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PART I

PHASE ZERO STUDY RESULTS - GEOTHERMAL POTENTIAL OF THE MADISON GROUP AT SHALLOW DEPTHS IN EASTERN MONTANA

FINAL REPORT

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TASK AGREEMENT NO. 2

INTRODUCTION

The study of shallow geothermal potential in the Madison Group limestone aquifer was started to provide information about large-volume, low-temperature reservoirs that could have potential for space heating or for extended-crop-season irrigation. The report summarizes data available from federal and state sources. To date, eighty-one hot or warm springs are known in Montana. Twenty-nine of these springs are believed to originate in limestone of the Madison Group.

DATA SUMMARY

Table 1 presents the data currently available for the springs believed to originate in the Madison Group. The springs are listed alphabetically and numbered sequentially. Some spring names have been changed to eliminate confusion (there are at least ten "Warm Springs Creeks" within Montana); for example, the three "Big Warm Springs" in sec. 24, T. 26 N., R. 2 E., have been redesignated Lodgepole no. 1, 2, and 3.

The system for locating springs is based on the U.S. Bureau of Land Management system of subdivision of the public lands using the Montana Principal Meridian system. The first segment of a data-point number indicates the township north or south of the baseline; the second, the range east of the principal meridian; and the third, the section in which the spring is located (Fig. 1). The letters A, B, C, and D, following the section number, locate the point within the section. The first letter denotes the 160-acre tract; the second, the 40-acre tract; the third, the 10-acre tract; and the fourth, the 2½-acre tract. The letters are assigned in a counter-clockwise direction, beginning in the northeast quadrant. It is important to note that the order of quarter-tract designations is exactly reversed from that commonly used by surveyors; here the order begins with the largest quarter and progresses to the smallest. Thus, in Figure 1, the designation 2 N. 41 E. 13 ABCD identifies a spring in the SE¼SW¼NW¼NE¼ sec. 13, T. 2 N., R. 41 E.

Information on spring discharge is presented in gallons per minute (gpm). If discharge rates for a specific spring differ, the best available maximum and minimum flows are listed. Similarly, the highest and lowest reported temperatures are presented. Comments on the reliability or range of the data are included at the end of the table.

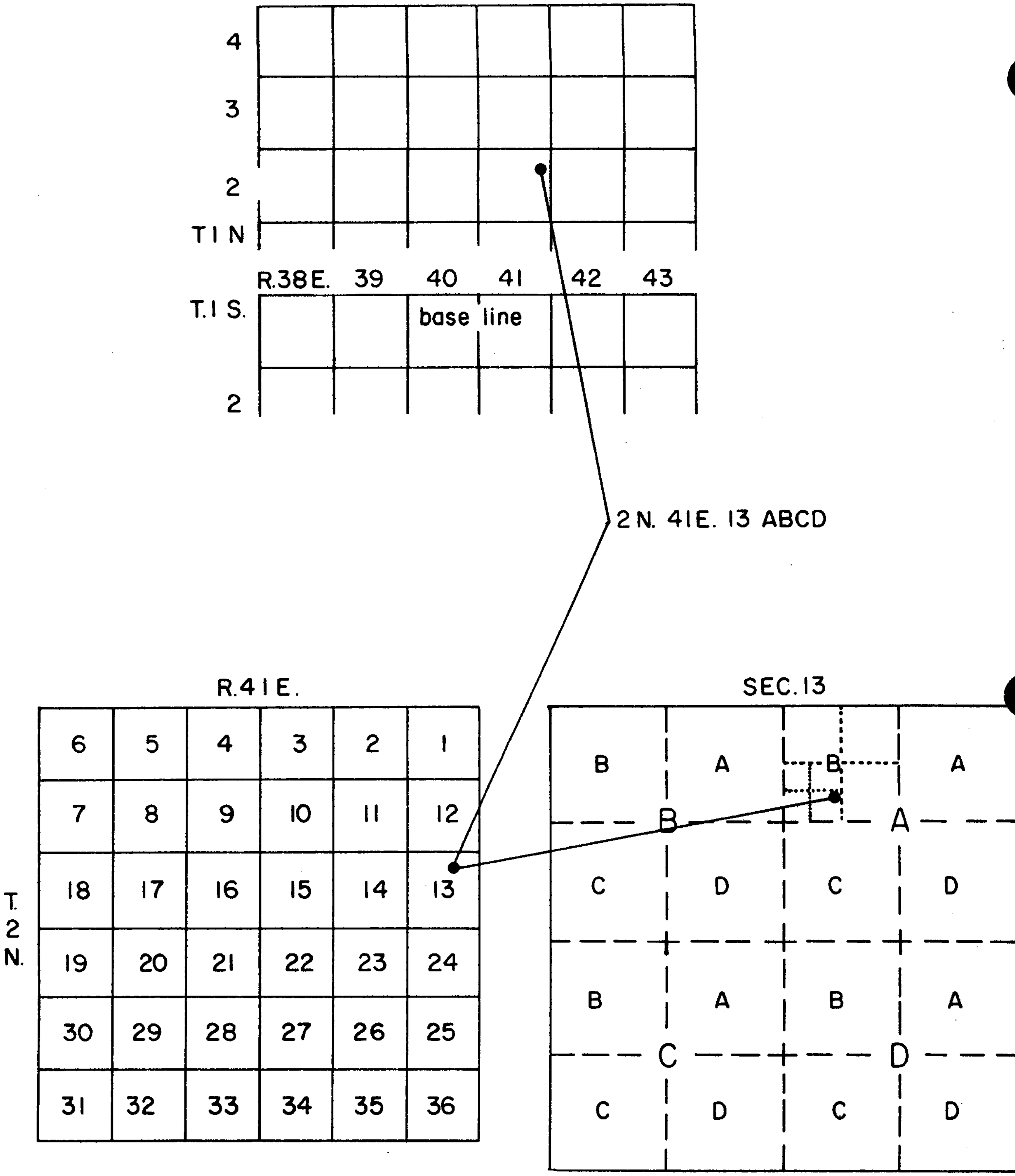

Figure 1. Spring location

The energy available as heat in the water was calculated from a metric base assuming: (1) that the energy released, per degree centigrade, in cooling the spring water to the reference temperature was the same as that released in cooling the same weight of water from 15.5°C to 14.5°C; (2) that one liter of water at the field temperature had a mass of 1 kilogram and a volume of 0.252 gallons; (3) that the cited discharge and temperature are constant; and (4) that the average year has 365.25 days. The equation used is

$$H = (T_{obs} - T_{ref})^{o}C \times Q(gpm) \times 525{,}960(min/yr) \times 3.785(l/gal) \times 3.968(Btu/kcal)$$

where H is expressed in British Thermal Units (Btu's) per year, $(T_{obs} - T_{ref})$ is the difference between the observed field temperature and the reference temperature in degrees Celsius, Q is the discharge in gallons per minute, 525,960 is the number of minutes in an average year, 3.785 is the number of liters per gallon, and 3.968 is the number of Btu's in one kilocalorie. The two reference temperatures employed in the calculations, 18°C(64.4°F) and 10°C(50°F) were judged to be the lowest temperatures applicable for space heating and for extended crop seasons utilizing flood irrigation, respectively.

Under "comments and source", springs for which chemical analyses are available are denoted; comments dealing with source depict our knowledge based upon a survey of existing data unless noted otherwise. Additional information is being gathered on springs numbered 26, 27, and 28. An explanation for the inclusion of springs numbered 7, 8, 24, and 30 is developed below, based upon the water chemistry.

