BIGHORN CANYON
NATIONAL RECREATION AREA
2009 WATER QUALITY REPORT

Adam Sigler
Montana State University
Land Resources & Environmental Sciences

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Executive Summary

This report provides a summary of water quality data and monitoring activities to assess the water quality of streams, rivers, and springs in Bighorn Canyon National Recreation Area (BICA) in 2009. *E. coli* results will be presented separately. Results were evaluated according to federal, Montana, and Wyoming water quality standards regardless of location with notes about which standards are legally applicable.

Overall, water quality data collected on the four 2009 BICA project visits is compliant with most national and state standards with the exception of the Montana draft nutrient standards. Montana standards are designed to protect designated beneficial uses and draft nutrients standards are specifically intended to protect against undesirable aspects of eutrophication (nuisance algae growth and reduced dissolved oxygen levels). Wyoming standards are directly tied to the support of cold and warm water fisheries. Nitrate nitrogen results for most of the sample events at most sample sites between 2007 and 2009 exceed the Montana draft water quality standards. Davis Creek and Layout Creek Below the Road are the only two sites where cattle or horse activity was observed in the riparian area during sampling in 2009 and these are the only two sites where nitrate exceedances were not observed. Water quality results in 2007 and 2008 for orthophosphate exceeded the Montana draft standards for total phosphorus at six sites for at least one event. No phosphorus data is available for 2009 due to loss of lab certification for phosphorus analysis. Nitrate and phosphorus detections above Montana draft standards in springs with no obvious sources of impairment suggest that geology may be partially responsible for elevated nutrients at some sample sites within BICA.

Introduction

This report provides a summary of water quality data and monitoring activities to assess the water quality of streams, rivers, and springs in Bighorn Canyon National Recreation Area (BICA) in 2009. It is intended to assist resource managers with decision making by documenting and reporting current water resources conditions in the context of water quality standards.

Objectives

To achieve these goals, this report summarizes chemical data with respect to national, Montana, and Wyoming water quality standards, documents the degree to which measurement quality objectives were met, describes notable events and observations, and makes recommendations for changes in the water quality monitoring protocol. *E. coli* data will be addressed in a separate report. Specifically, the objectives are to:

1. summarize the water quality 2009 data sets,
2. assess the nutrient status of rivers and springs according to the level III ecoregion based approach supported by the EPA
3. analyze the chemical character of stream and spring sites.

Stream and River Monitoring

Background

Federal Water Quality Criteria

The EPA aquatic life water quality standards along with Montana and Wyoming standards were used to assess the chemical condition of BICA streams and rivers. BICA does not monitor for any of the national priority pollutants. Federal criteria for non-priority pollutants are based on the 1986 Gold Book (US EPA, 1987) and Ecoregional Nutrient Criteria (US EPA, 2000; US EPA, 2001). Criteria for ammonia are based on EPA-822-R-99-014 (US EPA, 1999). Standards are presented in Table 1.

MT Classification of BICA Streams and Rivers and Water Quality Standards

Montana Surface Water Quality Standards and Procedures aim to "conserve water by protecting, maintaining, and improving the quality and potability of water for public water supplies, wildlife, fish and aquatic life, agriculture, industry, recreation, and other beneficial uses" (MT DEQ). All stations in Montana are classified as B-1. It has been suggested that many of the BICA stream sites in Montana may qualify for F-1 classification (streams with low or sporadic flow that, because of natural hydrogeomorphic and hydrologic conditions, are not able to support fish). However, no Montana streams have been given this classification by Montana DEQ. (MT DEQ, 2010b) B-1 waters are suitable for drinking (after conventional treatment); full contact; growth and propagation of salmonid fishes and associated aquatic life, waterfowl, and furbearers; agricultural and industrial water supply.

Montana water quality standards are based largely on EPA guidelines and are outlined in MT DEQ 7 (MT DEQ, 2008a) and Surface Water Quality Standards and Procedures (MT DEQ). Montana draft numeric nutrient criteria are outlined in Scientific and Technical Basis of the Numeric Nutrient Criteria for Montana's Wadeable Streams and Rivers (MT DEQ, 2008b). The current list of impaired waterbodies in Montana can be found at the MT Clean Water Act Information Center (http://cwaic.mt.gov) and in the most recent 305b report to congress (MT DEQ, 2009).

WY Classification of BICA Streams and Rivers and Water Quality Standards

The Wyoming surface water standards are based on the Wyoming Surface Water Classification List (Wyoming Department of Environmental Quality 2007). The water quality criteria for BICA streams and rivers within Wyoming closely follow the national standards. Class 2 waters in WY are designated as waters known to support fish or drinking water supplies or where those uses are attainable. The subcategory 2AB applies to waters known to support cold water game fish or spawning and nursery areas at least seasonally, their perennial tributaries and adjacent wetlands, as well as those waters where game fishery and drinking water uses are attainable. All lower quality uses apply including non-game fish, fish consumption, other aquatic life, recreation, wildlife, agriculture, industry, and scenic value.

Game fish are defined as those species present in the Wyoming Game and Fish Department's *Stream and Lakes Inventory Database* as of June 2000. These include cold and warm water game fish. Cold water game fish include burbot (*Lota*), grayling (*Thymallus*), trout, salmon and char (*Salmo, Oncorhynchus* and *Salvelinus*), and whitefish (*Prosopium*). Warm water game fish include bass (*Micropterus* and *Ambloplites*), catfish and bullheads (*Ameiurus*, *Ictalurus*, *Noturus* and *Pylodictus*), crappie (*Pomoxis*), yellow perch (*Perca*), sunfish (*Lepomis*), walleye and sauger (*Stizostedion*), pike (*Esox*), sturgeon (*Scaphirhynchus*) and freshwater drum (*Aplodinotus*). (WY DEQ, 2007).

Wyoming water quality standards are based largely on EPA guidelines and are outlined in chapter 1 of Water Quality Rules and Regulations most recently published in 2007. (WY DEQ, 2007) Wyoming's plan for developing and implementing numeric nutrient criteria are outlined in the Wyoming Nutrient Criteria Development Plan published in 2008. (WY DEQ, 2008) The current list of impaired waterbodies in Wyoming is found in the Wyoming Water Quality Assessment and Impaired Waters List published most recently in 2010. (WY DEQ, 2010).

Table 1. Water quality criteria for national, Wyoming, and Montana standards.

Regulatory Parameter	Std. Type	EPA Standard[1]	WY 2AB Standard[2]	MT Standard[3]
Temperature (°C)	Cold water fisheries	[4]	20 max Normal + 1.1	0-19.4 Normal + 0.28 Normal – 1.1
Temperature (°C)	Warm water fisheries	[4]	30 max Normal + 2.2	0-26.6 Normal + 0.28 Normal – 1.1
pH	Aquatic Life (chronic)	6.5 – 9.0	6.5 – 9.0	6.5 – 8.5 Normal ± 0.5
Dissolved Oxygen	Aquatic Life	[5]	[5]	[5]
Turbidity (NTU)	Cold water fisheries	Normal + 10%	Normal +10	Normal + 5
Turbidity (NTU)	Warm water fisheries	Normal + 10%	Normal +15	Normal + 10
Alkalinity (mg/L)	Aquatic Life (chronic)	<20		
Chloride (mg/L)	Fresh Water/Aquatic Life (chronic/acute)	230/860	230/860	
Sulfate (mg/L)	Drinking Water	250[6]		
Total Phosphorus-P (mg/L)	Aquatic Life	[7]		0.048-0.124[8]
Ammonia	Aquatic Life	[9]	[9]	[9]
Nitrate-N (mg/L)	Drinking Water	10	10	10
Nitrate-N (mg/L)	Aquatic Life & Recreation	[7]	[10]	0.076-0.100[8]

[1] (US EPA, 1987; US EPA, 1999; US EPA, 2006)
[2] (WY DEQ, 2007)
[3] (MT DEQ; MT DEQ, 2008a; MT DEQ, 2008b)
[4] (US EPA, 1973)
[5] Dissolved oxygen standards vary with fish species and life stage. (MT DEQ, 2008a; WY DEQ, 2007)
[6] There is no aquatic life standard for sulfate. The EPA has set a secondary drinking water standard of 250 for sulfate for aesthetic reasons (US EPA, 2009).
[7] The EPA provides guidelines for states and tribes to establish nutrient criteria based on ecoregion (US EPA, 2000; US EPA, 2001).
[8] Montana nutrient standards are set by level III ecoregion, the range represents the different ecoregions present within BICA (MT DEQ, 2008b).
[9] Ammonia is pH and temperature dependent and varies with fish species and life stage. (MT DEQ, 2008a; WY DEQ, 2007)
[10] Wyoming is currently in the data collection and review phase of ambient numeric nutrient standard establishment and projects nutrient standard development will occur in 2014 (WY DEQ, 2008).

Antidegradation

The antidegradation concept was developed to preserve the quality of waters that exceed standards for identified beneficial uses. The policy requires that waters that exceed standards for identified beneficial uses must be maintained at the higher quality. Continued water quality monitoring of waters entering the park will provide credible data of waters that exceed or fail to meet current classifications, if they exist. Because the park receives waters from outside the park influenced by agriculture, industry, and municipalities, the park needs to be an active participant in discussions about decisions, policy, permitting, and management of upstream water quality resources. By doing so, the park can ensure that quality does not fall below existing conditions, and that existing water uses are fully maintained and protected.

Methods

Study Area

BICA is located within the Big Horn River Basin which is a tributary to the Yellowstone River in the Upper Missouri Watershed. The basin is defined by the Absaroka Mountains to the west, and the Bighorn Mountains to the east. (USGS, 1999) Mountain streams in the basin can carry high sediment loads due to erodible geology but human activities such as grazing also increase sediment loads in the Big Horn River. Precipitation in lower elevation areas often comes in the form of thunderstorms that cause severe erosion of sparsely-vegetated soils. (WY DEQ, 2010)

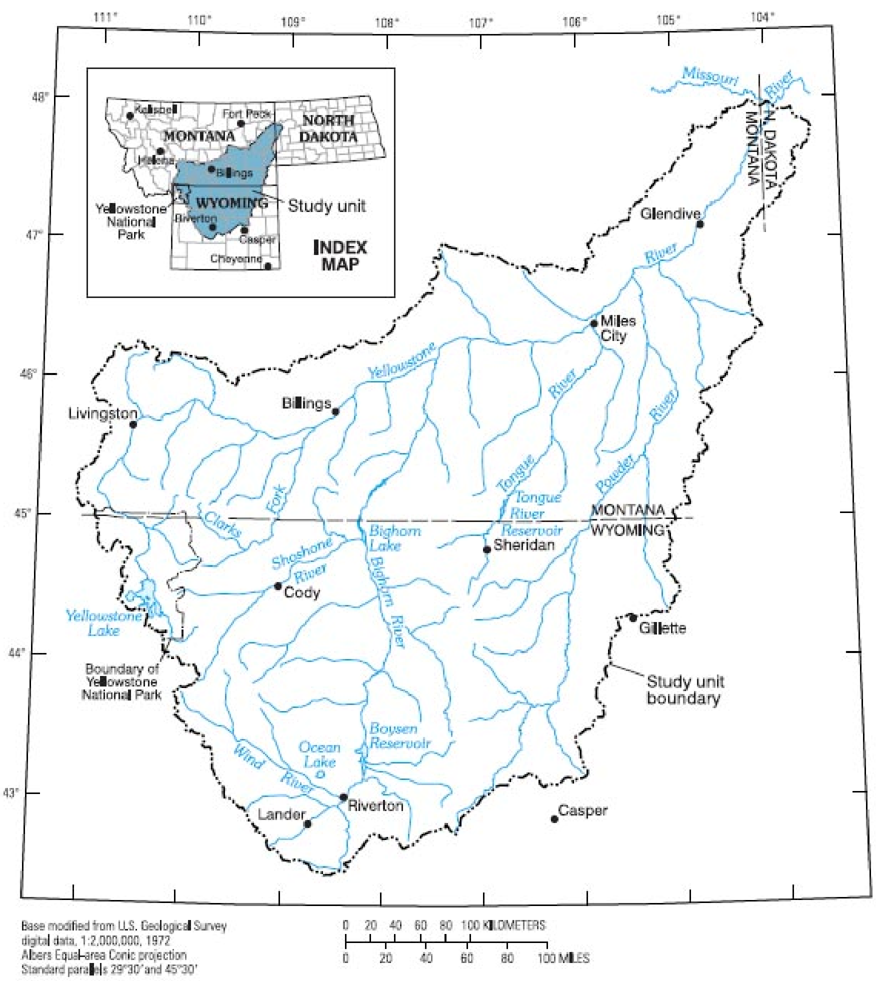


Figure 1: USGS map of Yellowstone Basin (from Environmental setting of the Yellowstone River Basin, Montana, North Dakota, and Wyoming)

