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Natural Resource Stewardship and Science

Water Quality Data Summary Report for Bighorn Canyon National Recreation Area

Preliminary Analysis of 2011 and 2012 Data

Natural Resource Data Series NPS/GRYN/NRDS—2013/482

ON THE COVER

Field activities in Layout Creek, Bighorn Canyon National Recreation Area
Photograph courtesy of NPS

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Data in this report were collected and analyzed using methods based on established, peer-reviewed protocols and were analyzed and interpreted within the guidelines of the protocols. This report received formal peer review by subject-matter experts who were not directly involved in the collection, analysis, or reporting of the data, and whose background and expertise put them on par technically and scientifically with the authors of the information.

This report is available from the Greater Yellowstone Network website (http://science.nature.nps.gov/im/units/gryn/), the Natural Resource Publications Management website (http://www.nature.nps.gov/publications/nrpm/), and the Integration of Natural Resource Management Applications website (https://irma.nps.gov/).

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Executive Summary

This report summarizes discharge and water quality monitoring data in Bighorn Canyon (BICA) National Recreation Area (NRA) for calendar years 2011 and 2012. Monitoring activities during this reporting period included the installation of continuous stage monitoring instrumentation in four springs and one stream and the chemical, biological, and discharge monitoring of springs, streams, and rivers within the NRA. Results presented include annual and long-term discharge summaries for the Bighorn and Shoshone Rivers, chemical characters and discharge of monitored springs, and an evaluation of chemical and biological conditions of rivers and streams relative to state and federal water quality standards. These results are considered provisional and, therefore, may be subject to change.

River discharge. Hydrographs for the Bighorn River and Shoshone River exhibit a general pattern of high spring flows and lower baseflows occurring in late summer and extending into fall. There are also marked changes in discharge associated with the seasonal management of reservoirs (Bighorn River at St. Xavier, Montana) or intentional water level manipulations for storage purposes (Shoshone River at Lovell, Wyoming). Daily river flows for all river sites in 2011 were at or near the 75^{th} percentile of daily flows for the periods of record. In contrast, 2012 daily discharge measurements were similar to the 25^{th} percentile of daily flows. High among-year variation in annual cumulative river flow has been documented for rivers in this region, but decadal flow summaries show current discharge patterns are lower than historic records.

Water quality monitoring of rivers. Analytical results show that dominant cations across all large river sites were calcium, sodium, and to a lesser extent, magnesium. Dominant anions for the Bighorn and Shoshone Rivers were bicarbonate and sulfate. Despite large differences in discharge between calendar years 2011 and 2012, there was little variation in the ionic composition and concentration of the dominant ions across years and sites.

Escherichia coli monitoring in the Shoshone River. *E. coli* levels from individual samples collected from the Shoshone River near Lovell, Wyoming and just outside the NRA boundary were elevated but variable during summer months. The five-day geometric mean *E. coli* concentration for all months (May to September) sampled across four calendar years (2009 to 2012) exceeded Wyoming state standards. *E. coli* levels were inversely correlated with river discharge and marginally, positively correlated with specific conductance.

Spring discharge. Discharge monitoring capabilities in BICA were dramatically improved in 2011 following the installation of continuous monitoring equipment at three springs and one stream. Water depth and temperature loggers were installed at Lockhart Stockpond Spring, Mason-Lovell Spring, Layout Spring, and Layout Creek. In addition, a pressure transducer was also installed in the orifice at Layout Spring. Water depth/stage discharge relationships were established for each of the above sites using water depth/stage estimates and field discharge measurements. Modeled discharge closely tracked field discharge measurements at Layout Creek, Layout Spring, and Mason-Lovell Spring. There was a poor relationship between discharge and stage at Lockhart Stockpond, however, and this may be related to field techniques used to estimate discharge at that site rather than variability in spring discharge.

Water quality monitoring of springs and streams. The ionic composition of streams and springs in BICA has been monitored since 2004 and continues to show that spring chemistry differs by geologic province. Sulfate levels in springs are typically high except for springs emerging from Bighorn Dolomite or Madison Limestone (e.g., Layout Spring). Nitrogen and phosphorus in monitored springs and streams in BICA were low and below detection levels during many monitoring visits. No exceedances of Montana's Numeric Nutrient Standards for wadeable streams were documented during the 2011 and 2012 reporting period.

Acknowledgments

The authors would like to acknowledge and thank the crew members that have assisted with field sampling: Jordanna Black, Ashley Kroon, and Kyle Mehrens. Thanks also to Kristin Legg for her support and valuable contributions in the field and on prior versions of this report. Cassity Bromley, Chief of Resources at Bighorn Canyon National Recreation Area, has been extremely helpful throughout the monitoring program and has contributed in the field, through reviews of reporting materials, and by orchestrating necessary logistical support to crews while in the field.

This work was funded by the National Park Service Greater Yellowstone Network Inventory & Monitoring Network and represents a collaboration between the National Park Service and Montana State University Extension Water Quality.

Introduction

Bighorn Canyon National Recreation Area (BICA) lies in a sparsely populated region between the Bighorn and Pryor Mountains in southeast Montana and north central Wyoming (Figure 1). At the heart of the recreation area is Bighorn Lake; at an elevation of 1,115 meters (3,657 feet), Bighorn Lake encompasses 7,001 surface hectares (17,300 acres) and is an important recreational destination for anglers, birders, boaters, and many more. At full pool, the lake impounds more than 1.6 billion m^3 (1.3 million acre-feet) of water (BOR 2012) and provides irrigation water, flood control, and power generation for the region (Komp et al. 2012). The Bighorn and Shoshone Rivers are the principal tributaries to the reservoir and at least 35 identified springs, many that flow year-round, are distributed throughout the park (Jacobs et al. 1996). Despite their relative abundance in BICA, springs represent less than 1% of the land area, but directly or indirectly provide the majority of surface water to 19,000 hectares (46,000 acres) of upland, riparian, and lotic ecosystems (Schmitz 2007).

The climate in BICA varies dramatically across its north-south orientation. Using the Köppen climate classification system (Pidwirny and Saundry 2011), the northern portions of the park are semi-arid (BSk–Midlatitude steppe), while the southern portions are more arid (BWk–Midlatitude desert). The climate is continental and influenced by the presence of the Absaroka Mountain Range and Beartooth Mountains to the west. The Prior and Bighorn Mountains also influence local weather patterns, particularly in northern portions of the park. These local ranges receive disproportionately more precipitation, much of it as snow, and create a rain shadow effect at lower elevations (Komp et al. 2012). In the northern-most regions of BICA, average annual precipitation is 45 cm with 57% of the moisture delivered from March to July (Figure 2a). The annual monthly temperature maxima occur in July; on average February is the driest month (Western Regional Climate Center 2013). From 1948 to 2012, the maximum and minimum recorded daily temperature range for the Yellowtail Dam Station (249240) is -37°C (February 17, 2006) to 42.8°C (July 14, 2002 and 2005).

In the southern portion of the park, rainfall is much reduced (approximately 37% of that measured at Yellowtail Dam; Komp et al. 2012) with a more arid climate characteristic of the high desert. In Lovell, Wyoming (just west of BICA in the south end of the national recreation area (NRA); Lovell Station 485770) average annual precipitation is approximately 17 cm with 58% of the moisture delivered from March to July (Figure 2b). At Lovell, weather summaries from 1897 to 2012 indicated that monthly mean temperatures are highest in July and August and lowest in January, and the maximum and minimum recorded daily temperature range is -44.4°C (February 5, 1899) to 43.9°C (June 29, 1919). Climographs from weather stations at Yellowtail Dam (St. Xavier, Montana) and Lovell, Wyoming are shown in Figure 2.

Overview of Bighorn Canyon NRA Water Resources

Surface waters in BICA located within the State of Wyoming have been designated as Class 2AB—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 fish and drinking water uses are attainable (WYDEQ 2007). The Bighorn River within the state of Montana has been classified as B-1 using the Montana Water Classification System. A B-1 water body is one that is suitable for: drinking (after conventional treatment), full contact recreation, growth and propagation of salmonid fishes and associated aquatic life, waterfowl, and furbearers, and agricultural and industrial water supply. Bighorn Lake has been classified as a C-3 water, which is suitable for all uses except drinking water; the C-3 designation indicates support of warm-water fish. Beneficial uses for some surface waters within BICA have not yet been classified by the state of Montana (e.g., Medicine Creek; MTDEQ 2012b).

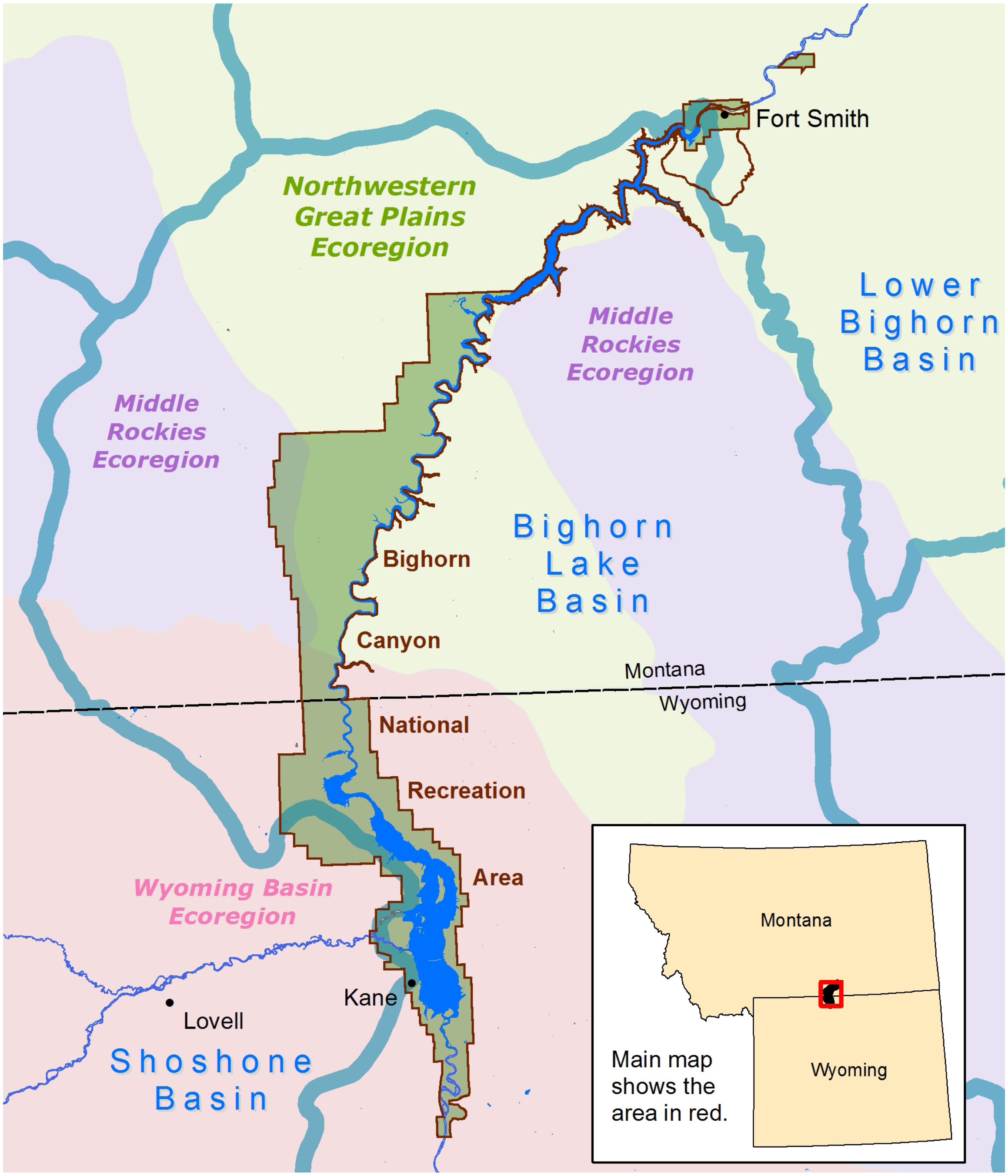


Figure 1. Bighorn Canyon National Recreation Area and U.S. Environmental Protection Agency Ecoregion Level III location maps.

