



Water Quality Summary for Bighorn Canyon National Recreation Area

Preliminary Analysis of 2013 Data

Natural Resource Data Series NPS/GRYN/NRDS—2015/751



ON THE COVER

Field activities in Upper Layout Creek, Bighorn Canyon NRA.
NPS photograph

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The Natural Resource Data Series is intended for the timely release of basic data sets and data summaries. Care has been taken to assure accuracy of raw data values, but a thorough analysis and interpretation of the data has not been completed. Consequently, the initial analyses of data in this report are provisional and subject to change.

All manuscripts in the series receive the appropriate level of peer review to ensure that the information is scientifically credible, technically accurate, appropriately written for the intended audience, and designed and published in a professional manner.

Data in this report were collected and analyzed using established methods based on peer-reviewed U.S. Geological Survey and National Park Service protocols and interpreted relative to relevant water quality standards.

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Executive Summary

This report summarizes discharge and water quality monitoring data in Bighorn Canyon National Recreation Area (NRA) for calendar year 2013. 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). Flows at all river locations in 2013 were very similar to the 25th percentile of daily flows at each site. High among-year variation in annual cumulative river flow has been documented for rivers in this region, but decadal summaries of river flow for the Bighorn and Shoshone rivers suggest that mean river flows in this region are generally decreasing.

Water quality monitoring of rivers. Water quality in the Bighorn River near St. Xavier, Montana exhibited exhibited some seasonal variability over the sampling period. The Shoshone River near Lovell, Wyoming had moderate-to-high and variable concentrations of nitrogen (expressed as NO₂ + NO₃) and total phosphorus.

Escherichia coli monitoring in the Shoshone River. *E. coli* levels in the Shoshone River are high and the five-day geometric mean *E. coli* concentration for all months sampled across five calendar years (2009 to 2013) exceeded Wyoming state standards. Although *E. coli* levels were consistently high, some variation was documented during summer months and *E. coli* levels were correlated with river discharge.

Spring discharge. Discharge patterns in three springs and one stream (Layout Creek) were characterized in 2013 creating what is now a three-year record. Overall, discrete measurements of discharge tracked variations in shallow water levels in wells and indicates that continuous estimates of spring discharge are possible. Interestingly, discharge patterns for monitored springs show very different responses to precipitation or snow-water equivalent (SWE) estimates. These support claims that springs within Bighorn Canyon NRA have distinct residence times, but suggests that some springs (e.g., Layout Spring) more closely mimic current precipitation and SWE patterns.

Water quality monitoring and state water quality standards. Chemical and biological monitoring of Bighorn Canyon NRA resources during calendar year 2013 suggests that most monitored resources are meeting state and water quality standards. The Shoshone River is the exception with *E. coli* levels exceeding the Wyoming Department of Water Quality's numeric standard (126 colonies/100 mL) between 1 May to 30 September.

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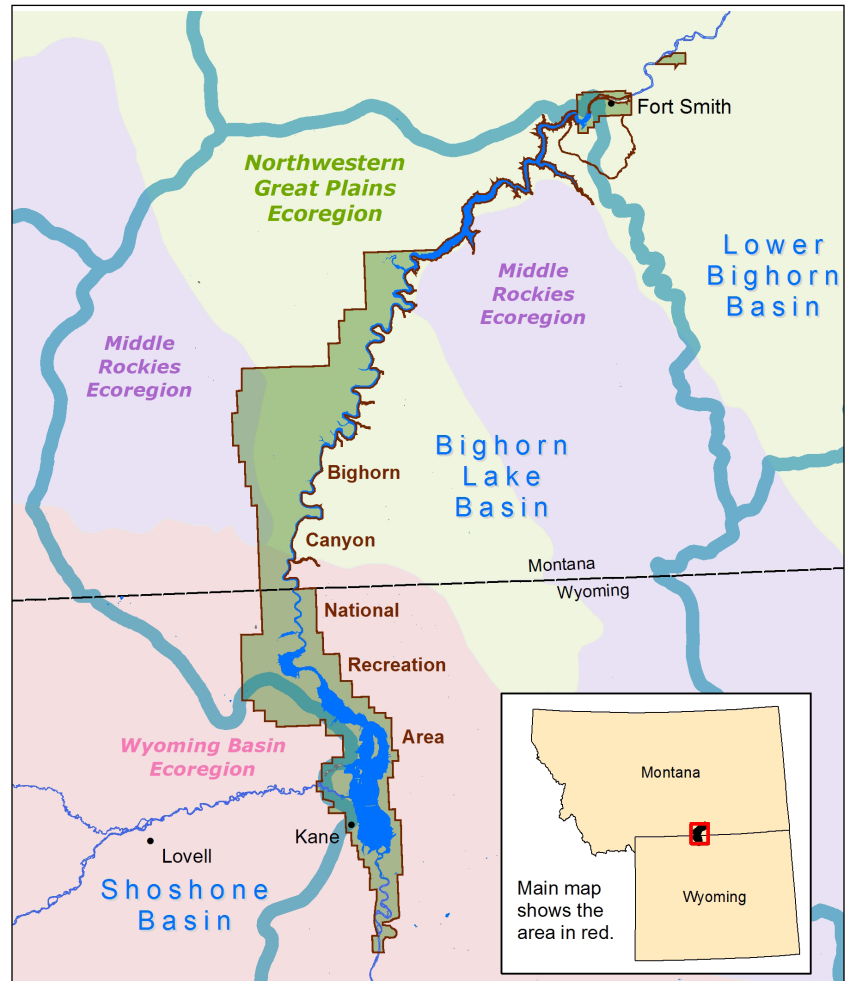
Introduction

Bighorn Canyon National Recreation Area (NRA) 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. This water body was created in the 1960s when the Bureau of Reclamation erected Yellowtail Dam at the north end of the canyon. Now, Bighorn Lake is nearly 113 km (70 miles) long occurring at an elevation of 1,115 meters (3,657 feet). The lake contains a total volume of 1.6 billion m³ (1.3 million acre-feet) of water (BOR 2012) and covers approximately 7,000 surface hectares (17,300 acres) at full pool. Bighorn Lake is an important recreation destination for boaters, anglers, and wildlife viewers 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 are distributed throughout the park, many flow year round (Jacobs et al. 1996). Despite their relative abundance in Bighorn Canyon NRA, 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 at Bighorn Canyon NRA varies dramatically across its north-south orientation. 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 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 Bighorn Canyon NRA, average annual precipitation is 45 cm with 57% of the moisture delivered from March to July



(Figure 2). The annual temperature maxima occur in July; on average February is the driest month (WRCC 2014). From 1948 to 2013, the maximum temperature range for the Yellowtail Dam Station (249240) was -37.2°C (February 2006) to 42.8°C (July 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 high desert. In Lovell, Wyoming (just west of the south end of Bighorn Canyon NRA; Lovell Station 485770) average annual precipitation is approximately 17 cm with 58% of the moisture delivered from March to July (Figure 2).

At Lovell, weather summaries from 1897 to 2013 indicated that monthly mean temperatures are highest in July and August