Sample Sites

Fixed stations along streams and rivers were chosen based on several factors. The Bighorn River at St. Xavier and the Shoshone River near Lovell were chosen because they are on the Montana and Wyoming 303d lists. The Big Horn at St. Xavier is listed for nitrogen and the Shoshone River near Lovell is listed for Fecal Coliform. Crooked Creek is listed by Wyoming DEQ as impaired due to flow alterations below a diversion dam at SWNW Section 29, T58N, R95W but a TMDL is not required and it is not included on the 303d list (WY DEQ, 2010). The text and the tables in the Wyoming 2010 305b report are contradictory as to which section of Crooked Creek is impaired so clarification from the author of the report was sought to determine that the preceding statement is true (Thorp, 2010). Bighorn River at Kane, Shoshone River near Lovell, and Crooked Creek were chosen to determine the water quality entering the park. North Trail Creek was chosen to capture the effects of the campground. Davis Creek was chosen to document the influence of grazing. Layout Spring was chosen to monitor a stream with few anthropogenic impacts. Layout Creek below the road was chosen to identify effects of cattle trailing, wild horse use, and the park road on water quality.

Table 2. Stream and river site names, IDs, basins, classifications, and 303d listing parameters for regulatory and non-regulatory sites.

Regulatory Stations				
Station Name	Station ID	Basin	Classification	303d listed for
Bighorn River at St. Xavier, MT	BICA_BHR1	Lower Big Horn	B-1 (MT)	Nitrogen
Shoshone River near Lovell, WY	BICA_SHR2	Shoshone	2AB (WY)	Fecal Bacteria
Non-regulatory Stations				
Station Name	Station ID	Basin	Classification	303d listed for
Bighorn River at Kane, WY	BICA_BHR2	Big Horn Lake	2AB (WY)	-
Crooked Creek, WY	BICA_CCR1	Big Horn Lake	2AB (WY)	-*
Layout Spring, MT	BICA_LAYOUTSPR1	Big Horn Lake	B-1 (MT)	-
Layout Creek Below Road, MT	BICA_LCR2	Big Horn Lake	B-1 (MT)	-
North Trail Creek, MT	BICA_TRC1	Big Horn Lake	B-1 (MT)	-
Davis Creek, MT	BICA_DACR1	Big Horn Lake	B-1 (MT)	-

*The lower portion of Crooked Creek is listed as impaired for flow alterations but no TMDL is required and it is not included on the 303d list.

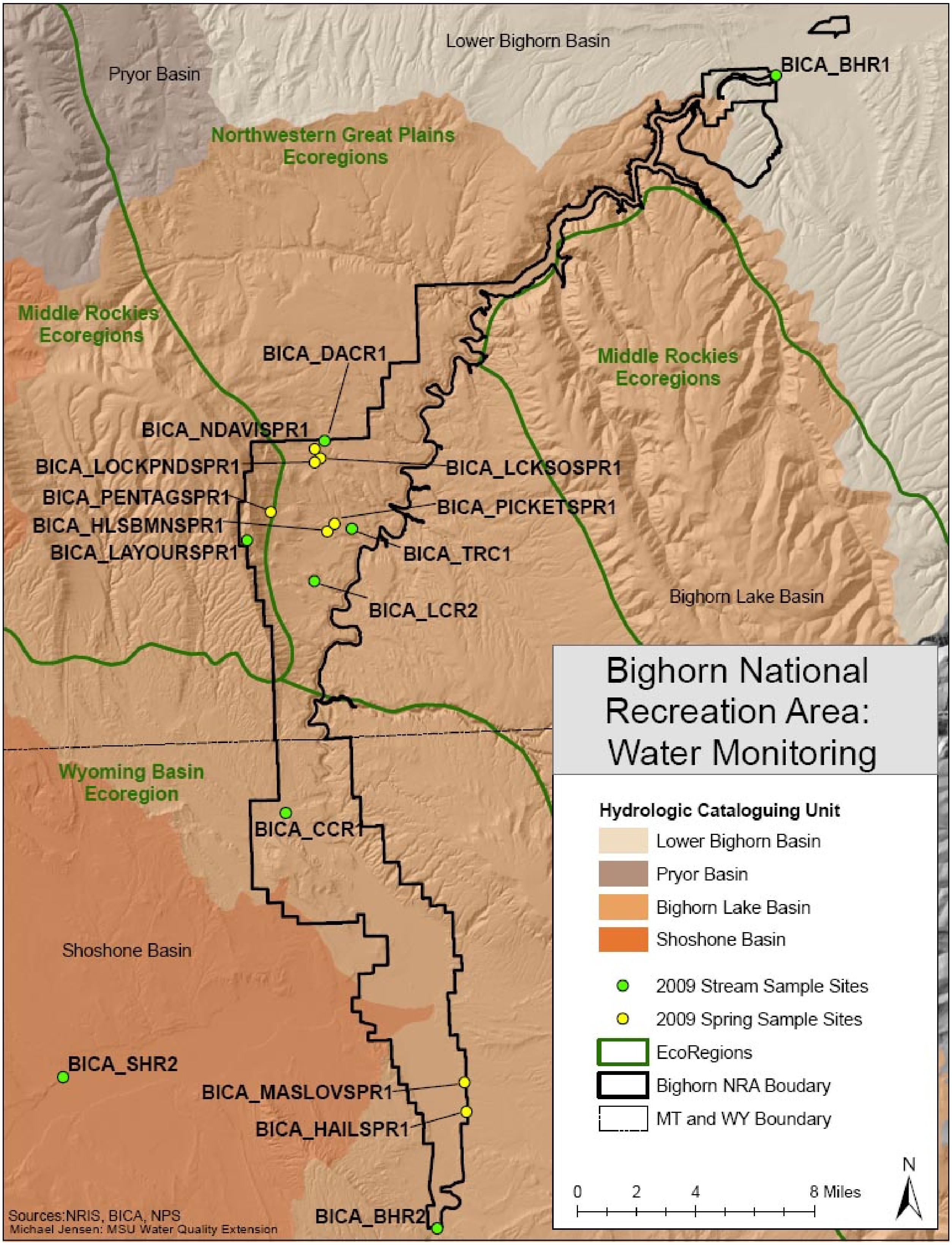


Figure 2. Map of BICA 2009 sample sites including basins and level III ecoregions.

Field & Analytical Methods

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

Environmental Testing and Consulting, Inc. (ETC) of Memphis Tennessee was contracted to conduct the laboratory analysis. Samples were preserved, chilled, and shipped overnight to ETC in sufficient time to allow for all analysis before the specified sample hold times. Table 4 outlines the analytes, the corresponding analytical method employed by ETC, and the reporting limits (MQL).

Table 3. Analytical methods used and corresponding method quantification limit (MQL).

Analyte	Method	MQL (mg/L)
Ammonia	4500NH3D	0.100
Chloride	300.0	1.00
Nitrate Nitrogen	300.0	0.100
Phosphorus, Orthophosphate (As P)	300.0	0.200
Sulfate	300.0	10.0
Total Alkalinity	2320 B	
Bicarbonate Alkalinity	2320 B	
Carbonate Alkalinity	2320 B	0.0
Calcium	200.7	0.100
Potassium	200.7	0.100
Magnesium	200.7	0.100
Sodium	200.7	0.500

Measurement Quality Objectives

All results collected at these stations during 2009 have been validated. Results indicate that precision criteria were exceeded on numerous occasions by the multi-probe (Hydrolab), especially related to in-field DO and pH measurements. The meter seems to be functioning much better after it was sent in for maintenance following the September sampling trip. Results also indicated the presence of ions (calcium, sodium and bicarbonate) in deionized water used for blank samples. The patterns of detection align with two different sources of water used, indicating that the ions were likely in the water used for the blanks rather than ions entering the samples during the sampling process in the field. The project leader will use higher quality deionized water in the future and will submit samples of the water directly from the deionizer for baseline blank data.
ETC laboratory lost accreditation for orthophosphate in 2009 so no orthophosphate data is reported. Laboratory quality control procedures and methods were consistently completed for all 2009 samples. All method blanks and laboratory control spikes returned results within QC limits. Sample matrix spikes were flagged on two occasions for calcium, sodium, and magnesium (for high recovery on one occasion and low recovery on the other) but dilution tests subsequently verified analyses were within QC limits. One sample matrix spike duplicate for sulfate did not generate reportable data due to the level of sulfate in the sample relative to the spike amount. Sodium was flagged for high recovery on two occasions however RPD was below 10% on one occasion and dilution tests verified analysis within QC limits on the other occasion.

Results for Streams and Rivers by Basin

Big Horn Lake Basin

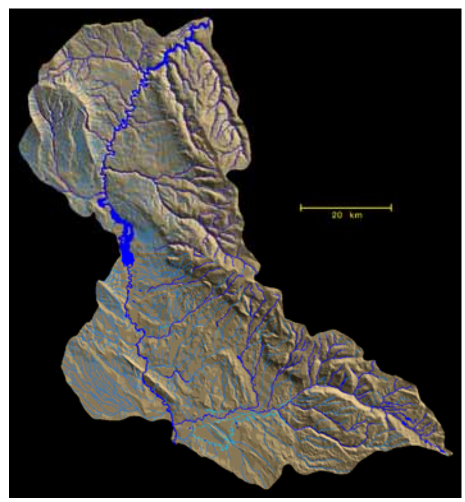


Figure 3. Big Horn Lake Basin

The Big Horn Lake Basin includes six of the eight stream/river sites in the project. See figure 2 for sample site locations. Water quality results were within standards for all parameters analyzed with the exception of temperature and nitrate nitrogen. Crooked Creek is classified as a 2AB cold water stream by Wyoming DEQ and exceeded the maximum temperature threshold for one sample event in 2009. Layout Spring and North Trail Creek are located in Montana within the Middle Rockies and the Northwestern Great Plains Ecoregions respectively. Montana has set draft water quality standards for nitrate nitrogen for these ecoregions as outlined in Table 4. Table 4 lists the number of exceedances of water quality standards for data collected between 2007 and 2009. The Montana nutrient standards are not applicable in Wyoming or on streams that are not considered wadeable, but the number of exceedances of the new standards are included for all sites for reference. Woods and Corbin (2003) reported a mean “dissolved nitrate” as N value of 0.10 mg/L and a max value of 0.57 mg/L for 85 samples collected between 1971 and 1979 at the Big Horn at Kane site and reported no significant trend in nitrate concentrations over this period. The mean nitrate plus nitrite as N concentration for The Big Horn River at Kane in 2009 was 0.23 mg/L and the maximum value was 0.29 mg/L.

