Appendix 4.1. Field Data and Classification of Springs

Field data of all springs and groundwaters sampled for this study are listed in Table A-4.1(i) at the end of this appendix. Grouping based on field criteria was used as a way of keeping track of what we were learning as the field season progressed, to help ensure comprehensive sampling, and thereby to direct ourselves to possible additional sample sites, or to return to previous sites for additional samples. The groups listed in the main text (Chapter 5.4.2.) are explained below along with the characteristics used to identify them. Chemical data were not available at the time of sampling but have been included in the descriptions below as an aid to further discussion. Hamilton et al (1988a) provided a more detailed description of the "physical" classification system outlined here, but the physical classification as modified by Hamilton (1990) is reproduced here to include the 1987 results.

A-4.1.1. Group P1 - Tufa springs

Springs that precipitate tufa are located throughout the study area, particularly in carbonate terrane. A number of these springs are situated along major faults, such as the Broken Skull Fault in the South Nahanni River Valley. Many of the other tufa springs are inferred to be associated with faults, mapped or unmapped. The tufa varies in colour from buff to bright orange depending on the amount of Fe and Mn oxides and hydroxides that have been co-precipitated. Deposits such as Rabbitkettle Hot Springs are large terraced structures. Other tufa springs form small crumbly deposits that line channels draining vents. The large size and colour of the tufa deposits aid in aerial identification.

The pH of tufa spring waters was usually slightly acidic to slightly basic but invariably rises sharply with distance from the vent due to exsolution of CO_2. Gas (mostly CO_2) was observed in many vents either bubbling or clinging to objects in the vent as it exsolved. The conductivity is usually moderately high (>500 µS/cm[1]). Temperatures were mainly low, though some of the springs are thermal (up to 48ºC).

The chemical analyses have shown that all springs in this group have Ca-HCO_3-dominated waters, but the total concentrations of these elements varied. TDS content is usually moderate to high, and in cases where it is high, there are often significant quantities of other ions, such as SO_4^{2-} or Cl^-, which suggest deeper circulation (021, 040, 041, 043, 082). The concentrations of most trace metals (Fe, Mn, Cu, Co, Cd, Ni and Zn) are low.

A-4.1.2. Group P2 - Iron springs

Springs precipitating iron hydroxides are located in shale terrane throughout the study area and are also in areas underlain by the Mattson Formation, a Mississippian sandstone in the Tlogotsho Plateau study area. The springs range from small reddish seeps to large springs with deposits covering an extensive area. The precipitate is usually a floccular ooze which dries into a red, poorly vegetated soil. The precipitate also can take the form of calcium carbonate, iron hydroxide or gypsum-cemented ferricrete. Streams with unusually low pH, or the presence of iron oxide (red) or sulphate (white) precipitate in the stream bed, also were sampled. In some streams, a zone of precipitation of iron hydroxides was located downstream of a particular spot along its course (e.g. 042, 049 and 071). Investigation revealed springs or small spring-fed streams entering the larger streams at these spots. Differences in pH or Eh between the spring and the larger stream caused the immediate precipitation.

Most waters from iron-precipitating springs were neutral to strongly acidic and, except in several cases (including the Flat River Springs), pH did not tend to rise after waters leave the vent. This indicates that sulphuric acid rather than carbonic acid is causing the acidity. Conductivity had a wide range from 50 µS/cm to over 3000 µS/cm. The temperature, measured at the vent, was low (<7ºC), except for Spring 069 where it was 11.5ºC.

Chemically, the group is quite variable. Most of the samples have high to very high Fe (500 to 122,000 ppb) and Mn (50 to 5400 ppb) concentrations. A large number of the springs in this group also have elevated trace metal (Cu, Co, Cd, Ni and Zn) concentrations. Of the major ions, commonly SO_4^{2-} is elevated and Ca/Mg-SO_4 dominates. A few of the springs discharging from or near the Mattson Formation (078, 079, 082, 083) have relatively high Mg^{2+} (45-65 ppm) although most are in the 10-25 ppm range (062, 069, 070, 080, 108, 109, 116, 121) and the highest Mg^{2+} values are in some shale-hosted springs along Flat River (56-58 @ 54-111 ppm), metalliferous hot springs in Meilleur River valley (72A & B @ 212-241ppm) and shale-hosted

[1] µS/cm is a unit of electrical conductivity (microsiemens per cm) and is the inverse of resistance.

hot springs in the Clausen Creek area (63, 64, 74, 123 @ 47-94 ppm).