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

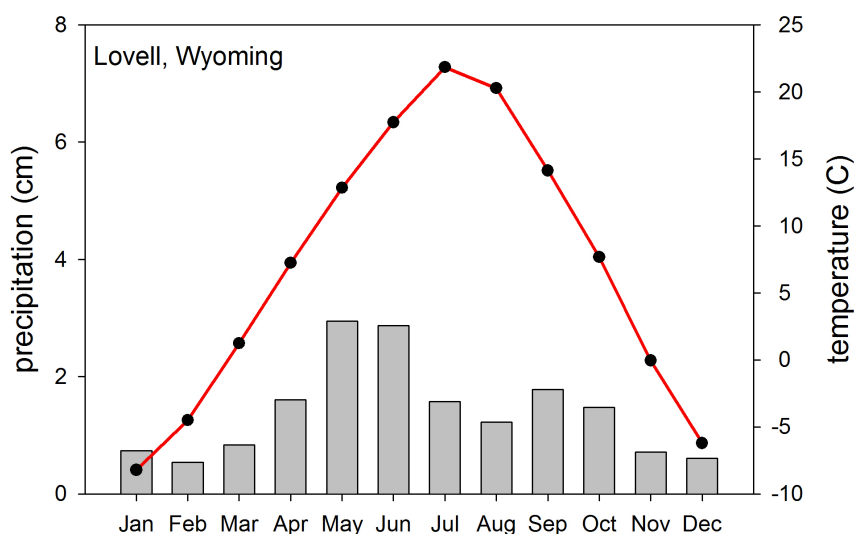
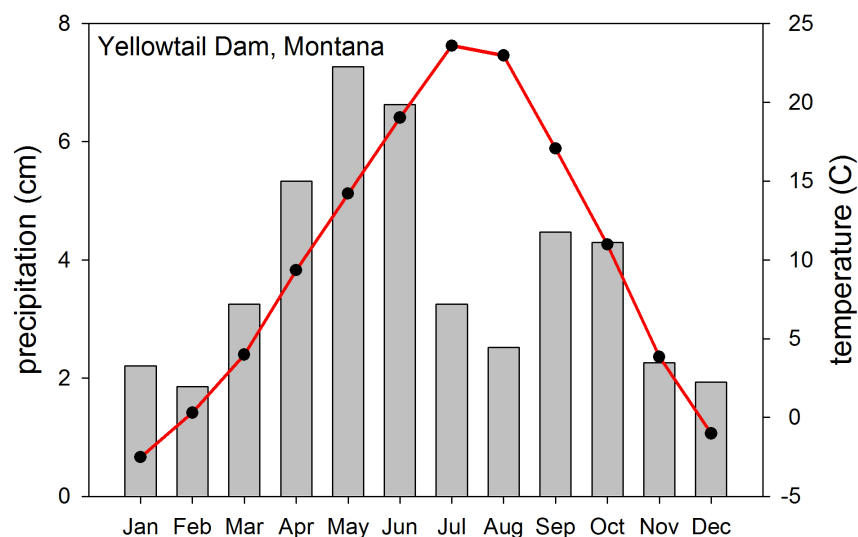


Figure 2. Climographs constructed from weather data from Yellowtail Dam Station (249240) near St. Xavier, Montana (top right) and from Lovell, Wyoming (485770; lower right). Average monthly precipitation (cm; gray bars) and temperature (°C; red line) are shown for each location.

and lowest in January. The maximum temperature range for the Lovell Station (485770) was -44.4°C (February 1899) to 41.7°C (July 1939). 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

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 one of the main contributors of suspended sediments to the Bighorn River (Soil Conservation Service 1994, USACOE 2010). The hydrograph of the Bighorn River is influenced by operations of Boysen Dam and Yellowtail Dam and in recent decades by reduced snowpacks and warmer temperatures. Yellowtail Dam also limits flow variability, which has influenced floodplain communities downstream of the dam. Specifically, cottonwood (*Populus deltoides*) recruitment has been limited (Ladenburger et al. 2006) and stands of

exotics such as Russian olive (*Elaeagnus angustifolia*) 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 north end of Bighorn Canyon NRA and below Yellowtail Dam.

Mercury in water and fish tissues is a growing water resource concern at Bighorn Canyon NRA. Fish tissue samples collected from throughout the NRA exhibit elevated levels of mercury (Hg). In particular, walleye (*Sander vitreus*) collected from the Shoshone River, Bighorn River, and Bighorn Lake exhibited mercury concentrations that were higher than any samples collected throughout the Yellowstone River Basin (Peterson and Boughton 2000) and across western national parks (Eagles-Smith et al. 2014). Importantly, levels measured in the waters of Bighorn Canyon NRA exceeded levels established to prevent detrimental effects to wildlife (Yeardley et al. 1998).

Like many semi-arid regions, seeps and springs are an important resource at Bighorn Canyon NRA. At least 35 springs have been located throughout the NRA. While the springs vary with respect to the type of conditions present at the point of discharge (see Springer and Stevens 2009), extent of development for human use, the amount and variability of discharge, and the geochemical signatures of discharge water, they undoubtedly exhibit some hydrogeochemical similarities. Spring discharge is an important characteristic of developed and undeveloped springs and is believed to be an expression of groundwater reservoir size and complexity. Because of these variations, the timing and magnitude of discharge responses to climate drivers likely varies by spring and across the NRA (*sensu* Manga 2001, Springer and Stevens 2009). The perennial nature of spring discharge interacts with the unique elevation, chemistry, and disturbance regime of each spring to structure unique biological assemblages that may be distinct to these resources (Myers and Resh 2002, Staglione 2008, von Fumetti and Nagel 2012).

Characterization and routine monitoring of water chemistry and discharge of Bighorn Canyon's major rivers and representative springs and seeps has been carried out by the Greater Yellowstone Inventory and Monitoring Network (GRYN), Bighorn Canyon NRA, and university researchers since 2006 (O'Ney et al. 2009). This report summarizes monitoring activities in Bighorn Canyon NRA during calendar year 2013.

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 Bighorn Canyon's streams and rivers were meeting water quality standards. Water resource monitoring in the NRA 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 standards are presented in Table 1.

Montana Water Quality Standards and Water Classification System

The Montana Department of Environmental Quality (MTDEQ) 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" (MTDEQ 2012a:4-33). 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, culinary and food processing, recreation, and agriculture. Standards are further divided into five categories: toxic, carcinogenic, radioactive,

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 (2012), B1 waters and Circular DEQ-12 Parts A and B	Wyoming Standard: WYDEQ Water Quality Rules and Regulations (2013)
Temperature (°C)	Cold-water fisheries	<i>Species-specific criteria</i>	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
	Warm-water fisheries	<i>Species-specific criteria</i>		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 $\pm$ 0.5; if pH is naturally >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: coldwater 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: coldwater criteria is 4.0
Turbidity (NTU)	Cold-water fisheries	Natural + $\leq$ 10%	Natural + $\leq$ 5	Natural + $\leq$ 10
Alkalinity (mg/L)	Aquatic life (chronic)	Freshwater (Chronic) = not <20	<i>not found in any MT guidance documents</i>	<i>not found in any WY guidance documents</i>
Chloride (mg/L)	Aquatic life	Freshwater (Acute) =860 mg/L Freshwater (Chronic) =230 mg/L	<i>not found in any MT guidance documents</i>	Aquatic Life/Acute=860 mg/L; Aquatic Life/Chronic=230 mg/L
Sulfate (mg/L)	Drinking water	no standard	<i>not found in any MT guidance documents</i>	<i>not found in any WY guidance documents</i>
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: 0.15 mg/L	<i>Nutrient criteria under development (see WYDEQ 2008)</i>

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 (2012), B1 waters and Circular DEQ-12 Parts A and B	Wyoming Standard: WYDEQ Water Quality Rules and Regulations (2013)
Ammonia (mg/L)	Aquatic life	Acute criteria/pH and temperature dependent; one-hour and 30-day criterion are based on the calculations (EPA 2013) 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 $\text{NH}_3\text{-N}$ plus $\text{NH}_4\text{-N}$ ranges from 0.885 to 32.6 mg/L for cold-water/salmonids present and from 1.32 to 48.8 mg/L when salmonids absent
	Drinking water	10 mg/L	10 mg/L	10 mg/L
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: 1.3 mg/L	<i>Nutrient criteria under development (see WYDEQ 2008)</i>
<i>Escherichia coli</i> (colonies/100 mL)	Recreation	Geomean of ≤ 126	1 April to 31 October: geomean of ≤ 126 (10% of the total samples may not exceed 252 during 30 days) 1 November to 31 March: geomean of ≤ 630 (10% of the total samples may not exceed 1,260 mL during 30 days)	1 May to 30 September: geomean of ≤ 126 during any 60-day period (primary contact recreation) 1 October to 30 April: geomean of ≤ 630

nutrients, and harmful. Our focus for assessment of Bighorn Canyon NRA'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 or 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 associations. Each class has associated with it the present or future beneficial uses the water body should be supporting (MTDEQ 2012b). Most of the waters within or adjacent to Bighorn Canyon NRA that have been assessed by the State of Montana are classified as B-1. Because of their ephemeral nature, it has also been noted that many of the NRA'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.

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 Bighorn Canyon NRA have not yet been classified by the state of Montana (e.g., Medicine Creek; MTDEQ 2012a).

Wyoming Water Quality Standards and Water Classification System

Wyoming's Department of Environmental Quality (WYDEQ) water quality standards are described in Chapter 1 of Water Quality Rules and Regulations (WYDEQ 2013) and the agencies plan for developing and implementing nutrient criteria are

outlined in the Wyoming Nutrient Criteria Development Plan (WYDEQ 2008).

The Wyoming surface-water standards are based on the Wyoming Surface Water Classification List (WYDEQ 2013) and closely follow federal standards. Rivers and streams within Bighorn Canyon NRA (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 2013).

