

DATA SUMMARY FOR BASELINE MONITORING OF SPRINGS
IN BIGHORN CANYON NATIONAL RECREATION AREA

Denine Schmitz
Montana State University
Land Resources & Environmental Sciences

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Introduction

Aridland seeps and springs in Bighorn Canyon National Recreation Area (BICA) were identified as a vital sign for the Greater Yellowstone Inventory and Monitoring Network (GRYN). Seeps and spring ecosystems have an ecological importance disproportionate to their spatial extent in this desert environment. Protecting seep and spring resources requires in-depth understanding of their ecological character, controlling factors, and natural variability over space and time.

A monitoring protocol was developed to track the ecological condition of BICA springs. To date only protocols for the physical parameters have been developed. There are 28 confirmed springs in the park. 24 springs have been established in NPSTORET. 20 of those have been sampled for baseline water quality. Three sites have not been sampled for water quality due to dry conditions. One site cannot be sampled until the park archeologist rules out disturbance to cultural resources. Two sites are seeps on the canyon walls above the reservoir and are not accessible. Four springs were used during protocol development and have been sampled for water quality seasonally since Fall 2004.

This report aims to assess spring water quality based on data collected through 2006. Specifically, the objectives are to 1) summarize the spring water quality data set, 2) assess the nutrient status of springs according to the EPA 1986 water quality standards (US Environmental Protection Agency 1987), 3) chemically characterize spring sites, 3) determine the recharge for BICA springs, and 5) estimate water residence time for each spring.

Methods

Data was collected according to Data Collection of Water Quality SOP #5 (Schmitz and others 2007a) and analyzed according to the Data Analysis SOP #9 (Schmitz and others 2007b).

Results and Discussion

Data Summary and Chemical Characterization

Water quality data for BICA springs spans 1968 to present. These data are summarized in the tables below in the following format. Data from pilot springs are shown first with the data for each spring shown in a different table (Table 1 through Table 4). Non-pilot springs are grouped such that springs visited more than once are listed first and in separate tables (Table 5 through Table 12). Data from the remaining sites are grouped in a single table at the end of this subsection (Table 13).

Bicarbonate levels indicate that 13 BICA springs are moderately sensitive (between 50 and 200 mg/L) to changes in pH caused by nutrients, organic inputs, and acid deposition (Camarero and others 1995). The remaining 13 springs with chemical data are not sensitive due to high acid neutralizing capacities (above 200 mg/L). No spring bicarbonate levels exceed the minimum recommended standard for aquatic life of 20 mg/L (Table 16) (US Environmental Protection Agency 1987).

Table 15 shows calcium and magnesium levels and the calcium: magnesium ratio for each geologic unit of spring waters. The calcium: magnesium molar ratio is commonly used as an indicator of flow path and source area (e.g. (Jensen and others 1997). Calcium: magnesium near 1.0 indicates water flow paths through dolomitic formations; 1.0-3.0 indicates a combination of limestone and dolomitic formations; >3.0 indicates primarily limestone formations. Table 15 illustrates that Cass, Cat Track, Hidden, Pickett's, Trail Creek CG, and Tyler's springs arise from limestone strata. All remaining BICA springs arise from a combination of dolomitic and limestone strata. This characteristic shows that springs in close proximity such as Hillsboro Main and Tyler's Torrent can have different chemical signatures. *Thus, the calcium: magnesium ratio may be useful for stratifying sites in a sample design for Objective 2 (water chemistry).*

Springs emerging from the Bighorn Dolomite/Madison Limestone appear to have a calcium: magnesium signature (Figure 1). Some springs emerging from the Tensleep Sandstone have a calcium: magnesium signature while others are influenced by waters emerging from the Chugwater Siltstone.

This suggests some mixing of waters from different sources in the subsurface environment through fault lines and fissures (Manga 2001). The geology of Finley spring is currently undetermined. However, the calcium: magnesium level suggests that it discharges from the Chugwater Siltstone formation. Pentagon spring emerges from a landslide at the base of the Pryor Mountain scarp which is predominately composed of Bighorn Dolomite and Madison Limestone. The calcium: magnesium levels support this interpretation.

Pilot Springs

Table 1. Headgate Seep occurs near the base of the Bighorn Dolomite, just uphill from a major fault to the west.

Date	pH	DO	DO%	T	SpEC	WT100	HCO ₃	CO ₃	Ca	K	Mg	Na	Cl	NO ₃	PO ₄	SO ₄
		mg/L	%sat	°C	µS	m	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
4/26/2005	7.21	10.5	NR	9.3	266	0.000	200	ND	30.0	2.000	25.0	4.000	0.01	0.085	ND	36.0
11/19/2005	7.59	11.9	104	12.0	329	0.000	200	ND	34.0	2.000	25.0	4.000	0.01	0.099	0.200	37.0
3/10/2006	NR	9.9	79	7.4	358	0.000	200	ND	36.0	2.000	24.0	4.000	0.01	0.089	0.600	35.0
6/28/2006	7.41	5.3	67	18.8	418	0.000	203	ND	49.9	1.840	26.3	3.860	3.05	NR	NR	28.6
9/22/2006	6.96	6.4	NR	12.5	411	0.000	203	NR	46.7	2.760	25.3	3.740	2.52	0.460	ND	25.4
Mean	7.29	8.8	83	12.0	356	0.000	201	NA	39.3	2.120	25.1	3.920	1.12	0.183	0.225	32.4
Standard Deviation	0.27	2.8	19	4.3	63	0.000	2	NA	8.6	0.364	0.8	0.117	1.53	0.185	0.263	5.1
Minimum	6.96	5.3	67	7.4	266	0.000	200	NA	30.0	1.840	24.0	3.740	0.01	0.085	0.000	25.4
Maximum	7.59	11.9	104	18.8	418	0.000	203	NA	49.9	2.760	26.3	4.000	3.05	0.460	0.600	37.0

NA – not applicable; ND – below detection limit; NR – not reported.

Table 2. Hillsboro Main Spring emerges from the Tensleep Sandstone.

Date	pH	DO	DO%	T	SpEC	WT100	HCO ₃	CO ₃	Ca	K	Mg	Na	Cl	NO ₃	PO ₄	SO ₄
		mg/L	%sat	°C	µS	L/sec	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
4/5/1968	NR	NR	NR	10.0	NA	14.5738	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
8/3/2004	7.70	NR	NR	NR	535	NR	239	ND	78.8	0.716	28.7	6.390	1.02	0.202	NR	111.0
4/26/2005	7.13	15.0	NR	10.1	127	11.4000	200	ND	53.0	1.000	31.0	7.000	ND	0.082	0.400	125.0
11/19/2005	7.47	11.6	104	10.3	512	3.9000	200	ND	58.0	1.000	31.0	7.000	ND	0.089	0.400	126.0
3/10/2006	NR	11.2	NR	10.1	506	11.3600	200	ND	59.0	1.000	30.0	6.000	ND	0.186	0.700	122.0
6/29/2006	7.36	8.3	87	10.2	576	4.9600	173	ND	78.7	0.691	29.8	6.190	2.41	NR	NR	127.0
9/23/2006	7.10	8.5	NA	10.1	580	11.9500	186	ND	78.2	0.769	30.4	6.020	1.54	0.156	0.275	119.0
Mean	7.35	10.94	95.25	10.15	472.63	9.69	199.73	NA	67.62	0.86	30.15	6.43	0.83	0.14	0.44	121.67
Standard Deviation	0.25	2.72	11.81	0.11	172.15	4.26	22.26	NA	12.17	0.15	0.87	0.46	1.01	0.06	0.18	5.99
Minimum	7.10	8.34	86.90	10.00	127.00	3.90	173.00	NA	53.00	0.69	28.70	6.00	0.01	0.08	0.28	111.00
Maximum	7.70	14.99	103.60	10.30	579.60	14.57	239.40	NA	78.80	1.00	31.00	7.00	2.41	0.20	0.70	127.00

NA – not applicable; ND – below detection limit; NR – not reported.

Table 3. Layout Spring emerges from the Bighorn Dolomite-Madison Limestone.

Date	pH	DO	DO%	T	SpEC	WT100	HCO ₃	CO ₃	Ca	K	Mg	Na	Cl	NO ₃	PO ₄	SO ₄
		mg/L	%sat	°C	µS	L/sec	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
11/18/2004	7.85	NR	NR	5.6	116	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
4/26/2005	7.74	13.8	NA	5.5	226	5.8190	200	ND	24.0	1.000	14.0	1.000	ND	0.085	0.500	9.0
5/4/2005	8.40	NR	NR	NR	308	NR	187	ND	42.4	0.621	15.5	0.680	0.25	0.250	NR	4.5
11/19/2005	7.91	NR	NR	5.6	275	5.0400	200	ND	40.0	0.100	16.0	1.000	ND	0.026	0.700	11.0
3/10/2006	NA	13.4	106	5.4	302	1.7600	200	ND	32.0	0.100	16.0	1.000	ND	0.028	0.600	11.0
6/29/2006	7.71	10.2	93	5.3	317	8.0080	178	ND	47.8	0.444	15.8	0.758	1.44	NR	NR	4.7
9/22/2006	7.85	10.0	NA	5.4	318	4.1850	177	ND	46.2	0.498	16.2	0.698	ND	0.258	ND	4.5
Mean	7.91	11.9	100	5.5	266	4.9624	190	0.0	38.7	0.461	15.6	0.856	0.29	0.129	0.450	7.4
Standard Deviation	0.25	2.0	9	0.1	74	2.2845	11	0.0	9.1	0.340	0.8	0.160	0.57	0.116	0.311	3.2
Minimum	7.71	10.0	93	5.3	116	1.7600	177	0.0	24.0	0.100	14.0	0.680	0.00	0.026	0.000	4.5
Maximum	8.40	13.8	106	5.6	318	8.0080	200	0.0	47.8	1.000	16.2	1.000	1.44	0.258	0.700	11.0

NA – not applicable; ND – below detection limit; NR – not reported.

Table 4. North Davis Spring emerges from the Chugwater Siltstone.

Date	pH	DO	DO%	T	SpEC	WT100	HCO ₃	CO ₃	Ca	K	Mg	Na	Cl	NO ₃	PO ₄	SO ₄
		mg/L	%sat	°C	µS	L/sec	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
6/30/1978	8.60	NR	NR	15.0	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
9/1/2004	7.41	NR	NR	14.7	798	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
4/26/2005	6.89	23.5	NA	8.8	1218	0.0320	200	ND	155.0	2.000	85.0	35.000	ND	0.025	ND	622.0*
11/19/2005	7.23	6.6	49	3.5	1374	0.0447	201	ND	179.0	2.000	84.0	33.000	ND	0.093	1.200	629.0*
3/10/2006	NR	5.6	NR	1.4	836	0.0600	200	ND	201.0	5.000	90.0	38.000	ND	0.083	0.700	641.0*
6/30/2006	7.31	4.2	51	17.1	1321	0.0001	258	ND	199.0	2.380	78.3	32.300	4.27	NR	NR	582.0*
9/23/2006	6.86	4.5	NR	8.5	1803	0.0008	239	ND	267.0	3.040	111.0	52.200	5.79	0.000	ND	832.0*
Mean	7.38	8.9	50	9.9	1225	0.0275	220	ND	200.2	2.884	89.7	38.100	2.02	0.050	0.525	661.2
Standard Deviation	0.64	8.2	2	6.0	374	0.0266	27	ND	41.7	1.257	12.6	8.187	2.80	0.045	0.538	98.0
Minimum	6.86	4.2	49	1.4	798	0.0001	200	ND	155.0	2.000	78.3	32.300	0.01	0.000	0.000	582.0
Maximum	8.60	23.5	51	17.1	1803	0.0600	258	ND	267.0	5.000	111.0	52.200	5.79	0.093	1.200	832.0

NA – not applicable; ND – below detection limit; NR – not reported.

*Exceeds recommended water quality standards for aquatic life (US Environmental Protection Agency 1986).

Non-pilot Springs Visited Multiple Times

Table 5. Cat Track Spring emerges from the Chugwater Siltstone.

Date	pH	DO	DO%	T	SpEC	WT100	HCO ₃	CO ₃	Ca	K	Mg	Na	Cl	NO ₃	PO ₄	SO ₄
		mg/L	%sat	°C	µS	L/sec	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
8/3/2004	8.10	NR	NR	NR	1827	NR	238	ND	330.0	2.820	97.00	31.000	2.5	0.625	NR	1033.0*
11/5/2006	7.11	8.4	88	11.3	2004	0.0780	173	ND	322.0	3.260	108.00	40.900	6.6	0.332	ND	1130.0*
Mean	7.61	8.4	88	11.3	1916	0.0780	205	ND	326.0	3.040	102.50	35.950	4.6	0.479	ND	1081.5
Standard Deviation	0.70	NA	NA	NA	125	NA	46	NA	5.7	0.311	7.78	7.000	2.9	0.207	ND	68.6
Minimum	7.11	8.4	88	11.3	1827	0.0780	173	ND	322.0	2.820	97.00	31.000	2.5	0.332	ND	1033.0
Maximum	8.10	8.4	88	11.3	2004	0.0780	238	ND	330.0	3.260	108.00	40.900	6.6	0.625	ND	1130.0

NA – not applicable; ND – below detection limit; NR – not reported.

*Exceeds recommended water quality standards for aquatic life (US Environmental Protection Agency 1986).

Table 6. Lockhart Springhouse emerges from the Tensleep Sandstone.

Date	pH	DO	DO%	T	SpEC	WT100	HCO ₃	CO ₃	Ca	K	Mg	Na	Cl	NO ₃	PO ₄	SO ₄
		mg/L	%sat	°C	µS	L/sec	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
8/4/2004	7.45	NR	NR	NR	1226	NR	252	ND	161.0	2.120	70.30	34.400	3.7	0.603	NR	523.0*
9/1/2004	7.22	NR	NR	11.0	1236	NR	NR	ND	NR	NR	NR	NR	NR	NR	NR	NR
6/30/2006	7.12	7.4	77	10.0	1284	0.2330	219	ND	NR	NR	NR	NR	NR	NR	NR	NR
10/29/2006	6.84	7.6	77	9.9	1235	0.5930	193	ND	179.0	2.330	69.60	37.000	5.0	0.431	ND	583.0*
Mean	7.16	7.5	77	10.3	1245	0.4130	221	ND	170.0	2.225	69.95	35.700	4.3	0.517	ND	553.0
Standard Deviation	0.25	0.1	0	0.6	26	0.2546	29	ND	12.7	0.148	0.49	1.838	0.9	0.122	ND	42.4
Minimum	6.84	7.4	77	9.9	1226	0.2330	193	ND	161.0	2.120	69.60	34.400	3.7	0.431	ND	523.0
Maximum	7.45	7.6	77	11.0	1284	0.5930	252	ND	179.0	2.330	70.30	37.000	5.0	0.603	ND	583.0

NA – not applicable; ND – below detection limit; NR – not reported.

*Exceeds recommended water quality standards for aquatic life (US Environmental Protection Agency 1986).

Table 7. Lockhart South Spring emerges from the Chugwater Siltstone.

Date	pH	DO	DO%	T	SpEC	WT100	HCO ₃	CO ₃	Ca	K	Mg	Na	Cl	NO ₃	PO ₄	SO ₄
		mg/L	%sat	°C	µS	L/sec	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
7/5/1978	7.50	NR	NR	11.0	NR	NR	NR	NR	NR	NR	93.20	NR	NR	NR	NR	NR
8/4/2004	8.31	NR	NR	NR	1330	NR	251	ND	179.0	2.130	75.20	34.600	4.0	0.250	NR	611.0*
11/4/2006	6.88	7.8	80	10.0	1445	0.0080	226	ND	201.0	2.970	78.60	37.500	5.2	0.314	ND	661.0*
Mean	7.56	7.8	80	10.5	1388	0.0080	239	ND	190.0	2.550	82.33	36.050	4.6	0.282	ND	636.0
Standard Deviation	0.72	NA	NA	0.7	81	NA	18	ND	15.6	0.594	9.56	2.051	0.8	0.045	ND	35.4
Minimum	6.88	7.8	80	10.0	1330	0.0080	226	ND	179.0	2.130	75.20	34.600	4.0	0.250	ND	611.0
Maximum	8.31	7.8	80	11.0	1445	0.0080	251	ND	201.0	2.970	93.20	37.500	5.2	0.314	ND	661.0

NA – not applicable; ND – below detection limit; NR – not reported.

*Exceeds recommended water quality standards for aquatic life (US Environmental Protection Agency 1986).

Table 8. Lockhart Stockpond emerges from the Chugwater Siltstone.

Date	pH	DO	DO%	T	SpEC	WT100	HCO ₃	CO ₃	Ca	K	Mg	Na	Cl	NO ₃	PO ₄	SO ₄
		mg/L	%sat	°C	µS	L/sec	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
9/1/2004	7.33	NR	NR	11.4	2293	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
6/30/2006	7.18	7.9	83	10.7	2383	0.0400	140	ND	NR	NR	NR	NR	NR	NR	NR	NR
Mean	7.26	7.9	83	11.0	2338	0.0400	140	ND	NR	NR	NR	NR	NR	NR	NR	NR
Standard Deviation	0.11	NA	NA	0.5	64	NA	NA	ND	NR	NR	NR	NR	NR	NR	NR	NR
Minimum	7.18	7.9	83	10.7	2293	0.0400	140	ND	NR	NR	NR	NR	NR	NR	NR	NR
Maximum	7.33	7.9	83	11.4	2383	0.0400	140	ND	NR	NR	NR	NR	NR	NR	NR	NR

NA – not applicable; ND – below detection limit; NR – not reported.

