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A Summary of Geothermal Studies in Montana, 1980 through 1983

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INTRODUCTION

The geothermal resources of Montana can be divided into two general areas and categories. In the mountainous western portion of the state, all of the known resources are related to valley-bounding fault systems, commonly with cross-valley faulting evidenced on one or both sides of the mountain blocks. Water is heated by deep circulation and rises along boundary faults or the intersection of boundary and cross-valley faults. A moderate amount of seismic activity (small earthquakes) is believed necessary to keep the fracture and fault conduits through which the thermal waters ascend from plugging with mineral deposits.

East of the main mountain ranges, thermal waters are encountered in the deeper sedimentary rock units. Temperatures of these waters are related to how deeply an aquifer has been buried relative to the current land surface. The major production has been from Mississippian age limestones, usually the Madison Group. Water in the Madison loses its heat slowly as the elevation of the aquifer rises, provided that flow is from deeper to more shallow areas. A thermal gradient study (bottom hole temperature divided by depth of well) by Balster (1974) reflected the configuration of this rock unit at depth. Thus the ideal exploration target is over a dome or anticline (a feature similar to a buried ridge) where warm or hot waters are rising and the drilling depth is reduced.

The reader is referred to Montana Bureau of Mines and Geology Bulletin 110 (Rautio and Sonderegger, 1980) for an annotated bibliography of research published prior to early 1980. The major emphasis of this report is to summarize the results of investigations and provide references for recent work done in various areas. General references include Sonderegger and Schmidt (1981) and the state geothermal map and tables of Sonderegger and Bergantino (1981).

WESTERN MONTANA

Northwestern Area

This area is characterized by surficial exposures of Precambrian sedimentary ("Belt") rocks which were subjected to Laramide overthrust stresses. Water temperatures at land surface are normally 50°C (122°F) or less. As currently known, the thermal water area runs in a north-south band from the Camp Aqua area in the north to the Blue Joint springs in the south, with most occurrences in the Little Bitterroot and Bitterroot valleys as shown on the enclosed map (Sonderegger and Bergantino, 1981).

The Little Bitterroot geothermal system is believed to consist of thermal waters ascending valley-bounding faults on both sides of the valley, with a common source at depth having a maximum reservoir temperature of 77°C (Donovan and others, 1980; Donovan and Sonderegger 1981a; Sonderegger and Donovan, 1981; Donovan, in manuscript). On the east side of the valley, the thermal water rises along fractures until encountering an areally-extensive gravel at the base of the Pleistocene deposits. It then flows laterally in the gravel deposit, presenting a much easier drilling target for development. As of December 1983, there are three wells which penetrate the gravel zone near the entry area of the thermal water. The oldest well of 6-inch diameter into the gravel supplies the Camp Aqua bath house. The intermediate well, drilled by the Montana

Bureau of Mines and Geology (MBMG) under a contract with the U.S. Department of Energy (DOE) as a 6-inch test hole, was cased through the gravel, has 980 feet of 2-inch liner pipe for geophysical probes, and receives water from fractured argillite and quartzite (Donovan and Sonderegger, 1981b). The latest well, drilled to a depth of 261 feet for Jackola Engineering in 1982, has a 10-inch casing perforated with a mills knife throughout the 10-foot gravel zone. The wells are artesian and flow rates depend upon completion and aquifer pressure, ranging from 200 to 1,000 gallons per minute (gpm).

The Green Springs warm pond was sampled in October of 1980; the sodium bicarbonate water is quite low in total dissolved solids (TDS = 182 milligrams per liter - mg/L). The interpretation of its setting is similar to that at Camas Hot Springs, with hot water rising in fractures associated with a valley- bounding fault and mixing slightly with cold meteoric water in the alluvium. The estimated reservoir temperature is 75°C at a depth of two to three kilometers.

The Quinns (Paradise) Hot Spring was dried up when the owners drilled for additional hot water. The higher silica content of this water suggests a hotter reservoir temperature (79°C) than previously estimated (Sonderegger and Bergantino, 1981). However, the association with the Perma Sills suggests that the warm water ascends along fractures associated with the sills. The well, drilled in 1980, is 145 feet (44m) deep and has a bottom hole temperature of 46.4°C (115.6°F); the yield from this 8-inch well was estimated at 50 to 100 gpm (3.15 to 6.31 liters/second - L/s) according to the owners.

The Lolo Hot Springs issue from a series of solution-widened fractures near the contact between the Idaho batholith and limestones of the Wallace Group. The low TDS and calcium content indicate limited contact time with the limestone unit. The combined discharge is approximately 180 gpm (11.4 L/s). The maximum measured temperature is 46.4°C (115.5°F). The thermal waters are believed to rise along fractures within the intrusive that are probably subparallel to the contact and the result of cooling and contraction, as the outer margin of the intrusive should have cooled more rapidly than the interior portions. Calculated reservoir temperatures (Fournier, 1981) are quite variable (Na-K-Ca geothermometer = 74.6°C; chalcedony geothermometer = 91.2°C; quartz (no steam loss) = 119.6°C) and a reasonable estimate of the depth to the reservoir cannot be made. The published estimate of the reservoir temperature (83°C, Sonderegger and Bergantino, 1981) is conservative.

The Florence (15°C, 59°F) test well shows that water at temperatures suitable for heat pump use is available at moderate depths (410 feet, 125 meters).

At Sleeping Child Hot Springs, the hot water issues from fractures in Precambrian granitic gneisses and quartzite(?) that have been intruded and hydrothermally "granitized" by the Idaho batholith. The 52°C (125.6°F) water issues from fractures at the base of a cliff north of the pool; a second spring which yields 43°C (109.4°F) water is located up the creek, northeast of the pool. Reported discharge values from the springs have varied widely. What appears to be the most reliable value for the useable combined flows is about 115 gpm (7.3 L/s) based upon information provided by the owners in 1964. The hotter spring contributes about 25 percent of the discharge. The estimated reservoir temperature published with the state geothermal map (Sonderegger and Bergantino, 1981) of 125°C is probably too high; the best value is in the range 85-90°C, which again suggests circulation to depths of 2 to 3 kilometers.

The Medicine Hot Springs appear to be controlled by fault-related fractures, possibly where the fault splayed (broke up into several faults with movement of the blocks of rock between the various smaller faults). The springs are located on the northwest side of the creek. They have been covered and their discharge is piped to the swimming pool and bath house. The 45°C (113°F) water is of low TDS; the chalcedony and sodium-potassium-calcium geothermometers agree closely for the estimated reservoir temperature of 82°C. This suggests 2 to 3 kilometer circulation depths, similar to the other springs in this group. The water issues from "granitic" rocks of the Idaho batholith. South of Laird Creek, aphanitic layers (sills?) were noted in a road cut along Highway 93, but it is not known if they also occur adjacent to the thermal springs.

The two Blue Joint spring areas are about one mile apart. They occur along the (sheared?) contact between the Idaho batholith and the Ravalli Quartzite (which in turn controls the location of the Blue Joint Creek in this immediate area) issuing from alluvial deposits adjacent to the quartzite contact. The chemistry gives widely ranging geothermometry reservoir temperatures for these low conductance (TDS values for no. 1 and no. 2 are 126 and 145 mg/L, respectively) waters. Circulation may be 2 kilometers or less as dilution by very pure shallow ground water is too difficult to evaluate. The low surface temperature (29°C, 84-85°F) limits the usefulness of these springs.

The Elkhorn Hot Springs are the easternmost springs included in the "northwestern" area. The springs issue from the Boulder batholith, but the water characteristics suggest a closer affinity with the other waters in this group than with the "southwestern" area. The springs produce 48-49^{o}C (118-120^{o}F) water with low dissolved solids (TDS = 179 mg/L). Reported discharge values have ranged widely ranging from 1 cubic foot per second (448 gpm, 28.3 L/s) reported to have been measured in 1938 down to 28 gpm (1.77 L/s) measured by the U.S. Geological Survey (USGS) in 1976. The observed temperature and calculated reservoir temperature (70-75^{o}C, 158-167^{o}F) suggest a two to three kilometer deep circulation system in relatively non-reactive rock type such as the Belt quartzites, as evidenced by the low TDS.

The Jackson Hot Spring area was recently studied by Geoff Black. His results (1984a, 1984b) suggest that listric faults control the movement of the thermal water (58^{o}C, 136^{o}F at land surface). Previous estimates of the reservoir temperature, using the uncorrected Na-K-Ca geothermometer were too high. The magnesium corrected Na-K-Ca, chalcedony, and oxygen 18 of sulfate and water geothermometers suggest a 70 to 75^{o}C reservoir temperature. The reason for the hotter surface temperature at Jackson is believed to be the greater insulating effect of the Tertiary sediments which cap the system. An alternate interpretation, preferred by Black, is that mixing or re-equilibration occursand that higher reservoir temperatures exist at greater depth. At Jackson and Sleeping Child, pre-existing U.S. Geological Survey (USGS) reservoir temperature estimates were used for the state geothermal map (Sonderegger and Bergantino, 1981); however, additional experience indicates that those values are probably too great unless substantial mixing has occurred. The discharge of 260 gpm (16.3 L/s) makes this a viable resource for direct use at the spring discharge temperature.

Southwestern Area

This area is characterized by Tertiary-age block-faulted valleys and mountain ranges which frequently cut features formed by earlier tectonic stresses. It is the author's personal belief many of the Tertiary features in this "block", bounded by the Montana Lineament on the north and the Snake River Valley zone of crustal melting to the south, have resulted from movement along pre-existing Precambrian basement fault zones.

The southwestern area contains the greatest variability of type for geothermal systems and is the only area with a remote chance of having a currently unrecognized igneous heat source due to the paucity of young igneous rocks elsewhere (Daniel and Berg, 1982). The Snake River Valley in eastern Idaho is a zone of thin continental crust, attributed by many to partial melting of the crust related to plate tectonics. The northeastern end of the valley has a sequence of volcanic rocks which become progressively younger as Yellowstone Park is approached. Within the Park, not too far from the Montana border, two domes are currently rising, and geophysical data show a non-solid condition--presumably molten magma--at depth. Areas on the western and northern edges of the Park have the potential for deep wells intersecting magmatically heated water, particularly along the Idaho boundary. This is the reason that a buffer zone of no geothermal devlopment was recommended by Don White (of the USGS) and others.

Establishing a widely accepted average geothermal gradient for southwestern Montana may be an unrealistic goal. However, such a value aids in comparisons of circulation depths. Data presented by Blackwell and Robertson (1973) for the Boulder batholith yield a calculated heat flow of 2.00 $\mu cal/cm^2$ sec. and a measured average of 1.98 $\pm$ 0.06 $\mu cal/cm^2$ sec. Using their figure D-2, the gradient fitted for the Butte area yields $\cong 30^oC/km$ for rock temperatures, which is slightly lower than their $31.9^oC/km$ interpretation (Table D-A). AMOCO's Hirschy number 1 well, located in the Big Hole Valley, Beaverhead County, was drilled to a total depth of 4.886 km (16,030 ft.) and had a bottom hole temperature of 183^oC (362^oF). This yields $36.6^oC/km$ as an average gradient; however, the temperature increase was greatest in the bottom 800 feet of the logged interval. An earlier Schlumberger run when the well was 13,374 feet (4.076 km) deep resulted in a $32.0^oC/km$ gradient. While recognizing that sedimentary basins normally have larger gradients than adjacent crystalline rocks (Rybach, 1981, p. 11), the depths and attained temperatures cited are such that the use of $30^oC/km$ as an average value is believed to be justified.

The southwestern Montana geothermal systems can be fit into three basic categories without too much difficulty. The first (type one) is similar to those previously discussed; fracture contolled circulation systems with a circulation depth of 2.5 kilometers (1.55 miles, 8,200 feet) or less, based upon calculated reservoir temperatures of 80^oC or less and an assumed regional gradient of $30^oC/km$. The second (type two) system is the same, with deep circulation (depth greater than 2 1/2 km) assumed, based upon higher calculated reservoir temperatures. The third type is a carbonate-related flow system (i.e., a permeable limestone) irrespective of depth and temperature although most of the thermal-spring systems are relatively shallow and do not contain high-temperature water.

This third type is typically a large-volume, low-temperature, system. Beaverhead and Madison counties have several systems of this type. Examples are the McMenomey Ranch, Brown's and Lovell's springs southwest of Dillon, the Apex and Beaverhead Rock springs north of Dillon, the Anderson's Pasture and Staudenmeyer springs in the Centennial Valley (Sonderegger and others, 1982), and the Trudau and Vigilante springs in the Ruby Valley (Sonderegger and Bergantino, 1981). Additional springs and wells of this type include Anderson's spring, the McLeod, Lucas and Ringling wells, the Bedford, Toston, and Plunket's Lake springs, the Bruce well, and the Carter's Bridge, Bridger Canyon, Garrison, Bearmouth, Nimrod, and Sun River springs. Wyatt (1984a, b) has studied the Radersburg basin area; however, most of these low-temperature systems have received very little study beyond discharge and temperature measurements, and selected water samples for chemical analysis.

There are a few, low-discharge, high-temperature carbonate system springs. Chico is a transitional sitution with a 320 gpm (20.17 L/s) discharge and a 45^{o}C (113^{o}F) temperature. The New Biltmore springs at 53^{o}C (127^{o}F) have a discharge of less than 100 gpm (6.3 L/s) with reported values ranging from 31 to 100 gpm (1.96 to 6.3 L/s). The reservoir temperature (Fournier, 1981) for New Biltmore calculated from chalcedony and Na-K-Ca geothermometers is 71^{o}C, more in line with what would be expected from a type one system. The higher temperature may be partly related to the lower thermal conductivity of the Tertiary sediments which overlie the carbonate bedrock.

The Corwin (LaDuke) hot spring discharges about 100 gpm (6.3 L/s) of 63°C water which is believed (Struhsacker, 1976) to ascend along the intersection of the Mammoth and Gardiner fault zones. Alternate interpretations of chemical data yield circulation depths of 2 to 4 kilometers with reservoir temperatures of from 75° to 130°C (see Rautio and Sonderegger, 1980, p. 19-20). This system, including the Bear Creek Spring, because of its proximity to the Mammoth and Norris areas in Yellowstone National Park, could possibly have some magmatic heat contribution as suggested by Struhsacker (1976).