Included in the iron springs group are several of the tufa precipitating springs of the Flat River Valley (017, 030 and 055). They were included because the iron-hydroxides that co-precipitate have a bright orange colour and the pH at the time of sampling was low. These springs have very high concentrations of Ca^{2+} and HCO_3^- and precipitate $CaCO_3$.

A-4.1.3. Group P3 - Hot springs in quartz monzonite terrane

The springs in this category are all thermal and are spatially associated with Cretaceous quartz monzonite plutons. There is no precipitate, but a white, kaolin-like alteration product coats cobbles and boulders of quartz monzonite around most vents making them easily visible from the air. Vegetation does not grow where the water flows, but surrounds the vent, being unusually lush with ferns, wild mint and stands of deciduous trees. These springs are so easily visible that most of the ones sampled had been previously discovered.

The waters of Group 3 are also quite distinct. The pH is high at the vent, in most cases between 8.5 and 9.2, and does not drop appreciably after sampling. The conductivity is quite low (<400 µS/cm) and the temperature, ranging from 40 to 65ºC, is the highest of any of the groups.

Chemical analyses show that the waters are Na-HCO_3 dominated, with very little Ca^{2+}. Elevated trace elements include F, Si, As, Mo, and W. The latter has very high concentrations for natural waters. Two water samples from the Tungsten Mine (019,020) show very similar results, although Ca^{2+} and SO_4^{2-} are high in one of them. The two samples of mine water are slightly thermal (16ºC) and have a high pH. As such, they are included in the hot springs field category.

A-4.1.4. Group P4 - Clausen Creek hot springs

Clausen Creek is located within the Tlogotsho Plateau study area and flows north into the national park. Near its mouth are the famous Kraus Hot Springs (063, 064). They have a high flow rate, which is large enough to produce a small stream flowing into the South Nahanni River and which has been extensively dammed by beavers. There are no deposits, but a suspended precipitate of $CaSO_4$ gives the water flowing from them a milky white appearance. Gas bubbles rise from a number of vents in the beaver pond. Smaller springs (122 and 123) and at least one other unsampled spring with similar characteristics are found between 2 km south of the river and the Kraus Hot Springs (063, 064). All of the springs have a very strong H_2S smell associated with them. The odour from Kraus was detectable more than 5 km down wind in the helicopter.

These waters are quite distinct in that the conductivity is always high, ranging from 2000-9000 µS/cm, indicating the brackish nature of the water. At the time of sampling, the pH was slightly acidic, but rose to above neutral by the time samples were analyzed. The temperatures of all four sampled springs in this group are elevated and range from 12 to 36ºC.

Chemical analyses show a high salt content as was expected. Mg^{2+} is elevated in two (64, 123) of these samples as noted under Iron Springs above. NaCl and $CaSO_4$ are the most common salts present, but HCO_3^- is also present. Most trace metals are present in detectable concentrations.

A-4.1.5. Group P5 - High discharge cold springs

This group includes many of the very large springs sampled throughout the study area. Some are re-emergent streams (007, 069, 104, 105) and the rest are mostly large springs in carbonate terrane with probable karstic flow systems (004, 065, 066, 075, 076). They seldom have precipitates and are visible mainly because of their very large flows. Estimated flow rates ranged from 100 to >10000 L/s in July-August.

The high-volume waters from both re-emergent streams and large springs in carbonate terrane have similar properties, despite the differences that might exist in the two environments. The pH is high, generally >7.5 and <8.3, which indicates equilibration with atmospheric or near-atmospheric levels of CO_2. Temperature and conductivity are low.

The chemical analyses show Ca-HCO_3 -dominated waters but Ca^{2+} and HCO_3^- concentrations rarely exceed 50 and 150 ppm, respectively. Therefore, these waters are undersaturated with respect to calcite. Concentrations of other major ions and trace elements vary over wide ranges.

A-4.1.6. Group P6 - Miscellaneous

This miscellaneous group comprises a heterogeneous array of samples that are generally not obviously related based on field characteristics, neither to each other, nor to any of the above five groups.

