National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science

Water Quality Summary Report for Bighorn Canyon National Recreation Area

Preliminary Analysis of 2014 Data

Natural Resource Data Series NPS/GRYN/NRDS—2015/810

ON THE COVER

TruTrack instrumentation during high flows at Upper Layout Creek, Bighorn Canyon NRA
NPS photo

Water Quality Data Summary Report for Bighorn Canyon National Recreation Area

Preliminary Analysis of 2014 Data

Natural Resource Data Series NPS/GRYN/NRDS—2015/810

Authors

Katie Kaylor
W. Adam Sigler

Montana State University
Water Quality Extension
Land Resources and Environmental Sciences
P.O. Box 173120
Bozeman, MT 59717-3120

Andrew Ray

Greater Yellowstone
Inventory and Monitoring Network
National Park Service
2327 University Way, Suite 2
Bozeman, Montana 59715

Editor

Nina Chambers

Northern Rockies Conservation Cooperative
P.O. Box 2705
Jackson, WY 83001

July 2015

U.S. Department of the Interior
National Park Service
Natural Resource Stewardship and Science
Fort Collins, Colorado

The National Park Service, Natural Resource Stewardship and Science office in Fort Collins, Colorado, publishes a range of reports that address natural resource topics. These reports are of interest and applicability to a broad audience in the National Park Service and others in natural resource management, including scientists, conservation and environmental constituencies, and the public.

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 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/).

Please cite this publication as:

K. Kaylor, W. A. Sigler, and A. Ray. 2015. Water quality data summary report for Bighorn Canyon National Recreation Area: Preliminary analysis of 2014 data. Natural Resource Data Series NPS/GRYN/NRDS—2015/810. National Park Service, Fort Collins, Colorado.

NPS 617/129077, July 2015

Contents

Figures

Tables

Executive Summary

This report summarizes discharge and water quality monitoring data in Bighorn Canyon National Recreation Area (NRA) for calendar year 2014. Results presented include annual and long-term discharge summaries for the Bighorn and Shoshone rivers, chemical characteristics 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 at Kane, Wyoming and Shoshone River at Lovell, Wyoming 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 were higher than average at all river locations in 2014 and were similar to the 75^{th} 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 the lowest seasonal variability over the sampling period. The Shoshone River near Lovell, Wyoming had moderate-to-high and variable concentrations of nitrogen (expressed as $NO_2 + NO_3$) and the Bighorn River at Kane, Wyoming exhibited moderate levels of 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 June through September sampled across six calendar years (2009 to 2014) exceeded Wyoming state standards. In 2014, *E. coli* levels were consistently high, with some documented variation. Samples collected during August displayed the highest levels of *E. coli* during the summer months.

Spring discharge. Discharge patterns in three springs and one stream (Layout Creek) were characterized in 2014 creating what is now a four-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 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 of springs and streams. Chemical and biological monitoring of Bighorn Canyon NRA resources during calendar year 2014 suggests that most monitored resources are meeting state 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 and 30 September.

Acknowledgments

The authors would like to acknowledge and thank the Bighorn Canyon NRA and Greater Yellowstone Inventory & Monitoring Network staff for their logistical support and with reviews of prior versions of this report. Special thanks to Cass Bromley, Bill Pickett, and Virginia DuBowy, who were extremely helpful throughout the monitoring year and have contributed in the field, reviewed reporting materials, and orchestrated necessary logistical support to crews while in the field.