Both the Shoshone and Bighorn Rivers have been greatly altered by several large irrigation, power, and flood control projects (Akashi 1988, WYDEQ 2012). Although many small, low-order streams are still unaffected by diversions and reservoirs, natural snowmelt hydrographs of the Shoshone and Bighorn Rivers no longer exist within the park and likely affect bank stability, channel substrates, and riparian vegetation. In fact, the Shoshone River is reportedly one of the main contributors of suspended sediments to the Bighorn River (Soil Conservation Service 1994). The hydrograph of the Bighorn River is influenced by operations of Yellowtail Dam and in recent decades by reduced snowpacks and warmer temperatures. Yellowtail Dam also limits flow variability, which has influenced floodplain communities. Specifically, cottonwood (*Populus deltoides*) recruitment has been limited (Ladenburger et al. 2006) and stands of exotics, such as Russian olive (*Elaeagnus angustifolia*)

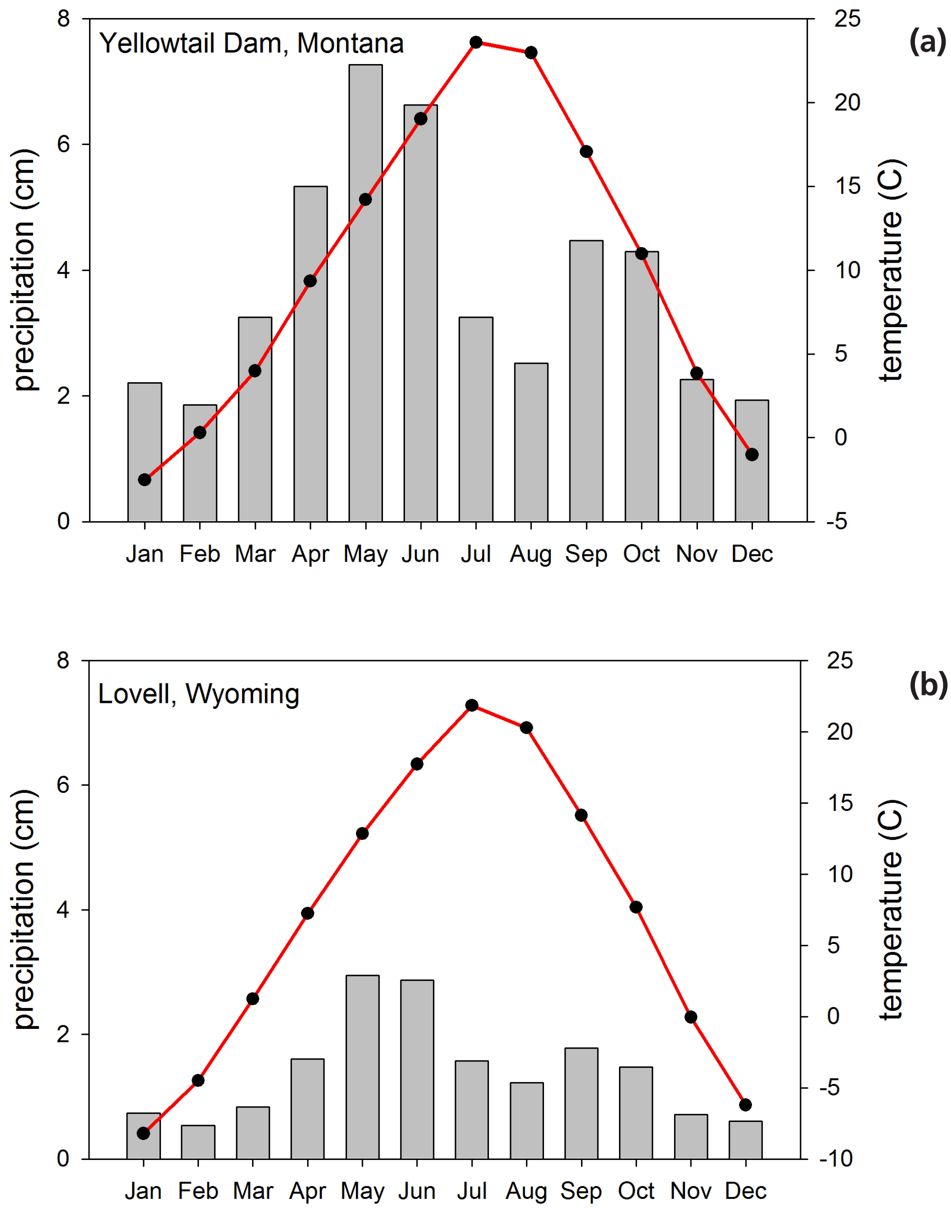


Figure 2. Climographs constructed from monthly meteorological data from (a) Yellowtail Dam Station (249240) near St. Xavier, Montana and (b) from Lovell, Wyoming (485770). Average monthly precipitation (cm; gray bars) and temperature (°C; red line) are shown for each location. Summaries were generated using the period of record at each station (Yellowtail Dam Station [1948-2012] and Lovell, Wyoming Station [1897-2012].

and saltcedar (*Tamarix* spp.), occur in portions of the NRA (Komp et al. 2012). The combined effects of flow alteration and shifts in the composition of riparian communities have likely contributed to changes in the structure and function of floodplains and riparian areas at the northern end of BICA and below Yellowtail Dam.

As noted, seeps and springs are relatively common in BICA and at least 35 springs have been located. While springs in BICA undoubtedly exhibit some hydrogeochemical similarities, temporal and spatial integration of geoclimatic factors in groundwater reservoirs are believed to produce unique chemical signatures for each spring. In addition, spring discharge is believed to be an expression of groundwater reservoir size and complexity and as a result, the timing and magnitude of discharge responses likely vary by spring (Manga 2001). The perennial nature of spring discharge interacts with the unique elevation, chemistry, and disturbance regime of each spring to structure aquatic assemblages that may be distinct to these resources (Stagliono 2008, Myers and Resh 2002).

Characterization and routine monitoring of water chemistry and discharge of BICA's major rivers and representative springs and seeps has been carried out by GRYN, BICA, and university researchers since 2006. This report summarizes monitoring activities in BICA during calendar years (CY) 2011 and 2012. We also briefly describe the installation of continuous monitoring equipment in springs and streams completed in 2011 and summarize chemical, biological, and discharge monitoring of springs, streams, and rivers within BICA during 2011 and 2012.

Water Quality Standards that Apply to Bighorn Canyon National Recreation Area

Federal Water Quality Criteria

The Environmental Protection Agency (EPA) aquatic life water quality standards were examined along with state (Montana and Wyoming) water quality criteria to assess whether BICA's streams and rivers were meeting water quality standards. Water resource monitoring in BICA does not include constituents on EPA's national priority pollutants (http://water.epa.gov/scitech/methods/cwa/pollutants.cfm), however, federal criteria for non-priority pollutants are based on EPA National Recommended Water Quality Criteria (http://water.epa.gov/scitech/swguidance/standards/criteria/current/index.cfm). Federal and state water quality criteria are presented in Table 1.

Pursuant to Section 305(b) of the Clean Water Act (CWA), on alternating years states are required to provide the EPA with a report summarizing their state's water quality conditions (see MTDEQ 2012b, WYDEQ 2012). Included in these reports are listings of waters that are fully supporting all beneficial uses (Category 1); waters where available data and information indicate that some, but not all, of the beneficial uses are supported (Category 2A); waters where available data and information indicate that a water quality standard is exceeded because of an apparent natural source in the absence of any identified anthropogenic sources (Category 2B); waters that have not been assessed or have insufficient data to evaluate their use support levels (Category 3); waters where one or more beneficial uses have been assessed as impaired or threatened, however, all necessary total maximum daily loads (TMDLs) either have been completed (Category 4A) or are not required (Category 4C); and waters where one or more applicable beneficial uses have been assessed as being impaired or threatened, and a TMDL is required to address the factors causing the impairment or threat (Category 5). A TMDL specifies the amount of a particular pollutant that may be present in a water body, allocates allowable pollutant loads among sources, and provides the basis for attaining or maintaining water quality standards. Category 5 waters are those included on a state's 303(d) list. Both Category 4 and Category 5 waters have failed to meet water quality standards and, as a result, are unable to attain their designated uses and are given a priority for monitoring.

Montana Water Quality Standards and Water Classification System

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 2012b:3). Montana numeric water quality standards were developed to protect designated beneficial uses for Montana's waters. Recognized uses include growth and propagation of fish, waterfowl, and furbearers, drinking water use, culinary and food processing, recreation, and agriculture. Standards are further divided into five categories: toxic, carcinogenic, radioactive, nutrients, and harmful. Our focus for assessment of BICA's water resources is on those pollutants that are classified as nutrients (e.g., nitrogen and phosphorus) or harmful (e.g., *E. coli*).

Montana's surface water quality standards vary by surface water classification and by accessibility/wadability. Montana's surface water classification system employs categories that are based primarily on water temperature, the presence of certain species or groups of fish, and aquatic life

Table 1. Summary of water quality criteria (U.S. Environmental Protection Agency, Wyoming, and Montana standards) that apply to surface waters in Bighorn Canyon National Recreation Area.

Regulatory Parameter	Beneficial Use	EPA National Recommended Water Quality Criteria (2012)	Montana Standard: Circular DEQ-7 (2012a), B1 waters and Circular DEQ-12 Parts A and B	Wyoming Standard: WYDEQ Water Quality Rules and Regulations (2007)
Temperature (°C)	Cold-water fisheries	*Species-specific criteria*	Naturally 32°F to 66°F: max change 1°F Naturally >66.5°F: max change 0.5°F	When ambient temp >60°F max change 2°F Max temp should not exceed 68°F
Temperature (°C)	Warm-water fisheries	*Species-specific criteria*		When ambient temp >60°F max change 4°F Max temp should not exceed 86°F
pH	Aquatic life (chronic)	6.5-9.0	6.5-8.5 Normal ± 0.5; if pH is natural >7, it must be maintained above 7	6.5-9.0
Dissolved Oxygen (mg/L)	Aquatic life	For early life stages, cold-water criteria: 8.0 (1-day min) for inter-gravel criteria; 5.0 for early life stages exposed to water column. For other life stages: cold-water criteria is 4.0	For early life stages, cold-water criteria: 8.0 (1-day min) for inter-gravel criteria; 5.0 for early life stages exposed to water column For other life stages: cold-water criteria is 4.0	For early life stages, cold-water criteria: 8.0 (1-day min) for inter-gravel criteria; 5.0 for early life stages exposed to water column. For other life stages: cold-water criteria is 4.0
Turbidity (NTU)	Cold-water fisheries	Natural + ≤10%	Natural + ≤5	Natural + ≤10
Alkalinity (mg/L)	Aquatic life (chronic)	Freshwater (Chronic)=not <20	*Not found in any MT guidance documents*	*Not found in any WY guidance documents*
Chloride (mg/L)	Aquatic life	Freshwater (Acute)=860 mg/L Freshwater (Chronic)=230 mg/L	*Not found in any MT guidance documents*	Aquatic life/Acute=860 mg/L; Aquatic life/ Chronic=230 mg/L
Sulfate (mg/L)	Drinking water	No standard	*Not found in any MT guidance documents*	*Not found in any WY guidance documents*
Total Phosphorus-P (mg/L)	Aquatic life	No standard	Phosphorus is recognized as a plant nutrient that, in excessive amounts, may cause violations of Administrative Rules of Montana (ARM) 17.30.637 (1)(e). Wadeable streams NW Great Plains ecoregion: 0.12 mg/L	*Nutrient criteria under development (see WYDEQ 2008)*
Ammonia (mg/L)	Aquatic life	Acute criteria/pH and temperature dependent; one-hour and 30-day criteria are based on the calculations (provided below)* that are specific to waters that support or lack salmonids or early life stages of fish.	Acute criteria/pH and temperature dependent; one-hour and 30-day criteria with and without salmonids present.	Acute criteria/pH and temperature dependent; from pH 6.5-9.0, acute values for NH3-N plus NH4-N ranges from 0.885 to 32.6 mg/L for coldwater/ salmonids present and from 1.32 to 48.8 mg/L when salmonids absent.
Nitrate+Nitrite-N (mg/L)	Drinking water	10 mg/L	10 mg/L	10 mg/L

Table 1. Summary of water quality criteria (U.S. Environmental Protection Agency, Wyoming, and Montana standards) that apply to surface waters in Bighorn Canyon National Recreation Area (continued).

