Appendix 4.2 Laboratory Data for Nahanni Spring Waters and Precipitates

This appendix includes lists of analytical techniques for major and trace elements (Table A-4.2(i)), comprehensive analytical results for major elements (Table A-4.2(ii)), results for trace elements (Table A-4.2(iii)) and results for stable isotopes (Table A-4.2(iv)). This appendix concludes with a section on analytical techniques and definitions for stable isotope analyses in Nahanni spring waters.

Table A-4.2(i) Analytical Techniques and Detection Limits for major and trace element analysis of Nahanni spring waters (from Hamilton, 1990, Appendix 6). These analyses were conducted at the Geological Survey of Canada or contracted by GSC to Bondar Clegg Ltd. of Ottawa.

Element	Method	Detection limit
Ca 1986	AA	0.2 ppm
Ca 1987	ICP MS	1 ppm
Mg 1986	AA	0.2 ppm
Mg 1987	ICP MS	1 ppm
Na 1986	AA	0.2 ppm
Na 1987	ICP MS	1 ppm
K 1986	AA	0.2 ppm
K 1987	Not analyzed	na
HCO_3 1986-7	titration	0.2 ppm
SO4 1986-7	DIONEX	0.2 ppm
Cl 1986-7	DIONEX	0.05 ppm
Si 1986-7	ICP MS	2 ppm
F 1986-7	DIONEX	0.04 ppm
Sr 1986-7	ICP MS	0.1(±) ppm
Ba 1986-7	1CP MS	1 ppm
Al 1986-7	ICP MS	1 ppm
Cr 1986-7	ICP MS	1 ppm
Fe 1986	AA	20 ppb
Fe 1987	AA	5 ppb
Mn 1986	AA	10 ppb
Mn 1987	AA	2 ppb
Cu 1986-7	AA	2 ppb
Ni 1986-7	AA	2 ppb
Co 1986-7	AA	2 ppb
Cd 1986-7	AA	2 ppb
Zn 1986	AA	2 ppb
Zn 1987	AA	2 ppb
Ag 1986	AA	2 ppb
As 1986	AA-silica	0.2 ppb
As 1987	AA-silica	0.3 ppb
U 1986	Fluorometric	0.02 ppb
Mo 1986-7	ICP MS*	0.1 ppb
W 1986-7	ICP MS*	0.1 ppb

AA= atomic absorbtion
ICP MS= inductively coupled plasma mass spectrometry
titration= acid titration to pH end point
DIONEX= DIONEX ion chromatography
Fluorometric= uranium fluorometric
ICP MS*= ICP MS after preconcentration with activated charcoal

Table A-4.2(ii) Major Ions in Spring Waters (from Hamilton, 1990, Appendix 1)

Element	Ca^{2+}			Mg^{2+}			Na^{+}			K^{+}	HCO_3^{-}		SO_4^{2-}		Cl^{-}		SiO_2	
DL(ppm)	**.2**	**1**	**1**	**.2**	**1**	**1**	**.2**	**1**	**1**	**.2**	**.2**	**.2**	**.2**	**3**	**3**	**.05**	**2**	**2**
method	**A**	**B**	**C**	**A**	**B**	**C**	**A**	**B**	**C**	**A**	**T©**	**T**	**D**	**B**	**C**	**D**	**B**	**C**
86-001	196.4	231	102	39.2	46	40	3.8	4	4	4.9	768.8	289.7	32.6	51	42	1.21	16	14
86-004	17.4	21	18	2.4	3	2	0.4	<1	<1	0.3	58.3	43.5	6.3	9	9	0.15	4	<2
86-006	65.5	79	58	22.5	28	23	1.9	2	2	2.3	270.0	230.9	38.3	54	45	1.28	8	6
86-007	19.9	25	21	7.7	10	8	<0.2	<1	<1	0.2	83.2	83.2	13.9	18	15	0.18	<2	<2
86-009	24.2	29	24	11.0	13	11	0.2	<1	<1	0.2	97.8	97.8	24.4	30	27	0.29	3	<2
86-010	114.2			19.3			1.4			0.2	227.0	227.0	189.3			0.33		
86-011	39.1	49	40	2.7	4	3	11.7	13	12	1.2	84.6	84.6	67.7	84	66	0.68	31	25
86-012	18.9	25	20	4.1	5	4	1.0	1	1	0.5	<0.2	<0.2	67.7	111	93	0.16	20	17
87-012		19	19		4	4		<1	<1	(1)	<0.2	<0.2	81.1	90	90	1.27	17	16
87-012B		26	26		3	3		<1	<1	(1)	12.6	12.6	62.9	69	69	0.10	11	11
87-012C		22	22		4	4		<1	<1	(1)	<0.2	<0.2	75.4	81	81	0.12	16	16
86-013	44.2	56	44	5.6	7	5	0.5	<1	<1	4.3	135.9	135.9	30.0	39	33	0.64	4	4
86-015	71.8	92	71	11.6	15	11	1.0	1	1	0.7	64.3	64.3	187.5	231	186	0.35	21	14
86-017	684.6	791	254	57.0	68	53	45.6	60	49	8.1	2428.0	717.6	55.3	93	69	3.05	94	73
87-017		635	42		55	52		46	40	(13)	2272.7	925.1	49.5	99	57	2.74	73	72
86-018	<0.2	8	6	0.8	<1	1	48.0	60	52	1.0	105.3	105.3	26.0	33	27	6.48	47	39
87-018		6	6		<1	<1		50	45	(1)	100.8	100.8	25.0	27	27	6.59	39	39
87-018B		7	6		<1	<1		55	51	(1)	109.4	109.4	28.3	33	33	7.48	43	43
86-019	30.6	36	28	2.9	4	2	18.6	22	19	0.3	28.2	28.2	92.0	117	96	2.09	26	19
86-020	3.8	4	4	2.1	3	2	84.5	115	106	0.9	144.1	144.1	60.2	615	60	25.17	38	34
86-021	251.3	333	266	65.2	82	64	19.2	25	21	15.3	476.8	326.6	539.6	663	582	2.58	50	41
86-022	72.8	94	72	17.0	23	18	1.9	2	2	0.5	293.4	239.9	14.8	24	18	0.32	7	6
86-023	72.4	98	64	31.6	42	32	0.6	<1	<1	0.7	292.8	246.5	69.2	99	72	0.55	7	6
86-024	76.6	97	57	31.9	42	31	0.6	<1	<1	0.7	306.7	228.1	69.5	96	69	0.51	8	6
86-025	26.3	35	30	1.9	3	2	0.3	<1	<1	0.6	<0.2	<0.2	122.9	153	129	0.08	13	11
86-026	46.0	58	48	23.1	30	24	1.9	2	2	1.5	212.5	212.5	45.5	57	48	3.48	15	13
86-027	129.4	155	80	26.6	34	27	1.3	1	1	2.7	496.9	272.0	29.5	45	39	0.40	20	17
87-027		128	55		27	26		1	<1	(3)	482.9	331.0	27.7	45	36	0.48	16	16
86-028	55.3	63	57	10.3	13	11	0.7	<1	<1	0.7	206.0	194.2	12.9	18	15	0.34	6	5
86-029	139.7	151	76	26.3	32	28	1.5	1	2	3.3	545.9	294.2	15.1	27	21	0.71	21	20
86-030	128.1	148	110	31.2	39	32	6.0	6	6	2.8	445.2	289.7	93.0	117	102	1.98	11	10
86-031	113.6	127	74	24.4	30	25	1.8	<1	1	3.1	444.9	274.4	24.9	36	30	0.78	18	16
86-032	77.6	93	78	22.1	29	23	2.4	2	2	3.8	254.0	208.4	81.7	105	90	0.91	51	43
86-033	20.7	2	2	<0.2	<1	<1	64.3	80	73	1.0	103.9	103.9	69.3	147	66	1.44	63	55
87-033		2	2		<1	<1		69	62	(1)	100.5	100.5	60.7	60	66	1.48	53	53
87-034		39	38		2	2		7	7	(1)	118.4	118.4	20.5	27	24	0.23	11	12
86-035	23.9	28	25	9.6	13	10	0.7	<1	<1	0.4	84.4	84.4	26.8	36	30	0.09	8	7
86-036	18.1		19	17.1		18	0.4		<1	0.2	<0.2	<0.2	181.0		183	0.10		7
86-037	135.1	171	138	7.1	10	8	1.1	1	<1	0.9	112.5	112.5	290.4	342	273	0.22	20	14
86-038	30.0	3	3	<0.2	<1	<1	53.4	68	62	1.5	79.5	79.5	37.9	60	39	10.95	83	72
86-040	168.2	216	148	51.8	67	52	49.7	66	57	33.3	431.4	337.5	396.1	492	390	23.42	41	33
86-041	26.1	218	139	6.1	68	52	50.7	68	57	33.7	726.0	281.9	389.2	510	393	23.57	41	33
86-042	25.9	33	28	6.1	9	7	0.5	<1	<1	0.8	<0.2	<0.2	140.2	183	141	0.19	13	11
86-043	108.7	139	107	25.4	35	27	21.9	26	22	23.2	201.8	201.8	218.5	276	219	32.15	43	34
86-044	26.7	35	28	13.2	19	14	1.0	<1	<1	0.8	132.0	132.0	18.5	24	21	0.38	22	17
86-045	27.1	33	27	2.8	4	3	<0.2	<1	<1	0.6	86.7	86.7	6.1	9	9	0.29	3	3