One of the enigmatic systems which may belong in this group occurs at Warm Springs State Hospital. The water chemistry is similar to that at Corwin, except somewhat lower in total dissolved solids. The travertine spring mound, which rises about 20 feet above the surrounding valley floor, may be a modern analogue of the extensive travertine terraces near Anaconda which were mined around the turn of the century (Weed, 1905). For this system, the surface spring temperature, the calculated reservoir temperature, and the temperature of water produced from a 1500 foot (457 meter) deep well are virtually identical ranging from 77 to 79°C (171-174°F), suggesting a relatively rapid upflow of the water. Discharge measurements of the spring and well yields probably give too low of an equilibrium discharge for the system because of leakage losses. Copious amounts of luke-warm water were encountered in a shallow gravel zone, at a depth of 15 to 18 feet (4.6-5.5 meters), when the MBMG test well to evaluate shallow aquifers was drilled southeast of the mound. Natural discharge from the system may be more in the 200 to 300 gpm (12.6-18.9 L/s) range. It has been suggested that the water quality at the Warm Springs site has been greatly modified by the Anaconda smelter operations and tailings. This could possibly been resolved by analyzing the sulfur isotope ratio ($^{34}S/^{32}S$) in the dissolved sulfate of the spring water. In hopes of sending a suite of samples from high sulfate springs, I kept waiting for the University of Utah sulfur isotope line to become functional and never did obtain these data. The reader is referred to Wideman, et. al. (1982) for a brief summary of geophysical studies in the Deer Lodge Valley.

The type two systems, because of their higher temperatures are probably of greatest interest. The major thermal systems in this category with calculated reservoir temperatures greater than $100^{o}C$ are: Alhambra, Boulder, Bozeman, Broadwater, Ennis, Gregson, Norris, and Silver Star. All but Bozeman, Norris and Ennis are within or on the margin of the Boulder batholith.

Alhambra and Broadwater were studied in some detail by Robert Leonard of the USGS. The report on radioactivity by Leonard and Janzer (1978) includes a discussion of the geohydrologic setting at Alhambra. MBMG Open-File Report 98 by Dan Vice (1982) has sections on both Broadwater and Alhambra denoting anomalously warm ground at these sites. A test well drilled in 1981 by the Bureau on a cooperative basis with the Renewable Energy Division of the Department of Natural Resources and Conservation (DNR&C) and with DOE failed to find hot water at the Broadwater anomaly selected by DNR&C (Donovan and Sonderegger, 1982).

Galloway (1977) presented an interpretative cross section of the Alhambra system based upon geologic mapping and resistivity studies. Several different reservoir temperatures can be calculated for Alhambra; the most conservative, using the chalcedony geothermometer, yields a value of 87°C, requiring circulation to depths slightly greater than 2.5 kilometers. The measured temperatures at Alhambra range from 50 to 59.4°C, with most being in the vicinity of 55°C. In contrast, the Broadwater Hot Springs surface temperatures appear to range from 65 to 67°C (Leonard and others, 1978) and contain higher dissolved silica content. Using 98 mg/L dissolved SiO_2, the chalcedony geothermometer yields a calculated reservoir temperature of 109°C which requires circulation to a depth of nearly 3.5 kilometers. The high calcium and magnesium contents of these waters suggests that the chalcedony calculations are the most reliable and the low chloride content (<40 mg/L) makes mixing-model calculations highly questionable. The systems both appear to be controlled by fracture permeability associated with valley-margin block faulting. The results of a drilling and pump testing program by the owner at Broadwater have not been made public but are believed to indicate a stable yield in the vicinity of 500 gpm (31.5 L/s).

Attempts to study the Boulder Hot Springs system and outlying geophysical anomalies were essentially thwarted by the owner. A summary by Wideman (1981) was included in MBMG Open-File Report 94. Spring improvement and numerous plumbing modifications make discharge measurements nearly impossible; estimates from visual inspection range from 250 to 1,000 gpm (15.8 to 63.1 L/s) with 500 gpm (31.5 L/s) probably being a reasonable figure. The hottest measured temperature is 76°C. A previous owner, Willard Mack, stated that there were 40 springs ranging from hot to cool on the property. The early description of this site by Weed (1900) concentrates on the veins (which contain both quartz and chalcedony) and is one of the earliest studies undertaken in this country to understand precious metal deposits of geothermal origin. Calculations using the chalcedony geothermometer yield a reservoir temperature of 116°C, while the quartz and Na-Ca-K calculations yield 143 and 137°C, respectively. Assuming a reservoir temperature of 140°C and a thermal gradient of 30°C/km requires a circulation system 4.25 kilometers (2.6 miles or nearly 14,000 feet) deep. Weed's descriptions include calcite from veins southeast of the hotel which suggest that calcium may now be lost at depth and that the 116°C reservoir temperature may be more valid for the Boulder system.

The Bozeman Hot Springs are located at the KOA Campground, operated by Charles Page, six miles west of Bozeman on U.S. Highway 191. Drilling by Mr. Page during 1980 provided additional water samples which have altered the interpretation of the system's depth and equilibration (reservoir) temperatures. Previous estimates of the reservoir temperature, using data from Mariner and others (1976), which were the best available data when the manuscript was written, were too low (Sonderegger and Bergantino, 1981, Table 1; based upon quartz = 115°C, chalcedony = 86°C, and Na-K-Ca = 75°C). New samples, run in the Bureau laboratory, yield reservoir temperatures of 118, 90, and 122°C for quartz, chalcedony and Na-K-Ca geothermometers, respectively. This difference is attributed to shallow ground water diluting the samples collected by earlier workers. Our analyses are included in Appendix I; the major differences with respect to earlier samples are the lower calcium and magnesium concentrations, and the slightly higher silica content.

Use of the quartz rather than chalcedony temperature is rarely warranted where the observed temperature is so low (54°C, 129°F). The computer program WATEQF (Plummer and others, 1976) was used to evaluate potential solubility controls on the calcium content (the lower the Ca content, the higher the calculated temperature). Calcite and fluorite were calculated to be less than 32 percent of saturation, consequently, the Na-K-Ca temperature is believed to be valid and the calculated reservoir temperature should be about 120°C. This implies a system circulation depth of at least 3.7 kilometers, considerably greater than the 2.5 kilometer depth previously estimated.

Test-flow results for the 1980 well were remarkably promising, with 1500 gpm (95 L/s) initial flow rates, and a projected long-term sustained yield of 790 gpm (50 L/s) at 54°C (Donovan and others, 1982). The state is currently permitting this Bozeman Hot Springs well for 4.2×10^8 gallons per year (800 gpm daily average).

The gravity study, (Donovan and others, 1982) had alternate interpretations (bedrock high or siliceous cementing). Resistivity studies (Lupindu, 1983) failed to define the deep, hot water zones, presumably due to the masking effect of shallow, cold ground water. A seismic profile was attempted to aid in interpreting the gravity data, however, energy dissipation was so great that first arrivals from the bedrock were questionable. Reversed, high-resolution, reflection seismic profiles using explosives are needed to attain proper definition. However, permitting may be very difficult in this area, due to the high density of domestic dwellings (and wells) adjacent to the area.

A soil mercury survey was also attempted to aid in delineating the trend of the system. Soil mercury values were mostly less than 20 parts per billion (ppb). Three "high" values (45, 51, and 61 ppb) were all along roads, and impact from the local weed control program is suspected. Based upon these data, it is believed that the Bozeman Hot Springs system never was hot enough to have a significant vapor phase (Varekamp and Buseck, 1983, fig. 17; 1984).

The Ennis system will be the subject of a separate report (Sonderegger, 1984). The interpretation of the permeability in the gneiss being due to Laramide overthrusting (Sonderegger and Zaluski, 1983) was supported by geophysical data presented at the 1983 American Association of Petroleum Geologists regional meeting (Rasmussen and Fields, 1983). Only a "shallow" essentially horizontal reservoir encountered at depths of 500-1100 feet (152-335 meters) was evaluated with these wells. Stable production at 88°C from this zone appears to be limited to 500 gpm or less ($\leq$31.5 L/s) based upon a 24-hour pump test of a 1220-foot (366-meter) deep well (Sonderegger, 1983). Calculated reservoir temperatures vary considerably: (1) quartz = 141°C; (2) chalcedony = 115°C; (3) Na-K-Ca-Mg = 163°C; and (4) $\Delta^{18}O$ (SO_4-H_2O) of 92-95°C depending upon which value is used from Leonard and Wood (1980, p. 14). WATEQF (Plummer and others, 1976), a computer program to evaluate equilibrium of waters with mineral species, was run with the thermal water chemistry. Calculations show that the water is slightly (58 percent) supersaturated with respect to calcite; these results make the Na-K-Ca-Mg calculations suspect. The oxygen isotope temperatures are subject to contamination by meteoric water; the isotope values are from the spring, as the samples were collected prior to drilling, and the lack of a complete water analysis to go with the isotope data makes it suspect also. Assuming a minimum reservoir temperature of 115°C, the circulation system must be at least 3.5 kilometers deep using the regional gradient of 30°C/km.

The Gregson (Fairmont) area is being studied by David Brodahl (1984 a, b). Drilling during the summer of 1983 by the MBMG on the resistivity anomaly described by Wideman and others (1982) resulted in production at 300 gpm (18.9 L/s) from the 6-inch well during a two-hour development period at a temperature of 68°C (155°F). The shallow geothermal gradient is about 400°C/km, but becomes isothermal once the fractured granite is encountered (Wideman and Sonderegger, 1984). The test well, 1/3 of a mile south of the hot springs, has been turned over to the landowner but has not yet been put to use other than for observation purposes. Quartz and Na-K-Ca geothermometers yield reservoir temperatures of 128 and 124°C, respectively, while the chalcedony calculation yields 101°C. If the maximum temperature truly is 128°C, this requires a convection system 4 kilometers deep; while the minimum depth (based upon chalcedony) is slightly over 3 kilometers.

An initial study of the Norris area by Peterson (1983) will be followed in the near future by her M.S. thesis (at Montana Tech). The Norris site data yields a variety of geothermometer calculations (130°C, quartz; 103°C, chalcedony; 88°C, Na-K-Ca-Mg); the chalcedony value is a reasonable estimate and implies circulation to depths of about 3 km. The water is of good quality (TDS ≅ 640 mg/L) as are most hot springs which issue from pre-Belt, metamorphic rocks. The areas of anomalous resistivity appear to have fault controlled trends; Peterson notes about eight square miles of anomalous area, however, the Waterlode mine-water temperatures are not abnormal and the anomalous area should be reduced a bit. Measured temperatures range from 45 to 52.5^{o}C; the temperature at the spring (rather than later discharge points) is believed to be 50 to 52.5^{o}C (122-127^{o}F).

The Silver Star (Barkell's Hot Springs) site has one of the highest calculated reservoir temperatures in the state. The quartz, Na-K-Ca, and $\Delta^{18}O$ (SO_4 - H_2O) geothermometers yield temperatures of 143, 139, an 135^{o}C, respectively. In the past, debris-filled spring boxes and corroded pipes have caused discharge losses. During a site visit in 1978, the author measured 20 gpm (1.26 L/s) at the pool, estimated 45 to 50 gpm (2.84-3.15 L/s) being delivered to the spring boxes, and 75 gpm (4.73 L/s) as potential spring discharge if the springs were cleaned out. For yields in excess of 100 gpm (6.31 L/s) wells would be required. The water temperature is about 72^{o}C (162^{o}F) as measured at a grate below the upper spring boxes. 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. This area has had very little attention since Abdul-Malik's (1977) resistivity survey despite his recommendation for a test well at this site. Using the regional geothermal gradient, the calculated circulation depth is about 4.3 kilometers.

CENTRAL MONTANA

Two central Montana springs that have been of particular interest for development are Hunter's Hot Springs and White Sulphur Springs, which because of location or quantity of discharge are attractive for utilization, despite their lower calculated reservoir temperatures.

The Hunter's site was not investigated as part of the Bureau effort. Leonard's (Leonard and others, 1978) discharge values of about 750 gpm (47.3 L/s) are measured, while Mariner's (Mariner and others, 1976) value of less than 1320 gpm (<83.33 L/s) may include an estimate of non-measurable flow. Reported temperatures range from 54 to 60°C (129 to 140°F) (Leonard and others, 1978).

The state school sections adjacent to Hunter's Hot Springs were considered a detriment to development until leases for geothermal rights could be obtained. When these sections were put up for bid, there were no bidders in 1983 for the geothermal lease; this suggests that the group which was interested in trying to drill a deep well has abandoned the project. The proposed deep well was based upon the interpretation that the hot springs are fed by the rise of water along a west-dipping thrust fault, which is supported by Weed's (1905) description of gypsum "reefs" to the west of the hot spring area.

Calculated reservoir temperatures at Hunter's are: quartz, 115°C; chalcedony, 85.5°C; and Na-K-Ca, 85.3°C. The minimum circulation depth is believed to be 2.5 kilometers for this system based upon an 85°C reservoir equilibration temperature and assuming that the 30°C/km gradient is valid. The water chemistry used (Mariner and others, 1976) is so free of alkaline earth elements (Ca<1 mg/L, Mg<0.1 mg/L) that mixing is not believed to be significant despite the low fluoride (5.6 mg/L) and chloride (18 mg/L) contents. This alkaline water (pH = 9.1) is low in dissolved solids (calculated TDS = 390 mg/L) and the only drawbacks to its use should be its alkalinity and a tendency toward silica scaling. The calculated Eh of -0.439 volts (pe = -6.644), based upon the sulfide/sulfate ratio, is very reducing (i.e., the water is essentially devoid of oxygen) and supports the hypothesized unmixed water which in turn implies the lower reservoir temperature and relatively shallow circulation system.