Regulatory Parameter	Beneficial Use	EPA National Recommended Water Quality Criteria (2012)	Montana Standard: Circular DEQ-7 (2012a), B1 waters and Circular DEQ-12 Parts A and B	Wyoming Standard: WYDEQ Water Quality Rules and Regulations (2007)
Nitrate+Nitrite-N (mg/L)	Aquatic life and recreation	No standard	Nitrate + Nitrite is recognized as a plant complex of nutrient that, in excessive amounts, may cause violations of Administrative Rules of Montana (ARM) 17.30.637 (1)(e).	10 mg/L
Total Nitrogen (mg/L)			Wadeable streams NW Great Plains ecoregion: 1.0 mg/L	*Nutrient criteria under development (see WYDEQ 2008)*
Escherichia coli (colonies/100 mL)	Recreation	Geomean of ≤126	Apr 1 to Oct 31: geomean of ≤126 (10% of the total samples may not exceed 252 during 30 day) Nov 1 to Mar 31: geomean of ≤630 (10% of the total samples may not exceed 1,260 mL during 30 day)	May 1 to Sep 30: geomean of ≤126 Oct 1 to Apr 30: geomean of ≤630

*One-hour acute ammonia-N criterion (in mg/L) is CMC = $(0.275/(1 + 10^{7.204\text{-pH}})) + (39.0/(1 + 10^{\text{pH-}7.204})$ (with salmonids)) or CMC = $(0.411/(1 + 10^{7.204\text{-pH}})) + (58.4/(1 + 10^{\text{pH-}7.204})$ (without salmonids))

30-day chronic ammonia-N criterion (in mg/L) is CCC = $((0.0577/(1+ 10^{7.688\text{-pH}})) + (2.487/(1 + 10^{7.688\text{-pH}}))) \times \text{MIN}(2.85, 1.45 \bullet 10^{0.028 \bullet (25 - T)})$ (when early life stages of fish are present) or CCC = $((0.0577/(1+ 10^{7.688\text{-pH}})) + (2.487/(1 + 10^{7.688\text{-pH}}))) \times 1.45 \bullet 10^{0.028 \bullet (25 - \text{MAX}(T,7))}$

associations. Each class has associated with it the present or future beneficial uses the water body should be supporting (MTDEQ 2012a). Most of the waters within or adjacent to BICA that have been assessed by the State of Montana are classified as B1. Because of their ephemeral nature, it has also been noted that many of BICA's stream sites that fall within the State of Montana may qualify for F-1 classification. Streams with an F-1 classification have low or sporadic flow that, because of natural hydrogeomorphic and hydrologic conditions, are not able to support fish.

Wyoming Water Quality Standards and Water Classification System

The Wyoming surface water standards are based on the Wyoming Surface Water Classification List (WYDEQ 2007) and closely follow federal standards. Rivers and streams within BICA (within Wyoming) have been classified as 2AB. Class 2 waters are waters, other than those designated as Class 1 (Class 1 waters are those surface waters in which no further water quality degradation by point source discharges other than from dams will be allowed), that are known to support fish or supply drinking water or where those uses are believed to be attainable. Class 2 waters are further designated as 2A or 2AB. These waters are known to support game fish populations or spawning and nursery areas at least seasonally and the classification includes all their perennial tributaries and adjacent wetlands. Class 2AB waters are also protected for non-game fisheries, fish consumption, aquatic life other than fish, primary contact recreation, wildlife, industry, agriculture, and scenic value uses (WYDEQ 2007).

Wyoming's water quality standards are described in Chapter 1 of Water Quality Rules and Regulations (WYDEQ 2007) and the agency's plan for developing and implementing nutrient criteria are outlined in the Wyoming Nutrient Criteria Development Plan (WYDEQ 2008).

Bighorn Canyon National Recreation Area's 303(d) Listed Waters

The current list of impaired water bodies in Montana and Wyoming are found in the Montana 2012 Final Water Quality Integrated Report (MTDEQ 2012b) and Wyoming Water Quality Assessment and Impaired Waters List published in 2012 (WYDEQ 2012).

In Montana, Crooked Creek (Category 4C)—24.25 km (15.07 miles) from its headwaters to the Wyoming border—was assessed in June 2006 and was rated as only partially supporting aquatic life uses and cold water fisheries. Montana DEQ states the probable cause as physical substrate alterations caused by an agricultural source. Montana's 2012 305(b)/303(d) list (MT DEQ 2012b) also includes 70.85 km (44.03 miles) of the Bighorn River (Class B-1) from Yellowtail Dam to the Crow Indian Reservation Boundary. This portion of the river is listed as only partially supporting for aquatic life and cold water fisheries because of elevated total nitrogen concentrations (MTDEQ 2012b).

The Shoshone River (Water Quality Reporting Category 5), from its confluence with Bighorn Lake upstream to a location 15.6 km (9.7 miles) upstream has been on Wyoming's 303(d) list since 2002; the cause of the listing stems from fecal coliform contamination. The sources of the contamination have not yet been determined, although cases of poorly operating septic systems reportedly have been documented (WYDEQ 2008). Crooked Creek (Category 4C) flows into Wyoming from Montana, and then flows into Bighorn Lake. Monitoring by WYDEQ indicates that the aquatic life uses in Crooked Creek are fully supported from the irrigation diversion in SWNW Section 29, T58N, R95W upstream to the Montana state line; however, the 6.1 km (3.8 mile) section downstream of this diversion appears in Wyoming's 2012 303(d)/305(b) report. Flow reductions in this section inhibit aquatic life to the extent that cold-water fisheries and aquatic life uses are affected. This effect has reached some sections below springs that appear to have perennial flows (WYDEQ 2008).

Monitoring Objectives

Our specific objectives for purposes of annual reporting are to:

1. Summarize annual discharge and water quality conditions of major rivers systems (Bighorn and Shoshone Rivers) within BICA.

2. Characterize seasonal *Escherichia coli* levels in the Shoshone River.

3. Characterize chemical character and discharge patterns of representative springs and streams.

4. Evaluate whether monitored resources with BICA are meeting state water quality standards.

Methods

Depth integrated water samples were collected four to six times each year for river sites: Bighorn River at Kane, Wyoming; Bighorn River at St. Xavier, Montana; and the Shoshone River at Lovell, Wyoming. In 2011, water samples were also collected from three streams (Crooked Creek, Layout Creek, and Trail Creek) and four springs (Hillsboro Main Spring, Mason-Lovell Spring, Layout Spring, and Trail Creek Campground Spring) following methods described by O'Ney et al. (2009).

In addition to water samples, core field water quality parameters (i.e., temperature, specific conductivity, DO, pH, and turbidity) were characterized in situ using a YSI handheld multi-parameter instrument and a Hach benchtop turbidity meter at a representative location on the river and stream cross-section or from a representative location within monitored springs.

Water samples were collected in wadeable flow conditions using a DH-81 Sampler (Federal Interagency Sedimentation Project, Vicksburg, Mississippi) affixed to a 1-m wading rod. Polypropylene bottles were used with the DH-81 samplers. These bottles were triple rinsed with deionized water between samples to prevent contamination.

Bacterial samples were collected using a grab sample from the Shoshone River near Lovell, Wyoming; water was introduced directly into pre-sterilized, seven-ounce Whirl-Pack containers. *Escherichia coli* and fecal coliforms were enumerated using the IDEXX Colilert following protocols described in Standard Methods (9221 B-2006).

Discharge estimates for river sites were taken from U.S. Geological Survey (USGS)-maintained stations for the Bighorn River (USGS Gage 06279500 for Kane, Wyoming and USGS Gage 06287000 for St. Xavier, Montana) and Shoshone River (USGS Gage 06285100 for Lovell, Wyoming). For stream sites, discharge was estimated at uniform stream sections. In brief, a measuring tape was stretched perpendicular to the stream flow (to divide the river into a minimum of 20 increments) to ensure that no more than 10% of the cross-sectional area was represented by each velocity measurement. If hydraulic irregularities were observed, additional increments were established to account for noticeable anomalies (Gore 1996). All flow measurements were made using an electromagnetic Marsh McBirney velocity meter affixed to a graduated, stainless-steel, top-setting wading rod (Nolan and Shields 2000).

The initial analyses of data presented in this data series report should be considered provisional and subject to change.

Results

Discharge of Bighorn and Shoshone Rivers

Hydrographs for the Bighorn River vary according to location, but exhibit a general pattern of high spring flows and lower baseflows occurring in late summer and extending into fall. There are also marked changes in discharge associated with the seasonal management of reservoirs or intentional water level manipulations for storage purposes. A comparison of Bighorn River hydrographs from Kane, Wyoming (upstream of Yellowtail Dam; Figure 3) and St. Xavier, Montana (downstream of Yellowtail Dam; Figure 4) illustrate such differences and show how operations at Yellowtail Dam affect river flows in the lower river. Despite dam operations, hydrographs in the Bighorn River are generally highest in the springtime with the months of April through June coinciding with the melt-off of snow at higher elevations and high flows (Figure 3).

During 2011, daily flows in the Bighorn River near Kane, Wyoming exceeded the 75th percentile of daily flows for the period of record (1929-2012), however, 2012 daily discharge at this site closely tracked the 25th percentile of daily flows (Figure 3). This level of among-year variation in annual cumulative river flow has been documented throughout the period of record (Figure 5), however, a decadal summary of river flows in the Bighorn River at Kane, Wyoming shows that average flows during the first decade of the 2000s are among the lowest recorded at that station (Figure 6).