Table 9. Mason-Lovell emerges from the alluvium over Mowry Shale.

Date	pH	DO	DO%	T	SpEC	WT100	HCO ₃	CO ₃	Ca	K	Mg	Na	Cl	NO ₃	PO ₄	SO ₄
		mg/L	%sat	°C	µS	L/sec	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
11/18/2004	7.50	NR	NR	6.9	2429	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
6/28/2006	6.88	1.6	20	15.5	1514	NR	206	0.00	254.0	3.390	120.00	152.000	46.5	NR	NR	2380.0*
Mean	7.19	1.6	20	11.2	1972	NR	206	0.00	254.0	3.390	120.00	152.000	46.5	NR	NR	2380.0
Standard Deviation	0.44	NA	NA	6.1	647	NR	NA	NA	NA	NA	NA	NA	NA	NR	NR	NA
Minimum	6.88	1.6	20	6.9	1514	NR	206	0.00	254.0	3.390	120.00	152.000	46.5	NR	NR	2380.0
Maximum	7.50	1.6	20	15.5	2429	NR	206	0.00	254.0	3.390	120.00	152.000	46.5	NR	NR	2380.0

NA – not applicable; ND – below detection limit; NR – not reported.

*Exceeds recommended water quality standards for aquatic life (US Environmental Protection Agency 1986).

Table 10. Rick's Spring emerges from the Chugwater Siltstone.

Date	pH	DO	DO%	T	SpEC	WT100	HCO ₃	CO ₃	Ca	K	Mg	Na	Cl	NO ₃	PO ₄	SO ₄
		mg/L	%sat	°C	µS	L/sec	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
8/4/2004	8.00	NR	NR	NR	1158	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
9/1/2004	7.47	NR	NR	11.3	1198	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
10/28/2006	6.66	8.1	85	11.5	1195	0.1500	222	ND	159.0	2.220	61.50	37.900	5.9	0.616	ND	519.0*
Mean	7.38	8.1	85	11.4	1184	0.1500	222	ND	159.0	2.220	61.50	37.900	5.9	0.616	ND	519.0
Standard Deviation	0.67	NA	NA	0.1	22	NA	NA	ND	NA	NA	NA	NA	NA	NA	ND	NA
Minimum	6.66	8.1	85	11.3	1158	0.1500	222	ND	159.0	2.220	61.50	37.900	5.9	0.616	ND	519.0
Maximum	8.00	8.1	85	11.5	1198	0.1500	222	ND	159.0	2.220	61.50	37.900	5.9	0.616	ND	519.0

NA – not applicable; ND – below detection limit; NR – not reported.

*Exceeds recommended water quality standards for aquatic life (US Environmental Protection Agency 1986).

Table 11. Sorenson Spring emerges from the Tensleep Sandstone.

Date	pH	DO	DO%	T	SpEC	WT100	HCO ₃	CO ₃	Ca	K	Mg	Na	Cl	NO ₃	PO ₄	SO ₄
		mg/L	%sat	°C	µS	L/sec	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
8/2/2004	7.65	NR	NR	NR	NR	NR	218	ND	55.4	0.605	21.70	3.220	0.3	0.176	NR	54.6
11/19/2004	7.56	NR	NR	9.9	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
6/29/2006	7.66	8.2	84	9.5	422	3.2400	190	ND	58.3	0.580	22.90	3.210	1.6	NR	NR	60.7
10/27/2006	7.49	8.0	NR	9.3	433	5.5800	176	NR	NR	NR	NR	NR	ND	0.127	ND	56.5
Mean	7.59	8.1	84	9.6	422	4.4100	195	ND	56.9	0.593	22.30	3.215	0.9	0.152	ND	57.267
Standard Deviation	0.08	0.1	NA	0.3	10	1.6546	21	ND	2.1	0.018	0.85	0.007	0.9	0.035	ND	3.121
Minimum	7.49	8.0	84	9.3	412	3.2400	176	ND	55.4	0.580	21.70	3.210	0.3	0.127	ND	54.600
Maximum	7.66	8.2	84	9.9	433	5.5800	218	ND	58.3	0.605	22.90	3.220	1.6	0.176	ND	60.700

NA – not applicable; ND – below detection limit; NR – not reported.

Table 12. Tyler's Torrent emerges from the Tensleep Sandstone.

Date	pH	DO	DO%	T	SpEC	WT100	HCO ₃	CO ₃	Ca	K	Mg	Na	Cl	NO ₃	PO ₄	SO ₄
		mg/L	%sat	°C	µS	L/sec	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
4/5/1968	NR	NR	NR	NR	NR	3.7223	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
4/26/2005	NR	NR	NR	NR	NR	4.0000	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
6/29/2006	NR	NR	NR	NR	NR	0.8800	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
9/23/2006	6.94	7.6	NR	9.4	1105	0.3964	140	ND	195.0	2.350	51.50	14.600	2.5	0.227	ND	*500.0
Mean	7.31	7.6	NR	10.2	1113	2.2497	140	ND	195.0	2.350	49.15	14.600	2.5	0.227	ND	500.0
Standard Deviation	0.60	NA	NR	0.7	11	1.8747	NA	ND	NA	NA	3.32	NA	NA	NA	ND	NA
Minimum	6.94	7.6	NR	9.4	1105	0.3964	140	ND	195.0	2.350	46.80	14.600	2.5	0.227	ND	500.0
Maximum	8.00	7.6	NR	10.6	1120	4.0000	140	ND	195.0	2.350	51.50	14.600	2.5	0.227	ND	500.0

NA – not applicable; ND – below detection limit; NR – not reported.

*Exceeds recommended water quality standards for aquatic life (US Environmental Protection Agency 1986).

Non-pilot Springs Visited Once

Table 13. Non-pilot springs visited once.

Feature	Date	pH	DO mg/L	DO %sat	T °C	SpEC µS	Flow L/sec	HCO ₃ mg/L	CO ₃ mg/L	Ca mg/L	K mg/L	Mg mg/L	Na mg/L	Cl mg/L	NO ₃ mg/L	PO ₄ mg/L	SO ₄ mg/L
Cass Spring	10/28/2006	7.14	8.7	89	10.0	182	6.8000	175	ND	281.0	2.590	92.90	36.800	4.6	0.379	ND	962.0*
Finley Spring	5/20/2007	6.97	7.9	82	10.8	1867	0.2150	183	ND	269.0	3.340	97.10	35.500	5.1	0.306	ND	969.0*
Hidden Spring	9/24/2006	6.88	9.1		11.6	1367	0.9000	203	ND	254.0	2.470	62.60	13.600	2.5	0.115	ND	633.0*
Hillsboro Side Spring 1	11/4/2006	7.59	9.2	93	10.0	414	0.0080	216	ND	54.2	0.848	27.30	5.850	2.7	0.237	ND	44.8
Hillsboro Side Spring 2	11/4/2006	7.48	9.2	94	9.9	479	0.0270	213	ND	56.9	1.310	27.00	8.050	2.7	0.230	ND	49.5
North Trail Creek Spring	7/5/1978	7.30			10.6												
Pentagon	10/27/2006	6.77	3.4		8.8	433		213	ND	46.1	2.140	26.10	6.370	2.3	0.532	ND	22.6
Pickett's Wall Seep	11/3/2006	6.89	9.6	95	8.7	875		163	ND	133.0	1.210	45.00	9.110	2.3	0.163	ND	345.0*
Trail Creek CG Spring-Main	11/3/2006	6.86	9.0	93	10.8	1844	0.6600	146	ND	350.0	2.680	79.20	20.600	4.2	0.351	ND	1050.0*
Trail Creek CG #2	11/3/2006	6.72	9.3	94	9.4	1286	0.2300	163	ND	211.0	2.130	62.80	14.400	3.1	0.231	ND	608.0*
Hailstorm Spring	6/28/2006																
Mason Lovell South	6/28/2006																
Bear Spring	6/28/2006																
Last South Spring	6/28/2006																
Mean		6.91	7.8	94	9.7	1109	0.4450	171	ND	185.0	2.040	53.28	12.620	3.0	0.319	ND	506.4
Standard Deviation		0.23	3.0	1	1.0	601	0.3041	29	ND	129.0	0.610	22.87	6.278	0.9	0.162	ND	434.3
Minimum		6.72	3.4	93	8.7	433	0.2300	146	ND	46.1	1.210	26.10	6.370	2.3	0.163	ND	22.6
Maximum		7.30	9.6	95	10.8	1844	0.6600	213	ND	350.0	2.680	79.20	20.600	4.2	0.532	ND	1050.0

NA – not applicable; ND – below detection limit; NR – not reported.

*Exceeds recommended water quality standards for aquatic life (US Environmental Protection Agency 1986).

Table 14. Geologic units from which non-pilot springs emerge.

Feature	Geology
Cass Spring	Chugwater Siltstone
Finley Spring	Undetermined
Hidden Spring	Tensleep Sandstone
Hillsboro Side Spring 1	Tensleep Sandstone
Hillsboro Side Spring 2	Tensleep Sandstone
North Trail Creek Spring	Chugwater Siltstone
Pentagon	Landslide Bighorn Dolomite-Madison Limestone
Pickett's Wall Seep	Chugwater Siltstone
Trail Creek CG Spring-Main	Tensleep Sandstone
Trail Creek CG #2	Tensleep Sandstone
Hailstorm Spring	Alluvium over Mowry Shale
Mason Lovell South	Alluvium over Mowry Shale
Bear Spring	Chugwater Siltstone
Last South Spring	Alluvium over Mowry Shale

Table 15. Calcium: magnesium ratios indicate all sampled BICA springs arise from a combination of limestone and dolomitic formations.

Feature	Geology	Date	Ca_mgl	Mg_mgl	Ca:Mg
Cass Spring	Chugwater Siltstone	10/28/2006	281.0	92.9	3.02
Cat Track Spring	Chugwater Siltstone	8/3/2004	330.0	97.0	3.40
Cat Track Spring	Chugwater Siltstone	11/5/2006	322.0	108.0	2.98
Finley Spring	Undetermined	5/20/2007	269.0	97.1	2.77
Headgate Seep	Bighorn Dolomite-Madison Limestone	4/26/2005	30.0	25.0	1.20
Headgate Seep	Bighorn Dolomite-Madison Limestone	11/19/2005	34.0	25.0	1.36
Headgate Seep	Bighorn Dolomite-Madison Limestone	3/10/2006	36.0	24.0	1.50
Headgate Seep	Bighorn Dolomite-Madison Limestone	6/28/2006	49.9	26.3	1.90
Headgate Seep	Bighorn Dolomite-Madison Limestone	9/22/2006	46.7	25.3	1.85
Hidden Spring	Tensleep Sandstone	9/24/2006	254.0	62.6	4.06
Hillsboro Main	Tensleep Sandstone	8/3/2004	78.8	28.7	2.75
Hillsboro Main	Tensleep Sandstone	4/26/2005	53.0	31.0	1.71
Hillsboro Main	Tensleep Sandstone	11/19/2005	58.0	31.0	1.87
Hillsboro Main	Tensleep Sandstone	3/10/2006	59.0	30.0	1.97
Hillsboro Main	Tensleep Sandstone	6/29/2006	78.7	29.8	2.64
Hillsboro Main	Tensleep Sandstone	9/23/2006	78.2	30.4	2.57
Hillsboro Side Spring 1	Tensleep Sandstone	11/4/2006	54.2	27.3	1.99
Hillsboro Side Spring 2	Tensleep Sandstone	11/4/2006	56.9	27.0	2.11
Layout Spring	Bighorn Dolomite-Madison Limestone	4/26/2005	24.0	14.0	1.71
Layout Spring	Bighorn Dolomite-Madison Limestone	5/4/2005	42.4	15.5	2.74
Layout Spring	Bighorn Dolomite-Madison Limestone	11/19/2005	40.0	16.0	2.50
Layout Spring	Bighorn Dolomite-Madison Limestone	3/10/2006	32.0	16.0	2.00
Layout Spring	Bighorn Dolomite-Madison Limestone	6/29/2006	47.8	15.8	3.03
Layout Spring	Bighorn Dolomite-Madison Limestone	9/22/2006	46.2	16.2	2.85
Lockhart South	Tensleep Sandstone	8/4/2004	161.0	70.3	2.29
Lockhart South	Tensleep Sandstone	10/29/2006	179.0	69.6	2.57
Lockhart Springhouse	Chugwater Siltstone	8/4/2004	179.0	75.2	2.38
Lockhart Springhouse	Chugwater Siltstone	11/4/2006	201.0	78.6	2.56
Mason_Lovell	Alluvium over Mowry Shale	6/28/2006	254.0	120.0	2.12
N Davis Ck Spring	Chugwater Siltstone	4/26/2005	155.0	85.0	1.82
N Davis Ck Spring	Chugwater Siltstone	11/19/2005	179.0	84.0	2.13
N Davis Ck Spring	Chugwater Siltstone	3/10/2006	201.0	90.0	2.23
N Davis Ck Spring	Chugwater Siltstone	6/30/2006	199.0	78.3	2.54
N Davis Ck Spring	Chugwater Siltstone	9/23/2006	267.0	111.0	2.41
Pentagon	Landslide-Bighorn/Madison	10/27/2006	46.1	26.1	1.77
Pickett's Wall Seep	Chugwater Siltstone	11/3/2006	133.0	45.0	2.96
Rick's Spring	Chugwater Siltstone	10/28/2006	159.0	61.5	2.59
Sorenson	Chugwater Siltstone	8/2/2004	55.4	21.7	2.55
Sorenson	Chugwater Siltstone	6/29/2006	58.3	22.9	2.55
Trail Creek CG #2	Tensleep Sandstone	11/3/2006	350.0	79.2	4.42
Trail Creek CG Spring-Main	Tensleep Sandstone	11/3/2006	211.0	62.8	3.36
Tyler's Torrent	Tensleep Sandstone	9/23/2006	195.0	51.5	3.79

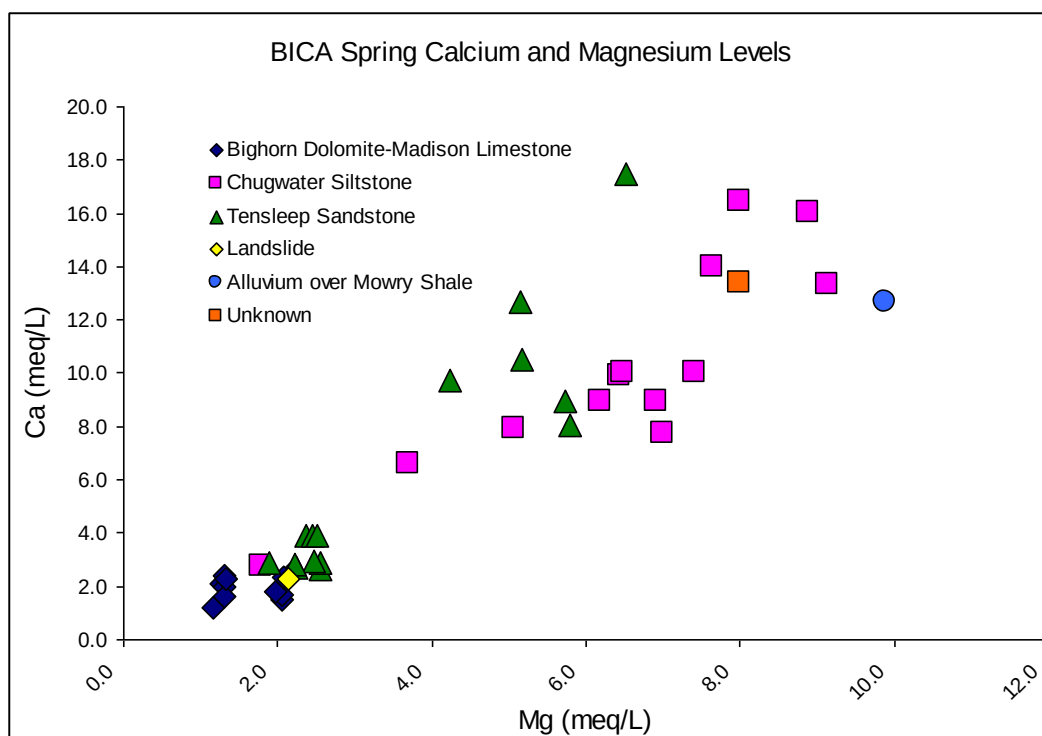


Figure 1. Calcium and magnesium levels for all sampled BICA springs indicates a strong geologic influence and mixing in the subsurface environment. Chemical data are graphed in equivalent weights to account for differences in the numbers of atoms reacting in a chemical reaction (e.g. HCO_3^- will adsorb one H^+ ion but CO_3^{2-} can adsorb 2 H^+ ions).

Chemical Profiles

The Piper plot (e.g. trilinear, ternary) is a visual reference for describing the chemical character of the water sample. The four piper plots below summarize all springs and stratify springs by geologic unit. All BICA springs are calcareous in nature. They differ mainly in sulfate and bicarbonate levels (Figure 2).

Springs emerging from the Bighorn Dolomite and Madison Limestone are chemically classified as calcium/magnesium bicarbonate types and have low sulfate levels (Figure 3). These springs (Layout, Headgate, and Pentagon) are geographically located along the scarp face of the Pryors and may be associated with faults and fissures (Lopez 2000).