At White Sulphur Springs, the situation is not nearly so clear cut. The spring location appears to be controlled by both thrust and normal faults, with substantial discharge into the valley alluvial fill (Gogas, 1984a, 1984b; Lipindu, 1983; Gierke, 1984). Chemical geothermometers yield quite variable results: quartz, 103°C; chalcedony 73°C; Na-K-Ca-Mg, 16°C; $\Delta^{18}O(SO_4 - H_2O)$, 52°C. The range of these temperatures shows that assumptions of equilibration at depth and a rapid ascent without mixing are not met in this case. Evaluation of Mariner's (1976) analysis using WATEQF indicates that the water is greatly supersaturated with respect to pyrite, supersaturated with respect to quartz, chalcedony and fluorite, and undersaturated with respect to calcite. If mixing during ascent has occurred, the Ralph Johnson well, drilled in Tertiary sediments and located about 3.5 miles east of White Sulphur Springs may represent a cooled thermal water with minor dilution. A copy of the laboratory analysis is included in Appendix I; the water is sodium dominant (99 percent) with bicarbonate plus carbonate (46.5 percent), sulfate (29.1 percent) and chloride (24.4 percent) as the anions.

Comparison of Mariners analysis of the springs to the analysis of the Johnson well yields ratios of 0.2176, 0.2254, and 0.2377 for Cl, Na, and SO_4, respectively, which permits the estimation that the spring water could be produced by mixing 23 percent geothermal water with 77 percent distilled water. The high chloride content suggests a thermal or oil-field brine origin, with a thermal origin the apparently more reasonable interpretation. A further discussion of the interpretation will be presented in the MBMG Memoir on geological and hydrogeochemical investigations (see Sonderegger, 1984). At this point in time, while previous reservoir temperature estimates are questioned and may need to be adjusted downward, there is still uncertainty as to how to treat these data.

EASTERN MONTANA

Madison Group Aquifer Units

In eastern Montana, the major potential geothermal resource is the Madison Group carbonate complex. Outside of the Little Rockies area, warm and hot water from these units can only be obtained by drilling wells. The first evaluation of the Madison Group for geothermal resource assessment was by Balster (1974). Since then, Richard Feltis with the U.S. Geological Survey has published a series of maps dealing with the Madison Group as MBMG Geologic Map Series numbers 9-12, 15-18, and 20-22, inclusive. These maps, at a scale of 1:125,000, permit reasonably accurate prediction of the depth that a well must be drilled to reach the top of the Madison Group at a specific site. When used in conjunction with Feltis' (1980l, 1980m) potentiometric and dissolved-solids maps, reasonable projections of aquifer pressure and ground-water quality can also be made for a site. Head and others (1978) have presented both temperature and structure contour data for the Madison Group in the Powder River Basin at a scale of 1:1,000,000. Downey (1982, p. 66) depicts temperatures for the eastern part of the state, however, this map is very large scale and generalized.

In the category of wells which incidentally encountered hot water, the best documented case is the Western Energy well at Colstrip. The well was drilled to a depth of 9200 feet (2800 m); the majority of the hot water is believed to have come from the Mission Canyon Limestone at a depth of 7700 feet (2350 m). Well tests by Van Voast (personal communication) yielded a transmissibility of 650 gpd/ft, and a storage coefficient of 2×10^{-4}; under test conditions, the well flowed 230 gpm of $97^{\circ}C$ ($207^{\circ}F$) water with a 16 psi confining pressure. A petroleum laboratory analysis of the water yielded a total dissolved solids content of about 1500 milligrams per liter. The pH value reported was 6.3, which is not very acidic, but, the water was sufficiently corrosive to cause casing leaks in a period of about five years. The well was cemented and abandoned seven years after being drilled.

Old petroleum test wells that produce warm or hot water frequently produce this water from the Madison Group. The Ringling and Lucas wells near White Sulphur Springs produce 800 and 100 gpm of $48^{\circ}C$ ($118^{\circ}F$) water from Mississippian age rocks (Leonard and others, 1978). The Saco well, now used by the Sleeping Buffalo Resort, produces a reported 290 gpm of 41.3°C (106°F) water from this same strata.

After several years of economic and engineering evaluation, it appears that hot-water producing (220-265°F, 104-129°C) wells in the Poplar area will finally be developed. The water quality of these brines has previously precluded their use.

SUMMARY

Development of geothermal resources is still occurring in Montana. The euphoric predictions of the early 1970's (e.g. Marysville) have passed and planning for development has become more realistic both in terms of the resource base and the costs of coming on-line with Montana's low- to intermediate-temperature resources.

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APPENDIX I

Water-Quality Information

MONTANA BUREAU OF MINES AND GEOLOGY
BUTTE, MONTANA 59701 (406)496-4101

WATER QUALITY ANALYSIS
LAB NO. 8002828

STATE	MONTANA	COUNTY	GALLATIN
LATITUDE-LONGITUDE	45D39'38"N 111D11'10"W	SITE LOCATION	2S 4E 14 DAD
UTM COORDINATES	Z N E	MBMG SITE	
TOPOGRAPHIC MAP	BOZEMAN 15'	STATION ID	453938111111002
GEOLOGIC SOURCE	120SDMS* *	* SAMPLE SOURCE	SPRING
DRAINAGE BASIN	AH	LAND SURFACE ALTITUDE	4735. FT < 10
AGENCY + SAMPLER	MBMG*FAS	SUSTAINED YIELD	
BOTTLE NUMBER	BOZ-3	YIELD MEAS METHOD	
DATE SAMPLED	17-DEC-80	TOTAL DEPTH OF WELL	
TIME SAMPLED	14:00 HOURS	SWL ABOVE(-) OR BELOW GS	
LAB + ANALYST	MBMG*FNA	CASING DIAMETER	
DATE ANALYZED	14-JAN-81	CASING TYPE	
SAMPLE HANDLING	4120	COMPLETION TYPE	*
METHOD SAMPLED	GRAB	PERFORATION INTERVAL	
WATER USE	RECREATIONAL		

SAMPLING SITE BOZEMAN HOT SPRINGS * ORIGINAL SPRING
GEOLOGIC SOURCE SEDIMENTS (TERTIARY)

	MG/L	MEQ/L		MG/L	MEQ/L
CALCIUM (CA)	5.1	0.25	BICARBONATE (HCO3)	62.5	1.02
MAGNESIUM (MG)	.6	0.05	CARBONATE (CO3)	22.1	0.74
SODIUM (NA)	135.	5.87	CHLORIDE (CL)	49.7	1.40
POTASSIUM (K)	2.8	0.07	SULFATE (SO4)	130.	2.71
IRON (FE)	.028	0.00	NITRATE (AS N)	.093	0.01
MANGANESE (MN)	.001	0.00	FLUORIDE (F)	9.9	0.52
SILICA (SIO2)	69.3		PHOSPHATE TOT (AS P)		
TOTAL CATIONS		6.25	TOTAL ANIONS		6.40

STANDARD DEVIATION OF ANION-CATION BALANCE (SIGMA) 0.74

CALCULATED DISSOLVED SOLIDS	455.41	TOTAL HARDNESS AS CACO3	15.20
SUM OF DISS. CONSTITUENT	487.12	TOTAL ALKALINITY AS CACO3	88.12
FIELD CNDUCTVY, MICROMHOS	770.	FIELD ALKALINITY AS CACO3	86.0
LAB CNDUCTVY, MICROMHOS	711.9	RYZNAR STABILITY INDEX	8.40
FIELD PH	8.45	LANGLIER SATURATION INDEX	0.44
LABORATORY PH	9.29	SODIUM ADSORPTION RATIO	15.07

PARAMETER	VALUE	PARAMETER	VALUE
FIELD TEMP. WATER	54.0 C		
ALUMINUM, DISS (MG/L-AL)	<.03	STRONTIUM,DISS (MG/L-SR)	.099
SILVER,DISS (MG/L AS AG)	<.002	TITANIUM DIS(MG/L AS TI)	.002
BORON ,DISS (MG/L AS B)	.28	VANADIUM,DISS(MG/L AS V)	<.001
CADMIUM,DISS(MG/L AS CD)	.004	ZINC,DISS (MG/L AS ZN)	.004
CHROMIUM, DISS (MG/L-CR)	<.002	ZIRCONIUM DIS(MG/L AS ZR	.006
COPPER,DISS (MG/L AS CU)	<.002	LITHIUM,DISS(MG/L AS LI)	.037
MOLYBDENUM,DISS(MG/L-MO)	.03	NICKEL,DISS (MG/L AS NI)	<.01
LEAD,DISS (MG/L AS PB)	.06	ARSENIC,DISS(UG/L AS AS)	5.0
SULFIDE,TOTAL(MG/L AS S)	.11	DISSLVD SOLIDS(CALC MG/L	455.

REMARKS: ORIGINAL SPRING AT HOT SPRINGS SITE * BOTTOM HOLE TEMP 55.3 C * (LEONARD, USGS, 1980) *

EXPLANATION: MG/L = MILLIGRAMS PER LITER, UG/L = MICROGRAMS PER LITER, MEQ/L MILLIEQUIVELENTS PER LITER. FT = FEET, MT = METERS. (M) = MEASURED, (E) = ESTIMATED, (R) = REPORTED. TR = TOTAL RECOVERABLE. TOT = TOTAL. BIO = BIOLOGICALLY AVAILABLE.

QW WA S2 WI OW PW AT OTHER
OTHER AVAILABLE DATA
OTHER FILE NUMBERS:

PROJECT: COST:
LAST EDIT DATE: 03-FEB-83 BY: JKS*JKS
PROCESSING PROGRAM: F1730P V3 (09/1/83) PRINTED: 01-MAR-84

PERCENT MEQ/L (FOR PIPER PLOT)

CA	MG	NA	K	CL	SO4	HCO3	CO3
4.1	0.8	94.0	1.2	23.9	46.1	17.5	12.5

NOTE: IN CORRESPONDENCE, PLEASE REFER TO LAB NUMBER: 8002828

MONTANA BUREAU OF MINES AND GEOLOGY — WATER QUALITY ANALYSIS
BUTTE, MONTANA 59701 (406)496-4101 — LAB NO. 8002829

STATE	MONTANA	COUNTY	GALLATIN
LATITUDE-LONGITUDE	45D39'37"N 111D11'10"W	SITE LOCATION	2S 4E 14 DAD
UTM COORDINATES	Z N E	MBMG SITE	
TOPOGRAPHIC MAP	BOZEMAN 15'	STATION ID	
GEOLOGIC SOURCE	400PRBL* *	* SAMPLE SOURCE	WELL
DRAINAGE BASIN	AH	LAND SURFACE ALTITUDE	4735. FT < 50
AGENCY + SAMPLER	MBMG*FAS	SUSTAINED YIELD	30. GPM
BOTTLE NUMBER	BOZ-4	YIELD MEAS METHOD	BUCKET/STOPWATCH
DATE SAMPLED	16-DEC-80	TOTAL DEPTH OF WELL	540. FT
TIME SAMPLED	16:00 HOURS	SWL ABOVE(-) OR BELOW GS	FLOWING
LAB + ANALYST	MBMG*FNA	CASING DIAMETER	
DATE ANALYZED	20-JAN-81	CASING TYPE	
SAMPLE HANDLING	4120	COMPLETION TYPE	*
METHOD SAMPLED	GRAB	PERFORATION INTERVAL	
WATER USE	RESEARCH		

SAMPLING SITE BOZEMAN HOT SPRINGS * OWNER - CHARLES PAGE
GEOLOGIC SOURCE PRE-BELT

	MG/L	MEQ/L		MG/L	MEQ/L
CALCIUM (CA)	2.3	0.11	BICARBONATE (HCO3)	52.5	0.86
MAGNESIUM (MG)	.05	0.00	CARBONATE (CO3)	26.4	0.88
SODIUM (NA)	115.	5.00	CHLORIDE (CL)	50.	1.41
POTASSIUM (K)	2.4	0.06	SULFATE (SO4)	131.	2.73
IRON (FE)	.005	0.00	NITRATE (AS N)	.084	0.01
MANGANESE (MN)	.001	0.00	FLUORIDE (F)	10.1	0.53
SILICA (SIO2)	71.2		PHOSPHATE TOT (AS P)		
TOTAL CATIONS		5.18	TOTAL ANIONS		6.42

STANDARD DEVIATION OF ANION-CATION BALANCE (SIGMA) 6.46

CALCULATED DISSOLVED SOLIDS	434.40	TOTAL HARDNESS AS CACO3	5.95
SUM OF DISS. CONSTITUENT	461.04	TOTAL ALKALINITY AS CACO3	87.09
FIELD CNDUCTVY, MICROMHOS	734.	FIELD ALKALINITY AS CACO3	90.0
LAB CNDUCTVY, MICROMHOS	715.1	RYZNAR STABILITY INDEX	8.99
FIELD PH	8.60	LANGLIER SATURATION INDEX	0.21
LABORATORY PH	9.41	SODIUM ADSORPTION RATIO	20.52

PARAMETER	VALUE	PARAMETER	VALUE
FIELD TEMP, WATER	59.0 C		
ALUMINUM, DISS (MG/L-AL)	.05	STRONTIUM,DISS (MG/L-SR)	.056
SILVER,DISS (MG/L AS AG)	.007	TITANIUM DIS(MG/L AS TI)	.001
BORON ,DISS (MG/L AS B)	.26	VANADIUM,DISS(MG/L AS V)	.011
CADMIUM,DISS(MG/L AS CD)	.007	ZINC,DISS (MG/L AS ZN)	.011
CHROMIUM, DISS (MG/L-CR)	<.002	ZIRCONIUM DIS(MG/L AS ZR	.016
COPPER,DISS (MG/L AS CU)	.005	LITHIUM,DISS(MG/L AS LI)	.038
MOLYBDENUM,DISS(MG/L-MO)	.03	NICKEL,DISS (MG/L AS NI)	.02
LEAD,DISS (MG/L AS PB)	<.04	ARSENIC,DISS(UG/L AS AS)	5.0
SULFIDE,TOTAL(MG/L AS S)	.11		

REMARKS: SEEP EMITTING FROM MOUND AROUND NEW (1980) WELL *
MAY BE LEAKAGE AROUND CASING OR LEAK IN WELD *
LAB: FU NA OF 145 MG/L GIVES -.329 SIGMA *

EXPLANATION: MG/L = MILLIGRAMS PER LITER, UG/L = MICROGRAMS PER LITER, MEQ/L MILLIEQUIVELENTS PER LITER. FT = FEET, MT = METERS. (M) = MEASURED, (E) = ESTIMATED, (R) = REPORTED. TR = TOTAL RECOVERABLE. TOT = TOTAL. BIO = BIOLOGICALLY AVAILABLE.

