is above natural land surface and is considerably higher than local groundwater, based on water levels in nearby wells. The artesian head associated with the inactive geyser suggests that it is not hydraulically connected to shallow groundwater. Sonderegger and others (1981) postulated that given the slightly elevated temperature, the surrounding travertine deposit, and location relative to the fault, it is reasonable to expect that the geyser is hydraulically connected to deep faulting, and that the fault plane may serve as a conduit for upward migration of deep-circulating geothermal groundwater to other sites in the valley.

Previous reservoir temperature estimates range from ~36 to 75°C, and the new geothermometer estimates are very similar at ~30 to 70°C (mean of 50.7°C). These temperature estimates result in a calculated circulation depth of about 1.6 km, using a geothermal gradient of 30°C/km. Although these springs are not good candidates for geothermal energy development, their location and proximity to a large fault provide clues for finding other places in the area that may interact with this valley-scale system and yield larger volumes of higher temperature water.

ENNIS (FORMERLY THEXTON) HOT SPRING

The current owner reported that the hot springs north of Ennis (fig. 1; table 1) were first developed for public bathing and swimming in the 1880s, at locations where hot water flowed from multiple places along the edge of an alluvial terrace. A 372-m-deep well was completed just north of the hot springs in the 1980s. When the owners of the new well began pumping large volumes of water (about 568 Lpm) to heat greenhouses, the springs dried up. The current owner further reported that the owners of the old resort did not hold water rights for the springs, so nothing could be done to stop their neighbors' pumping.

Eventually, the greenhouse business closed and the well was abandoned, but left open, with very hot water (88.0°C) flowing freely from the "new spring" (outlet pipe) at approximately 230 Lpm. The old springs and the abandoned well were purchased by the current owner and the property now operates as an RV camping area. With the surrounding area being very marshy, the current owner established a wildlife pond (~1 acre) using the hot well discharge (figs. 11 and 12). Because discharge from the pond flows into Moore's Creek and then the Madison River, the owner said that he must monitor the seasonal water flow and temperature to ensure that there are no negative impacts to the river.

The Ennis geothermal area is believed to be an elliptical field, roughly 0.8 km north–south and 0.4 km wide, located 2.4 km north of Ennis (Sonderegger and Zaluski, 1983). Geophysical investigations by Leonard and Wood (1988) suggested that the spring overlies the eastern edge of a buried block of fractured crystalline rock, bounded on the east and northeast by subsurface fault scarps. The north-striking fault beneath the hot springs is not a range-front fault of major displacement, like those of the Madison Range fault system along the east side of the valley. Rather, the west side of the valley may be bounded by a series of downthrown to the east, north-striking step faults that have relatively small displacement.

Figure 11. Steam rising from the "wildlife pond" that receives discharge from the flowing well at Ennis Hot Springs.

Figure 12. Mineral staining near the edge of the pond on the left and discharge from the flowing well at Ennis Hot Springs on the right. The barrel at the mouth of the outlet pipe disperses the force from water discharging at about 230 Lpm.

During MBMG investigations in the 1980s, multiple, smaller-diameter test wells were installed to explore for hot water. A “shallow, essentially horizontal” reservoir was encountered with these wells between 150 and 330 m below land surface. Bottom-hole temperatures ranged from 92 to 97°C, and pumping-rate tests showed stable production from the reservoir zone to be limited to less than 1,890 Lpm (Sonderegger, 1984). Lithologic logs from the area indicate that an uppermost layer of alluvium and floodplain deposits (about 6 m) overlies about 150 m of older basin-fill deposits that in turn rest on Archean crystalline rock (Leonard and Wood, 1988).

Reservoir temperature estimates based on historic samples vary considerably by method; quartz method = 141°C, chalcedony method = 115°C, and Na-K-Ca = 163°C (all from Sonderegger, 1984). Current water-quality analyses yield similar, though lower geothermometer estimates, as seen in table 3 (129, 105, and 154°C, respectively). The Na-K-Ca estimate for Ennis is the only value in table 3 corrected for Mg, because it is the only site which met the requirements based upon Mg concentration. The Mg-Li geothermometer yields the lowest estimate of 96°C, which is within the range of temperatures measured in the deepest exploration wells in this area. Other reservoir temperature estimates indicate that the circulation system must extend at least 3 km deep (Type Two system).

Even at the lowest estimated reservoir temperature, the temperature and circulation depth of water at the Ennis flowing well may be conducive to power generation through a binary power plant. The current well does not produce enough flow for a binary power plant, but a new extraction well may achieve more production (limited to less than 1,890 Lpm; Sonderegger, 1984). In addition to power generation, the hot water in Ennis may be utilized for other energy-saving projects. A local non-profit gardening group began leasing property near the hot spring in 2010. Their project installed a closed-loop system to heat two small greenhouses. In other places on the campground owner’s property, the ambient ground temperature is high enough at a depth of 2.1 m to heat the plumbing system for camping sites to ~40°C. With elevated ground temperatures at such shallow depths, these areas could be developed with heat-pump technology to heat nearby structures.

BROADWATER ATHLETIC CLUB AND HOT SPRINGS

Birkby (1999) reports that “Wassweiler’s Hot Springs” was developed into a public swimming pool in 1866, approximately 2 km from the current Broadwater Club (fig. 1; table 1). By 1889, a new owner had established the Broadwater Hotel and Natatorium at a cost of more than $500,000. The enormous facility boasted a 2,787 m^2 swimming pool, 100 dressing rooms, and 1,115 m^2 of windows. However, a severe earthquake irreparably damaged the Natatorium in 1935 and it was demolished in 1946. The small, current facility is a private athletic club, featuring indoor and outdoor pools and Jacuzzis (fig. 13).

Figure 13. The exterior of the Broadwater Athletic Club and Hot Springs just off of U.S. Hwy 12. The springs are covered and not accessible, so samples were collected from the indoor distribution system.

There are four hot springs used by the Broadwater Club; however, the springs are covered and are not directly accessible. Hot water (64.0°C) is piped from the springs into a storage pool, at a combined flow rate of about 320 Lpm, with negligible temperature loss (oral commun., Broadwater staff). For this study, water samples were taken from the pipe that connects the storage pool to the plumbing system, which can then be used to regulate flow and temperatures around the facility.

Previous investigations measured surface-water temperatures between 65 and 67°C, and also reported that a well installed near the springs produced about 1,300 Lpm of water at approximately the same temperature as the springs (Sonderegger, 1984; pers. oral commun. with R.B. Leonard). However, the results and duration of a pumping test on the well are not publicly available, and it is unknown whether the system would provide a sustained yield at that rate and temperature.

Aerial infrared images taken of the Broadwater area in 1978 provided information about local thermal anomalies. The MBMG explored the area further in 1981 by completing a 85-m-deep well near one of the anomalies; however, the well yielded cold water in several zones and a measured geothermal gradient of only 8.7°C/km (Vice, 1982). Despite the failed attempt at locating another productive heat zone, the study gained further information about the area, concluding that the Broadwater Spring system is likely controlled by fracture permeability associated with valley-margin block faulting.

Previous reservoir temperature estimates vary, but agree with estimates based on recent sampling (table 3): quartz method = 129°C, chalcedony method = 109°C, and Na-K-Ca = 98°C (questionable reliability; Sonderegger, 1984). With a relatively high silica concentration, the chalcedony estimate might be most reliable, and because of the low chloride content (less than 40 mg/L), mixing-model type calculations involving chloride might be questionable (Sonderegger, 1984). The new reservoir temperature estimates show less variation (126, 102, and 129°C respectively) and indicate that the circulation system at Broadwater must extend at least 3 km deep (Type Two system). These reservoir temperature estimates indicate that power generation may be possible at Broadwater Hot Springs, but the natural springs do not provide enough flow. Instead, a high-capacity well would need to be installed (in addition to a cold-water source), but as the MBMG experienced in 1981, it may be difficult to intercept a zone of sufficiently hot water.

WOLF CREEK HOT SPRING

Wolf Creek Hot Spring is privately owned and located on the Sun Ranch property, south of Cameron, Montana (fig. 1; table 1). The spring is on an alluvial gravel terrace, approximately 5 km from the Madison Range front. The spring discharges hot water (59.8°C) from the bottom of a primary pool, which then drains through a small channel to a secondary pond at about 55 Lpm (figs. 14 and 15). A small amount of water is also diverted from the channel to heat an on-site hot tub (~ 4 Lpm). At the time of the site visit, the guide mentioned another small hot spring on the property, but was not sure of the location. Samples for analysis were only collected from the primary pool, near the hottest point (north end).

Figure 14. Wolf Creek Hot Spring, with upwelling water and bubbles rising near the center and north end of the pool (~4 m wide).