Springs emerging from the Chugwater Siltstone are chemically classified as calcium sulfate types (Figure 4). This type is characteristically high in sulfate due to the gypsiferous inclusion of this formation (Richards 1955). Sorenson spring appears to discharge from the Chugwater Siltstone near a fault. However, it has low sulfate, unlike other Chugwater springs (note the outlier). This suggests that mixing occurs with other low sulfate strata such as the Tensleep Sandstone or Madison Limestone via the faults in the area.

Springs emerging from the Tensleep Sandstone are chemically classified as calcium bicarbonate and calcium sulfate types (Figure 5). They vary in their sulfate and bicarbonate levels. This suggests that water from these springs mixes with water from other strata or is influenced by other strata as it flows through them.

Chemical profiles for each site are shown in Appendix A.

Chemical Profile All BICA Springs 2006

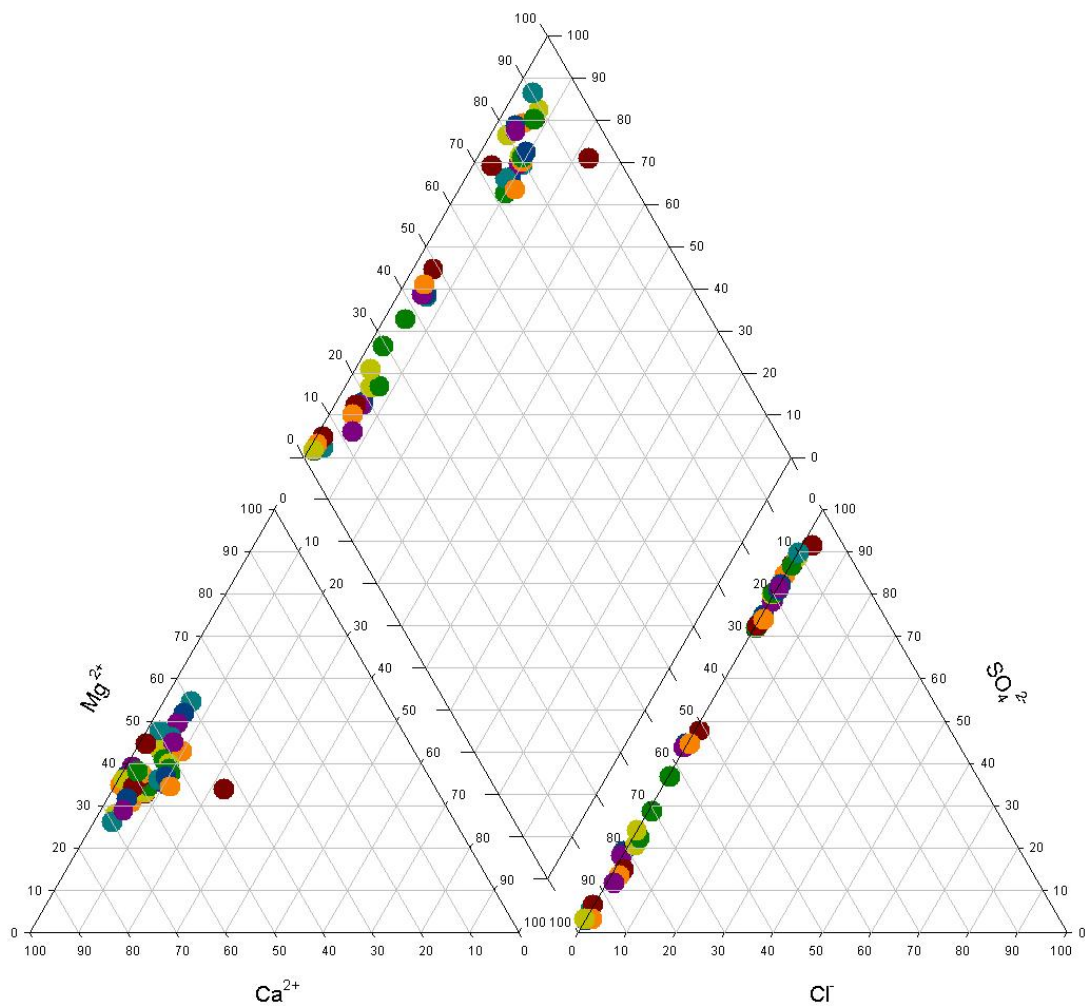


Figure 2. BICA springs are chemically classified as calcium bicarbonate, calcium sulfate, and magnesium sulfate types.

BICA Springs Chemical Profile Bighorn Dolomite-Madison Limestone

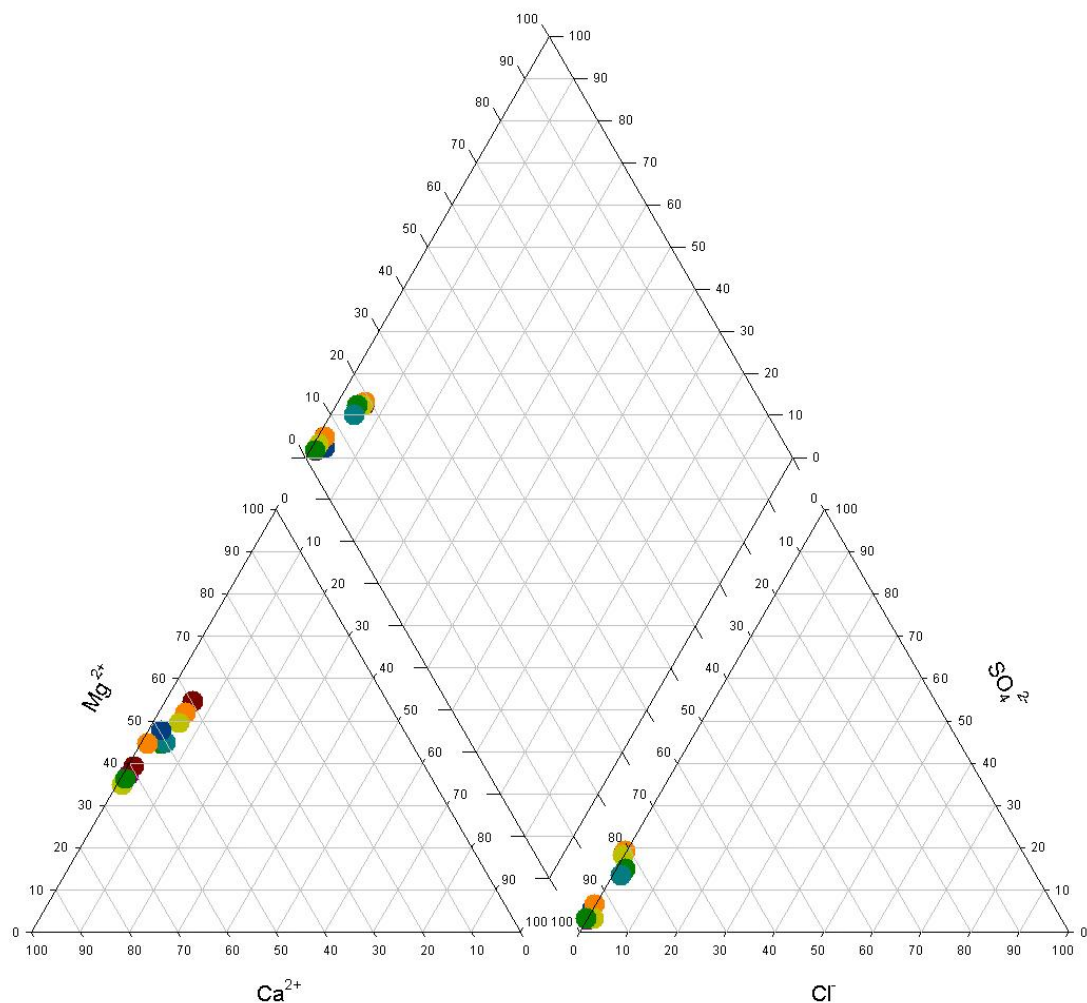


Figure 3. Springs emerging from the Bighorn Dolomite and Madison Limestone are chemically classified as calcium/magnesium bicarbonate types.

BICA Springs Chemical Profile Chugwater Siltstone

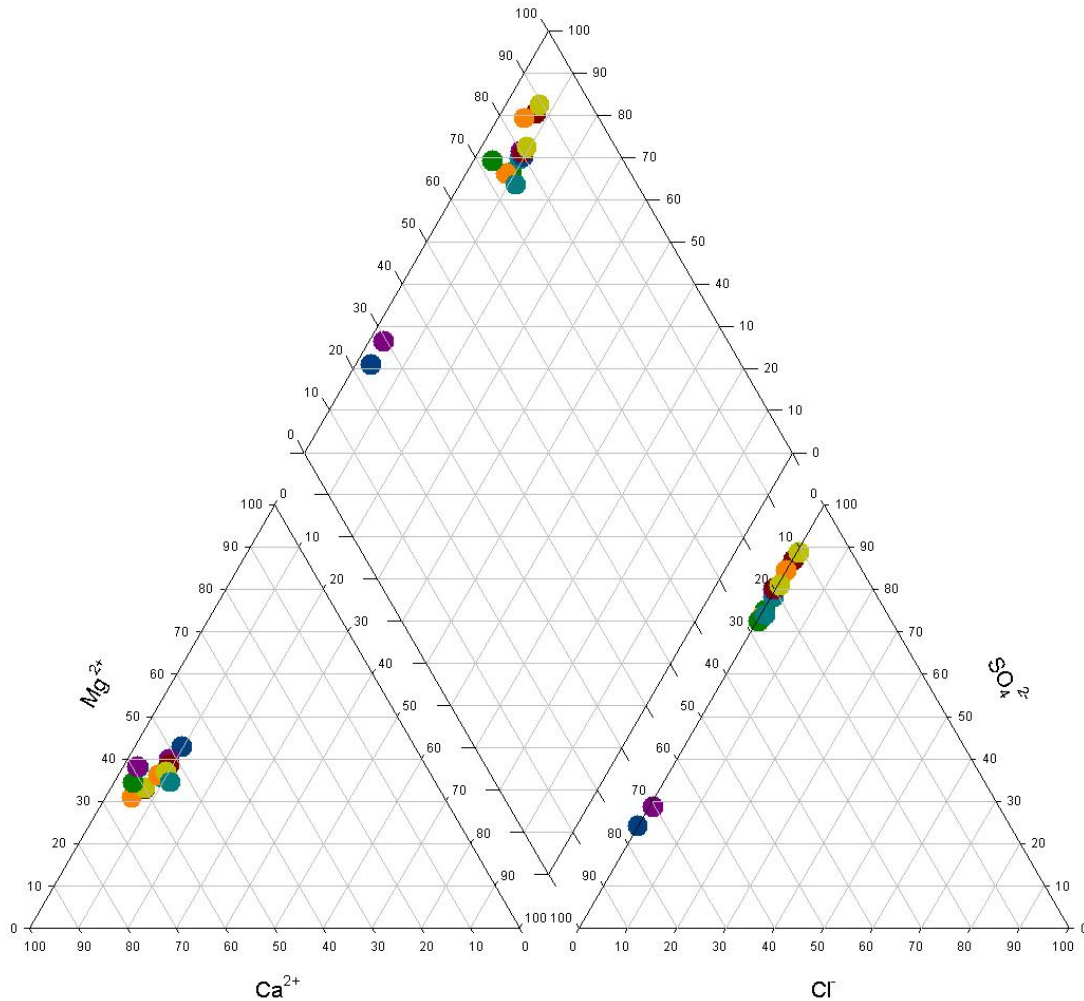


Figure 4. Springs emerging from the Chugwater Siltstone are chemically classified as calcium sulfate. The outliers are from Sorenson Spring. Sorenson Spring emerges near a fault which likely introduces groundwater from low sulfate strata such as Tensleep Sandstone or Madison Limestone.

BICA Springs Chemical Profile Tensleep Sandstone

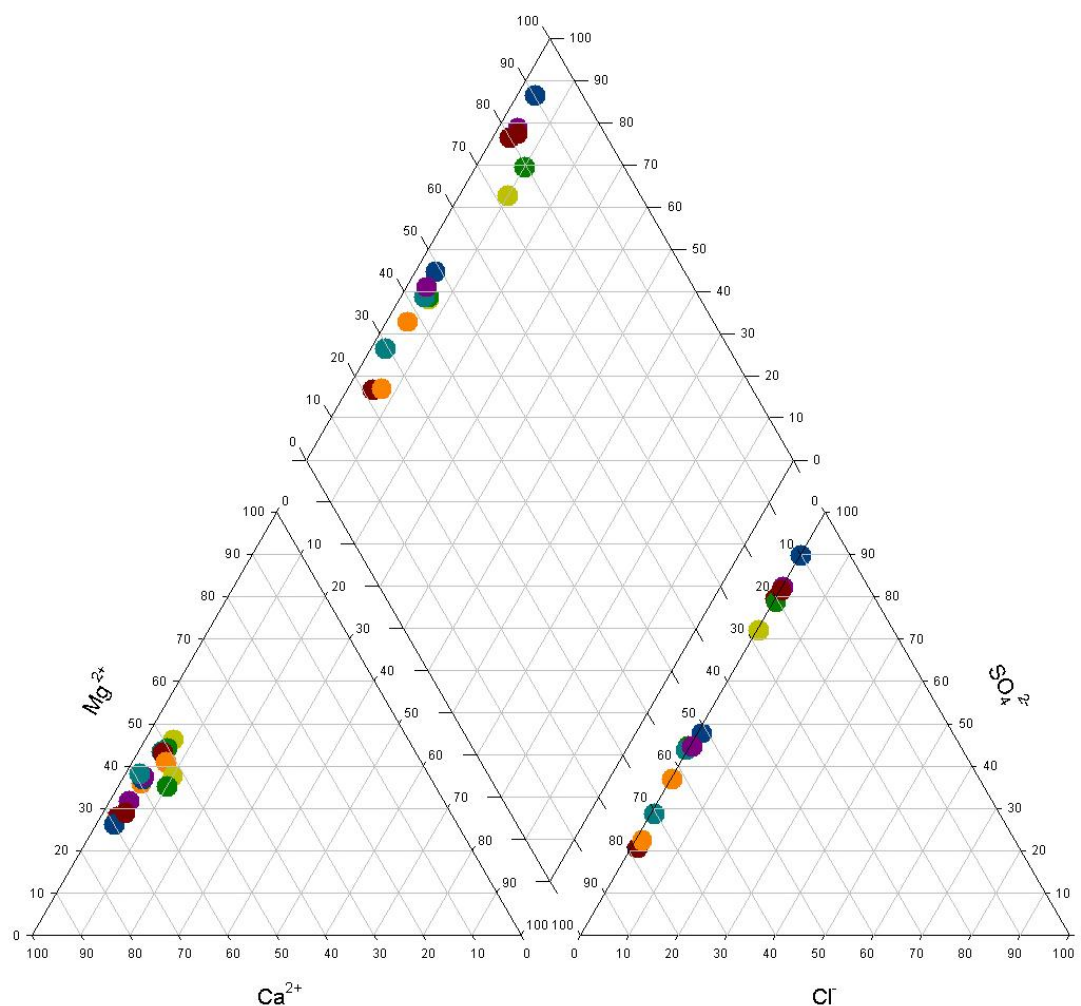


Figure 5. Springs emerging from the Tensleep Sandstone are classified as calcium bicarbonate and calcium sulfate types.

Spring Nutrient Assessment

BICA spring nutrient concentrations were assessed according to the Water Quality Criteria for 1986 (Table 16) (US Environmental Protection Agency 1987). Thirteen springs exceed recommended aquatic life standards for sulfate concentrations (Table 1 through Table 13) due to the influence of gypsiferous units in the Chugwater and overlying formations. No springs exceed recommended standards for aquatic life for nitrate or phosphate concentrations.

Table 16. Nutrient level standards based on the Water Quality Criteria for 1986 (US Environmental Protection Agency 1987), also known as the “Gold Book”.

Regulatory Parameter	Std. Type	Std. Value
		mg/L
Nitrate (mg/l)	Ambient Water	10

Sulfate (mg/l)	Ambient Water	250
Phosphate	Flowing waters	100
Acid Neutralizing Capacity	Ambient Water	<20

Currently there are no total maximum daily load (TMDL) criteria for nutrients on the Lower Bighorn River for Montana. The tables below calculate nutrient loads for sulfate, nitrate, and ortho-phosphate for pilot and non-pilot springs. Of particular interest are the sulfate loads. Because the concentrations of sulfate exceed aquatic life standards and are naturally occurring, these data can be used in the future to document trends in nutrient exports from BICA springs should TMDLs be set for the Lower Bighorn River watershed.

Pilot Springs

Table 17. Nutrient exports for Hillsboro Main Spring.

Date	Flow	SO ₄	NO ₃	PO ₄
	L/sec	kg/yr	kg/yr	kg/yr
4/26/2005	11.4000	4.3852	0.0029	0.0140
11/19/2005	3.9000	1.5122	0.0011	0.0048
3/10/2006	11.3600	4.2649	0.0065	0.0245
6/29/2006	4.9600	1.9385	ND	ND
9/23/2006	11.9500	4.3761	0.0057	0.0101
Mean		3.2954	0.0032	0.0107
Standard Deviation		1.4419	0.0028	0.0094
Minimum		1.5122	ND	ND
Maximum		4.3852	0.0065	0.0245

Table 18. Nutrient exports for Layout Spring.

