BIGHORN CANYON
NATIONAL RECREATION AREA
2010 WATER QUALITY REPORT

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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 2010. *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 six 2010 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 2010 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 2009/10 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 or 2010 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 2010. 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 2010 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, 2010).

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). Standards would apply July 1 – September 30th (growing season months).
[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)

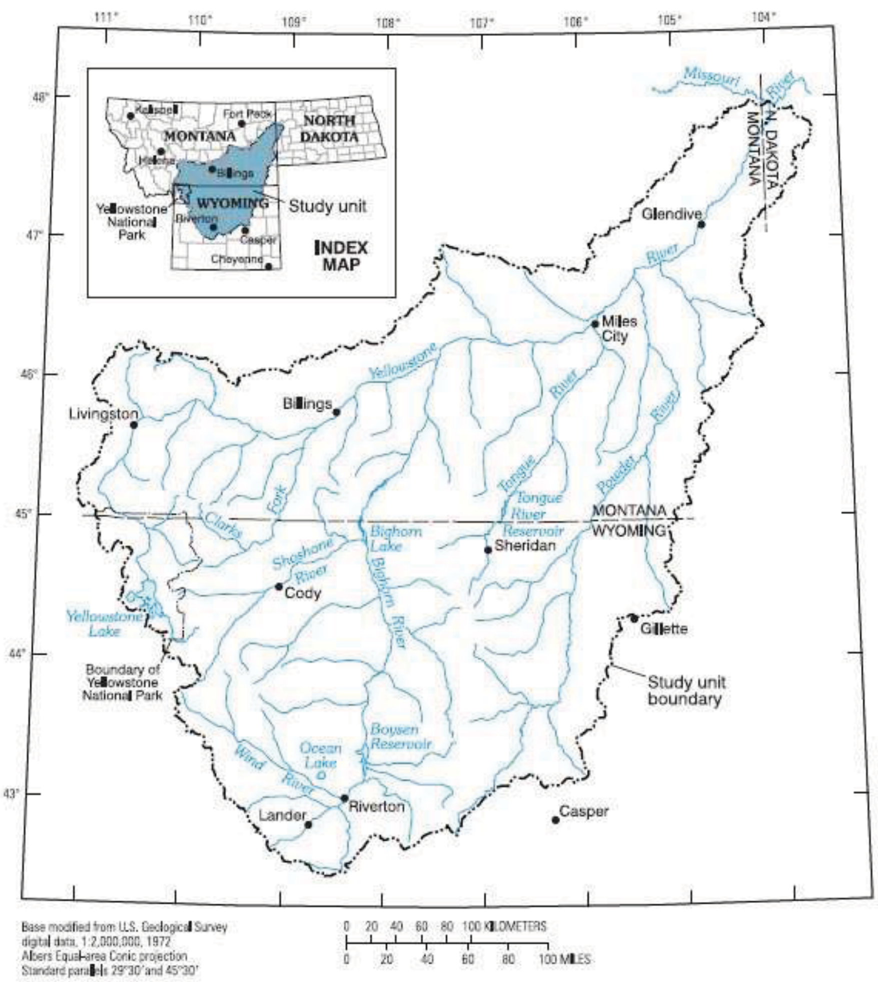

Figure 1: USGS map of Yellowstone Basin (from Environmental setting of the Yellowstone River Basin, Montana, North Dakota, and Wyoming)

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)	-

*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.