Table A-4.2(ii) Major Ions in Spring Waters (from Hamilton, 1990, Appendix 1)

Element	**Ca^{2+}**			**Mg^{2+}**			**Na^{+}**			**K^{+}**	**HCO_3^-**		**SO_4^{2-}**		**Cl^-**		**SiO_2**	
DL(ppm)	**.2**	**1**	**1**	**.2**	**1**	**1**	**.2**	**1**	**1**	**.2**	**.2**	**.2**	**.2**	**3**	**3**	**.05**	**2**	**2**
method	**A**	**B**	**C**	**A**	**B**	**C**	**A**	**B**	**C**	**A**	**T©**	**T**	**D**	**B**	**C**	**D**	**B**	**C**
86-046	57.4	71	59	24.4	33	26	1.8	2	2	1.4	239.0	239.0	45.9	60	51	3.69	15	13
86-047	65.9	81	63	26.9	36	28	1.5	2	1	1.4	257.6	257.6	57.0	75	60	2.47	13	12
86-048	6.2	7	6	0.2	<1	<1	1.0	1	<1	1.2	20.8	20.8	0.8	<3	<3	0.13	4	<2
86-049	96.7	122	96	18.8	26	21	1.9	2	1	1.0	<0.2	<0.2	562.4	630	567	0.16	22	17
86-050	44.5	57	45	1.7	2	1	0.4	<1	<1	0.8	83.4	83.4	58.1	72	57	0.12	7	5
86-051	58.5	73	59	1.1	1	<1	0.2	<1	<1	0.7	179.8	179.8	2.8	6	6	0.29	7	6
86-052	15.1	1	2	<0.2	<1	<1	28.1	30	27	0.6	61.4	61.4	7.9	9	9	2.03	68	58
86-053	12.2	1	1	<0.2	<1	<1	28.8	31	29	0.5	63.0	63.0	8.7	9	9	2.18	70	59
87-053		1	1		<1	<1		28	25	(1)	50.7	50.7	6.6	9	6	1.90	57	58
86-054	6.0	8	6	3.5	5	4	1.8	2	2	0.6	24.8	24.8	12.8	15	12	0.17	21	17
86-055	345.0	425	338	42.0	53	44	10.1	10	10	3.4	1099.7	447.3	126.2	171	147	5.25	25	20
86-056	579.2	782	285	111.3	138	110	84.9	119	107	38.0	2235.9	806.9	282.8	372	306	22.39	12	10
86-057	456.4	577		95.3	119		56.2	74		31.5	1721.7	633.3	243.2	306		20.34	10	
86-058	530.0	647	250	54.5	66	52	29.1	32	30	5.6	1918.0	487.7	38.0	66	51	3.76	15	13
87-058		484	53		51	46		25	22	(8)	1759.4	685.9	26.9	69	33	3.10	13	11
86-059	127.9	151	84	19.9	26	21	6.9	7	7	0.9	483.4	285.8	13.2	24	21	0.44	6	5
86-060	21.7	2	2	<0.2	<1	<1	61.7	75	70	1.3	111.7	111.7	30.2	432	33	10.49	82	71
87-060		2	2		<1	<1		67	64	(2)	07.0	107.0	28.8	24	30	10.27	69	70
86-061	44.5	56	44	20.0	27	21	2.2	2	1	0.6	207.8	207.8	31.3	51	33	0.50	6	5
86-062	69.0	7	6	15.2	21	17	0.4	<1	<1	1.2	16.6	16.6	76.4	93	72	1.19	10	8
86-063	509.6	610	467	93.0	114	89	1168.0	601	1099	88.1	194.6	194.6	853.9	705	819	2347.0	30	23
86-064	502.0	617	492	94.1	116	94	1118.5	601	1100	84.4	224.8	224.8	860.4	711	819	2333.0	30	24
87-064		502	499		92	93		1252	1570	(345)	264.8	264.8	829.0	1650	828	2368.0	23	24
86-065	39.0	46	38	7.9	10	8	0.3	<1	<1	<0.2	147.4	147.4	9.0	6	12	1.05	3	<2
86-066	32.2	38	32	13.2	17	14	0.2	<1	<1	<0.2	160.6	160.6	3.9	<3	6	0.35	3	3
86-067	148.4	182	150	54.1	67	55	0.5	<1	<1	0.5	271.8	271.8	393.0	441	390	1.17	6	5
86-068	27.3	33	28	13.8	18	15	<0.2	<1	<1	<0.2	132.0	132.0	20.4	24	21	0.31	<2	<2
86-069	35.9	43	36	30.0	38	31	59.4	71	67	2.3	<0.2	<0.2	722.5	651	597	20.42	27	23
86-070	86.4	102	85	45.4	58	52	9.4	10	11	2.2	<0.2	<0.2	482.2	507	477	3.25	23	19
86-071	77.8	92	76	56.5	71	58	9.6	11	10	0.9	<0.2	<0.2	611.3	672	627	0.60	16	14
86-072A	516.2	613	504	241.2	310	260	14.4	18	17	2.5	115.0	115.0	2403.8	711	939	16.83	12	5
86-072B	344.2	413	346	212.4	268	227	14.8	18	17	2.1	<0.2	<0.2	2284.5	711	939	2.47	19	17
87-072B		253	257		151	154		18	18	(3)	<0.2	<0.2	1450.8	1602	1521	2.02	14	15
87-072BH		253			149			18		(3)				1233			13	
87-073A		363	360		212	210		20	18	(3)	190.9	190.9	1609.7	1737	1653	1.09	7	7
87-073B		299	280		175	164		20	19	(3)	<0.2	<0.2	1489.7	1632	1494	1.00	10	9
87-073C		354	336		206	194		18	18	(3)	275.1	275.1	1507.7	1710	1596	1.00	6	6
86-074	157.5	179	141	47.3	57	48	122.7	146	150	8.8	672.6	256.2	301.1	339	303	0.51	15	13
86-075	27.7	32	28	10.5	14	11	<0.2	<1	<1	<0.2	130.8	130.8	9.8	9	9	1.60	<2	<2
86-076	54.1	63	53	10.1	13	10	0.5	<1	<1	0.4	196.7	196.7	24.3	21	21	2.19	5	4
86-077	54.0	61	54	17.5	22	19	1.1	<1	<1	0.3	220.1	220.1	33.3	39	39	0.24	4	4
86-078	87.5	96	85	52.6	64	54	0.9	<1	1	2.8	64.9	64.9	405.0	453	411	0.29	7	5
86-079	66.1	73	65	33.4	41	35	0.6	<1	<1	1.4	211.5	211.5	132.3	153	141	0.36	7	7
86-080	10.6	12	11	4.1	5	5	1.7	1	2	1.3	0.2	<0.2	91.4	102	90	2.02	32	
86-081	91.6	103	77	21.1	26	22	3.5	3	3	1.6	342.4	240.2	41.6	51	45	0.69	12	11
86-082	151.7	171	153	45.9	54	47	30.2	31	33	13.8	320.0	289.4	373.3	348	333	31.54	41	38

Table A-4.2(ii) Major Ions in Spring Waters (from Hamilton, 1990, Appendix 1)