Date	Flow	SO ₄	NO ₃	PO ₄
	L/sec	kg/yr	kg/yr	kg/yr
4/26/2005	5.8190	0.1612	0.0015	0.0090
11/19/2005	5.0400	0.1706	0.0004	0.0109
3/10/2006	1.7600	0.0596	0.0002	0.0032
9/22/2006	4.1850	0.0577	0.0033	ND
Mean		0.1123	0.0014	0.0058
Standard Deviation		0.0620	0.0014	0.0050
Minimum		0.0577	0.0002	ND
Maximum		0.1706	0.0033	0.0109

Table 19. Nutrient exports for North Davis Spring.

Date	Flow	SO ₄	NO ₃	PO ₄
	L/sec	kg/yr	kg/yr	kg/yr
4/26/2005	0.0320	0.0613	ND	ND
11/19/2005	0.0447	0.0865	ND	0.0002
3/10/2006	0.0600	0.1183	ND	0.0001
6/30/2006	0.0001	0.0002	NR	NR
9/23/2006	0.0008	0.0020	ND	ND
Mean		0.0537	ND	0.0001
Standard Deviation		0.0521	ND	0.0001
Minimum		0.0002	ND	ND
Maximum		0.1183	ND	0.0002

Non-pilot Springs

Table 20. Nutrient exports for non-pilot springs.

Feature	Date	Flow	SO ₄	NO ₃	PO ₄
Cass Spring	10/28/2006	6.8000	20.1307	0.0079	ND
Cat Track Spring	11/5/2006	0.0780	0.2712	0.0001	ND
Finley Spring	5/20/2007	0.2150	0.6411	0.0002	ND
Hidden Spring	9/24/2006	0.9000	1.7532	0.0003	ND
Hillsboro Side Spring 1	11/4/2006	0.0080	0.0011	ND	ND
Hillsboro Side Spring 2	11/4/2006	0.0270	0.0041	ND	ND
Lockhart Springhouse	10/29/2006	0.5930	1.0639	0.0008	ND
Lockhart South	11/4/2006	0.0080	0.0163	ND	ND
Rick's Spring	10/28/2006	0.1500	0.2396	0.0003	ND
Sorenson	10/27/2006	5.5800	0.9702	0.0022	ND
Trail Creek Campground Spring-Main	11/3/2006	0.6600	2.1326	0.0007	ND
Trail Creek Campground #2	11/3/2006	0.2300	0.4303	0.0002	ND
Tyler's Torrent	9/23/2006	0.3964	0.6099	0.0003	ND
Mean			2.1742	0.0010	ND
Standard Deviation			5.4359	0.0022	ND
Minimum			0.0011	ND	ND
Maximum			20.1307	0.0079	ND

Recharge Area

For monitoring the condition of BICA springs, stable naturally occurring isotopes can be used to estimate recharge area. The recharge area loosely estimates the region of water percolation into an aquifer that potentially influences BICA spring discharge. Recharge area was estimated using the ratio of 18-oxygen (¹⁸O) to deuterium (²H) and noted from here forward as $\delta^{18}\text{O}:\delta^2\text{H}$. This ratio indicates two conditions at the time water recharges into an aquifer: temperature at which condensation occurred (rain vs. snow) and the amount of evaporation prior to infiltration. A regional representation of $\delta^{18}\text{O}:\delta^2\text{H}$ values was derived from precipitation collected from a series of regional sites ($r^2=0.98$) (Benjamin and others 2004). This regional relationship is called a local meteoric water line.

Values which plot high on the meteoric water line arise from rain water. Values which plot low on the line arise from snow. Because the $\delta^{18}\text{O}:\delta^2\text{H}$ values for the local meteoric water line were derived directly from precipitation, regional values which plot below the line represent waters subject to evaporation prior to infiltration. Figure 6 illustrates the $\delta^{18}\text{O}:\delta^2\text{H}$ relationship between water discharging from BICA springs and precipitation falling in the region. Increasingly negative $\delta^{18}\text{O}$ and $\delta^2\text{H}$ values arise from larger distances inland, lower temperatures, and higher latitudes and altitudes. Further, departures from the local meteoric water line indicate evaporation prior to recharge. BICA spring $\delta^{18}\text{O}$ and $\delta^2\text{H}$ values are highly negative and plot low on the local meteoric water line. This suggests that BICA spring water arose from snow pack, at altitude, in the region. Combined with an understanding of the climate and topography surrounding BICA, *spring water likely originated from the Pryor Mountains during winter snow.*

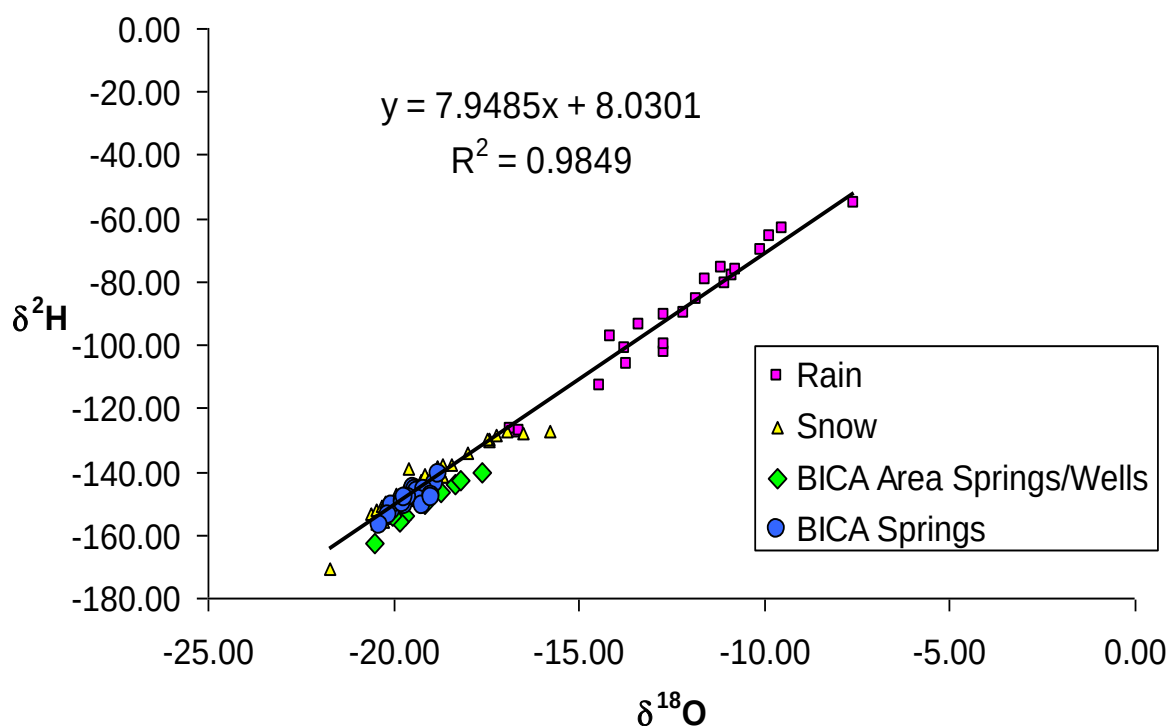


Figure 6. Springs from BICA and surrounding areas are plotted on the local meteoric water line developed for the Montana, Idaho, and Wyoming region (Benjamin and others 2004). Clustering low on the local meteoric water line indicates snow as the spring water source and negligible evaporative enrichment.

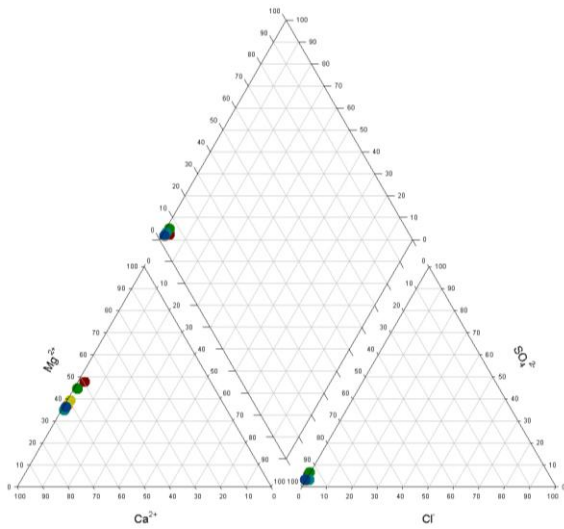
Residence Time

Residence time is the time of entry of a water molecule into an aquifer to the time it discharges at a spring (some would call this travel time through the aquifer). Springs are indicators of the groundwater environment in that springs may be fed by local and regional aquifers in which water residence time could range from a few months to hundreds of years. Residence time determines the temporal scale at which impacts to groundwater quality evoke a spring water quality response (Sada pers. comm. 2004). Residence time was assessed with four independent parameters – seasonality of flow and chemical composition, $\delta^{18}\text{O}$: $\delta^2\text{H}$ values, and tritium values.

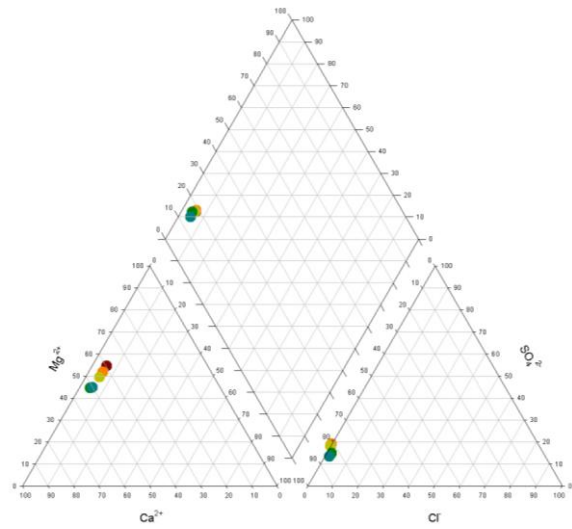
The pilot springs Layout, Headgate, Hillsboro Main, and North Davis have been sampled for chemistry and flow seasonally since 2004 (Table 1 through Table 4). Most BICA springs have been sampled for isotopes once – the pilot springs in 2004; the non-pilot springs in 2006. Flow data are somewhat variable suggesting water from the current season flows from these sites in the spring season. Seasonal piper plots of the pilot springs show no discernible variation suggesting residence time greater than two years (Figure 7). $\delta^{18}\text{O}$: $\delta^2\text{H}$ values indicate snow as the source of water recharging to fill the aquifers of these springs. From the regional estimates (Figure 8), ^3H from a BICA spring can be used to broadly date when the water left the atmosphere and entered the aquifer supplying the spring.

Table 21 summarizes tritium levels for all sampled springs their estimated recharge periods interpreted from Figure 8. Most BICA springs are estimated to discharge water with residence times less than 30 years. Tritium levels from Cass, Cat Track, Lockhart South, Lockhart Springhouse, and Rick's springs indicate water older than 50 years. *Note: These estimates are made from one time samples. More accurate estimates can be made from repeat sampling, an expensive endeavor.*

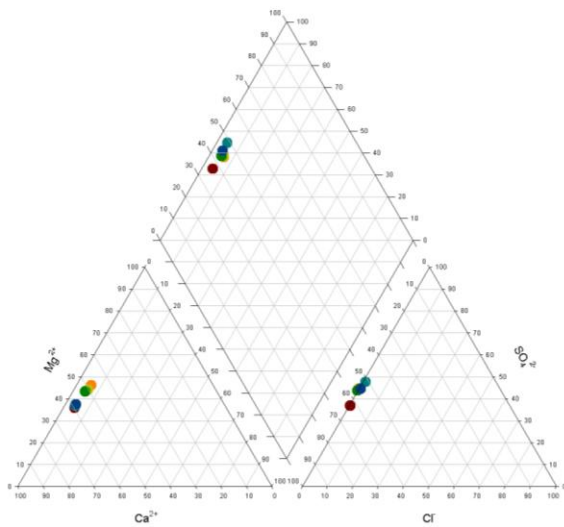
Chemical Profile
Layout Spring
Quarterly Sampling 2004-2006



Chemical Profile
Headgate Seep
Quarterly Sampling 2004-2006



Chemical Profile
Hillsboro Main Spring
Quarterly Sampling 2004-2006



Chemical Profile
North Davis Spring
Quarterly Sampling 2004-2006

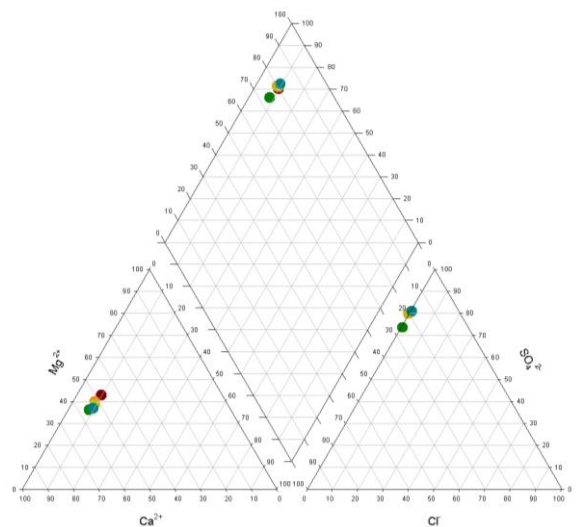


Figure 7. Seasonal chemical profiles of pilot springs indicate stable chemical compositions.

Table 21. Tritium levels for BICA springs. ³H column holds tritium values from spring sample. TU_X holds projected ³H values for Time_X. Time_X indicates year on half life (12.34) prior to sample date or projected date.

Station	Est. Residence Time	Sample Date	³ H	TU_1	Time_1	TU_2	Time_2	TU_3	Time_3	TU_4	Time_4	TU_5	Time_5
	Years		TU	TU	Year	TU	Year	TU	Year	TU	Year	TU	Year
Pilot Springs													
Layout Spring	<30	2005	11.1	22.2	1993	44.4	1980	88.8	1968	177.6	1955	355.2	1943
Headgate Seep	<30	2005	14.1	28.2	1993	56.4	1980	112.8	1968	225.6	1955	451.2	1943
Hillsboro Main Spring	<30	2005	13.8	27.6	1993	55.2	1980	110.4	1968	220.8	1955	441.6	1943
North Davis Spring	<30	2005	7.5	15	1993	30	1980	60	1968	120	1955	240	1943
Non-pilot Springs													
Cass Spring	>50	2005	2.5	5	1993	10	1980	20	1968	40	1955	80	1943
Cat Track Spring	>50	2005	1.5	3	1993	6	1980	12	1968	24	1955	48	1943
Hidden Spring	<30	2005	11.1	22.2	1993	44.4	1980	88.8	1968	177.6	1955	355.2	1943
Hillsboro Side Spring #1	<30	2005	13.0	26	1993	52	1980	104	1968	208	1955	416	1943
Hillsboro side Spring #2	<30	2005	12.7	25.4	1993	50.8	1980	101.6	1968	203.2	1955	406.4	1943
Lockhart South Spring	>50	2005	1.6	3.2	1993	6.4	1980	12.8	1968	25.6	1955	51.2	1943
Lockhart Springhouse	>50	2005	4.7	9.4	1993	18.8	1980	37.6	1968	75.2	1955	150.4	1943
Mason-Lovell Spring	<30	2005	6.0	12	1993	24	1980	48	1968	96	1955	192	1943
North Trail Ck Spring	>50	2005	2.2	4.4	1993	8.8	1980	17.6	1968	35.2	1955	70.4	1943
Pentagon	<30	2005	12.7	25.4	1993	50.8	1980	101.6	1968	203.2	1955	406.4	1943
Pickett's Wall Seep	<30	2005	6.8	13.6	1993	27.2	1980	54.4	1968	108.8	1955	217.6	1943
Rick's	>50	2005	3.2	6.4	1993	12.8	1980	25.6	1968	51.2	1955	102.4	1943
Sorenson Spring	<30	2005	10.9	21.8	1993	43.6	1980	87.2	1968	174.4	1955	348.8	1943
Trail Creek CG Main Spring	<30	2005	7.5	15	1993	30	1980	60	1968	120	1955	240	1943
Trial Creek CG Spring #2	<30	2005	6.8	13.6	1993	27.2	1980	54.4	1968	108.8	1955	217.6	1943
Tyler's Torrent	<30	2005	6.6	13.2	1993	26.4	1980	52.8	1968	105.6	1955	211.2	1943