Daily flow summaries for the Bighorn River below Yellowtail Dam and near St. Xavier, Montana also show dramatic differences between calendar years 2011 and 2012 (Figure 4). In 2012, an abbreviated peak in the hydrograph occurred on 10 April 2012 and was followed by declining or stable flows throughout the remainder of the year. The 2012 hydrograph contrasts dramatically with 2011 flows and with the long-term hydrographic record (Figure 4). Over the period of record, flows in the Bighorn River below Yellowtail Dam and near St. Xavier, Montana typically peaked during the 4th week of June (approximately day 180), but remained elevated above baseflow

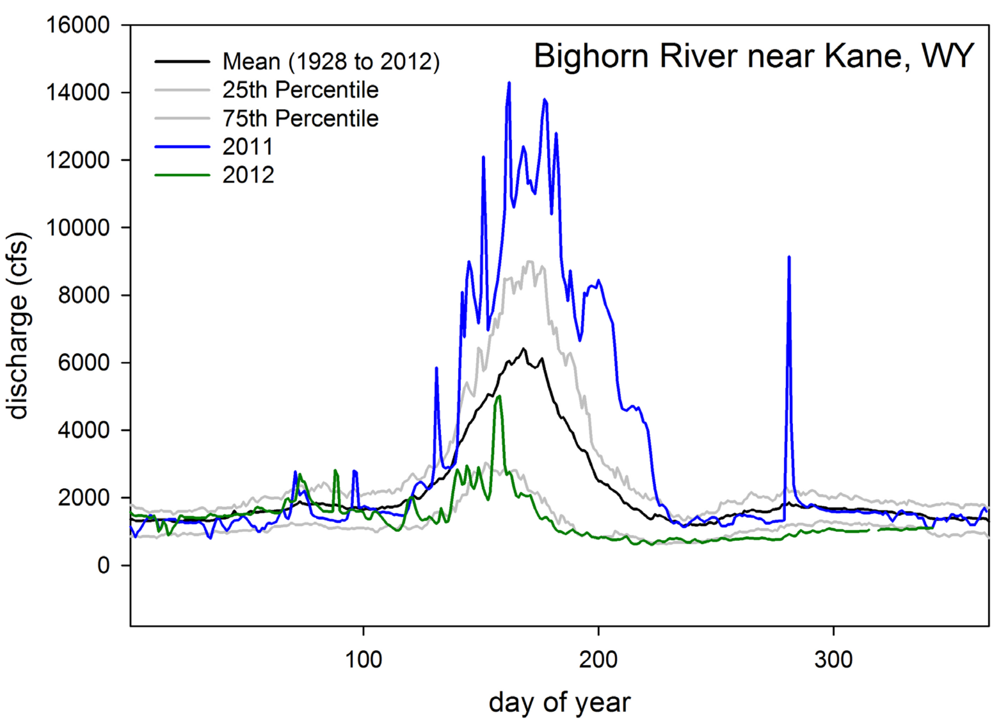


Figure 3. Long-term summary of average daily discharge (in cfs) at the Bighorn River near Kane, Wyoming (USGS Gage 06279500). River flows are presented by day of year where day 1 refers to January 1st of each calendar year. The period of record summarized for this gage extends from 1928 to 2012. Mean daily discharge for the period of record is shown in black and the 25th and 75th percentiles of daily flows are shown in grey. A summary of 2011 (blue) and 2012 (green) are also presented.

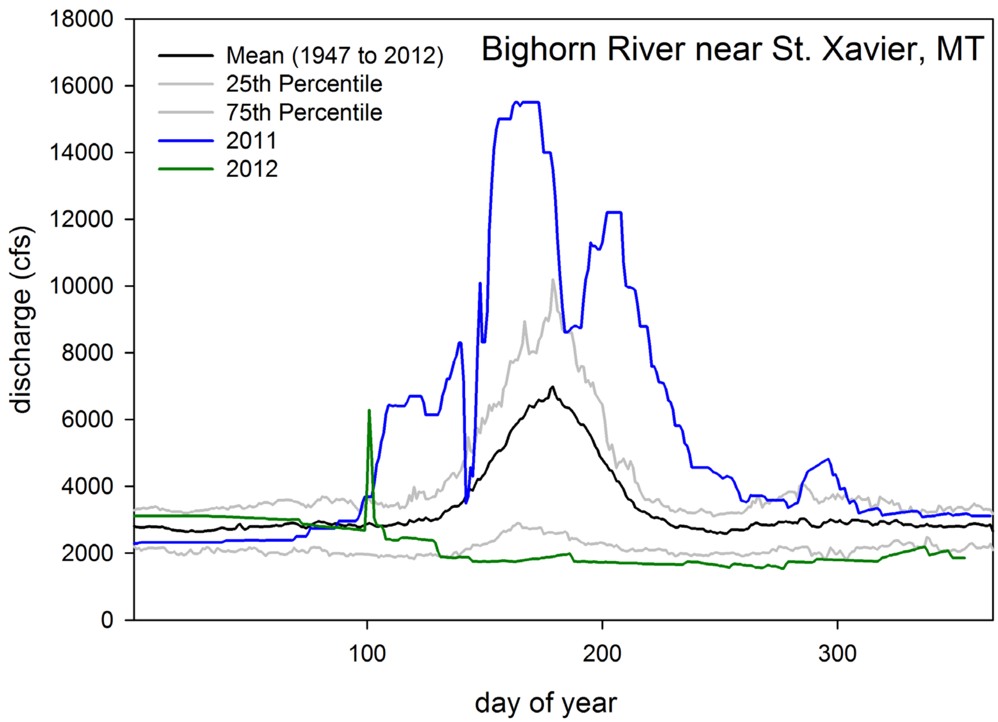


Figure 4. Long-term summary of average daily discharge (in cfs) at the Bighorn River near St. Xavier, Montana (USGS Gage 06287000). River flows are presented by day of year where day 1 refers to January 1st of each calendar year. The period of record summarized for this gage extends from 1947 to 2012. Mean daily discharge for the period of record is shown in black and the 25th and 75th percentiles of daily flows are shown in grey. A summary of 2011 (blue) and 2012 (green) are also presented.

conditions for several weeks (Figure 4). Decadal flow summaries for the lower portion of the Bighorn River mirror those displayed in Figure 6 near Kane, Wyoming and also show that flows during the first decade of the 2000s have been lower than any other decade on record (Figure 7).

Calendar year 2011 and 2012 hydrographs for the Shoshone River at Lovell, Wyoming depict evidence of extensive flow manipulation or irrigation withdrawls/diversions (Figure 8). Alterations of the hydrograph were most apparent in 2011 when daily flows typically exceeded the 75th percentile of daily flows for the period of record. In contrast, 2012 daily flows were considerably lower than the average daily flow during most of the year (Figure 8). Decadal daily flow summaries for the Shoshone River also suggest that peak flows during the first decade of the 2000s are lower and occur earlier in the year than they did in the 1960s, 1970s, and 1980s (Figure 9).

Water Quality of Bighorn and Shoshone Rivers

The ionic composition of BICA's large rivers (Bighorn and Shoshone; Figure 10) were summarized quarterly and by location during calendar years 2011 and 2012 using

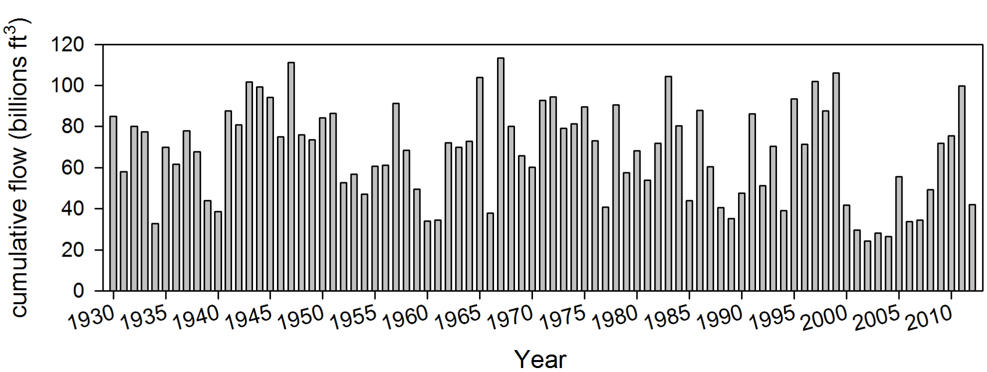
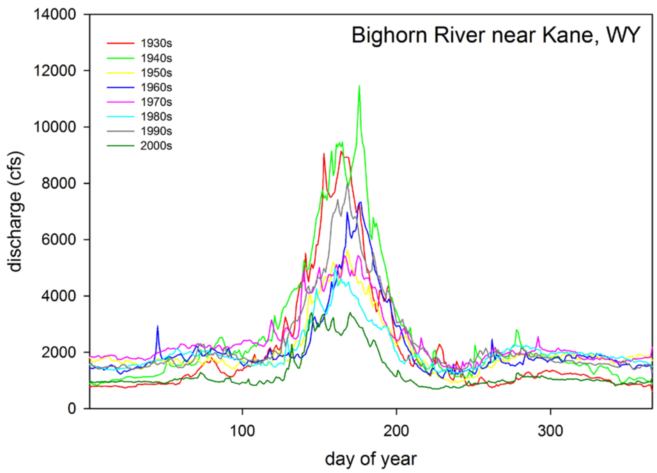


Figure 5. Histogram of annual river flow (in billion ft³) at the Bighorn River near Kane, Wyoming USGS Gage (06279500). Years 1930 to 2012 are summarized and show year fluctuations in annual river flow.



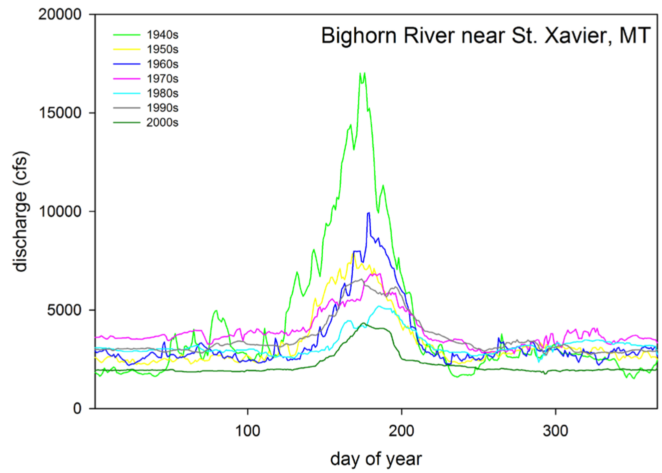
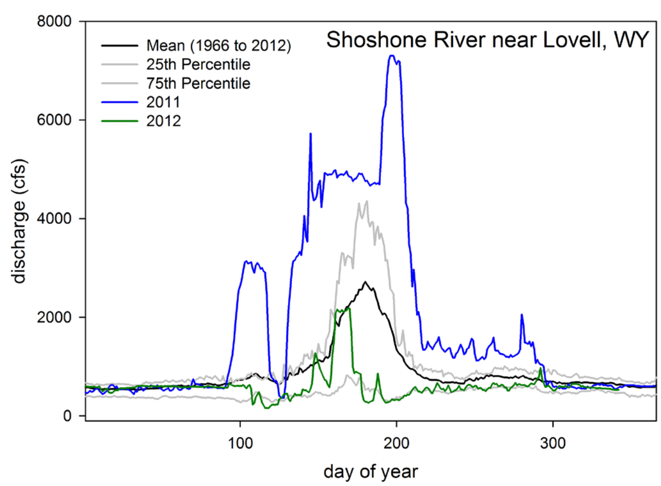


Figure 6. Decadal hydrographs for the Bighorn River near Kane, Wyoming (USGS Gage 06279500). River flows are presented by day of year where day 1 refers to January 1st each year. Years included in this summary span from 1930 to 2010.

Figure 7. Decadal hydrographs for the Bighorn River near Bighorn River near St. Xavier, Montana (USGS Gage 06287000). River flows are presented by day of year where day 1 refers to January 1st each year. Years included in this summary span from 1947 to 2010.