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 2012a) 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 (MTDEQ 2012) 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 aquatic life and cold-water fisheries because of elevated total nitrogen concentrations (MTDEQ 2012a).

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 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 river systems (Bighorn and Shoshone rivers) within Bighorn Canyon NRA.
2. Characterize seasonal *Escherichia coli* levels in the Shoshone River.
3. Characterize discharge patterns of representative springs and streams.
4. Evaluate whether monitored resources with Bighorn Canyon NRA are meeting state water quality standards.

Methods

We collected depth-integrated water samples quarterly for three river sites: Bighorn River at Kane (Wyoming), Bighorn River at St. Xavier (Montana), and the Shoshone River at Lovell (Wyoming) in 2013.

In addition to water samples, we characterized core field water quality parameters (i.e., temperature, specific conductivity, DO, pH, and turbidity) *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.

We collected water samples in wadeable flow conditions using a DH-81 Sampler (Federal Interagency Sedimentation Project, Vicksburg, Mississippi) affixed to a 1-m wading rod. We used polypropylene bottles with the DH-81 samplers. We rinsed the

bottles three times with deionized water between samples to prevent contamination.

We collected bacterial samples using a grab sample from the Shoshone River near Lovell, Wyoming; water was introduced directly into pre-sterilized 7 oz 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; Figure 3). For stream sites, discharge was estimated at uniform stream sections. In brief, we stretched a measuring tape perpendicular to the stream flow (to divide the river into a minimum of 20 increments) and ensured that no more than 10% of the cross-sectional area was represented by each velocity measurement. If we observed hydraulic irregularities, we established additional increments to account for noticeable anomalies (Gore 1996). We made all flow measurements using an electro-magnetic Marsh McBirney velocity meter affixed to a graduated, stainless-steel, top-setting wading rod (Nolan and Shields 2000).

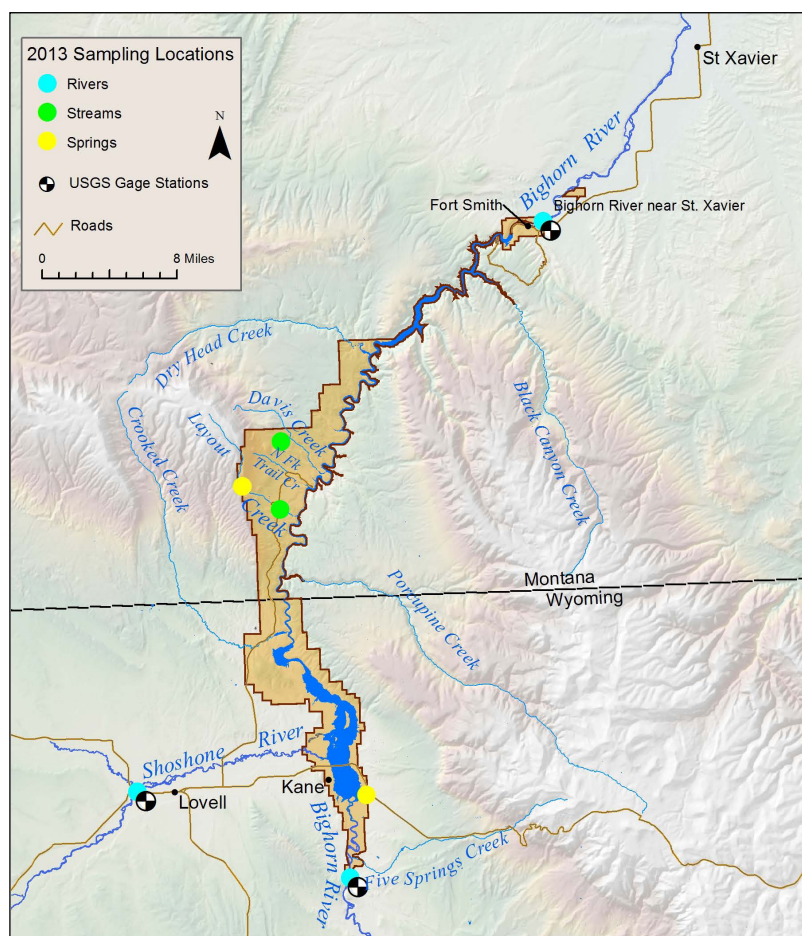


Figure 3. Sampling locations for rivers, streams, and spring sampled in Bighorn Canyon National Recreation Area in calendar year 2013.

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 4) and St. Xavier, Montana (downstream of Yellowtail Dam; Figure 5) 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 4).

During 2013, daily flows in the Bighorn River near Kane, Wyoming closely tracked the 25th percentile of daily flows for the period of record (1929-2013; Figure 4). A relatively high level of among-year variation in annual cumulative river flow has been documented throughout the period of record (Figure 6); 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 7).

Daily flow summaries for the Bighorn River below Yellowtail Dam and near St. Xavier, Montana also show how 2013 flows are consistent with the 25th percentile of daily flows for this location (Figure 5). Over the period of record, daily flows in the Bighorn River below Yellowtail Dam and near St. Xavier, Montana typically peaked during the 4th week of June (approximately day 180) and remained elevated above baseflow conditions for several weeks (Figure 5). Decadal flow summaries for the lower portion of the Bighorn River mirror those displayed in Figure 7 near Kane, Wyoming and also show that flows during the first

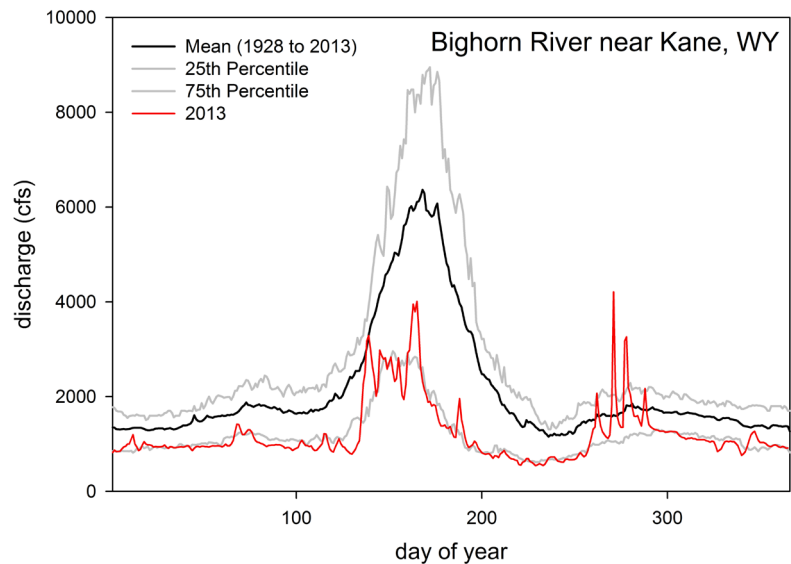


Figure 4. Long-term summary of average daily discharge (in cfs) at the Bighorn River near Kane, Wyoming (USGS Gage 06279500). River flows are presented by day of year where day 1 refers to January 1st of each calendar year. The period of record summarized for this gage extends from 1928 to 2013. Mean 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 2013 (red) is also presented.

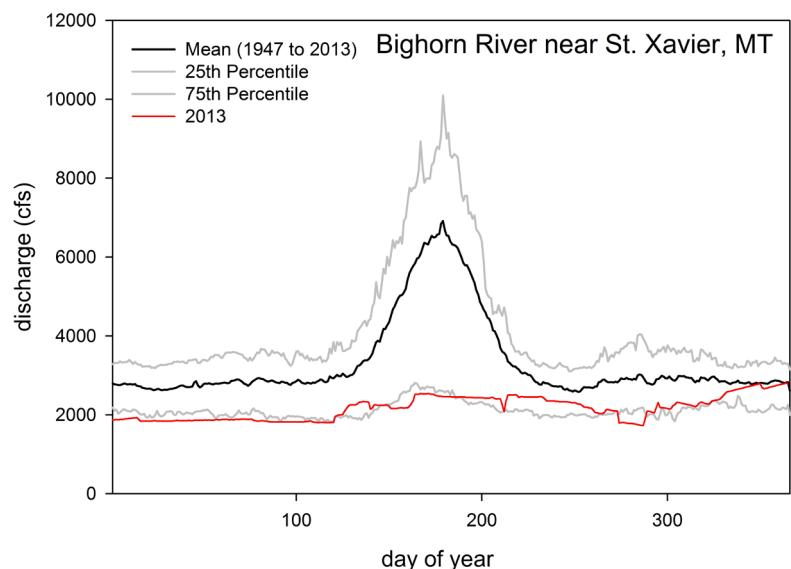


Figure 5. Long-term summary of average daily discharge (in cfs) at the Bighorn River near St. Xavier, Montana (USGS Gage 06287000). River flows are presented by day of year where day 1 refers to January 1st of each calendar year. The period of record summarized for this gage extends from 1947 to 2013. 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 2013 (red) is also presented.