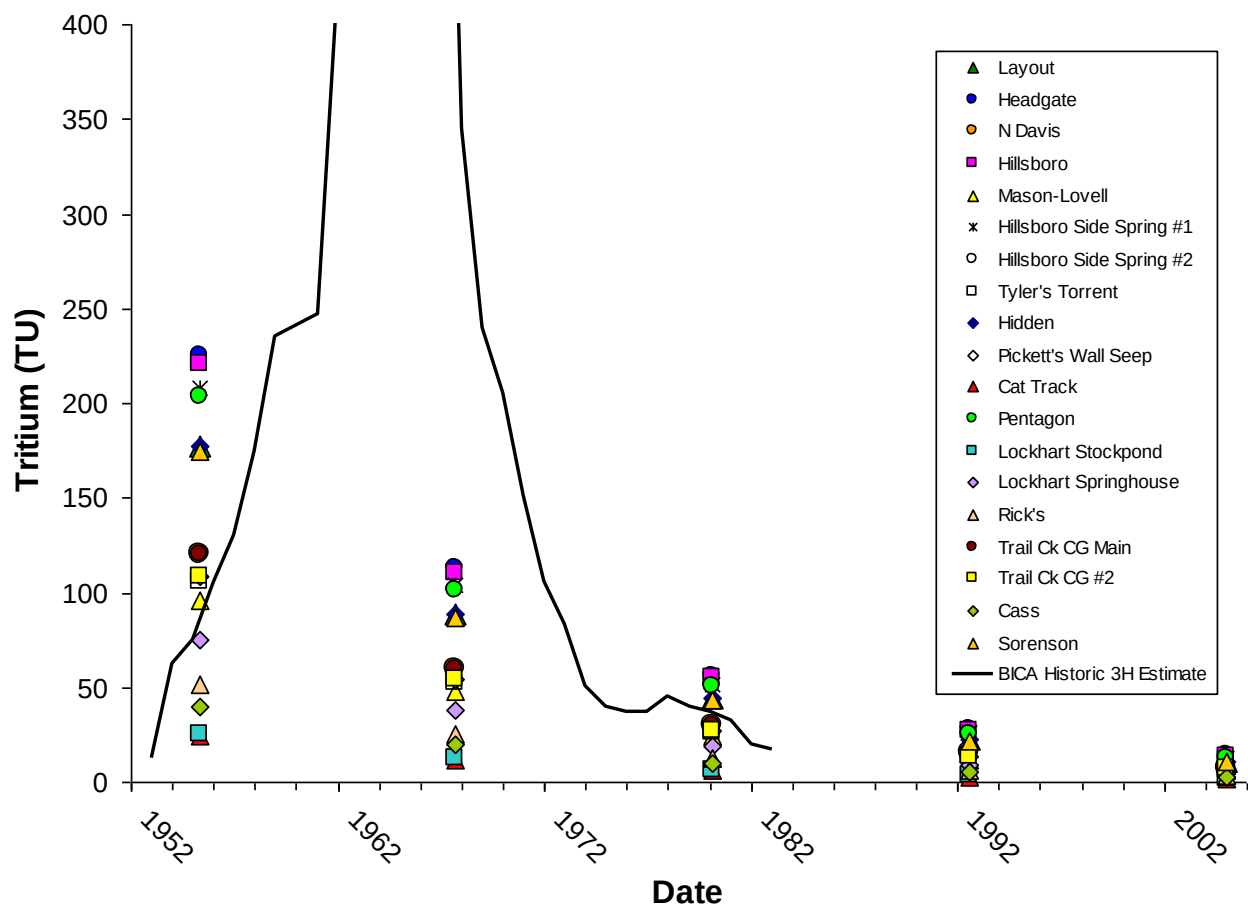


Figure 8. Tritium levels were projected back in time to determine potential date of recharge.

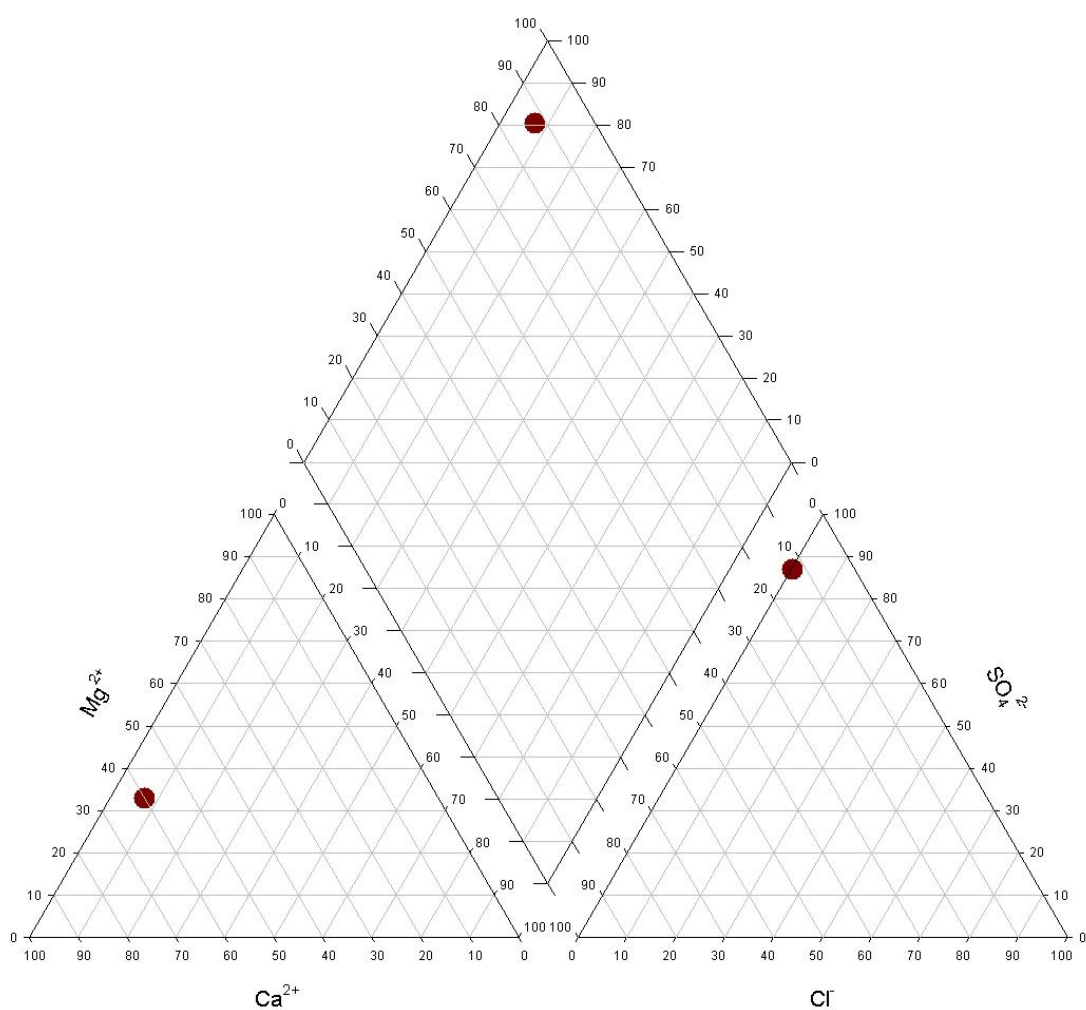
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Appendix A

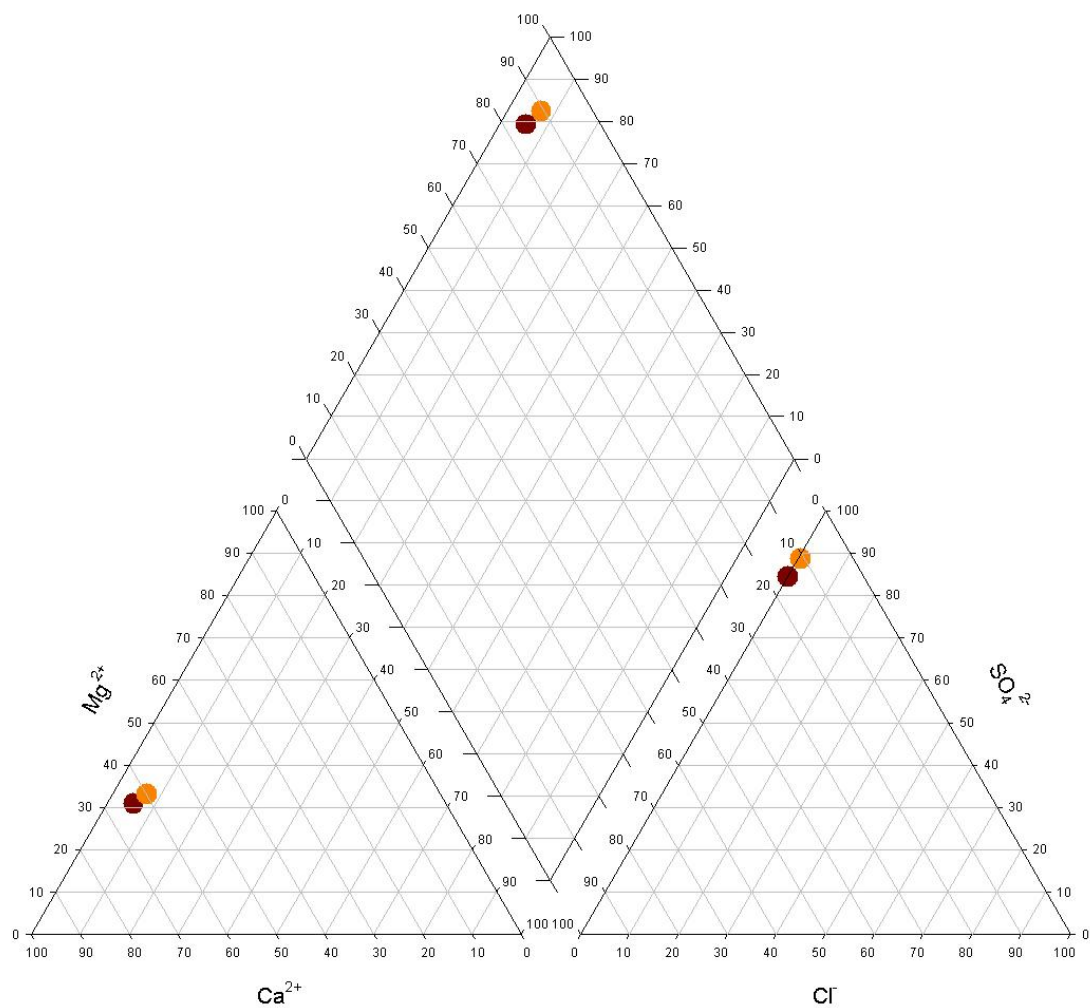
Piper Plots for All Bighorn Canyon Springs