Given the location of the spring along the Madison Range Front, it is likely that the geothermal water is associated with north–south-trending faults. However, instead of following the steep thrust faults associated with the Madison Range, the water probably follows a relatively shallow fault pathway. The reservoir temperature estimates (discussed below) support this “shallow route” interpretation.

Previous reservoir temperature estimates vary: quartz = 103°C, chalcedony = 73°C, and Na-K-Ca = 64°C (Sonderegger, 1984). The new temperature estimates, as shown in table 3, are similar (101, 70, and 78°C respectively). However, the low Mg-Li geothermometer estimate (49°C, actually lower than surface temperature) is considered to be unreliable due to very low lithium concentrations. The other temperature estimates indicate that the circulation system at Wolf Creek Hot Spring must be relatively

Figure 15. The channel shown in the left photograph carries water away from the Wolf Creek Hot Spring to the large, relatively cool stock-water pond shown in the right photograph.

shallow (about 2.5 km). Also, with a relatively small difference between reservoir and surface temperatures, water must flow upwards quickly from the reservoir. Water isotope results ($\delta^{18}O$ and ^{2}H) also indicate that Wolf Creek Hot Spring experiences shallow circulation and relatively quick recharge from meteoric waters (discussed in *Water Isotopes* section).

Considering the discharge, temperature, and circulation depth estimates, Wolf Creek Hot Spring does not appear to have potential for geothermal power production. Even using the resource for space heating seems uneconomical due to its isolated location and lack of nearby structures.

SUMMARY

The goal of this work was to reevaluate a select number of geothermal sites, with an emphasis on providing new information on the water chemistry, surface-water and reservoir temperatures, discharge rates, and the potential of resources that could be used for power generation.

The water-chemistry analyses indicate that varying types of geothermal waters exist in southwest Montana (table 1; fig. 2; appendix A). Sodium-sulfate type waters are present at Silver Star, Fairmont, and Broadwater Hot Springs. Sodium-bicarbonate-sulfate type waters occur at Ennis and Wolf Creek Hot Springs, which are both located in the Madison Valley (about 45 km apart). The waters from the Warm Springs and Geyser Gulch sites were the only calcium-sulfate type waters that were encountered in this study, and data support the hypothesis that these two sites may be connected through a large-scale, carbonate-related flow system. The other geothermal sites appear to have fracture-controlled circulation systems.

The average reservoir temperature estimates derived from multiple methods range from 49.4 to 124°C, with the lowest temperatures occurring at the Geyser Gulch sites, Warm Springs, and Wolf Creek Hot Spring. These sites likely have relatively shallow circulation (less than 2.5 km) and have little potential for geothermal power generation. Fairmont (well and spring), Broadwater, Ennis, and Silver Star Hot Springs have reservoir temperature estimates greater than 110°C, which implies a circulation depth greater than 3 km.

For the sites with deep circulation depths, there may be potential for further economic development, whether for power generation or space heating. In all cases, the temperatures are too low for steam-driven power plants, but binary plant systems may be viable. Current flow rates are relatively low for all sites and may not be sufficient for binary power plants. High-capacity wells would need to be installed to produce more hot water, in addition to finding nearby sources of cold water. These supplemental wells should be installed early in the development process to determine whether a site is truly suitable for power generation. In cases where power plants are not economically possible, the geothermal resource could still be developed further to heat multiple structures, swimming pools, or aquaculture facilities.

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APPENDIX A. WATER-QUALITY DATA

Ground-Water Information Center Water Quality Report

Site Name: WARM SPRINGS STATE HOSPITAL

Report Date: 2/5/2011

Location Information

Sample Id/Site Id:	2011Q0510 / 5375	Sample Date:	10/1/2010 12:00:00 PM
Location (TRS):	05N 10W 24 ABBD	Agency/Sampler:	MBMG / ICOPINI, GARY
Latitude/Longitude:	46° 10' 41" N 112° 47' 39" W	Field Number:	WARM SPRINGS
Datum:	NAD27	Lab Date:	12/1/2010
Altitude:	4835	Lab/Analyst:	MBMG / SM
County/State:	DEER LODGE / MT	Sample Method/Handling:	/ 5000
Site Type:	SPRING	Procedure Type:	DISSOLVED
Geology:		Total Depth (ft):	NR
USGS 7.5' Quad:	WARM SPRINGS	SWL-MP (ft):	NR
PWS Id:		Depth Water Enters (ft):	NR
Project:	GEOTHERM, WSSH		

Major Ion Results

	mg/L	meq/L		mg/L	meq/L
Calcium (Ca)	236.000	11.776	Bicarbonate (HCO3)	260.600	4.271
Magnesium (Mg)	18.700	1.539	Carbonate (CO3)	0.000	0.000
Sodium (Na)	109.000	4.742	Chloride (Cl)	4.920	0.139
Potassium (K)	18.400	0.471	Sulfate (SO4)	675.900	14.079
Iron (Fe)	1.160	0.062	Nitrate (as N)	<0.05	0.000
Manganese (Mn)	0.047	0.002	Fluoride (F)	3.430	0.181
Silica (SiO2)	44.500		Orthophosphate (as P)	<0.1	0.000
Total Cations		18.667	**Total Anions**		18.670

Trace Element Results (µg/L)

Aluminum (Al):	<10.0	Cesium (Cs):	69.300	Molybdenum (Mo):	<1.0	Strontium (Sr):	2,924.000
Antimony (Sb):	8.420	Chromium (Cr):	<1.0	Nickel (Ni):	<0.9	Thallium (Tl):	<1.0
Arsenic (As):	20.400	Cobalt (Co):	<0.9	Niobium (Nb):	<0.9	Thorium (Th):	<1.0
Barium (Ba):	46.400	Copper (Cu):	<2.5	Neodymium (Nd):	<1.0	Tin (Sn):	<1.0
Beryllium (Be):	1.550	Gallium (Ga):	<0.9	Palladium (Pd):	<2.5	Titanium (Ti):	5.560
Boron (B):	94.100	Lanthanum (La):	<1.0	Praseodymium (Pr):	<1.0	Tungsten (W):	41.200
Bromide (Br):	<50	Lead (Pb):	<1.0	Rubidium (Rb):	102.000	Uranium (U):	<1.0
Cadmium (Cd):	<1.0	Lithium (Li):	334.000	Silver (Ag):	<1.0	Vanadium (V):	<1.0
Cerium (Ce):	<1.0	Mercury (Hg):	NR	Selenium (Se):	<0.9	Zinc (Zn):	<5.0
						Zirconium (Zr):	1.060

Field Chemistry and Other Analytical Results

**Total Dissolved Solids (mg/L):	1,240.270	Field Hardness as CaCO3 (mg/L):	NR	Ammonia (mg/L):	NR
**Sum of Diss. Constituents (mg/L):	1,372.700	Hardness as CaCO3:	666.260	T.P. Hydrocarbons (µg/L):	NR
Field Conductivity (µmhos):	1628	Field Alkalinity as CaCO3 (mg/L):	NR	PCP (µg/L):	NR
Lab Conductivity (µmhos):	1473	Alkalinity as CaCO3 (mg/L):	214.06	Phosphate, TD (mg/L as P):	<0.030
Field pH:	6.45	Ryznar Stability Index:	6.673	Field Nitrate (mg/L):	NR
Lab pH:	6.82	Sodium Adsorption Ratio:	1.838	Field Dissolved O2 (mg/L):	2.210
Water Temp (°C):	78.6	Langlier Saturation Index:	0.073	Field Chloride (mg/L):	NR
Air Temp (°C):	NR	Nitrite (mg/L as N):	<0.05	Field Redox (mV):	247
Nitrate + Nitrite (mg/L as N)	<0.2	Hydroxide (mg/L as OH):	NR	Lab, Dissolved Organic Carbon (mg/L):	NR
Total Kjeldahl Nitrogen (mg/L as N)	NR	Lab, Dissolved Inorganic Carbon (mg/L):	NR	Lab, Total Organic Carbon (mg/L):	NR
Total Nitrogen (mg/L as N)	<1.0				

Notes

Sample Condition:

Field Remarks: FIELD PARAMETERS COLLECTED ON A SAMPLE THAT WAS COOLED TO ABOUT 45 DEGREES C. SAMPLE COLLECTED FROM TOP OF THE MOUND.

Lab Remarks: SIO2 FROM PRESERVED AND DILUTED SAMPLE.

Explanation: **mg/L** = milligrams per Liter; **µg/L** = micrograms per Liter; **ft** = feet; **NR** = No Reading in GWIC

Qualifiers: **A** = Hydride atomic absorption; **E** = Estimated due to interference; **H** = Exceeded holding time; **K** = Na+K combined; **N** = Spiked sample recovery not within control limits; **P** = Preserved sample; **S** = Method of standard additions; ***** = Duplicate analysis not within control limits; ****** = Sum of Dissolved Constituents is the sum of major cations (Na, Ca, K, Mg, Mn, Fe) and anions (HCO3, CO3, SO4, Cl, SiO2, NO3, F) in mg/L. Total Dissolved Solids is reported as equivalent weight of evaporation residue.