Figure 6. Histogram of annual river flow (in billion ft³) at the Bighorn River near Kane, Wyoming (USGS Gage (06279500)). Years 1930 to 2013 are summarized and show year fluctuations in annual river flow.

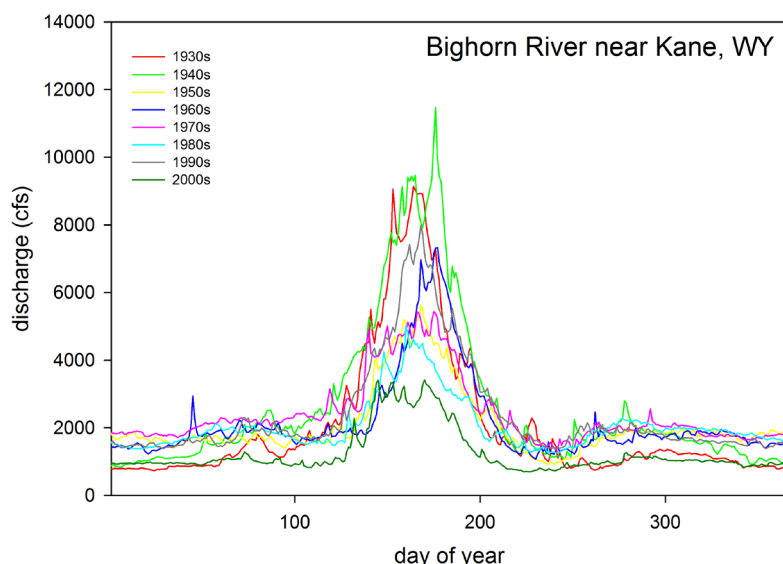
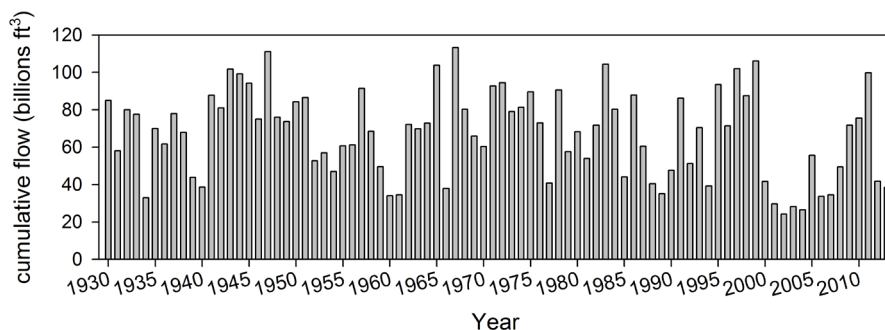


Figure 7. Decadal hydrographs for the Bighorn River near Kane, Wyoming (USGS Gage 06279500). River flows are presented by day of year where day 1 refers to January 1st each year. Years included in this summary span from 1930 to 2010.

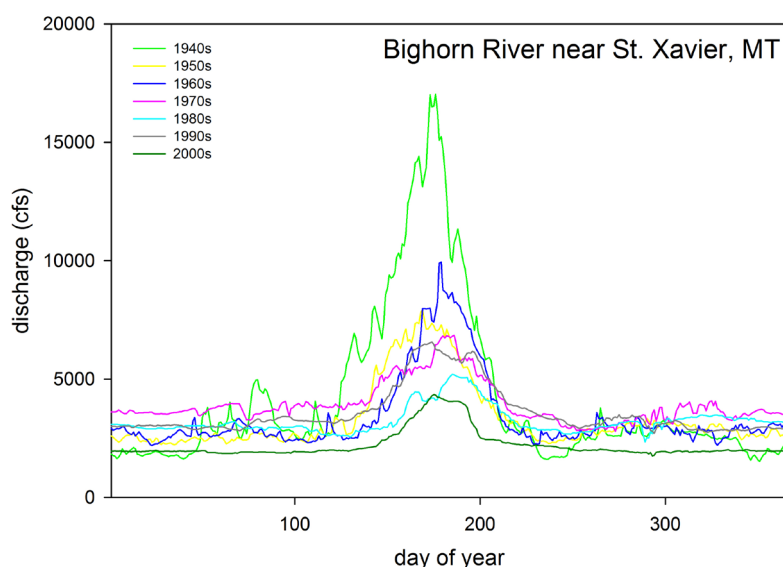


Figure 8. Decadal hydrographs for the Bighorn River near Bighorn River near St. Xavier, Montana (USGS Gage 06287000). River flows are presented by day of year where day 1 refers to January 1st each year. Years included in this summary span from 1947 to 2010.

decade of the 2000s have been lower than any other decade on record (Figure 8).

The 2013 calendar year hydrograph for the Shoshone River at Lovell, Wyoming depicts evidence of flow manipulation or irrigation withdrawals or diversions (Figure 9). Alterations of the hydrograph were very apparent in 2013 when daily flows varied dramatically among days and weeks compared with the more unregulated hydrograph present in the Bighorn River near Kane, Wyoming. Still, daily flows in the Shoshone River during 2013 were more similar to the long-term average daily flows than either Bighorn River monitoring site (Figure 9). 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 10).

Water Quality of Bighorn and Shoshone Rivers

The ionic composition of Bighorn Canyon's large rivers (Bighorn and Shoshone) were summarized using quarterly sampling in 2013 using depth-integrated sampling approaches (see Methods section). 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. Analytical results show that the dominant cations across large river sites were calcium, sodium, and to a lesser extent, magnesium (Table 2). Dominant anions were bicarbonate and sulfate. The least amount of variation in dominant cations and anions was documented at the

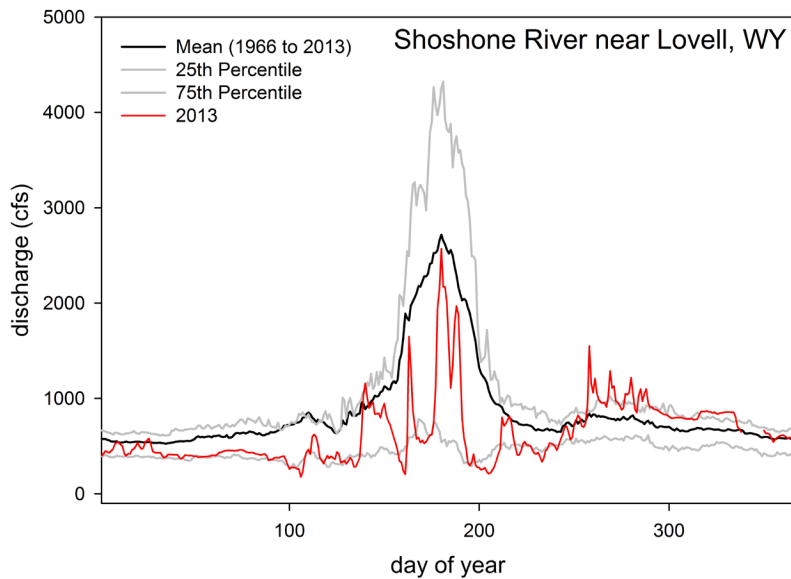


Figure 9. Long-term summary of average daily discharge (in cfs) at the Shoshone River near Lovell, Wyoming (USGS Gage 06285100). River flows are expressed by day of year where day 1 refers to January 1st each year. The period of record summarized for this gage extends from 1966 to 2013. Mean daily discharge 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 2013 (red) is also presented.