This work was funded by the National Park Service (NPS) Greater Yellowstone Network Inventory & Monitoring Network and represents a collaboration between the NPS 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. This water body was created in the 1960s when the Bureau of Reclamation erected Yellowtail Dam at the northern end of the canyon. Now, Bighorn Lake is a nearly 113 km (70 miles) long lake occurring at an elevation of 1,115 meters (3,657 feet). The lake contains a total volume of 1.6 billion m^3 (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 recreational destination for boaters, anglers, and wildlife viewers, but also 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 at BICA, 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. 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 Pryor 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 temperature maxima occur in July; on average February is the driest month (WRCC 2015). From 1948 to 2013, the maximum temperature range for the Yellowtail Dam Station (249240) is -37.2°C (February 2006) to 42.8°C (July 2002 and 2005). In the southern portion of the park, rainfall is reduced (approximately 37% of that measured at Yellowtail Dam; Komp et al. 2012) with arid, high desert climate characteristics. In Lovell, Wyoming (just west of BICA in the south end of the 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 2013 indicated that monthly mean temperatures are highest in July and August and lowest in January. The maximum temperature range for the Lovell Station (485770) is -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

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 2013). 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 2012).

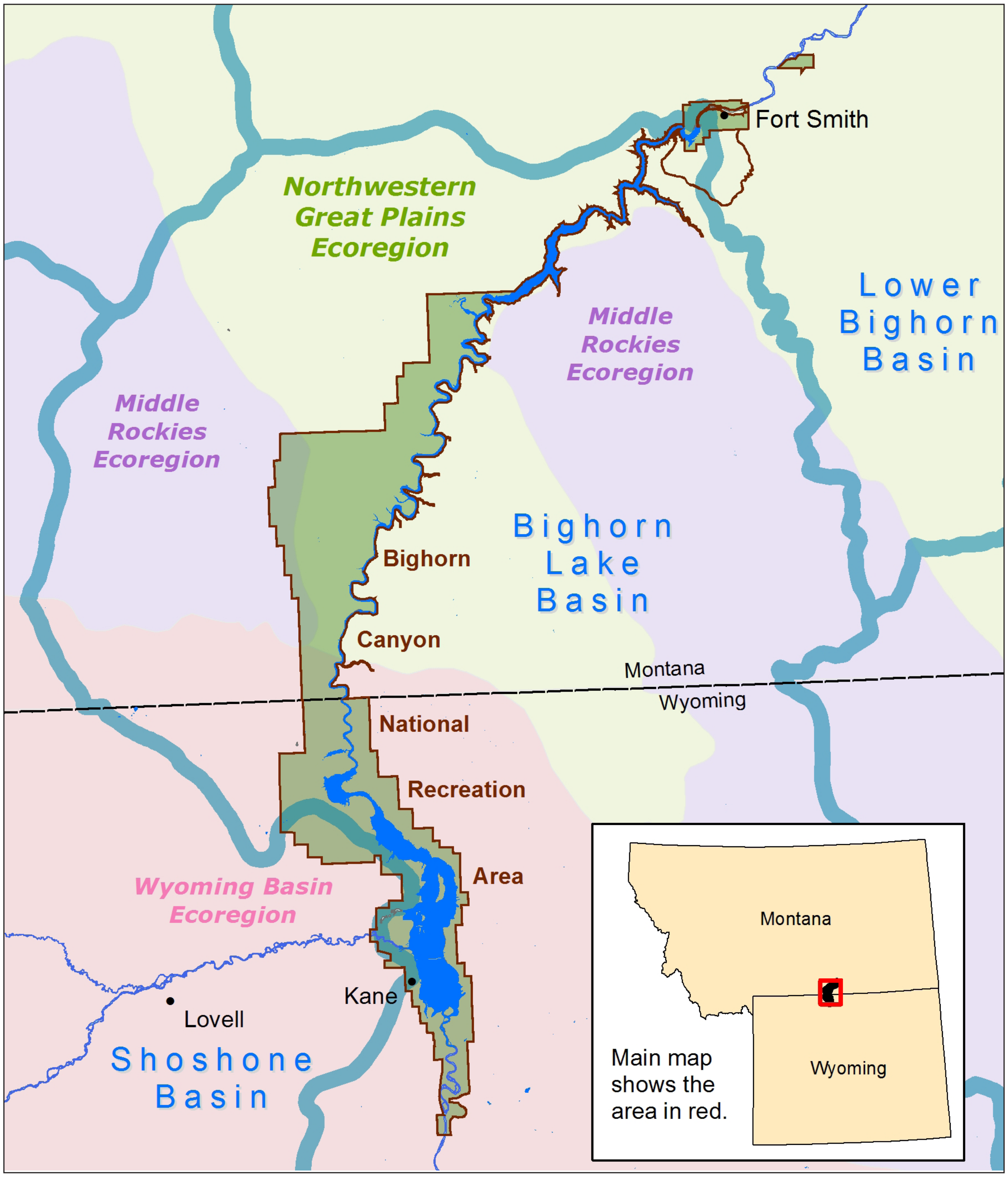


Figure 1. Bighorn Canyon National Recreation Area and U.S. Environmental Protection Agency Ecoregion Level III location maps.

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 reportedly 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