Disclaimer

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Ground-Water Information Center Water Quality Report

Site Name: BARKELL'S (SILVER STAR) HOT SPRINGS *

Report Date: 2/5/2011

Location Information

Sample Id/Site Id:	2011Q0617 / 8987	Sample Date:	10/8/2010 3:00:00 PM
Location (TRS):	02S 06W 01 CDD	Agency/Sampler:	MBMG / SMITH, GARRETT
Latitude/Longitude:	45° 41' 7" N 112° 17' 45" W	Field Number:	SILVER STAR
Datum:	NAD83	Lab Date:	12/1/2010
Altitude:	4680	Lab/Analyst:	MBMG / SM
County/State:	MADISON / MT	Sample Method/Handling:	GRAB / 5340
Site Type:	SPRING	Procedure Type:	DISSOLVED
Geology:	500GNSC	Total Depth (ft):	NR
USGS 7.5' Quad:	SILVER STAR	SWL-MP (ft):	NR
PWS Id:		Depth Water Enters (ft):	NR
Project:			

Major Ion Results

	mg/L	**meq/L**		**mg/L**	**meq/L**
Calcium (Ca)	8.110	0.405	Bicarbonate (HCO3)	155.200	2.544
Magnesium (Mg)	0.247	0.020	Carbonate (CO3)	4.880	0.262
Sodium (Na)	180.000	7.830	Chloride (Cl)	29.880	0.843
Potassium (K)	5.230	0.134	Sulfate (SO4)	195.700	4.076
Iron (Fe)	0.007	0.000	Nitrate (as N)	0.095	0.007
Manganese (Mn)	0.023	0.001	Fluoride (F)	8.140	0.428
Silica (SiO2)	99.900		Orthophosphate (as P)	<0.1	0.000
Total Cations		8.419	**Total Anions**		8.160

Trace Element Results (µg/L)

Aluminum (Al):	6.420	Cesium (Cs):	31.300	Molybdenum (Mo):	41.200	Strontium (Sr):	392.000
Antimony (Sb):	1.260	Chromium (Cr):	<0.2	Nickel (Ni):	<0.2	Thallium (Tl):	<0.2
Arsenic (As):	8.630	Cobalt (Co):	0.247	Niobium (Nb):	<0.2	Thorium (Th):	<0.2
Barium (Ba):	52.200	Copper (Cu):	0.512	Neodymium (Nd):	<0.2	Tin (Sn):	<0.2
Beryllium (Be):	<0.2	Gallium (Ga):	1.110	Palladium (Pd):	<0.5	Titanium (Ti):	0.944
Boron (B):	214.000	Lanthanum (La):	<0.2	Praseodymium (Pr):	<0.2	Tungsten (W):	171.000
Bromide (Br):	87.000	Lead (Pb):	<0.2	Rubidium (Rb):	20.300	Uranium (U):	<0.2
Cadmium (Cd):	<0.2	Lithium (Li):	213.000	Silver (Ag):	<0.2	Vanadium (V):	<0.2
Cerium (Ce):	<0.2	Mercury (Hg):	NR	Selenium (Se):	<0.2	Zinc (Zn):	<1.0
						Zirconium (Zr):	<0.2

Field Chemistry and Other Analytical Results

**Total Dissolved Solids (mg/L):	608.720	Field Hardness as CaCO3 (mg/L):	NR	Ammonia (mg/L):	NR
**Sum of Diss. Constituents (mg/L):	687.360	Hardness as CaCO3:	21.270	T.P. Hydrocarbons (µg/L):	NR
Field Conductivity (µmhos):	915.9	Field Alkalinity as CaCO3 (mg/L):	130	PCP (µg/L):	NR
Lab Conductivity (µmhos):	847	Alkalinity as CaCO3 (mg/L):	135.47	Phosphate, TD (mg/L as P):	<0.030
Field pH:	8.12	Ryznar Stability Index:	8.368	Field Nitrate (mg/L):	NR
Lab pH:	8.55	Sodium Adsorption Ratio:	16.985	Field Dissolved O2 (mg/L):	2.610
Water Temp (°C):	67.5	Langlier Saturation Index:	0.091	Field Chloride (mg/L):	NR
Air Temp (°C):	NR	Nitrite (mg/L as N):	<0.05	Field Redox (mV):	338
Nitrate + Nitrite (mg/L as N)	5.380	Hydroxide (mg/L as OH):	NR	Lab, Dissolved Organic Carbon (mg/L):	NR
Total Kjeldahl Nitrogen (mg/L as N)	NR	Lab, Dissolved Inorganic Carbon (mg/L):	NR	Lab, Total Organic Carbon (mg/L):	NR
Total Nitrogen (mg/L as N)	5.940				

Notes

Sample Condition:	
Field Remarks:	WATER SAMPLED FROM WEST-MOST SPRING
Lab Remarks:	SIO2 FROM PRESERVED AND DILUTED SAMPLE.

Explanation: **mg/L** = milligrams per Liter; **µg/L** = micrograms per Liter; **ft** = feet; **NR** = No Reading in GWIC

Qualifiers: **A** = Hydride atomic absorption; **E** = Estimated due to interference; **H** = Exceeded holding time; **K** = Na+K combined; **N** = Spiked sample recovery not within control limits; **P** = Preserved sample; **S** = Method of standard additions; ***** = Duplicate analysis not within control limits; ****** = Sum of Dissolved Constituents is the sum of major cations (Na, Ca, K, Mg, Mn, Fe) and anions (HCO3, CO3, SO4, Cl, SiO2, NO3, F) in mg/L. Total Dissolved Solids is reported as equivalent weight of evaporation residue.

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Ground-Water Information Center Water Quality Report **Site Name:** MGR FAIRMONT HOT SPRINGS ANACONDA MT

Report Date: 2/5/2011

Location Information

Sample Id/Site Id:	2011Q0648 / 5116	Sample Date:	10/12/2010 1:00:00 PM
Location (TRS):	03N 10W 02 BDCA	Agency/Sampler:	MBMG / SMITH, GARRETT
Latitude/Longitude:	46° 2' 34" N 112° 48' 45" W	Field Number:	FAIRMONT SPRING
Datum:	WGS84	Lab Date:	12/1/2010
Altitude:	5135	Lab/Analyst:	MBMG / SM
County/State:	SILVER BOW / MT	Sample Method/Handling:	GRAB / 5230
Site Type:	SPRING	Procedure Type:	DISSOLVED
Geology:		Total Depth (ft):	NR
USGS 7.5' Quad:	ANACONDA	SWL-MP (ft):	NR
PWS Id:		Depth Water Enters (ft):	NR
Project:	ARWWS, GEOTHERM		

Major Ion Results

	mg/L	meq/L		mg/L	meq/L
Calcium (Ca)	4.270	0.213	Bicarbonate (HCO3)	124.900	2.047
Magnesium (Mg)	0.070	0.006	Carbonate (CO3)	12.200	0.655
Sodium (Na)	180.000	7.830	Chloride (Cl)	17.520	0.494
Potassium (K)	3.900	0.100	Sulfate (SO4)	181.700	3.785
Iron (Fe)	<0.002	0.000	Nitrate (as N)	0.163	0.012
Manganese (Mn)	<0.001	0.000	Fluoride (F)	16.920	0.891
Silica (SiO2)	71.700		Orthophosphate (as P)	<0.1	0.000
Total Cations		8.182	**Total Anions**		7.884

Trace Element Results (µg/L)

Aluminum (Al):	12.000	Cesium (Cs):	67.600	Molybdenum (Mo):	27.500	Strontium (Sr):	108.000
Antimony (Sb):	0.960	Chromium (Cr):	<0.2	Nickel (Ni):	<0.2	Thallium (Tl):	<0.2
Arsenic (As):	4.290	Cobalt (Co):	<0.2	Niobium (Nb):	0.250	Thorium (Th):	<0.2
Barium (Ba):	3.170	Copper (Cu):	1.560	Neodymium (Nd):	<0.2	Tin (Sn):	<0.2
Beryllium (Be):	<0.2	Gallium (Ga):	1.400	Palladium (Pd):	<0.5	Titanium (Ti):	1.050
Boron (B):	316.000	Lanthanum (La):	<0.2	Praseodymium (Pr):	<0.2	Tungsten (W):	301.000
Bromide (Br):	<50	Lead (Pb):	<0.2	Rubidium (Rb):	18.800	Uranium (U):	<0.2
Cadmium (Cd):	<0.2	Lithium (Li):	695.000	Silver (Ag):	<0.2	Vanadium (V):	<0.2
Cerium (Ce):	<0.2	Mercury (Hg):	NR	Selenium (Se):	<0.2	Zinc (Zn):	<1.0
						Zirconium (Zr):	<0.2