Chemical Profile Cass Spring 2006

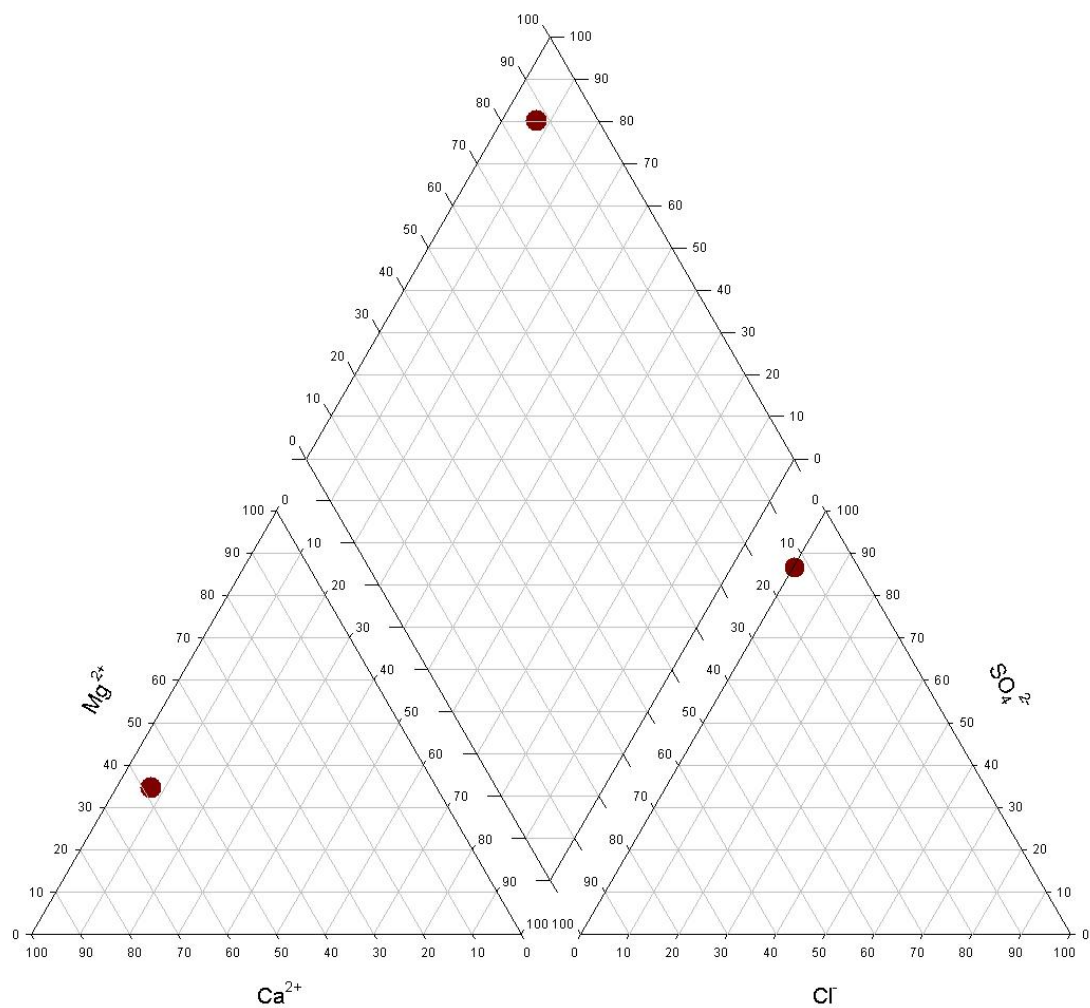


Chemical Profile

Cat Track Spring 2006



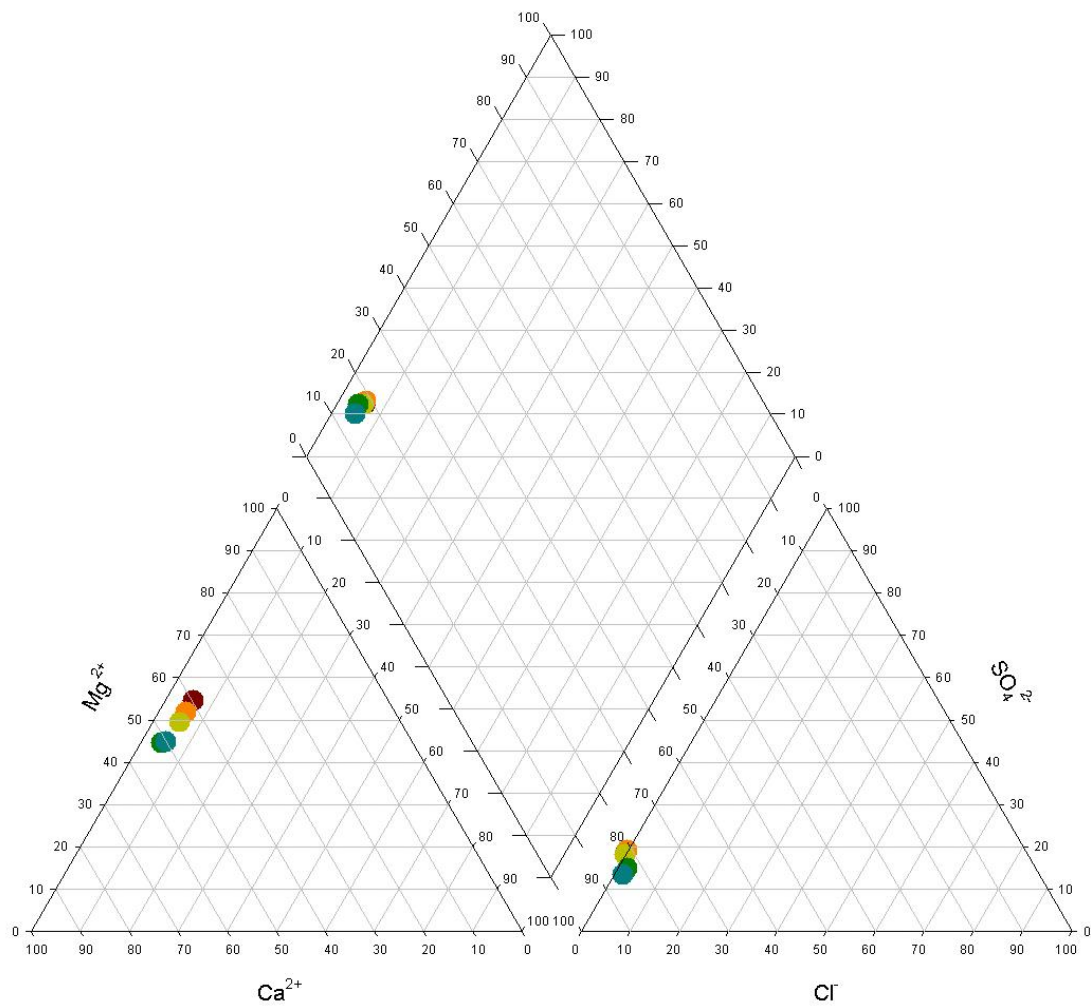
Chemical Profile Finley Spring 2007



Chemical Profile

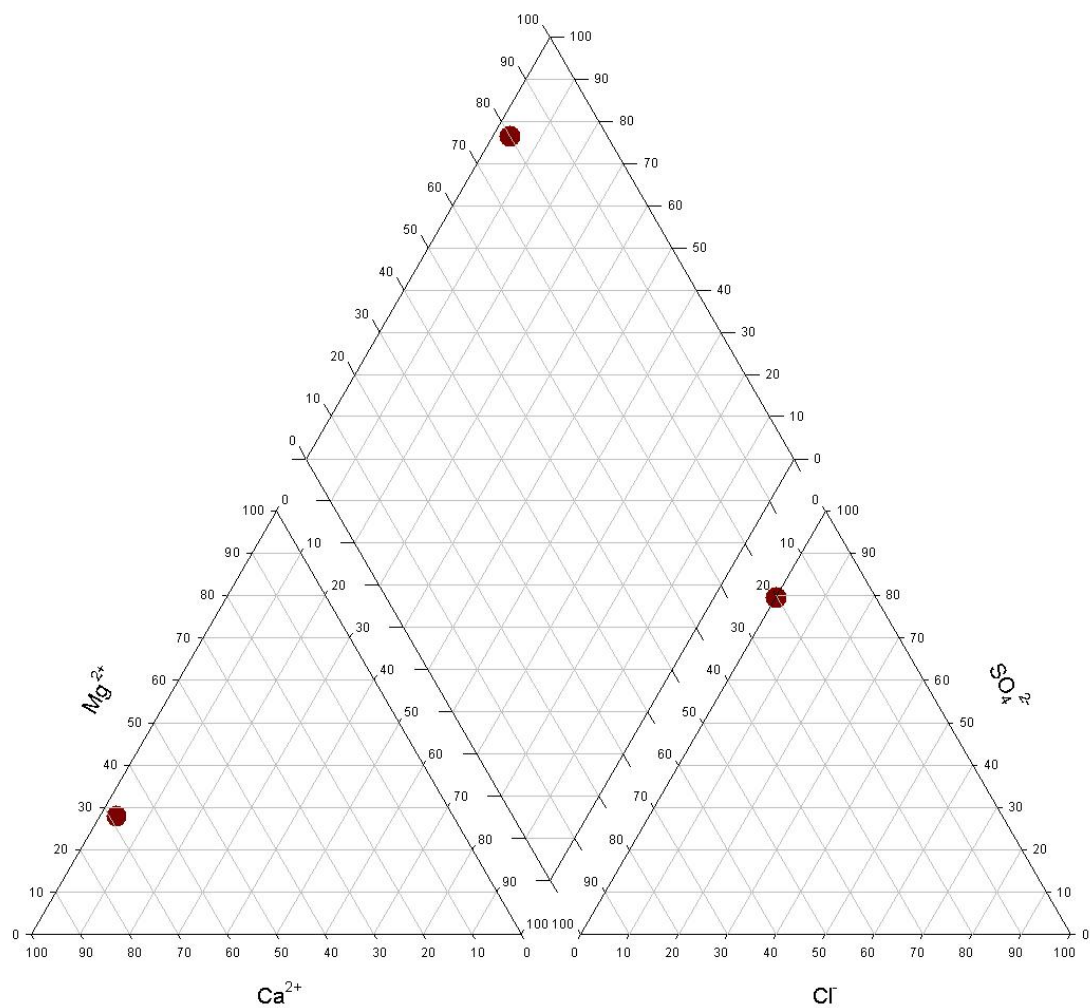
Headgate Seep

Quarterly Sampling 2004-2006



Chemical Profile

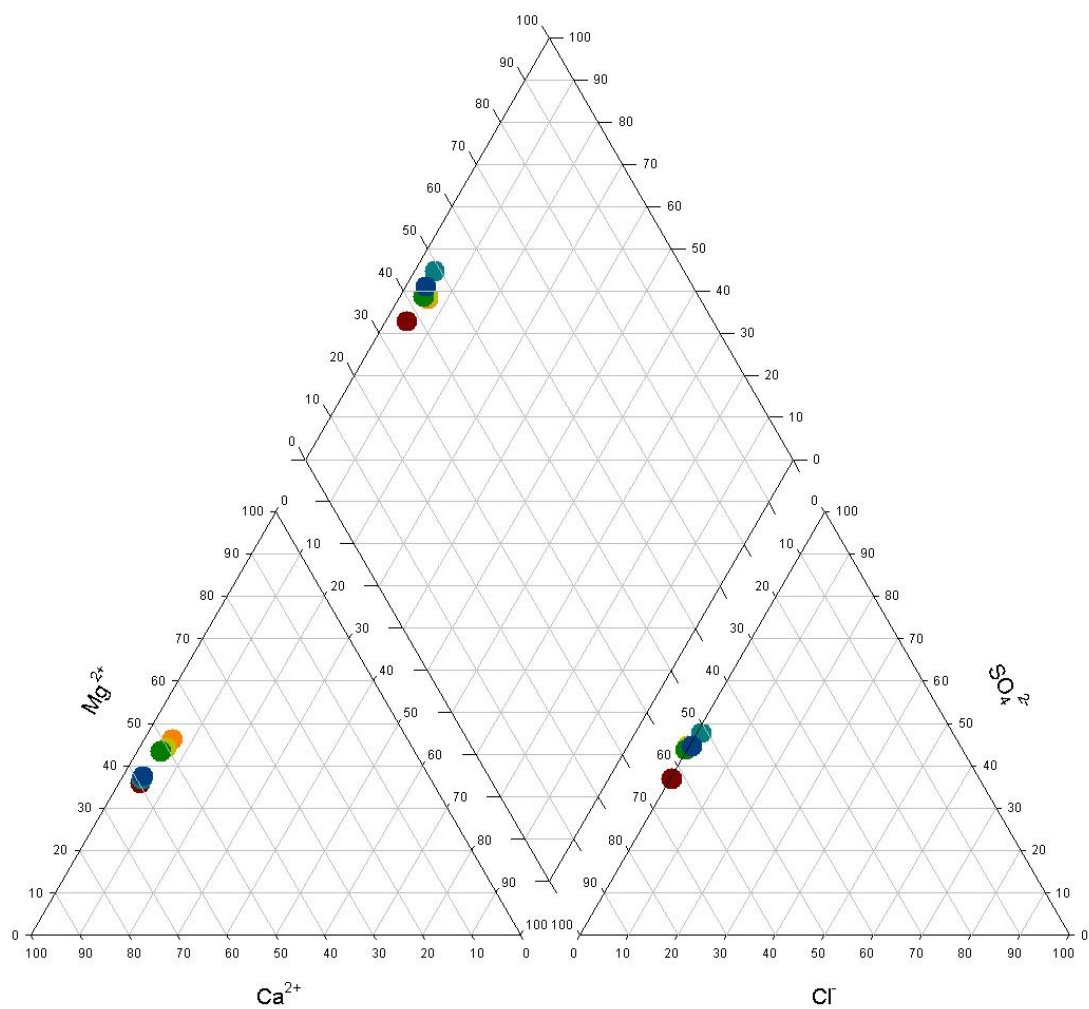
Hidden Spring 2006



Chemical Profile

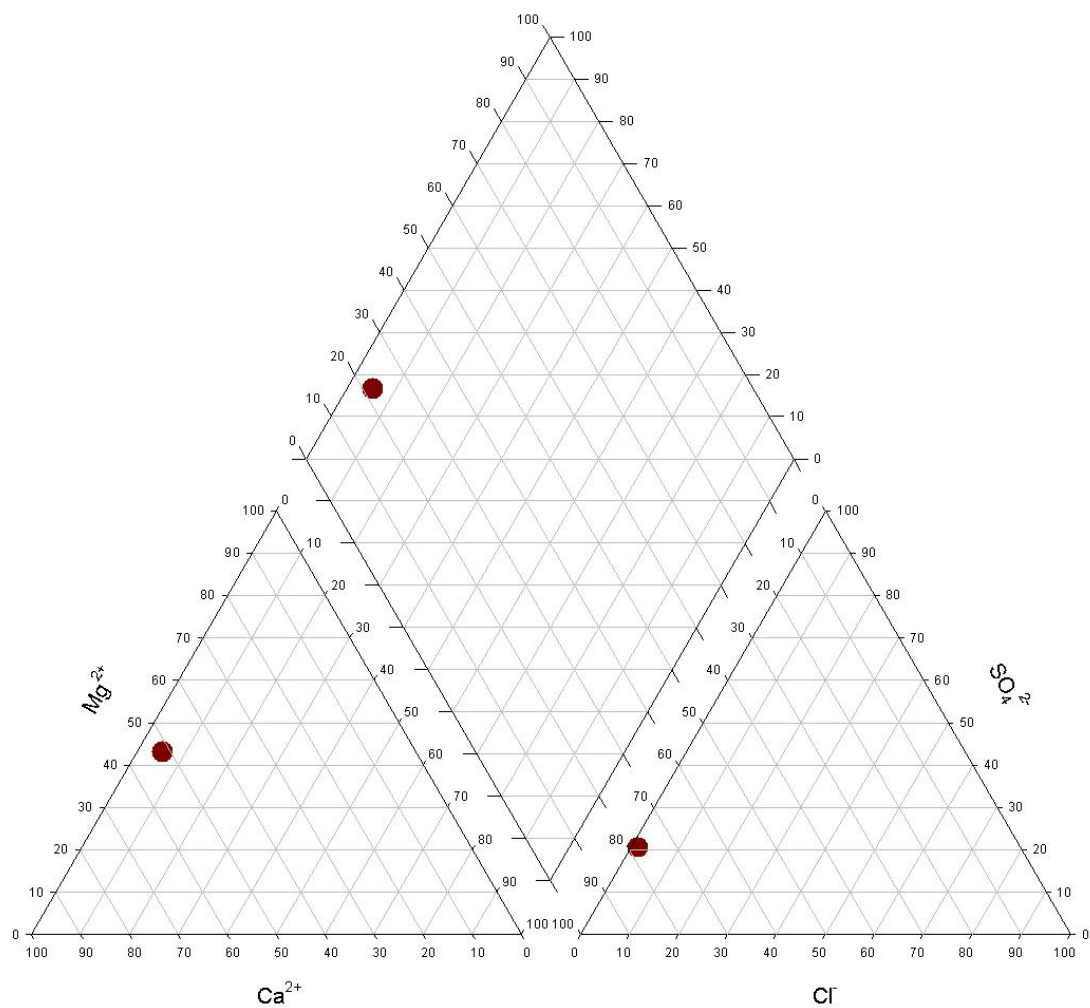
Hillsboro Main Spring

Quarterly Sampling 2004-2006



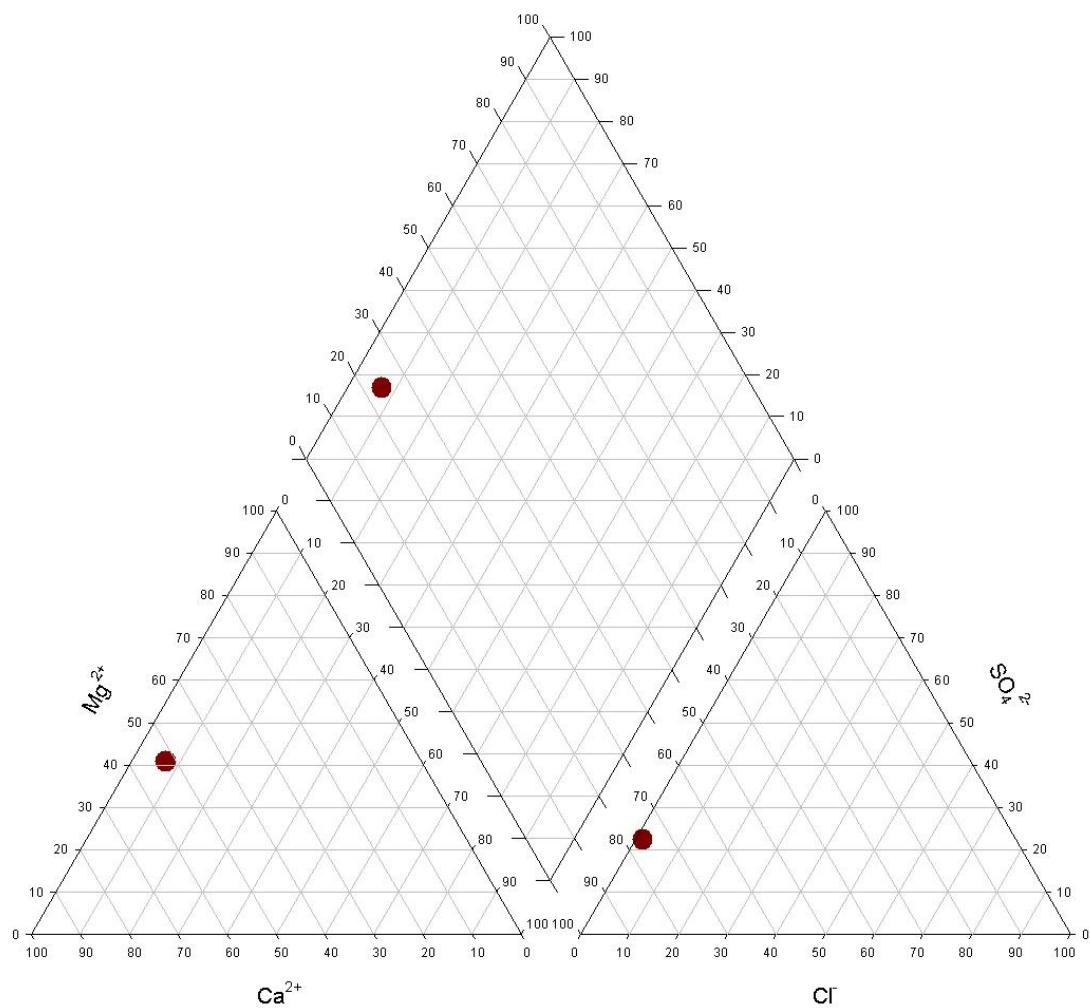
Chemical Profile