QW WA S2 WI OW PW AT OTHER
OTHER AVAILABLE DATA
OTHER FILE NUMBERS:

PROJECT: — COST:
LAST EDIT DATE: 06-APR-81 — BY: TP *CLG
PROCESSING PROGRAM: F1730P V3 (09/1/83) — PRINTED: 01-MAR-84

PERCENT MEQ/L (FOR PIPER PLOT)

CA	MG	NA	K	CL	SO4	HCO3	CO3
2.2	0.1	96.5	1.2	24.0	46.1	14.6	15.0

NOTE: IN CORRESPONDENCE, PLEASE REFER TO LAB NUMBER: 8002829

MONTANA BUREAU OF MINES AND GEOLOGY
BUTTE, MONTANA 59701 (406)496-4101

WATER QUALITY ANALYSIS
LAB NO. 8002830

STATE	MONTANA	COUNTY	GALLATIN
LATITUDE-LONGITUDE	45D39'37"N 111D11'10"W	SITE LOCATION	2S 4E 14 DAD
UTM COORDINATES	Z N E	MBMG SITE	
TOPOGRAPHIC MAP	BOZEMAN 15'	STATION ID	453937111111001
GEOLOGIC SOURCE	400PRBLX *	* SAMPLE SOURCE	WELL
DRAINAGE BASIN	AH	LAND SURFACE ALTITUDE	4735. FT < 50
AGENCY + SAMPLER	MBMG*FAS	SUSTAINED YIELD	
BOTTLE NUMBER	BOZ-2	YIELD MEAS METHOD	
DATE SAMPLED	17-DEC-80	TOTAL DEPTH OF WELL	460. FT (R)
TIME SAMPLED	13:00 HOURS	SWL ABOVE(-) OR BELOW GS	22.8 FT (R)
LAB + ANALYST	MBMG*FRA	CASING DIAMETER	
DATE ANALYZED	14-JAN-81	CASING TYPE	
SAMPLE HANDLING	4120	COMPLETION TYPE	*
METHOD SAMPLED	GRAB	PERFORATION INTERVAL	
WATER USE	RECREATIONAL		

SAMPLING SITE BOZEMAN HOT SPRINGS * OLD WELL
GEOLOGIC SOURCE PRE-BELT

	MG/L	MEQ/L		MG/L	MEQ/L
CALCIUM (CA)	1.3	0.06	BICARBONATE (HCO3)	53.7	0.88
MAGNESIUM (MG)	<.01		CARBONATE (CO3)	25.2	0.84
SODIUM (NA)	144.	6.26	CHLORIDE (CL)	50.	1.41
POTASSIUM (K)	2.8	0.07	SULFATE (SO4)	132.	2.75
IRON (FE)	.003	0.00	NITRATE (AS N)	.18	0.01
MANGANESE (MN)	<.001		FLUORIDE (F)	10.1	0.53
SILICA (SIO2)	70.3		PHOSPHATE TOT (AS P)		
TOTAL CATIONS		6.40	TOTAL ANIONS		6.42

STANDARD DEVIATION OF ANION-CATION BALANCE (SIGMA) 0.11

CALCULATED DISSOLVED SOLIDS	462.34	TOTAL HARDNESS AS CACO3	3.25
SUM OF DISS. CONSTITUENT	489.58	TOTAL ALKALINITY AS CACO3	86.07
FIELD CNDUCTVY, MICROMHOS	775.	FIELD ALKALINITY AS CACO3	92.0
LAB CNDUCTVY, MICROMHOS	713.9	RYZNAR STABILITY INDEX	9.47
FIELD PH	8.50	LANGLIER SATURATION INDEX	-0.02
LABORATORY PH	9.43	SODIUM ADSORPTION RATIO	

PARAMETER	VALUE	PARAMETER	VALUE
FIELD TEMP. WATER	54.0 C		
ALUMINUM, DISS (MG/L-AL)	<.04	STRONTIUM,DISS (MG/L-SR)	.065
SILVER,DISS (MG/L AS AG)	<.002	TITANIUM DIS(MG/L AS TI)	.001
BORON ,DISS (MG/L AS B)	.26	VANADIUM,DISS(MG/L AS V)	.003
CADMIUM,DISS(MG/L AS CD)	<.002	ZINC,DISS (MG/L AS ZN)	.004
CHROMIUM, DISS (MG/L-CR)	<.002	ZIRCONIUM DIS(MG/L AS ZR	.005
COPPER,DISS (MG/L AS CU)	<.002	LITHIUM,DISS(MG/L AS LI)	.038
MOLYBDENUM,DISS(MG/L-MO)	.03	NICKEL,DISS (MG/L AS NI)	<.01
LEAD,DISS (MG/L AS PB)	<.04	ARSENIC,DISS(UG/L AS AS)	5.4
SULFIDE,TOTAL(MG/L AS S)	.15		

REMARKS: OLD WELL AT HOT SPRINGS * NOT CASED INTO BEDROCK - HOLE SLOWLY CLOSING *

EXPLANATION: MG/L = MILLIGRAMS PER LITER, UG/L = MICROGRAMS PER LITER, MEQ/L MILLIEQUIVELENTS PER LITER. FT = FEET, MT = METERS. (M) = MEASURED, (E) = ESTIMATED, (R) = REPORTED. TR = TOTAL RECOVERABLE. TOT = TOTAL. BIO = BIOLOGICALLY AVAILABLE.

QW WA S2 WI OW PW AT OTHER

OTHER AVAILABLE DATA
OTHER FILE NUMBERS:

PROJECT: COST:
LAST EDIT DATE: 13-JUL-82 BY: TP *JKS
PROCESSING PROGRAM: F1730P V3 (09/1/83) PRINTED: 01-MAR-84

PERCENT MEQ/L (FOR PIPER PLOT)

CA	MG	NA	K	CL	SO4	HCO3	CO3
1.0	0.0	97.9	1.1	24.0	46.8	15.0	14.3

NOTE: IN CORRESPONDENCE, PLEASE REFER TO LAB NUMBER: 8002830

MONTANA BUREAU OF MINES AND GEOLOGY
BUTTE, MONTANA 59701 (406)496-4101

WATER QUALITY ANALYSIS
LAB NO. 8002831

STATE	MONTANA	COUNTY	GALLATIN
LATITUDE-LONGITUDE	45D39'37"N 111D11'10"W	SITE LOCATION	2S 4E 14 DAD
UTM COORDINATES	Z N E	MBMG SITE	
TOPOGRAPHIC MAP	BOZEMAN 15'	STATION ID	
GEOLOGIC SOURCE	400PRBL* *	* SAMPLE SOURCE	WELL
DRAINAGE BASIN	AH	LAND SURFACE ALTITUDE	4735. FT < 50
AGENCY + SAMPLER	MBMG*FAS	SUSTAINED YIELD	1000. GPM
BOTTLE NUMBER	B0Z-1	YIELD MEAS METHOD	ESTIMATED
DATE SAMPLED	17-DEC-80	TOTAL DEPTH OF WELL	540. FT (R)
TIME SAMPLED	12:00 HOURS	SWL ABOVE(-) OR BELOW SS	FLOWING
LAB + ANALYST	MBMG*FNA	CASING DIAMETER	
DATE ANALYZED	20-JAN-81	CASING TYPE	
SAMPLE HANDLING	4120	COMPLETION TYPE	*
METHOD SAMPLED	GRAB	PERFORATION INTERVAL	
WATER USE	RESEARCH		

SAMPLING SITE BOZEMAN HOT SPRINGS * OWNER - CHARLES PAGE
GEOLOGIC SOURCE PRE-BELT

	MG/L	MEQ/L		MG/L	MEQ/L
CALCIUM (CA)	2.68	0.13	BICARBONATE (HCO3)	55.1	0.90
MAGNESIUM (MG)	<.01		CARBONATE (CO3)	24.7	0.82
SODIUM (NA)	136.	5.92	CHLORIDE (CL)	50.3	1.42
POTASSIUM (K)	2.5	0.06	SULFATE (SO4)	133.	2.77
IRON (FE)	<.002		NITRATE (AS N)	.14	0.01
MANGANESE (MN)	<.001		FLUORIDE (F)	10.2	0.54
SILICA (SIO2)	70.2		PHOSPHATE TOT (AS P)		
TOTAL CATIONS		6.11	TOTAL ANIONS		6.46

STANDARD DEVIATION OF ANION-CATION BALANCE (SIGMA) 1.75

CALCULATED DISSOLVED SOLIDS	456.86	TOTAL HARDNESS AS CACO3	6.69
SUM OF DISS. CONSTITUENT	484.82	TOTAL ALKALINITY AS CACO3	86.39
FIELD CNDUCTVY, MICROMHOS	741.	FIELD ALKALINITY AS CACO3	72.0
LAB CNDUCTVY, MICROMHOS	716.8	RYZNAR STABILITY INDEX	8.86
FIELD PH	8.71	LANGLIER SATURATION INDEX	0.27
LABORATORY PH	9.41	SODIUM ADSORPTION RATIO	

PARAMETER	VALUE	PARAMETER	VALUE
FIELD TEMP. WATER	55.0 C		
ALUMINUM, DISS (MG/L-AL)	.04	STRONTIUM,DISS (MG/L-SR)	.067
SILVER,DISS (MG/L AS AG)	<.002	TITANIUM DIS(MG/L AS TI)	.001
BORON ,DISS (MG/L AS B)	.25	VANADIUM,DISS(MG/L AS V)	.003
CADMIUM,DISS(MG/L AS CD)	.003	ZINC,DISS (MG/L AS ZN)	<.003
CHROMIUM, DISS (MG/L-CR)	<.002	ZIRCONIUM DIS(MG/L AS ZR	.005
COPPER,DISS (MG/L AS CU)	<.002	LITHIUM,DISS(MG/L AS LI)	.038
MOLYBDENUM,DISS(MG/L-MO)	.02	NICKEL,DISS (MG/L AS NI)	<.01
LEAD,DISS (MG/L AS PB)	<.04	ARSENIC,DISS(UG/L AS AS)	5.0
SULFIDE,TOTAL(MG/L AS S)	.27	DISSLVD SOLIDS(CALC MG/L	457.

REMARKS: NEW WELL (1980) AT HOT SPRINGS SITE *
LAB: FU NA OF 144 MG/L GIVES -.010 SIGMA *

EXPLANATION: MG/L = MILLIGRAMS PER LITER, UG/L = MICROGRAMS PER LITER, MEQ/L
MILLIEQUIVELENTS PER LITER. FT = FEET, MT = METERS. (M) = MEASURED, (E) =
ESTIMATED, (R) = REPORTED. TR = TOTAL RECOVERABLE. TOT = TOTAL.
BIO = BIOLOGICALLY AVAILABLE.

QW WA S2 WI OW PW AT OTHER
OTHER AVAILABLE DATA.
OTHER FILE NUMBERS:

PROJECT: COST:
LAST EDIT DATE: 03-FEB-83 BY: JKS*JKS
PROCESSING PROGRAM: F1730P V3 (09/1/83) PRINTED: 01-MAR-84

PERCENT MEQ/L (FOR PIPER PLOT)

CA	MG	NA	K	CL	SO4	HCO3	CO3
2.2	0.0	96.8	1.1	24.0	46.8	15.3	13.9

NOTE: IN CORRESPONDENCE, PLEASE REFER TO LAB NUMBER: 8002831

MONTANA BUREAU OF MINES AND GEOLOGY
BUTTE,MONTANA 59701 (406)496-4101

WATER QUALITY ANALYSIS
LAB NO. 82Q0862

STATE	MONTANA	COUNTY	MEAGHER
LATITUDE-LONGITUDE	46D32'40"N 110D54'22"W	SITE LOCATION	09N 06E 13 ADAA
UTM COORDINATES	Z N E	MBMG SITE	WSS026
TOPOGRAPHIC MAP	WHITE SULPHUR SPRINGS 7 1	STATION ID	463240110542201
GEOLOGIC SOURCE	120SDMS* * *	SAMPLE SOURCE	WELL
DRAINAGE BASIN	BC	LAND SURFACE ALTITUDE	5040. FT < 10
AGENCY + SAMPLER	MBMG*WGG	SUSTAINED YIELD	
BOTTLE NUMBER	WSS026	YIELD MEAS METHOD	
DATE SAMPLED		TOTAL DEPTH OF WELL	175. FT (R)
TIME SAMPLED	: HOURS	SWL ABOVE(-) OR BELOW GS	31.5 FT (M)
LAB + ANALYST	MBMG*FNA	CASING DIAMETER	6 IN
DATE ANALYZED	04-FEB-83	CASING TYPE	STEEL
SAMPLE HANDLING		COMPLETION TYPE	*
METHOD SAMPLED		PERFORATION INTERVAL	
WATER USE	IRRIGATION		

SAMPLING SITE RALPH JOHNSON,P.O.BOX 65,WHITE SULPHUR SPR
GEOLOGIC SOURCE SEDIMENTS (TERTIARY)

	MG/L	MEQ/L		MG/L	MEQ/L
CALCIUM (CA)	2.5	0.12	BICARBONATE (HCO3)	2533.	41.51
MAGNESIUM (MG)	3.4	0.28	CARBONATE (CO3)	86.4	2.88
SODIUM (NA)	2130.	92.65	CHLORIDE (CL)	827.	23.33
POTASSIUM (K)	19.	0.49	SULFATE (SO4)	1332.	27.73
IRON (FE)	.009	0.00	NITRATE (AS N)	.56	0.04
MANGANESE (MN)	.007	0.00	FLUORIDE (F)	7.7	0.41
SILICA (SIO2)	44.0		PHOSPHATE TOT (AS P)		
TOTAL CATIONS		93.55	TOTAL ANIONS		95.90

STANDARD DEVIATION OF ANION-CATION BALANCE (SIGMA) 1.59

CALCULATED DISSOLVED SOLIDS	5700.36	TOTAL HARDNESS AS CACO3	20.24
SUM OF DISS. CONSTITUENT	6985.58	TOTAL ALKALINITY AS CACO3	2221.60
FIELD CNDUCTVY, MICROMHOS		FIELD ALKALINITY AS CACO3	
LAB CNDUCTVY, MICROMHOS	7878.	RYZNAR STABILITY INDEX	6.88
FIELD PH		LANGLIER SATURATION INDEX	0.87
LABORATORY PH	8.63	SODIUM ADSORPTION RATIO	206.04

PARAMETER	VALUE	PARAMETER	VALUE
FIELD TEMP, AIR	68. F	FIELD TEMP, WATER	59.5 F
ALUMINUM, DISS (MG/L-AL)	.03	NICKEL,DISS (MG/L AS NI)	<.01
SILVER,DISS (MG/L AS AG)	<.002	LEAD,DISS (MG/L AS PB)	.10
BORON ,DISS (MG/L AS B)	25.2	STRONTIUM,DISS (MG/L-SR)	.62
CADMIUM,DISS(MG/L AS CD)	<.002	TITANIUM DIS(MG/L AS TI)	.003
CHROMIUM, DISS (MG/L-CR)	<.002	VANADIUM,DISS(MG/L AS V)	.038
COPPER,DISS (MG/L AS CU)	<.002	ZINC,DISS (MG/L AS ZN)	<.004
LITHIUM,DISS(MG/L AS LI)	2.02	ZIRCONIUM DIS(MG/L AS ZR	.026
MOLYBDENUM,DISS(MG/L-MO)	.60	ARSENIC,DISS(UG/L AS AS)	11.8
DISSLVD SOLIDS(CALC MG/L	5700.		