Field Chemistry and Other Analytical Results

**Total Dissolved Solids (mg/L):	550.930	Field Hardness as CaCO3 (mg/L):	NR	Ammonia (mg/L):	NR
**Sum of Diss. Constituents (mg/L):	614.350	Hardness as CaCO3:	10.950	T.P. Hydrocarbons (µg/L):	NR
Field Conductivity (µmhos):	824.7	Field Alkalinity as CaCO3 (mg/L):	126	PCP (µg/L):	NR
Lab Conductivity (µmhos):	747	Alkalinity as CaCO3 (mg/L):	122.54	Phosphate, TD (mg/L as P):	<0.030
Field pH:	8.61	Ryznar Stability Index:	8.533	Field Nitrate (mg/L):	NR
Lab pH:	9.03	Sodium Adsorption Ratio:	23.671	Field Dissolved O2 (mg/L):	3.730
Water Temp (°C):	49.4	Langlier Saturation Index:	0.249	Field Chloride (mg/L):	NR
Air Temp (°C):	NR	Nitrite (mg/L as N):	<0.05	Field Redox (mV):	300
Nitrate + Nitrite (mg/L as N)	2.280	Hydroxide (mg/L as OH):	NR	Lab, Dissolved Organic Carbon (mg/L):	NR
Total Kjeldahl Nitrogen (mg/L as N)	NR	Lab, Dissolved Inorganic Carbon (mg/L):	NR	Lab, Total Organic Carbon (mg/L):	NR
Total Nitrogen (mg/L as N)	2.810				

Notes

Sample Condition:	
Field Remarks:	TAKEN FROM SMALLEST AND HOTTEST OF 3 SPRINGS NEAR RESORT UNDER PYRAMID-TYPE ENCLOSURES
Lab Remarks:	SIO2 FROM PRESERVED AND DILUTED SAMPLE.

Explanation: **mg/L** = milligrams per Liter; **µg/L** = micrograms per Liter; **ft** = feet; **NR** = No Reading in GWIC

Qualifiers: **A** = Hydride atomic absorption; **E** = Estimated due to interference; **H** = Exceeded holding time; **K** = Na+K combined; **N** = Spiked sample recovery not within control limits; **P** = Preserved sample; **S** = Method of standard additions; ***** = Duplicate analysis not within control limits; ****** = Sum of Dissolved Constituents is the sum of major cations (Na, Ca, K, Mg, Mn, Fe) and anions (HCO3, CO3, SO4, Cl, SiO2, NO3, F) in mg/L. Total Dissolved Solids is reported as equivalent weight of evaporation residue.

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Ground-Water Information Center
Water Quality Report
Report Date: 2/5/2011

Site Name: MBMG RESEARCH WELL *
FAIRMONT HOT SPRINGS WELL #6

Location Information

Sample Id/Site Id:	2011Q0646 / 5118	Sample Date:	10/12/2010 5:00:00 PM
Location (TRS):	03N 10W 02 CADB	Agency/Sampler:	MBMG / SMITH, GARRETT
Latitude/Longitude:	46° 2' 18" N 112° 48' 39" W	Field Number:	FAIRMONT WELL
Datum:	WGS84	Lab Date:	12/1/2010
Altitude:	5165	Lab/Analyst:	MBMG / SM
County/State:	SILVER BOW / MT	Sample Method/Handling:	PUMPED / 5230
Site Type:	WELL	Procedure Type:	DISSOLVED
Geology:	124LDCK	Total Depth (ft):	600
USGS 7.5' Quad:	OPPORTUNITY	SWL-MP (ft):	NR
PWS Id:		Depth Water Enters (ft):	1
Project:	GWCP05, BPSOU_BPARCO, ARWWS, GEOTHERM		

Major Ion Results

	mg/L	meq/L		mg/L	meq/L
Calcium (Ca)	3.970	0.198	Bicarbonate (HCO3)	128.300	2.103
Magnesium (Mg)	0.017	0.001	Carbonate (CO3)	14.640	0.786
Sodium (Na)	168.000	7.308	Chloride (Cl)	16.230	0.458
Potassium (K)	3.640	0.093	Sulfate (SO4)	167.800	3.495
Iron (Fe)	0.016	0.001	Nitrate (as N)	0.060	0.004
Manganese (Mn)	0.002	0.000	Fluoride (F)	15.350	0.808
Silica (SiO2)	69.200		Orthophosphate (as P)	<0.1	0.000
Total Cations		7.634	**Total Anions**		7.655

Trace Element Results (µg/L)

Aluminum (Al):	19.500	Cesium (Cs):	70.600	Molybdenum (Mo):	24.200	Strontium (Sr):	134.000
Antimony (Sb):	0.840	Chromium (Cr):	<0.2	Nickel (Ni):	<0.2	Thallium (Tl):	<0.2
Arsenic (As):	4.350	Cobalt (Co):	<0.2	Niobium (Nb):	<0.2	Thorium (Th):	<0.2
Barium (Ba):	2.120	Copper (Cu):	0.901	Neodymium (Nd):	<0.2	Tin (Sn):	<0.2
Beryllium (Be):	<0.2	Gallium (Ga):	1.550	Palladium (Pd):	<0.5	Titanium (Ti):	0.952
Boron (B):	290.000	Lanthanum (La):	<0.2	Praseodymium (Pr):	<0.2	Tungsten (W):	265.000
Bromide (Br):	<50	Lead (Pb):	0.579	Rubidium (Rb):	19.700	Uranium (U):	0.254
Cadmium (Cd):	<0.2	Lithium (Li):	619.000	Silver (Ag):	<0.2	Vanadium (V):	0.874
Cerium (Ce):	<0.2	Mercury (Hg):	NR	Selenium (Se):	<0.2	Zinc (Zn):	<1.0
						Zirconium (Zr):	<0.2

Field Chemistry and Other Analytical Results

**Total Dissolved Solids (mg/L):	522.060	Field Hardness as CaCO3 (mg/L):	NR	Ammonia (mg/L):	NR
**Sum of Diss. Constituents (mg/L):	587.010	Hardness as CaCO3:	9.980	T.P. Hydrocarbons (µg/L):	NR
Field Conductivity (µmhos):	771.2	Field Alkalinity as CaCO3 (mg/L):	NR	PCP (µg/L):	NR
Lab Conductivity (µmhos):	762	Alkalinity as CaCO3 (mg/L):	130	Phosphate, TD (mg/L as P):	<0.030
Field pH:	8.51	Ryznar Stability Index:	8.635	Field Nitrate (mg/L):	NR
Lab pH:	8.94	Sodium Adsorption Ratio:	23.139	Field Dissolved O2 (mg/L):	2.110
Water Temp (°C):	64.6	Langlier Saturation Index:	0.153	Field Chloride (mg/L):	NR
Air Temp (°C):	NR	Nitrite (mg/L as N):	<0.05	Field Redox (mV):	269
Nitrate + Nitrite (mg/L as N)	1.810	Hydroxide (mg/L as OH):	NR	Lab, Dissolved Organic Carbon (mg/L):	NR
Total Kjeldahl Nitrogen (mg/L as N)	NR	Lab, Dissolved Inorganic Carbon (mg/L):	NR	Lab, Total Organic Carbon (mg/L):	NR
Total Nitrogen (mg/L as N)	2.150				

Notes

Sample Condition:
Field Remarks: WELL CONSTANTLY PUMPING HOT WATER SENDING IT TO RESORT LOCATED SE OF HOTEL.
Lab Remarks: SIO2 FROM PRESERVED AND DILUTED SAMPLE.

Explanation: **mg/L** = milligrams per Liter; **µg/L** = micrograms per Liter; **ft** = feet; **NR** = No Reading in GWIC

Qualifiers: **A** = Hydride atomic absorption; **E** = Estimated due to interference; **H** = Exceeded holding time; **K** = Na+K combined; **N** = Spiked sample recovery not within control limits; **P** = Preserved sample; **S** = Method of standard additions; ***** = Duplicate analysis not within control limits; ****** = Sum of Dissolved Constituents is the sum of major cations (Na, Ca, K, Mg, Mn, Fe) and anions (HCO3, CO3, SO4, Cl, SiO2, NO3, F) in mg/L. Total Dissolved Solids is reported as equivalent weight of evaporation residue.