Hillsboro Side Spring #1 2006

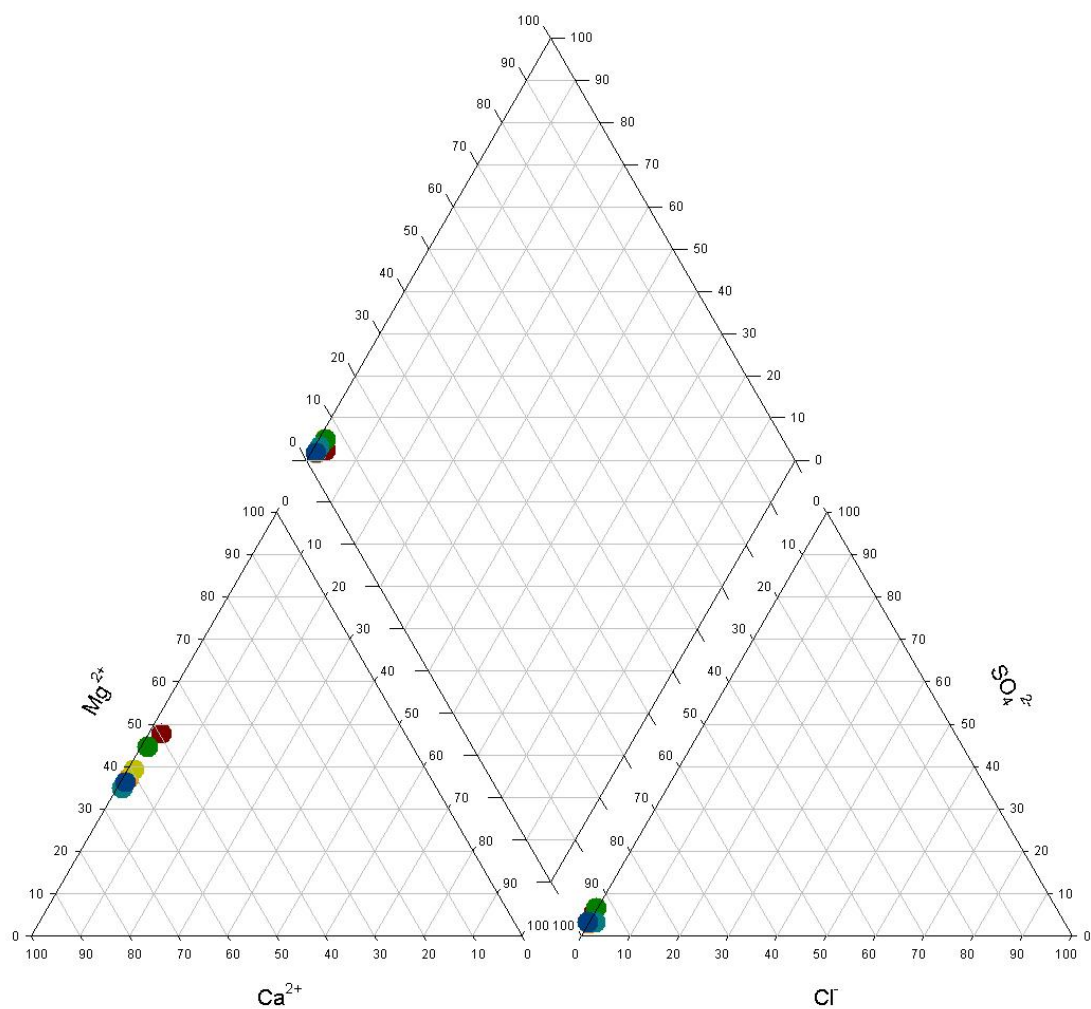


Chemical Profile

Hillsboro Side Spring #2 2006

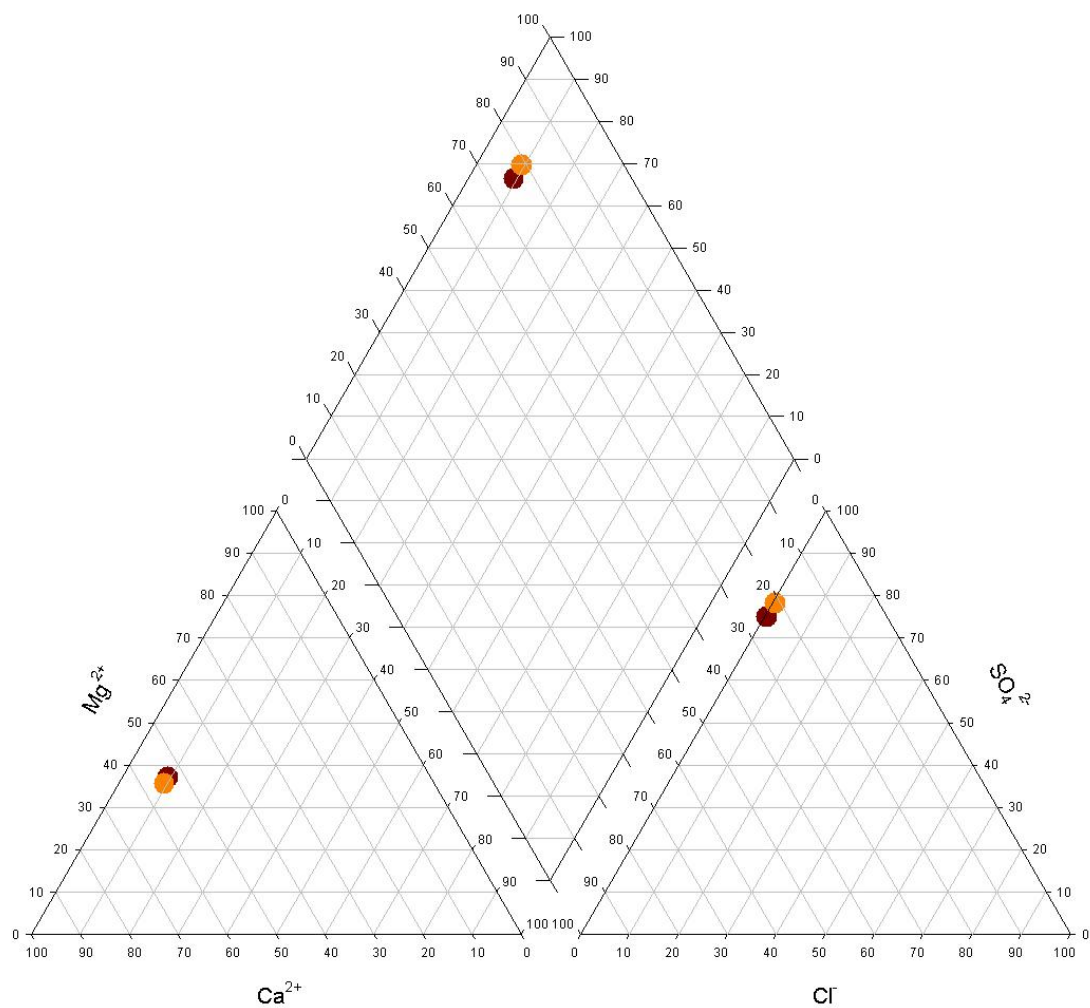


Chemical Profile Layout Spring Quarterly Sampling 2004-2006



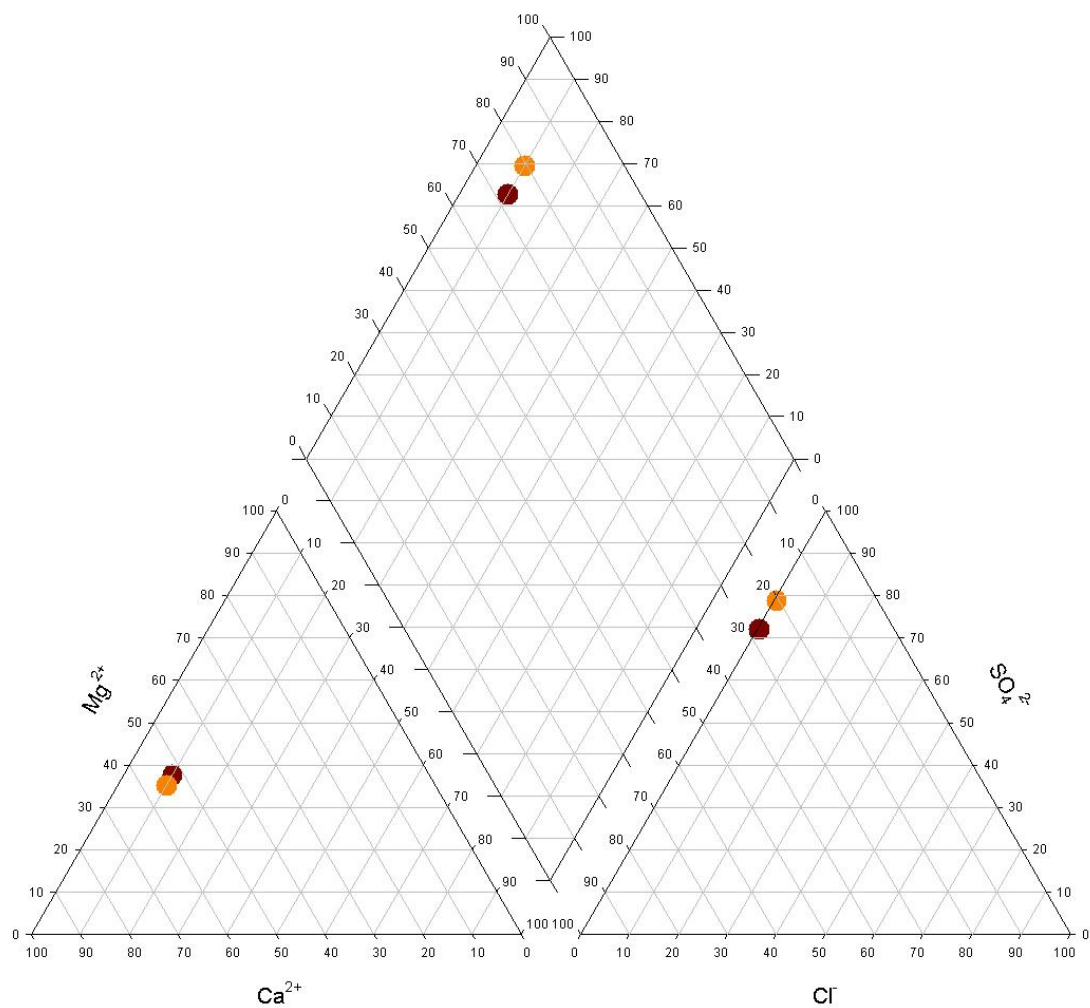
Chemical Profile

Lockhart South Spring 2006



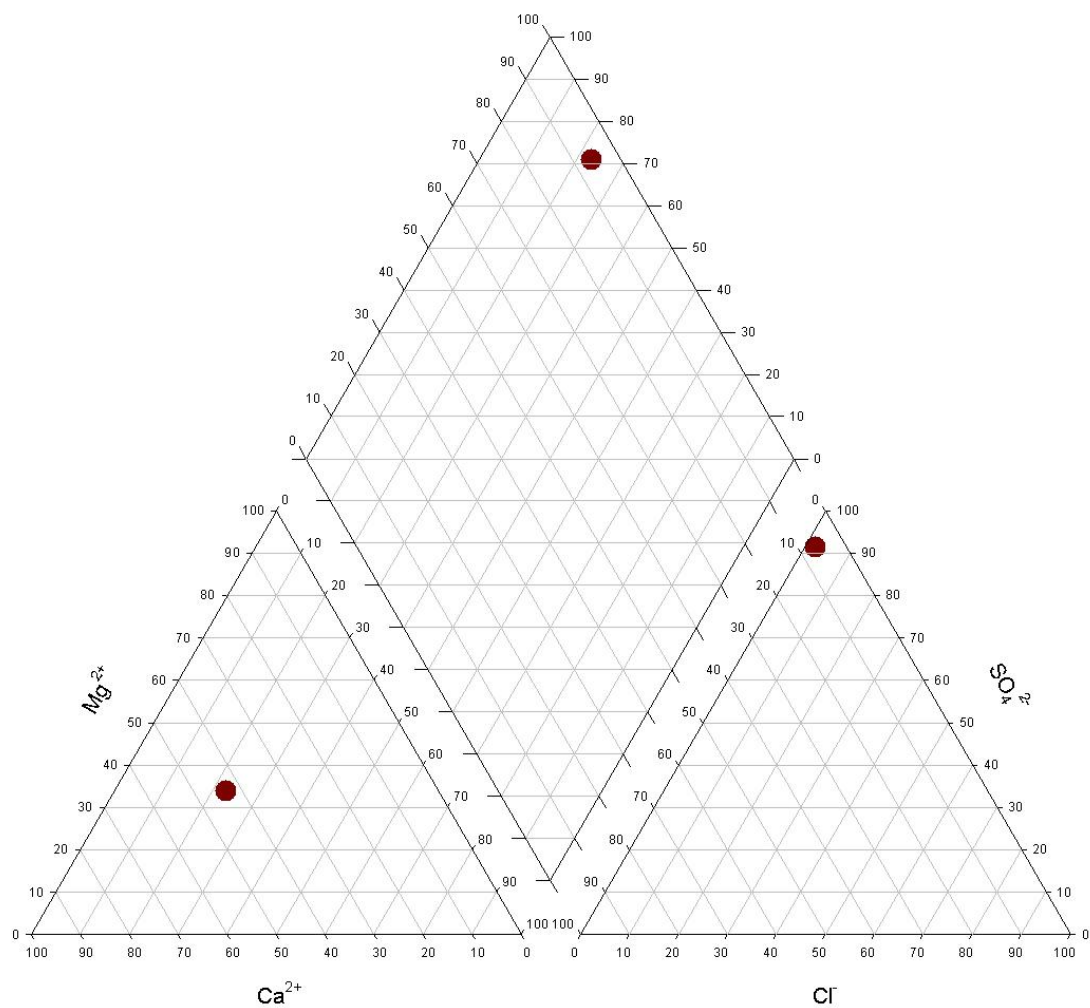
Chemical Profile

Lockhart Springhouse 2006



Chemical Profile

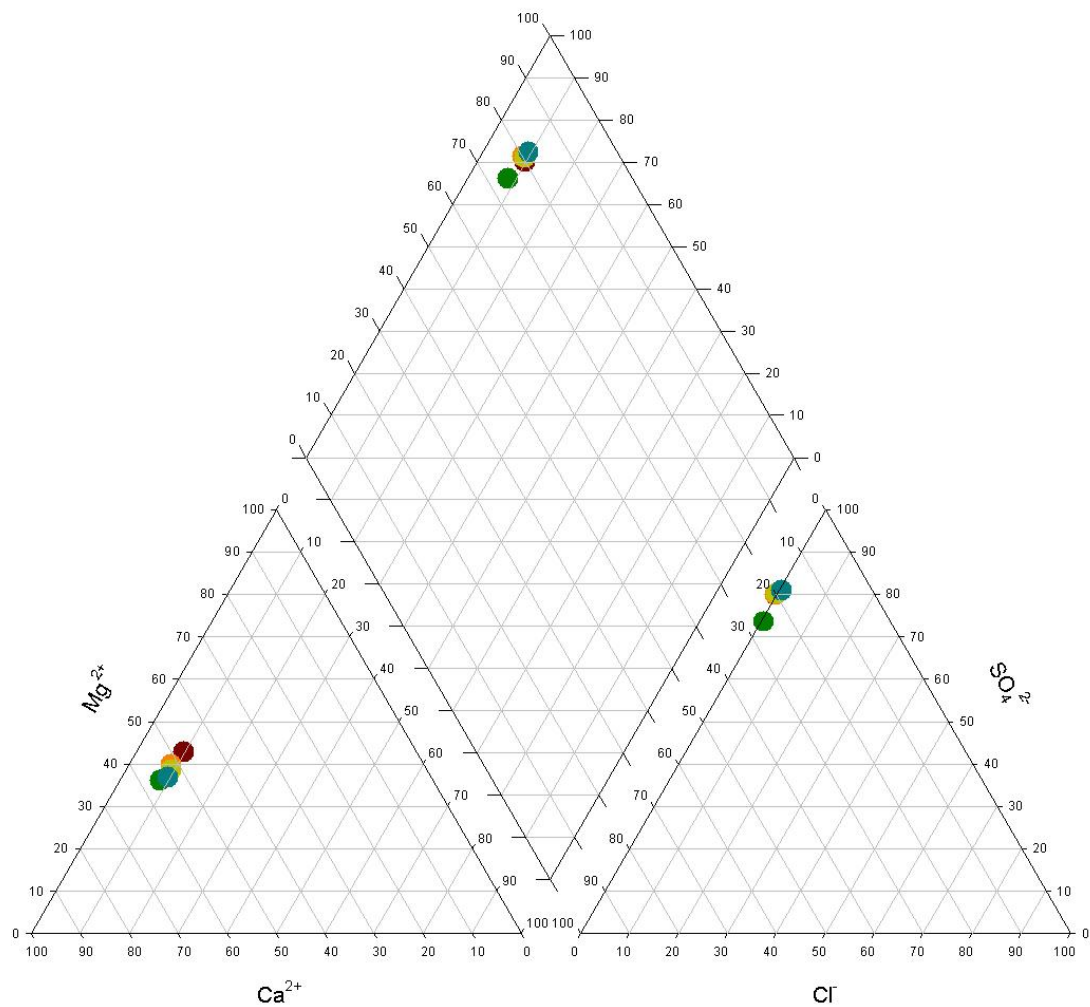
Mason-Lovell Spring 2006



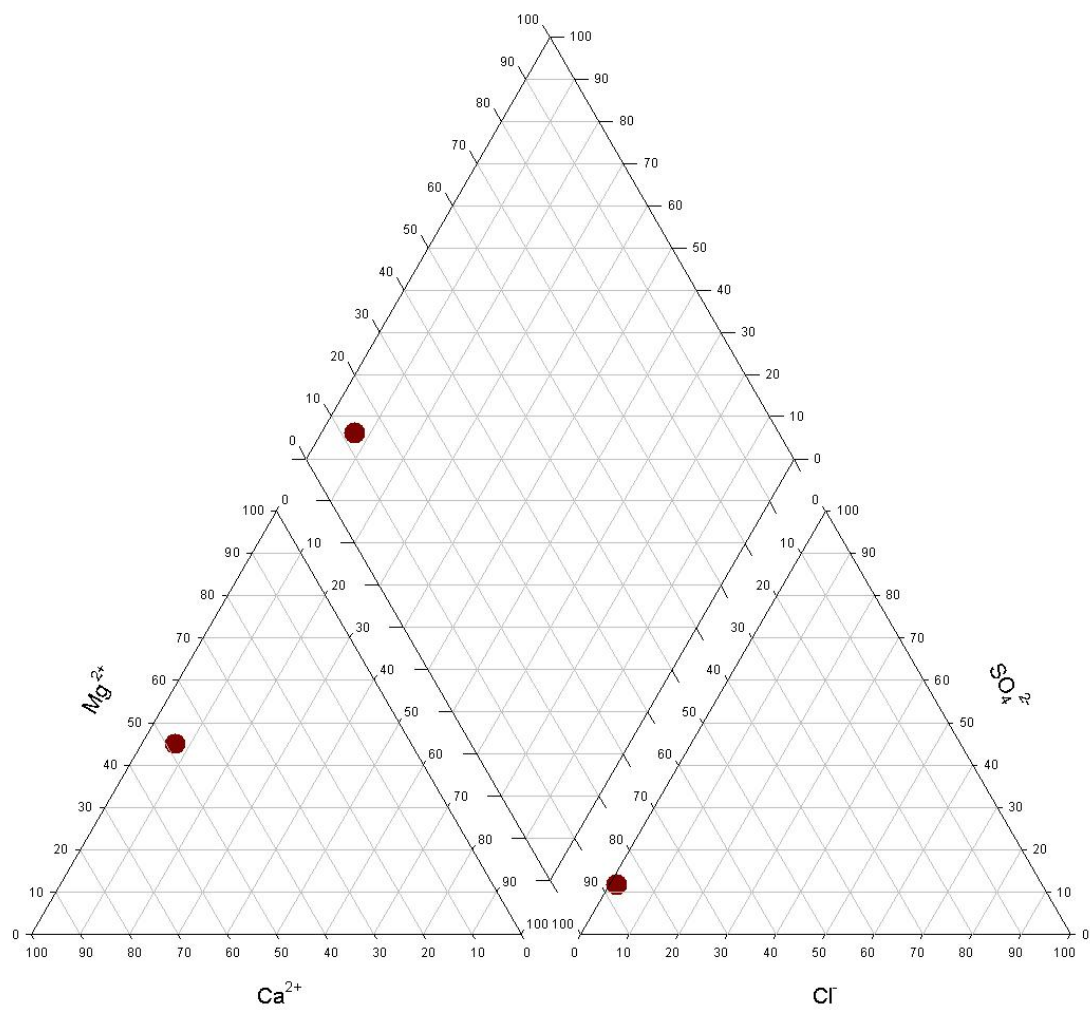
Chemical Profile