Element	Ca^{2+}			Mg^{2+}			Na^{+}			K^{+}	HCO_3^-		SO_4^{2-}		Cl^-		SiO_2	
DL(ppm)	**.2**	**1**	**1**	**.2**	**1**	**1**	**.2**	**1**	**1**	**.2**	**.2**	**.2**	**.2**	**3**	**3**	**.05**	**2**	**2**
method	**A**	**B**	**C**	**A**	**B**	**C**	**A**	**B**	**C**	**A**	**T©**	**T**	**D**	**B**	**C**	**D**	**B**	**C**
87-082		151	99		46	44		30	30	(17)	377.6	377.6	297.4	330	303	24.81	36	36
87-082H		147			45			30		(16)				324			34	
87-082B		131	103		45	44		29	29	(16)	305.7	305.7	291.0	327	306	23.96	35	36
86-083	208.0	228	182	38.7	45	39	152.1	184	193	4.6	254.6	254.6	451.0	483	441	212.65	17	15
87-100		8	8		6	5		<1	<1	(0)	<0.2	<0.2	56.1	60	57	0.19	8	8
87-101		61	56		6	6		<1	<1	(0)	63.3	63.3	114.8	138	120	0.15	8	8
87-102		76	72		9	8		2	2	(1)	223.1	223.1	44.0	57	51	0.66	4	4
87-103		40	37		39	36		38	37	(11)	365.4	365.4	44.6	54	48	1.07	11	10
87-104		6	5		<1	<1		<1	<1	(0)	7.3	7.3	11.3	12	12	0.09	<2	<2
87-105		8	8		4	4		<1	1	(1)	<0.2	<0.2	40.3	45	42	0.63	4	5
87-106		30	28		14	13		1	1	(1)	130.3	130.3	23.2	27	24	0.28	8	9
87-107		66	61		20	18		5	4	(1)	195.1	195.1	87.9	99	90	0.84	3	3
87-108		1	1		1	1		<1	<1	(1)	<0.2	<0.2	13.4	15	12	0.19	4	5
87-109		25	23		45	43		12	12	(4)	122.5	122.5	168.4	183	168	1.70	12	11
87-110		119	111		49	48		207	198	(3)	394.9	394.9	552.6	639	618	1.76	5	4
87-111		278	175		31	29		<1	<1	(2)	484.5	322.1	373.7	438	408	0.23	7	8
87-112		397	392		160	158		254	251	(7)	31.9	31.9	2122.0	2277	2295	14.90	5	4
87-112H		402			161			260		(8)				2301			5	
87-113		79	75		24	23		<1	<1	(0)	304.6	304.6	32.0	48	42	0.49	3	4
87-114		95	90		20	19		2	<1	(1)	305.4	305.4	69.2	84	75	1.26	6	6
87-115		116	91		43	42		5	4	(2)	342.7	342.7	171.7	204	189	3.48	9	9
87-116		37	28		27	25		247	229	(3)	429.4	429.4	313.3	351	333	3.80	<2	<2
87-117		45	43		18	17		<1	<1	(0)	188.5	188.5	26.2	33	30	0.23	3	3
87-118		31	30		14	14		<1	<1	(0)	138.4	138.4	19.1	24	21	0.27	<2	3
87-119		31	29		16	15		<1	<1	(0)	149.6	149.6	13.8	18	15	0.36	<2	<2
87-120		49	47		21	21		1	<1	(1)	215.1	215.1	31.8	42	36	0.30	3	3
87-121		17	17		16	16		<1	<1	(0)	<0.2	<0.2	211.0	231	222	0.24	15	15
87-122		157	131		42	41		183	180	(22)	300.9	300.9	243.0	252	249	278.00	14	15
87-123		431	381		93	89		1164	1065	(334)	367.5	367.5	727.0	720	729	2212.0	22	23
87-124		27	26		4	4		<1	<1	(0)	91.6	91.6	10.8	15	12	0.85	<2	<2
87-125		127	83		23	21		<1	<1	(0)	383.0	383.0	87.2	105	93	0.32	8	9
87-126		49	46		15	14		<1	1	(0)	199.5	199.5	15.8	24	18	0.80	5	4
87-127		135	83		25	24		5	5	(1)	420.9	420.9	91.5	111	99	0.82	6	7
87-128		39	37		9	9		2	2	(0)	119.8	119.8	30.3	36	33	2.61	4	4

Abbreviations:

A = AA on acidified samples; B = ICP on acidified samples; C = ICP on non acidified samples; D = Dionex (ion chromatography); T= HCO_3^- determined by titration; T(c) = HCO_3^- corrected by major ion charge balance; DL = detection limit; H = duplicate samples acidified with HCl instead of HNO_3. Underlining refers to data with significant analytical errors. Errors were more common in the 1986 analyses because water standards were not available for the ICP at the Geological Survey of Canada laboratories and therefore rock standards were used instead. (K^+) data analysed on the ICP (1987 K^+ results) can be considered only relatively high or low due to serious systematic problems with analysing K^+ on the ICP at the time (1985-86).

Table A-4.2(iii) Trace Elements in Spring Waters (from Hamilton, 1990, Appendix 2)

Element	Fe		Mn		Zn	Cu	Cd	Co	Ni	Pb	Al
D.L.	20/5	(.1)	10/2	(.1)	5	2	2	2	2	5	(.1)
units	ppb	ppm	ppb	ppm	ppb	ppb	ppb	ppb	ppb	ppb	ppm
method	AA	ICP	AA	ICP	AA	AA	AA	AA	AA	AA	ICP
86-001	129	0.3	13	<.1	8	3	<2	<2	<2		0.1
86-004	361	0.4	12	<.1	<5	4	3	3	<2		0.6
86-006	<20	<.1	<10	<.1	<5	<2	<2	<2	<2		0.1
86-007	<20	<.1	<10	<.1	<5	3	<2	<2	<2		<.1
86-009	33	<.1	<10	<.1	<5	<2	<2	<2	<2		<.1
86-010	108		12		<5	3	<2	5	16		
86-011	<20	<.1	<10	<.1	10	5	<2	<2	<2		0.1
86-012	<20	<.1	135	0.2	366	10	5	28	101		4.1
87-012B	<5	<.1	3	<.1	220	3	5	<2	35	<5	0.4
87-012	60	0.2	80	0.1	305	15	5	13	130	<5	3.5
87-012C	103	<.1	45	<.1	445	3	10	5	75	<5	0.8
86-013	<20	<.1	<10	<.1	<5	3	<2	<2	<2		<.1
86-015	14416	16.4	430	0.5	652	<2	3	23	173		0.2
86-017	20766	21.4	1503	1.7	<5	11	3	<2	<2		0.4
87-017	58	0.3	1498	1.3	8	3	<2	<2	<2	<5	0.1
86-018	<20	<.1	<10	<.1	<5	4	<2	<2	<2		<.1
87-018	<5	<.1	3	<.1	<2	<2	<2	<2	<2	<5	<.1
87-018B		<.1		<.1							<.1
86-019	199	0.2	37	<.1	<5	<2	<2	<2	<2		0.2
86-020	65	<.1	<10	<.1	<5	5	<2	<2	<2		<.1
86-021	243	0.5	165	0.2	<5	4	<2	<2	<2		0.7
86-022	33	<.1	<10	<.1	<5	4	<2	<2	<2		<.1
86-023	<20	<.1	<10	<.1	<5	13	<2	6	<2		<.1
86-024	<20	<.1	<10	<.1	<5	<2	<2	<2	<2		<.1
86-025	147	0.1	169	0.2	3936	<2	<2	<2	<2		7.0
86-026	<20	<.1	<10	<.1	<5	<2	<2	<2	<2		<.1
86-027	26	<.1	<10	<.1	<5	4	<2	<2	<2		<.1
87-027	15	0.1	<2	<.1	5	<2	<2	<2	<2	<5	<.1
86-028	<20	<.1	<10	<.1	<5	<2	<2	<2	<2		<.1
86-029	24	0.1	<10	<.1	7	4	<2	13	<2		0.1
86-030	1710	1.8	15	<.1	<5	4	<2	5	<2		0.2
86-031	<20	<.1	<10	<.1	<5	<2	3	5	<2		<.1
86-032	460	0.6	23	<.1	<5	<2	<2	3	<2		0.2
86-033	36	<.1	<10	<.1	<5	13	3	<2	11		0.1
87-033	<5	<.1	<2	<.1	<2	<2	<2	<2	<2	<5	<.1
87-034	<5	<.1	<2	<.1	<2	<2	<2	<2	<2	<5	<.1
86-035	972	1.0	10	<.1	7	16	<2	40	63		0.7
86-036	645		534		640	4	<2	46	168		
86-037	19082	20.8	425	0.5	306	3	<2	<2	8		0.2
86-038	26	<.1	<10	<.1	8	5	<2	<2	<2		<.1
86-040	65	0.2	<10	<.1	<5	5	3	<2	8		0.3
86-041	440	0.6	<10	<.1	6	6	<2	<2	3		0.5
86-042	5816	6.8	225	0.3	1488	25	39	29	273		8.0
86-043	138	0.2	30	<.1	5	<2	<2	6	<2		0.2
86-044	91	0.1	<10	<.1	<5	3	<2	<2	<2		0.1
86-045	57	<.1	<10	<.1	6	4	<2	<2	<2		<.1
86-046	36	<.1	<10	<.1	10	3	<2	<2	<2		0.1
86-047	72	<.1	<10	<.1	13	3	<2	<2	<2		0.2
86-048	451	0.5	11	<.1	<5	5	3	11	<2		0.5
86-049	122307	75.3	856	1.1	331	<2	3	50	233		28.4
86-050	91	<.1	16	<.1	92	<2	3	<2	23		0.3
86-051	79	<.1	<10	<.1	8	<2	<2	<2	<2		<.1
86-052	57	<.1	<10	<.1	<5	4	<2	<2	<2		0.2
86-053	72	<.1	<10	<.1	8	3	<2	15	4		0.1
87-053	5	<.1	<2	<.1	<2	<2	<2	<2	<2	<5	<.1
86-054	3194	3.4	152	0.2	19	4	<2	<2	<2		0.5
86-055	15850	16.0	587	0.7	412	6	<2	18	125		0.3
86-056	33	0.3	34	1.6	<5	4	<2	8	16		0.3
86-057	161	0.5	521	1.0	<5	4	<2	10	8		0.3
86-058	28	0.2	158	0.3	<5	5	<2	4	<2		0.2
87-058	<5	0.3	275	0.2	8	<2	<2	<2	<2	8	<.1
86-059	480	0.6	157	0.2	<5	<2	<2	3	<2		0.1
86-060	120	0.1	<10	<.1	<5	6	<2	3	8		0.1
87-060	<5	<.1	<2	<.1	<2	3	<2	<2	<2	<5	<.1
86-061	1817	2.0	123	0.1	<5	6	<2	<2	3		<.1