Table A-4.1(i). List of springs, coordinates and field data (from Hamilton, 1990, Appendix 3). Named or noteworthy springs are in table at bottom.

Sample	T	pH		Cond.	flow	Easting	Northing	Comments
	ºC	field	lab	µS/cm	L/s			
86-001	21	6.85	7.80	580	9	595,400	6,868,800	Carbonate
86-004	5.2	8.30	7.76	98	>10000	567,400	6,868,900	Carbonate
86-006	11.1	7.52	7.89	385	1000	572,100	6,920,200	Local spr.
86-007	8.8	8.27	8.02	152	>10000	585,700	6,922,200	Local spr.
86-009	5	7.60	8.10	186	10	583,800	6,923,000	Local spr.
86-010	22	8.15	7.95	600	<1	569,500	6,914,300	
86-011	14.7	7.67	7.81	262	1	562,900	6,895,000	Granite CS
86-012	1.1	4.77	4.37	183	5	560,500	6,889,200	Granite CS
87-012	2	5.12	4.20	180	20	560,500	6,889,200	Granite CS
87-012B	1	6.95	7.10	161	6	560,500	6,889,200	Granite CS
87-012C	1	5.51	4.80	169	2	560,500	6,889,200	Granite CS
86-013	2.1	8.1*	8.09	250	5	568,500	6,881,500	Local spr.
86-015	3.5	7.06	8.21	415	20	573,600	6,885,000	Shale
86-017	5.5	6.27	7.87	1000	5	583,100	6,831,000	Carbonate
87-017	5.5	6.11	7.80	2730	15	583,100	6,831,000	Carbonate
86-018	41	8.17	8.22	252	10	540,800	6,868,600	Granite HS
87-018	41	8.60	8.00	242	4	540,800	6,868,600	Granite HS
87-018B	43.7	8.60	8.00	268	10	540,800	6,868,600	Granite HS
86-019	16	8.38	7.73	240	1000	539,200	6,870,000	Granite HS
86-020	16	8.48	8.39	440	<1	539,200	6,870,000	Granite HS
86-021	17	7.03	8.14	1180	1	599,500	6,899,000	Carbonate
86-022	2.5	7.75	8.22	400	3	591,300	6,891,800	Carbonate
86-023	3.8	7.24	8.15	480	5	572,000	6,902,700	Carbonate
86-024	11.1	7.82	8.39	488	0	572,700	6,904,000	
86-025	5	4.02	4.10	246	3	574,000	6,888,900	Granite CS
86-026	18	6.36	8.39	378	10	285,000	6,883,500	Carbonate
86-027	25	7.32	8.12	457	30	629,300	6,812,300	Carbonate
87-027	28	6.94	7.90	586	30	629,300	6,812,300	Carbonate
86-028	10	7.60	8.12	323	1000	633,400	6,824,400	Carbonate
86-029	14	7.19	8.04	475	3	627,000	6,813,200	Carbonate
86-030	17.7	6.75	8.17	575	5	620,900	6,808,600	Carbonate
86-031	12.1	7.74	8.14	440	<1	628,000	6,807,200	Carbonate
86-032	54	7.00	8.16	458	5	543,800	6,911,700	
86-033	58	9.05	9.30	310	15	516,800	6,915,400	Granite HS
87-033	55	9.24	9.10	301	15	516,800	6,915,400	Granite HS