Table 2 presents the currently available chemical data for 16 of the 29 thermal springs. Where such springs issue from an indeterminate source (such as Tertiary sediments) and the Madison Group crops out near the spring, the chemical composition of the spring water was used to interpret whether the water has passed through a carbonate aquifer. A carbonate aquifer "imprint" was assumed if the calcium content was greater than or equal to the sodium content (in milligrams per liter (mg/l), which is equivalent to 1.15:1.0 expressed as milliequivalents per liter). This assumption can be justified on the basis of the analytical data contained in the U.S. Geologival Survey Open-File Report 76-480, which contains analytical data for 21 hot springs in Montana. Figure 2 is a log-log plot of sodium versus calcium for these hot spring waters. Although the trend lines are located only approximately, it is evident that the plot contains points representing two different chemical types of water. The New Biltmore sample

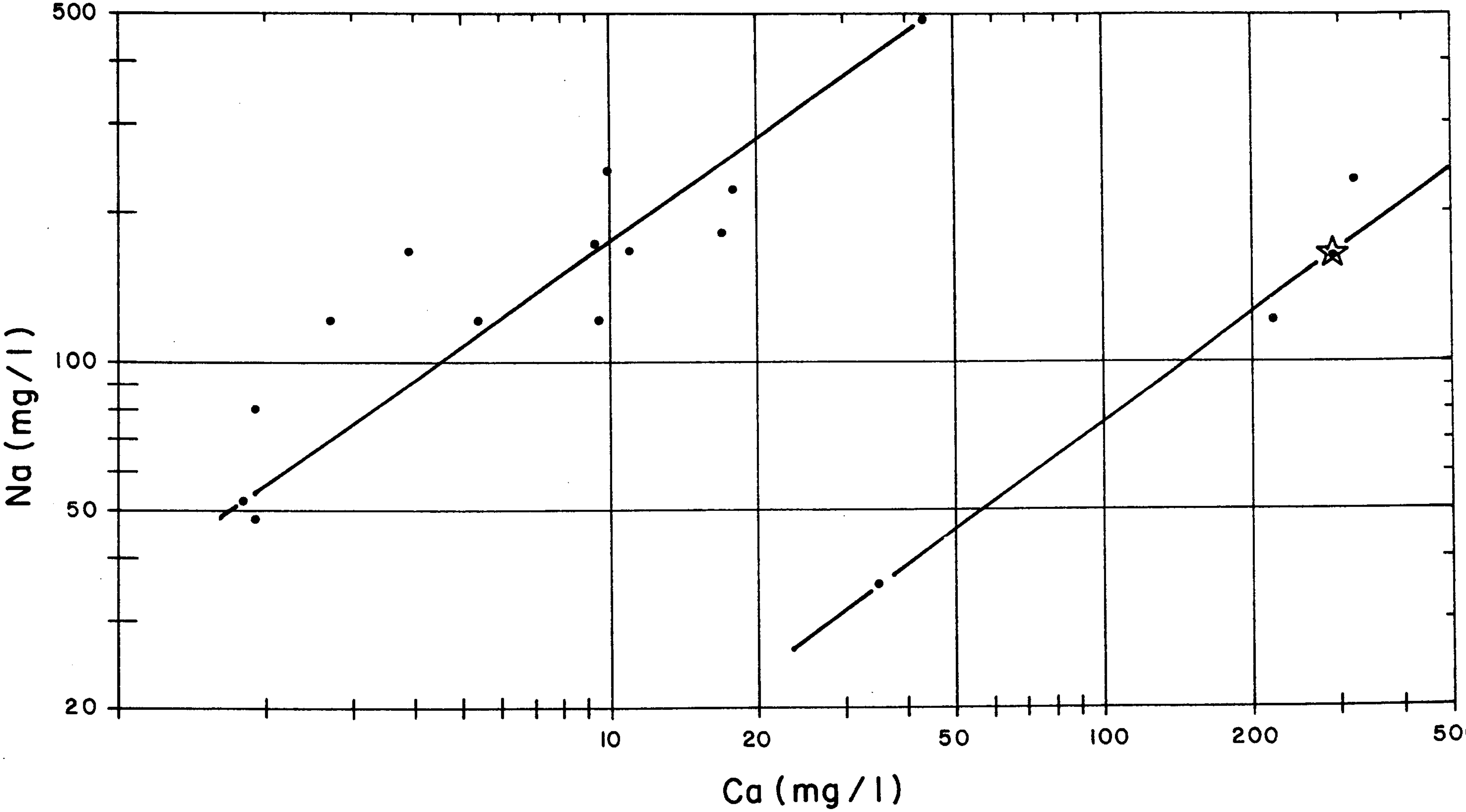

Figure 2. A log-log plot of sodium versus calcium for the spring water analyses in "Chemical characteristics of the major thermal springs of Montana (U.S.G.S. Open-File Report 76-480).

(star) is the only one of the four samples on the lower trend line known to issue in an area mapped as Madison.

The Ca/Na ratios range from 1.0 to 39.1. A plot of these ratios versus temperature, presented in Figure 3, suggests to the authors that only three of the springs (numbers 1, 5, and 9) represent waters that were almost exclusively in contact with carbonate aquifers. The other spring waters are believed to have acquired their sodium content by interaction with sodium-containing minerals or as a result of the mixing of carbonate and noncarbonate waters prior to spring discharge.

DISCUSSION

In terms of available Btu's based upon temperature and flow data, the most promising area for shallow geothermal potential in the Madison Group seems to be the Little Rocky Mountains area (Plate 1). The Landusky, Little Warm and Lodgepole spring series are all located on the southern and eastern sides of this mountain range. These springs are currently known to release 890 billion Btu's per year that could be used for space heating (ΔH_1).

Three different locations are believed to have a second level of geothermal potential. The Brooks warm spring (no. 5) releases a very large flow (68,000 gpm) of low-temperature ($\simeq$ 21°C) water. Because this water is interpreted to have had little contact with noncarbonate aquifers, and because the spring is just north of the South Moccasin Mountain Tertiary intrusive mass, we conclude that there is only a very low probability of significantly warmer water at shallow depth. Durfee Creek number 2 (spring no. 10) also has a large flow (15,000 gpm) and low temperature (22°C). There is no known heat source in that general area, suggesting either deep circulation or a shallow buried intrusive body as the heat source.

The high flow and low temperature suggest that dilution occurs in the Madison. The evaluation of this location is that there is only a slight possibility of significantly warmer water at shallow depth. The Staudenmeyer springs area is currently under investigation as an additional task associated with this study. A preliminary interpretation of potential in this area will be presented in Part II of this report, upon completion of the September field work.