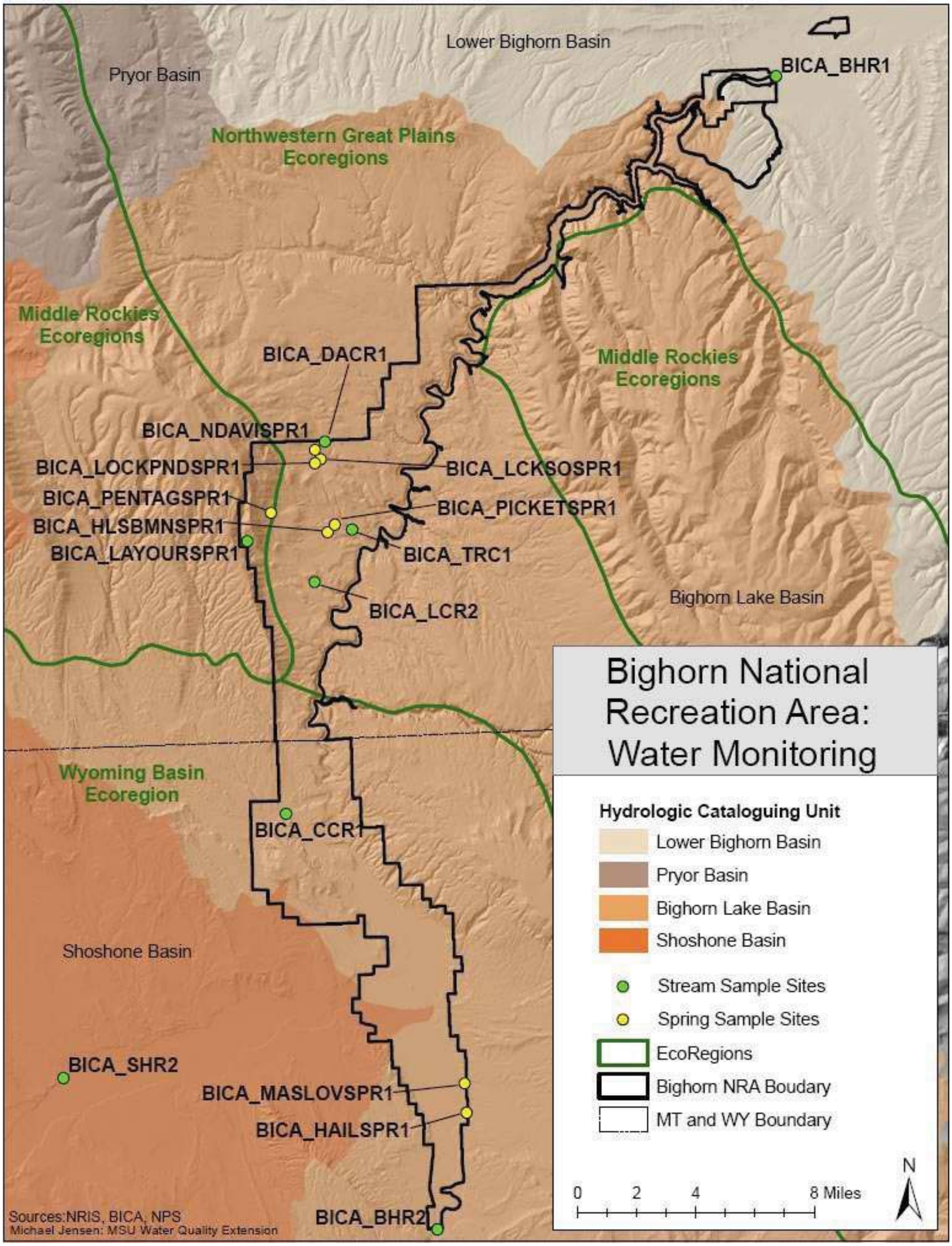

Figure 2. Map of BICA sample sites including basins and level III ecoregions.

Field & Analytical Methods

Data were 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 2010 have been validated (see validation and verification reports for details).

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. Bighorn River at Kane is classified as a 2AB cold water stream by Wyoming DEQ and exceeded the maximum temperature threshold for one sample event in 2010. 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 2010. 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 was 0.23 mg/L and 0.17 mg/L for 2009 and 2010 respectively.

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 2010.

Site	Parameter	Year	Standard	Units	Exceedance/ # of visits	Range of values
Big Horn River at Kane	Nitrate plus nitrite as N	2007	0.076[1&2]	mg/L	1/1 (4/4)[4]	0.233-0.478
		2008			0/0 (3/3)[4]	0.285-0.482
		2009			1/1 (4/4)[4]	0.19-0.29
		2010			1/2 (5/6)[4]	<0.1-0.25
	Sulfate	2007	250	mg/L	3/4	89-413
		2008			2/2	279-308
		2009			1/4	235-312
		2010			3/6	133-309
	Temperature	2010	20	degrees C	1/6	0.05 - 23.86
Crooked Creek	Nitrate plus nitrite as N	2007	0.076[1]	mg/L	0/1 (3/4)[4]	<0.1-0.832
		2008			0/0 (2/3)[4]	<0.1-0.353
		2009			1/1 (2/4)[4]	<0.1-0.384
		2010			1/2 (4/6)[4]	<0.1-0.35
	Sulfate	2007	250	mg/L	3/4	83-300
		2008			3/3	275-288
		2009			4/4	276-485
		2010			3/6	114-811
	Temperature	2009	20	degrees C	1/4	2.91 – 20.74
Layout Spring	Nitrate plus nitrite as N	2007	0.1[3]	mg/L	1/1 (4/4)[4]	0.139-0.238
		2008			0/0 (3/3)[4]	0.230-0.368
		2009			1/1 (4/4)[4]	0.125-0.238
		2010			2/2 (6/6)[4]	0.14-0.29
Layout	Nitrate plus	2008	0.076[3]	mg/L	0/1 (1/3)[4]	<0.1-0.169
North Trail Creek	Nitrate plus nitrite as N	2007	0.076[3]	mg/L	0/1 (3/4)[4]	<0.1-0.160
		2008			0/0 (3/3)[4]	0.119-0.265
		2009			0/1 (3/4)[4]	<0.1-0.160
		2010			0/2 (3/6)[4]	<0.1-0.17
	Sulfate	2007	250	mg/L	4/4	728-813
		2008			3/3	779-840
		2009			4/4	757-840
		2010			6/6	775-825

[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.