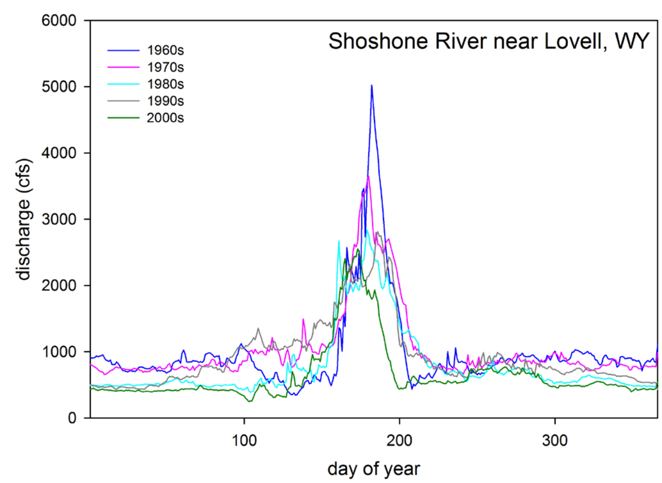


Figure 8. Long-term summary of average daily discharge (in cfs) at the Shoshone River near Lovell, Wyoming (USGS Gage 06285100). River flows are expressed by day of year where day 1 refers to January 1st each year. The period of record summarized for this gage extends from 1966 to 2012. Mean daily discharge for the period of record is shown in black and the 25th and 75th percentiles of daily flows are shown in grey. A summary of 2011 (blue) and 2012 (green) are also presented.

Figure 9. Decadal hydrographs for the Shoshone River near Lovell, Wyoming (USGS Gage 06285100). River flows are presented by day of year where day 1 refers to January 1st each year. Years included in this summary span from 1966 to 2010.

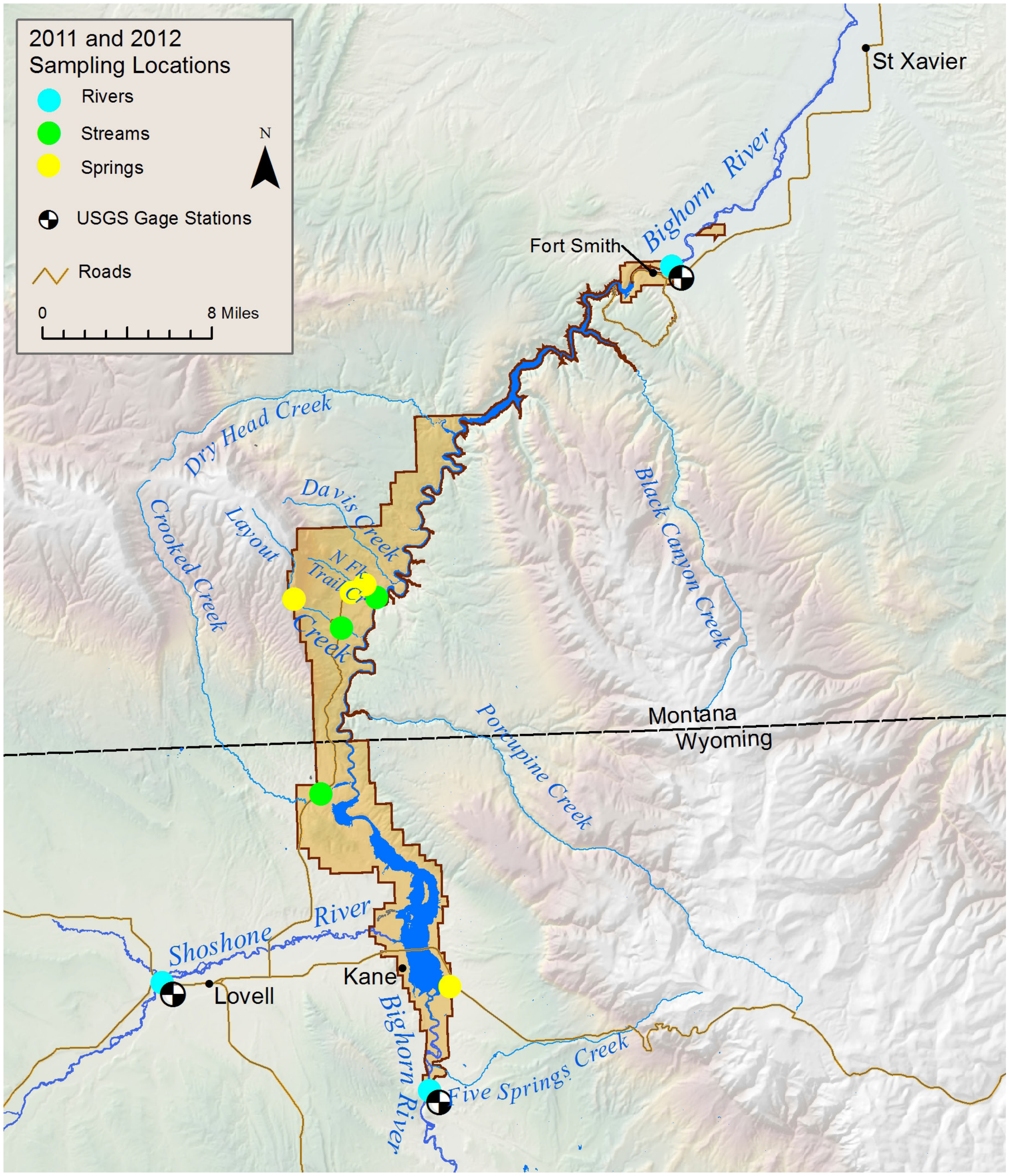


Figure 10. Sampling locations for rivers, streams, and spring sampled in Bighorn Canyon National Recreation Area in calendar years 2011 and 2012.

depth integrated sampling approaches (see Methods). Sampling locations for large river sampling coincided with USGS gaging stations on the Bighorn River (Kane, Wyoming and St. Xavier, Montana) and the Shoshone River near Lovell, Wyoming (Figure 10). Analytical results show that the dominant cations across all large river sites were calcium, sodium, and to a lesser extent, magnesium (Figure 11). Dominant anions were bicarbonate and sulfate. Despite large differences in discharge between calendar years 2011 and 2012, there was little variation in the concentration of the dominant ions across years and sites (Figure 11).

Median two-year concentrations of primary plant nutrients (nitrogen and phosphorus) were greater in the Shoshone River than at either location in the Bighorn River (Figure 12). Variations in these nutrients were also greatest in the Shoshone River (coefficient of variation for NO_3-N was 0.40 and total P was 0.66) with higher levels of both N and P documented throughout the period of sampling. For example, NO_3-N

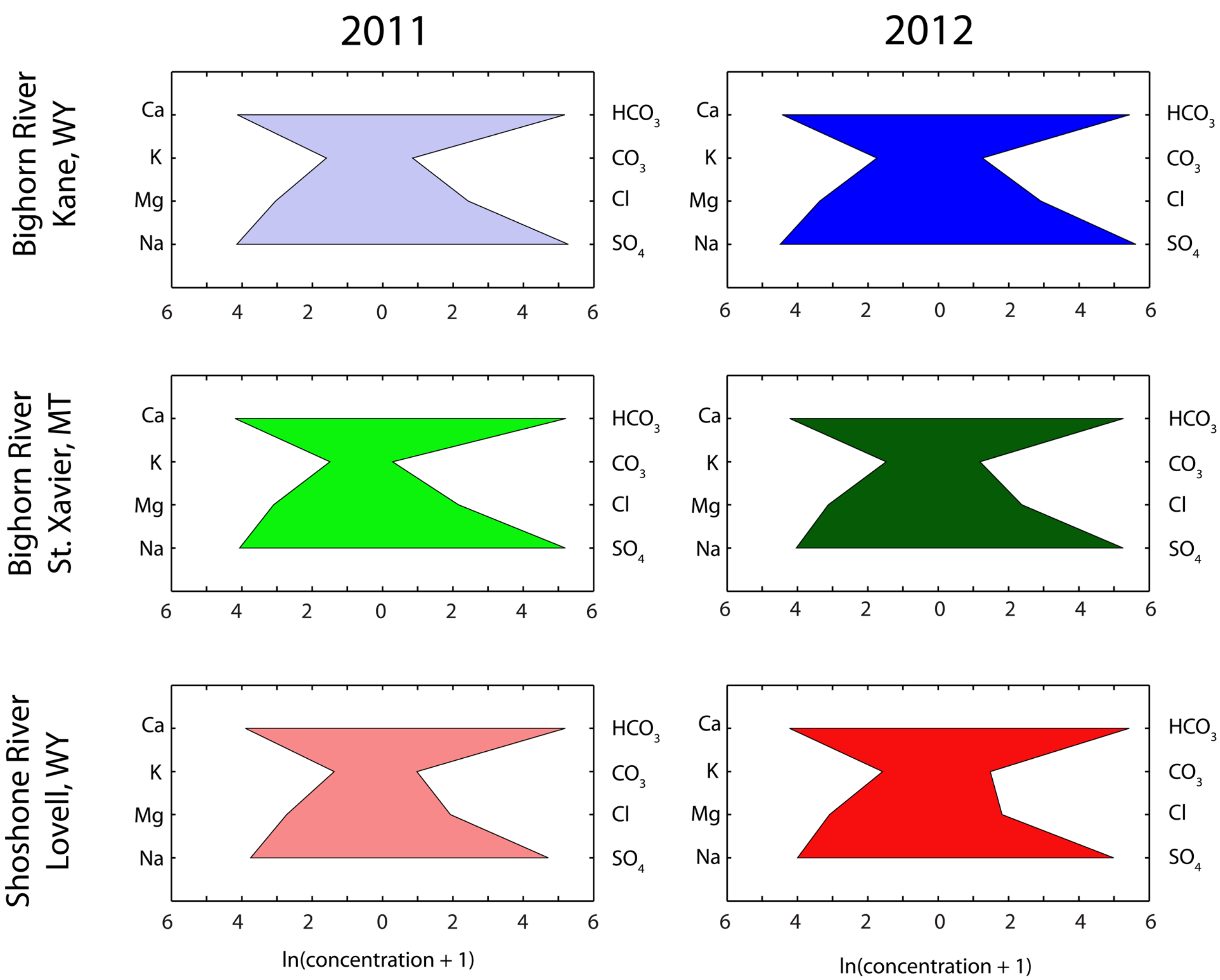


Figure 11. Stiff pattern diagrams summarizing concentrations of major cations (Ca, K, Mg, and Na) and anions (HCO_3, CO_3, Cl, and SO_4) for the Bighorn River (Kane, Wyoming and St. Xavier, Montana) and Shoshone River (near Lovell, Wyoming). All concentrations are natural log-transformed.

concentrations exceeded 1 mg/L in the Shoshone River during the May, September, and December sampling dates in 2012. Despite its partial support designation for aquatic life and cold-water fisheries, the Bighorn River below Yellowtail Dam had a median NO_3-N concentration of 0.4 mg/L (Figure 12) and NH_3-N was always below detection (<0.2 mg/L). Based on these values, it appears that the Bighorn River at both sampling locations is meeting Montana's drinking water standards and is even below Montana's recommended N criteria for wadeable streams (1.0 mg/L Total N).

Seasonal *Escherichia coli* Levels in the Shoshone River

The Shoshone River is listed on Wyoming's 303(d) list for fecal coliform contamination. Accordingly, water samples have been collected from the Shoshone River near Lovell, Wyoming and outside of BICA since 2009. Samples have been collected throughout this period to document trends in *E. coli* levels during summer months (Figure 13) and across different hydrologic years.