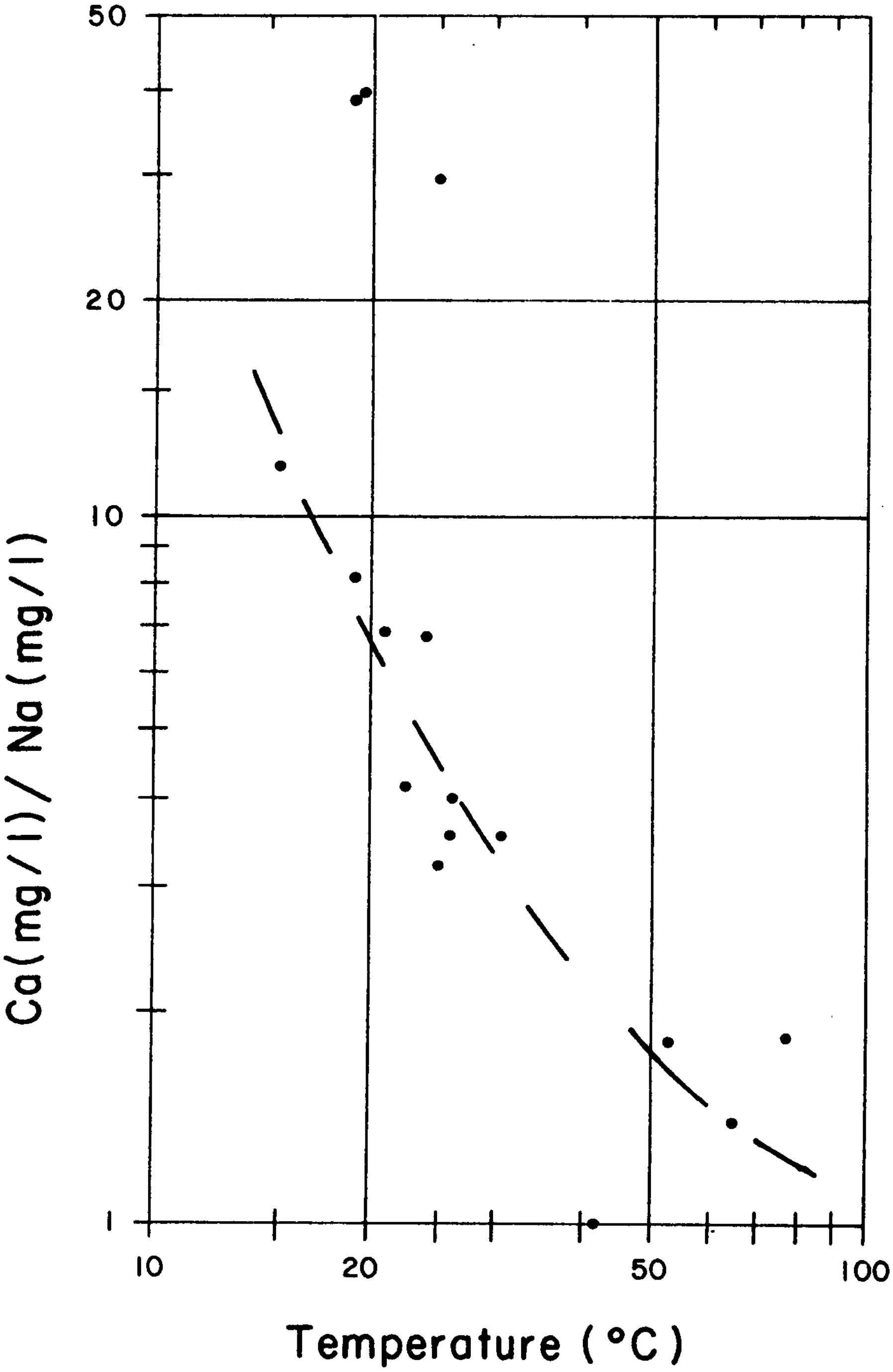

Figure 3. Plot of Ca-Na ratios versus temperature for the data in Table 2.

The Corwin (La Duke) area has already been designated as a Known Geothermal Resource Area (KGRA). The reader is referred to Robert Leonard of the U.S. Geological Survey (Helena, Montana) for a current assessment of the area.

REFERENCES CITED

Mariner, R. H., Presser, T. S., and Evans, W. C., 1976 Chemical characteristics of the major thermal springs of Montana: U.S. Geological Survey Open-File Report 76-480, 31 pages.

PART II

A RECONNAISSANCE STUDY OF GEOTHERMAL POTENTIAL IN THE UPPER PARTS OF RED ROCK CREEK AND MADISON RIVER VALLEYS, SOUTHWESTERN MONTANA

PRELIMINARY RESULTS

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Introduction

The study of shallow geothermal potential in the Upper Red Rock Creek Drainage and the Lower Madison River Drainage is being conducted to evaluate the geothermal prospects of the area for any possible space-heating potential.

This report includes some of the hydrologic field data obtained during the months of July through September, 1977, when 47 streams (Table 1), and 46 springs were field inventoried (Table 2).

Also, there is discussion of geologic mapping and an aerial thermal scan conducted during this same period.

Discussion

The last two and one half (2½) months were spent doing a hydrologic investigation and geological mapping of the study area (Fig. 1). This includes locating all streams, springs, and wells in the valleys and their perimeters. In the early summer, streams were monitored at 47 sites for flow, temperature, and specific conductance (Table 1), and each of the sites will be remeasured during the last week in September to obtain the lower flow information for the area.

In conjunction with the stream monitoring, 46 springs in the area were located and field inventoried for: discharge, temperature, specific conductance (using a Yellowsprings S.C. meter), silica (SiO_2) (using Hach chemical kit model SI-5), and fluoride (F) (using Hach chemical kit model FL-3).

Values obtained from the field silica and fluoride tests will be used to determine which springs to include on the high-priority list for water-quality sampling. All springs in which SiO_2 content is 20 parts per million (ppm) or more or fluoride content is 2 ppm or more will be sampled. After deciding on the streams and wells to sample, an areal-distribution sampling will be conducted, using the entire 125 samples allocated for this fall.

Of 42 wells in the area, 32 were inventoried according to U.S. Geological Survey System 2000 (Ground Water Site Inventory System) specifications and forms.

This procedure includes recording the following information if available: total depth, static water level, flow, diameter, pump type, etc.

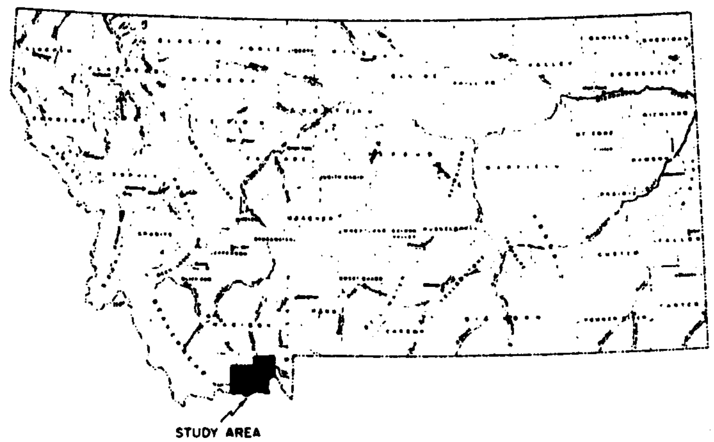

Figure 1. Location of study area.

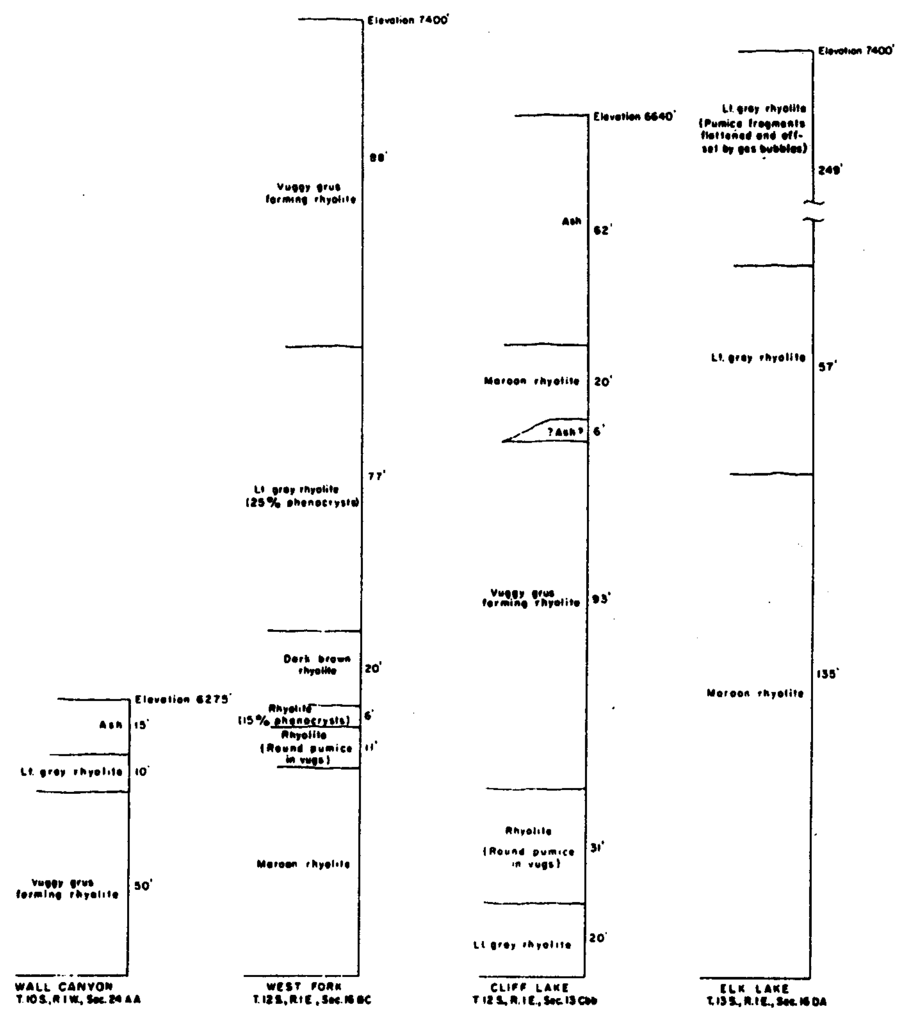

Figure 2. Stratigraphic sections of young volcanic rocks.