[4] Draft Montana standards would only apply during the growing season from July 1 through September 30. The first ratio is exceedances over samples during the growing season and the second ratio (in parentheses) is the exceedance ratio for all samples disregarding growing season.

Lower Big Horn Basin

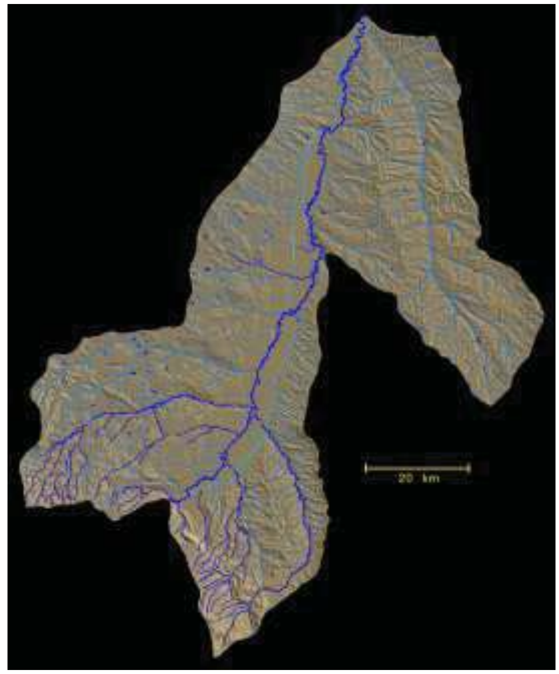

Figure 4. Lower Big Horn Basin

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 2007-2010 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 was 0.40 mg/L and 0.38 mg/L for 2009 and 2010 respectively.

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 2010.

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	1/1 (4/4)[2]	0.414-0.719
		2008			0/0 (3/3)[2]	0.446-0.614
		2009			1/1 (4/4)[2]	0.294-0.480
		2010			1/1 (4/4)[2]	0.253-0.516

[1] This is a Montana draft nitrate standard for wadeable streams. The Big Horn is considered a big river rather than a wadeable stream so the standard will not be applicable.

[2] Draft Montana standards would only apply during the growing season from July 1 through September 30. The first ratio is exceedances over samples during the growing season and the second ratio (in parentheses) is the exceedance ratio for all samples disregarding growing season.

Shoshone River Basin

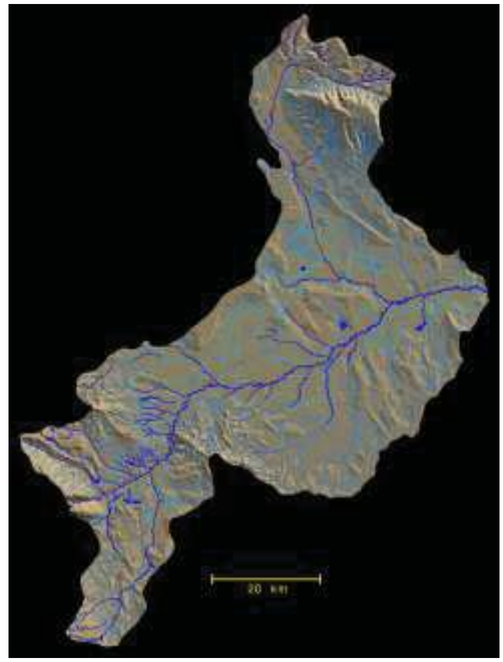

Figure 5. Shoshone Basin

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 2007-2010 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) was 0.82 mg/L and 0.99 mg/L in 2009 and 2010 respectively.

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 2010.

Site	Parameter	Year	Standard[1]	Units	Exceedance/ # of visits	Range of values
Shoshone River near Lovell	Nitrate plus nitrite as N	2007	0.076[4]	mg/L	1/1 (4/4)[5]	0.730-1.25
		2008			0/1 (3/3)[5]	0.738-1.12
		2009	0.076[4]	mg/L	1/1 (4/4)[5]	0.49-1.00
		2010			2/2 (6/6)[5]	0.33-1.66

[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.
[5] Draft Montana standards would only apply during the growing season from July 1 through September 30. The first ratio is exceedances over samples during the growing season and the second ratio (in parentheses) is the exceedance ratio for all samples disregarding growing season.