Table A-4.2(iii) Trace Elements in Spring Waters (from Hamilton, 1990, Appendix 2)

Element	Fe		Mn		Zn	Cu	Cd	Co	Ni	Pb	Al
D.L.	20/5	(.1)	10/2	(.1)	5	2	2	2	2	5	(.1)
units	ppb	ppm	ppb	ppm	ppb	ppb	ppb	ppb	ppb	ppb	ppm
method	AA	ICP	AA	ICP	AA	AA	AA	AA	AA	AA	ICP
86-062	9721	10.5	707	0.9	<5	6	<2	13	13		<.1
86-063	852	0.7	75	0.1	30	19	3	6	4		0.6
86-064	129	0.3	57	<.1	13	16	3	<2	<2		0.5
87-064	163	0.4	85	<.1	13	8	<2	<2	<2	25	0.2
86-065	136	0.1	<10	<.1	10	4	<2	6	6		0.1
86-066	67	<.1	<10	<.1	40	9	<2	<2	3		0.1
86-067	337	0.4	92	0.1	61877	448	135	9	65		0.3
86-068	81	<.1	<10	<.1	14	8	3	<2	<2		0.1
86-069	51793	31.5	1180	1.3	86	6	<2	58	115		30.3
86-070	2870	2.6	1294	1.5	67	11	<2	45	94		6.9
86-071	21517	21.0	1047	1.2	187	18	<2	46	103		21.5
86-072A	136	0.4	2824	3.2	4977	14	34	170	2318		43.0
86-072B	1402	1.7	5396	5.8	5351	49	30	405	2311		57.2
87-072B	470	0.8	3568	3.9	2350	15	13	268	1120	5	29.2
87-072BH		0.9		3.8							28.8
87-073A	10	0.2	15	<.1	1613	<2	3	<2	768	13	0.1
87-073B	13	0.2	3818	4.0	2713	3	15	95	1513	<5	15.0
87-073C	<5	0.2	18	<.1	155	<2	3	<2	633	<5	0.2
86-074	465	0.6	653	0.7	58	11	4	10	16		0.5
86-075	337	0.3	<10	<.1	36	9	<2	<2	<2		<.1
86-076	158	0.2	10	<.1	<5	6	<2	<2	8		<.1
86-077	96	<.1	11	<.1	23	10	<2	<2	<2		<.1
86-078	63347	35.2	1180	1.3	15	5	<2	18	34		0.1
86-079	1942	1.8	101	0.1	6	8	<2	4	<2		<.1
86-080	9820	9.6	217	0.2	12	9	<2	5	11		3.5
86-081	705	0.7	222	0.3	9	4	<2	<2	5		<.1
86-082	159	0.2	23	<.1	44	9	<2	<2	<2		0.2
87-082	<5	0.1	3	<.1	18	<2	<2	<2	<2	<5	<.1
87-082	H		0.1		<.1						<.1
87-082B		0.1		<.1							<.1
86-083	5179	5.1	437	0.5	15	11	<2	4	<2		0.3
87-100	80	0.1	108	0.2	98	8	<2	3	38	<5	2.9
87-101	<5	<.1	<2	<.1	38	<2	<2	<2	<2	<5	<.1
87-102	<5	<.1	<2	<.1	<2	<2	<2	<2	<2	<5	<.1
87-103	6363	9.5	305	0.5	3	<2	<2	5	<2	<5	0.5
87-104	<5	<.1	<2	<.1	<2	<2	<2	<2	<2	<5	<.1
87-105	35	<.1	48	<.1	50	3	<2	3	13	<5	1.1
87-106	<5	<.1	<2	<.1	<2	<2	<2	3	<2	<5	<.1
87-107	<5	<.1	<2	<.1	565	3	<2	<2	<2	<5	<.1
87-108	65	<.1	83	<.1	10	<2	<2	<2	<2	<5	0.8
87-109	5373	8.6	250	0.4	3	<2	<2	<2	<2	<5	<.1
87-110	2013	2.9	190	0.2	8	3	<2	3	<2	<5	<.1
87-111	10	0.2	<2	<.1	353	<2	<2	<2	80	<5	<.1
87-112	>20000	98.1	3098	2.8	538	5	<2	60	303	<5	0.2
87-112H		96.1		2.9							0.2
87-113	18	<.1	<2	<.1	28	<2	<2	<2	5	<5	<.1
87-114	<5	<.1	8	<.1	3	<2	<2	<2	<2	<5	<.1
87-115	8	<.1	<2	<.1	3	3	<2	<2	<2	<5	<.1
87-116	105	0.2	<2	<.1	5	3	<2	<2	<2	<5	0.2
87-117	<5	<.1	<2	<.1	<2	<2	<2	<2	<2	<5	<.1
87-118	<5	<.1	<2	<.1	10	<2	<2	<2	<2	<5	<.1
87-119	<5	<.1	<2	<.1	10	<2	<2	<2	<2	5	<.1
87-120	<5	<.1	<2	<.1	5	<2	<2	<2	<2	<5	<.1
87-121	3763	6.3	313	0.5	58	8	<2	<2	50	<5	14.7
87-122	250	0.3	78	<.1	3	3	<2	<2	<2	15	<.1
87-123	123	0.3	230	0.2	8	8	<2	<2	<2	20	0.1
87-124	50	0.1	<2	<.1	<2	<2	<2	<2	<2	<5	<.1
87-125	<5	<.1	<2	<.1	58	<2	<2	<2	<2	<5	<.1
87-126	523	1.0	10	<.1	10	3	<2	<2	<2	<5	0.5
87-127	33	0.1	10	<.1	40	3	<2	<2	<2	<5	<.1
87-128	115	0.3	<2	<.1	5	<2	<2	3	<2	<5	0.2

Table A-4.2(iii) continued: More Trace Elements in Spring Waters (from Hamilton, 1990, Appendix 2)