Ground-Water Information Center Water Quality Report

Site Name: GEYSER GULCH ACTIVE GEYSER

Report Date: 2/5/2011

Location Information

Sample Id/Site Id:	2011Q0650 / 252930	Sample Date:	10/13/2010 3:00:00 PM
Location (TRS):	04N 11W 13	Agency/Sampler:	MBMG / SMITH, GARRETT
Latitude/Longitude:	46° 6' 16" N 112° 54' 13" W	Field Number:	GEYSER GULCH EAST
Datum:	WGS84	Lab Date:	12/1/2010
Altitude:		Lab/Analyst:	MBMG / SM
County/State:	DEER LODGE / MT	Sample Method/Handling:	GRAB / 5230
Site Type:	SPRING	Procedure Type:	DISSOLVED
Geology:		Total Depth (ft):	NR
USGS 7.5' Quad:		SWL-MP (ft):	NR
PWS Id:		Depth Water Enters (ft):	NR
Project:	ARWWS		

Major Ion Results

	mg/L	meq/L		mg/L	meq/L
Calcium (Ca)	464.000	23.154	Bicarbonate (HCO3)	410.900	6.735
Magnesium (Mg)	36.700	3.020	Carbonate (CO3)	0.000	0.000
Sodium (Na)	164.000	7.134	Chloride (Cl)	8.180	0.231
Potassium (K)	16.900	0.432	Sulfate (SO4)	1,381.000	28.766
Iron (Fe)	0.101	0.005	Nitrate (as N)	0.055	0.004
Manganese (Mn)	0.376	0.014	Fluoride (F)	2.400	0.126
Silica (SiO2)	20.800		Orthophosphate (as P)	<0.1	0.000
Total Cations		33.901	**Total Anions**		35.862

Trace Element Results (μg/L)

Aluminum (Al):	<10.0	Cesium (Cs):	27.300	Molybdenum (Mo):	13.900	Strontium (Sr):	5,858.000
Antimony (Sb):	<1.0	Chromium (Cr):	<1.0	Nickel (Ni):	<0.9	Thallium (Tl):	<1.0
Arsenic (As):	3.800	Cobalt (Co):	<0.9	Niobium (Nb):	<0.9	Thorium (Th):	<1.0
Barium (Ba):	10.300	Copper (Cu):	4.610	Neodymium (Nd):	<1.0	Tin (Sn):	<1.0
Beryllium (Be):	<1.0	Gallium (Ga):	<0.9	Palladium (Pd):	<2.5	Titanium (Ti):	11.100
Boron (B):	91.100	Lanthanum (La):	<1.0	Praseodymium (Pr):	<1.0	Tungsten (W):	<1.0
Bromide (Br):	<50	Lead (Pb):	<1.0	Rubidium (Rb):	85.500	Uranium (U):	2.320
Cadmium (Cd):	<1.0	Lithium (Li):	215.000	Silver (Ag):	<1.0	Vanadium (V):	<1.0
Cerium (Ce):	<1.0	Mercury (Hg):	NR	Selenium (Se):	<0.9	Zinc (Zn):	<5.0
						Zirconium (Zr):	<0.9

Field Chemistry and Other Analytical Results

**Total Dissolved Solids (mg/L):	2,296.170	Field Hardness as CaCO3 (mg/L):	NR	Ammonia (mg/L):	NR
**Sum of Diss. Constituents (mg/L):	2,504.700	Hardness as CaCO3:	1,309.670	T.P. Hydrocarbons (μg/L):	NR
Field Conductivity (μmhos):	NR	Field Alkalinity as CaCO3 (mg/L):	NR	PCP (μg/L):	NR
Lab Conductivity (μmhos):	2500	Alkalinity as CaCO3 (mg/L):	337.09	Phosphate, TD (mg/L as P):	<0.150
Field pH:	NR	Ryznar Stability Index:	5.151	Field Nitrate (mg/L):	NR
Lab pH:	7.46	Sodium Adsorption Ratio:	1.972	Field Dissolved O2 (mg/L):	NR
Water Temp (°C):	NR	Langlier Saturation Index:	1.154	Field Chloride (mg/L):	NR
Air Temp (°C):	NR	Nitrite (mg/L as N):	<0.05	Field Redox (mV):	NR
Nitrate + Nitrite (mg/L as N)	<0.2	Hydroxide (mg/L as OH):	NR	Lab, Dissolved Organic Carbon (mg/L):	NR
Total Kjeldahl Nitrogen (mg/L as N)	NR	Lab, Dissolved Inorganic Carbon (mg/L):	NR	Lab, Total Organic Carbon (mg/L):	NR
Total Nitrogen (mg/L as N)	<1.0				

Notes

Sample Condition:
Field Remarks: COLLECTED FROM TOP OF STEEP, INTACT TRAVERTINE CORE
Lab Remarks: SIO2 FROM PRESERVED AND DILUTED SAMPLE.

Explanation: **mg/L** = milligrams per Liter; **μg/L** = micrograms per Liter; **ft** = feet; **NR** = No Reading in GWIC

Qualifiers: **A** = Hydride atomic absorption; **E** = Estimated due to interference; **H** = Exceeded holding time; **K** = Na+K combined; **N** = Spiked sample recovery not within control limits; **P** = Preserved sample; **S** = Method of standard additions; ***** = Duplicate analysis not within control limits; ****** = Sum of Dissolved Constituents is the sum of major cations (Na, Ca, K, Mg, Mn, Fe) and anions (HCO3, CO3, SO4, Cl, SiO2, NO3, F) in mg/L. Total Dissolved Solids is reported as equivalent weight of evaporation residue.

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Ground-Water Information Center Water Quality Report

Site Name: GEYSER GULCH DORMANT GEYSER

Report Date: 2/5/2011

Location Information

Sample Id/Site Id:	2011Q0649 / 252931	Sample Date:	10/13/2010 3:30:00 PM
Location (TRS):	04N 11W 13	Agency/Sampler:	MBMG / SMITH, GARRETT
Latitude/Longitude:	46° 6' 17" N 112° 54' 12" W	Field Number:	GEYSER GULCH WEST
Datum:	WGS84	Lab Date:	12/1/2010
Altitude:		Lab/Analyst:	MBMG / SM
County/State:	DEER LODGE / MT	Sample Method/Handling:	GRAB / 5230
Site Type:	SPRING	Procedure Type:	DISSOLVED
Geology:		Total Depth (ft):	NR
USGS 7.5' Quad:		SWL-MP (ft):	NR
PWS Id:		Depth Water Enters (ft):	NR
Project:	ARWWS		

Major Ion Results

	mg/L	**meq/L**		**mg/L**	**meq/L**
Calcium (Ca)	472.000	23.553	Bicarbonate (HCO3)	418.700	6.862
Magnesium (Mg)	65.800	5.415	Carbonate (CO3)	0.000	0.000
Sodium (Na)	166.000	7.221	Chloride (Cl)	8.140	0.230
Potassium (K)	17.200	0.440	Sulfate (SO4)	1,393.000	29.016
Iron (Fe)	0.113	0.006	Nitrate (as N)	0.103	0.007
Manganese (Mn)	0.278	0.010	Fluoride (F)	2.510	0.132
Silica (SiO2)	19.600		Orthophosphate (as P)	<0.1	0.000
Total Cations		36.790	**Total Anions**		36.248

Trace Element Results (µg/L)

Aluminum (Al):	<10.0	Cesium (Cs):	29.600	Molybdenum (Mo):	14.100	Strontium (Sr):	5,979.000
Antimony (Sb):	<1.0	Chromium (Cr):	<1.0	Nickel (Ni):	<0.9	Thallium (Tl):	<1.0
Arsenic (As):	2.090	Cobalt (Co):	<0.9	Niobium (Nb):	<0.9	Thorium (Th):	<1.0
Barium (Ba):	7.940	Copper (Cu):	<2.5	Neodymium (Nd):	<1.0	Tin (Sn):	<1.0
Beryllium (Be):	<1.0	Gallium (Ga):	<0.9	Palladium (Pd):	<2.5	Titanium (Ti):	11.200
Boron (B):	95.700	Lanthanum (La):	<1.0	Praseodymium (Pr):	<1.0	Tungsten (W):	<1.0
Bromide (Br):	<50	Lead (Pb):	<1.0	Rubidium (Rb):	86.700	Uranium (U):	2.380
Cadmium (Cd):	<1.0	Lithium (Li):	213.000	Silver (Ag):	<1.0	Vanadium (V):	<1.0
Cerium (Ce):	<1.0	Mercury (Hg):	NR	Selenium (Se):	<0.9	Zinc (Zn):	<5.0
						Zirconium (Zr):	<0.9