Since the risk of human contact to fecal-contaminated surface water is greatest during summer months, water quality standards for *E. coli* are more stringent during summer months (see Table 1). Figure 14 summarizes *E. coli* levels enumerated in the Shoshone River along with river discharge for the period May 1 to September 30 and relative to the State of Wyoming's standard of a geometric mean of 126 organisms per 100 mL (based on a minimum of ≥5 samples obtained during separate 24-hour periods) of source water. *E. coli* levels from individual samples collected from the Shoshone River

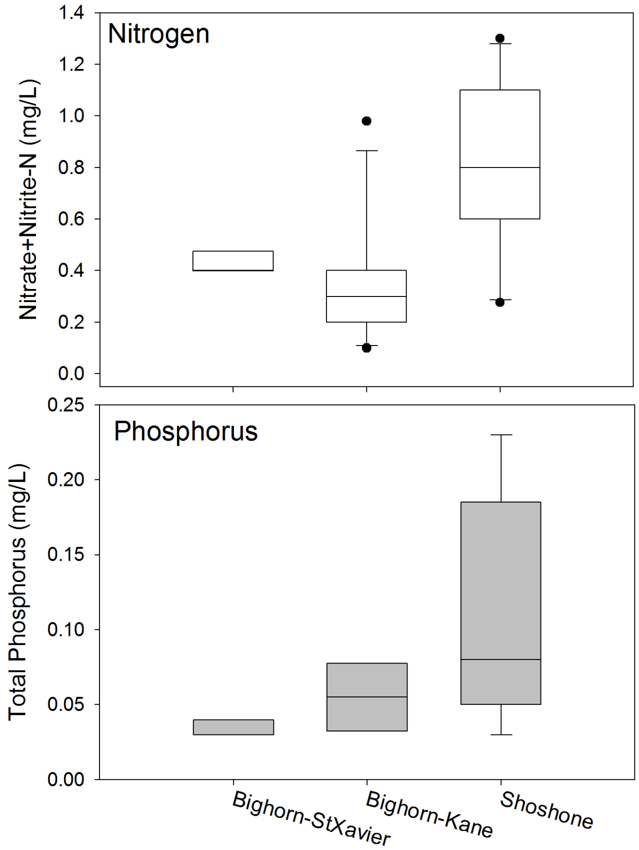


Figure 12. Box plots summarizing nitrogen (expressed as NO_3-N) and total phosphorus concentrations in surface waters collected from the Bighorn River (at St. Xaiver, Montana and Kane, Wyoming) and the Shoshone River (near Lovell, Wyoming). Boxes represent the upper and lower quartiles of the dataset; internal lines indicate the medians. Boxed summaries represent a minimum of three observations. Whiskers are produced when there was a minimum of seven observations and represent the 10th and 90th percentiles.

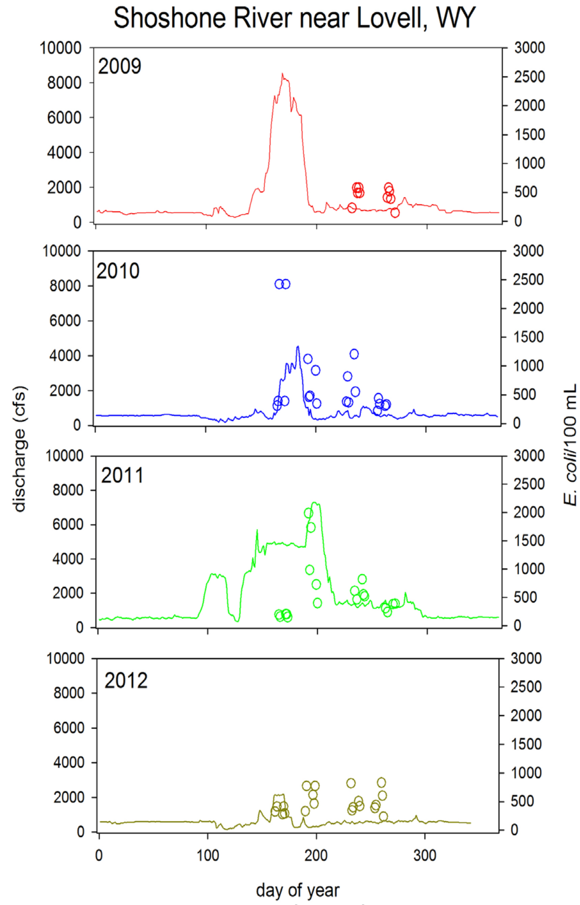


Figure 13. *Escherichia coli* levels (circles) in the Shoshone River near Lovell, Wyoming. *E. coli* levels are plotted by calendar day and along with river discharge (solid line) for years 2009 to 2012. Day of year 1 refers to January 1st of each calendar year.

outside the park boundary were elevated but variable during summer months (Figure 14). Importantly, the five-day geometric mean *E. coli* concentration for all months sampled across four calendar years exceeded Wyoming State Standards (range in five-sample geometric mean: 179 cfu/100 mL [June 2011] to 995 cfu/100 mL [July 2011]; Figure 14).

To further explore which water quality characteristics may be associated with elevated *E. coli* levels, we used correlation analysis to examine the relationship between log-transformed *E. coli* concentrations and several predictor variables: river discharge (average daily discharge in cfs), water temperature (°C), dissolved oxygen (mg/L), pH, conductance (µS/cm), day of year, and time of day. Further, we used linear regression techniques to examine predictive models to summarize *E. coli* concentrations during summer months (May 1 to September 30). Specifically, we used multiple regression to select the best model using only those sampling dates when *E. coli* was enumerated in 2012 (n=20). We used 2012 data because we had a complete set of core water quality parameters measured coincident with samples used for *E. coli* enumeration.

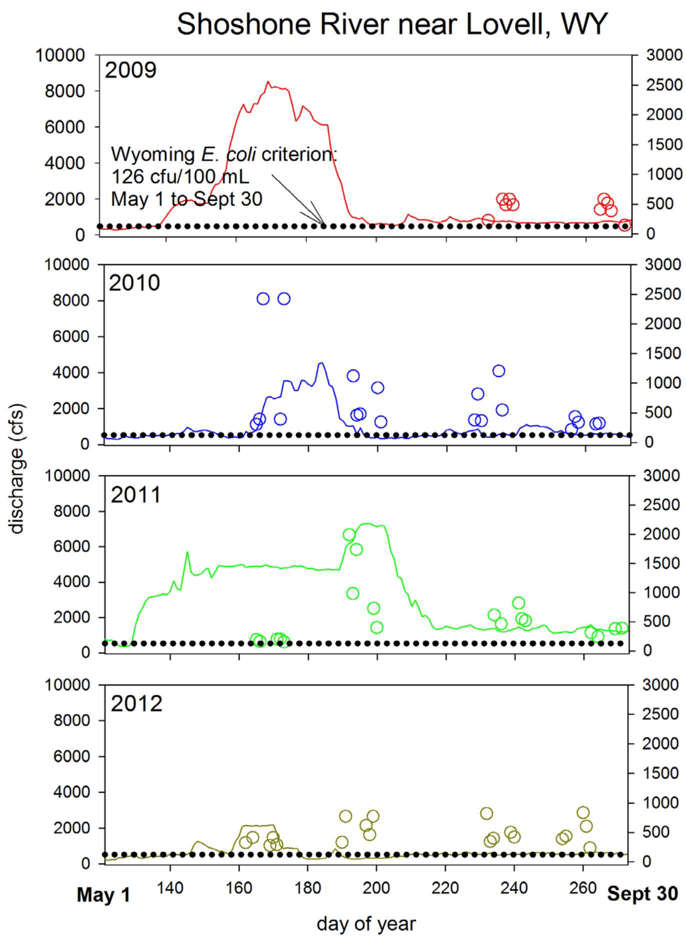


Figure 14. *Escherichia coli* levels (circles) in the Shoshone River near Lovell, Wyoming. *E. coli* levels (colonies/100 mL) are plotted by calendar day along with river discharge (solid line) for years 2009 to 2012. The period of the calendar year (May 1 to September 30) is displayed and corresponds to the Wyoming numeric standard for *E. coli* (126 colonies/100 mL; shown as a dotted line).

We used a stepwise method (Gotelli and Ellison 2004) and the stepping method criteria employed for entry and removal were based on the significance level of the F value and set at 0.05 and 0.10, respectively. Multicollinearity was examined using variance inflator factors (VIF) for each predictor variable; inclusion of additional predictors required VIFs ≤4.

Correlation analysis indicated that log-transformed *E. coli* levels were inversely correlated with river discharge (R=-0.484, P=0.031) and positively correlated with conductance (R=0.459, P=0.042). Using 2012 data, a stepwise regression model selected river discharge as the only explanatory variable and discharge explained only 23% of the variation in Shoshone River *E. coli* levels.

Chemical Character and Discharge Patterns of Representative Springs and Streams

During 2011 and 2012, water quality sampling and discharge measurements were completed in three streams (Crooked Creek, North Trail Creek, and Layout Creek) and four springs (Hillsboro Spring, Layout Spring, Mason-Lovell Spring and Trail Creek Campground Main Spring). A brief description of the chemical composition and continuous discharge measurements are contained below.

Stream and Spring Chemistry

Water quality in streams and springs showed unique chemical signatures. Dissolved calcium (Ca) concentrations in North Trail Creek were, on average, five times higher than Layout Creek and 2.5 times higher

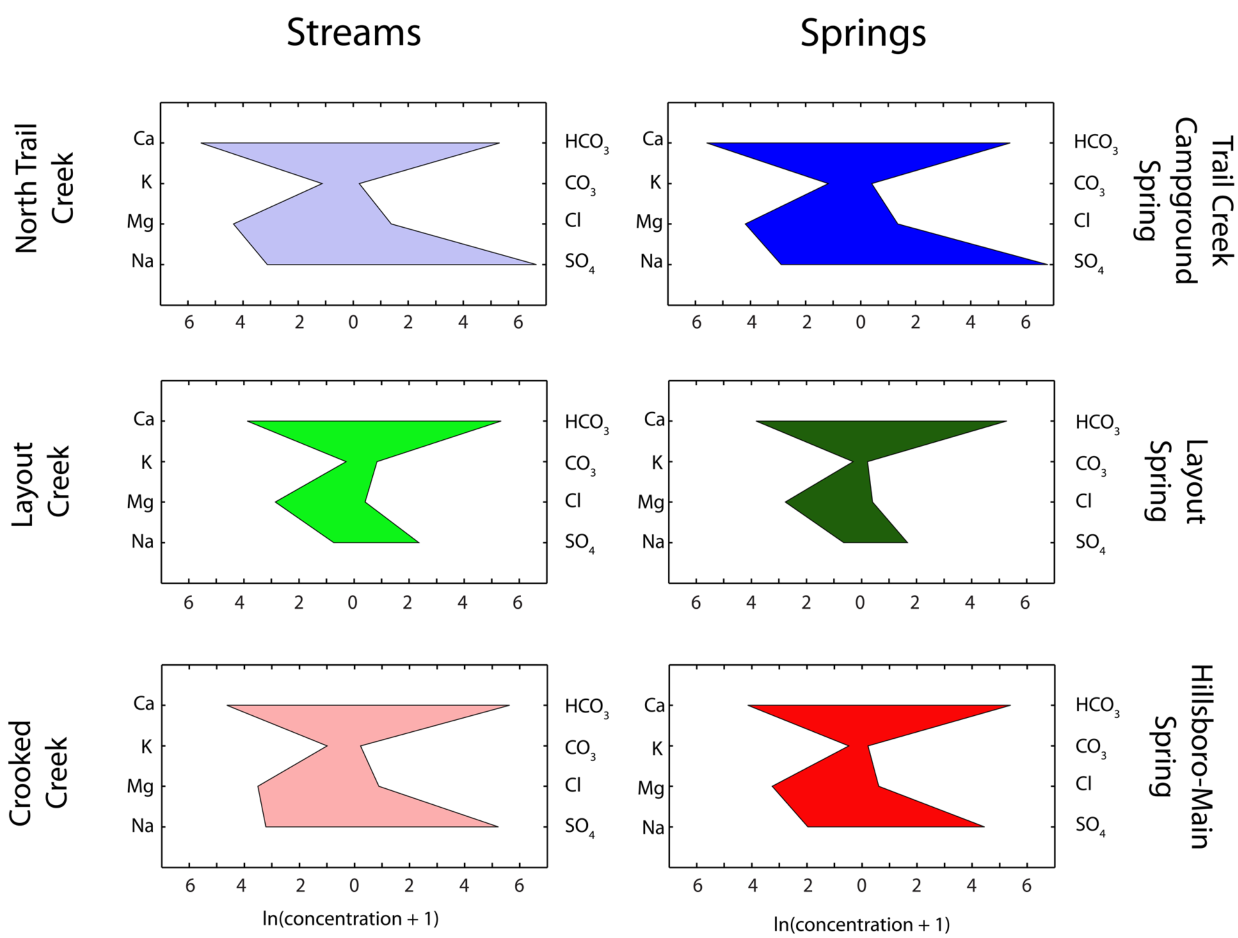


Figure 15. Stiff pattern diagrams summarizing concentrations of major cations (Ca, K, Mg, and Na) and anions (HCO_3, CO_3, Cl, and SO_4) for representative streams and springs in Bighorn Canyon National Recreation Area. All concentrations are natural log-transformed.

than Crooked Creek. Similarly, sulfate concentrations in North Trail Creek were more than 80 times higher than SO_4 levels in Layout Creek. Springs in BICA showed similar levels of variation in major ions; Trail Creek Campground Spring had mean Ca concentrations that were four and five times higher than Hillsboro and Layout Spring. Sulfate levels in the Trail Creek Campground Spring were more than 200 times greater than Layout Spring and more than ten times greater the SO_4 concentrations measured in Hillsboro Spring (Figure 15).