REMARKS: WATER FOAMS WHEN AGITATED;SALTY;YELLOW;SUSPENDED CLAYS;DIRTY FILTER*
NO PRESSURE TANK, WELL HAS BEEN USED VERY LITTLE SINCE INSTALLATION I
APRIL 1982*OWNER CLAIMS THE WATER IS KILLING HIS TREES*SUB PUMP 12 GP
LAB: FU NA 2230 MG/L; GIVES 97.9 TOTAL CATION MEQVS AND BORON PRESENT AS
LAB: H3BO3 GIVES 98.2 TOTAL ANION MEQVS FOR .2 SIGMA*

EXPLANATION: MG/L = MILLIGRAMS PER LITER, UG/L = MICROGRAMS PER LITER, MEQ/L
MILLIEQUIVELENTS PER LITER. FT = FEET, MT = METERS. (M) = MEASURED, (E) =
ESTIMATED, (R) = REPORTED, TR = TOTAL RECOVERABLE, TOT = TOTAL.
BIO = BIOLOGICALLY AVAILABLE.

QW WA S2 WI OW PW AT OTHER
OTHER AVAILABLE DATA
OTHER FILE NUMBERS:

PROJECT: COST:
LAST EDIT DATE: 23-SEP-83 BY: TP *JKS
PROCESSING PROGRAM: F173QP V3 (09/1/83) PRINTED: 28-FEB-84

PERCENT MEQ/L (FOR PIPER PLOT)

CA	MG	NA	K	CL	SO4	HCO3	CO3
0.1	0.3	99.0	0.5	24.4	29.1	43.5	3.0

NOTE: IN CORRESPONDENCE, PLEASE REFER TO LAB NUMBER: 82Q0862

MBMG

TABLES FOR GEOTHERMAL RESOURCES MAP OF MONTANA

compiled by

John L. Sonderegger,

R. N. Bergantino

and

Sandra Kovacich

TABLES

Table 1—Springs, Inventory Data

Table 2—Springs, Water Analysis Information

Table 3—Wells, Inventory Data

Table 4—Wells, Water-Quality Data

Prepared in cooperation with DOE and NOAA.

Hydrogeologic Map 4 1981

Montana Bureau of Mines and Geology

A Department of

Montana College of Mineral Science and Technology

PREFACE

This geothermal resource information is largely derived from materials previously available only as open-file reports of the Montana Bureau of Mines and Geology (MBMG). Information on most other sources of data is given in MBMG Bulletin 110.

Financial support for this report was provided by the U.S. Department of Energy, Division of Geothermal Energy, under Cooperative Agreement No. DE-FC07-79ID12033.

In certain areas, the map size did not permit complete display of all the information. Tables contain additional well information for the Camas-Hot Springs area where some flows were estimated from shut-in pressures and where some variation in temperature is shown; additional information is also shown for the Radersburg basin area. Confidential data are not included. They have been considered, however, in establishing the size of the map areas denoted in gray; most of these data suggest reductions in the size of the resource area. In those cases where only confidential information was available for an area, the area was not plotted.

We thank the many investigators who have published their work or permitted us to incorporate their results in this study. We also thank the many landowners who allowed us access to their wells and springs. Their friendliness and helpfulness made collecting data for this project a pleasure.

John L. Sonderegger
Hydrogeologist
R. N. Bergantino
Hydrogeologist

Butte
June 22, 1981

TABLE 1 — SPRINGS, INVENTORY DATA

Spring Name	Location T	R	S	Tr.	Latitude	Longitude	Altitude (Ft.)	Topographic Map	Source of Water	Estimated Reservoir Temp. °C	Observed Temp. °C	Dates	Agency	pH	SC (μ mho/cm) @ 25° C	TDS
Alhambra	8N	3W	16	ACAA	46.4486	111.9828	4,360	Clancy 15′	Boulder batholith:	96	55.6	08-23-74	USGS*	7.23	929	660
									See U.S.G.S. Open-File			09-01-72	MBMG	8.84†	929	630
									Report 78-438							
Anaconda	4N	11W	13	AAA	46.1044	112.9039	5,490	Anaconda 15′	Tertiary volcanics	75	21.7	06-23-78	MBMG	7.31	2624	2310
									or Madison							
Anderson's	3S	13E	29	ABAB	45.5530	110.1422	5,540	McLeod Basin 7.5′	Madison	30	25.0	07-25-72	MBMG	7.84	414	270
Anderson's Pasture	13S	2W	18	ACD	44.7044	111.8925	6,840	Lower Red Rock Lake 15′	Madison	45	26.0	10-03-77	MBMG*	7.4	609	400
									2 springs							
Apex	5S	9W	10	AADADD	45.4203	112.6911	5,240	Glen 7.5′	Madison	76	25.0	05-25-78	MBMG	7.78	520	340
Avon	10N	8W	24	BBC	46.6111	112.5536	4,900	Avon 15′	Tertiary volcanics, Terrace	--	25.5	06-16-78	MBMG	6.9	870	650†
Bear Creek	9S	9E	19	CAA	45.0320	110.6670	5,600	Gardiner 15′	Tertiary volcanics:	--	24.0	05-23-78	MBMG	9.5	2700	2000†
									Precambrian							
Bearmouth 1 & 2	11N	14W	12	CD	46.7169	113.3031	3,835	Bearmouth 15′	Madison	--	20.2	06-17-78	MBMG	7.6	642	480†
										35	19.6	03-18-72	USGS	7.69	610	420
Beaverhead Rock	5S	7W	22	ABBD	45.3919	112.4511	4,810	Beaverhead Rock 7.5′	Tertiary sediments	--	27.0	08-21-66	MBMG	7.2	--	--
									over Madison (?)							
Bedford	7N	1E	23	BAAD	46.3542	111.5667	3,880	Townsend 15′	Tertiary sediments	30	23.6	06-23-78	MBMG	7.2	467	350†
Blue Joint 1	2S	23W	1	ABB	45.6973	114.3809	5,040	Painted Rocks Lake 15′	Idaho batholith:	45	29.0	08-11-72	MBMG	8.12†	162	145
									Precambrian Ravalli							
Blue Joint 2	2S	22W	6	BAD	45.6964	111.3642	4,940	Painted Rocks Lake 15′	Idaho batholith:	45	29.0	08-11-72	MBMG	8.22†	180	145
									Precambrian Ravalli							
Boulder	5N	4W	10	CBA	46.1981	112.0947	4,850	Boulder 15′	Boulder batholith	136	76.0	08-22-74	USGS*	8.50	523	423
												11-24-64	HEALTH	--	--	388
Bozeman	2S	4E	14	DDBAA	45.6608	111.1869	4,735	Bozeman 15′	Pre-Belt,	80	54.6	08-25-74	USGS*	8.58	624	433
									Tertiary sediments	--		1964	HEALTH	--	--	428
Bridger Canyon	1S	6E	34	BCDD	45.7078	110.9750	4,890	Bozeman Pass 15′	Madison	25	20.2	--	USFWS	7.7	448	270
Broadwater	10N	4W	28	ACA	46.5958	112.1097	4,100	Helena 15′	Belt and Boulder batholith	118	62.0	08-24-74	USGS*	8.53	796	596
												09-17-64	HEALTH	--	--	563
Brooks	17N	18E	19	DBDBB	47.2192	109.4729	3,760	Lewistown 15′	Kootenai: Madison			08-19-64	HEALTH	--	--	670
												06-12-78	MBMG	7.33	900	680†
										25	19.9	09-23-75	USGS	7.68†	882	622
Browns	8S	9W	30	DCB	45.1047	112.7508	5,575	Dalys 7.5′	Madison:	30	23.7	06-21-78	MBMG	7.4	645	480†
									Tertiary volcanics							
Camas	21N	24W	3	BBDB	47.6136	114.6672	2,830	Hot Springs 7.5′	Piegan: Diorite sill			11-24-64	MBMG	--	--	270
										100	45.0	07-03-75	USGS*	9.39	367	330
												09-15-75	USGS	9.11	394	274
Carter's Bridge	3S	9E	1	AADA	45.6108	110.5694	4,560	Brisbin 7.5′	Madison	40	28.0	12-22-78	MBMG	7.8†	850	600
Chico	6S	8E	1	CDCD	45.3381	110.6911	5,280	Emigrant 15′	Tertiary sediments	58	45.0	08-25-74	USGS*	7.38	379	255
									with Tertiary granite			11-24-64	HEALTH	--	--	254
									and Madison							
Deer Lodge Prison	7N	10W	29	BC	46.3331	112.8864	4,960	Racetrack 7.5′	Precambrian Ravalli,	40	26.0	03-27-78	MBMG	9.3	220	170
									4 springs							
Durfee Creek	12N	23E	19	BB	46.7933	108.8833	4,500	Roundup 1° x 2°	Madison		21.1	06-13-78	MBMG	7.25	1960	1470†
										30	--	08-15-73	MBMG	8.08†	2540	2630
Elkhorn	4S	12W	29	ACAD	45.4592	113.1069	7,200	Polaris 15′	Boulder batholith	65	48.5	08-20-74	USGS*	8.94	209	179
												07-27-72	MBMG	8.49†	219	180
Ennis	5S	1W	28	DCAD	45.3675	111.7256	4,920	Ennis 15′	Tertiary sediments			02-06-69	HEALTH (?)	--	--	310
									over pre-Belt	129	83.2	04-01-76	USGS*	7.7	1510	1030
Gallogly	1S	19W	15	BCCCAC	45.7497	113.9400	5,400	Lost Trail Pass 7.5′	Idaho batholith		49.0	08-05-64	HEALTH	--	--	144
										56	--	08-10-72	MBMG	7.81†	202	149
											41.7	10-07-80	MBMG	9.12†	192	153
Garrison	10N	9W	19	ACB	46.6097	112.7747	4,900	Garrison 15′	Cretaceous —	35	25.0	08-08-72	MBMG	7.30†	737	530
									near Madison							
Granite	11N	23W	7	ABDBA	Combined w/Lolo		4,180	Lolo Hot Springs 7.5′	Wallace: Idaho batholith	80	51.0	06-19-78	MBMG	9.3	280	210†
Green Springs	20N	24W	33	CBA	47.4506	114.6486	2,820	Perma 15′	Alluvium:			1964	HEALTH	--	--	162
									Precambrian Piegan	--	26.0	06-17-78	MBMG	9.2	370	280†