Table 4. Stations within the Big Horn Lake Basin, parameters, standards and frequency of standard exceedance, and range of recorded values for BICA stream/river sites between 2007 and 2009.

Site	Parameter	Year	Standard	Units	Exceedance/ # of visits	Range of values
Bighorn River at Kane	Nitrate plus nitrite as N	2007	0.076[1&2]	mg/L	4/4	0.233-0.478
		2008			3/3	0.285 – 0.482
		2009			4/4	0.19-0.29
Crooked Creek	Nitrate plus nitrite as N	2007	0.076[1]	mg/L	3/4	<0.002-0.832
		2008			2/3	<0.002-0.353
		2009			2/4	<0.002-0.384
	Temperature	2009	20	degrees C	1/4	2.91 – 20.74
Layout Spring	Nitrate plus nitrite as N	2007	0.1[3]	mg/L	4/4	0.139-0.238
		2008			3/3	0.230-0.368
		2009			4/4	0.125-0.238
Layout Creek Below Road	Nitrate plus nitrite as N	2008	0.076[3]	mg/L	1/3	<0.002-0.169
North Trail Creek	Nitrate plus nitrite as N	2007	0.076[3]	mg/L	3/4	<0.002-0.160
		2008			3/3	0.119-0.265
		2009			3/4	<0.002-0.160
Davis Creek	Nitrate plus nitrite as N	2008	0.076[3]	mg/L	1/3	<0.002-0.175

[1] This is a Montana draft nitrate standard for wadeable streams. This station is in Wyoming so the standard will not be applicable.

[2] This site would not be considered wadeable so the standard will not be applicable.

[3] This is a Montana draft nitrate standard for wadeable streams. The standard has not been adopted by the Montana Board of Environmental Review and has not been written into law.

Lower Big Horn Basin

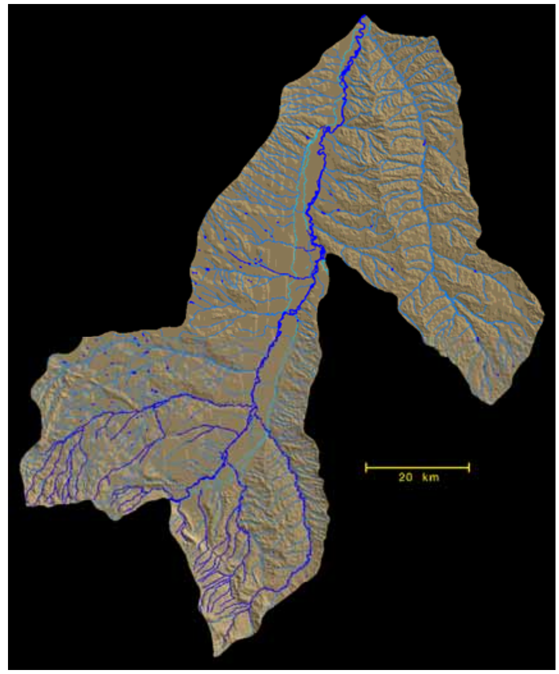


Figure 4. Lower Big Horn Basin

The Big Horn River at St. Xavier is the single sample site in the BICA project located within the Lower Big Horn Basin. See figure 2 for sample site locations. The site is just downstream from Yellowtail dam at the head of a popular trout fishing section of the Big Horn River. Water quality results were within standards for all parameters analyzed for this site. This sample site is located within the Northwestern Great Plains Ecoregion which has a Montana draft nutrient standard for nitrate nitrogen set at 0.076 mg/L. This section of the river is not considered wadeable, so the new Montana standards will not apply, but exceedances of the draft standards for the 2007-2009 data are included for reference. Woods and Corbin (2003) reported a mean "dissolved nitrate" as N value of 0.21 mg/L and a max value of 0.66 mg/L for 72 samples collected between 1966 and 1970 at the Big Horn at St. Xavier site and reported no significant trend in nitrate concentrations over this period. The mean nitrate plus nitrite as N concentration for the Big Horn River at St. Xavier in 2009 was 0.402 mg/L and the maximum value was 0.480 mg/L.

Table 5. Stations within the Lower Big Horn Basin, parameters, standards and frequency of standard exceedance, and range of recorded values for BICA stream/river sites between 2007 and 2009.

Site	Parameter	Year	Standard	Units	Exceedance/ # of visits	Range of values
Big Horn River near St. Xavier	Nitrate plus nitrite as N	2007	0.076[1]	mg/L	4/4	0.414-0.719
		2008			3/3	0.446-0.614
		2009			4/4	0.294-0.480

[1] This is a Montana draft nitrate standard for wadeable streams. This station is in Wyoming so the standard will not be applicable.

Shoshone River Basin

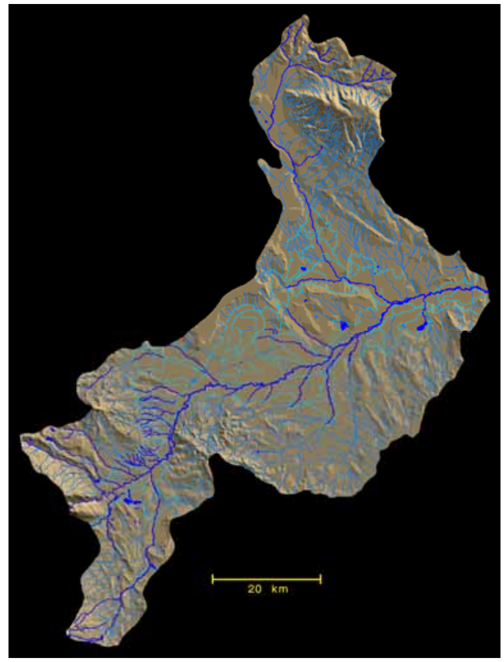


Figure 5. Shoshone Basin

The Shoshone near Lovell is the single sample site in the BICA project located within the Shoshone River Basin. See figure 2 for sample site locations. The site is just west of Lovell and was selected to represent the quality of the Shoshone River entering BICA. Water quality results were within existing Wyoming standards for all chemical parameters analyzed during 2009. This sample site is located within the Wyoming Basin Ecoregion. The Montana draft standards have assigned a nitrate nitrogen value of 0.076 mg/L for this ecoregion. This section of the Shoshone is in Wyoming so Montana standards do not apply, but exceedances of the draft Montana standards for the 2007-2009 data are included for reference. Woods and Corbin (2003) reported a mean “dissolved nitrate” as N value of 0.7 mg/L and a max value of 1.5 mg/L for 148 samples collected between 1959 and 1968 on the Shoshone River at Kane and reported a significant decrease in “dissolved nitrate” concentrations over this period but no significant trend in “total nitrate” over the same period. The mean nitrate plus nitrite as N concentration for the Shoshone River near Lovell (more than 5 miles downstream from the Kane site) in 2009 was 0.82 mg/L and the maximum value was 1.0 mg/L.

Table 6. Stations within the Shoshone Basin, parameters, standards and frequency of standard exceedance, and range of recorded values for BICA stream/river sites between 2007 and 2009.

Site	Parameter	Year	Standard[1]	Units	Exceedance/ # of visits	Range of values
Shoshone River near Lovell	*E. coli*[2]	2007	126 cfu[3] / 100 mL	Geometric mean of five samples: cfu/100 mL	4/4	299.6–633.3
		2008			1/4	4–157
	Nitrate plus nitrite as N	2007	0.076[4]	mg/L	4/4	0.730-1.25
		2008			3/3	0.738-1.12
		2009			4/4	0.49-1.00

[1] (WY DEQ, 2007)

[2] Data from 2008 GRYN Inventory and Monitoring Report

[3] cfu = colony forming unit

[4] This is a Montana draft nitrate standard for wadeable streams. This station is in Wyoming and is marginal as to whether it would be considered wadeable so the standard will not be applicable.

Streams/Rivers Discussion and Management Implications

General Water Quality Overview

Water quality results for most parameters monitored in the 2009 BICA study were within applicable water quality standards. Table 8 presents the range of values for each parameter in the study along an appropriate standard for comparison. The lowest alkalinity result recorded was 121 mg/L which is far above the 20 mg/L minimum standard set by the EPA 1987 Gold Book. Ammonia was not detected in any samples at the 0.1 mg/L reporting limit. The largest chloride concentration detected was 19 mg/L which is far below the 230 mg/L Wyoming chronic aquatic life standard which is the most restrictive of the applicable chloride standards. The lowest dissolved oxygen concentration detected was 8.0 mg/L which is equal to the single day minimum for protection of early stages of aquatic life. Nitrate nitrogen exceeded Montana draft numeric standards (0.076 mg/L for the Northwest Great Plains Ecoregion) for the majority of samples collected but no samples exceeded the drinking water standard of 10 mg/L. None of the pH results fell outside the 6.5 to 9.0 Wyoming range and only one sample exceeded the Montana pH upper limit of 8.5 and this sample was for the Shoshone River which is in Wyoming. No phosphorus data is available for 2009 for comparison to standards. Sulfate concentration exceeded the secondary drinking water standard of 250 mg/L at the Big Horn River at Kane, Crooked Creek, and the North Trail Creek sites. These sulfate levels are of little concern as they are most likely from natural geologic sources and the standard is set for aesthetic protection of drinking water. The discreet temperature measurements collected for this study assist with interpretation of other parameters and do not have resolution necessary to determine departure from normal for comparison to standards. Turbidity standards are based on divergence from natural background which requires baseline or reference conditions which are not available at this time to facilitate evaluation.

Nutrients

The mean nitrate plus nitrite values observed in 2009 were greater than the mean dissolved nitrate values reported for earlier time periods by Woods and Corbin (2003) for each of the three basins within BICA (Table 7). However, the sample locations do not match for the Shoshone Basin and different methods may help explain some of this difference. Woods and Corbin list values for both “dissolved nitrate” and “total nitrate” and definitions of these parameters do not appear to be provided. Values reported in this table are “dissolved nitrate” reported by Woods and Corbin. Maximum historic nitrate nitrogen values are greater for all basins than maximum values detected in 2009. This is not surprising due to the much larger sample sizes for the historic dataset. The maximum nitrate value for the 2007 to 2009 period of the BICA project is greater than for the 2009 dataset alone for each of the three sample sites in the table.

Table 7. Historic nitrate nitrogen reported by Woods and Corbin (2003) and 2009 BICA project nitrate nitrogen values for the three basins within BICA.

Mean Nitrate (mg/L as N)		Max Nitrate (mg/L as N)		
Big Horn at Kane 1971-1979 (n = 85)	**Big Horn at Kane 2009 (n = 4)**	**Big Horn at Kane 1971-1979 (n = 85)**	**Big Horn at Kane 2009 (n = 4)**	**Big Horn at Kane 2007-2009 (n = 11)**
0.10	0.23	0.57	0.29	0.482
Big Horn at St. Xavier 1966-1970 (n = 72)	**Big Horn at St. Xavier 2009 (n = 4)**	**Big Horn at St. Xavier 1966-1970 (n = 72)**	**Big Horn at St. Xavier 2009 (n = 4)**	**Big Horn at St. Xavier 2007-2009 (n = 11)**
0.21	0.402	0.66	0.48	0.719
Shoshone at Kane 1959-1968 (n = 148)	**Shoshone near Lovell 2009 (n = 4)**	**Shoshone at Kane 1959-1968 (n = 148)**	**Shoshone near Lovell 2009 (n = 4)**	**Shoshone near Lovell 2007-2009 (n = 11)**
0.7[1]	0.82[1]	1.5[1]	1.0[1]	1.25

[1] The Shoshone near Lovell is more than 5 miles downstream from the Shoshone at Kane, so these numbers are not directly comparable for change through time.