Nitrogen and P in streams in BICA were low, and during most sampling dates, samples from Layout Creek and Trail Creek were below detection levels (Figure 16). No exceedances of Montana's Numeric Nutrient Standards for wadeable streams were documented during the 2011 and 2012 reporting period.

In contrast to streams within BICA, nitrate levels of representative springs were often measurable. Mean nitrate concentrations in Hillsboro, Layout, and Trail Creek Campground springs were 0.191, 0.364, and 0.280 mg NO_3-N/L. A single sample from Mason-Lovell Spring indicated that NO_3-N levels were below 0.100 mg NO_3-N/L. Total phosphorus in surface samples collected from representative springs was almost always below detection levels.

Stream and Spring Discharge

Continuous discharge monitoring of springs in BICA began in 2011 (see Sigler 2012) and continued through 2012 (Figure 17). As with river hydrographs, spring and stream discharge shows dramatic among-year variations at some locations. For example, in Layout Spring and Layout Creek modeled discharge was dramatically higher in

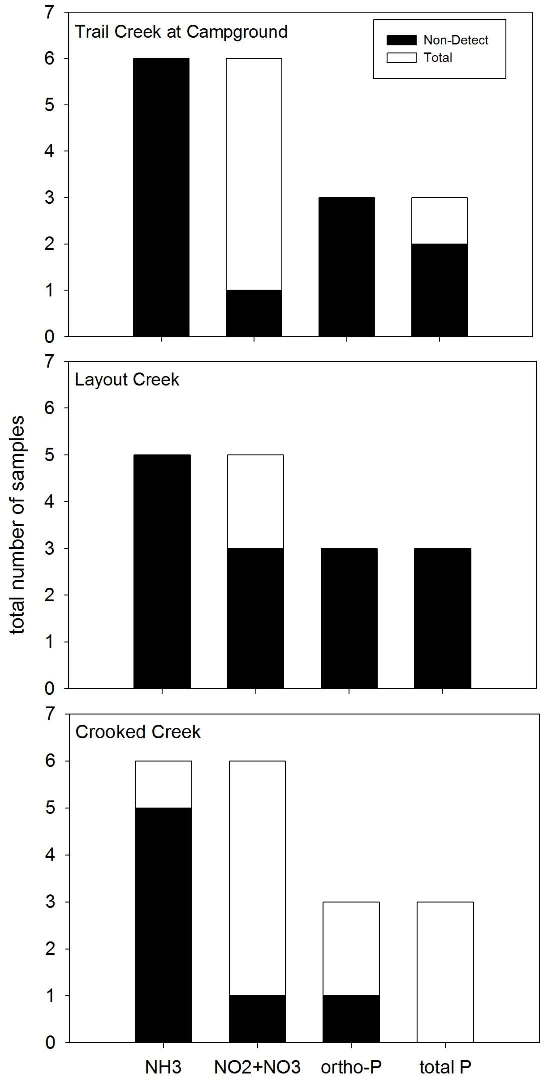


Figure 16. Grouped box plots showing the number of water quality samples with nutrients (ammonia [NH_3], nitrate plus nitrite [NO_2 + NO_3], ortho-phosphorus [ortho-P], and total phosphorus [total P]) results that were below detection (black bars) as a fraction of total number of samples (clear bars) collected from three streams: Trail Creek, Layout Creek, and Crooked Creek.

2011 compared to 2012 (Figure 17). The maximum measured discharge occurred on 22 June 2011, when the measured discharge in Layout Spring was 22 cfs. The empirically derived rating curves for 2011 and 2012 at Layout Spring and Layout Creek are statistically significant ($P<0.05$) however, estimates of discharge above 22 cfs should be viewed carefully since the stage/discharge relationship above this discharge could not be confirmed.

The 2011 and 2012 discharge records for Layout Spring and Layout Creek (Figure 17) are plotted along with commonly used predictors of discharge (USDA NRCS 2013), precipitation and current snow water equivalent (SWE) estimates, measured at local weather (Hillsboro, Montana [HBOM8] Weather Station) and snotel (Bald Mountain, Wyoming snotel courtesy of NRCS) stations. These summaries show that discharge in Layout Spring and Layout Creek track changes in SWE and suggest that this system is predominantly derived from shallow groundwater (Figure 17). Despite the overwhelming suggestion of groundwater influence, there are examples of increased discharge following precipitation events (see early August 2011; Figure 17). During such precipitation events, water may reach the spring from overland flow.

Pressure transducer measurements collected in 2012 in the orifice above Layout Spring (Photo 1) shows much greater variability in stage when compared with continuous readings collected using TruTrack water level loggers (Figure 18). The nature of this pressure variation is unknown and may

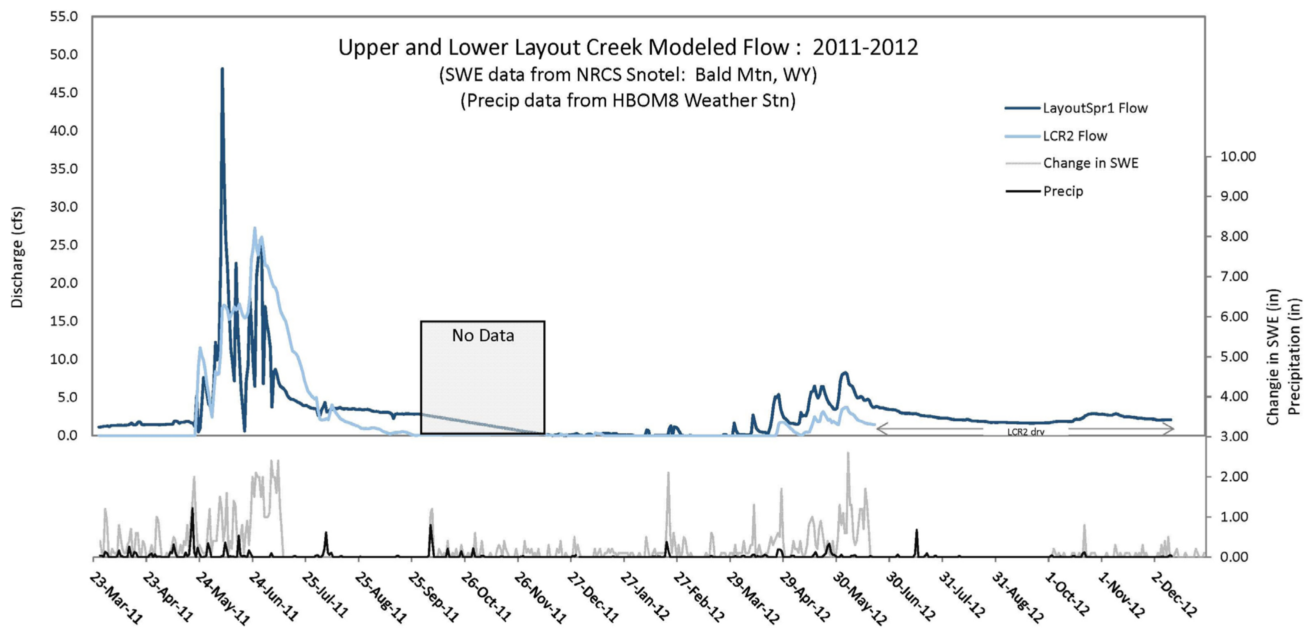


Figure 17. Discharge at Layout Spring (LayoutSpr1) and lower Layout Creek (LCR2). Discharge calculations were based on the rating curves for each year (years were not combined to form a single rating curve). Change in snow water equivalent (SWE) and precipitation were measured from nearby snotel and weather stations.

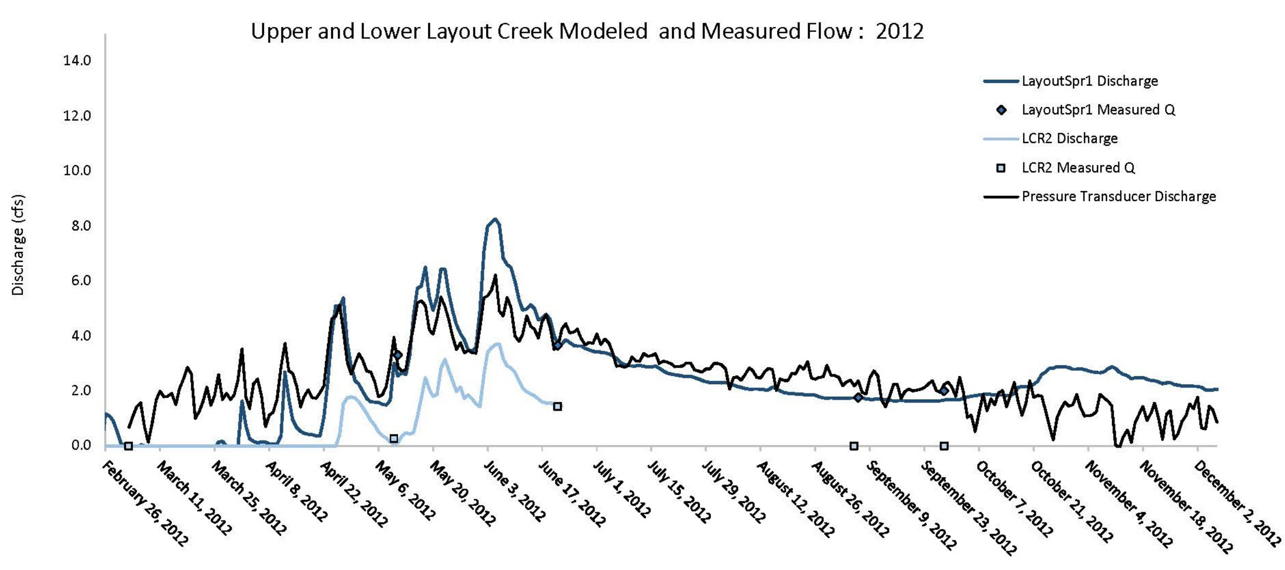


Figure 18. Pressure transducer discharge in conjunction with discharge calculated from the TruTracks on Layout Creek. LayoutSp1=Layout spring, LCR2=lower Layout Creek.

reflect actual variations in water levels or may suggest that measurement-related errors or problems with our current post-processing approach. Collection of data through CY 2013 should shed additional light on this topic.