Field Chemistry and Other Analytical Results

**Total Dissolved Solids (mg/L):	2,351.200	Field Hardness as CaCO3 (mg/L):	NR	Ammonia (mg/L):	NR
**Sum of Diss. Constituents (mg/L):	2,563.800	Hardness as CaCO3:	1,449.420	T.P. Hydrocarbons (µg/L):	NR
Field Conductivity (µmhos):	NR	Field Alkalinity as CaCO3 (mg/L):	NR	PCP (µg/L):	NR
Lab Conductivity (µmhos):	2550	Alkalinity as CaCO3 (mg/L):	343.65	Phosphate, TD (mg/L as P):	<0.150
Field pH:	NR	Ryznar Stability Index:	5.370	Field Nitrate (mg/L):	NR
Lab pH:	7.21	Sodium Adsorption Ratio:	1.897	Field Dissolved O2 (mg/L):	NR
Water Temp (°C):	NR	Langlier Saturation Index:	0.920	Field Chloride (mg/L):	NR
Air Temp (°C):	NR	Nitrite (mg/L as N):	<0.05	Field Redox (mV):	NR
Nitrate + Nitrite (mg/L as N)	<0.2	Hydroxide (mg/L as OH):	NR	Lab, Dissolved Organic Carbon (mg/L):	NR
Total Kjeldahl Nitrogen (mg/L as N)	NR	Lab, Dissolved Inorganic Carbon (mg/L):	NR	Lab, Total Organic Carbon (mg/L):	NR
Total Nitrogen (mg/L as N)	<1.0				

Notes

Sample Condition:	
Field Remarks:	COLLECTED FROM SMALLER COLLAPSED TRAVERTINE CORE
Lab Remarks:	SIO2 FROM PRESERVED AND DILUTED SAMPLE.

Explanation: **mg/L** = milligrams per Liter; **µg/L** = micrograms per Liter; **ft** = feet; **NR** = No Reading in GWIC

Qualifiers: **A** = Hydride atomic absorption; **E** = Estimated due to interference; **H** = Exceeded holding time; **K** = Na+K combined; **N** = Spiked sample recovery not within control limits; **P** = Preserved sample; **S** = Method of standard additions; ***** = Duplicate analysis not within control limits; ****** = Sum of Dissolved Constituents is the sum of major cations (Na, Ca, K, Mg, Mn, Fe) and anions (HCO3, CO3, SO4, Cl, SiO2, NO3, F) in mg/L. Total Dissolved Solids is reported as equivalent weight of evaporation residue.

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Ground-Water Information Center Water Quality Report

Site Name: PRIVATE GEOTHERMAL TEST * ENNIS HOT SPRINGS

Report Date: 2/5/2011

Location Information

Sample Id/Site Id:	2011Q0647 / 9025	Sample Date:	10/15/2010 12:00:00 PM
Location (TRS):	05S 01W 28 DBAA	Agency/Sampler:	MBMG / SMITH, GARRETT
Latitude/Longitude:	45° 22' 12" N 111° 43' 33" W	Field Number:	ENNIS HOT SPRING
Datum:	NAD83	Lab Date:	12/1/2010
Altitude:	4912	Lab/Analyst:	MBMG / SM
County/State:	MADISON / MT	Sample Method/Handling:	GRAB / 5230
Site Type:	WELL	Procedure Type:	DISSOLVED
Geology:	400PCMB	Total Depth (ft):	1220
USGS 7.5' Quad:	ENNIS	SWL-MP (ft):	NR
PWS Id:		Depth Water Enters (ft):	NR
Project:	GEOTHERM		

Major Ion Results

	mg/L	meq/L		mg/L	meq/L
Calcium (Ca)	5.590	0.279	Bicarbonate (HCO3)	430.900	7.062
Magnesium (Mg)	0.335	0.028	Carbonate (CO3)	0.000	0.000
Sodium (Na)	352.000	15.312	Chloride (Cl)	113.900	3.213
Potassium (K)	14.300	0.366	Sulfate (SO4)	216.700	4.514
Iron (Fe)	0.200	0.011	Nitrate (as N)	0.052	0.004
Manganese (Mn)	0.016	0.001	Fluoride (F)	9.470	0.499
Silica (SiO2)	91.600		Orthophosphate (as P)	<0.1	0.000
Total Cations		16.055	**Total Anions**		15.292

Trace Element Results (µg/L)

Aluminum (Al):	12.100	Cesium (Cs):	20.800	Molybdenum (Mo):	11.500	Strontium (Sr):	151.000
Antimony (Sb):	1.030	Chromium (Cr):	<1.0	Nickel (Ni):	<0.9	Thallium (Tl):	<1.0
Arsenic (As):	22.300	Cobalt (Co):	<0.9	Niobium (Nb):	<0.9	Thorium (Th):	<1.0
Barium (Ba):	35.000	Copper (Cu):	<2.5	Neodymium (Nd):	<1.0	Tin (Sn):	<1.0
Beryllium (Be):	<1.0	Gallium (Ga):	1.210	Palladium (Pd):	<2.5	Titanium (Ti):	1.610
Boron (B):	588.000	Lanthanum (La):	<1.0	Praseodymium (Pr):	<1.0	Tungsten (W):	48.600
Bromide (Br):	457.000	Lead (Pb):	<1.0	Rubidium (Rb):	77.300	Uranium (U):	<1.0
Cadmium (Cd):	<1.0	Lithium (Li):	198.000	Silver (Ag):	<1.0	Vanadium (V):	<1.0
Cerium (Ce):	<1.0	Mercury (Hg):	NR	Selenium (Se):	<0.9	Zinc (Zn):	<5.0
						Zirconium (Zr):	<0.9

Field Chemistry and Other Analytical Results

**Total Dissolved Solids (mg/L):	1,016.250	Field Hardness as CaCO3 (mg/L):	NR	Ammonia (mg/L):	NR
**Sum of Diss. Constituents (mg/L):	1,234.940	Hardness as CaCO3:	15.340	T.P. Hydrocarbons (µg/L):	NR
Field Conductivity (µmhos):	1495	Field Alkalinity as CaCO3 (mg/L):	323	PCP (µg/L):	NR
Lab Conductivity (µmhos):	1443	Alkalinity as CaCO3 (mg/L):	353.49	Phosphate, TD (mg/L as P):	<0.030
Field pH:	7.83	Ryznar Stability Index:	8.238	Field Nitrate (mg/L):	NR
Lab pH:	8.17	Sodium Adsorption Ratio:	39.113	Field Dissolved O2 (mg/L):	1.850
Water Temp (°C):	88	Langlier Saturation Index:	-0.034	Field Chloride (mg/L):	NR
Air Temp (°C):	NR	Nitrite (mg/L as N):	<0.05	Field Redox (mV):	131
Nitrate + Nitrite (mg/L as N)	<0.2	Hydroxide (mg/L as OH):	NR	Lab, Dissolved Organic Carbon (mg/L):	NR
Total Kjeldahl Nitrogen (mg/L as N)	NR	Lab, Dissolved Inorganic Carbon (mg/L):	NR	Lab, Total Organic Carbon (mg/L):	NR
Total Nitrogen (mg/L as N)	1.930				

Notes

Sample Condition:	
Field Remarks:	COLLECTED RIGHT FROM OUTLET PIPE BEFORE WATER ENTERS POND
Lab Remarks:	SIO2 FROM PRESERVED AND DILTUED SAMPLE.

Explanation: **mg/L** = milligrams per Liter; **µg/L** = micrograms per Liter; **ft** = feet; **NR** = No Reading in GWIC

Qualifiers: **A** = Hydride atomic absorption; **E** = Estimated due to interference; **H** = Exceeded holding time; **K** = Na+K combined; **N** = Spiked sample recovery not within control limits; **P** = Preserved sample; **S** = Method of standard additions; ***** = Duplicate analysis not within control limits; ****** = Sum of Dissolved Constituents is the sum of major cations (Na, Ca, K, Mg, Mn, Fe) and anions (HCO3, CO3, SO4, Cl, SiO2, NO3, F) in mg/L. Total Dissolved Solids is reported as equivalent weight of evaporation residue.