Several weeks were spent measuring the stratigraphic thickness of the Huckleberry Ridge Welded Tuff, which is the youngest volcanic unit (1.9 m.y.) in the study area and a potential heat source. Figure 2 shows the thickness and sequence of beds within the Tertiary volcanic rocks.

The only warm ground water found in the Centennial Valley is located on Les Staudenmeyer's property (T. 13 S., R. 2 W., sec. 17 and 18), where water temperatures range from 22 to 29°C; this water is used to extend the grass-growing season in the pastures.

Mapping of the area north of Staudenmeyer's land indicated a small anticlinal structure passing over the warm springs and the Staudenmeyer ranch. Explanations of the relationship between the anticline and the warm water have not been completely evaluated and will be withheld until the submission of a later report.

A reconnaissance map is being done for the north half of the Lower Red Rock Lake 15' Quadrangle (60% complete) and we hope to also complete the Upper Red Rock Lake 15' Quadrangle, which will tie into I. J. Witkind's U.S. Geological Survey map I-943.

Gerald Weinheimer, a graduate student at Montana State University, is assisting with the work in the Madison Valley portion of the research area. We have provided financial support for his field work, have provided aerial photos of his area, and have allocated part of our analytical budget for his water samples. The results of Gerald's thesis work will be incorporated in the final report, on which he will be a coauthor.

Conclusions

At this time it can be stated that:

(1) Faults along the north side of the Centennial Valley have appreciable displacement, exposing rocks of Mississippian age.

(2) The young volcanic rocks, which dip into the Centennial Valley from the north, are not continuous, as older rocks are exposed where the ash-flow tuff has been breached by erosion.

(3) The application of warm waters in this area will probably be restricted to space heating and agricultural use.

Table 2. Spring Data (July/August 1977) - Part II

Location	Description	Flow gpm	Temp (^oC)	S. C. 25^oC	PPM SiO_2	Fl
10S01E09BBB	Wolf Creek Hot Springs	359	55.	536**	90	2
11S02E32C	E. of Ghosttown of Cliff Lake Spring	2.2*	11.7	247	10	1
12S01E11ADD	Wade Lake Spring	50*	11.8	204	10	1
12S02E20D	Horn Creek Spring	2.77	11.5	260	19	1
13S03W22CCBC	Lousy Spring	.92*	7.5	380	17	1
22DAAB		4	9.5	322	17	1
23ABD		3	7	313	30	1
13S02W05CAAA	Cayuse Spring	.05	5.9	336	20	
18BDAD	Staudenmeyers Horse Water Spring	5.39*	22	709	20	2
18DB	--------do--------	25	24.5	614	20	1
13S01W04DCC	Tepee Creek Spring	200	5	79	15	1
10BBA	Tepee Creek Spring	2	7.4	61	15	1
12DAAC	Springs S. of Two Drink Springs	8	9.2	91	24	1
		8	6.1	94		
		3	11	84	21	1
13S01E07AAD	Brimstone Creek Spring	5.	9.9	86		1
09DBC	Hidden Lake Spring	37.5	6.9	192	34	1
28AACD	Spring for Stock	2	9.	322	15	1
31DCAB	Upper Elk Springs	1.4*	8.5	223	31.5	1
33AAC	Limestone Creek Spring	2	11.75	235	20	1
36DDD	Spring for Livestock	.5	18.9	150	17	1
13S02E19DADB	--------do--------	10	17.8	168	26	
20CBB	--------do--------	18	10.8	189	27	1
31CADD	--------do--------	5	11.3	80	11	1
32BB	Upper Antelope Creek Spring	1*	8.9	158	15	1
32CAB	Main Antelope Creek	56	7.9	122	17	1
32CDA	--------do--------	24	11.25	53	17	
14S03W23BBD	Huntsman Ranch	58	9.5	292	26	1
14S01W21DCCB	Upper Red Rock Lake Camp Spring	15	8.75	396	11	1
22DAB	Numerous Springs in marsh above lake	1.*	8	418	4	1
23DBA	--------do--------	1	6.1	355	10	1
23DBC	--------do--------	1	6	356	10	1
21DDD	--------do--------	2	8.5	362		
14S01E03CAD	Springs for Livestock	1.5*	5.5	140	15	1
03CBAD	--------do--------	5	17.8	176	15	1
08DACC	Culver Spring (west)	30*	7.5	294	13	1
13BDA	Huntsman Spring (Alaska Basin)	1.82*	8.	283	16	1
15CC	Fruin Spring	18.75	8.2	290	17	1
20CAB	Spring above Walsh Ranch	.25	14	78	23	1
23BCC	E. of Tobe Morton's	59	7	102	28	1
23CDC	Picnic Creek Spring	107	5.8	50	23	1
29DBAB	Spring @ W. Fk. of Antelope Creek source	77	5.1	80	12	1
14S02E06CBD	Spring for Stock	13	21.2	216	12	1
06CCCB	--------do--------	29	19	230	12	1
[illegible]	[illegible]	1*	8	207	11	1

Table 1. Stream Data (July/August 1977) - Part II

Location	Description	Flow (cfs)	Temp (°C)	Spec. Cond. (µmhos @ 25°C)
10S01E07ACCA	Wolf Creek	4.	20.	189
17DBD	Moose Creek	14.9	16.	110
33DDBD	Squaw Creek	0.6	15.	75
11S01E10DCB	Gazelle Creek	11.2	11.	109
10DCB	Papoose Creek	7.9	13.	67
15DDC	Bogus Creek	0.26	12.	188
22DDCD	Soap Creek	6.6	14.5	78
24BACD	Deadman Creek	3.1	12.8	92
24BBD	Curlew Creek	1.2	16	134
34BAB		0.02	17.1	166
12S01E08DDA	Freeze Out Creek	8.3	15.5	153
09BBD		0.04	14	166
17BD	Elk River	22.5	16.	231
12S02E03C	Mile Creek	4.	17	202
13S03W27CCC		0.4	21	147
13S02W17CCCC	Murphy Creek	7.8	27.	616
18CDC	Metzel Creek	4.9	16.1	384
18DCC		.007	21.	131
13S02E20BAAB	Poison Creek	0.5	10.6	220
14S03W13DAAB	Creek west of Curry Creek	1.1	13.	352
13DBA		0.02	19.5	454
21DDDA	Tipton Creek	8.	16.	308
22AAD		1.4	19.9	369
28BAC	Jones Creek	3.9	15.1	309
29AAC	Creek west of Jones Cemetery	0.1	23.9	555
14S02W06BDD	At lower Red Rock Lake Dam	83.7	15.8	164
16CCAA	Duff Creek	0.4	12.	371
17CBDC	Matsingale Creek			
18ACD	Creek east of Lakeview Cemetery	2.7	11.9	260
18BCD		4.7	10.	192
18CBB	Curry Creek	Dry		
18DAA		1.6	12.	333
22BAAD	Humphrey Creek	1.6	12.	247
24CCCD	Irrigation Ditch	2.9	17.4	209
25AABB	-----do-------	7.9	14.	163
25ABAA	O'dell Creek	2.1	19.	168
14S01W01AADA	Elk Springs Creek	25.8	17.	211
21DDC		0.07	10.	346
21DDDB		0.4	7.5	300
23BDD	Shambow Creek	5.7	7.	148
30AAAA	Irrigation Ditch	6.8	13.	157
30BAAB	------do------	4.5	13.	156
14S01E18BCAB	Red Rock Creek	22.5	16.2	216
18CCA		0.2	11.5	293
24BCC		0.8	11.9	181
24BDDC	Hell Roaring Creek	13.2	17.	239
29ACD	E. Fk. of Mt. Creek above W. Fk. of Antelope Creek	0.6	15.2	299

Table 1.—Thermal springs originating in the Madison Group.