The new Montana draft nutrient standards provide an interesting new frame of reference for evaluation of water quality data from BICA. The mean nitrate nitrogen concentration for all sites and sample events for BICA in 2009 was 0.371 mg/L. The fact that most of the rivers and streams exhibit nitrate nitrogen concentrations above the draft standards for most sample events is troublesome. However, Layout Spring was selected as a site with relatively little human influence up-gradient and nitrate results for this spring consistently came back above the draft standard threshold. This suggests that some amount of the nitrate loading in the system is derived from geology. The nitrate nitrogen detection limit reported by ETC is 0.002 mg/L but the quantification limit is 0.1 mg/L. In order to produce nitrate data which can be meaningfully compared to the new Montana standards, it will be critical for the contracting lab to provide lower quantification values.

The few detections for phosphorus that occurred in Layout Spring in 2008 suggest that geology may also be a source for phosphorus. Phosphorus data was not generated in 2009 nor has any been generated at the time of reporting due to the loss of phosphorus analytical certification by ETC. Long term phosphorus monitoring and short term exploration of the source of the phosphorus requires that the contracting lab is certified to conduct phosphorus analysis and can return these values.

Table 8. Water quality standards/guidelines and observed BICA stream/river water quality values in 2009. Yellow indicates parameters where relevant standards were exceeded.

Parameter	Standard or Guideline	Standard or Guideline Source	Range of Values in BICA Streams/Rivers in 2009
Field Parameters			
Dissolved Oxygen (mg/L)	8.0 mg/L [1]	MT & WY	8.0 - 13.2
pH	6.5 - 8.5 [2]	MT	7.06 – 8.63
Specific Conductance (µs/cm [3])	3,000 µs/cm [3]	USDA	282.6 – 1572.0
Temperature (°C)	classification dependent [4]	MT & WY	-0.19 – 20.74
Turbidity (NTU)	NA [5]	MT & WY	0.3 – 471.0
Lab Analysis			
Ammonia Nitrogen (mg/L)	Temp and pH dependent [6]	MT & WY	0
Alkalinity (mg/L as $CaCO_3$)	minimum of 20 mg/L[7]	EPA	121 - 302
Bicarbonate (mg/L as $CaCO_3$)	See Alkalinity	-	121 - 302
Calcium (mg/L)	NA	-	39.9 – 262.0
Carbonate (mg/L as $CaCO_3$)	See Alkalinity	-	0
Chloride (mg/L)	860 mg/L [8]	WY	1.08 – 19.0
Magnesium (mg/L)	NA	-	12.2 – 74.5
Nitrate + Nitrate as N (mg/L)	0.076 mg/L	MT	<0.100 – 1.00
Orthophosphate (mg/L)	Total P = 0.124 mg/L [9]	MT	No Data
Potassium (mg/L)	NA	-	0.31 – 5.24
Sodium (mg/L)	NA [10]	-	0.6 – 91.6
Sulfate (mg/L)	NA [11]	-	1.9 – 840.0

[1] 8.0 mg/L is the 1 day minimum to protect early states of aquatic life in cold water systems. 9.5 mg/L is the minimum 7 day mean to protect early life stages in cold water aquatic systems and is the most restrictive standard in MT or WY standards, but because only single data points were collected, values cannot be compared to 7 day minimum mean values.

[2] WY standards call for pH between 6.5 and 9.0 and MT standards 6.5 to 8.5

[3] the USDA has recommended a 3,000 µs/cm specific conductance threshold for water intended for irrigation of terrestrial plants

[4] Temperature standards include thresholds as well as allowable divergence from natural conditions and are dependent on whether streams are classified as supporting cold or warm water fish. Montana cold water threshold is 19.4 degrees C and warm water is 26.6 degrees C. Wyoming cold water threshold is 20 degrees C and warm water is 30 degrees C.

[5] Turbidity standards refer to divergence from natural conditions. MT standards preclude a turbidity increase of more than 5 or 10 NTUs above natural. Wyoming standards preclude turbidity increases of more than 10 to 15 NTUs above natural.

[6] Ammonia standards range over 3 orders of magnitude depending on pH and temperature of the water. These standards are very similar for MT and WY. Ammonia was not detected in any BICA samples in 2009

[7] The EPA Gold Book sets a minimum alkalinity standard of 20 mg/L as $CaCO_3$ except for where natural concentrations are less

[8] 860 mg/L is the Wyoming acute aquatic life standard. All detections are also far below the Wyoming chronic aquatic life standard is at 230 mg/L.

[9] MT draft nutrient standards do not address orthophosphate but set 0.124 mg/L as the total phosphorus limit for the Northwest Glaciated Plains Ecoregion

[10] Standards for sodium adsorption ratio (measure of sodium concentration relative to calcium and magnesium) have been set for some MT basins.

[11] EPA has established a secondary sulfate drinking water standard of 250 mg/L for aesthetic reasons related to potability.

[12] This standard is noted in the EPA Gold Book for “Freshwater Bathing.” E. coli standards are recreation classification and season dependent. The 126 CFU standard is for primary recreation during summer months and is calculated from at least 5 samples collected 24 hours apart over a 30 day period. Montana and Wyoming standards are similar.

Spring Monitoring

<u>Background</u>

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, these protocols only address physical parameters. There are 28 confirmed springs in the park. Twenty-four springs have been established in NPSTORET. Twenty 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.

Methods

<u>Springs Monitored in 2009</u>

Table 9. Spring site names, IDs, and basins.

Fixed Sites		
Station Name	Station ID	Basin
Layout Spring	BICA_LAYOURSPR1	Bighorn Lake
Hillsboro Main Spring	BICA_HLSBMNSPR1	Bighorn Lake
South Lockhart Spring	BICA_LCKSOSPR1	Bighorn Lake
Mason-Lovell Spring	BICA_MASLOVSPR1	Bighorn Lake
2009 Variable Spring Sites		
Station Name	Station ID	Basin
North Davis Spring	BICA_NDAVISPR1	Big Horn Lake
Lockhart Stockpond Spring	BICA_LOCKPNDSPR1	Big Horn Lake
Hailstorm Spring	BICA_HAILSPR1	Big Horn Lake
Pickette's Wall Seep	BICA_PICKETSPR1	Big Horn Lake
Pentagon Spring	BICA_PENTAGSPR1	Big Horn Lake
Hillary Spring	BICA_HILLARYSPR1	Big Horn Lake

In 2009, water quality data was collected for springs in May and again in December. Layout Spring was also sampled on the other two sample trips in March and September because it is considered a hybrid spring/stream site. This is because the amount of water emerging from the cliff results in the initiation of a stream. Layout, South Lockhart, Hillsboro, and Mason Lovell South Springs were considered "fixed" springs through this year. North Davis, Lockhart Stockpond, Pentagon, Hailstorm, and Pickett's Springs are variable springs that will be sampled in a rotation which will cover all accessible springs. Hillary's Spring was also sampled once in May of 2009 but was not visited in December.

Field & Analytical Methods

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

Environmental Testing and Consulting, Inc. (ETC) of Memphis Tennessee was contracted to conduct the laboratory analysis. Samples were preserved, chilled, and shipped overnight to ETC in sufficient time to allow for all analysis before the specified sample hold times. Table 4 outlines the analytes, the corresponding analytical method employed by ETC, and the reporting limits (MQL).

Results and Discussion

Data Summary and Chemical Characterization

Results from May and December 2009 sample events for each spring are summarized in Appendix B. Bicarbonate levels in 2009 are similar to 2008 and indicate that Hillsboro Main, Layout, Mason-Lovell South, Lockhart Stockpond and Picket springs are moderately sensitive (between 50 and 200 mg/L) to changes in pH caused by nutrients, organic inputs, and acid deposition (Camarero et al., 1995). North Davis, South Lockhart, Pentagon, and Hillary springs are not sensitive due to high acid neutralizing capacities (above 200 mg/L). Hailstorm Spring was dry throughout the monitoring year. No spring bicarbonate levels were below the minimum recommended standard for aquatic life of 20 mg/L listed in Table 1. In 2009, Layout, Lockhart South, Mason Lovell, North Davis, Picket, Hillary and Lockhart Stockpond springs had sulfate results above the EPA secondary drinking water standards due to the influence of gypsiferous units in the Chugwater and overlying formations (Sessoms, 2008). Montana draft nutrient standards for nitrate were exceeded for at least one 2009 sample event at Layout, Hillsboro, Lockhart South, Lockhart Stockpond, Mason Lovell, North Davis and Picket springs. Nutrient concentrations and instantaneous loads are provided in tables in Appendix C.

Table 10. Nutrient level standards based on EPA Gold Book, Montana draft nutrient standards and EPA drinking water standards.

Regulatory parameter	Std. Type	Std. Source	Std. Value
			mg/l
Acid Neutralizing Capacity (as $CaCO_3$)	Ambient Water	EPA[1]	<20
Nitrate (mg/l)	Mt Wadeable Streams	MT DEQ[2]	0.076 – 0.100
Total Phosphorus	MT Wadeable Streams	MT DEQ[2]	0.048-0.124
Sulfate (mg/l)	Drinking Water	EPA[3]	250

[1] US EPA, 1986
[2] MT DEQ, 2008b
[3] US EPA, 2009

Currently there are no total maximum daily load (TMDL) criteria for nutrients on the Lower Bighorn River for Montana. Nutrient concentrations and load calculations provided in Appendix C may be useful to the MT DEQ as they develop the nitrogen TMDL for the Lower Big Horn River. In 2007, Schmitz (2008) noted that sulfate levels rose with spring runoff. She hypothesized that groundwater recharge that occurs in the spring flushes sulfate pools that have accumulated due to chemical weathering during low groundwater flow during the winter (Rice, 1995).

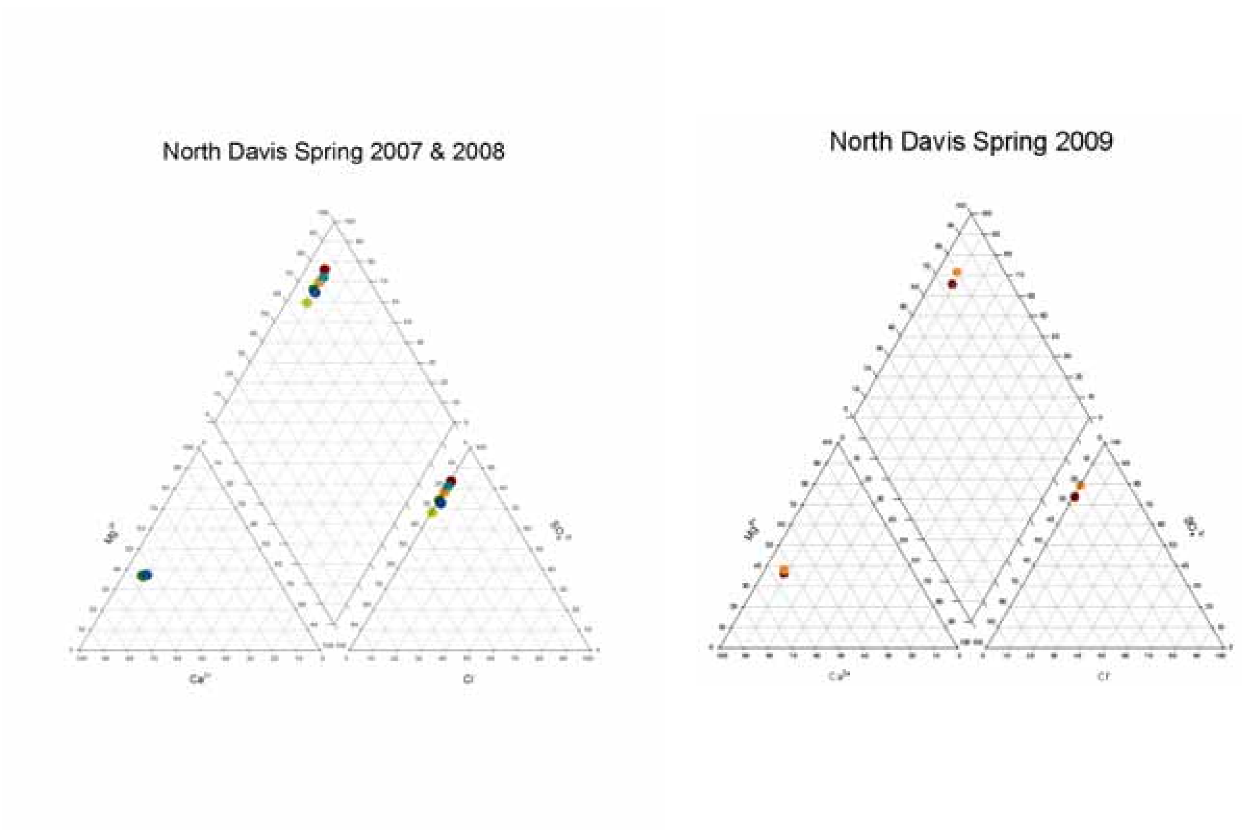
The calcium: magnesium molar ratio is commonly used as an indicator of flow path and source area (e.g. (Jensen and others 1997). Calcium: magnesium (Ca:Mg) near 1.0 indicates water flow paths through dolomitic formations; 1.0-3.0 indicates a combination of limestone and dolomitic formations; >3.0 indicates primarily limestone formations. Hillsboro Main, Layout, Mason-Lovell South, Finley, South Lockhart, and North Davis spring all have Ca:Mg ratios ranging from 2.1 to 3.0, suggesting that these springs emerge from limestone and dolomitic formations. Lockhart Stockpond and Hillary springs had a Ca:Mg ratios greater than 3, suggesting they emerge from limestone formations. Pentagon Spring had a Ca:Mg ratio of 1.7 in 2009 indicating emergence from a formation tending towards dolomitic than the other springs.