Element	Mo	W	Ag	Au	U	Sb	As	F	Sr	Ba
D.L.	0.1	0.1	2	1	.01/.1	0.3	0.3	0.04	(.1)	(.1)
units	ppb	ppb	ppb	pptr	ppb	ppb	ppb	ppm	ppm	ppm
method	ICP-MS	ICP-MS	AA	AA	Fluor.	AA-Sil.	AA-Sil.	D	ICP	ICP
86-001	1.8	<.1	<2		6.40		0.3	0.53	0.7	0.2
86-004	0.2	<.1	<2		0.40		1.4	0.07	<.1	<.1
86-006	0.6	<.1	<2		1.92		0.5	0.25	0.4	<.1
86-007	0.7	<.1	<2		0.84		<.2	0.10	0.1	<.1
86-009	1.2	0.1	<2		4.40		<.2	0.15	0.2	<.1
86-010	7.3	<.1	<2		14.20			0.24		
86-011	3.8	2.0	<2		3.60		0.5	1.33	<.1	<.1
86-012	0.6	<.1	<2		4.40		0.8	0.12	<.1	<.1
87-012B	3.0	0.2			1.7	0.4	<.3	0.13	<.1	<.1
87-012	1.0	0.1		<1.0	1.6	<.3	<.3	0.05	<.1	<.1
87-012C	0.1	<.1			2.8	<.3	<.3	0.15	<.1	<.1
86-013	1.0	0.2	<2		0.92		32.9	0.14	0.1	<.1
86-015	2.1	<.1	<2		2.38		1.4	0.58	0.2	<.1
86-017	<.1	<.1	<2		0.60		0.4	0.92	2.9	0.2
87-017	<.1	<.1			0.5	<.3	<.3	0.56	2.3	0.1
86-018	8.0	59.6	<2		0.92		1.8	4.09	<.1	0.2
87-018	9.1	75.1			1.4	<.3	1.9	4.27	<.1	0.1
87-018B	9.9	83.0		7.8		<.3	1.8	4.71	<.1	0.1
86-019	8.1	21.0	3		0.96		5.2	1.10	0.1	<.1
86-020	1.1	169.0	3		0.24		<.2	9.31	<.1	<.1
86-021	0.4	0.2	<2		7.80		99.3	0.73	5.6	<.1
86-022	2.5	<.1	<2		1.20		0.7	0.14	0.2	0.2
86-023	4.0	0.2	<2		6.20		2.4	0.24	0.2	0.1
86-024	8.0	0.4	<2		5.70		0.3	0.23	0.2	0.1
86-025	<.1	<.1	<2		4.00		0.4	0.25	<.1	<.1
86-026	4.3	0.1	<2		2.80		1.0	0.21	0.2	0.2
86-027	1.2	0.1	4		2.40		0.8	0.31	1.2	0.1
87-027	1.7	0.3		2.1	3.8	0.4	0.8	0.33	1.0	<.1
86-028	2.0	0.2	<2		0.96		0.2	0.12	0.2	0.1
86-029	0.6	0.1	<2		3.60		0.5	0.34	1.4	0.1
86-030	1.6	<.1	3		4.00		1.2	0.38	1.5	<.1
86-031	0.9	0.1	<2		3.20		0.3	0.46	1.7	0.1
86-032	1.4	0.2	<2		1.64		2.4	0.42	0.5	0.1
86-033	19.0	20.8	<2		0.66		0.2	2.95	<.1	<.1
87-033	18.8	18.0		5.0	1.3	<.3	0.3	2.94	<.1	<.1
87-034	9.5	1.8			28.0	<.3	2.1	0.31	<.1	<.1
86-035	<.1	<.1	<2		0.44		0.5	0.13	0.3	<.1
86-036	<.1	0.2	<2		0.40			0.10		
86-037	0.4	<.1	<2		4.00		2.2	0.40	0.5	<.1
86-038	30.0	224.0	<2		0.40		163.5	7.79	<.1	<.1
86-040	<.1	<.1	<2		3.80		1.5	1.52	4.0	<.1
86-041	0.1	0.2	<2		5.20		0.8	1.53	4.0	<.1
86-042	<.1	<.1	<2		3.20		0.6	0.08	0.2	0.1
86-043	0.1	<.1	<2		5.00		5.2	0.91	1.8	<.1
86-044	0.5	0.1	<2		2.40		0.6	0.15	0.1	<.1
86-045	<.1	0.2	<2		0.24		0.3	0.11	<.1	<.1
86-046	3.1	<.1	<2		3.20		1.2	0.22	0.2	0.2
86-047	3.0	0.2	<2		3.40		0.6	0.23	0.3	<.1
86-048	1.4	0.2	<2		3.60		<.2	0.04	<.1	<.1
86-049	<.1	<.1	<2		4.40		<.2	0.98	0.7	<.1
86-050	2.4	0.2	<2		2.60		1.0	0.09	0.2	<.1
86-051	0.6	0.2	<2		2.80		0.6	0.08	<.1	<.1
86-052	10.0	14.9	<2		7.40		23.7	2.62	<.1	<.1
86-053	21.0	17.6	<2		7.20		25.5	2.77	<.1	<.1
87-053	20.3	17.1		<1.0	6.6	0.4	20.9	2.77	<.1	<.1
86-054	0.5	0.3	<2		2.00		4.0	0.19	<.1	<.1
86-055	1.7	<.1	<2		6.60		0.9	0.66	0.8	0.1
86-056	0.7	<.1	<2		4.68		0.5	1.23	3.3	<.1
86-057	<.1	0.2	<2		3.00		0.2	0.96	2.5	<.1
86-058	<.1	<.1	<2		1.44		<.2	0.53	2.0	0.2
87-058	0.2	0.3		1.1	<.3	<.3	0.38	1.6	0.2	
86-059	<.1	0.2	<2		0.66		<.2	0.15	0.5	0.1
86-060	19.0	121.0	<2		0.27		0.5	6.53	<.1	<.1
87-060	17.8	118.4		9.6	1.2			6.77	<.1	<.1
86-061	0.6	0.1	<2		0.74		0.5	0.20	0.1	<.1

Table A-4.2(iii) continued: More Trace Elements in Spring Waters (from Hamilton, 1990, Appendix 2)

Element	Mo	W	Ag	Au	U	Sb	As	F	Sr	Ba
D.L.	0.1	0.1	2	1	.01/.1	0.3	0.3	0.04	(.1)	(.1)
units	ppb	ppb	ppb	pptr	ppb	ppb	ppb	ppm	ppm	ppm
method	ICP-MS	ICP-MS	AA	AA	Fluor.	AA-Sil.	AA-Sil.	D	ICP	ICP
86-062	<.1	0.1	<2		0.10		<.2	0.13	<.1	<.1
86-063	0.2	0.4	<2		15.60		7.2	0.83	15.0	<.1
86-064	<.1	0.3	<2		5.40		1.4	0.82	15.3	<.1
87-064	0.7	0.5		<1.0	15.2	<.3	0.3		14.1	<.1
86-065	0.6	0.2	<2		1.20	0.3	0.12	<.1	<.1	
86-066	1.7	0.3	<2		2.00	0.6	0.10	<.1	<.1	
86-067	0.6	<.1	3		3.80	49.6	0.49	0.2	<.1	
86-068	<.1	<.1	<2		2.00	0.2	0.11	<.1	0.1	
86-069	<.1	<.1	<2		3.00	<.2	0.28	0.4	<.1	
86-070	<.1	<.1	<2		3.12		0.2	0.15	0.5	<.1
86-071	<.1	<.1	<2		2.40		1.3	0.34	1.0	<.1
86-072A	<.1	0.2	4		5.40		0.4	0.49	5.3	<.1
86-072B	0.8	0.1	<2		26.00		1.9	0.48	4.5	<.1
87-072B	0.3	0.5		3.6	13.2			1.30	3.2	<.1
87-072BH									3.1	<.1
87-073A	0.4	0.2		12.4	<.3	<.3	1.32	3.8	<.1	
87-073B	0.4	0.6		9.8	<.3	<.3	2.18	3.5	<.1	
87-073C	0.3	0.2		12.7	<.3	<.3	1.36	3.4	<.1	
86-074	0.8	<.1	<2		4.40		0.8	0.06	3.5	0.1
86-075	0.3	0.1	<2		2.40		0.3	0.10	<.1	<.1
86-076	2.5	0.2	<2		2.40		0.4	0.26	0.1	0.1
86-077	2.7	<.1	<2		4.60		3.4	0.24	0.2	0.6
86-078	<.1	0.2	<2		0.66		0.8	0.46	0.2	<.1
86-079	<.1	<.1	<2		0.92		1.5	0.27	<.1	<.1
86-080	<.1	<.1	<2		0.44		0.4	0.09	<.1	<.1
86-081	3.9	<.1	<2		2.40		4.5	0.37	0.4	<.1
86-082	4.5	1.2	<2		5.00		10.9	0.99	1.4	<.1
87-082	4.6	1.6		3.8	14.0			0.79	1.6	<.1
87-082									1.5	<.1
87-082B	4.5	1.6						0.76	1.5	<.1
86-083	3.0	0.4	3		5.40		12.7	0.09	1.7	<.1
87-100	<.1	<.1			3.5	<.3	<.3	0.04	<.1	<.1
87-101	5.5	<.1			6.9	<.3	0.9	0.11	<.1	<.1
87-102	0.6	<.1			2.5	<.3	<.3	0.09	0.2	<.1
87-103	0.1	0.1			0.5	0.3	12.6	1.54	0.7	<.1
87-104	0.5	<.1			0.3	0.4	14.9	0.04	<.1	<.1
87-105	<.1	<.1			0.7	<.3	<.3	0.07	<.1	<.1
87-106	0.3	<.1		1.0	0.7	<.3	0.3	0.12	<.1	<.1
87-107	1.8	<.1			5.8	0.7	0.7	0.18	0.3	0.1
87-108	<.1	<.1			<.1	<.3	<.3	0.04	<.1	<.1
87-109	<.1	<.1			0.8	<.3	0.3	0.36	<.1	<.1
87-110	6.0	<.1			20.0	<.3	1.2	0.82	1.3	<.1
87-111	11.0	0.1		2.6	27.9	<.3	<.3	0.40	0.8	<.1
87-112	0.2	0.2		<1.0			7.7	1.13	3.4	<.1
87-112H									3.4	<.1
87-113	6.7	<.1		5.9	11.2	<.3	0.5	0.16	0.2	0.1
87-114	5.5	<.1		3.7	7.9	<.3	<.3	0.25	0.2	<.1
87-115	10.2	<.1		<1.0	4.7	0.4	0.3	0.91	0.7	<.1
87-116	0.4	<.1			14.4	<.3	0.4	0.91	1.1	<.1
87-117	1.1	<.1			1.4	<.3	<.3	0.10	<.1	<.1
87-118	1.0	<.1			1.4	<.3	<.3	0.09	<.1	<.1
87-119	1.1	<.1		1.0	3.1	0.4	0.4	0.10	<.1	0.2
87-120	1.4	<.1		1.0	6.0	<.3	<.3	0.12	0.2	0.1
87-121	<.1	<.1		1.2	2.5	<.3	<.3	0.11	<.1	<.1
87-122	0.3	0.3		2.5	16.8	0.4	2.4	0.93	2.9	<.1
87-123	0.3	0.4		1.5	6.6	<.3	<.3		12.3	<.1
87-124	4.6	<.1		<1.0	0.7	0.4	0.5	0.12	<.1	1.0
87-125	15.3	<.1		<1.0	12.2	0.6	<.3	0.21	0.3	<.1
87-126	2.8	<.1			1.7	0.4	0.3	0.16	0.1	0.2
87-127	1.2	<.1			4.2	<.3	<.3	0.23	0.6	0.3
87-128	2.3	0.3		<1.0	7.6	0.4	0.8	0.11	0.2	0.3