No.	Name	T.	R.	Sec.	Tract	Discharge (gpm)	Temp °C	ΔH_1 (18°C) (billion Btu/yr.)	ΔH_2 (10°C) (billion Btu/yr.)	Source and comments
1.	Anderson's	3 S.	13 E.	29	ABAB	10 45	21 25	0.24 2.5	0.87 5.3	MBMG Analysis 72-861; Madison.
2.	Bear Creek	9 S.	9 E.	19	DB	30	32	3.3	5.2	Madison
3.	Bear Mouth No. 1	11 N.	14 W.	11	DCCCD	?	?			Madison
4.	Bear Mouth No. 2	11 N.	13 W.	18	AB	?	15			MBMG Analysis 72-109; Madison
5.	Brooks	17 N.	18 E.	19	DBDBB	68,000	19.5 21	810. 1,610.	5,100. 5,910.	MBMG Analysis 75M1510; Madison (?) through Kootenai (Cretaceous). Water used for irrigation.
6.	Brown's	8 S.	9 W.	30	DCB N½	360	22 42	11.4 >25.	34. >33.	Madison (?) under Tertiary volcanics. Discharge reported in USGS Prof. Paper 492; visual estimate in August 1975 was 3,000 gpm.
7.	Chico	6 S.	8 E.	1	CDCD	>130	48	>31.	>39.	Analysis by USGS; Madison (?) through Tertiary volcanics and sediments. Water used for resort.
8.	Corwin (LaDuke)	8 S.	8 E.	32	CDBA	500	65	186.	220.	Analysis by USGS; Madison (?) along fault. Water unused (July 1975); previously used for space heating.
9.	Durfee Creek No. 1	12 N.	22 E.	13	DDD	1	19 23	0.008 0.039	0.071 0.102	MBMG Analysis 73-842; spring near Madison-Pennsylvanian contact. Water used for livestock.
10.	Durfee Creek No. 2	12 N.	23 E.	19	BB	15,000	22	470.	1,420.	Spring near Madison-Pennsylvanian contact.
11.	Gallatin Canyon	6 S.	4 E.	33	BCC	?	?			Best location currently available; Madison.
12.	Garrison	10 N.	9 W.	19	Center	?	25			MBMG Analysis 72-868; Madison. Water not used (8/8/72).
13.	Giant Springs	21 N.	4 E.	33	BDAC	90,000	12	—	1,420	Not a "warm" spring, but included for purposes of comparison.
14.	Landusky No. 1	25 N.	24 E.	32	DABCC	950 1,250	18 20	— 19.7	60. 99.	MBMG Analysis 73-844; spring near Madison-Jurassic contact. 1,250 gpm flow measured by MBMG in May 1977.
15.	Landusky No. 2	25 N.	24 E.	32	DACAA	?	?			Spring near Madison-Jurassic contact.
16.	Landusky Plunge	24 N.	24 E.	12	CDDAB	3,200	24	152.	350	MBMG Analysis 73-843; spring near Madison-Jurassic contact. Flow measured by MBMG in May 1977. Domestic and livestock water use.
17.	Little Warm Springs No. 1	26 N.	26 E.	30	DABD	?	?			Spring near Madison-Jurassic contact.
18.	Little Warm Springs No. 2	26 N.	26 E.	32	ACAAA	1,200 5,000	26 26	76. 320.	152. 640.	MBMG Analysis 73-841; spring near Madison-Jurassic contact. 5,000 gpm flow measured by MBMG in May 1977. Domestic and livestock use.
19.	Little Warm Springs No. 3	26 N.	26 E.	32	ADB	1,200	22	38.	114.	MBMG Analysis 73-879; spring near Madison-Jurassic contact. Water used for irrigation.
20.	Lodgepole No. 1	26 N.	25 E.	24	CAAD	1,500	29	130.	230.	MBMG Analysis 73-878; these three Lodgepole springs issue from the Madison Group. We have a second analysis (MBMG 73-840), but the location is not precise enough to assign it to the proper spring. Total flow for all three springs was estimated at 3,000 gpm, yielding ΔH_1 and ΔH_2 values of 284 and 474 billion Btu's per year, respectively. Prof. Paper 492 lists flow at 10,000 gpm, and some estimates have been as high as 50,000 gpm.
21.	Lodgepole No. 2	26 N.	25 E.	24	CABD	?	32			
22.	Lodgepole No. 3	26 N.	25 E.	24	DBC	?	32			
23.	Lovell	8 S.	9 W.	28	BD	1,125	22	36.	107.	Tertiary sediment adjacent to Madison outcrop. Tertiary volcanics to west. Location corrected from that in USGS Prof. Paper 492.
24.	New Biltmore	4 S.	7 W.	28	BDA	100	54	28.	35.	Analysis by USGS; Madison.
25.	Nimrod	11 N.	15 W.	14	CDAA	100	19 22	0.79 3.2	7.1 9.5	MBMG Analysis 72-112; Cambrian or Mississippian limestone along faults—spring issues from Tertiary sediments.
26.	Staudenmeyer's Spring No. 1	13 S.	2 W.	17	CB	3,200	27	230.	430.	Spring adjacent to contact between Tertiary (?) volcanics and limestone of uncertain age. Flow estimated with float and watch. Composite of four warm springs and one cold spring.
27.	Staudenmeyer's Spring No. 2	13 S.	2 W.	18	ACC	900	26	57.	114.	Spring issues from silicified limestone (?) of uncertain age. Staudenmeyer's springs are used for flood irrigation of hay.
28.	Staudenmeyer's Spring No. 3	13 S.	2 W.	18	BAD	2,400	22	76.	230.	Spring issues near contact of volcanics and limestone.
29.	Sun River	22 N.	10 W.	26	CABA	500	29	43.	75.	Madison, Jurassic, or Kootenai.
30.	Warm Springs State Hospital	5 N.	10 W.	24	A	150	77	70.	80.	Analysis by USGS; source beneath Tertiary sediments. Ca/Na ratio suggests limestone aquifer contact. Water being considered for space heating.

Table 2.—Chemical composition of thermal springs originating in the Madison Group.

Spring number	1	4	5	7	8	9	12	14	16	18	19	20	20, 21, or 22?	24	25	30
Temperature (°C)	25	15	19.5	42	65	19	25	21	24	26	22.5	26	30.6	53	19	77
Laboratory pH	7.84	7.69	7.68	7.38*	6.52*	8.08	7.30	8.03	8.09	8.06	7.92	7.96	8.06	6.76*	7.63	6.46*
Specific conductance (µmho/cm)	414	610	882	379	2,460	2,535	737	801	1,262	2,082	1,823	1,430	1,980	2,160	856	1,510
SiO_2 (mg/l)	12.2	16	8.9	34	49	12.8	18.2	18.2	17.8	16	15.9	14.5	16.3	46	21	56
Fe (mg/l)	<.01	0.03	<.01	–	–	0.09	<.01	<.01	<.01	0.10	<.01	<.01	<.01	–	0.01	–
Mn (mg/l)	<.01	0.01	<.01	<.02	0.02	0.02	<.01	<.01	<.01	<.01	<.01	<.01	<.01	0.03	0.01	0.05
Ca (mg/l)	47	89	133	35	320	533	77	266	161	289	276	187	268	290	126	220
Mg (mg/l)	23	28	40.3	8.8	58	165	35	86	65	110	91	69	96	73	36	22
Na (mg/l)	1.6	7.6	3.4	35	230	14	24	39	24	72	66.3	52.5	75	160	15.5	120
K (mg/l)	1.3	1.8	1.4	6.8	23	3.2	5.2	9.0	6.7	13.3	10.4	8.5	13	24	3.4	26
HCO_3 (mg/l)	88	220	195	170*	297*	59	59	109	101	101	196	153	81	226*	168	258*
SO_4 (mg/l)	139	163	336	41	1,200	1,870	335	982	620	1,140	936	650	1,062	1,100	340	670
Cl (mg/l)	0.5	1.5	0.95	10	45	4.1	3.4	18.8	9.5	59	42	38	57	46	2.7	5.0
F (mg/l)	0.4	0.5	1.3	0.9	3.6	1.8	1.3	1.5	1.6	1.4	1.7	0.9	1.1	3.3	0.8	3.9
NO_3 (mg/l)	0.3	0.2	0.8	–	–	ND	0.2	1.1	1.1	0.1	ND	1.7	0.1	–	0.4	–
B (mg/l)	–	–	–	0.06	0.46	–	–	–	–	–	–	–	–	0.92	–	0.10
Al (mg/l)	–	–	–	–	<.001	–	–	–	–	–	–	–	–	0.002	–	<.001
Li (mg/l)	<.01	–	–[1]	0.03	0.24	0.04	0.15	0.09	0.05	0.14	–	–	0.14	0.18	–	0.36
H_2S* (mg/l)	–	–	–	0.6	<1.	–	–	–	–	–	–	–	–	1.1	–	0.7
NH_4* (as N, mg/l)	–	–	–	<.1	0.22	–	–	–	–	–	–	–	–	0.2	–	<.1
Total Dissolved Solids (calculated, mg/l)	313	527	622	256	2,076	2,665	558	1,531	1,008	1,806	1,635	1,175	1,669	1,856	715	1,251
Total hardness as $CaCO_3$ (mg/l)	211	334	498	124	1,038	1,998	335	1,014	669	1,171	1,056	747	1,059	1,025	462	640
Total alkalinity as $CaCO_3$ (mg/l)	72	180	195	139	244	48	48	89	83	83	161	125	67	185	138	212
Sodium Adsorption Ratio	0.0	0.2	0.0	1.4	3.1	0.1	0.6	0.5	0.4	0.9	0.9	0.8	1.0	2.2	0.3	2.1