Sample	T	pH		Cond.	flow	Easting	Northing	Comments
	ºC	field	lab	µS/cm	L/s			
87-034	5	8.20	8.10	216	5	516,800	6,915,400	
86-035	4.4	7.89	7.89	181		510,000	6,951,700	Shale
86-036		4.29	4.29	318		510,000	6,951,700	Shale
86-037	4.2	6.98	8.12	630	5	550,400	6,957,800	Shale
86-038	63.5	7.91	8.96	390	20	508,000	6,964,200	Granite HS
86-040	49	6.48	8.11	1090	15	543,800	6,958,400	Carbonate
86-041	30.5	7.03	8.11	800	10	543,800	6,958,400	Carbonate
86-042	4	4.92	4.12	280		542,600	6,959,200	Shale
86-043	44	6.92	8.11	775	10	556,800	6,949,200	Carbonate
86-044	32	7.75	8.17	230	5	530,500	6,886,600	
86-045	4	8.1*	8.10	142	40	546,600	6,881,800	Local spr.
86-046	8	7.80	8.36	397	10	585,000	6,883,500	Carbonate
86-047	13	8.2*	8.23	453	<1	586,200	6,882,400	
86-048	1.5	7.4*	7.43	40	2	574,600	6,874,500	
86-049	5.5	4.88	3.00	1080	2	574,800	6,879,700	Shale
86-050	3	8.2*	8.11	238		574,800	6,879,700	
86-051	6.5	8.3*	8.33	263	<1	571,200	6,875,400	Shale
86-052	42	8.51	7.81	121	10	588,700	6,850,200	Granite HS
87-052	40.5	9.18	130	10		588,700	6,850,200	Granite HS
86-053	47.5	7.86	7.86	124	20	588,700	6,850,200	Granite HS
87-053	46	9.13	8.10	130	20	588,700	6,850,200	Granite HS
86-054	10	7.41	7.41	68	<1	593,000	6,851,500	Shale
86-055	1.6	5.88	8.10	961	5	597,200	6,824,700	Carbonate
87-055	6	6.04		1820	5	597,200	6,824,700	Carbonate
86-056	7.7	6.10	8.06	1587	<1	583,600	6,832,700	Carbonate
86-057	14.2	6.81	8.08	1256	0	583,600	6,832,700	Carbonate
86-058	8.9	6.20	8.07	870	<1	573,600	6,839,000	Carbonate
87-058	11	6.23	7.70	2010	<1	573,600	6,839,000	Carbonate
86-059	5.5	7.22	8.16	870	5	570,900	6,841,600	Carbonate
86-060	46	9.08	8.66	295	2	542,400	6,879,400	Granite HS
87-060	46	9.30	8.80	282	2	542,400	6,879,400	Granite HS
86-061	8	7.37	8.29	346	<1	404,700	6,770,300	
86-062	3	6.15	7.41	181	15	405,000	6,761,500	Sandstone
86-063	38.5	6.62	7.89	7780	5	442,700	6,791,500	Shale
86-064	37.5	6.62	7.95	9100	<1	442,700	6,791,500	Shale

Table A-4.1(i). List of springs, coordinates and field data (from Hamilton, 1990, Appendix 3). Named or noteworthy springs are in table at bottom.