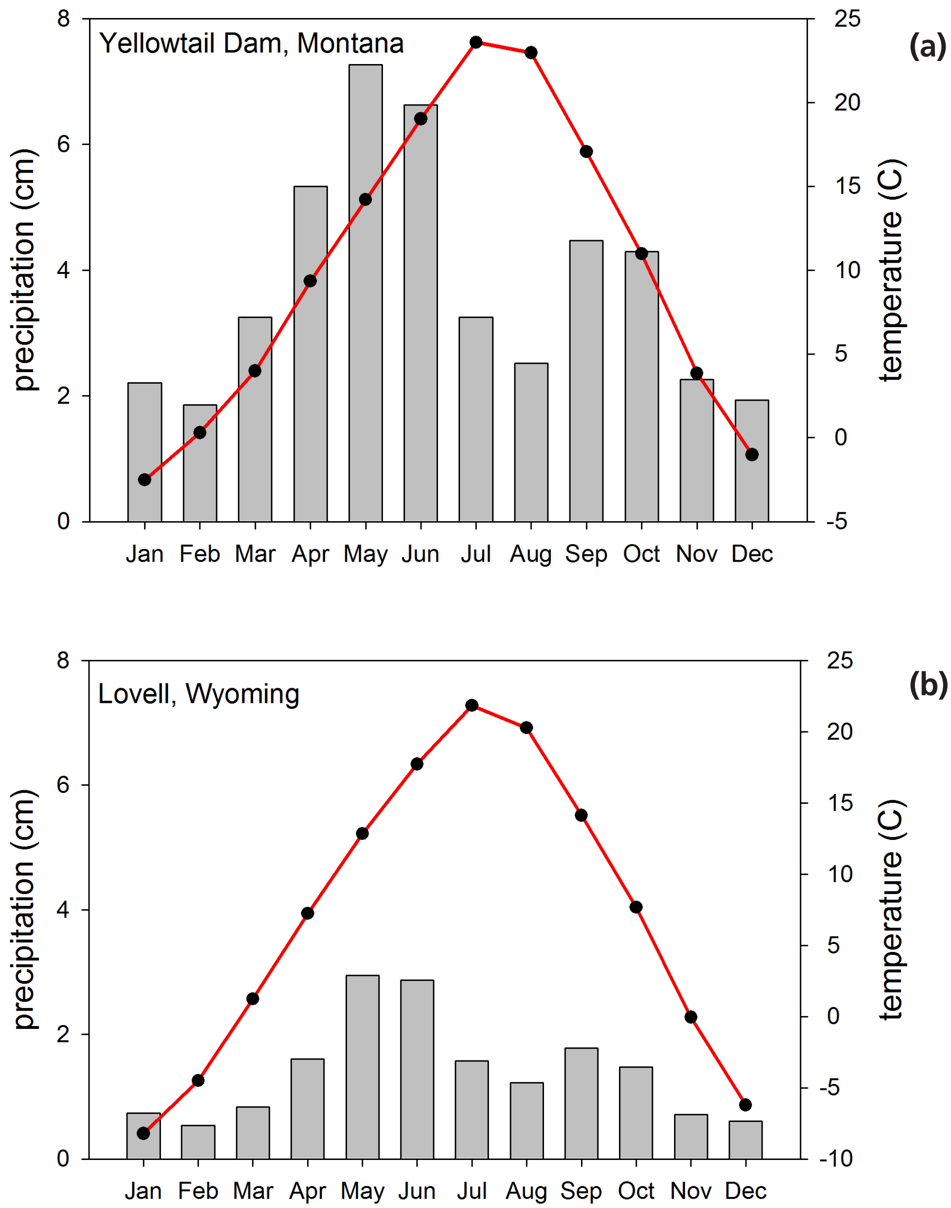


Figure 2. Climographs constructed from weather data from (a) Yellowtail Dam Station (249240) near St. Xavier, Montana and (b) from Lovell, Wyoming (485770). Average monthly precipitation (cm; gray bars) and temperature (°C; red line) are shown for each location.

Russian olive (*Elaeagnus angustifolia*) and saltcedar (*Tamarix* spp.), occur in portions of BICA (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 the NRA and below Yellowtail Dam.

Mercury in water and fish tissues is a growing water resource concern in BICA. Fish tissue samples collected throughout BICA exhibit elevated levels of Hg. In particular, walleye (*Sander vitreus*) collected from the Shoshone River, Bighorn River and Bighorn Lake exhibited Hg 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 BICA exceeded levels considered to be protective of wildlife (Yeardley et al. 1998). In 2015 and 2016, BICA will be working with scientists from USGS, Montana State University, and the Greater Yellowstone Network (GRYN) on a study to better understand the factors within Bighorn Lake that contribute to elevated mercury in water and sediments. Specific project objectives are to: (1) understand natural versus anthropogenic mercury inputs entering Bighorn Lake from the major tributaries (Shoshone River and Bighorn River) during spring runoff and summer low flow; (2) investigate mercury cycling in Bighorn Lake and try to identify potential "hotspots" where areas of concentrated mercury transform to methylmercury (most dangerous form); and (3) understand the bioaccumulation and transfer of mercury through the food web to top fish predators (e.g., walleye).

Like many semi-arid regions, seeps and springs are an important resource at BICA. At least 35 springs have been located throughout the NRA. While springs in BICA vary with respect to the types 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 BICA (*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, Stagliono 2008, von Fumetti and Nagel 2012).