Table 11. Spring Calcium to Magnesium Ratios

Fixed Sites		
Station Name	Station ID	Ca:Mg Ratio 2009 Average
Layout Spring	BICA_LAYOURSPR1	2.97
Hillsboro Main Spring	BICA_HLSBMNSPR1	2.59
South Lockhart Spring	BICA_LCKSOSPR1	2.45
Mason-Lovell Spring	BICA_MASLOVSPR1	2.24
2009 Variable Spring Sites		
Station Name	Station ID	Basin
North Davis Spring	BICA_NDAVISPR1	2.43
Lockhart Stockpond Spring	BICA_LOCKPNDSPR1	3.86
Hailstorm Spring	BICA_HAILSPR1	NR
Pickette’s Wall Seep	BICA_PICKETSPR1	2.85
Pentagon Spring	BICA_PENTAGSPR1	1.70
Hillary Spring	BICA_HILLARYSPR1	4.16

Spring Chemical Profiles

The Piper plot (e.g. trilinear, ternary) is a visual reference for describing the chemical character of the water sample. The piper plots below for North Davis Spring illustrate a degree of seasonal chemical variation but the 2009 results fall within the range of 2007 and 2008 results indicating relative stability over the 2007 to 2009 time period. The variability in the North Davis Spring is likely due to seasonal influences wherein sulfate concentration appears to spike in late winter/early spring. This may be due to spring flushing of sulfate pools that have accumulated during the winter, as suggested by Schmitz (2008) and Rice and Bricker (1995). Piper plots for springs sampled in 2009 are in Appendix C and show similar stability in chemical signature for all springs sampled previously.



Figures 6 & 7. Seasonal chemical profiles for North Davis Spring.

Project Recommendations

The availability of the new Montana draft nutrient standards provide an interesting new frame of reference for the nutrient data collected at BICA. Spring and seep data will provide critical insight into what nutrient levels may be associated with natural background from geologic sources versus impacts from livestock and wildlife sources. With the new Montana draft nutrient criteria moving toward implementation and Wyoming moving in the same direction under direction from EPA, it will be important to collect quality data for both nitrogen and phosphorus with a sufficiently low quantification threshold to compare to standards. The ability of ETC to reliably provide this service should be critically evaluated.

An investigation of the area up-gradient from Layout Spring should be conducted to verify that there are no anthropogenic sources of nutrients contributing to the spring. This will help to determine whether geology is the most likely explanation for the levels of nutrients observed at that site. A nutrient weathering study on the parent material is another option to determine what levels of nutrients are derived from weathering of geology associated with the springs.

It is possible that background nutrient concentrations are naturally higher than the draft Montana nutrient criteria within portions of Big Horn Canyon NRA. Montana DEQ acknowledges that the ecoregion based standards will not be appropriate for all locations and that site specific standards may need to be developed in those cases. The nutrient data being collected under this project will be very valuable to informing the possible need for standards specific to the Bighorn Lake Basin. Montana DEQ has draft guidance available for data collection to assess stream compliance with nutrient standards (MT DEQ, 2010a). In addition to collection of nutrient chemistry samples, collection of chlorophyll and/or photo documentation of algae growth is useful for making the assessment. Collection of dissolved oxygen data between the hours of 6 and 8 am is also useful. Discussions between NPS, MSUEWQ and MT DEQ should be pursued to determine how to best align monitoring under this project with the methods suggested by MT DEQ to assess nutrient impairment in wadeable streams.

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Table 12. Summary of results from all river and stream stations. Yellow highlighting indicates samples where relevant standards were exceeded. HCO_3, CO_3 and Alk are bicarbonate alkalinity, carbonate alkalinity, and total alkalinity respectively, reported as $CaCO_3$; PO_4 is orthophosphate is reported as P; NO_3 is nitrate plus nitrite reported as N.

Station ID	T	pH	SpEC	DO	DO	Turbidity	Q	Ca	K	Mg	Na	Cl	HCO_3	CO_3	Alk	SO_4	PO_4	NH_3	NO_3
All Stations	^oC		µS/m	mg/L	%sat	NTU	cfs	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
Count	30	30	30	29	29	30	30	30	30	30	30	30	30	30	30	30	0	30	30
Average	9.17	7.92	793.8	10.6	102.3	40.1	679	99.8	2.37	32.8	35.5	5.79	201	0	201	257.7	NR	0	0.371
ST Dev	6.34	0.37	377.6	1.5	12.4	94.4	1133	66.1	1.35	19.8	26.9	4.99	48	0	49	243.0	NR	0	0.264
Minimum	-0.19	7.06	282.6	8.0	81.4	0.3	0	39.9	0.31	12.2	0.6	1.08	121	0	121	1.9	NR	0	<0.10
Maximum	20.74	8.63	1572.0	13.2	140.6	471.0	4070	262.0	5.24	74.5	91.6	19.00	302	0	302	840.0	NR	0	1.000

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

Table 13. Summary results for regulatory stations. Green highlighting indicates samples where MT wadeable stream standards were exceeded but the site is in Wyoming where standards have not yet been set. HCO_3, CO_3 and Alk are bicarbonate alkalinity, carbonate alkalinity, and total alkalinity respectively, reported as CaCO3; PO_4 is orthophosphate is reported as P; NO_3 is nitrate plus nitrite reported as N.

Date	T	pH	SpEC	DO	DO	Turbidity	Q	Ca	K	Mg	Na	Cl	HCO_3	CO_3	Alk	SO_4	PO_4	NH_3	NO_3
	°C		µS/m	mg/L	%sat	NTU	cfs	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
Bighorn River near St. Xavier (BICA_BHR1)																			
3/25/2009	2.31	7.97	758.3	11.65	101	0.97	4070	75.1	3.62	23.6	63.4	9.88	189	0	189	241	NR	ND	0.459
5/18/2009	4.82	8.02	761	12.83	117.5	0.69	2370	70.7	3.82	22.4	64.7	11.6	164	0	164	235	NR	ND	0.48
9/15/2009	18.53	7.62	486	8.03	86	2.62	2900	41.3	2.28	12.2	33.6	4.86	121	0	121	117	NR	ND	0.294
12/17/2009	7.09	8.45	660.2	13.25	108.8	1.8	2800	58.4	3.12	18.6	52.8	7.7	159	0	159	191	NR	ND	0.374
Count	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	0	4	4
Average	8.19	8.02	666.38	11.44	103.33	1.52	3035.00	61.38	3.21	19.20	53.63	8.51	158.25	0.00	158.25	196.00	NR	0.00	0.402
ST Dev	7.17	0.34	129.07	2.37	13.37	0.87	727.30	15.13	0.69	5.13	14.37	2.91	28.09	0.00	28.09	57.19	NR	0.00	0.085
Minimum	2.31	7.62	486.00	8.03	86.00	0.69	2370.00	41.30	2.28	12.20	33.60	4.86	121.00	0.00	121.00	117.00	NR	0.00	0.294
Maximum	18.53	8.45	761.00	13.25	117.50	2.62	4070.00	75.10	3.82	23.60	64.70	11.60	189.00	0.00	189.00	241.00	NR	0.00	0.480
Shoshone River near Lovell (BICA_SHR2)																			
3/25/2009	6.58	8.29	733.3	9.11	87.2	471	515	82.6	4.34	23.4	54.1	6.6	222	0	222	184	NR	ND	0.49
5/18/2009	19.34	8.63	578.1	NR	NR	88.4	570	52.6	2.95	15.8	54	5.36	165	0	165	136	NR	ND	1
9/14/2009	16.63	8.3	602.1	12.04	126.7	31.4	738	53.1	2.53	16.9	41.9	4.05	180	0	170	135	NR	ND	0.979
12/20/2009	-0.19	8.12	716.2	12.63	96	8.4	*Present	77.1	3.6	22.6	46.6	6.09	235	0	235	169	NR	ND	0.829
Count	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	0	4	4
Average	10.59	8.34	657.43	11.26	103.30	149.80	607.67	66.35	3.36	19.68	49.15	5.53	200.50	0.00	198.00	156.00	NR	0.00	0.82
ST Dev	9.04	0.21	78.67	1.89	20.74	216.76	116.17	15.75	0.79	3.88	5.97	1.11	33.33	0.00	35.67	24.45	NR	0.00	0.24
Minimum	-0.19	8.12	578.10	9.11	87.20	8.40	515.00	52.60	2.53	15.80	41.90	4.05	165.00	0.00	165.00	135.00	NR	0.00	0.49
Maximum	19.34	8.63	733.30	12.63	126.70	471.00	738.00	82.60	4.34	23.40	54.10	6.60	235.00	0.00	235.00	184.00	NR	0.00	1.00

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

Table 14. Summary results for non-regulatory stations. Yellow highlighting indicates samples where relevant standards were exceeded. Green highlighting indicates samples where MT wadeable stream standards were exceeded but the site is in Wyoming where standards have not yet been set. HCO_3, CO_3 and Alk are bicarbonate alkalinity, carbonate alkalinity, and total alkalinity respectively, reported as $CaCO_3$; PO_4 is orthophosphate is reported as P; NO_3 is nitrate plus nitrite reported as N.