Sample	T °C	pH field	pH lab	Cond. µS/cm	flow L/s	Easting	Northing	Comments
87-064	36	6.61	7.80	8030	<1	442,700	6,791,500	
86-065	4.3	7.81	8.27	770	5000	438,700	6,797,000	Carbonate
86-066	8.2	8.23	8.15	239	50	435,700	6,825,800	Carbonate
86-067	3	7.55	8.21	937	<1	404,500	6,825,800	Carbonate
86-068	3.3	8.03	8.23	232	30	408,900	6,822,100	
86-069	11.5	2.91	2.91	1342	<1	465,300	6,783,600	
86-070	6.2	6.77	4.93	800	3	465,000	6,777,300	Sandstone
86-071	7	3.86	3.34	1062		420,900	6,782,600	Sandstone
86-072A	5	6.29	7.72	2970	<1	405,000	6,785,200	Shale
86-072B	5	3.78	3.57	2730	3	405,000	6,785,200	Shale
87-072B	5	3.65	3.50	2040	5	405,000	6,785,200	Shale
87-073A	4	6.93	8.00	2390	2	405,000	6,785,200	Shale
87-073B	11.5	5.24	4.80	2080	1. 5	405,000	6,785,200	Shale
87-073C	3	7.23	8.10	2350	8	405,000	6,785,200	Shale
86-074	16	7.40	8.02	1475	10	445,200	6,790,800	Shale
86-075	5	7.95	8.24	218	50	425,800	6,829,100	Carbonate
86-076	4	7.57	8.21	314	>10000	440,000	6,830,200	Carbonate
86-077	8	7.51	8.34	365	0	407,000	6,799,300	
86-078	1.5	7.00	7.99	772	10	425,200	6,751,600	Sandstone
86-079	6.5	8.34	8.34	518	0	434,500	6,762,500	Sandstone
86-080	12	3.64	3.64	285		455,300	6,779,100	Sandstone
86-081	4	8.2*	8.16	445	<1	456,000	6,792,900	Local spr.
86-082	38.5	8.2*	8.18	1038	0	397,500	6,778,200	Carbonate
87-082	37	6.75	8.10	1032	50	397,500	6,778,200	Carbonate
87-082B	30	7.58	8.10	972	45	397,500	6,778,200	Carbonate
86-083	3.5	8.1*	8.15	1632	<1	463,400	6,795,500	Shale
87-100	0	4.74	4.50	129	50	563,300	6,855,000	Local spr.
87-101	2	7.05	7.90	325	2	563,200	6,852,500	
87-102	3.5	6.58	8.00	387	5	576,800	6,836,400	
87-103	4	5.80	7.90	582	5	598,100	6,842,800	Shale
87-104	8	7.72	6.80	38	50	573,600	6,890,700	Local spr.
87-105	4.5	7.75	4.60	97	5000	567,800	6,592,100	Local spr.
87-106	19	7.50	8.10	235	25	546,100	6,912,800	
87-107	4	7.50	8.30	430	3	482,300	6,770,900	Local spr.
87-108	1	5.01	4.50	41	50	418,000	6,781,900	Sandstone
87-109	0	6.63	7.80	482	2	400,600	6,763,100	Shale
87-110	9	7.64	8.20	1517	50	398,400	6,774,000	Shale
87-111	7	7.62	7.80	1204	25	397,600	6,776,200	Carbonate
87-112	3	6.09	7.00	3060	5	400,000	6,776,000	Shale
87-113	8	7.96	8.30	475	5	401,400	6,782,300	Carbonate
87-114	3.5	7.69	8.30	541		450,600	6,811,000	Carbonate
87-115	3	7.63	8.30	751		450,300	6,811,400	Carbonate
87-116	11	8.54	8.40	1178	0	447,000	6,773,600	Shale
87-117		7.95	8.20	316	5	397,000	6,788,000	Local spr.
87-118	3.5	8.20	8.20	238	50	406,800	6,822,400	
87-119	3.5	8.31	8.10	241	5	406,800	6,822,400	Carbonate
87-120	2	7.79	8.30	353	15	407,400	6,829,000	Local spr.
87-121	4	3.76	3.30	500	200	427,000	6,779,500	Sandstone
87-122	22.5	7.02	8.00	1862	10	443,100	6,791,900	
87-123	12	7.09	8.00	7480	1	441,800	6,788,700	
87-124	18	8.20	7.90	160	0	443,400	6,827,400	
87-125	1	7.61	8.30	658	3	443,600	6,825,400	Carbonate
87-126	6	7.40	8.30	319	5	415,500	6,798,600	
87-127	3.5	7.02	8.10	731		480,500	6,768,200	
87-128	12	7.96	8.00	253		480,500	6,768,200	

Three-digit numbers are independent of year sampled, some being repeated. * = pH measured in laboratory

The following named or noteworthy springs and one well water sample are included in Figures 6.2 and 6.3 and detailed in the above table:

001	Rabbitkettle Hot Springs	038	Nah. Headwater H Sp.	065	White Spray cold spring
011	Mo,W,F Thermal RagRng	040, 041	Broken Skull Hot Springs	067	Prairie Creek Mine waters
015	Glacier Lake Iron Spring			069	Twisted Mountain
018	Cantung W. Hot Springs	043	Grizzly Bear Hot Spring	072, 073	Meilleur R. Metalliferous springs of Group B1
019, 020	Cantung Mine waters	044	Cantung N. Hot Spring		
		052	Hole-in-the-wall Hot Spr	076	Bubbling Spring (cold)
027	Wild Mint Hot Spring	053	Hole-in-the-wall Hot Spr	082	White Aster Hot Spring Meilleur R.PbZn tufa
028	Old Pot Mineral Springs	058	Flat Fruit Mineral Springs		
032	Moores/HoneymoonHSpr.	060	Cantung East Hot Spring	111	Meilleur R. PbZnNi in tufa
033, 034	Nahanni N. Hot Spring AKA Lened Creek H.Sp.	063, 064	Kraus (prev. Clausen Creek) Hot Springs	112	Meilleur R Metal. Grp B1
				127	Well water Nahanni Butte