North Davis Spring

Quarterly Sampling 2004-2006

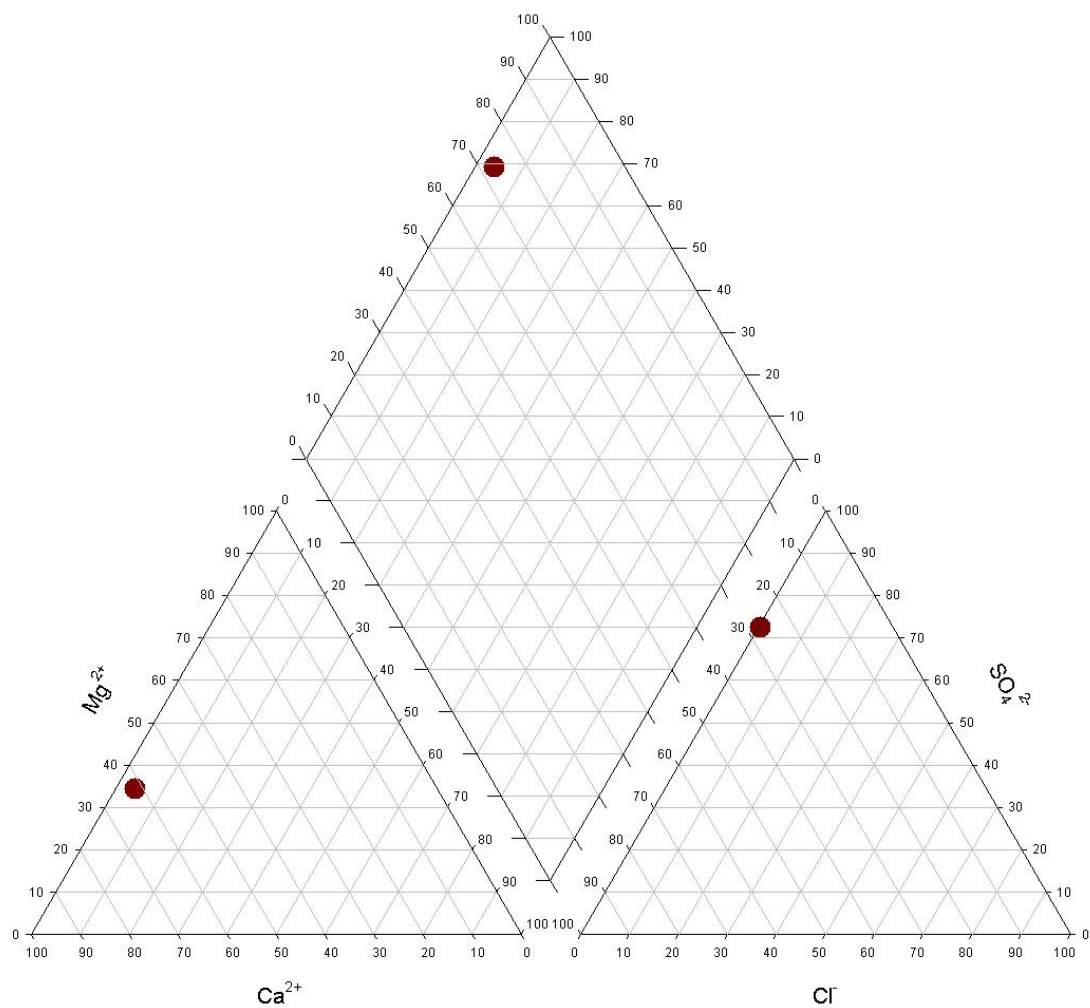


Chemical Profile Pentagon Seep 2006



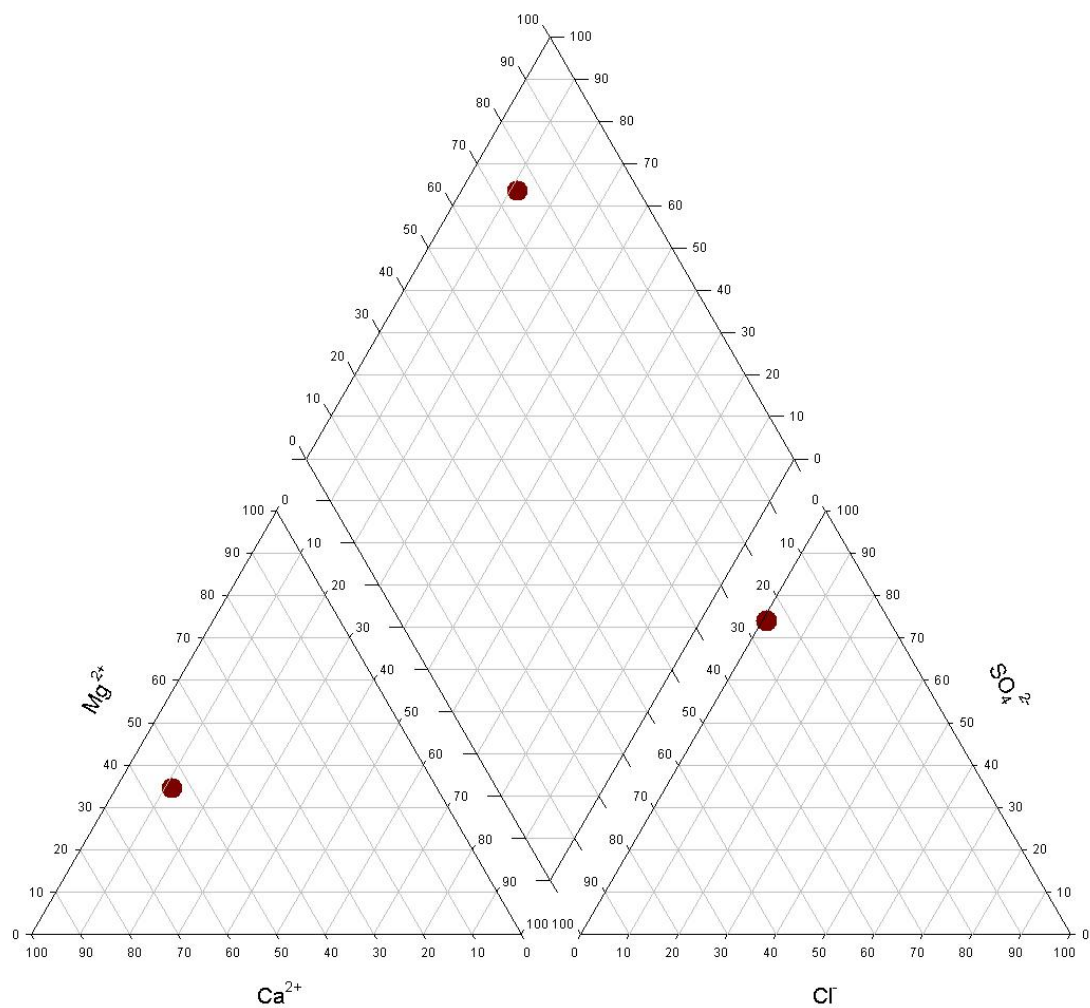
Chemical Profile

Pickett's Wall Seep 2006



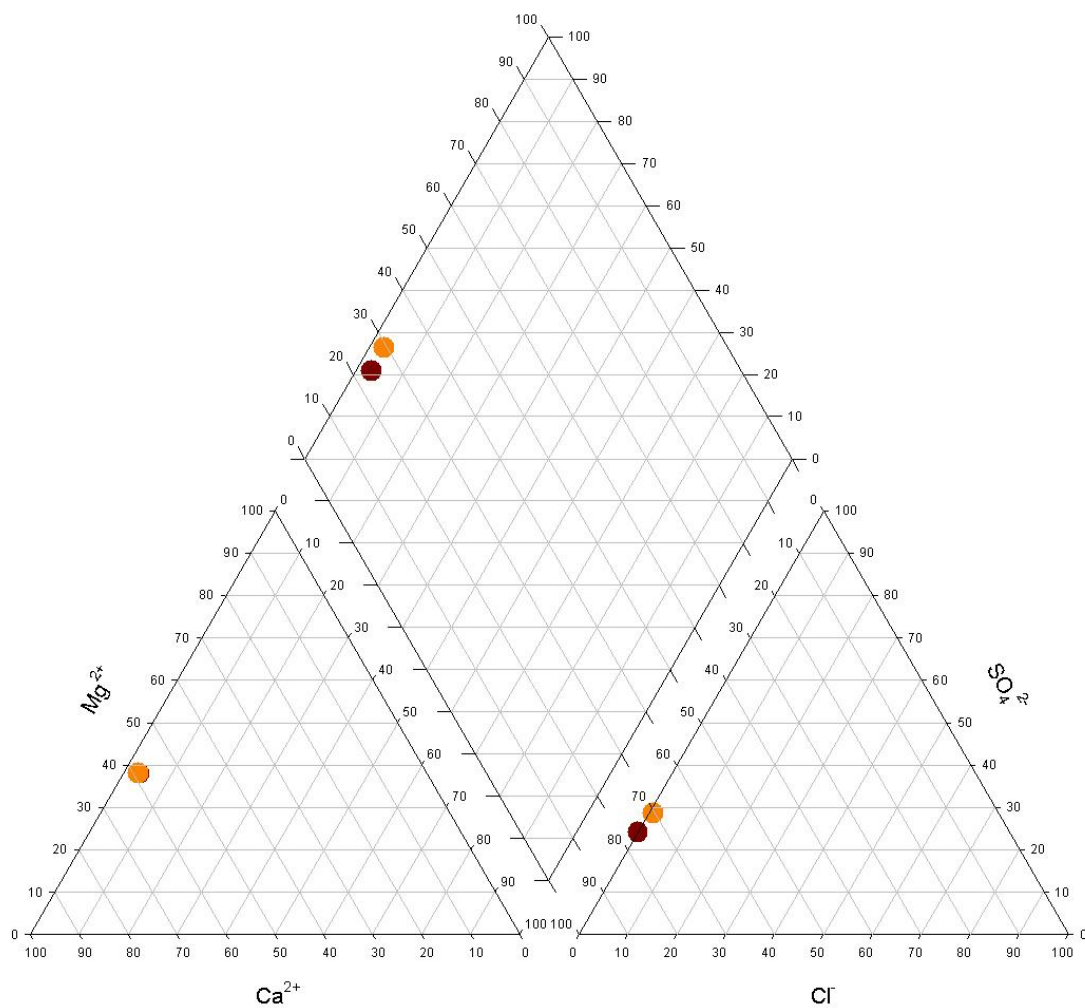
Chemical Profile

Rick's Spring 2006



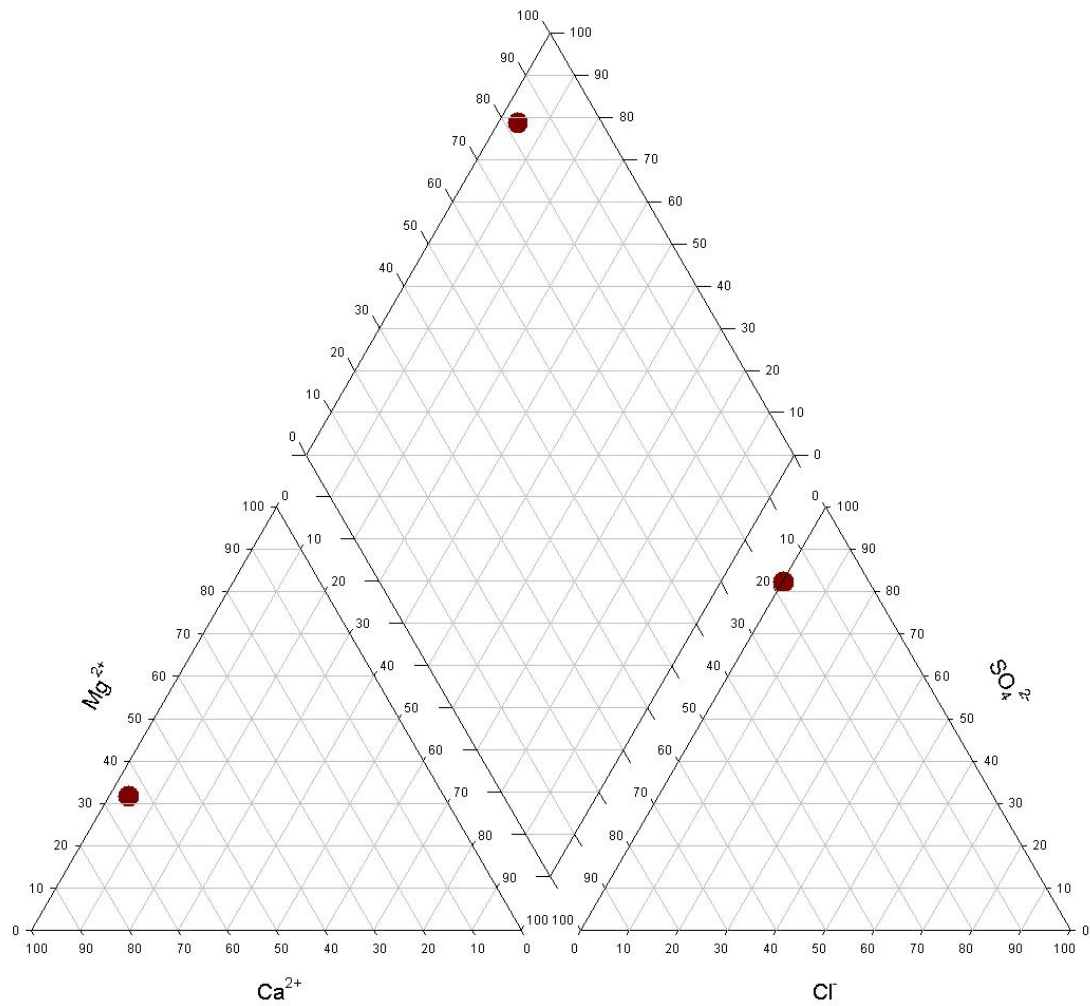
Chemical Profile

Sorenson Spring 2006



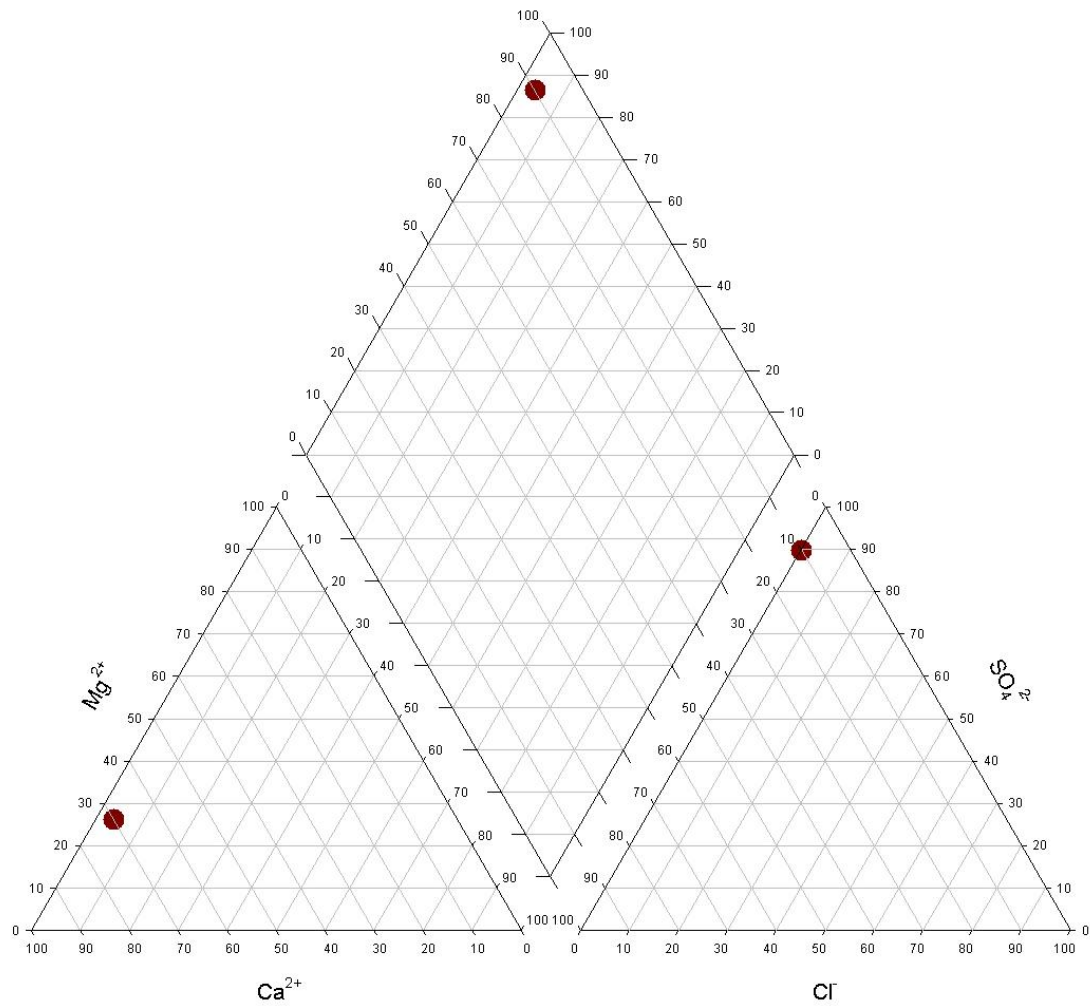
Chemical Profile

Trail Creek CG Spring #2 2006



Chemical Profile

Trail Creek CG Main Spring 2006



Chemical Profile

Tyler's Torrent 2006