Date	T	pH	SpEC	DO	DO	Turb.	Q	Ca	K	Mg	Na	Cl	HCO_3	CO_3	Alk	SO_4	PO_4	NH_3	NO_3
	°C		µS/m	mg/L	%sat	NTU	cfs	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
Bighorn River at Kane (BICA_BHR2)																			
3/25/2009	6.08	8.07	963.3	9.73	91.5	91.5	1480	88	5.24	30	91.6	19	193	0	193	312	NR	ND	0.187
5/19/2009	18.45	8.08	780.7	8.34	104.4	104.4	1,170	71.9	4.04	23	75.7	13.3	163	0	163	249	NR	ND	0.249
9/14/2009	8.3	8.32	808.4	11.99	110	110	985	72.5	3.68	22.9	57.5	10.1	170	0	170	243	NR	ND	0.204
12/20/2009	-0.13	7.61	781.3	12.11	92.2	92.2	*Present	74.4	3.84	23.5	64.8	15.4	180	0	180	235	NR	ND	0.294
Count	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	0	4	4
Average	8.18	8.02	833.43	10.54	99.53	99.53	1211.67	76.70	4.20	24.85	72.40	14.45	176.50	0.00	176.50	259.75	NR	0.00	0.23
ST Dev	7.72	0.30	87.54	1.83	9.16	9.16	250.12	7.61	0.71	3.44	14.82	3.73	13.03	0.00	13.03	35.30	NR	0.00	0.05
Minimum	-0.13	7.61	780.70	8.34	91.50	91.50	985.00	71.90	3.68	22.90	57.50	10.10	163.00	0.00	163.00	235.00	NR	0.00	0.19
Maximum	18.45	8.32	963.30	12.11	110.00	110.00	1480.00	88.00	5.24	30.00	91.60	19.00	193.00	0.00	193.00	312.00	NR	0.00	0.29
Crooked Creek (BICA_CCR1)																			
3/26/2009	4.52	7.35	897.3	12.88	115.6	7.42	7.6	125	1.58	41.5	35.9	1.38	245	0	245	294	NR	ND	ND
5/19/2009	20.74	8.15	1213	10.92	140.6	6.59	0.81	126	4.04	53.6	87	3.21	249	0	249	485	NR	ND	ND
9/14/2009	15.32	7.06	1037	9.58	95.6	41	7.53	127	1.95	42.9	33.2	1.66	265	0	265	313	NR	ND	0.358
12/20/2009	2.91	8.21	941.6	12.2	101.1	25.2	7.69	121	1.45	38.8	27.5	1.32	280	0	280	276	NR	ND	0.384
Count	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	0	4	4
Average	10.87	7.69	1022.23	11.40	113.23	20.05	5.91	124.75	2.26	44.20	45.90	1.89	259.75	0.00	259.75	342.00	NR	0.00	0.19
ST Dev	8.58	0.58	139.90	1.46	20.11	16.39	3.40	2.63	1.21	6.49	27.62	0.89	16.03	0.00	16.03	96.52	NR	0.00	0.21
Minimum	2.91	7.06	897.30	9.58	95.60	6.59	0.81	121.00	1.45	38.80	27.50	1.32	245.00	0.00	245.00	276.00	NR	0.00	0.00
Maximum	20.74	8.21	1213.00	12.88	140.60	41.00	7.69	127.00	4.04	53.60	87.00	3.21	280.00	0.00	280.00	485.00	NR	0.00	0.38
Davis Creek (BICA_DACR1)																			
3/26/2009	2.46	7.7	976.6	11.36	96.6	15.9	0.06	150	2	55.3	22	1.82	297	0	297	224	NR	ND	ND
5/19/2009	13.83	7.89	781.6	8.81	99.8	80.8	0.25	98.4	2.38	41.4	18.1	1.68	279	0	279	192	NR	ND	ND
9/15/2009	15.24	7.96	496.3	9.1	105.9	242	0.26	59.6	1.98	29	8	1.08	250	0	250	58.7	NR	ND	ND
12/20/2009	1.22	8.29	869.4	12.09	95.7	11	*Present	108	1.69	44.5	17.8	1.47	302	0	302	225	NR	ND	ND
Count	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	0	4	4
Average	8.19	7.96	780.98	10.34	99.50	87.43	0.19	104.00	2.01	42.55	16.48	1.51	282.00	0.00	282.00	174.93	NR	0.00	0.00
ST Dev	7.37	0.25	205.85	1.63	4.62	107.85	0.11	37.12	0.28	10.82	5.97	0.32	23.51	0.00	23.51	78.98	NR	0.00	0.00
Minimum	1.22	7.70	496.30	8.81	95.70	11.00	0.06	59.60	1.69	29.00	8.00	1.08	250.00	0.00	250.00	58.70	NR	0.00	0.00
Maximum	15.24	8.29	976.60	12.09	105.90	242.00	0.26	150.00	2.38	55.30	22.00	1.82	302.00	0.00	302.00	225.00	NR	0.00	0.00

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

Table 14 cont.

Date	T	pH	SpEC	DO	DO	Turb.	Q	Ca	K	Mg	Na	Cl	HCO_3	CO_3	Alk	SO_4	PO_4	NH_3	NO_3
	°C		µS/m	mg/L	%sat	NTU	cfs	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
Layout Spring (BICA_LAYOUTSPR1)																			
3/27/2009	5.35	7.41	310	10.66	98.1	0.53	15.88	44.6	0.445	15.4	0.619	ND	168	0	168	5.08	NR	ND	0.238
5/21/2009	4.91	7.52	285	10	100	1.08	1.07	39.9	0.412	13	ND	ND	149	0	149	1.91	NR	ND	0.125
9/15/2009	5.5	7.24	312.9	10.61	98	0.32	1.54	48.7	0.394	16.2	0.766	ND	174	0	174	6.18	NR	ND	0.221
12/18/2009	5.33	7.97	316.7	10.21	89.6	0.33	1	46.8	0.404	16	0.645	ND	177	0	177	5.02	NR	ND	0.237
Count	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	0	4	4
Average	5.27	7.54	306.15	10.37	96.43	0.57	4.87	45.00	0.41	15.15	0.68	0.00	167.00	0.00	167.00	4.55	NR	0.00	0.21
ST Dev	0.25	0.31	14.36	0.32	4.64	0.36	7.34	3.79	0.02	1.47	0.08	0.00	12.57	0.00	12.57	1.84	NR	0.00	0.05
Minimum	4.91	7.24	285.00	10.00	89.60	0.32	1.00	39.90	0.39	13.00	0.62	0.00	149.00	0.00	149.00	1.91	NR	0.00	0.13
Maximum	5.50	7.97	316.70	10.66	100.00	1.08	15.88	48.70	0.45	16.20	0.77	0.00	177.00	0.00	177.00	6.18	NR	0.00	0.24
Layout Creek Below Road (BICA_LCR2)																			
3/26/2009	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	ND	NR
5/19/2009	11.88	7.75	282.6	9.9	104.6	9.7	6.8	39.9	0.65	13.2	0.627	ND	162	0	162	5.37	NR	ND	ND
9/14/2009	14.14	7.58	382.9	8.37	81.4	1.61	*Present	51.7	0.31	18.7	1.56	ND	191	0	191	13.3	NR	ND	ND
12/20/2009	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	ND	NR
Count	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	0	2	2
Average	13.01	7.67	332.75	9.14	93.00	5.66	6.80	45.80	0.48	15.95	1.09	0.00	176.50	0.00	176.50	9.34	NR	0.00	0.00
ST Dev	1.60	0.12	70.92	1.08	16.40	5.72	NA	8.34	0.24	3.89	0.66	0.00	20.51	0.00	20.51	5.61	NR	0.00	0.00
Minimum	11.88	7.58	282.60	8.37	81.40	1.61	6.80	39.90	0.31	13.20	0.63	0.00	162.00	0.00	162.00	5.37	NR	0.00	0.00
Maximum	14.14	7.75	382.90	9.90	104.60	9.70	6.80	51.70	0.65	18.70	1.56	0.00	191.00	0.00	191.00	13.30	NR	0.00	0.00
North Trail Creek (BICA_TRC1)																			
3/26/2009	7.28	7.93	1458	10.5	100.5	1.2	0.95	261	2.03	74.5	21.1	2.75	178	178	178	759	NR	ND	0.126
5/19/2009	15.19	8.08	1550	9.06	115.1	1.03	0.92	262	2.23	72.9	21.5	3.18	166	166	166	840	NR	ND	ND
9/15/2009	14.83	7.85	1503	9.35	108.4	3.8	0.82	230	1.93	70.2	13.5	2.7	175	175	175	757	NR	ND	0.109
12/20/2009	6.74	8.21	1572	10.81	99.3	0.97	0.81	237	2.04	72.1	19.5	2.86	186	186	186	822	NR	ND	0.16
Count	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	0	2	2
Average	11.01	8.02	1520.75	9.93	105.83	1.75	0.88	247.50	2.06	72.43	18.90	2.87	176.25	176.25	176.25	794.50	NR	0.00	0.10
ST Dev	4.63	0.16	50.78	0.85	7.38	1.37	0.07	16.42	0.13	1.79	3.70	0.22	8.26	8.26	8.26	42.79	NR	0.00	0.07
Minimum	6.74	7.85	1458.00	9.06	99.30	0.97	0.81	230.00	1.93	70.20	13.50	2.70	166.00	166.00	166.00	757.00	NR	0.00	0.00
Maximum	15.19	8.21	1572.00	10.81	115.10	3.80	0.95	262.00	2.23	74.50	21.50	3.18	186.00	186.00	186.00	840.00	NR	0.00	0.16

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

Appendix B
Spring Data Summary Tables

Table 15. Layout Spring emerges from the Bighorn Dolomite-Madison Limestone.

Station ID	Date	pH	DO	DO	SpEC	T	Turb.	Q	CO_3	HCO_3	Ca	K	Mg	Na	Cl	SO_4	PO_4	NO_3
			mg/L	%sat	µS/m	°C	NTU	ft^3/sec	meq/L	mg /L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
BICA_LAYOUTSPR1	3/27/2009	7.41	10.66	98.1	310	5.35	0.53	1.54	ND	168	44.6	0.445	15.4	0.619	ND	247	NR	0.238
BICA_LAYOUTSPR1	5/21/2009	7.52	10	100	285	4.91	1.08	15.88	ND	149	39.9	0.412	13	ND	ND	957	NR	0.125
BICA_LAYOUTSPR1	9/15/2009	7.24	10.61	98	313	5.5	0.32	1.07	ND	174	48.7	0.394	16.2	0.766	ND	209	NR	0.221
BICA_LAYOUTSPR1	12/18/2009	7.97	10.21	89.6	317	5.33	0.33	1	ND	177	46.8	0.404	16	0.645	ND	158	NR	0.237
Count		4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	0	4
Mean		7.54	10.37	96.43	306	5.27	0.57	4.87	NA	167.00	45.00	0.41	15.15	0.68	NA	393	NR	0.205
ST Dev		0.31	0.32	4.64	14	0.25	0.36	7.34	NA	12.57	3.79	0.02	1.47	0.08	NA	378	NR	0.054
Minimum		7.24	10.00	89.60	285	4.91	0.32	1.00	NA	149.00	39.90	0.39	13.00	0.62	NA	158	NR	0.125
Maximum		7.97	10.66	100.00	317	5.50	1.08	15.88	NA	177.00	48.70	0.45	16.20	0.77	NA	957	NR	0.238

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

Table 16. South Lockhart Spring emerges from the base of the Tensleep Sandstone.

Station ID	Date	pH	DO	DO	SpEC	T	Turb.	Q	CO_3	HCO_3	Ca	K	Mg	Na	Cl	SO_4	PO_4	NO_3
			mg/L	%sat	µS/m	°C	NTU	L/sec	meq /L	meq /L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
BICA_LCKSOSPR1	5/20/2009	6.82	8.57	94.3	1396	13.47	5.03	0.0138	ND	220.0	194	2.39	77	38.1	4.17	654	NR	0.373
BICA_LCKSOSPR1	12/19/2009	6.92	9.02	86.6	1407	8.55	2.82	0.099	ND	213.0	186	2.06	78.1	33.7	3.62	687	NR	0.299
Mean		6.87	8.80	90.45	1401	11.01	3.93	0.06	NA	216.5	190.00	2.23	77.55	35.90	3.90	671	NR	0.336
Standard Deviation		0.07	0.32	5.44	8	3.48	1.56	0.06	NA	4.9	5.66	0.23	0.78	3.11	0.39	23	NR	0.052

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

Table 17. Hillsboro Main Spring emerges from the Tensleep Sandstone.