*Field determination; ND-Not detected; – Not determined;

[1] Value of 0.02 mg/l on previous sample; analyses for spring 7, 8, 24, and 30 from U.S. Geological Survey Open-File Report 76-480.

PRELIMINARY LIST OF THERMAL SPRINGS IN MONTANA
BY THE MONTANA BUREAU OF MINES AND GEOLOGY
(Compilation by R. N. Bergantino and J. L. Sonderegger, November 1977; revised, November 1978)

NAME	LOCATION T	R	S	tract	TEMPERATURE °C	°F	FLOW l/min	gpm	cfs	TOPOGRAPHIC MAP	ALTITUDE meters	feet	APPARENT SOURCE OF WATER	SAMPLED BY agency	date	WATER CHEM. DATA sc @ 25°C	pH	St.Anal
Alhambra	8N	3W	16	ACAA	56.5 (55)	(134) 131	40	(10) 150-250		Clancy 15′	1330	4360	Boulder batholith; see U.S.G.S. Open-File Report 78-438	USGS* MBMG	08-23-74 09-01-72	929 929	7.23 8.84	Yes Yes
Anaconda	4N	11W	13	AAA	21.7	(71)		3.2		Anaconda 15′	1675	5490	Tertiary volcanics or Madison	MBMG	06-23-78	2624	7.31	Yes
Andersons	3S	13E	29	ABAB	(25)	77		75		McLeod Basin 7.5′	1690	5540	Madison	MBMG	07-25-72	414	7.84	Yes
Andersons Pasture	13S	2W	18	ACD	23.5-28	(74-82)		(900)	2.0	Lower Red Rock Lake 15′	2085	6840	Pleistocene volcanics, 2 springs	MBMG*	10-03-77	609	7.4	Yes
Apex	5S	9W	10	AADADD	25	(77)		750		Glen 7.5′	1600	5240	Quadrant or Madison	MBMG	05-25-78	520	7.78	Yes
Avon	10N	8W	24	BBC	25.5	(78)		24		Avon 15′	1493	4900	Tertiary volcanics, Terrace	MBMG	06-16-78	870	6.9	No
Barkells (see Silver Star)																		
Bear Creek	9S	9E	19	CDD	21.5-27	(71-81)		10		Gardiner 15′	1700	5600	Tertiary volcanics; Precambrian	MBMG	05-23-78	2700	9.5	No
Bearmouth 1	11N	14W	11	DCCCD	20.2	(68)		—		Bearmouth 15′	1170	3840	Madison	MBMG	06-17-78	642	7.6	No
Bearmouth 2	11N	14W	12	CD	19.6	(67)		(1100)	2.4	Bearmouth 15′	1169	3835	Madison	USGS	03-18-72	610	7.69	Yes
Beartrap (see Norris)																		
Beaverhead Rock	5S	7W	22	ABBD	(27)	81		100		Beaverhead Rock 7.5′	1470	4810	Tertiary sediments over Madison(?)	MBMG	08-21-66	—	7.2	No
Bedford	7N	1E	23	ABBC	23.6	(74)		(1500)	3.4	Townsend 15′	1180	3880	Tertiary sediments	MBMG	06-23-78	467	7.2	No
Big Hole (see Jackson)																		
Big Warm Springs (see Lodgepole 1, 2, 3)																		
Big Warm Springs (see Brooks)																		
Birch Creek (see Apex)																		
Blue Joint 1	2S	23W	1	A	(29)	84		100		Painted Rocks Lake 15′	1535	5040	Idaho bath.; Precambrian Ravalli	MBMG	08-11-72	162	8.12	Yes
Blue Joint 2	2S	22W	6	BA	(29)	85		100		Painted Rocks Lake 15′	1505	4940	Idaho bath.; Precambrian Ravalli	MBMG	08-11-72	180	8.22	Yes
Boulder	5N	4W	10	C	64-76 (38)	(147-169) 100		590 250		Boulder 15′	1480	4860	Boulder batholith	USGS* Health	08-22-74 11-24-64	523 TDS 388	8.50 —	Yes No
Bozeman	2S	4E	14	DDBAA	50-54.6 (54-57)	(122-130) 130-135		75		Bozeman 15′	1443	4735	pre-Belt, Tertiary sediments	USGS* Health	08-25-74 1964	624 TDS 428	8.58 —	Yes No
Brewers (see White Sulphur Springs)																		

NAME	LOCATION T	R	S	tract	TEMPERATURE °C	°F	FLOW l min	gpm	cfs	TOPOGRAPHIC MAP	ALTITUDE meters	feet	APPARENT SOURCE OF WATER	SAMPLED BY agency	date	WATER CHEM sc @ 25°C	pH	DATA St. Anal.
Bridger Canyon	1S	6E	34	BCDD	21	(70)		80-237		Bozeman Pass 15′	1490	4890	Madison	USFWS	—	448	7.7	Yes
Broadwater	10N	4W	28	A	62	(144)	< 50	(≤ 13)		Helena 15′	1250	4100	Belt and Boulder batholith	USGS*	08-24-74	796	8.53	Yes
					(59)	138		75						Health	09-17-64	TDS 563	—	No
Brooks	17N	18E	19	DBDBB	(21)	70		80000		Lewistown 15′	1145	3760	Kootenai; Madison	Health	08-19-64	TDS 670	—	No
					19.9	(69)		(72000)	160					MBMG	06-12-78	900	7.33	No
					19.5	(67)		(68000)	151					USGS	09-23-75	882	7.68	Yes
Browns	8S	9W	30	DCB	23.7	(75)		(1100)	2.4	Dalys 7.5′	1700	5575	Madison; Tertiary volcanics	MBMG	06-21-78	645	7.4	No
Byrnes (see Nimrod)																		
Camas	21N	24W	3	BBB	(43-46)	110-114		—		Hot Springs 7.5′	860	2830	Piegan; Diorite sill	MBMG	11-24-64	TDS 270	—	No
					45	(113)	> 200	(> 53)						USGS*	07-03-75	367	9.39	Yes
					44	(111)		24						USGS	09-15-75	394	9.11	Yes
Camp Aqua (well)	22N	23W	29	CAA	50.8	(123)		> 330		Hot Springs NE 7.5′	849	2785	Tertiary sediments	MBMG	06-18-78	640	8.3	No
Chico	6S	8E	1	CDCD	42-46	(108-115)		320		Emigrant 15′	1610	5280	Tertiary sediments with Tertiary granite and Madison	USGS*	08-25-74	379	7.38	Yes
					(48)	119		—						MBMG	11-24-64	TDS 254	—	No
Clarks (see Potosi 1)																		
Cliff Lake (see W. Fork Swimming Hole)																		
Corwin (see La Duke)																		
Deer Lodge Prison	7N	10W	32	DD	27	(81)		100		Racetrack 7.5′	1512	4960	Precambrian Ravalli, 4 springs	MBMG	03-27-78	220	9.3	Yes
Diamond Bar Inn (see Jackson)																		
Diamond S (see Boulder)																		
Durfee Creek	12N	23E	19	BB	21.1	(70)		(2300)	5.1	Roundup 1°x 2°	1550	5100	Madison	MBMG	06-13-78	1960	7.25	No
Elkhorn	4S	12W	29	ACAD	48.5	(119)		30		Polaris 15′	2190	7200	Boulder batholith	USGS*	08-20-74	209	8.94	Yes
					(46)	114		—						MBMG	07-27-72	219	8.49	Yes
Emigrant Gulch (see Chico)																		
Ennis	5S	1W	28	DCAD	(78)	172		15		Ennis 15′	1500	4920	Tertiary sediments over pre-Belt	Health(?)	02-06-69	TDS 310	—	No
					83.2	(182)		< 20						USGS*	04-01-76	1510	7.7	Yes
Fairmont (see Gregson)																		
Ferris (see Bozeman)																		
Gallogly	1S	19W	15	BCCCAC	(38)	100		120		Lost Trail Pass 7.5′	1645	5400	Idaho batholith	Health	08-05-64	TDS 144	—	No
					(49)	120		120						MBMG	08-10-72	202	7.81	Yes
					29	(84)	(at pool)	30						MBMG	06-19-78	253	—	No