Streams/Rivers Discussion and Management Implications

General Water Quality Overview

Water quality results for most parameters monitored in the 2010 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 65 mg/L which is well 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 22.8 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 8.2 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 three samples exceeded the Montana pH upper limit of 8.5 and these were for the Shoshone River and the Big Horn River at Kane which are in Wyoming. No phosphorus data is available for 2010 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 similar to in 2009. 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. However, one measurement at the Big Horn at Kane site did exceed the 20 degree C threshold suggested for a cold water fisheries upper limit under Wyoming 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 2010 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. Data collected between 2007-2010 produced greater maximum nitrate nitrogen concentrations than historic data for the Big Horn St. Xavier site and the Shoshone River Site but not for the Big Horn at Kane site.

Table 7. Historic mean nitrate nitrogen reported by Woods and Corbin (2003) and 2009/10 BICA project nitrate nitrogen values for the three basins within BICA.

Mean Nitrate (mg/L as N)		
Big Horn at Kane 1971-1979 (n = 85)	**Big Horn at Kane 2009 (n = 4)**	**Big Horn at Kane 2010 (n = 6)**
0.10	0.23	0.17
Big Horn at St. Xavier 1966-1970 (n = 72)	**Big Horn at St. Xavier 2009 (n = 4)**	**Big Horn at St. Xavier 2010 (n = 4)**
0.21	0.402	0.38
Shoshone at Kane 1959-1968 (n = 148)	**Shoshone near Lovell 2009 (n = 4)**	**Shoshone near Lovell 2010 (n = 6)**
0.7[1]	0.82[1]	0.99

[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.

Table 8. Historic maximum nitrate nitrogen reported by Woods and Corbin (2003) and 2009/10 BICA project nitrate nitrogen values for the three basins within BICA.

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 2010 (n = 6)**	**Big Horn at Kane 2007-2009 (n = 17)**
0.57	0.29	0.25	0.482
Big Horn at St. Xavier 1966-1970 (n = 72)	**Big Horn at St. Xavier 2009 (n = 4)**	**Big Horn at St. Xavier 2010 (n = 4)**	**Big Horn at St. Xavier 2007-2009 (n = 15)**
0.66	0.48	0.52	0.719
Shoshone at Kane 1959-1968 (n = 148)	**Shoshone near Lovell 2009 (n = 4)**	**Shoshone near Lovell 2010 (n = 6)**	**Shoshone near Lovell 2007-2009 (n = 17)**
1.5[1]	1.0[1]	1.66	1.66

[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 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 were not generated in 2009 or 2010 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 9. Water quality standards/guidelines and observed BICA stream/river water quality values in 2010. Yellow indicates parameters where relevant standards were exceeded.

Parameter	Standard or Guideline	Standard or Guideline Source	Range of Values in BICA Streams/Rivers in 2010
Field Parameters			
Dissolved Oxygen (mg/L)	8.0 mg/L [1]	MT & WY	8.2 - 13.23
pH	6.5 - 8.5 [2]	MT	7.61 – 8.78
Specific Conductance (µs/cm [3])	3,000 µs/cm [3]	USDA	174 – 1626
Temperature (°C)	classification dependent [4]	MT & WY	0.05 – 23.86
Turbidity (NTU)	NA [5]	MT & WY	0.15 – 474
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	65 - 372
Bicarbonate (mg/L as $CaCO_3$)	See Alkalinity	-	65 – 294
Calcium (mg/L)	NA	-	39.3 – 250.0
Carbonate (mg/L as $CaCO_3$)	See Alkalinity	-	0
Chloride (mg/L)	860 mg/L [8]	WY	<1– 22.80
Magnesium (mg/L)	NA	-	12.1 – 78.2
Nitrate + Nitrate as N (mg/L)	0.076 mg/L[9]	MT	<0.100 – 1.66
Orthophosphate (mg/L)	Total P = 0.124 mg/L [9]	MT	No Data
Potassium (mg/L)	NA	-	0.21 – 5.22
Sodium (mg/L)	NA [10]	-	0.52 – 146.0
Sulfate (mg/L)	NA [11]	-	2.08 – 825.0

[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 would apply from July 1 through September 30. The draft 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

Background

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

Springs Monitored in 2010

Table 10. Spring site names, IDs, and basins.