Station ID	Date	pH	DO	DO	SpEC	T	Turb.	Q	CO_3	HCO_3	Ca	K	Mg	Na	Cl	SO_4	PO_4	NO_3
			mg/L	%sat	µS/m	°C	NTU	L/sec	meq /L	meq /L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
BICA_HLSBMNSPR1	5/20/2009	6.73	8.86	99.7	537	13.22	0.37	8.21	ND	185.0	72.4	0.73	27.6	6.34	1.33	109	NR	0.169
BICA_HLSBMNSPR1	12/19/2009	7.47	9.18	91.2	529	10.14	0.29	5.66	ND	190.0	71.9	0.652	28.2	5.89	1.15	92	NR	0.169
Mean		7.10	9.02	95.45	533	11.68	0.33	6.94	NA	187.5	72.15	0.69	27.90	6.12	NA	100	NR	0.169
Standard Deviation		0.52	0.23	6.01	6	2.18	0.06	1.80	NA	3.5	0.35	0.06	0.42	0.32	NA	12	NR	0.000

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

Appendix B
Spring Data Summary Tables

Table 18. Mason-Lovell South Spring emerges from the alluvium overlying Mowry Shale.

Station ID	Date	pH	DO	DO	SpEC	T	Turb.	Q	CO_3	HCO_3	Ca	K	Mg	Na	Cl	SO_4	PO_4	NO_3
			mg/L	%sat	µS/m	°C	NTU	L/sec	meq /L	meq /L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
BICA_MLS_SPR1	5/19/2009	7.02	4.76	72.4	2739	28.69	53	Present	ND	151.0	405	3.28	179	275	27.3	2150	NR	0.303
BICA_MLS_SPR1	12/19/2009	7.1	7.74	69.3	3420	5.41	0.35	Present	ND	141.0	390	2.29	176	263	24.3	2170	NR	0.000
Mean		7.06	6.25	70.85	3080	17.05	26.68	NA	NA	146.0	397.50	2.79	177.50	269.00	25.80	2160	NR	0.152
Standard Deviation		0.06	2.11	2.19	482	16.46	37.23	NA	NA	7.1	10.61	0.70	2.12	8.49	2.12	14	NR	0.214

NA – not applicable; ND – below detection limit; NR – not reported; P – present but not measurable.

Table 19. North Davis Spring emerges from the Chugwater Siltstone.

Station ID	Date	pH	DO	DO	SpEC	T	Turb.	Q	CO_3	HCO_3	Ca	K	Mg	Na	Cl	SO_4	PO_4	NO_3
			mg/L	%sat	µS/m	°C	NTU	L/sec	meq /L	meq /L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
BICA_NDAVISPR1	5/20/2009	6.91	5.81	62.1	1583	11.06	1.47	0.04	ND	247.0	223	1.58	89.1	42.2	5.08	559	NR	0.951
BICA_NDAVISPR1	12/19/2009	6.79	5.97	53.7	1316	6.17	7.04	0.04	ND	260.0	174	1.57	74.4	29.5	2.96	788	NR	ND
Mean		6.85	5.89	57.90	1450	8.62	4.26	0.04	NA	253.5	198.50	1.58	81.75	35.85	4.02	674	NR	0.476
Standard deviation		0.08	0.11	5.94	189	3.46	3.94	0.00	NA	9.2	34.65	0.01	10.39	8.98	1.50	162	NR	0.672

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

Table 20. Lockhart Stockpond Spring emerges from the Tensleep Sandstone.

Station ID	Date	pH	DO	DO	SpEC	T	Turb.	Q	CO_3	HCO_3	Ca	K	Mg	Na	Cl	SO_4	PO_4	NO_3
			mg/L	%sat	µS/m	°C	NTU	L/sec	meq /L	meq /L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
BICA_LOCKPNDSP1	5/20/2009	6.72	7.94	88.4	2359	12.5	1.42	0.078	ND	180.0	469	2.37	118	29.7	3.05	1520	NR	ND
BICA_LOCKPNDSP1	12/19/2009	7.14	8.75	82	2424	7.36	1.7	Present	ND	120.0	441	2.23	118	25.5	4.18	1570	NR	0.731
Mean		6.93	8.35	85.20	2392	9.93	1.56	0.08	NA	150.0	455.00	2.30	118.00	27.60	3.62	1545	NR	0.366
Standard deviation		0.30	0.57	4.53	46	3.63	0.20	#DIV/0!	NA	42.4	19.80	0.10	0.00	2.97	0.80	35	NR	0.517

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

Appendix B
Spring Data Summary Tables

Table 21. Pentagon Spring.

Station ID	Date	pH	DO	DO	SpEC	T	Turb.	Q	CO_3	HCO_3	Ca	K	Mg	Na	Cl	SO_4	PO_4	NO_3
			mg/L	%sat	µS/m	°C	NTU	L/sec	meq /L	meq /L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
BICA_PENTAGSPR1	5/20/2009	7.26	8.35	93.7	530	13.07	445	Present	ND	297.0	60.5	1.8	35.2	8.3	2.35	18	NR	ND
BICA_ PENTAGSPR1	12/18/2009	7.59	8.02	65	549	2.42	1.72	Present	ND	280.0	64.1	1.39	38.2	6.41	1.55	23	NR	ND
Mean		7.43	8.19	79.35	540	7.75	223.36	NA	NA	288.5	62.30	1.60	36.70	7.36	1.95	21	NR	ND
Standard deviation		0.23	0.23	20.29	13	7.53	313.45	NA	NA	12.0	2.55	0.29	2.12	1.34	0.57	4	NR	NA

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

Table 22. Hailstorm Spring was dry throughout the year.

Station ID	Date	pH	DO	DO	SpEC	T	Turb.	Q	CO_3	HCO_3	Ca	K	Mg	Na	Cl	SO_4	PO_4	NO_3
			mg/L	%sat	µS/m	°C	NTU	L/sec	meq /L	meq /L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
BICA_HAILSPR1	5/19/2009							0.00										
BICA_HAILSPR1	12/19/2009							0.00										

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

Table 23. Hillary's Spring – Sykes Mountain.

Station ID	Date	pH	DO	DO	SpEC	T	Turb.	Q	CO_3	HCO_3	Ca	K	Mg	Na	Cl	SO_4	PO_4	NO_3
			mg/L	%sat	µS/m	°C	NTU	L/sec	meq /L	meq /L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
BICA_HILLARYSPR	5/20/2009	6.28	4.75	54.5	1577	13.67	12.48	Present	ND	210	252	3.48	60.6	68.9	9.53	817	ND	ND

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

Table 24. Pickett's Spring.

Station ID	Date	pH	DO	DO	SpEC	T	Turb.	Q	CO_3	HCO_3	Ca	K	Mg	Na	Cl	SO_4	PO_4	NO_3
			mg/L	%sat	µS/m	°C	NTU	L/sec	meq /L	meq /L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
BICA_PICKETSPR1	5/19/2009	6.88	8.47	100.9	899	15.95	3.41	Present	ND	3.42	148	1.29	51.3	11.6	1.86	372	NR	0.210
BICA_ PICKETSPR1	12/18/2009	7.92	10.6	91.7	921	4.69	0.51	Present	ND	3.4	136	1.1	48.2	9.32	1.75	401	NR	0.264
Mean		7.40	9.54	96.30	910	10.32	1.96	NA	NA	3.41	142.00	1.20	49.75	10.46	1.81	387	NR	0.237
Standard deviation		0.74	1.51	6.51	16	7.96	2.05	NA	NA	0.01	8.49	0.13	2.19	1.61	0.08	21	NR	0.038

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

Appendix C
Fixed Spring Site Nutrient Loads

Table 25. Nutrient exports for Layout Spring.

Station ID	Date	Q	NO_3	NO_3 load	PO_4	PO_4 load	SO_4	SO_4 load	NH_3	NH_3
		L/sec	mg/L	kg/yr	mg/L	kg/yr	mg/L	kg/yr	mg/L	kg/yr
BICA_LAYOUTSPR1	3/27/2009	1.54	0.238	11.56	NR	NR	5.08	247	ND	ND
BICA_LAYOUTSPR1	5/21/2009	15.88	0.125	62.60	NR	NR	1.91	957	ND	ND
BICA_LAYOUTSPR1	9/15/2009	1.07	0.221	7.46	NR	NR	6.18	209	ND	ND
BICA_LAYOUTSPR1	12/18/2009	1	0.237	7.47	NR	NR	5.02	158	ND	ND
Mean		4.87	0.21	22.27	NR	NR	4.55	393	ND	ND
Standard deviation		7.34	0.05	26.95	NR	NR	1.84	378	NA	NA

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

Table 26. Nutrient exports for Hillsboro Main Spring.

Station ID	Date	Q	NO_3	NO_3 load	PO_4	PO_4 load	SO_4	SO_4 load
		L/sec	mg/L	kg/yr	mg/L	kg/yr	mg/L	kg/yr
BICA_HLSBMNSPR1	5/20/2009	8.21	0.169	43.76	NR	NR	109	28221
BICA_HLSBMNSPR1	12/19/2009	5.66	0.17	30.17	NR	NR	91.8	16386
Mean		6.94	0.17	36.96	NR	NR	100.40	22303
Standard deviation		1.80	0.00	9.61	NR	NR	12.16	8369

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

Table 27. Nutrient exports for South Lockhart Spring.

Station ID	Date	Q	NO_3	NO_3 load	PO_4	PO_4 load	SO_4	SO_4 load
		L/sec	mg/L	kg/yr	mg/L	kg/yr	mg/L	kg/yr
BICA_LCKSOSPR1	5/20/2009	0.0138	0.373	0.16	NR	NR	654.00	285
BICA_LCKSOSPR1	12/19/2009	0.099	0.299	0.93	NR	NR	687.00	2145
Mean		0.06	0.34	0.55	NR	NR	670.50	1215
Standard deviation		0.06	0.05	0.55	NR	NR	23.33	1315

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

Appendix C
Variable Spring Site Nutrient Loads

Table 28. Nutrient exports for North Davis Spring.

Station ID	Date	Q	NO_3	NO_3 load	PO_4	PO_4 load	SO_4	SO_4 load
		L/sec	mg/L	kg/yr	mg/L	kg/yr	mg/L	kg/yr
BICA_NDAVISPR1	5/20/2009	0.04	0.951	1.14	NR	NR	559.00	670
BICA_NDAVISPR1	12/19/2009	NR	ND	ND	NR	NR	788.00	NR
Mean		NR	NR	NR	NR	NR	673.50	NR
ST Dev		NR	NR	NR	NR	NR	161.93	NR

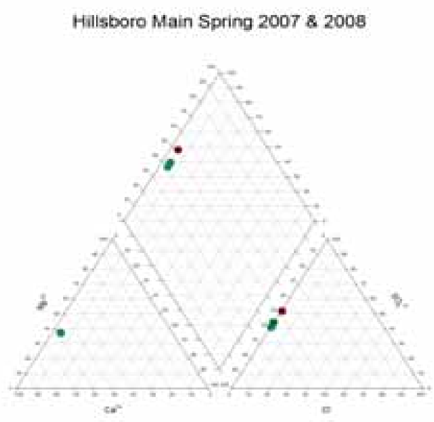
NA – not applicable; ND – below detection limit; NR – not reported.