NAME	LOCATION T	R	S	tract	TEMPERATURE °C	°F	FLOW l min	gpm	cfs	TOPOGRAPHIC MAP	ALTITUDE meters	feet	APPARENT SOURCE OF WATER	SAMPLED BY agency	date	WATER CHEM. DATA sc @ 25°C	pH	St.Anal.
Garrison	10N	9W	19	AC	(25)	77		54		Garrison 15′	1495	4900	Cretaceous-near Madison	MBMG	08-08-72	737	7.30	Yes
Granite	11N	23W	7	ABDBA	(51)	123		100		Lolo Hot Springs 7.5′	1275	4180	Wallace; Idaho batholith	MBMG	06-19-78	280	9.3	No
Green Springs	20N	24W	33	ADDD	(19)	66		–		Perma 15′	860	2820	alluvium; Precambrian Piegan	MBMG	1964	TDS 162	–	No
					(26)	79.5		>80						MBMG	06-18-78	370	9.2	No
Gregson	3N	10W	2	BDCA	70	(158)		10-69		Anaconda 15′	1565	5130	Tertiary volcanics; Boulder	USGS*	08-19-74	761	8.41	Yes
					(68)	154		–					batholith	Health(?)	04-08-65	TDS 560	–	No
Greyson	6N	2E	21	ABBB	17.9	(64)		900		Duck Creek Pass 15′	1164	3820	Tertiary sediments	MBMG	06-03-78	610	7.6	No
Halvorson	12N	38E	27	ADDB	–	–		–		Vanstel 7.5′	945	3100	No data to date					
Hapgood (see Norris)																		
Helena (see Broadwater)																		
Hunters	1S	12E	9	CCADC	59 (avg.)	(138)	5000	(1300)		Hunters Hot Springs 7.5′	1335	4380	Livingston; Cretaceous volcanics;	USGS*	07-02-75	354	9.13	Yes
					(66)	150		700-1500					Tertiary granite	MBMG	07-25-72	387	8.52	Yes
Jackson	5S	15W	25	CBBB	(57)	134		–		Jackson (advance) 7.5′	1970	6470	alluvium; Tertiary sediments;	MBMG	08-06-64	TDS 662	–	No
					(58)	136		–					Missoula Group	MBMG	07-28-72	1020	9.04	Yes
					58	(136)	1000	(260)						USGS*	08-16-74	972	6.77	Yes
Jardine (see Jackson)																		
Kimpton (see Warner)																		
La Duke	8S	8E	32	CDBA	65	(149)	500	(130)		Miner 15′	1610	5280	Madison	USGS*	07-02-75	2460	6.52	Yes
					(66)	151		500						MBMG	07-26-72	2400	7.62	Yes
Landusky 1	25N	24E	32	DABCC	(21)	70		3100		Hays 7.5′	1130	3710	Madison; Jurassic	MBMG	08-16-73	801	8.03	Yes
Landusky 2	25N	24E	32	DACAAA	–	–		<50		Hays 7.5′	1130	3710	Madison; Jurassic					
Landusky Plunge	24N	24E	12	CDDAB	(24)	76		2900		Hays SE 7.5′	1125	3690	Madison; Jurassic	MBMG	08-16-73	1262	8.09	Yes
Lithia (see Andersons)																		
Little Warm Springs 1	26N	26E	30	DABD	–	–		<1		Bear Mountain 7.5′	1085	3560	Madison; Jurassic					
Little Warm Springs 2	26N	26E	32	ACAAA	(26)	79		1200		Bear Mountain 7.5′	1025	3360	Madison; Jurassic	MBMG	08-16-73	2082	8.06	Yes
					(22)	72		5000						MBMG	05- ? -77	–	–	No
Little Warm Springs 3	26N	26E	32	ADB	22.5	(72)		–		Bear Mountain 7.5′	1025	3360	Madison; Jurassic	USGS	10-04-73	1823	7.92	Yes
Lodgepole 1	26N	25E	24	CAAD						Bear Mountain 7.5′	1100	3600	Madison					
Lodgepole 2	26N	25E	24	CABD	29-32	(84-90)		2700		Bear Mountain 7.5′	1125	3700	Madison	analysis by USGS and MBMG— identification of spring not clear				Yes
Lodgepole 3	26N	25E	24	DBC						Bear Mountain 7.5′	1100	3600	Madison					

NAME	LOCATION T	R	S	tract	TEMPERATURE °C	°F	FLOW l min	gpm	cfs	TOPOGRAPHIC MAP	ALTITUDE meters	feet	APPARENT SOURCE OF WATER	SAMPLED BY agency	date	WATER CHEM. DATA sc @ 25°C	pH	St.Anal.
Potosi 1	3S	2W	7	CABA	(38)	100		550		Harrison 15′	1860	6100	Tobacco Root Stock	MBMG	1964	TDS 320	–	No
														(Cannot determine which Potosi Spring.)				
Potosi 2[1] (See note at end of table.)	3S	2W	6	CACC	–	–		–		Harrison 15′	1850	6080	Tobacco Root Stock					
Potosi 3	3S	2W	6	CBD	49.5	(121)	>200	(>53)		Harrison 15′	1870	6130	Tobacco Root Stock	USGS*	08-21-74	471	8.63	Yes
														(Possibly Potosi 3)				
Pullers	8S	5W	1	AACC	44.4	(112)		50		Metzel Ranch 7.5′	1670	5485	Tertiary sediments; pre-Belt	USGS*	05-14-76	1680	7.7	Yes
Quinns	18N	25W	9	CDADA	–	–		–		Plains 15′	780	2560	Precambrian Piegan	?	04-08-65	TDS 192	–	No
					(43)	109		20						MBMG	08-09-72	205	7.91	Yes
					43.4	(110)		17						MBMG	06-18-78	170	8.9	No
Renova	1N	4W	32	DBC	48.9-50.0	(120-122)		40		Vendome 7.5′	1340	4400	Cambrian, Meagher Limestone	USGS*	08-13-76	1100	7.5	Yes
Ross' Hole (see Gallogly)																		
Ryan Canyon (see Browns)																		
Silver Star	2S	6W	1	CBD	71.5	(161)	150	(40)		Twin Bridges 15′	1430	4700	Boulder batholith—pre-Belt contact zone	USGS*	08-18-74	808	8.17	Yes
					(72)	162		150						MBMG	07-10-72	847	8.40	Yes
Siparyann 1 & 2 (see Landusky 1 & 2)																		
Sleeping Child	4N	19W	7	DCDDBB	(51)	124		115		Deer Mountain 7.5′	1450	4750	Idaho batholith; 2 sources	Health	08-04-64	TDS 400	–	No
					(42)	108		115						MBMG	08-10-72	568	7.98	Yes
					45	(113)	>2000	(>530)						USGS*	08-15-74	538	8.20	Yes
Sloan Cow Camp	12S	1E	19	CDA	29.5-30	(85-86)		(350)	0.77	Cliff Lake 15′	2000	6560	alluvium; Pleistocene volcanics (?)	MBMG*	09-29-77	410	10.05	Yes
State Hospital (see Warm Springs)																		
Staudenmeyer Ranch	13S	2W	17	CBA	28	(82)		(1800)	4.0	Lower Red Rock Lake 15′	2055	6750	Pleistocene rhyolite, 5 springs; chemistry suggests Madison source	MBMG*	10-03-77	646	7.5	Yes
Sunnyside (see Alhambra)																		
Sun River	22N	10W	26	CAB	30.4	(87)		710		Arsenic Peak 7.5′	1465	4800	Madison, 5 springs	MBMG	06-15-78	1190	7.2	No
Symes (well)	21N	24W	4	AAD	(46)	115				Hot Springs 7.5′	865	2830	Precambrian; water enters well from base of alluvium (217-226 feet)	MBMG	08-09-72	394	8.42	Yes
					36-40	(97-104)		100						MBMG	06-18-78	330	9.8	No
Thexton (see Ennis)																		
Toston	4N	3E	6	DADC	(14)	57		(9000)	20	Toston 15′	1205	3960	Madison	MBMG	11-24-64	TDS 238	–	No
					15.2	(59)		(20000)	44					MBMG	06-02-78	440	7.5	No
Trudau	7S	4W	7	DCACCC	22.7	(73)		175		Metzel Ranch 7.5′	1730	5675	pre-Belt and Paleozoic	MBMG	05-25-78	850	8.4	Yes
Tyler 1 & 2 (see Durfee Creek 1 & 2)																		