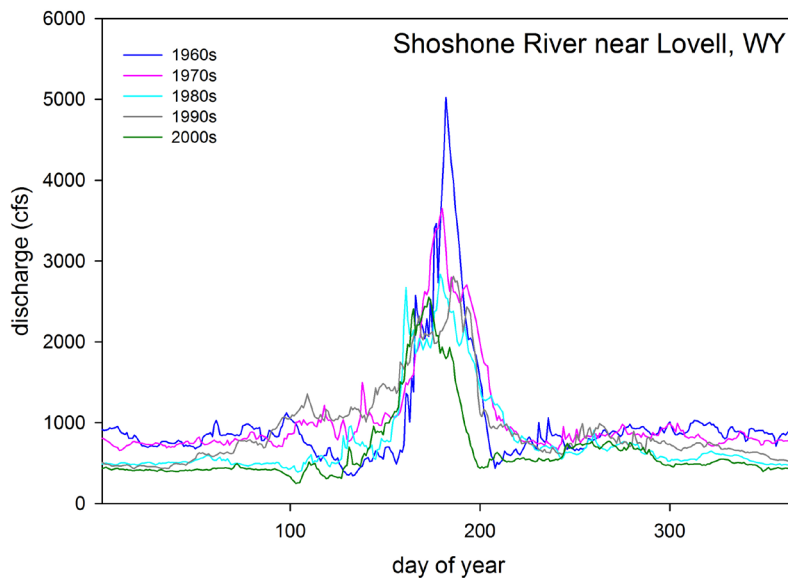


Figure 10. Decadal hydrographs for the Shoshone River near Lovell, Wyoming (USGS Gage 06285100) River flows are presented by day of year where day 1 refers to January 1st each year. Years included in this summary span from 1966 to 2010.

Table 2. Concentrations (mean $\pm$ 1 standard deviation of quarterly samples) of major cations (Ca, K, Mg, and Na) and anions (HCO_3^- , CO_3^{2-} , Cl^- , and SO_4^{2-}) for the Bighorn River (Kane, Wyoming and St. Xavier, Montana) and Shoshone River (near Lovell, Wyoming).

Site	Cations (mg/L)				Anions (mg/L)			
	Ca	K	Mg	Na	HCO_3^-	CO_3^{2-}	Cl	SO_4^{2-}
Bighorn River Kane, WY	85.2 $\pm$ 17.8	4.7 $\pm$ 1.2	28.6 $\pm$ 7.0	76.4 $\pm$ 26.7	242.5 $\pm$ 73.2	9.3 $\pm$ 8.4	16.3 $\pm$ 5.7	267.8 $\pm$ 89.5
Bighorn River St. Xavier, MT*	80.6 $\pm$ 2.1	3.70 $\pm$ 0.4	27.4 $\pm$ 1.2	67.6 $\pm$ 2.2	224.7 $\pm$ 9.2	10.0 $\pm$ 11.3	12.0 $\pm$ 1.0	252.7 $\pm$ 5.5
Shoshone River Lovell, WY	73.5 $\pm$ 14.1	3.6 $\pm$ 0.8	23.5 $\pm$ 4.6	51.6 $\pm$ 7.5	235.5 $\pm$ 45.9	10.3 $\pm$ 2.3	6.3 $\pm$ 2.6	157.8 $\pm$ 48.7

*Represents the average of three samples from this site.

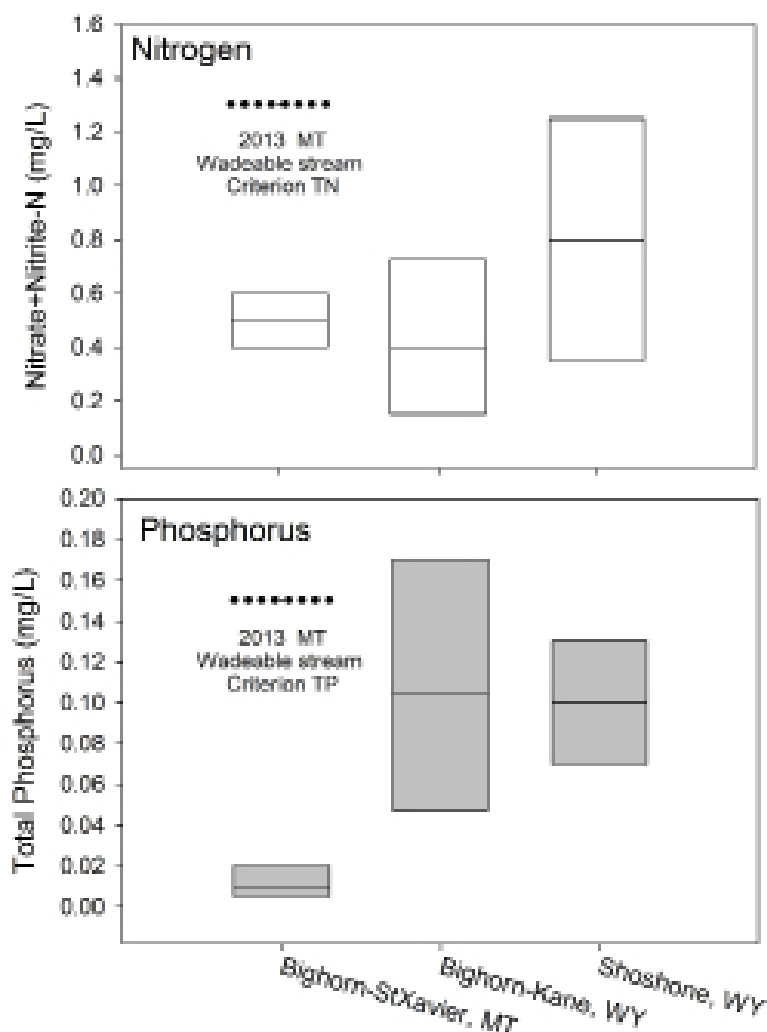


Figure 11. Box plots summarizing nitrogen (expressed as $\text{NO}_2 + \text{NO}_3\text{-N}$) and total phosphorus concentrations in surface waters collected from the Bighorn River (at St. Xavier, Montana and Kane, Wyoming) and the Shoshone River (near Lovell, Wyoming) in 2013. Boxes represent the upper and lower quartiles of the dataset; internal lines indicate the medians. Boxed summaries represent a minimum of three observations. The 2013 total nitrogen (TN) and total phosphorus (TP) for Montana's Northwestern Great Plains Ecoregion is shown. The period when the criteria applies is 16 June to 30 September (Suplee and Watson 2013).

Bighorn River near St. Xavier, Montana (Table 2).

Median concentrations of nitrogen ($\text{NO}_2 + \text{NO}_3$) were greater in the Shoshone River than at either location in the Bighorn River (Figure 11) and concentrations exceeded 1 mg/L in the Shoshone River during the September and December sampling dates in 2013. Mean total phosphorus (TP) was similar between the Shoshone River near Lovell, Wyoming and the Bighorn River near Kane, Wyoming. The highest TP concentration measured during our 2013 quarterly sampling was in the Bighorn River near Kane, Wyoming (0.18 mg/L TP in June 2013).

Variation in both primary nutrients was greater in the Shoshone River and Bighorn River at Kane than at the Bighorn River near St. Xavier (see Figure 11). High TP levels at the Shoshone River did not coincide with peak flow levels; the highest TP was documented in mid-December when flows were similar to the long-term mean at this station.

Despite its partial support designation for aquatic life and cold-water fisheries, the Bighorn River near St. Xavier below Yellowtail Dam had a quarterly mean $\text{NO}_2 + \text{NO}_3\text{-N}$ concentration of 0.5 mg/L (Figure 11) and $\text{NH}_3\text{-N}$ was always below detection (<0.2 mg/L). Based on these values, it appears that the Bighorn River near St. Xavier is meeting Montana's drinking water standards and is even below Montana's 2013 criteria for wadeable streams for Total N (1.3 mg/L Total N; Suplee and Watson 2013).

Seasonal *Escherichia coli* Levels in the Shoshone River

The Shoshone River is listed on Wyoming's 303(d) list for fecal coliform contamination. Because of sufficient year-round flows, the Shoshone River has been designated as a primary contact recreation water (WYDEQ 2013). Accordingly, water samples have been collected from the Shoshone River near Lovell, Wyoming and outside Bighorn Canyon NRA since 2009. Samples have been collected throughout this period to document trends in the levels of the fecal coliform bacterium, *E. coli*, during summer months (Figure 12) 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 the fecal coliform bacterium *E. coli* are more stringent during summer months (see Table 1) for waters designated for primary contact recreation. Figure 12 summarizes *E. coli* levels enumerated in the Shoshone River along with river discharge for the period of 1 May to 30 September and relative to the State of Wyoming's standard of a geometric mean of 126 organisms per 100 mL (based on a minimum of at least five samples obtained during separate 24-hour periods) of source water and during any consecutive 60-day period (WYDEQ 2013).