Table A-4.2(iv) Isotopes in Spring Waters (from Hamilton, 1990, Appendix 5)

Sample	$^{18}O-H_20$	$^{2}H-H_20$	^{3}H	$^{13}C(DIC)$	Temp.	HCO_3-	H_2CO_3	pCO_2	$^{13}C(gas)$
number	$^{o}/oo$	$^{o}/oo$	(T.U.)	$^{o}/oo$	º C	mg/l	mg/l	bars	calc.
86-001	-23.0	-181	34	-2.32	21	768.8	262	-0.96	-2.32
86-004	-23.1	-179		-5.43	5.2	58.3	1	-3.61	-5.43
86-006	-23.3	-184		-4.09	11.1	270.0	24	-2.13	-4.09
86-007	-23.5			-4.51	8.8	83.2	1	-3.41	-5.51
86-011	-23.6								
86-012	-23.4	-185							
87-012B	-23.4			-11.34	1	12.6			
86-015	-23.4	-186		-8.36	3.5	64.3			
86-017	-23.4	-184	87	-0.44	5.5	2428.0	4346	0.05	-0.54
86-017	-23.2			.54					
86-018	-23.1	-180	7	-9.32	41	105.3	1	3.46	-9.32
86-019	-22.7			-7.19	16	28.2	0	3.95	-7.19
86-020	-23.4	-186		-5.42	16	144.1	1	3.34	-5.42
86-021	-24.8	-191	11	-5.56	17	476.8	115	1.37	-5.56
86-022	-23.0								
86-023	-23.1	-188		-8.83	3.8	292.8	59	1.85	-8.83
86-025	-23.5	-184		-19.51	5	0.2			
86-027	-22.6			-2.10	25	496.9	55	1.21	-2.10
87-027	-22.5	-180	15	-3.20	28	482.9	123	1.59	-3.20
86-028	-22.6	-180		-7.23	10	206.0	15	2.34	-7.23
86-029	-22.4			0.60	14	545.9	97	1.48	0.60
86-030	-22.6	-181	8	-5.15	17.7	445.2	202	1.11	-5.98
86-031	-23.1			-1.73	12.1	444.9	23	2.13	-1.73
86-032	-23.3	-183		-5.98	54	254.0	49	1.36	-5.98
86-033	-23.8	-186	<6	-7.83	58	103.9	0	4.00	-7.83
86-034	-22.8	-183							
86-036	-22.0	-177							
86-037	-21.8	-170		-5.76	4.2	112.5			
86-038	-22.8	-182		-6.37	63.5	79.5	2	2.71	-6.37
86-039	-21.8	-171	24						
86-040	-23.0	-186	<6	-3.62	49	431.4	281	0.65	-3.62
86-041	-23.0			-1.96	30.5	726.0	146	1.10	-1.96
86-042	-22.6			-23.53	4	0.2			
86-042				-19.76					
86-043	-23.7	-186	<6	-3.59	44	201.8	48	1.45	-3.59
86-044	-23.1	-182							
86-044		-183							
86-045	-22.5	-179							
86-046	-23.4			-7.81	8	239.0	12	2.48	
86-049	-23.3	-184		-10.64	5.5	0.2			
86-050	-23.1								
86-052	-22.9	-181	15	-10.74	42	61.4	0	3.57	-10.74
86-055	-22.9	-183		2.48	1.6	1099.7	5357	0.08	0.93
86-056	-21.6		12						
86-057	-20.8			3.94	14.2	1721.7	728	0.60	2.48
86-058	-22.5	-179	55	0.37	8.9	1918.0	3686	0.03	3.94
86-059	-22.3								
86-060	-23.9	-187	<6	-6.44	46	111.7	0	3.86	-6.44
86-060		-186							
86-062	-22.0	-178		-13.69	3	16.6			
86-063	-22.4	-180		-9.34	38.5	194.6	95	1.21	-9.34
86-064	-22.4		20						
86-065	-21.4	-170							
86-066	-20.5								
86-067	-21.8	-172		-6.95	0	271.8	27	2.20	-6.95
86-068	-21.5								
86-070	-22.0	-176	43	-11.99	6.2	0.2			
86-072A	-22.4			-17.51	5	115.0			
86-072B	-22.2	-180	27						
87-073A	-21.9	-175							
86-074	-23.4	-179		-6.55	16	672.6	71	1.59	-6.55
86-075	-21.6	-170							
86-076	-22.3	-176		-10.41	4	196.7	18	2.35	-10.41
86-076		-178							

Table A-4.2(iv) Isotopes in Spring Waters (from Hamilton, 1990, Appendix 5)

Sample	$^{18}O-H_20$	$^{2}H-H_20$	^{3}H	^{13}C(DIC)	Temp.	HCO_3-	H_2CO_3	pCO_2	^{13}C(gas)
number	^{o}/oo	^{o}/oo	(T.U.)	^{o}/oo	º C	mg/l	mg/l	bars	calc.
86-077	-21.9			-7.13	8	220.1	21	2.23	-7.13
86-078	-21.6	-169		-4.02	1.5	64.9			
86-079	-22.0								
86-080	-22.1								
86-081	-21.1								
86-082	-23.0	-181	<6	-5.74	38.5	320.0	21	1.06	-5.74
87-100	-22.1	-176							
87-106	-22.4	-180							
87-107	-21.6	-169							
87-109	-22.2			-15.29	0	122.5			
87-111	-22.5	-180	59	-12.46	7	484.5	37	2.00	-12.46
87-112	-21.5	-171	<6						
87-116	-19.6								
87-119	-21.6								
87-122	-22.4	-176							
87-123	-22.4	-180	11(&16)						
87-124	-15.4								
87-125	-22.4	-179		-14.54	1	383.0	35	2.12	-14.54
87-127	-22.2								

A-4.2.1. Analytical Methods for Stable Isotopes in Nahanni Water Samples

Oxygen-18 and Deuterium

^{18}O and ^{2}H are expressed in ^{O}/oo SMOW (Standard Mean Ocean Water) in the above table. Not all waters in the study area were analyzed for these two isotopes. 79 analyses were obtained for ^{18}O and 51 for ^{2}H. When concentrations of both of these isotopes have been determined for a water sample, the results can be plotted on a graph. When worldwide precipitation data are plotted, they define a line known as the global meteoric water line (GMWL). The line results from the proportional distillation process of ^{18}O and ^{2}H as water vapour moves away from the ocean where it originated. Precipitation over the ocean and very near coasts tends to have $\delta^{18}O$ and $\delta^{2}H$ values of close to that of seawater (0 ^{O}/oo SMOW). As a vapour mass moves inland, preferential condensation of the heavier isotopes results in a depletion of oxygen-18 and deuterium in precipitation which increases with distance from the coast.

The isotopic signature of precipitation is also affected by factors such as temperature and altitude. Cooler climates have precipitation which is more depleted in both these isotopes than warmer climates. Increased altitude has the same effect. Shallow meteoric waters in a given region, in most cases, plot along a line near the GMWL known as the local meteoric water line (LMWL). This is produced by fitting a line through precipitation data from an area which has been plotted on a graph.

Precipitation data are not available for the Nahanni region and therefore an approximation was made by plotting a regression through the spring water data (Figure 5.4). The similarity in the slope of the resulting line and the GMWL (Gat, 1980) is close enough to suggest that this is a good approximation of the LMWL. Data from the study area all fall close to the "LMWL" in Figure 5.4 and within a fairly small range. This would suggest little or no water-rock exchange reactions have taken place, even in the C, D1 or E group springs (see Chapter 5, text).