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Ground-Water Information Center Water Quality Report

Site Name: BROADWATER HOT SPRINGS

Report Date: 2/5/2011

Location Information

Sample Id/Site Id:	2011Q0703 / 258694	Sample Date:	10/19/2010 12:00:00 PM
Location (TRS):	10N 04W 28	Agency/Sampler:	MBMG / SMITH, GARRETT
Latitude/Longitude:	46° 35' 41" N 112° 6' 45" W	Field Number:	BROADWATER
Datum:	NAD83	Lab Date:	12/1/2010
Altitude:	4123	Lab/Analyst:	MBMG / SM
County/State:	LEWIS AND CLARK / MT	Sample Method/Handling:	GRAB / 5230
Site Type:	SPRING	Procedure Type:	DISSOLVED
Geology:		Total Depth (ft):	NR
USGS 7.5' Quad:		SWL-MP (ft):	NR
PWS Id:		Depth Water Enters (ft):	NR
Project:			

Major Ion Results

	mg/L	**meq/L**		**mg/L**	**meq/L**
Calcium (Ca)	9.300	0.464	Bicarbonate (HCO3)	163.000	2.672
Magnesium (Mg)	0.295	0.024	Carbonate (CO3)	13.660	0.734
Sodium (Na)	186.000	8.091	Chloride (Cl)	36.010	1.016
Potassium (K)	5.400	0.138	Sulfate (SO4)	189.800	3.954
Iron (Fe)	<0.002	0.000	Nitrate (as N)	<0.05	0.000
Manganese (Mn)	0.012	0.000	Fluoride (F)	9.000	0.474
Silica (SiO2)	86.700		Orthophosphate (as P)	<0.1	0.000
Total Cations		8.797	**Total Anions**		8.849

Trace Element Results (µg/L)

Aluminum (Al):	3.720	Cesium (Cs):	63.700	Molybdenum (Mo):	17.300	Strontium (Sr):	201.000
Antimony (Sb):	1.420	Chromium (Cr):	<0.2	Nickel (Ni):	<0.2	Thallium (Tl):	<0.2
Arsenic (As):	7.100	Cobalt (Co):	<0.2	Niobium (Nb):	<0.2	Thorium (Th):	<0.2
Barium (Ba):	3.320	Copper (Cu):	1.500	Neodymium (Nd):	<0.2	Tin (Sn):	<0.2
Beryllium (Be):	<0.2	Gallium (Ga):	0.694	Palladium (Pd):	<0.5	Titanium (Ti):	1.010
Boron (B):	800.000	Lanthanum (La):	<0.2	Praseodymium (Pr):	<0.2	Tungsten (W):	198.000
Bromide (Br):	<50	Lead (Pb):	<0.2	Rubidium (Rb):	28.100	Uranium (U):	<0.2
Cadmium (Cd):	<0.2	Lithium (Li):	540.000	Silver (Ag):	<0.2	Vanadium (V):	<0.2
Cerium (Ce):	<0.2	Mercury (Hg):	NR	Selenium (Se):	<0.2	Zinc (Zn):	<1.0
						Zirconium (Zr):	<0.2

Field Chemistry and Other Analytical Results

**Total Dissolved Solids (mg/L):	616.900	Field Hardness as CaCO3 (mg/L):	NR	Ammonia (mg/L):	NR
**Sum of Diss. Constituents (mg/L):	699.600	Hardness as CaCO3:	24.440	T.P. Hydrocarbons (µg/L):	NR
Field Conductivity (µmhos):	882.6	Field Alkalinity as CaCO3 (mg/L):	NR	PCP (µg/L):	NR
Lab Conductivity (µmhos):	980	Alkalinity as CaCO3 (mg/L):	157.04	Phosphate, TD (mg/L as P):	<0.030
Field pH:	7.91	Ryznar Stability Index:	8.151	Field Nitrate (mg/L):	NR
Lab pH:	8.52	Sodium Adsorption Ratio:	16.374	Field Dissolved O2 (mg/L):	2.950
Water Temp (°C):	64	Langlier Saturation Index:	0.184	Field Chloride (mg/L):	NR
Air Temp (°C):	NR	Nitrite (mg/L as N):	<0.05	Field Redox (mV):	288
Nitrate + Nitrite (mg/L as N)	<0.2	Hydroxide (mg/L as OH):	NR	Lab, Dissolved Organic Carbon (mg/L):	NR
Total Kjeldahl Nitrogen (mg/L as N)	NR	Lab, Dissolved Inorganic Carbon (mg/L):	NR	Lab, Total Organic Carbon (mg/L):	NR
Total Nitrogen (mg/L as N)	<1.0				

Notes

Sample Condition:
Field Remarks:
Lab Remarks: SIO2 FROM PRESERVED AND DILUTED SAMPLE.

Explanation: **mg/L** = milligrams per Liter; **µg/L** = micrograms per Liter; **ft** = feet; **NR** = No Reading in GWIC

Qualifiers: **A** = Hydride atomic absorption; **E** = Estimated due to interference; **H** = Exceeded holding time; **K** = Na+K combined; **N** = Spiked sample recovery not within control limits; **P** = Preserved sample; **S** = Method of standard additions; ***** = Duplicate analysis not within control limits; ****** = Sum of Dissolved Constituents is the sum of major cations (Na, Ca, K, Mg, Mn, Fe) and anions (HCO3, CO3, SO4, Cl, SiO2, NO3, F) in mg/L. Total Dissolved Solids is reported as equivalent weight of evaporation residue.

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Ground-Water Information Center Water Quality Report

Site Name: WOLF CREEK HOT SPRING

Report Date: 2/5/2011

Location Information

Sample Id/Site Id:	2011Q0704 / 8876	Sample Date:	10/20/2010 12:00:00 PM
Location (TRS):	10S 01E 09 BBB	Agency/Sampler:	MBMG / SMITH, GARRETT
Latitude/Longitude:	44° 59' 2" N 111° 36' 59" W	Field Number:	WOLF CRK.
Datum:	NAD83	Lab Date:	12/1/2010
Altitude:	6051	Lab/Analyst:	MBMG / SM
County/State:	MADISON / MT	Sample Method/Handling:	GRAB / 5230
Site Type:	SPRING	Procedure Type:	DISSOLVED
Geology:		Total Depth (ft):	NR
USGS 7.5' Quad:	CLIFF LAKE 15'	SWL-MP (ft):	NR
PWS Id:		Depth Water Enters (ft):	NR
Project:	GEOTHERM		

Major Ion Results

	mg/L	meq/L		mg/L	meq/L
Calcium (Ca)	4.020	0.201	Bicarbonate (HCO3)	104.400	1.711
Magnesium (Mg)	0.841	0.069	Carbonate (CO3)	26.840	1.442
Sodium (Na)	120.000	5.220	Chloride (Cl)	20.110	0.567
Potassium (K)	1.710	0.044	Sulfate (SO4)	49.320	1.027
Iron (Fe)	<0.002	0.000	Nitrate (as N)	0.076	0.005
Manganese (Mn)	<0.001	0.000	Fluoride (F)	17.420	0.917
Silica (SiO2)	48.500		Orthophosphate (as P)	<0.1	0.000
Total Cations		5.540	**Total Anions**		5.670

Trace Element Results (µg/L)

Aluminum (Al):	20.200	Cesium (Cs):	6.870	Molybdenum (Mo):	24.900	Strontium (Sr):	25.800
Antimony (Sb):	<0.2	Chromium (Cr):	<0.2	Nickel (Ni):	<0.2	Thallium (Tl):	<0.2
Arsenic (As):	5.250	Cobalt (Co):	<0.2	Niobium (Nb):	<0.2	Thorium (Th):	<0.2
Barium (Ba):	6.940	Copper (Cu):	<0.5	Neodymium (Nd):	<0.2	Tin (Sn):	<0.2
Beryllium (Be):	<0.2	Gallium (Ga):	2.260	Palladium (Pd):	<0.5	Titanium (Ti):	0.338
Boron (B):	34.600	Lanthanum (La):	<0.2	Praseodymium (Pr):	<0.2	Tungsten (W):	26.500
Bromide (Br):	127.000	Lead (Pb):	<0.2	Rubidium (Rb):	13.600	Uranium (U):	<0.2
Cadmium (Cd):	<0.2	Lithium (Li):	53.700	Silver (Ag):	<0.2	Vanadium (V):	0.267
Cerium (Ce):	<0.2	Mercury (Hg):	NR	Selenium (Se):	<0.2	Zinc (Zn):	<1.0
						Zirconium (Zr):	<0.2

Field Chemistry and Other Analytical Results

**Total Dissolved Solids (mg/L):	340.110	Field Hardness as CaCO3 (mg/L):	NR	Ammonia (mg/L):	NR
**Sum of Diss. Constituents (mg/L):	392.880	Hardness as CaCO3:	13.500	T.P. Hydrocarbons (µg/L):	NR
Field Conductivity (µmhos):	535.8	Field Alkalinity as CaCO3 (mg/L):	NR	PCP (µg/L):	NR
Lab Conductivity (µmhos):	552	Alkalinity as CaCO3 (mg/L):	130.33	Phosphate, TD (mg/L as P):	<0.030
Field pH:	8.53	Ryznar Stability Index:	8.261	Field Nitrate (mg/L):	NR
Lab pH:	9.3	Sodium Adsorption Ratio:	14.212	Field Dissolved O2 (mg/L):	3.500
Water Temp (°C):	59.8	Langlier Saturation Index:	0.519	Field Chloride (mg/L):	NR
Air Temp (°C):	NR	Nitrite (mg/L as N):	<0.05	Field Redox (mV):	241
Nitrate + Nitrite (mg/L as N)	<0.2	Hydroxide (mg/L as OH):	NR	Lab, Dissolved Organic Carbon (mg/L):	NR
Total Kjeldahl Nitrogen (mg/L as N)	NR	Lab, Dissolved Inorganic Carbon (mg/L):	NR	Lab, Total Organic Carbon (mg/L):	NR
Total Nitrogen (mg/L as N)	<1.0				

Notes

Sample Condition:

Field Remarks:

Lab Remarks: SIO2 FROM PRESERVED AND DILUTED SAMPLE.