In 2013, *E. coli* levels from individual samples collected from the Shoshone River outside the park boundary were elevated but variable during summer months (Figure 13). The five-day geometric mean *E. coli* concentration for all months sampled across 2013 (range 217 cfu/100 mL [August 2013] to 787 [September 2013]) exceeded the Wyoming state standards for primary contact recreation (126 cfu/100 mL). These exceedances now represent five calendar years (2009 to 2013) of exceedances of the standard (range in five-sample geometric mean: 179 cfu/100 mL [June 2011] to 995 cfu/100 mL [July 2011]; Figure 12).

Based on previous work in this river, *E. coli* was most strongly associated with discharge patterns (Ray et al. 2013). Given this empirical relationship, we explored the association using 2013 mean daily discharge

and the mean *E. coli* concentrations (mean of duplicate samples) collected on that same day. Consistent with previous years, discharge was a modest predictor ($R^2=0.309$) of *E. coli* levels between mid-June and mid-September 2013.

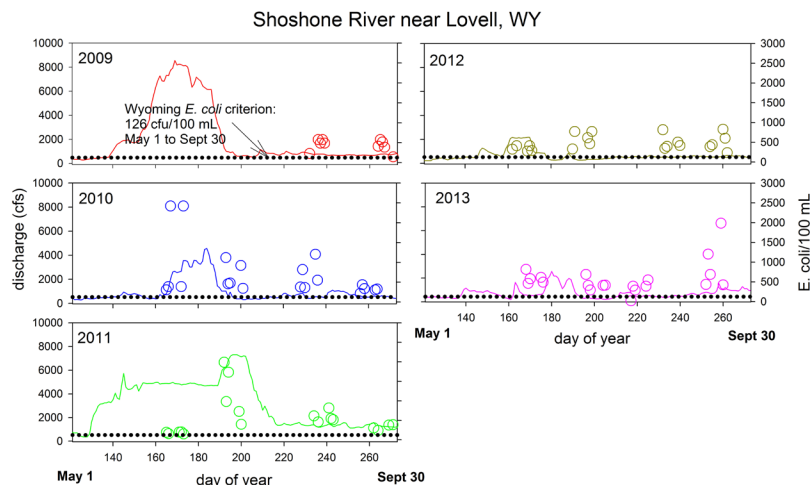


Figure 12. *Escherichia coli* levels (circles) in the Shoshone River near Lovell, Wyoming. *E. coli* levels (colonies/100 mL) are plotted by calendar day along with river discharge (solid line) for years 2009 to 2013. The period of the calendar year (1 May to 30 September) is displayed and corresponds to the Wyoming numeric standard for *E. coli* (126 colonies/100 mL; shown as a dotted line) for waters designated for primary contact recreation.

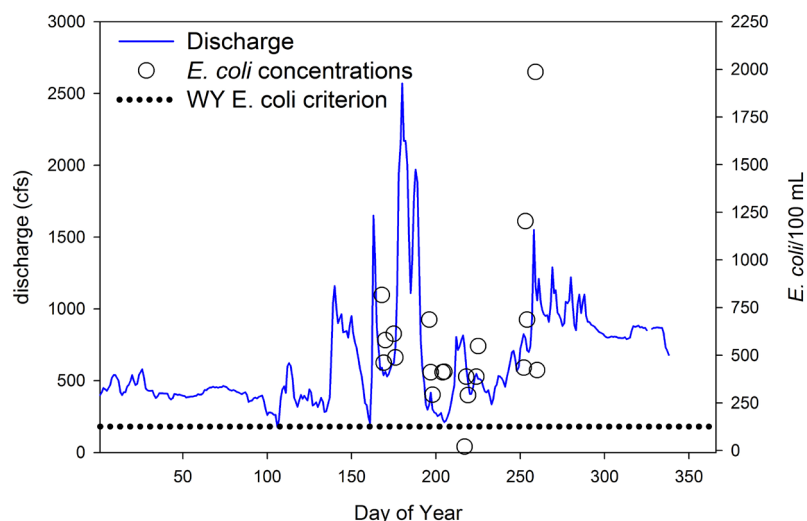


Figure 13. *Escherichia coli* levels (circles) in the Shoshone River near Lovell, Wyoming. *E. coli* levels (colonies/100 mL) are plotted by calendar day along with river discharge (blue solid line) for 2013. The Wyoming numeric standard for *E. coli* (126 colonies/100 mL; shown as a dotted line) applies from 1 May to 30 September.

Discharge Patterns of Representative Springs and Streams

Continuous discharge monitoring of springs in Bighorn Canyon NRA began in 2011 (see Sigler 2011, 2012) and continued through 2013 (Figure 14). As with river hydrographs, spring and stream discharge varies markedly among years at some locations. For example, in Layout Spring (measured at upper Layout Creek) and lower Layout Creek measured and modeled discharge was dramatically higher in 2011 compared to 2012 and 2013 (Figure 14).

The maximum measured discharge at upper Layout Creek occurred on 22 June 2011, when the measured discharge was 22 cfs. The maximum measured discharge at lower Layout Creek was 18 cfs on that same day. The empirically derived rating curves used to model flows for both Layout Creek sites (data from 2011 to 2013) were statistically significant (upper Layout Creek [$R^2=0.864$; $n=16$] and lower Layout Creek [$R^2=0.944$; $n=8$]). Modeled estimates of discharge above maximum levels mentioned above and shown in Figure 15 should be viewed carefully since the stage/discharge relationship above these discharge levels could not be confirmed. Continuous stage levels recorded by data loggers are discrete data points not derived from a rating curve, and can be used as a surrogate variable to infer maximum flows.

According to the 2012 stage data, water levels were highest on 5 June at upper and lower Layout Creek sites. The modeled discharge levels derived from the stage data

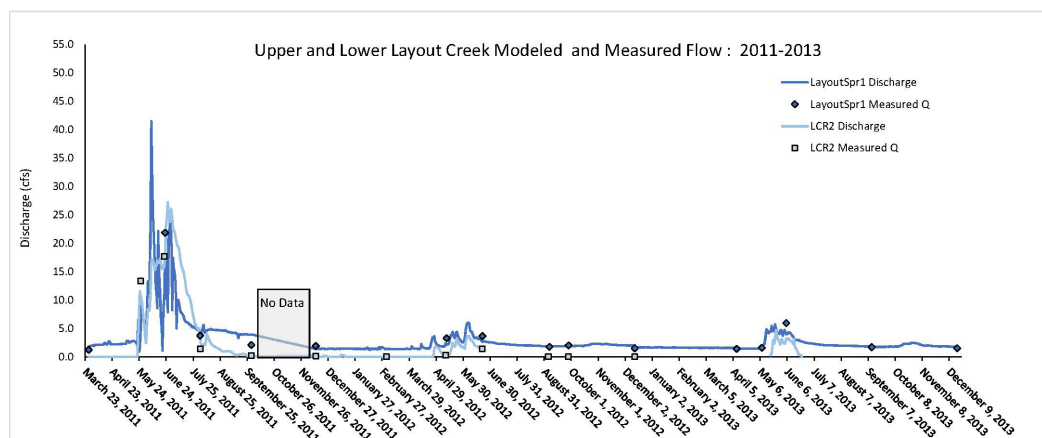
were 7.6 cfs at upper Layout Creek and 3.7 cfs at lower Layout Creek. In 2013, the max stage recorded occurred on 24 May at upper and lower Layout Creek sites and modeled discharge levels were 6.4 cfs at upper Layout Creek and 4.7 cfs at lower Layout Creek.