In contrast to Layout Spring and Layout Creek discharge summaries, the empirical relationship between discharge and stage at Lockhart Stockpond was poor (R^2=0.0436). The poor relationship at this site may be associated with the weir technique used to estimate discharge (Photo 2) rather than complications associated with measuring shallow water depths. Despite the poor rating curve relationship, water table measurements at Lockhart Stockpond were collected in 2011 and 2012 and exhibit only minor variations over the reporting period (Figure 19). This small amount of variation is surprising given the dramatic variation in surface water discharge between 2011 and 2012 documented in stream and river sites and the documented variation in Layout Spring (Figure 17). Overall, the water table measured at Lockhart Stockpond showed an increase in elevation in September and October of each year interrupted by a subtle decrease in elevation from March to June 2012.

Shallow groundwater temperatures in Lockhart Stockpond vary between 5 and 15°C and are roughly synchronized, rather than lagging behind, seasonal changes in air temperature. This synchrony is surprising given the relative insensitivity of waters to changes in precipitation. Finally, continuous monitoring at Mason Lovell Spring shows water table levels slowly increasing from November 2011 to December 2012 (Figure 20). Similar to Lockhart Stockpond, the greatest increases in water table level in 2012 occurred in late September and early October. This increase in water level in the Fall may reflect a dramatic decrease in evapotranspiration (note the inverse relationship with air temperature) or may occur coincident with regional groundwater use for irrigation purposes.

Overall, modeled water table levels at Mason Lovell Spring track onsite flow measurements (Figure 20) and appeared to be relatively unresponsive to precipitation events. Because of the lack of association with local surface water, SWE, or precipitation patterns, groundwater feeding Mason Lovell Spring may be integrating precipitation or groundwater dynamics over longer periods than the other spring monitoring sites. The apparent asynchrony between surface conditions and shallow groundwater was also documented between water and air temperature; changes in water temperatures appear to lag changes in air temperatures by nearly two months (Figure 20).

Photo 1. Orifice site at the origin of Layout Spring.

Photo 2. Example of a temporary aluminum weir developed for use in BICA NRA. This type of weir has been used to measure discharge at Lockhart Stockpond.

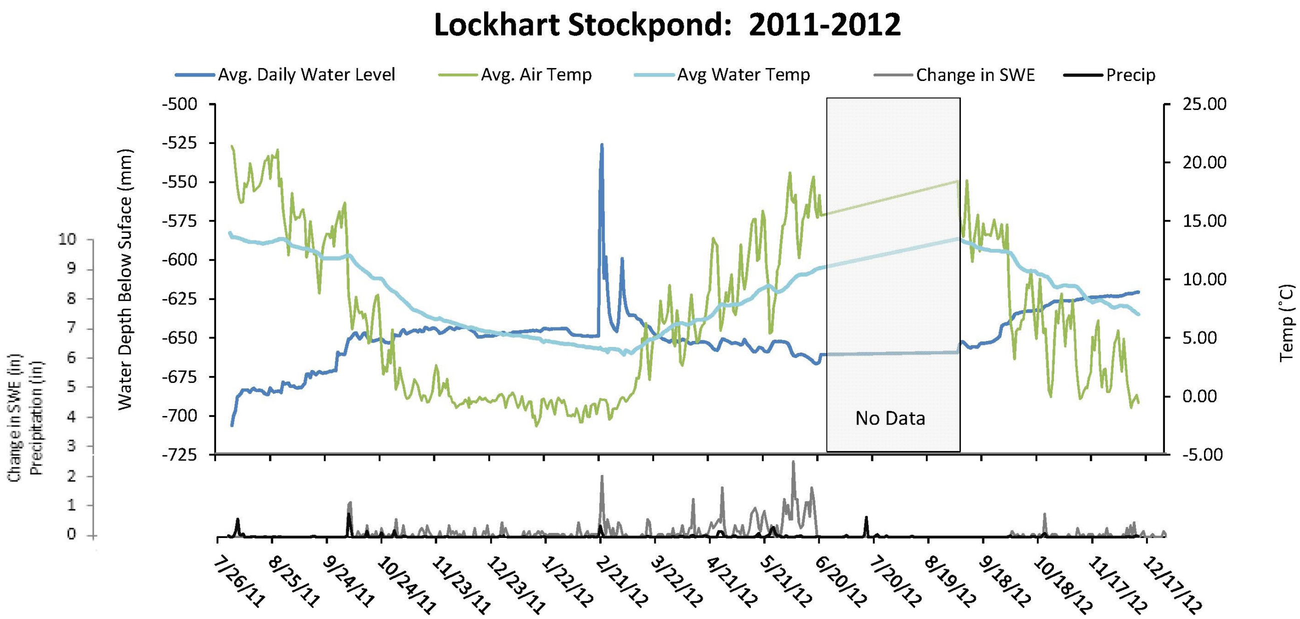


Figure 19. Water table levels (depth below the surface), air, and water temp at Lockhart Stockpond. Precipitation and change in snow water equivalent (SWE) are summarized from nearby monitoring stations.

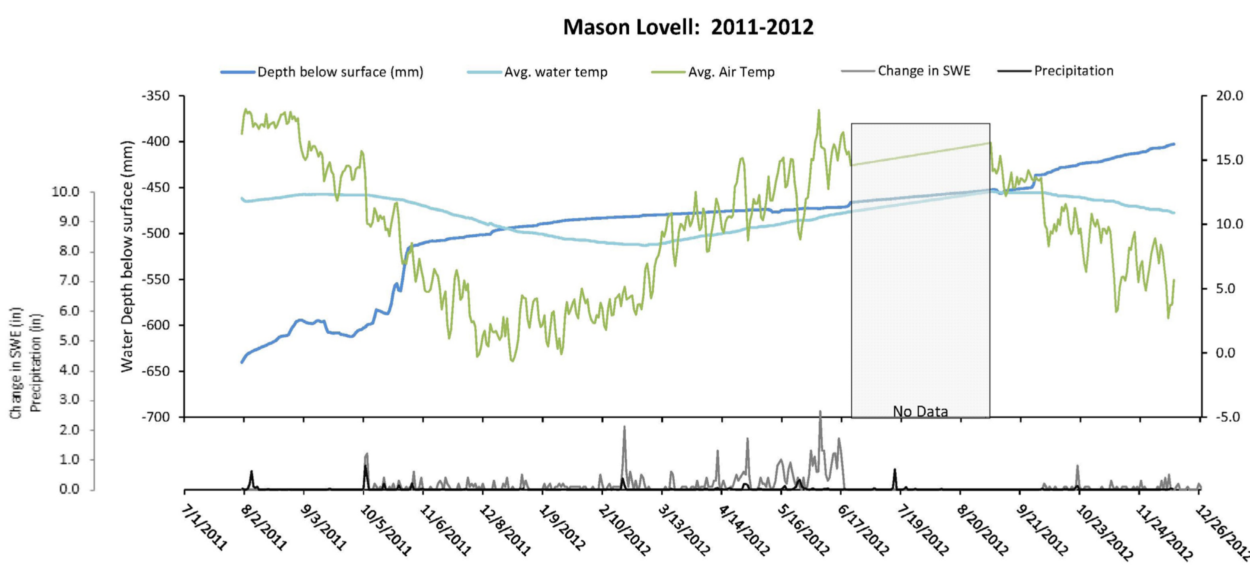


Figure 20. Modeled discharge and measured discharge, air and water temperatures recorded at Mason Lovell Spring. Change in snow water equivalent (SWE) and precipitation were measured from nearby SNOTEL and RAWS weather stations.

Discussion

Water resources are critical to the health and productivity of arid and semi-arid landscapes like those found within BICA. In addition, water resources are important to visitor recreation experiences, as well as their perceptual evaluations of BICA's aesthetic features (*sensu* Burmil et al. 1999). During the 2011 and 2012 calendar years, ongoing monitoring activities further characterized water quality and discharge patterns in BICA's rivers, streams, and springs. These summaries will contribute to our understanding of the variability of water resources in BICA, but also reveal whether these resources are meeting state and federal water quality standards.

Flow patterns in the Bighorn and Shoshone Rivers varied strongly among calendar years. Flows at all river locations in 2011 were very similar to the 75th percentile of daily flows for the periods of record, however, 2012 daily discharges were much more similar to the 25th percentile of daily flows. This high among-year variation in annual cumulative river flow has been documented over the last several decades; however, decadal summaries of river flow for the Bighorn and Shoshone Rivers suggest that mean river flows in this region are decreasing.

Water quality in the Bighorn River exhibited little variability over the sampling period. In contrast, the Shoshone River had moderate to high and variable concentrations of nitrogen (expressed as NO_2+NO_3) and total phosphorus. Currently, the WYDEQ has no standard for primary nutrients in streams and rivers (see WYDEQ 2008) for assessing the status of the Shoshone River. *E. coli* levels in the Shoshone River are also high and the five-day geometric mean *E. coli* concentration for all months sampled across four calendar years (2009 to 2012) exceeded Wyoming State Standards. Although, *E. coli* levels were consistently high, some variation was documented during summer months and *E. coli* levels were inversely correlated with river discharge.

Discharge patterns in three springs and one stream (Layout Creek) were characterized in 2011 and 2012 following the installation of continuous monitoring equipment. Overall, discrete measurements of discharge tracked variations in shallow water levels in wells and indicates that continuous estimates of spring discharge will be possible. Interestingly, discharge patterns for monitored springs show very different responses to precipitation or SWE estimates. These support claims that springs within BICA have distinct residence times, but suggest that some springs (e.g., Layout Spring) more closely mimic current precipitation and SWE patterns.

Chemical and biological monitoring of BICA resources during calendar years 2011 and 2012 suggests that most monitored resources are meeting state and water quality standards. The exception, the Shoshone River, has *E. coli* levels between May 1 to September 30 that exceed the Wyoming DEQ's numeric standard (126 colonies/100 mL). Sampling of *E. coli* in the Shoshone River should continue in 2013 to document levels in this major tributary to Bighorn Lake. Benthic macroinvertebrate samples were also collected in Fall of 2012. We are currently waiting on laboratory results, but macroinvertebrate assemblage data will provide further information on the condition of BICA's water resources.

Based on provisional results presented from the 2011 and 2012 monitoring summarized within this report, the GRYN recommends the following:

- Continued monitoring of major cations and anions, growth limiting nutrients, and alkalinity in the Bighorn (Kane, Wyoming and St. Xavier, Montana) and Shoshone Rivers. Monitoring sites quarterly should provide an understanding of the within year variation at these sites.
- Continued monitoring of *E. coli* in the Shoshone River at Lovell, Wyoming.
- Continued characterization of discharge using water level loggers and field discharge measurements at three springs (Layout Spring, Lockhart

Stockpond, and Mason-Lovell Spring) and one stream (Layout Creek). We recommend a minimum of six manual measurements of discharge collected during the 2013 field season including a minimum of three measurements during peak flows (mid-April to mid-June).

- Installation of staff gauges (by permit or permission from the Chief of Resources) at both continuous monitoring locations on Layout Creek. Staff gauges would allow other GRYN personnel and BICA staff to record stage height on visits to these locations. Additional measurements will help develop and refine empirically derived rating curves at these locations.

- Consider the purchase and installation of a barometric pressure logger near the orifice of Upper Layout Spring. The current pressure transducer does not record barometric pressure, which is needed to correct for changes in atmospheric pressure. Although atmospheric pressure is available from a nearby weather station, the variability in stage data suggests that local atmospheric pressure readings may improve the quality of the record at this site.

- Consider the construction or installation of a permanent weir at Lockhart Stockpond Spring. A staff gauge could also be installed on the weir or in the pool behind the weir. Current discharge measurement techniques (using the aluminum v-notch weir; Photo 2) at this location limit our ability to accurately estimate discharge and cause minor disturbances to the spring substrates each site visit.

- Establish a set of protocols for measuring water depths in wells. In 2013, an electronic tape will be used to estimate water depths with a resolution of ±0.01 in.

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