Explanation: **mg/L** = milligrams per Liter; **µg/L** = micrograms per Liter; **ft** = feet; **NR** = No Reading in GWIC

Qualifiers: **A** = Hydride atomic absorption; **E** = Estimated due to interference; **H** = Exceeded holding time; **K** = Na+K combined; **N** = Spiked sample recovery not within control limits; **P** = Preserved sample; **S** = Method of standard additions; ***** = Duplicate analysis not within control limits; ****** = Sum of Dissolved Constituents is the sum of major cations (Na, Ca, K, Mg, Mn, Fe) and anions (HCO3, CO3, SO4, Cl, SiO2, NO3, F) in mg/L. Total Dissolved Solids is reported as equivalent weight of evaporation residue.

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APPENDIX B. GREEN MACHINE EVALUATION FORM

ELECTRATHERM

Delivering cleantech energy solutions for a sustainable future, now

Office Use Only:

N.S. #: ____________________

P.E.F. # ____________________

Estimated Output kWe: __________

PROJECT EVALUATION FORM

Date: ________________

With your hot & cold water temperatures and flow rates, ElectraTherm can estimate recoverable power output at your project location. Your attention to detail while filling out this form is greatly appreciated. Missing or inaccurate information may prevent ElectraTherm from accurately responding to your request.

Contact: ____________________ **Phone:** ________________ **Email:** ______________________

Contact Address: ____

City: ________________ **State or Province:** __________ **Zip Code:** ________ **Country:** ______________

Are you a:

ElectraTherm Dealer: ☐ **Prospective End User:** ☐ **Other:** ☐ *Please explain:* ____________________

Brief Project Description: ____

____

Installation Site Conditions

Location of Project: ______________

Hours of available heat & condensing flow: ________________ hrs per year

End User Electrical Cost (required): ________________ per average kWh from power bill

IF HOT WATER IS CURRENTLY AVAILABLE, PLEASE COMPLETE THIS SECTION. IF NOT, SKIP TO THE NEXT SECTION.

HOT WATER **Temp** ________°F; **Flow** ________GPM (Gallons per Minute)

(Target Temperature Range: 185-240°F; Minimum Flow 150 GPM)

If hot water circulates back to the heat source after running through ElectraTherm equipment (Example: stationary engine, solar collector, boiler, etc.) please provide the amount of heat available.

Heat Available ____________ ☐ BTU/hr; or ☐ kW (select one)

Source of Hot Water: Please check one and include any available spec/data sheets:

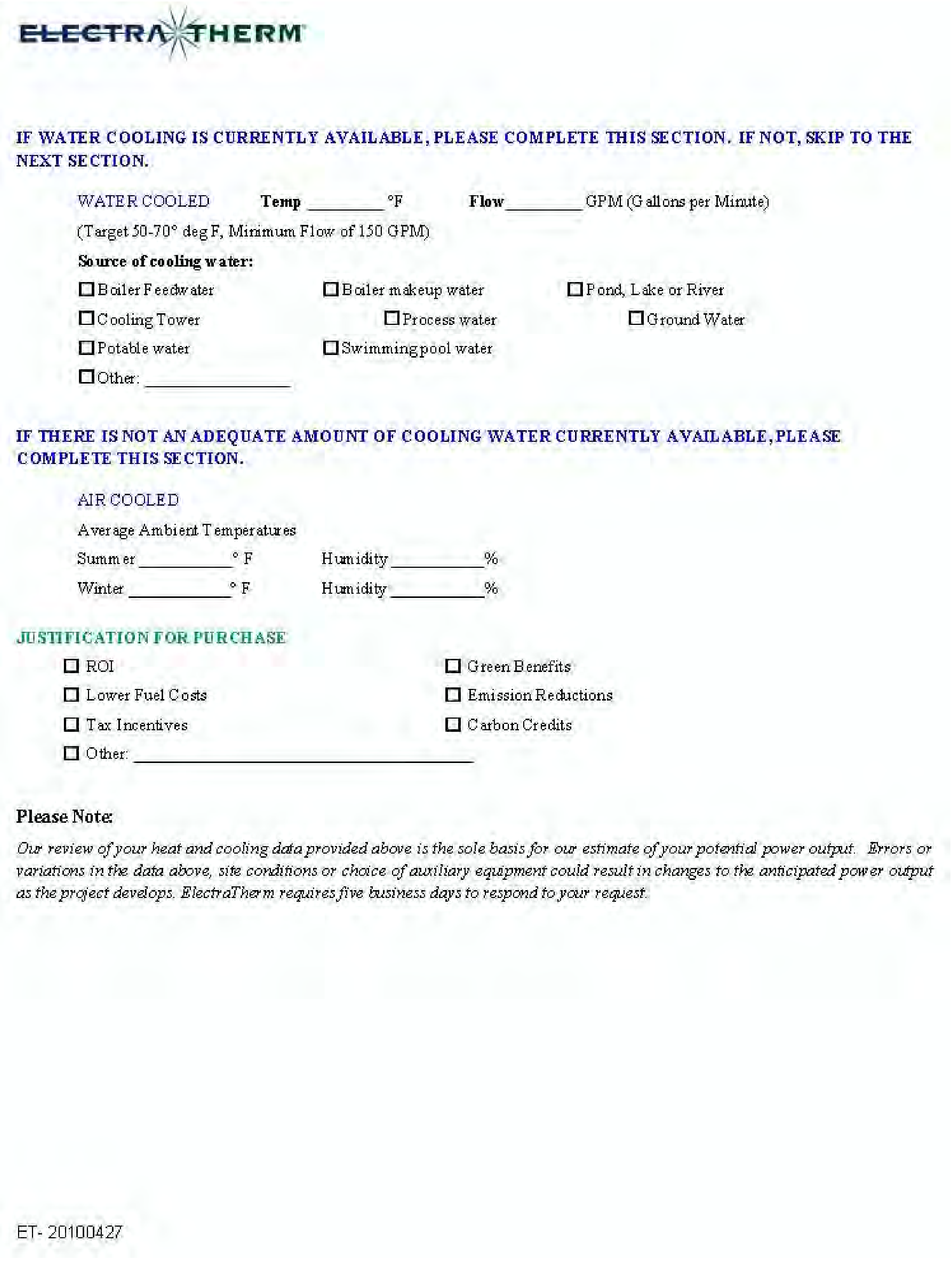
☐ Stationary Engine ☐ Boiler ☐ Geothermal ☐ Solar ☐ Process Heat ☐ Other: __________

IF HEAT IS CURRENTLY AVAILABLE FROM ENGINE OR STACK EXHAUST, PLEASE COMPLETE THIS SECTION. IF NOT, SKIP TO THE NEXT SECTION.

ENGINE EXHAUST OR STACK HEAT **Temp** ______° F; **Flow** _______ ☐* SCFM or ACFM (Please check one)

*It is ***critical*** that the above flow rate is accurately identified as being in SCFM or ACFM. If both are unknown please provide the amount of stack heat in mass flow rate ____________lbs/hr.

ET- 20100427



ELECTRATHERM

IF WATER COOLING IS CURRENTLY AVAILABLE, PLEASE COMPLETE THIS SECTION. IF NOT, SKIP TO THE NEXT SECTION.

WATER COOLED **Temp** _________ °F **Flow**_________ GPM (Gallons per Minute)

(Target 50-70° deg F, Minimum Flow of 150 GPM)

Source of cooling water:

☐ Boiler Feedwater ☐ Boiler makeup water ☐ Pond, Lake or River

☐ Cooling Tower ☐ Process water ☐ Ground Water

☐ Potable water ☐ Swimming pool water

☐ Other: _________________

IF THERE IS NOT AN ADEQUATE AMOUNT OF COOLING WATER CURRENTLY AVAILABLE, PLEASE COMPLETE THIS SECTION.

AIR COOLED

Average Ambient Temperatures

Summer ___________ ° F Humidity ___________%

Winter ____________ ° F Humidity ___________%

JUSTIFICATION FOR PURCHASE

☐ ROI ☐ Green Benefits

☐ Lower Fuel Costs ☐ Emission Reductions

☐ Tax Incentives ☐ Carbon Credits

☐ Other: ____

Please Note:

Our review of your heat and cooling data provided above is the sole basis for our estimate of your potential power output. Errors or variations in the data above, site conditions or choice of auxiliary equipment could result in changes to the anticipated power output as the project develops. ElectraTherm requires five business days to respond to your request.

ET- 20100427