Fixed Sites		
Station Name	Station ID	Basin
Layout Spring	BICA_LAYOURSPR1	Bighorn Lake
2009 Variable Spring Sites		
Station Name	Station ID	Basin
Hillsboro Main Spring	BICA_HLSBMNSPR1	Bighorn Lake
Trail Campground Main Spring	BICA_TRCPGDSPR1	Bighorn Lake

In 2010, water quality data were collected for springs in May and again in December. Layout Spring was also sampled on the other four sample trips in March, June, July 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.

Field & Analytical Methods

Data were 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 2010 sample events for each spring are summarized in Appendix B. Bicarbonate levels in 2010 are similar to 2008 and 2009 and indicate that Hillsboro Main, Layout and Trail Creek Campground 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). No spring bicarbonate levels were below the minimum recommended standard for aquatic life of 20 mg/L listed in Table 1. In 2010, Layout and Trail Creek Campground 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 all 2010 sample events at all three springs.

Table 11. 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 discharge measurements provided in Appendix B 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 and Layout have Ca:Mg ratios ranging from 2.1 to 3.0, suggesting that these springs emerge from limestone and dolomitic formations. Trail Creek Campground spring has a Ca:Mg ratio on the order of 3.8 to 4.1 suggesting it emerges from limestone formations.

Table 12. Spring Calcium to Magnesium Ratios

2010 Spring Sites		
Station Name	Station ID	Ca:Mg Ratio 2009 Average
Layout Spring	BICA_LAYOURSPR1	2.96
Hillsboro Main Spring	BICA_HLSBMNSPR1	2.57
Trail Campground Main Spring	BICA_TRCPGDSPR1	4.00

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.

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.

Continuous measurement of water quantity at the BICA spring would also provide valuable insight into changes in water availability in arid environments in the context of climate variability.

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Table 13. Results for BICA stream and river stations for 2010. Yellow highlighting indicates samples where relevant standards or draft were exceeded. Green highlighting indicates samples where MT draft wadeable stream nutrient standards were exceeded but the site is in Wyoming and/or the stream is not wadeable so the standards do not apply. 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. ANC is acid neutralizing capacity determined from titration in the field. NA – not applicable; ND – below detection limit; NR – not reported.

Bighorn near St Xavier

Date	T °C	pH	SpEC µS/m	DO mg/L	DO %sat	Turbidity NTU	Q cfs	Ca mg/L	K mg/L	Mg mg/L	Na mg/L	Cl mg/L	HCO_3 mg/L	CO_3 mg/L	Alk mg/L	SO_4 mg/L	PO_4 mg/L	NH_3 mg/L	NO_3 mg/L
3/17/2010	2.12	8.14	764	13.1	102.40	0.93	1920	80	3.52	24.6	61.7	10.7	176	0	176	216	NR	<0.1	0.39
5/11/2010	3.92	7.77	713	12.66	NR	0.76	3190	68.1	3.48	21.9	65.9	11.6	170	0	170	236	NR	<0.1	0.374
9/15/2010	16.79	7.79	527	8.34	NR	3.26	5260	47.4	2.73	14.8	43.3	5.58	123	0	123	131	NR	<0.1	0.253
12/5/2010	8.83	7.69	729	9.54	NR	4.31	2220	62.6	3.11	19.7	56.5	9.57	157	0	157	221	NR	<0.1	0.516
Count	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	0	4	4
Average	7.92	7.85	683.25	10.91	102.40	2.32	3147.50	64.53	3.21	20.25	56.85	9.36	156.50	0.00	156.50	201.00	NR	0.00	0.38
Standard Deviation	6.56	0.20	106.32	2.33	NA	1.75	1509.03	13.53	0.37	4.15	9.82	2.65	23.70	0.00	23.70	47.43	NR	0.00	0.11
Minimum	2.12	7.69	527.00	8.34	102.40	0.76	1920.00	47.40	2.73	14.80	43.30	5.58	123.00	0.00	123.00	131.00	NR	0.00	0.25
Maximum	16.79	8.14	764.00	13.10	102.40	4.31	5260.00	80.00	3.52	24.60	65.90	11.60	176.00	0.00	176.00	236.00	NR	0.00	0.52