Tritium

^{3}H is the radioactive isotope of hydrogen and is produced naturally in the upper atmosphere by cosmic ray bombardment of hydrogen in water vapour. Natural levels are in the order of 1-2 T.U. (tritium units). Anthropogenic tritium, however, has been introduced into the atmosphere in much larger quantities (more than 4 orders of magnitude higher than natural levels) since atmospheric testing of thermonuclear weapons began in 1952. The half life of tritium is approximately 12 years and the levels in the atmosphere have been steadily dropping since atmospheric nuclear testing was ended in 1963. The presence of tritium in groundwater, indicates that a component of the water is less than 35 years old (samples were taken in 1986 and 1987). If the record of tritium has been kept over a period of time for an area, it is possible, using the decay equation of tritium, to make approximations of the age of groundwaters. This assumes that there has been no subsurface mixing or dilution of the groundwater. This calculation works better on waters from wells than on spring waters because springs are often located at the break in slope or on a fault where many flow systems may merge prior to discharge.

In many cases in this study it is likely that waters have been mixed in the subsurface and for this reason age calculations have not been attempted on the water. Knowing the exact age of the groundwaters was not essential to the project but tritium analysis, nonetheless proved very useful in determining whether a spring had relatively old or young groundwater.

Carbon-13

^{13}C was measured on the dissolved inorganic carbon (DIC) in the water. DIC in groundwater usually comes from both dissolution of carbonate rocks and from CO_2 according to equations 5.6 and 5.7. Calculations can be made to determine the equilibrium concentrations of $^{13}C_{(gas)}$, based on known enrichment factors between dissolved CO_2 and the various carbonate species in solution (H_2CO_3, HCO_3^-, CO_3^{2-}). Isotopic exchange reactions between dissolved CO_2 and carbonate species in solution have very fast reaction rates and therefore, the calculations can be a good measure of the ^{13}C composition of the gas phase.

In order to calculate the ^{13}C composition of the gas, concentrations of the major carbonate species in solution must first be known. These can be calculated based on the following formulae provided their respective equilibrium constants are known.

$K_1 = [H_2CO_3]/PCO_2$

$K_2 = [H^+]x[HCO_3^-]/[H_2CO_3]$

$K_3 = [H^+]x[CO_3^{2-}]/[HCO_3^-]$

Therefore, knowing the pH and HCO_3^- concentration it is possible to calculate pCO_2 and H_2CO_3 and CO_3^{2-} concentrations.

Equilibrium constants (K) for the above formulae were obtained for the various temperatures from Hem (1985) which allowed the molarities of the various carbonate species to be calculated (see Table A-4.2(iv)).

$\varepsilon(H_2CO_3\text{-}CO_2) = -0.373 \times 10^3 \times T^{-1}+0.19$ (Mook et al., 1974)

$\varepsilon(HCO_3^-\text{-}CO_2) = 9.483 \times 10^3 \times T^{-1} - 23.89$ (Mook et al., 1974)

$\varepsilon(CO_3^{2-}\text{-}CO_2) = 0.87 \times 10^6 \times T^{-2} - 3.4$ (Deines et al., 1974)

In waters with pH less than 8, CO_3^{2-} can usually be neglected because it makes up such a small proportion of the DIC. With the molarities of the carbonate species and the enrichment factors of the exchange reactions, $^{13}C_{(gas)}$ can now be calculated using the following formula:

$$\delta^{13}C_{(DIC)}\ M_{(DIC)} = [M_{(H2CO3)}\ (\delta^{13}C_{(CO2)} + \varepsilon_{(H2CO3\text{-}CO2)}] + [M_{(HCO3\text{-})}\ (\delta^{13}C_{(CO2)} + \varepsilon_{(HCO3\text{-}CO2)}]$$

Where M = concentration of the species. Calculated $^{13}C_{(gas)}$, H_2CO_3 and pCO_2 concentrations are shown in the above Table A-4.2(iv). PCO_2 and $^{13}C_{(gas)}$ for each of the spring groups are given in Figures 5.13 and 5.14 respectively.

Laboratories

^{18}O and the 1987 ^{13}C analyses were conducted at the Stable Isotope Laboratory, Ottawa-Carleton Geoscience Centre. A mass spectrometer was used and the detection limit for both isotopes is ± 0.2 $^{O}/oo$.

^{2}H and 1986 ^{13}C were analyzed at the Stable Isotope Laboratory, Department of Earth Sciences, University of Waterloo. Analyses were conducted using a mass spectrometer with detection limits of ± 2.0 and 0.2 $^{O}/oo$ respectively. ^{3}H was also analyzed at the University of Waterloo. Tritium analysis was conducted using direct counting liquid scintillation with a detection limit of 6 ± 8 T.U..

The ^{34}S and $^{18}O_{(SO4)}$ results reported in the text were analyzed by Dr. R. Krouse at the Stable Isotope Laboratory, Department of Physics, University of Calgary. The analyses were conducted on a mass spectrometer with detection limits of ± 0.2 $^{O}/oo$ for both isotopes.

Table A-4.2 (v) Major elements in selected precipitates from springs, South Nahanni River region. All sample numbers are 86 or 87-JPN-# # #.