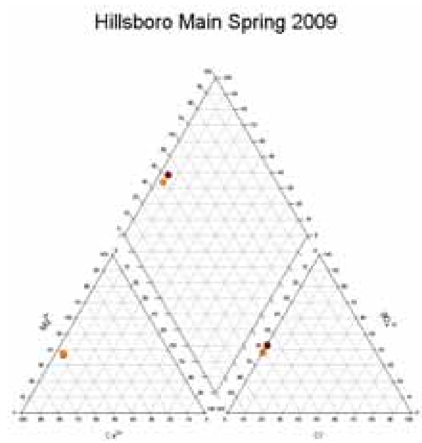
Table 29. Nutrient exports for Lockhart Stockpond Spring.

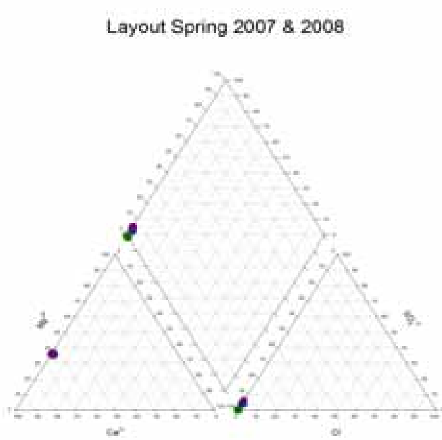
Station ID	Date	Q	NO_3	NO_3 load	PO_4	PO_4 load	SO_4	SO_4 load
		L/sec	mg/L	kg/yr	mg/L	kg/yr	mg/L	kg/yr
BICA_LOCKPNDSP1	5/20/2009	0.08	ND	ND	NR	NR	1520.00	3742
BICA_LOCKPNDSP1	12/19/2009	NR	0.731	NR	NR	NR	1570.00	NR
Mean		NR	0.366	NR	NR	NR	1545.00	NR
ST Dev		NR	0.517	NR	NR	NR	35.36	NR

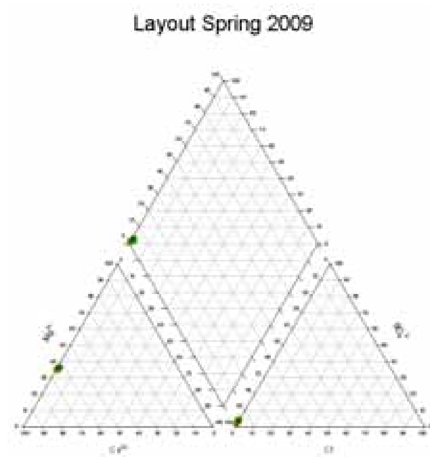
NA – not applicable; ND – below detection limit; NR – not reported.

Appendix D
Piper Plots for Seeps and Springs



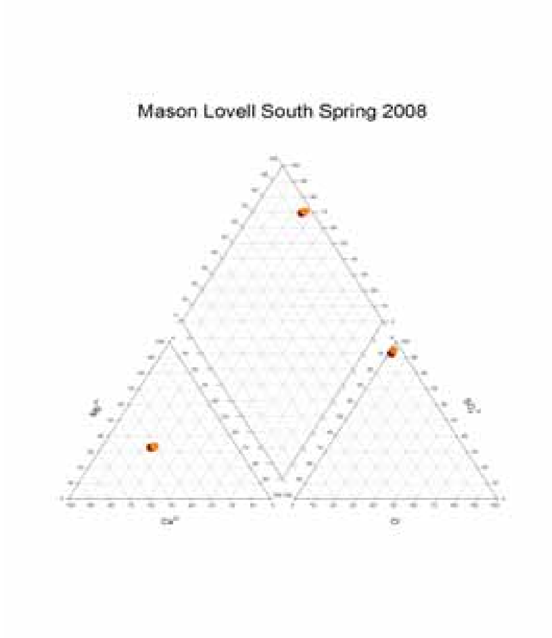


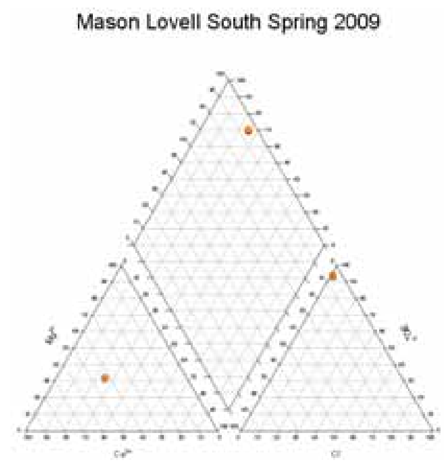


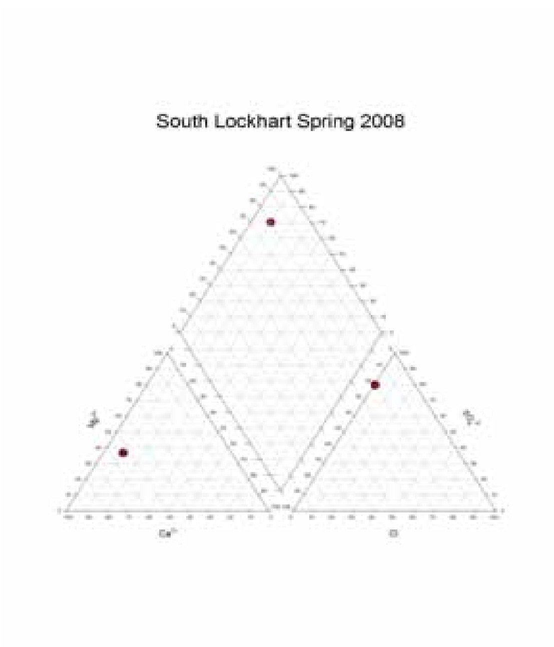


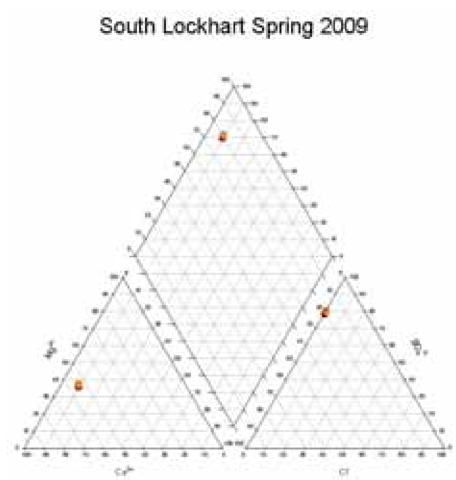
Figures 8-11. Seasonal chemical profiles of fixed spring sites.

Appendix D
Piper Plots for Seeps and Springs



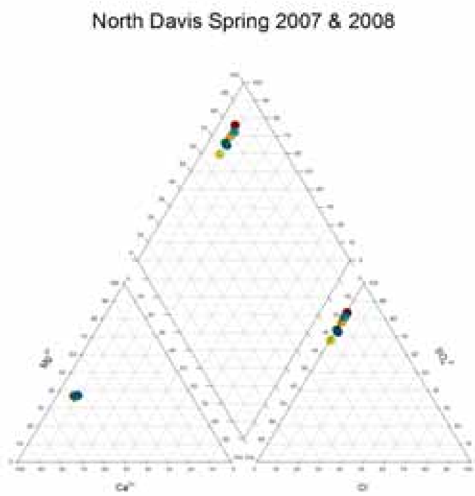


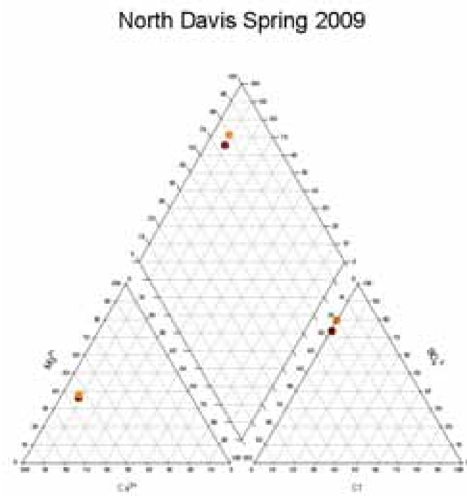


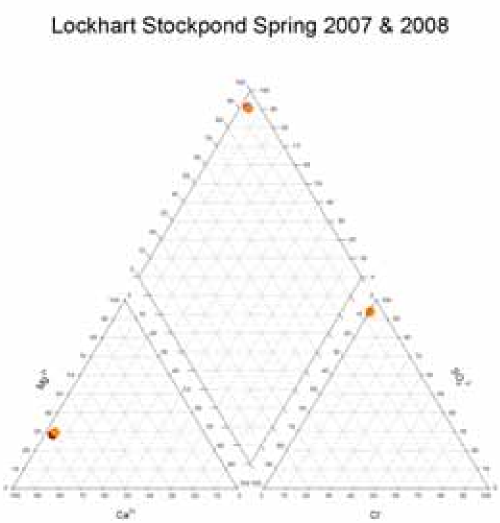


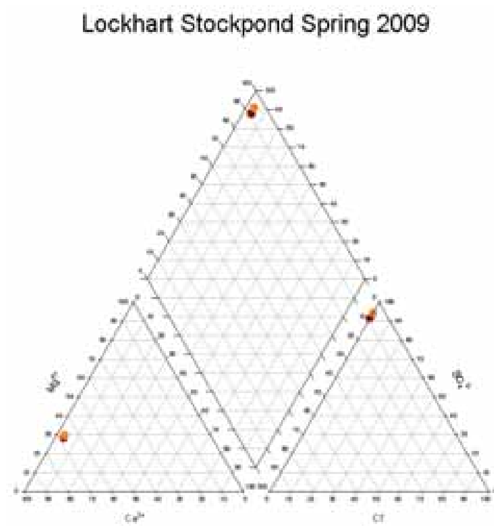
Figures 12-15. Seasonal chemical profiles of fixed spring sites.

Appendix D
Piper Plots for Seeps and Springs



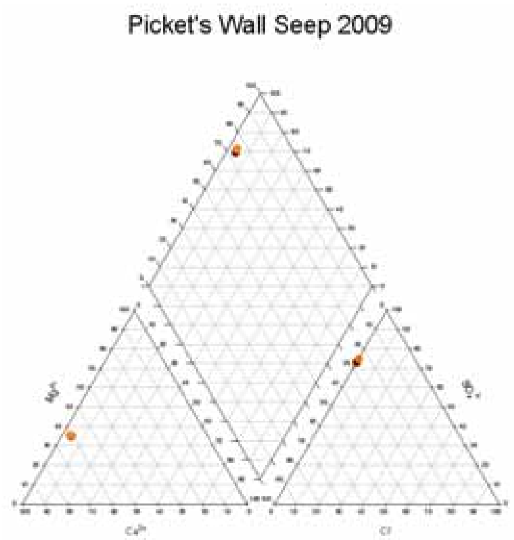


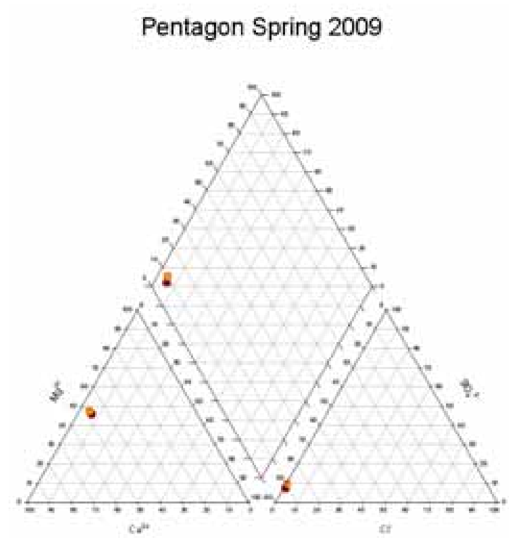




Figures 6, 7, 16 and 17. Seasonal chemical profiles of variable spring sites.

Appendix D
Piper Plots for Seeps and Springs





Figures 18 & 19. Seasonal chemical profiles of variable spring sites.