Bighorn at Kane

Date	T °C	pH	SpEC µS/m	DO mg/L	DO %sat	Turbidity NTU	Q cfs	Ca mg/L	K mg/L	Mg mg/L	Na mg/L	Cl mg/L	HCO_3 mg/L	CO_3 mg/L	Alk mg/L	SO_4 mg/L	PO_4 mg/L	NH_3 mg/L	NO_3 mg/L
3/17/2010	8.88	8.58	1007	11.17	107.4	42.3	1180	90.3	5.22	30.6	93.6	22.8	185	0	185	309	NR	<0.1	0.179
5/11/2010	11.08	8.19	714	8.84	NR	174	2480	64	3.31	20.6	73	14	175	0	175	245	NR	<0.1	0.211
6/11/2010	14.69	8.02	482.9	8.64	95	461	11800	39.3	2.42	12.1	39.3	7.38	116	0	116	133	NR	<0.1	0.161
7/22/2010	23.86	8.41	729.2	8.42	111.1	69.3	1550	65.9	3.3	20.1	62.1	11.1	150	0	150	231	NR	<0.1	0.226
9/15/2010	18.94	8.53	894	9.86	NR	24.5	1150	78.1	3.8	25.9	86.7	11.6	173	0	173	284	NR	<0.1	<0.1
12/7/2010	0.05	8.2	926	13.21	NR	5.42	NR	77.6	4.12	24.8	75.3	19.8	175	0	175	282	NR	<0.1	0.246
Count	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	0	6	6
Average	12.92	8.32	792.18	10.02	104.50	129.42	3632.00	69.20	3.70	22.35	71.67	14.45	162.33	0.00	162.33	247.33	NR	0.00	0.17
Standard Deviation	8.30	0.22	189.82	1.86	8.43	172.93	4597.57	17.48	0.94	6.32	19.29	5.79	25.48	0.00	25.48	62.76	NR	0.00	0.03
Minimum	0.05	8.02	482.90	8.42	95.00	5.42	1150.00	39.30	2.42	12.10	39.30	7.38	116.00	0.00	116.00	133.00	NR	0.00	<0.1
Maximum	23.86	8.58	1007.00	13.21	111.10	461.00	11800.00	90.30	5.22	30.60	93.60	22.80	185.00	0.00	185.00	309.00	NR	0.00	0.25

Table 13 cont.

Shoshone River near Lovell

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
3/16/2010	9.64	8.7	716.8	12.61	118.8	29.7	570	78.2	3.6	78.2	49.3	6.41	205	0	205	167	NR	<0.1	0.325
5/11/2010	9.32	8.25	623	10.03	NR	120	375	54.5	2.8	17.2	64.4	7.05	65	0	65	180	NR	<0.1	1.39
6/11/2010	12.18	8.09	636.4	9.24	96	474	689	51	2.93	16	60.6	7.07	168	0	168	168	NR	<0.1	1.66
7/21/2010	19.63	8.47	679.3	8.8	106.7	41.6	371	58.6	3.11	18.4	60.8	6.99	178	0	178	176	NR	<0.1	0.948
9/15/2010	17.55	8.78	673	10.45	NR	23.1	523	57.1	2.95	19	60.7	6	175	0	175	163	NR	<0.1	0.8
12/5/2010	1.19	7.99	783	11.99	NR	85.2	NR	76.7	3.7	21.7	48.4	7.82	222	0	222	187	NR	<0.1	0.814
Count	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	0	6	6
Average	11.59	8.38	685.25	10.52	107.17	128.93	505.60	62.68	3.18	28.42	57.37	6.89	168.83	0.00	168.83	173.50	NR	0.00	0.99
Standard Deviation	6.60	0.32	58.30	1.51	11.41	173.05	135.33	11.73	0.38	24.46	6.76	0.63	54.84	0.00	54.84	9.09	NR	0.00	0.47
Minimum	1.19	7.99	623.00	8.80	96.00	23.10	371.00	51.00	2.80	16.00	48.40	6.00	65.00	0.00	65.00	163.00	NR	0.00	0.33
Maximum	19.63	8.78	783.00	12.61	118.80	474.00	689.00	78.20	3.70	78.20	64.40	7.82	222.00	0.00	222.00	187.00	NR	0.00	1.66

Crooked Creek

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
3/17/2010	9.17	8.42	935.9	10.99	106.5	19.6	8.41	117	1.4	39.4	30.9	1.37	232	0	232	276	NR	<0.1	0.181
5/12/2010	8.96	8.14	1626	8.2	NR	1.58	0.66	147	2.2	71.4	146	4.3	271	0	271	811	NR	<0.1	<0.1
6/11/2010	12.76	8.12	587	9.74	102.8	192	29.79	75	1.15	23	12.5	<1.0	225	0	225	114	NR	<0.1	0.18
7/22/2010	16.77	8.22	695.8	9.76	111.8	4.07	15.3	90.9	1.45	29.8	13.5	1.02	232	0	232	161	NR	<0.1	<0.1
9/16/2010	13.86	8.21	1162	10.15	NR	51.4	6.8	140	3	45.2	46.9	1.67	294	0	294	384	NR	<0.1	0.256
12/7/2010	1.57	7.97	899	13.23	NR	23.5	12.75	118	1.18	34.1	23	1.13	248	0	248	249	NR	<0.1	0.352
Count	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	0	6	6
Average	10.52	8.18	984.28	10.35	107.03	48.69	12.29	114.65	1.73	40.48	45.47	1.58	250.33	0.00	250.33	332.50	NR	0.00	0.24
Standard Deviation	5.28	0.15	372.57	1.68	4.52	72.44	9.96	27.72	0.73	16.97	50.86	1.37	27.03	0.00	27.03	252.56	NR	0.00	0.08
Minimum	1.57	7.97	587.00	8.20	102.80	1.58	0.66	75.00	1.15	23.00	12.50	<1.0	225.00	0.00	225.00	114.00	NR	0.00	<0.1
Maximum	16.77	8.42	1626.00	13.23	111.80	192.00	29.79	147.00	3.00	71.40	146.00	4.30	294.00	0.00	294.00	811.00	NR	0.00	0.35