TABLE 1 — SPRINGS, INVENTORY DATA *(CONTINUED)*

Spring Name	Location T	R	S	Tr.	Latitude	Longitude	Altitude (Ft.)	Topographic Map	Source of Water	Estimated Reservoir Temp. °C	Observed Temp. °C	Dates	Agency	pH	SC (μmho/cm) @ 25° C	TDS
Gregson	3N	10W	2	BDCA	46.0433	112.8106	5,130	Anaconda 15'	Tertiary volcanics:	118	70.0	08-19-74	USGS*	8.41	761	559
									Boulder batholith			04-08-65	HEALTH (?)	—	—	560
Greyson	6N	2E	21	BAAA	46.2678	111.4825	3,820	Duck Creek Pass 15'	Tertiary sediments	25	17.9	06-03-78	MBMG	7.6	610	460†
Hunsaker	4N	2E	32	DBDB	46.0531	111.5011	4,600	Radersburg 15'	Greyson Shale	40	24.5	06-26-79	MBMG	6.90	590	350
Hunters	1S	12E	9	CCADC	45.7572	110.2572	4,380	Hunter's Hot Springs 7.5'	Livingston:	78	59.0	07-02-75	USGS*	9.13	354	280
									Cretaceous volcanics:			07-25-72	MBMG	8.52†	387	280
									Tertiary granite							
Jackson	5S	15W	25	CBBB	45.3677	113.4030	6,470	Jackson (Advance) 7.5'	Alluvium:			08-06-64	MBMG	--	--	662
									Tertiary sediments:			07-28-72	MBMG	9.04†	1020	660
									Missoula Group	125	58.0	08-16-74	USGS*	6.77	972	660
La Duke	8S	8E	32	CDBA	45.0903	110.7733	5,280	Miner 15'	Madison	73	65.0	07-02-75	USGS*	6.52	2460	2080
												07-26-72	MBMG	7.62†	2400	2030
Landusky 1 & 2	25N	24E	32	DBAD	47.8764	108.6572	3,710	Hays 7.5'	Madison: Jurassic	35	21.0	08-16-73	MBMG	8.03†	1800 (?)	1480
Landusky Plunge	24N	24E	12	CDDAB	47.8431	108.5986	3,690	Hays SE 7.5'	Madison: Jurassic	30	24.0	08-16-73	MBMG	8.09†	1262	960
Little Warm Springs 1, 2, 3	26N	26E	32	ACAAA	47.9692	108.3964	3,360	Bear Mountain 7.5'	Madison: Jurassic		--	08-16-73	MBMG	8.06†	2082	1750
										35	22.5	10-04-73	USGS	7.92†	1823	1540
Lodgepole 1, 2, 3	26N	25E	24	CABD	47.9939	108.4444	3,700	Bear Mountain 7.5'	Madison	35	30.0	10-04-73	USGS	8.0†	1430	1100
Lolo	11N	23W	7	ADCC	46.7253	114.5328	4,155	Lolo Hot Springs 7.5'	Wallace: Idaho batholith	83	44.0	08-17-74	USGS*	9.27	225	200
												08-09-72	MBMG	7.87†	234	200
												06-19-78	MBMG	9.6	307	230†
Lovells	8S	9W	28	BDBA	45.1114	112.7150	5,490	Gallagher Mountain 7.5'	Tertiary sediments:	30	19.4	06-21-78	MBMG	7.9	620	420†
									Tertiary volcanics:							
									Madison							
McMenomey Ranch	9S	10W	29	AAA	45.0272	112.8444	5449	Dalys 7.5'	Madison-Beaverhead	30	19.0	03-24-78	PRVT.	7.4†	722	480
									contact							
Medicine	1N	20W	12	CCA	45.8456	114.0361	4,440	Medicine Hot Springs 7.5'	Idaho batholith			08-05-64	HEALTH	--	--	170
												08-09-72	MBMG	8.08†	377	260
										82	45.0	08-16-74	USGS*	8.59	343	260
New Biltmore	4S	7W	28	BDA	47.4620	112.4744	4,783	Beaverhead Rock 7.5'	Madison	--		08-06-64	HEALTH	--	--	2004
												07-10-72	MBMG	7.34†	2140	1780
										71	53.0	08-17-74	USGS*	6.76	2160	1860
Nimrod	11N	15W	14	CDAA	46.7056	113.4569	3,800	Bearmouth 15'	Cambrian: Madison			08-03-64	HEALTH	--	--	722
										30	20.5	03-18-72	USGS	7.63	856	630
												06-17-78	MBMG	7.8	860	645†
Norris	3S	1W	14	DAB	45.5750	111.6831	4,805	Norris 15'	Pre-Belt:	107	52.5	08-21-74	USGS*	7.58	903	640
									Tobacco Root stock			11- ? -64	HEALTH	--	--	620
												05-04-70	HEALTH	--	--	700
Pipestone 1 & 2	2N	5W	28	BDDD	45.8964	112.2319	4,530	Dry Mountain 7.5'	Boulder batholith	88	57.0	08-18-74	USGS*	8.72	455	340
												08-06-64	HEALTH	--	--	328
Plunkets	4N	1E	27	AA	46.0744	111.5844	4,180	Radersburg 15'	Madison			06-02-78	MBMG	8.1	510	380†
										20	16.5	07-10-79	MBMG	7.9	400	260
Potosi 1	3S	2W	7	CABA	45.5894	111.8986	6,100	Harrison 15'	Tobacco Root stock	60	49.5	08-21-74	USGS*	8.6	470	330
Potosi 2 & 3	3S	2W	6	CACC	45.6017	111.9003	6,080	Harrison 15'	Tobacco Root stock	60	37.0	06-25-79	MBMG	8.36†	470	360
Pullers	8S	5W	1	AACC	45.1714	112.1525	5,485	Metzel Ranch 7.5'	Tertiary sediments:	90	44.4	05-14-76	USGS*	7.7	1680	1160
									pre-Belt							
Quinn's Hot Springs	18N	25W	9	CDADA	47.3297	114.7881	2,560	Plains 15'	Precambrian Piegan			04-08-65	HEALTH	--	--	192
										99	43.4	08-09-72	MBMG	7.91†	205	190
												06-18-78	MBMG	8.9	170	130†
Renova	1N	4W	32	DBC	45.7914	112.1265	4,400	Vendome 7.5'	Cambrian, Meagher	90	50.0	08-13-76	USGS*	7.5	1100	655
									Limestone							
Silver Star	2S	6W	1	CCBA	45.6881	112.2942	4,700	Twin Bridges 7.5'	Boulder batholith:	131	71.5	08-18-74	USGS*	8.17	808	610
									pre-Belt contact zone			07-10-72	MBMG	8.40†	847	640
Sleeping Child	4N	19W	7	DCDDBB	46.1053	114.0042	4,750	Deer Mountain 7.5'	Idaho batholith:			08-04-64	HEALTH	--	--	400
									2 sources			08-10-72	MBMG	7.98†	568	390
										125	52.0	08-15-74	USGS*	8.20	538	390
Sloan Cow Camp	12S	1E	19	CDA	44.7692	111.6500	6,560	Cliff Lake 15'	Alluvium:	85	29.5	09-29-77	MBMG*	10.05	410	260
									Pleistocene volcanics (?)							
Staudenmeyer Ranch	13S	2W	17	CBA	44.7019	111.8775	6,750	Lower Red Rock Lake 15'	Pleistocene rhyolite,	45	28.0	10-03-77	MBMG*	7.5	646	390
									5 springs: Chemistry							
									suggests Madison source							

TABLE 3 — WELLS, INVENTORY DATA

Well Name	Location T	Location R	Location S	Location Tr.	Latitude	Longitude	Altitude (M)	Producing Depth (M)	Topographic Map	Source of Water	Dates	Agency	Estimated Reservoir Temp. °C	Observed Temp. °C	Yield GPM	Field pH	Field SC (μ mho/cm@25°)	Lab TDS
Angela Hot Springs	11N	43E	21	CDCA	46.6881°N	106.3225°W	919	2496-2530	Alkali Creek 7½′	Lodgepole	11-20-80	MBMG	85	82.	1200 F	7.4	8,320.	6,240.†
Bakers Hole (#WYO26)	13S	05E	15	ABAB	44.7081°N	111.0991°W	2022	19	West Yellowstone 15′	Glacial outwash	08-22-79	MBMG	45	16.	16+ F	6.5	260.	330.
Brant Coulee	02N	34E	15	BBBD	45.9258°N	107.4842°W	969	1809-1826	Dudley Spring 7½′	Tensleep	--	--	76	74.	44 F	--	--	--
Bruce	04N	01E	04	ADDCB	46.1328°N	111.6014°W	1269	50.5-122	Radersburg 15′	Tertiary (Madison Group)	06-29-79	MBMG	45	18.	--	8.34	2,540.	1,370.
Campaqua	22N	23W	29	ACBB	47.6411°N	114.5708°W	835	74	Hot Springs NE 7½′	Ravalli Group	09-15-75 10-22-80	USGS MBMG	100 --	50. 52.	200 F 116 F	8.3* 8.4	660.* --	410. 420.
Colstrip	02N	41E	34	BADCD	45.8869°N	106.6189°W	986	2580	Colstrip East 7½′	Madison Group	01-26-72	MBMG	100	97.	230 F	7.1*	1,890.*	1,470.†
Florence	10N	20W	12	BBBA	46.6461°N	114.0636°W	975	125	Florence 7½′	Pleistocene (?)	08-25-80	MBMG	70	15.	10	8.8*	327.	291.
Fox Inc.	08N	13E	28	CADD	46.4208°N	110.1036°W	1372	183-335 229	Twodot 7½′	Madison Group	10-31-80	MBMG	22	19.	50 F	7.5	930.	429.†
Halvorson Hot Springs	12N	38E	27	ADAC	46.7675°N	106.9194°W	946	916-919	Vanstel 7½′	Piper Limestone	09-05-80	BLM	50	45.	300 F	7.2	9,700.	4,760.
Hanover	16N	17E	22	DCDD	47.1300°N	109.5530°W	1213	232	Spring Creek Junction 7½′	Madison Group	11-12-64	MSBH	22	20.	60 F	--	--	410.
Hanser	08N	13E	31	AACC	46.4136°N	110.1394°W	1407	313	Twodot NW 7½′	Madison Group	10-31-80	MBMG	22	18.	200 F	7.4	1,840.	1,380.†
Hunsaker	04N	02E	18	ACAC	46.1022°N	111.5231°W	1251	33	Radersburg 15′	Tertiary	06-31-80	MBMG	45	15.	17.1	8.17	400.	240.
Koehler	21N	24W	04	ADAB	47.6122°N	114.6700°W	869	91	Hot Springs 7½′	Prichard Formation	12-03-79	MBMG	90	44.8	30 F	9.2	590.	340.
Leistner	21N	24W	04	DABD	47.6075°N	114.6714°W	870	128	Hot Springs 7½′	Prichard Formation	12-03-79	MBMG	90	29.8	30 F	9.49	360.	330.
Lucas	07N	08E	23	AAAC	46.3580°N	110.6814°W	1774	210-1284	Hamen 7½′	Kibbey (?)	05-26-76	USGS	45	42.2	100 F	--	3,300.	3,150.
Marysville	12N	06W	32	ABDC	46.7534°N	112.3760°W	1622	1747	Granite Butte 7½′	Tertiary plutonics	08-29-75	USGS	122	96.5	--	7.9*	950.*	680.
McLeod	02S	13E	15	BCBD	45.6631°N	110.1142°W	1466	686	McLeod 7½′	Kibbey (?)	11-24-64	MSBH	50	48.	15 F	--	--	2,100.
Montaqua	04S	23E	08	AAAA	45.5074°N	108.9027°W	1088	293-1227	Montaqua 7½′	Mowry or Madison Group	11-17-60	USGS	50	39.	--	7.6	3,040.	3,260.
Quinn's Hot Springs	18N	25W	09	DCBC	47.3300°N	114.7869°W	777	44	Plains 15′	Prichard Formation	01-16-81	MBMG	--	25.	75 F	9.2	196.	--
Ringling	07N	07E	25	ADCAC	46.3394°N	110.7865°W	1637	646-707	Ringling 7½′	Madison Group	05-26-76	USGS	50	48.	800 F	6.8	1,630.	1,360.
Rocky Ranch	01S	32E	14	CCDD	45.7367°N	107.7344°W	937	1204	Walker Hill 7½′	Madison Group	11-25-80	MBMG	45	42.	2000 F	7.4	2,790.	3,116.†
Saco (Sleeping Buffalo)	32N	32E	35	DCBC	48.4847°N	107.5275°W	679	975	Bowdoin 7½′	Madison Group	05-10-77 10-27-80	USGS MBMG	45 --	41.3 42.	-- 90+ F	7.38* 7.0	3,490. 3,467.	3,411. 3,420.
Scott Feed Lot #1	02S	29E	05	DACC	45.6819°N	108.1567°W	1119	913	Woody Mountain NW 7½′	Pryor Conglomerate Morrison	11-25-80	MBMG	46	43.	45 F	7.3	1,870.	1,400.†
Scott Feed Lot #2	02S	29E	05	DABD	45.6839°N	108.1552°W	1125	921	Woody Mountain NW 7½′	Lakota Sandstone	11-25-80	MBMG	46	44.	50	7.3	1,650.	1,240.†
Stellar Creek	10N	39E	09	BBBA	46.6417°N	106.8313°W	882	~~5671~~ 1119	Flat Bottom Coulee NE 7½′	Madison Group	09-05-80	BLM	50	50.	900 F	7.6	7,000.	5,250.†
Symes	21N	24W	04	ADCA	47.6102°N	114.6711°W	864	76	Hot Springs 7½′	Ravalli Group	08-09-72	MBMG	88	38.	100 F	9.8	330.	290.
Two Dot	08N	13E	27	ADAD	46.4260°N	110.0715°W	1350	274	Twodot 7½′	Madison Group	10-31-80	MBMG	22	20.	20 F	7.3	795.	392.
Uranium Test	02S	15W	14	CB	45.6594°N	113.4255°W	1853	150 (?)	Mud Lake 7½′	Insert ?	12-10-75	PRVT.	50	15.5	--	7.85*	2,029.*	1,260.
Wendt	03N	10W	11	BABD	46.0322°N	112.8117°W	1582	61	Anaconda 15′	Tertiary volcanics	10-08-80	MBMG	50	24.	15	8.3	210.	175.

-- Not determined.

*Laboratory pH or SC.

†Calculated from field SC using equation TDS (mg/L) = SC (μ mho/cm) x 0.75 (mg/L)/(μ mho/cm).

F = Flowing well.