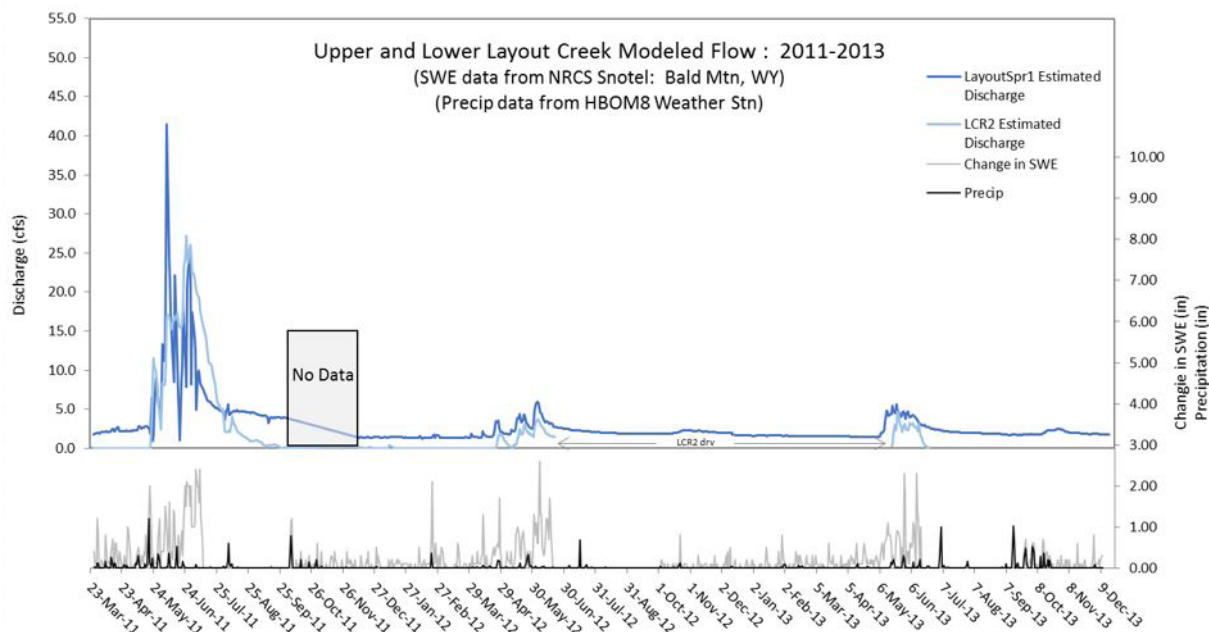
Empirical and modeled discharge data suggest that Layout Spring and upper Layout Creek support perennial flows (Figure 14). In contrast, lower Layout Creek flowed intermittently and extended periods with no flow were regularly documented (Figure 14). Throughout 2012-2013, lower Layout Creek was predicted to be dry 86% of the time.

Modeled 2011 to 2013 discharge records for upper and lower Layout Creek were also plotted along with precipitation and snow water equivalent (SWE; Hillsboro, Montana [HBOM8] Weather Station) and snotel (Bald Mountain, Wyoming; Figure 15). These summaries suggest that flows in Layout Creek are groundwater derived except possibly during large precipitation events and rain-on-snow events where water may reach the spring orifice and upper Layout Creek during overland flow (Figure 15). Despite the overwhelming suggestion of groundwater influence there are examples of increased discharge following large precipitation events (see early August 2011; Figure 15).

Unlike variations in discharge documented in upper and lower Layout Creek, Lockhart Stockpond Spring water table levels display only small variations between 2011 and 2013. One notable exception was a dramatic change in water level in February 2012. This dramatic water level change corresponds

Figure 14. Measured and modeled discharge at Layout Spring (LayoutSpr1) and lower Layout Creek (LCR2). Discharge calculations were based on the rating curves incorporating data from years 2011 to 2013.





with changes in SWE from a nearby snotel site (Bald Mountain, Wyoming), however, the pronounced but short-term change in water level measured may be associated with snow accumulation and melting directly up-gradient from the spring. Such a local change in snow cover during 2012 may have elicited the short-term, but pronounced response captured there.

Water levels measured at Lockhart Stockpond also show some influence of precipitation and snowmelt (SWE). Specifically, water levels in April and May 2012 and May 2013 indicate some response to regional precipitation and snowmelt (SWE) events. Water levels generally show declines in both 2012 (March to September) and 2013 (May to August), and may possibly be linked to increased evapotranspiration as the spring outfall supports dense vegetative stands during the growing season. A notable increase in water levels occurring in the Fall may likewise be, in part, the result of reduced evapotranspiration rates. Despite the subtle variations in water levels described above, water levels at the Lockhart Stockpond Spring appear to have increased approximately 5 cm over the period of record (Figure 16).

Water temperatures in Lockhart Stockpond varied between 5 and 15°C over the period of record and are roughly synchronized with, 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 2013. The magnitude of change over the period of record is on the order of 30 cm (Figure 17); a nearly 10 cm increase in water level was documented in 2013. Similar to Lockhart Stockpond Spring, the greatest increases in water table level in both 2012 and 2013 occurred in late September and early October. This increase in water level

Figure 15. 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). Daily change in snow water equivalent (SWE) and precipitation were measured from nearby snotel and weather stations.



Dense vegetation at Lockhart Stockpond Spring during the September visit.

Figure 16. Water table levels (depth below the surface), air and water temperatures recorded at Lockhart Stockpond. Precipitation and daily change in snow water equivalent (SWE) are summarized from nearby monitoring stations.

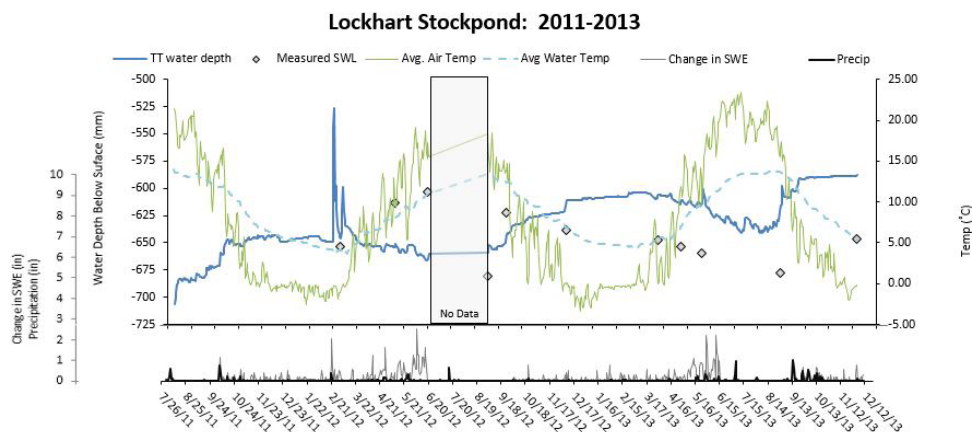
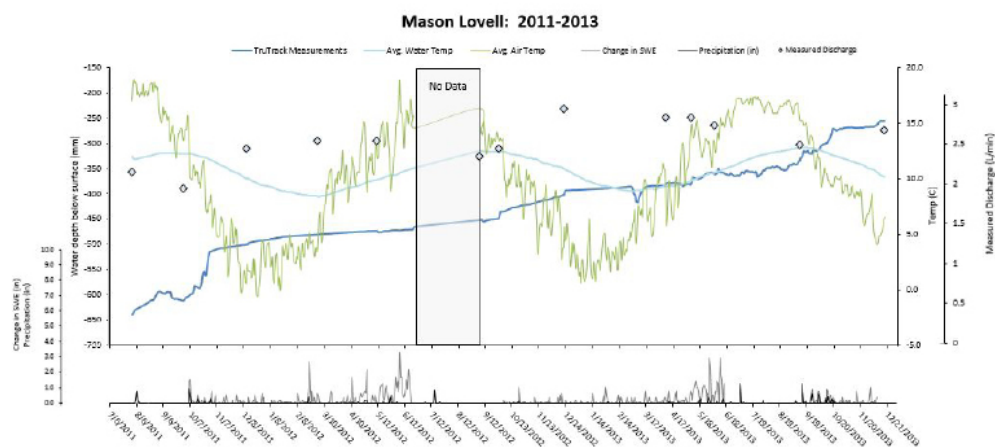


Figure 17. Modeled discharge and measured discharge, air and water temperatures recorded at Mason Lovell Spring. Daily change in snow water equivalent (SWE) and precipitation were measured from nearby snotel and weather stations.



Downloading continuous water level record from TruTrack logger to laptop computer at Mason-Lovell Spring.

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 (Figure 17) track on-site flow measurements and appear 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 behind changes air temperatures by nearly two months (Figure 17).

Discussion

Water resources are critical to the health and productivity of arid and semi-arid landscapes like those found within Bighorn Canyon NRA. In addition, water resources are important to visitor recreation experiences and their perceptions of the NRA's aesthetic features (*sensu* Burmil et al. 1999). During the 2013 calendar year, ongoing monitoring activities further characterized water quality and discharge patterns in Bighorn Canyon's rivers, streams, and springs. These summaries will contribute to the understanding of the variability of water resources in the NRA and reveal whether these resources are meeting state and federal water quality standards.

Flow patterns in the Bighorn and Shoshone rivers vary strongly among calendar years. Flows at all river locations in 2013 were very similar to the 25th percentile of daily flows at each site. High among-year variation in annual cumulative riverflow 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 generally decreasing.