Element	SiO_2	TiO2	Al_2O_3	Cr_2O_3	$Fe_2O_{3T}T$	Fe_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	H_2OT	CO_2T	CO_2	C	P_2O_5	S	Ba	Nb	Rb	Sr	Y	Zr
DL(ppm)	0.40	0.02	0.40	0.02	0.10	0.20	0.20	0.01	0.10	0.10	0.50	0.05	0.10	0.10	0.10	?	0.02	0.04	0.0	0.0	0.0	0.0	0.0	0.0
method	XRF	XRF	XRF	XRF	XRF	Calc.	Rap	XRF	XRF	XRF	XRF	XRF	Rap	Rap	Rap	Rap	XRF	Rap	XRF	XRF	XRF	XRF	XRF	XRF
86JPN-001	0.00	0.05	0.00	0.00	0.00	0.00	0.10	0.00	0.50	54.13	0.00	0.00	0.50	44.30	44.40	0.00	0.01	0.05	109.0	0.0	5.0	213.0	5.0	5.0
86JPN-015	12.40	0.02	6.90	0.01	58.80	58.70	0.10	0.01	0.06	0.57	0.10	0.03	18.40	2.00	0.80	0.30	0.02	0.35	89.0	1.0	3.0	6.0	481.0	0.0
86JPN-017	0.50	0.02	0.00	0.00	1.30	1.00	0.20	0.14	0.20	54.70	0.00	0.00	0.60	42.20	42.90	0.00	0.01	0.24	93.0	6.0	5.0	722.0	0.0	39.0
86JPN-021	0.90	0.09	0.10	0.00	0.20			0.02	0.82	50.51	0.10	0.02	2.00	45.30	40.80	1.20	0.04	0.40	57.0	8.0	7.0	1983.0	0.0	124.0
86JPN-023	0.00	0.12	0.10	0.00	0.00	0.00	0.20	0.00	0.80	51.37	0.00	0.00	2.30	46.90	40.80	1.70	0.01	0.09	266.0	8.0	9.0	199.0	0.0	0.0
86JPN-027	0.00	0.02	0.30	0.00	0.00			0.00	0.52	55.50	0.00	0.00	0.90	44.30	42.90	0.40	0.01	0.04	93.0	10.0	0.0	678.0	0.0	41.0
86JPN-028	0.90	0.05	0.40	0.00	0.10			0.00	0.44	54.20	0.00	0.06	1.80	45.70	41.60	1.10	0.04	0.02	204.0	4.0	14.0	154.0	1.0	9.0
86JPN-029	0.00	0.03	0.10	0.00	0.00			0.00	0.64	52.96	0.00	0.00	1.90	46.00	41.40	1.30	0.02	0.08	87.0	10.0	14.0	865.0	1.0	49.0
86JPN-030w	0.00	0.02	0.00	0.00	0.00			0.00	0.72	53.80	0.00	0.00	1.30	45.00	42.10	0.80	0.01	0.07	110.0	4.0	0.0	958.0	7.0	62.0
86JPN-030r	0.10	0.01	0.20	0.00	3.20	3.00	0.10	0.02	0.59	51.48	0.10	0.00	1.70	43.00	40.30	0.70	0.03	0.09	105.0	12.0	0.0	970.0	5.0	67.0
86JPN-031	0.30	0.04	0.20	0.00	0.00			0.00	0.64	53.18	0.00	0.02	1.10	44.60	42.70	0.50	0.01	0.08	113.0	7.0	10.0	916.0	0.0	60.0
86JPN-033	1.30	0.08	0.20	0.00	0.10	0.00	0.30	0.00	0.30	52.27	0.10	0.03	1.40	44.70	41.70	0.80	0.02	0.05	112.0	0.0	3.0	190.0	13.0	6.0
86JPN-037	6.30	0.01	0.00	0.00	70.70	70.70	0.00	0.09	0.02	2.24	0.10	0.00	17.00	2.70	2.20	0.10	0.01	0.05	162.0	8.0	0.0	130.0	426.0	0.0
86JPN-046	0.40	0.02	0.10	0.00	0.00	0.00	0.20	0.00	0.96	53.19	0.10	0.01	1.50	45.90	42.20	1.00	0.02	0.04	284.0	0.0	4.0	236.0	5.0	1.0
86JPN-049	10.40	0.10	6.20	0.01	52.40			0.01	0.61	1.05	0.10	0.40		2.20	0.60	0.40	0.05	3.32	2241.0	0.0	21.0	58.0	43.0	27.0
86JPN-055	1.50	0.02	0.20	0.00	22.20	22.20	0.00	0.80	0.29	35.59	0.10	0.00	7.80	37.90	28.00	2.70	0.03	0.08	389.0	0.0	14.0	144.0	44.0	218.0
86JPN-056	1.00	0.03	0.40	0.00	18.80	18.20	0.50	0.15	0.62	39.26	0.10	0.03	6.00	35.80	31.10	1.30	0.03	0.27	124.0	0.0	7.0	815.0	38.0	53.0
86JPN-057	0.30	0.04	0.10	0.00	2.00	1.50	0.50	0.20	0.44	52.91	0.10	0.00	1.70	42.60	32.80	2.70	0.02	0.56	35.0	3.0	13.0	866.0	19.0	59.0
86JPN-058r	0.00	0.01	0.10	0.00	0.30	0.20	0.10	0.15	0.45	54.10	0.10	0.00	1.00	44.40	43.60	0.20	0.01	0.11	80.0	4.0	11.0	586.0	0.0	56.0
86JPN-058w	0.00	0.00	0.00	0.00	0.10	0.10	0.00	0.07	0.64	53.14	0.10	0.00	1.30	44.50	43.20	0.40	0.01	0.09	130.0	14.0	4.0	1294.0	0.0	81.0
86JPN-059	8.00	0.09	1.70	0.00	5.10	5.10	0.00	1.19	0.52	43.55	0.10	0.40	2.70	36.80	34.70	0.60	0.07	0.04	379.0	7.0	24.0	233.0	52.0	33.0
86JPN-061	17.10	0.11	2.80	0.00	42.20	41.90	0.30	0.03	0.33	12.01	0.30	0.49	14.50	10.50	8.60	0.50	0.15	0.02	822.0	14.0	36.0	729.0	274.0	59.0
86JPN-062	4.00	0.01	0.10	0.00	79.70	79.60	0.10	0.01	0.03	0.04	0.00	0.00	14.50	2.00	0.00	0.50	0.04	0.44	71.0	0.0	0.0	0.0	55.0	0.0
86JPN-070r	0.40	0.01	0.30	0.00	67.10			0.01	0.02	0.01	0.00	0.01		7.00	0.00	1.90	0.02	3.71	6.0	0.0	0.0	0.0	4.0	0.0
86JPN-082M	29.20	0.25	6.00	0.00	2.70			0.01	10.73	14.78	0.30	1.35		26.30	21.90	1.20	0.16	5.00	808.0	17.0	55.0	86.0	42.0	67.0
87JPN-082Y	1.20	0.02	0.20	0.00	0.10			0.02	1.06	51.54	0.10	0.04	2.60	45.80	40.50	1.40	0.04	0.44	70.0	14.0	5.0	878.0	25.0	54.0
87JPN-111	0.00	0.03	0.00	0.00	0.10			0.04	0.29	52.96	0.10	0.00	1.40	44.70	42.20	0.70	0.01	0.34	59.0	8.0	0.0	311.0	5.0	15.0
87JPN-112	16.40	0.14	3.50	0.01	61.80	61.50	0.30	0.08	0.33	0.92	0.20	0.57	12.90	3.40	0.20	0.90	0.03	0.85	1324.0	0.0	34.0	69.0	107.0	12.0
87JPN-124	12.50	0.08	1.80	0.00	2.00	1.60	0.30	0.04	0.90	44.42	0.20	0.29	1.80	36.90	35.50	0.a	0.07	0.06	328.0	9.0	33.0	139.0	33.0	46.0
87JPN-125	1.60	0.02	0.20	0.00	0.10	0.00	0.30	0.00	0.28	53.45	0.10	0.02	0.90	44.20	42.70	0.40	0.02	0.15	127.0	7.0	19.0	180.0	0.0	4.0
87JPN-12B	17.40	0.08	36.10	0.01	0.90			0.04	0.35	0.34	0.10	0.28		18.50	0.40	4.90	0.12	1.54	326.0	11.0	18.0	46.0	299.0	21.0
256-88-35	0.40	0.04	0.10	0.00	0.00			0.00	0.95	51.87	0.10	0.02	1.70	46.30	42.70	1.00	0.02	0.02	270.0	1.0	7.0	228.0	0.0	27.0
87JPN-70b2	4.20	0.01	26.40	0.00	28.60			0.01	0.14	0.33	0.00	0.04		25.40	0.20	6.90	0.02	3.23	15.0	4.0	4.0	9.0	46.0	1.0

XRF = X-RAY Fluorescence; Calc = calculated using Fe_2O_3 (XRF) – 1.11134*FeO (Volumetric); Rap = individual rapid chemical methods unique to each element.

Table A-4.2(vi) Trace elements in selected precipitates from springs, South Nahanni River region.

Sample #	Ag	Be	Co	Cr	Cu	La	Ni	Pb	V	Yb	Zn
DL(ppm)	2	0.5	5	10	10	10	10	20	5	0.5	5
method	AA	ICP-TR1	ICP-TR1	ICP-TR1	ICP-TR1	ICP-TR1	ICP-TR1	AA	ICP-TR1	ICP-TR1	ICP-TR1
86JPN-001	0	0.6	0	0	0	0	0	0	0	0.4	22
86JPN-015	0	13.0	6	0	16	240	120	0	29	15.0	2600
86JPN-017	0	1.9	0	0	0	0	0	0	0	0.4	0
86JPN-021	0	0.5	0	0	0	0	0	5	0	0.3	0
86JPN-023	0	0.5	0	0	0	0	0	5	0	0.3	26
86JPN-027	0	0.6	0	0	0	0	0	1	0	0.3	7
86JPN-028	0	0.6	0	0	0	0	0	3	0	0.5	31
86JPN-029	0	0.5	0	0	0	0	0	0	0	0.4	17
86JPN-030w	0	0.5	0	0	0	0	0	2	0	0.4	0
86JPN-030r	0	0.9	0	2	0	0	1	0	2	0.3	0
86JPN-031	0	0.5	0	0	0	0	0	1	0	0.4	8
86JPN-033	0	2.7	0	0	0	0	0	1	0	0.4	99
86JPN-037	0	6.6	61	0	11	120	220	18	0	4.3	2900
86JPN-046	0	0.5	0	0	0	0	0	4	0	0.4	300
86JPN-049	0	1.4	0	0	17	25	0	8	190	2.3	120
86JPN-055	0	7.0	61	1	0	3	230	4	19	2.0	660
86JPN-056	0	18.0	0	0	0	0	11	5	9	0.8	97
86JPN-057	0	5.5	0	2	0	0	0	6	0	0.7	7
86JPN-058r	0	1.6	0	0	0	0	0	6	0	0.5	0
86JPN-058w	0	1.2	0	0	0	0	0	6	0	0.4	0
86JPN-059	0	1.4	41	28	1	15	37	7	22	1.1	79
86JPN-061	0	24.0	1	0	12	96	6	12	240	14.0	15
86JPN-062	0	5.1	0	0	17	1	0	3	0	0.4	3
86JPN-070r	0	0.1	0	0	10	0	0	5	15	0.0	17
86JPN-070b	0	8.3	0	0	0	0	0	0	0	0.0	0
86JPN-072a	0	15.0	4	8	5	1	18	1	0	2.4	13
87JPN-12B	0	71.0	48	41	230	49	91	3	420	14.0	590
87JPN-082Y	0	4.7	0	0	0	0	3	12	1	0.3	290
86JPN-082M	0	3.0	32	42	30	14	810	61	170	0.7	9600
87JPN-111	0	0.5	0	0	0	0	130	11	0	0.0	2700
87JPN-112	1	0.7	21	0	14	11	110	8	40	0.2	1400
87JPN-124	0	0.8	8	8	1	1	130	17	37	0.8	810
87JPN-125	0	0.5	0	0	0	0	9	7	0	0.0	480
256-88-35	0	0.5	0	0	0	0	0	8	0	0.0	310
87JPN-70B-2	0	11.0	1	7	1	0	13	12	0	0.6	54

AA – Atomic Absorption;
ICPTR1 = 1.0 g of sample (acid + fusion of residue) dissolved in 10% HCl and diluted to 100 ml, analyzed by ICP – ES.