TABLE 4 — WELLS, WATER-QUALITY DATA

Well Name	Agency	Dates	Ca	Mg	Na	K	SiO_2	HCO_3	CO_3	Cl	SO_4	F	Na + K	Fe	Mn	$NO_2 + NO_3$ as N	NO_3	P	CO_2	As	B	Al	H_2S	Li	Field pH	TDS	Sr	Zn
Angela Hot Springs	MBMG	11-20-80	380.0	60.6	1,556.0	115.0	50.1	293.0	0.0	2,636.	1,535.	5.3	--	0.078	0.005	0.01	0.04	--	--	--	2.82	0.19	--	1.88	7.4	8,320.	11.4	0.019
Baker's Hole (#WYO26)	MBMG	08-22-79	11.2	6.0	48.0	7.0	79.9	152.0	0.0	17.0	8.8	3.7	--	0.01	0.01	0.14	--	--	--	0.0218	0.12	0.07	--	0.15	6.5	260.	--	--
Brant Coulee	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Bruce	MBMG	06-29-79	279.0	3.0	129.0	5.5	31.9	30.7	0.0	59.2	850.0	1.2	--	0.03	0.01	0.29	--	--	--	0.0013	0.38	--	--	0.07	8.3	1,370.	2.4	--
Campaqua	USGS	09-15-75	2.88	0.34	150.0	3.4	40.0	352.34	0.0	33.75	1.70	5.2	--	< .01	< .01	0.023	--	--	--	--	--	--	--	--	8.3*	410.	--	--
	MBMG	10-22-80	3.2	0.3	152.0	4.0	42.2	351.0	5.0	32.5	4.1	3.9	--	0.17	0.01	0.01	--	--	--	< .0001	0.64	0.09	--	0.087	8.4	420.	0.10	< .004
Colstrip	MBMG	01-26-72	232.0	23.0	131.0	70.8	79.0	149.0	0.0	96.0	759.0	3.9	--	0.80	0.21	--	0.1	--	--	--	--	--	--	0.67	7.1*	1,470.†	--	0.02
Florence	MBMG	08-25-80	1.0	0.2	81.3	2.9	4.9	164.5	5.9	4.5	20.1	3.1	--	2.7	0.02	.01	--	--	--	--	--	--	--	0.017	8.8*	291.	--	--
Fox Inc.	MBMG	10-31-80	0.6	.1	197.0	0.4	14.0	368.0	60.0	4.4	31.4	0.49	--	0.011	0.003	0.06	0.06	--	--	--	0.16	.03	--	0.055	7.5	429.†	0.022	.004
Halvorson Hot Springs	BLM	09-05-80	481.0	96.0	690.0	83.0	19.4	261.0	0.0	246.0	2,450.0	4.85	--	0.72	0.03	0.1	--	0.01	--	--	1.9	--	--	--	7.2	4,760.	--	0.05
Hanover	MSBH	11-12-64	98.0	25.0	--	--	--	207.0	0.0	2.0	163.0	1.2	0.0	0.0	--	--	0.0	--	--	--	--	--	--	--	--	410.	--	--
Hanser	MBMG	10-31-80	1.1	0.2	290.0	0.9	0.012	604.0	60.0	6.8	20.6	1.43	--	0.012	0.001	0.04	0.20	--	--	--	2.8	0.07	--	0.098	7.4	1,380.†	0.04	.004
Hunsaker	MBMG	06-31-80	21.6	12.5	44.4	2.5	29.9	179.0	0.0	9.6	34.1	1.5	--	0.02	0.01	0.35	--	--	--	--	0.18	--	--	0.025	8.2	240.	0.27	--
Koehler	MBMG	12-03-79	0.9	0.1	87.8	1.2	67.4	100.0	31.2	9.0	34.7	5.0	--	0.90	0.01	0.067	--	--	--	< .0001	0.511	< .12	--	0.039	9.2	290.	--	--
Leistner	MBMG	12-03-79	0.9	0.1	92.3	0.1	67.0	84.6	49.8	7.8	21.2	5.2	--	0.61	0.01	0.1	--	--	--	< .0001	0.46	< .12	--	0.018	9.49	330.	--	--
Lucas	USGS	05-26-76	660.0	140.0	32.0	13.0	25.0	115.0	--	6.0	2,200.0	2.8	--	0.16	--	--	--	0.0	--	--	0.18	--	--	0.01	--	3,150.	0.12	--
Marysville	USGS	08-29-75	7.7	5.0	210.0	10.0	69.0	260.0	0.0	51.0	180.0	20.0	--	0.02	0.09	0.23	1.0	--	--	--	0.1	--	--	0.2	7.9*	680.	--	0.07
McLeod	MSBH	11-24-64	473.0	72.0	--	--	--	122.0	0.0	3.0	1,350.0	3.5	16.0	0.40	--	--	0.0	--	--	--	--	--	--	--	--	2,100.	--	--
Montaqua	USGS	11-17-60	665.0	136.0	14.0	24.0	18.0	180.0	0.0	4.0	1,980.0	4.0	--	1.5	--	0.0	--	--	--	--	0.14	--	--	--	--	3,260.	--	--
Quinn's Hot Springs	MBMG	01-16-81	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Ringling	USGS	05-26-76	300.0	66.0	8.8	6.5	25.0	164.0	0.0	2.1	860.0	2.7	--	0.01	0.0	--	--	--	42.0	0.001	0.08	--	--	0.06	6.8	1,360.	0.43	--
Rocky Ranch	MBMG	11-25-80	775.0	166.0	15.8	30.4	17.2	150.1	0.0	4.3	2,173.0	3.09	--	0.32	0.03	0.01	2.04	--	--	--	0.42	1.92	--	0.28	7.4	3,116.	11.1	0.065
Saco (Sleeping Buffalo)	USGS	05-10-77	490.0	174.0	293.0	25.4	17.1	151.0	0.0	195.5	2,147.0	2.9	--	0.03	0.02	0.039	--	--	--	--	--	--	0.31	--	--	3,411.	12.10	--
	MBMG	10-27-80	521.0	156.0	254.0	25.1	17.1	721.0	0.0	183.0	1,900.0	1.87	--	0.46	0.08	0.01	0.04	--	--	--	0.95	0.21	--	0.26	7.0	3,420.	9.62	0.014
Scott Feed Lot #1	MBMG	11-25-80	1.2	0.2	512.0	1.2	19.4	1,016.0	48.0	60.3	119.0	7.1	--	0.22	0.002	0.04	0.19	--	--	--	1.85	0.03	--	0.065	7.3	1,400.†	0.046	0.013
Scott Feed Lot #2	MBMG	11-25-80	1.2	0.2	559.0	1.1	20.0	1,169.0	42.0	72.0	83.4	9.0	--	0.083	0.003	0.06	0.25	--	--	--	2.29	0.03	--	0.074	7.3	1,260.	0.05	.004
Stellar Creek	BLM	09-05-80	561.0	116.0	580.0	94.0	15.8	249.0	0.0	543.0	2,225.0	4.89	--	0.13	0.03	0.1	--	0.02	--	--	2.7	--	--	--	7.6	7,000.	--	--
Symes	MBMG	08-09-72	1.2	0.2	90.5	1.7	68.0	142.0	8.0	9.3	40.0	5.8	--	0.10	0.00	--	0.01	--	--	--	--	--	--	--	9.8	295.	--	--
Two Dot	MBMG	10-31-80	1.1	0.1	178.0	0.5	13.2	312.0	51.0	2.4	43.1	0.36	--	0.054	0.006	< .01	0.02	--	--	--	0.10	0.03	--	0.052	7.3	392.	0.028	0.004
Uranium Test	PRVT.	12-10-75	15.14	1.26	472.0	20.0	30.6	1,090.68	0.0	6.40	168.5	6.6	--	0.23	0.05	1.04	--	--	--	--	--	--	--	--	7.85*	1,250.	--	--
Wendt	MBMG	11-08-80	20.7	1.0	29.1	2.8	43.1	106.8	0.0	4.9	17.4	1.07	--	0.22	0.01	0.44	--	--	--	--	--	--	--	--	8.3	175.	--	--

All water quality information is in milligrams per liter (mg/L).

-- Not determined.

*Laboratory pH.

†Calculated from field SC using equation TDS (mg/L) = SC (μ mho/cm) x 0.75 (mg/L)/(μ mho/cm).

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TABLE 1 — SPRINGS, INVENTORY DATA *(CONTINUED)*

Spring Name	Location T	Location R	Location S	Location Tr.	Latitude	Longitude	Altitude (Ft.)	Topographic Map	Source of Water	Estimated Reservoir Temp. °C	Observed Temp. °C	Dates	Agency	pH	SC (μ mho/cm) @ 25° C	TDS
Sun River	22N	10W	26	CAB	47.6325	112.8542	4,800	Arsenic Peak 7.5'	Madison, 5 springs	35	30.4	06-15-78	MBMG	7.2	1190	890†
Targhee Sulphur	13S	4E	27	AACA	44.6769	111.2183	6,673	West Yellowstone 15'	Glacial till: volcanics	18	18.0	08-23-79	MBMG	6.69	560	370
Toston	4N	3E	6	DADC	46.1256	111.3908	3,960	Toston 15'	Madison			11-24-64	HEALTH	--	--	238
												06-02-78	MBMG	7.5	440	330†
										20	15.2	06-29-79	MBMG	7.5	440	265
Trudau	7S	4W	7	DCAD	45.2350	112.1347	5,675	Metzel Ranch 7.5'	Pre-Belt and Paleozoic	45	22.7	05-25-78	MBMG	8.4	850	540
Vigilante	9S	3W	22	BDDD	45.0375	111.9508	6,200	Varney 15'	Madison	30	23.5	05-25-78	MBMG	7.5	620	400
Warm Springs State Hospital	5N	10W	24	A	46.1786	112.7942	4,820	Anaconda 15'	Boulder batholith (?)	79	77.0	08-19-74	USGS*	6.46	1510	1251
									Madison (?)			04-08-65	HEALTH	--	--	1308
Warner	5N	1E	22	DBBC	46.1708	111.5856	4,100	Radersburg 15'	Alluvium: Tertiary			06-02-78	MBMG	8.2	200	123
									dediments: Precambrian	23	18.0	06-16-79	MBMG	8.1	200	125
West Fork Swimming Hole	12S	1E	18	DB	44.7865	111.6450	6,700	Cliff Lake 15'	Alluvium:	30	26.0	09-29-77	MBMG*	8.30	322	180
									Pleistocene volcanics (?)							
White Sulphur Springs	9N	7E	18	BB	46.5473	110.9039	5,025	White Sulphur Springs 7.5'	Tertiary sediments:			09-01-61	HEALTH	--	--	1450
									Precambrian	125	46.0	08-17-74	USGS*	6.8	2220	1520
Wolf Creek	10S	1E	9	BBBA	44.9843	111.6151	6,100	Cliff Lake 15'	Tertiary sediments:			09-30-77	MBMG	11.03	494	320
									Precambrian	77	68.0	05-13-76	USGS*	8.6	659	360

*Symbol after analysis indicates a preferred analysis, conducted for geothermal evaluation, with a field (rather than laboratory) pH measurement.

†Laboratory pH value, or TDS calculated from specific conductance data using the relationship TDS = 0.75 x SC.

TABLE 2 — SPRINGS, WATER ANALYSIS

Spring Name	Agency	Dates	Ca	Mg	Na	K	SiO_2	HCO_3	CO_3	Cl	SO_4	F	Na + K	Fe	Mn	NO_3	P	CO_2	As	B	H_2S	Li	Field pH	T.D.S.
Alhambra	USGS	04-08-76	27.	5.2	310.	17.	61.	712.	0	20.	150.	9.0	--	0.12	0.02	0.0	0.02	227.	0.036	0.41	--	0.71	7.2	660
Anaconda	MBMG	06-23-78	470.	67.	147.	10.6	22.7	439.	0	7.	1360.	2.5	--	1.21	0.48	< 0.10	--	--	--	--	--	0.25	7.0	2,310
Anderson's	MBMG	07-25-72	47.	23.	1.6	1.3	12.2	88.	0	0.5	139.	0.4	--	N.D.	N.D.	0.3	--	--	--	--	--	< .01	7.4	270
Anderson's Pasture	MBMG	10-03-77	66.5	24.	27.7	7.3	21.4	246.	0	9.7	114.	1.7	--	< .01	< .01	0.16	--	--	0.0136	0.20	< .10	0.05	7.4	400
Apex	MBMG	05-25-78	62.	16.2	23.4	3.2	19.8	140.	0	11.55	135.	0.6	--	< .01	< .01	0.92	--	--	--	--	--	--	7.6	340
Avon	MBMG	06-16-78																					6.9	650†
Bear Creek	MBMG	05-23-78																					9.5	2,000†
Bearmouth 1 & 2	USGS	03-18-72	89.	28.	7.6	1.8	16.	220.	0	1.5	163.	0.5	--	0.03	0.01	0.2	--	--	--	--	--	--	7.5	420
Beaverhead Rock	MBMG	08-21-66																					7.2	--
Bedford	HEALTH	12-09-64	57.	22.	--	--	--	155.	0	9.	103.	0.7	8.	--	--	0.9	--	--	--	--	--	--	7.2	350†
Blue Joint 1 & 2	MBMG	08-11-72	2.6	0.1	37.5	0.34	54.	67.	0	3.1	4.8	9.5	--	N.D.	N.D.	N.D.	--	--	--	--	--	--	8.2	145
Boulder	USGS	08-22-74	2.2	< .1	120.	3.8	110.	161.	4.	19.	74.	11.	--	0.02	< 0.02	--	--	--	--	0.56	--	0.24	8.5	420
Bozeman	USGS	08-25-74	9.5	2.7	120.	2.8	66.	130.	3.	46.	110.	9.2	--	0.02	0.02	--	--	0.5	--	0.20	0.6	0.04	8.6	430
Bridger Canyon	USFW	--	54.8	22.7	4.26	1.4	8.2	209.	0	0.19	80.	0.47	--	< .025	0.0015	0.05	--	--	--	--	--	--	7.7	270
Broadwater	USGS	08-24-74	11.	0.9	160.	5.8	98.	210.	5.	33.	170.	9.4	--	0.07	0.05	--	--	1.1	--	0.80	< .5	0.48	8.5	600
Brooks	USGS	09-23-75	133.	40.3	3.4	1.4	8.9	195.2	0	0.95	336.	1.3	--	< .01	< .01	3.60	--	--	--	--	--	--	7.3	620
Browns	MBMG																						7.4	480†
Camas	USGS	09-15-75	1.12	.39	83.	1.8	58.0	112.2	19.2	5.50	43.7	5.7	--	< .01	< .01	1.20	--	--	--	--	--	--	9.1*	270
Carter's Bridge	MBMG	12-22-78	129.	35.4	7.3	4.1	19.4	187.	0	3.2	307.	1.3	--	< .01	0.01	0.57	--	--	0.0011	0.11	--	0.03	7.8*	600
Chico	USGS	08-25-74	35.	8.8	35.	6.8	34.	170.	< 1.	10.	41.	0.9	--	< .02	< .02	--	--	11.	--	0.06	0.6	0.03	7.4	250
Deer Lodge Prison	MBMG	03-27-78	3.9	0.1	45.8	0.5	45.8	40.9	12.5	2.55	33.	7.5	--	< .01	< .01	0.51	--	--	--	--	--	0.07	9.3	170
Durfee Creek	MBMG	08-15-73	533.	165.	14.0	3.2	12.8	59.	0	4.1	1872.	1.8	--	0.09	0.02	0	--	--	--	--	--	0.04	7.2	2,630
Elkhorn	USGS	08-20-74	1.9	< .1	48.	0.7	55.	77.	4.	1.7	27.	2.6	--	< .02	< .02	--	--	0.02	--	0.04	0.9	0.05	8.9	180
Ennis	USGS	04-01-76	5.8	0.6	340.	17.	96.	442.	0	120.	220.	11.	--	0.02	0.01	--	0.02	14.	0.025	0.61	--	0.26	7.7	1,030
Gallogly	MBMG	10-07-80	3.0	< .1	42.8	0.7	43.7	63.7	12.2	1.2	12.1	5.8	--	0.005	< .001	0.04	--	--	0.0008	0.05	--	0.09	9.1*	150
Garrison	MBMG	08-08-72	77.	35.	24.	5.2	18.2	59.	0	3.4	335.	1.3	--	N.D.	N.D.	0.2	--	--	--	--	--	0.15	7.1	530
Granite	MBMG																						9.3	210†