Table 13 cont.

Layout Spring

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	ANC
	°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	mg/L
3/17/2010	5.42	8.24	314	10.77	94.9	0.63	1.172	46.9	0.468	16	0.612	<1.0	163	0	163	5.34	NR	<0.1	0.285	173
5/12/2010	5.55	7.93	305	9.98	NR	1.62	1.39	41.4	0.299	14.4	0.524	<1.0	162	0	162	5.69	NR	<0.1	0.261	166
6/11/2010	4.75	7.83	174	11.16	96.6	0.45	11.5	42	0.21	14.5	0.543	<1.0	210	0	210	2.08	NR	<0.1	0.135	173
7/22/2010	5.09	7.61	314.5	10.62	92.3	0.15	3.16	47.2	0.342	15.3	0.704	<1.0	168	0	168	4.15	NR	<0.1	0.141	180
9/16/2010	5.36	8.02	329	11.15	NR	0.57	1.82	44.5	0.386	15	0.647	<1.0	169	0	169	4.07	NR	<0.1	0.143	173
12/6/2010	5.48	8.3	321	9.31	NR	0.26	1.32	42.3	0.217	14	<0.5	<1.0	162	0	162	5	NR	<0.1	0.231	160
Count	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	0	6	6	6
Average	5.28	7.99	292.92	10.50	94.60	0.61	3.39	44.05	0.32	14.87	0.61	#DIV/0!	172.33	0.00	172.33	4.39	NR	0.00	0.20	171
Standard Deviation	0.30	0.26	58.80	0.73	2.17	0.53	4.04	2.55	0.10	0.72	0.07	#DIV/0!	18.70	0.00	18.70	1.30	NR	0.00	0.07	7
Minimum	4.75	7.61	174.00	9.31	92.30	0.15	1.17	41.40	0.21	14.00	<0.5	0.00	162.00	0.00	162.00	2.08	NR	0.00	0.14	160
Maximum	5.55	8.30	329.00	11.16	96.60	1.62	11.50	47.20	0.47	16.00	0.70	0.00	210.00	0.00	210.00	5.69	NR	0.00	0.29	180

Layout Creek blw Road

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
3/17/2010	Dry						0												
5/12/2010	Dry						0												
6/11/2010	8.51	8.29	311.1	10.7	101.9	2.46	11.7	42.5	0.237	14.6	0.729	<1.0	174	0	174	3.54	NR	<0.1	<0.1
7/22/2010	15.95	8.34	333.5	8.51	96.5	1.07	0.89	46.5	0.293	16.3	0.938	<1.0	172	0	172	9.66	NR	<0.1	<0.1
9/16/2010	11.16	8.04	398	8.4	NR	3.37	NR	51.7	0.261	18.4	1.42	<1.0	NR	0	372	13.2	NR	<0.1	<0.1
12/6/2010	Dry						0												
Count	6	3	3	3	3	3	6	3	3	3	3	3	3	3	3	3	0	3	3
Average	11.87	8.22	347.53	9.20	99.20	2.30	2.52	46.90	0.26	16.43	1.03	#DIV/0!	173.00	0.00	239.33	8.80	NR	0.00	0.00
Standard Deviation	3.77	0.16	45.12	1.30	3.82	1.16	5.15	4.61	0.03	1.90	0.35	#DIV/0!	1.41	0.00	114.90	4.89	NR	0.00	0.00
Minimum	8.51	8.04	311.10	8.40	96.50	1.07	0.00	42.50	0.24	14.60	0.73	0.00	172.00	0.00	172.00	3.54	NR	0.00	0.00
Maximum	15.95	8.34	398.00	10.70	101.90	3.37	11.70	51.70	0.29	18.40	1.42	0.00	174.00	0.00	372.00	13.20	NR	0.00	0.00

Table 13 cont.