Water quality in the Bighorn River near St. Xavier, Montana exhibited little variability over the sampling period. In contrast, the Shoshone River near Lovell, Wyoming had moderate-to-high and variable concentrations of nitrogen (expressed as $\text{NO}_2 + \text{NO}_3$) 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 five calendar years (2009-2013) exceeded Wyoming state standards. Although *E. coli* levels were consistently high, some variation was documented during summer months and *E. coli* levels were correlated with river discharge.

Discharge patterns in three springs and one stream (Layout Creek) were characterized in 2013 creating what is now a three-year

record. Overall, discrete measurements of discharge tracked variations in shallow water levels in wells and indicate that continuous estimates of spring discharge are possible. Interestingly, discharge patterns for monitored springs show very different responses to precipitation or SWE estimates. These support claims that springs within Bighorn Canyon NRA 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 Bighorn Canyon NRA resources during calendar year 2013 suggests that most monitored resources are meeting state and water quality standards. The Shoshone River is the exception; there *E. coli* levels between 1 May to 30 September exceed the Wyoming DEQ's numeric standard (126 colonies/100 mL). Continued sampling of *E. coli* in the Shoshone River should continue to document levels in this major tributary to Bighorn Lake. Benthic macroinvertebrate samples were also collected in Fall of 2013 at two locations (Bighorn River at St. Xavier and Crooked Creek). We are working with our cooperators to summarize laboratory results (for 2011 to 2013), but macroinvertebrate assemblage data will provide further information on the condition of Bighorn Canyon NRS's water resources.

Recommendations

Based on results presented from the 2013 monitoring summarized within this report, the GRYN recommends the following:

- Continue monitoring 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.
- Continue monitoring *E. coli* in the Shoshone River at Lovell, Wyoming. Monitoring *E. coli* and water quality at the current Shoshone River location

should also be discussed. River access at the Highway 310 location can be challenging with eroded banks and high flows. Access to the Shoshone River at State Highway 37 entering the NRA may provide a suitable alternative.

- Continue 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 per field season including a minimum of three measurements during peak flows (from the middle of April to middle of June).
- Because of the variable responses to seasonal and annual precipitation among springs, consider the use of dissolved gases to assist with groundwater aging from monitored springs (Layout Spring, Lockhart Stockpond, and Mason-Lovell Spring). Chlorofluorocarbons are manmade compounds that can assist with aging waters that are less than 50 years old. Age dating the waters may further help to understand the fate of spring flows under variable weather years and in a changing climate.
- Consider the construction or installation of a permanent weir at Lockhart Stockpond Spring. A staff plate could also be installed on the weir or in the pool behind the weir. Past discharge measurement techniques using an aluminum v-notch weir at this location were unsuccessful in accurately estimating discharge at this site. Moreover, temporary installation of the weir caused minor disturbances to the spring substrates each site visit.
- Consider stabilizing slope above Mason-Lovell PVC standpipe that houses a groundwater-level logger. Stabilization is needed due to sloughing and unstable slopes above the standpipe. Sloughed soil around the standpipe should be removed paying careful attention not to damage the PVC standpipe or alter the vertical position of the enclosed logger.
- Establish permanent photo points at all monitoring sites.
- Establish a set of protocols for measuring water depths in wells.

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Appendix A. 2013 Water Quality Laboratory Results for River Monitoring Sites

The following tables present laboratory results for three river monitoring sites: Bighorn River at St. Xavier, Montana (Table A1); Bighorn River at Kane, Wyoming (Table A2), and the Shoshone River at Lovell, Wyoming (Table A3).

All values presented in mg/L. Ca=calcium, K=potassium, Mg=magnesium, Na=sodium, Total Alk as CaCO_3 =total alkalinity as calcium carbonate, HCO_3^- =bicarbonate, CO_3^{2-} =carbonate, OH^- =hydroxide, $\text{NH}_3\text{-N}$ =ammonium nitrogen, $\text{NO}_2^- + \text{NO}_3^-$ =combined result for nitrite + nitrate, SO_4^{2-} =sulfate, P=phosphorus.

Table A1. Water quality lab results for Bighorn River at St. Xavier, Montana.

Analytes	4/8/2013	6/4/2013	9/10/2013
Total Ca	82.2	81.5	78.2
Total K	4.0	3.9	3.2
Total Mg	27.7	28.4	26.1
Total Na	68.3	69.4	65.2
Total Alk as CaCO_3	218.0	175.0	192.0
HCO_3^-	230.0	214.0	230.0
CO_3^{2-}	18.0	<1.0	2.0
CO_2	190.0	155.0	169.0
OH	<1.0	<1.0	<1.0
$\text{NH}_3\text{-N}$	<0.2	<0.2	<0.2
Cl	13.0	12.0	11.0
$\text{NO}_3^- + \text{NO}_2^-$	0.6	0.4	0.5
SO_4^{2-}	258.0	247.0	253.0
Ortho-P	<0.01	0.01	<0.01
Total P	<0.01	0.01	0.02

Table A2. Water quality lab results for Bighorn River at Kane, Wyoming.

Analytes	4/8/2013	6/4/2013	9/10/2013	12/17/2013
Total Ca	92.7	58.6	96.5	93.0
Total K	4.7	3.3	6.3	4.5
Total Mg	33.0	18.1	31.3	31.9
Total Na	88.6	38.1	99.0	79.7
Total Alk as CaCO ₃	216.0	136.0	219.0	272.0
HCO ₃	224.0	156.0	258.0	332.0
CO ₃	19.0	5.0	4.0	<1.0
CO ₂	188	119	192	240
OH	<1.0	<1.0	<1.0	<1.0
NH ₃ -N	<0.2	<0.2	<0.2	<0.2
Cl	18.0	8.0	18.0	21.0
NO ₃ +NO ₂	0.1	0.3	0.8	0.5
SO ₄	319.0	135.0	324.0	293.0
Ortho-P	<0.01	0.02	<0.01	<0.01
Total P	0.07	0.18	0.14	0.04

Table A3. Water quality lab results for Shoshone River at Lovell, Wyoming.

Analytes	4/9/2013	6/5/2013	9/10/2013	12/17/2013
Total Ca	80.3	53.7	74.1	86.0
Total K	4.4	2.6	3.4	4.1
Total Mg	25.9	16.6	26.1	25.2
Total Na	50.4	43.9	61.9	50.0
Total Alk as CaCO ₃	228.0	159.0	201.0	238.0
HCO ₃	278.0	175.0	226.0	263.0
CO ₃	<1.0	9.0	9.0	13.0
CO ₂	204.0	137.0	175.0	208.0
OH	<1.0	<1.0	<1.0	<1.0
NH ₃ -N	<0.2	<0.2	<0.2	<0.2
Cl	10.0	5.0	4.0	6.0
NO ₃ +NO ₂	0.5	0.3	1.3	1.1
SO ₄	225.0	125.0	119.0	162.0
Ortho-P	<0.01	0.01	<0.01	<0.01
Total P	0.06	0.10	0.10	0.14

Appendix B. 2013 Upper and Lower Layout Creek Measured and Modeled Flow Comparison Tables

Table B1. Measured and modeled flow comparison for Upper Layout Creek.

Date	Stage (mm)	Measured Discharge (cfs)	Modeled Discharge (cfs)	%RPD
4/9/2013	474	1.39	1.1	12%
5/8/2013	481	1.58	1.4	6%
6/5/2013	575	5.93	5.8	1%
9/11/2013	492	1.71	1.7	0%
12/18/2013	491	1.51	1.8	9%

RPD=relative percent difference

Table B2. Measured and modeled flow comparison for Lower Layout Creek.

Date	Stage (mm)	Measured Discharge (cfs)	Modeled Discharge (cfs)	%RPD
4/9/2013	0	dry	dry	--
5/8/2013	0	dry	dry	--
6/5/2013	46	2.47	3.22	26%
9/11/2013	0	dry	dry	--
12/18/2013	0	dry	dry	--

RPD=relative percent difference

Appendix C. 2011-2013 Upper and Lower Layout Creek Maximum Stage Measurements

Table C1. Upper Layout Creek maximum stage measurements.

Year	Date	Max Stage	Modeled Discharge (cfs)
2011	6/7/2011	736	45.2
2012	6/5/2012	605	7.6
2013	5/24/2013	600	6.4

Table C2. Lower Layout Creek maximum stage measurements.

Year	Date	Max Stage	Modeled Discharge (cfs)	Number of Days Flowing	Number of Days Dry	Percentage of the Year Dry
2011	6/26/2011	320	26.8	No data 1 September - 12 December 2011		
2012	6/5-6/6/2012	90	3.7	62	303	83%
2013	5/24/2014	68	4.69	37	328	90%

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