TABLE 2 — SPRINGS, WATER ANALYSIS *(CONTINUED)*

Spring Name	Agency	Dates	Ca	Mg	Na	K	SiO_2	HCO_3	CO_3	Cl	SO_4	F	Na + K	Fe	Mn	NO_3	P	CO_2	As	B	H_2S	Li	Field pH	T.D.S.
Green Springs	HEALTH	01-05-65	N.D.	N.D.	--	--	--	101.	12.	5.	18.	2.2	61.	0.14	--	N.D.	--	--	--	--	--	--	9.2	280†
Gregson	USGS	08-19-74	3.9	< .1	170.	3.9	85.	160.	3.	17.	180.	18.	--	< .02	< .02	--	--	1.1	--	0.30	1.6	0.64	8.4	560
Greyson	MBMG																						7.6	460†
Hunsaker	MBMG	06-26-79	71.2	18.8	22.3	11.4	23.3	325.	0	11.	30.	0.75	--	0.58	0.20	0.18	--	--	0.0034	0.10	--	0.019	6.9	350
Hunters	USGS	07-02-75	< 1.0	< .1	85.	0.6	65.	170.	15.	18.	11.	5.6	--	< .02	< .02	--	--	0.3	--	0.67	5.3	0.03	9.1	280
Jackson	USGS	08-16-74	10.	3.7	240.	10.	52.	610.	< 1.	7.7	45.	2.0	--	< .02	0.04	--	--	155.	--	0.83	0.6	0.32	6.8	660
La Duke	USGS	07-02-75	320.	58.	230.	23.	49.	300.	< 1.	45.	1200.	3.6	--	0.16	0.02	--	--	152.	--	0.46	< 1.0	0.24	6.5	2,080
Landusky 1 & 2	MBMG	08-16-73	266.	86.	39.	9.	18.2	109.	0	18.8	982.	1.5	--	N.D.	N.D.	1.1	--	--	--	--	--	0.09	8.0*	1,480
Landusky Plunge	MBMG	08-16-73	161.	65.	24.	6.7	17.8	101.	0	9.5	620.	1.6	--	N.D.	N.D.	1.1	--	--	--	--	--	0.05	8.1*	960
Little Warm Springs 1, 2, 3	MBMG	08-16-73	289.	110.	72.	13.3	16.	101.	0	59.	1144.	1.4	--	0.10	N.D.	0.1	--	--	--	--	--	0.14	8.1*	1,750
Lodgepole 1, 2, 3	MBMG	08-16-73	268.	96.	75.	13.	16.3	81.	0	57.	1062.	1.1	--	N.D.	N.D.	0.1	--	--	--	--	--	0.14	8.1*	1,630
Lolo	USGS	08-15-74	1.8	< .1	52.	1.2	72.	70.	8.	6.1	18.	6.4	--	< .02	< .02	--	--	0.1	--	0.11	< .5	0.03	9.3	200
Lovells	MBMG																						7.3*	420†
McMenomey Ranch	PRVT.	03-24-78	88.	27.5	28.3	4.5	17.5	217.	0	16.15	191.	0.7	--	< .01	< .01	0.67	.134	--	0.0145	--	--	0.04	7.4*	480
Medicine	USGS	08-16-74	1.9	< .1	80.	1.4	60.	120.	3.	6.7	33.	14.	--	< .02	< .02	--	--	0.5	--	0.12	0.6	0.20	8.6	260
New Biltmore	USGS	08-17-74	290.	73.	160.	24.	46.	230.	< 1.	46.	1100.	3.3	--	0.10	0.03	--	--	58.	--	0.92	1.1	0.18	6.8	1,860
Nimrod	USGS	03-18-72	126.	36.	15.5	3.4	21.	168.	0	2.7	340.	0.8	--	0.01	0.01	0.4	--	--	--	--	--	--	7.7	630
Norris	USGS	08-21-74	17.	3.2	180.	10.	88.	380.	1.	23.	130.	7.4	--	0.02	0.02	--	--	15.	--	0.10	< 1.0	0.09	7.6	640
Pipestone 1 & 2	USGS	08-18-74	2.6	< .1	98.	1.9	66.	100.	4.	20.	94.	5.3	--	< .02	< .02	--	--	0.3	--	0.28	2.3	0.09	8.7	340
Plunkets	MBMG	07-17-79	38.5	23.5	22.4	2.4	15.5	87.2	16.2	9.0	87.	0.7	--	< .002	< .002	3.05	--	--	0.0017	.11	--	0.032	7.8	260
Potosi 1	USGS	08-21-74	10.	< .1	91.	1.6	46.	63.	2.	5.9	140.	6.2	--	< .02	< .02	--	--	0.3	--	< .02	< .5	0.05	8.6	330
Potosi 2 & 3	MBMG	06-25-79	13.2	0.1	94.6	1.7	47.7	67.3	0	6.	170.	6.1	--	0.01	< .01	< .10	--	--	--	0.03	--	0.056	8.4*	360
Pullers	USGS	05-14-76	56.	19.	330.	24.	33.	511.	0	91.	350.	2.2	--	0.04	--	0	0	16.	0.034	0.69	--	0.19	7.7	1,160
Quinn's Hot Springs	MBMG	08-09-72	3.6	0.2	39.2	1.5	76.6	71.	0	3.1	29.	2.1	--	N.D.	N.D.	N.D.	--	--	--	--	--	0.01	8.9	190
Renova	USGS	08-13-76	51.	13.	150.	13.	37.	310.	0	34.	200.	3.0	--	0.08	0.03	--	0.03	14.	0.019	0.48	--	0.13	7.5	650
Silver Star	USGS	08-18-74	9.3	0.3	170.	6.4	110.	170.	2.	31.	190.	8.7	--	< .02	0.02	--	--	1.8	--	0.25	1.0	0.34	8.2	610
Sleeping Child	USGS	08-15-74	5.4	< .1	120.	2.9	66.	170.	2.	9.5	87.	15.	--	< .02	< .02	--	--	1.8	--	0.35	0.8	0.18	8.2	390
Sloan Cow Camp	MBMG	09-29-77	0.9	0.1	88.	1.1	50.9	64.2	74.4	7.65	3.7	3.1	--	0.17	< .01	0.22	--	--	0.002	0.16	0.94	0.01	10.0	260
Staudenmeyer Ranch	MBMG	10-03-77	68.	24.	29.	7.7	21.4	251.	0	9.35	116.	1.8	--	< .01	< .01	0.22	--	--	0.0154	0.23	< .10	0.05	7.6	390
Sun River	MBMG																						7.2	890†
Targhee Sulphur	MBMG	08-23-79	72.9	27.5	7.1	4.5	14.4	63.3	0	1.7	156.	1.1	--	0.01	0.02	--	--	--	0.0151	0.06	--	0.03	6.7	320
Toston	MBMG	06-29-79	48.7	20.2	13.6	3.6	19.8	193.	0	6.8	56.6	0.70	--	< .01	< .01	1.68	--	--	--	0.12	--	0.047	7.5	240
Trudau	MBMG	05-25-78	78.	30.	70.	11.1	19.0	425.	0	18.20	102.	0.8	--	< .01	< .01	0.77	--	--	--	--	--	--	8.4	540
Vigilante	MBMG	05-24-78	84.5	27.	6.7	3.1	15.5	182.	0	1.90	174.	0.9	--	0.01	0.01	0.67	--	--	--	--	--	--	7.5	400
Warm Springs State Hospital	USGS	08-19-74	220.	22.	120.	26.	56.	260.	< 1.	5.0	670.	3.9	--	0.05	0.05	--	--	132.	--	0.10	0.7	0.36	6.5	1,250
Warner	MBMG	06-16-79	25.8	7.2	5.3	0.8	17.1	101.	0.6	1.8	16.4	0.2	--	0.01	< .01	0.97	--	--	0.0009	< .02	--	0.005	8.2	125
West Fork Swimming Hole	MBMG	09-29-77	19.	29.	4.8	1.9	13.7	194.	0	2.75	11.8	0.4	--	< .01	< .01	0.44	--	--	0.0028	0.02	0.17	0.01	8.3	180
White Sulphur Springs	USGS	08-24-74	44.	12.	480.	20.	51.	830.	< 1.	180.	310.	7.4	--	0.11	0.15	--	--	420.	--	9.10	0.7	1.30	6.5	1,530
Wolf Creek	MBMG	09-30-77	8.7	1.6	100.	1.8	50.3	154.	7.3	19.4	42.6	16.	--	< .01	< .01	0.28	--	--	0.005	0.03	0.2	0.07	8.6*	320

All water quality information is in milligrams per liter (mg/L)

Symbol explanations:

-- — Not determined.

N.D. — Not detected, detection limit not known.

* — Laboratory pH.

† — Laboratory value for TDS calculated from specific conductance data using the relationship TDS = 0.75 x SC.

MONTANA BUREAU OF MINES AND GEOLOGY
A Department of Montana College of Mineral Science and Technology

Hydrogeologic Map HM 4
Geothermal Resources of Montana
Sonderegger and Bergantino, 1981

Geothermal Resources of Montana

Compiled by
John L. Sonderegger
and
R.N. Bergantino

1981

Low-Temperature Geothermal Waters

Existing knowledge does not permit the inference that thermal water will be found everywhere within the gray areas, nor do the boundaries represent precise knowledge of the areal extent of geothermal systems or aquifers.

Bounded darker gray. Areas where discovery and development of additional sources of low-temperature (less than 100°C) water for direct heat application are highly probable. Areas are defined on the basis of thermal springs and/or thermal wells, plus geohydrologic settings generally favorable for recovery of thermal water at depths of less than 1000 meters.

Unbounded lighter gray. *West of the 109th meridian:* Areas which, because of their geologic history and similarity to areas with known thermal systems, are expected to contain geothermal resources suitable for direct heat applications, in addition to the depicted wells and springs. The primary exploration targets are valley fill sedimentary units (less than 1000 meters in depth) receiving water from deeper basement sources. North of Garrison the area is significantly expanded to maintain private data confidentiality.
East of the 109th meridian: Area without thermal springs or shallow thermal wells, but which contains the Madison Group and deeper aquifers with water temperatures of 60°C (140°F) or greater (modified from U.S. Geological Survey Open-File Report 81-629). In much of the area wells must be deeper than 2000 meters. Holes of opportunity may be economically viable; however, corrosiveness or salinity of the water and/or limited well yield caused by low aquifer permeability or cementing of casing may impede utilization of this resource. Most successful wells have been located near structural highs. Potential users of this resource are advised to contact the Montana Bureau of Mines and Geology for information about specific areas.

Heat Flow

▲70 Heat flow in milliwatts/m^2
1 milliwatt/m^2 = 0.024 Heat Flow Unit (HFU)
See Sass, J.H., and Lachenbruch, A.H., 1979, Heat flow and conduction-dominated thermal regimes, *in* Muffler, L.J.P., ed., Assessment of geothermal resources of the United States-1978: U.S. Geological Survey Circular 790.

Thermal Springs

- Surface temperature ≤ 50°C
- Surface temperature > 50°C

Thermal Wells

- Surface temperature ≤ 50°C
- Surface temperature > 50°C

* Recently obtained well information, not listed in accompanying tables

Temperature, °Celsius	Flow, liters/minute (L/min)
Total Dissolved Solids, milligrams/liter (mg/L)	Producing Depth, meters

Known Geothermal Resources Area (KGRA) as designated by the U.S. Department of Interior. Name in red lettering

Indian Reservation

National Forest

National Park, National Wilderness Area, National Wildlife Refuge

Private lands may exist within federal boundaries

Metric Conversion Factors

1 liter = 0.2642 gallon
1 meter = 3.281 feet
1 milligram/liter = 1 part per million
°Celsius = 5/9 (°Fahrenheit − 32)
°Fahrenheit = 9/5 °Celsius + 32
1 kilometer = 0.621 mile

State capital
County seat
City, town, or village
Scheduled service airport
Built-up areas shown for towns over 5,000 population

Interstate highway
U.S. highway
State highway
Other principal roads

POPULATION KEY

GREAT FALLS	more than 50,000
MISSOULA	10,000 to 50,000
Lewistown	2,500 to 10,000
Fort Benton	1,000 to 2,500
Stanford	less than 1,000

Population indicated by size of letters

SCALE 1:1,000,000
1 centimeter equals 10 kilometers
1 inch equals approximately 16 miles

Contour interval 500 feet
Datum is mean sea level
1927 North American Datum
Lambert conformal conic projection based on standard parallels 33° and 45°

Map produced by David M. Clark, NOAA/NGSDC, and Ronald H. Smith, Cooperative Institute for Research in Environmental Sciences (CIRES), University of Colorado/NOAA, Boulder, Colorado, in cooperation with the Earth Science Laboratory/University of Utah Research Institute, Salt Lake City, Utah

Digital thermal well and spring data available from GEOTHERM Project, U.S. Geological Survey, 345 Middlefield Road, MS84, Menlo Park, California 94025

Base map data is reduced from 1:500,000 scale topographic map of Montana (U.S. Geological Survey, 1965)

Data for thermal springs and most thermal wells in Montana are in the accompanying tables. For additional information about the geothermal resources of Montana contact the Montana Bureau of Mines and Geology. Published literature is listed in:
Rautio, S.A., and Sonderegger, J.L., 1980, Annotated bibliography of the geothermal resources of Montana: Montana Bureau of Mines and Geology Bulletin 110, 25 p

Map available free of charge from: Montana Bureau of Mines and Geology, Montana College of Mineral Science and Technology, Butte, Montana 59701

Geothermal data compiled by the
Montana Bureau of Mines and Geology
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