Trail Creek																			
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
3/17/2010	6.67	8.24	1592	11.1	101.5	0.75	0.99	250	1.91	74.2	19.6	2.75	177	0	177	790	NR	<0.1	0.153
5/12/2010	8.94	7.89	1500	9.9	NR	0.75	0.85	215	1.88	65.5	20	3.77	185	0	185	824	NR	<0.1	0.112
6/11/2010	11.71	8.08	1527	9.87	101.8	1.17	0.77	215	1.74	64.9	19.1	2.62	175	0	175	811	NR	<0.1	<0.1
7/22/2010	13.02	7.98	1479	9.38	99.3	1.76	0.19	234	2.08	69	18.5	2.86	170	0	170	825	NR	<0.1	<0.1
9/16/2010	14.36	8.1	1496	9.2	NR	14.8	0.63	229	1.98	67	19.4	2.21	170	0	170	775	NR	<0.1	<0.1
12/6/2010	6.5	7.9	1529	8.63	NR	2.98	0.68	225	1.86	63.6	17.6	2.6	177	0	177	795	NR	<0.1	0.165
Count	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	0	6	6
Average	10.20	8.03	1520.50	9.68	100.87	3.70	0.69	228.00	1.91	67.37	19.03	2.80	175.67	0.00	175.67	803.33	NR	0.00	0.14
Standard Deviation	3.32	0.13	39.92	0.84	1.37	5.50	0.27	13.18	0.11	3.83	0.86	0.52	5.57	0.00	5.57	20.03	NR	0.00	0.03
Minimum	6.50	7.89	1479.00	8.63	99.30	0.75	0.19	215.00	1.74	63.60	17.60	2.21	170.00	0.00	170.00	775.00	NR	0.00	<0.1
Maximum	14.36	8.24	1592.00	11.10	101.80	14.80	0.99	250.00	2.08	74.20	20.00	3.77	185.00	0.00	185.00	825.00	NR	0.00	0.17

Appendix B
Spring Data Summary Tables

Table 14. Results for BICA springs in 2010. NA – not applicable; ND – below detection limit; NR – not reported.

Trail Creek Campground Spring															
Date	T	pH	SpEC	DO	DO	Turbidity	Q	Ca	K	Mg	Na	Cl	SO_4	NO_3	ANC
	°C		µS/m	mg/L	%sat	NTU	Liters/sec	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
5/12/2010	10.57	7.44	1630	8.64	NR	0.51	6.1	247	2	63.8	17.5	2.62	881	0.241	183
12/6/2010	10.79	7.5	1653	7.47	NR	0.67	1.015	255	1.93	61.7	16.6	2.54	930	0.237	173
Count	2	2	2	2	0	2	2	2	2	2	2	2	2	2	2
Average	10.68	7.47	1641.50	8.06	NR	0.59	3.56	251.00	1.97	62.75	17.05	2.58	905.50	0.24	178.00
Standard Deviation	0.16	0.04	16.26	0.83	NR	0.11	3.60	5.66	0.05	1.48	0.64	0.06	34.65	0.00	7.07
Minimum	10.57	7.44	1630.00	7.47	0.00	0.51	1.02	247.00	1.93	61.70	16.60	2.54	881.00	0.24	173.00
Maximum	10.79	7.50	1653.00	8.64	0.00	0.67	6.10	255.00	2.00	63.80	17.50	2.62	930.00	0.24	183.00

Hillsboro Main Spring															
Date	T	pH	SpEC	DO	DO	Turbidity	Q	Ca	K	Mg	Na	Cl	SO_4	NO_3	ANC
	°C		µS/m	mg/L	%sat	NTU	cfs	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
5/12/2010	10.32	7.47	512	8.02	NR	0.15	0.33	62.3	0.55	24.7	6.08	1.22	94.6	0.178	199
12/6/2010	10.31	7.61	515	6.73	NR	0.17	0.34	61.3	0.58	23.4	5.24	1.05	82.3	0.162	190
Count	2	2	2	2	0	2	2	2	2	2	2	2	2	2	2
Average	10.32	7.54	513.50	7.38	NR	0.16	0.34	61.80	0.57	24.05	5.66	1.14	88.45	0.17	194.50
Standard Deviation	0.01	0.10	2.12	0.91	NR	0.01	0.01	0.71	0.02	0.92	0.59	0.12	8.70	0.01	6.36
Minimum	10.31	7.47	512.00	6.73	0.00	0.15	0.33	61.30	0.55	23.40	5.24	1.05	82.30	0.16	190.00
Maximum	10.32	7.61	515.00	8.02	0.00	0.17	0.34	62.30	0.58	24.70	6.08	1.22	94.60	0.18	199.00