NAME	LOCATION				TEMPERATURE		FLOW			TOPOGRAPHIC MAP	ALTITUDE		APPARENT SOURCE OF WATER	SAMPLED BY		WATER CHEM. DATA		
	T	R	S	tract	°C	°F	l min	gpm	cfs		meters	feet		agency	date	sc @ 25°C	pH	St.Anal.
Lolo	11N	23W	7	ADCCC	44	(111)	100	(26)		Lolo Hot Springs 7.5′	1266	4155	Wallace; Idaho batholith;	USGS*	08-17-74	225	9.27	Yes
					(44)	112		50						MBMG	08-09-72	234	7.87	Yes
					(41-47)	105-116		180					3 springs	MBMG	06-19-78	307	9.6	No
Lost Trail (see Gallogly)																		
Lovells	8S	9W	28	BD	19.4	(67)		3500		Gallagher Mountain 7.5′	1675	5490	Tertiary sediments; Tertiary volcanics; Madison	MBMG	06-21-78	620	7.9	No
McMenomey Ranch	9S	10W	29	AAA	19.0	(66)		(7300)	16.2	Dalys 7.5′	1660	5449	Madison-Beaverhead contact	MBMG	06-21-78	722	7.4	Yes
Matthews (see Bozeman)																		
Medicine	1N	20W	12	CCA	(49)	120		100		Medicine Hot Springs 7.5′	1355	4440	Idaho batholith	Health	08-05-64	TDS 170	—	No
								100						MBMG	08-09-72	377	8.08	Yes
					45-47	(113-117)		85-105						USGS*	08-16-74	343	8.59	Yes
Medicine (see Gallogly)																		
Medicine (see Sun River)																		
Medicine Rock (see Sleeping Child)																		
Mockels (see Plunkets)																		
Morrison Butte (see Landusky Plunge)																		
Naves (see Plunkets)																		
New Biltmore	4S	7W	28	BDA	(52)	126		100		Beaverhead Rock 7.5′	1458	4783	Madison	MBMG	08-06-64	TDS 2004	—	No
					(54)	130		100						MBMG	07-10-72	2140	7.34	Yes
					53	(127)	>100	(>26)						USGS*	08-17-74	2160	6.76	Yes
Nimrod	11N	15W	14	CDAA	(22)	72		200		Bearmouth 15′	1160	3800	Cambrian; Madison	Health	08-03-64	TDS 722	—	No
					19	(66)		—						USGS	03-18-72	856	7.63	Yes
					20.5	(69)		3200						MBMG	06-17-78	860	7.8	No
Norris	3S	1W	14	DAB	52.5	(126)	400	(106)		Norris 15′	1465	4805	pre-Belt; Tobacco Root Stock	USGS*	08-21-74	903	7.58	Yes
					—	—		—						MBMG	11- ? -64	TDS 620	—	No
					(51)	124		90						Private	05-04-70	TDS 700	—	No
Paradise (see Quinns)																		
Pipestone 1 & 2	2N	5W	28	BDDD	57	(135)	300	(79)		Dry Mountain 7.5′	1380	4530	Boulder batholith	USGS*	08-18-74	455	8.72	Yes
					(57)	134		140						MBMG	08-06-64	TDS 328	—	No
Plunkets	4N	1E	27	AA	16.5	(62)		4000		Radersburg 15′	1275	4180	Madison	MBMG	06-02-78	590	8.1	No
Polaris (see Elkhorn)																		

NAME	LOCATION T	R	S	tract	TEMPERATURE °C	°F	FLOW l min	gpm	cfs	TOPOGRAPHIC MAP	ALTITUDE meters	feet	APPARENT SOURCE OF WATER	SAMPLED BY agency	date	WATER CHEM. DATA sc @ 25°C	pH	St.Anal.
Vigilante	9S	3W	22	BDDD	23.5	(74)		(2200)	4.9	Varney 15′	1890	6200	Madison	MBMG	05-24-78	620	7.5	Yes
Warm Springs-State Hospital	5N	10W	24	A	77-78	(171-172)	600	(160)		Anaconda 15′	1470	4820	Boulder batholith(?), Madison(?)	USGS*	08-19-74	1510	6.46	Yes
					(71)	160		60						MBMG	04-08-65	TDS 1308	—	No
Warm Springs (see Medicine Lodge)																		
Warm Springs (see Landusky Plunge)																		
Warner	5N	1E	22	DBBC	18.0	(64.4)		130		Radersburg 15′	1250	4100	alluvium; Tertiary sediments; Precambrian	MBMG	06-02-78	200	8.2	Yes
Weeping Child (see Sleeping Child)																		
West Fork Swimming Hole	12S	1E	18	CAD	25-28	(77-82)		(500)	1.1	Cliff Lake 15′	2040	6700	alluvium; Pleistocene volcanics(?)	MBMG*	09-29-77	322	8.30	Yes
White Sulphur Springs	9N	7E	18	BB	(35-52)	95-125?		500		White Sulphur Spgs. 7.5′	1530	5025	Tertiary sediments; Precambrian	MBMG	09-01-61	TDS 1450	—	No
					46	(115)	>1500	(>400)						USGS*	08-17-74	2220	6.8	Yes
Wolf Creek[2]	10S	1E	9	BBBA	54-66	(129-151)		(310)	0.7	Cliff Lake 15′	1860	6100	Tertiary sediments; Precambrian	MBMG*	09-30-77	494	11.03	Yes
					68.0	(154)		53						USGS*	05-13-76	659	8.6	Yes
Ziegler (see Apex or New Biltmore)																		

() Bracket indicates temperature or flow reported in other units and calculated value presented for purposes of comparison.

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

A standard analysis includes: Ca, Mg, Na, K, Fe, Mn, SiO_2, CO_3, HCO_3, SO_4, Cl, F, NO_3, pH, and specific conductance.

Flow values and chemistry for some springs may not agree because of multiple sampling; some questionable values have been included.

Abbreviations: Health—Montana State Board of Health
MBMG—Montana Bureau of Mines and Geology
USGS—United States Geological Survey
USFWS—United States Fish and Wildlife Service

Notes:

[1]The Potosi Spring area in sec. 6 was inventoried on 05-24-78. The lower spring area contained a spring and pool south of the road ($Q \cong 40$ gpm; T = 35.0°C; SC = 560 μmho/cm; pH = 8.45) and a spring north of the road (Q = 20 gpm; T = 26.1°C; SC = 415 μmho/cm; pH = 8.85). The upper spring ($Q \cong 20$ gpm; T = 37.1°C; SC = 464 μmho/cm; pH = 8.45) also had a lower temperature than previously reported (Leonard and others, 1978, U.S. Geological Survey Open-File Report 78-438); these differences are attributed to dilution by snowmelt.

[2]The Wolf Creek hot spring was disturbed by backhoe work at an adjacent warm spring late in 1976 or early 1977. By 09-29-78 the hot spring temperature had recovered to 65°C (149°F). The MBMG flow value was taken at the road and includes contributions from warm and cool springs and seeps.