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 (O'Ney et al. 2009). This report summarizes monitoring activities in Bighorn Canyon National Recreation Area during calendar year (CY) 2014.

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 standards are presented in Table 1.

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" (MTDEQ 2012). 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 associations. Each class has associated with

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	*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*	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 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 intergravel 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 intergravel 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 Ecoregion reference range 0.010 - 0.055 mg/L (EPA 2000)	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). Pryor-Bighorn Foothilles (43v) Ecoregion: 0.033 mg/L (July 1 to September 30; MTDEQ 2014b)	*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 NH_3-N plus NH_4-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.

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)
Nitrate+Nitrite-N (mg/L)	Drinking Water	10 mg/L	10mg/L	10mg/L
Nitrate+Nitrite-N (mg/L)	Aquatic life and recreation	No standard	Nitrate + Nitrite is recognized as a plant complex of nutrients 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)	Aquatic Life & Recreation	no standard Ecoregion reference range 0.22 - 0.90 (EPA 2000)	Wadeable streams, Prior-Bighorn Foothills (43v) Ecoregion: 0.44 mg/L (July 1 to September 30; MTDEQ 2014b)	*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 days) Nov 1 to Mar 31: geomean of ≤630 (10% of the total samples may not exceed 1,260 mL during 30 days)	May 1 to Sep 30: geomean of ≤126 during any 60 day period. 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 = $((0.0577/(1+ 10^{7.688\text{-pH}})) + (2.487/(1 + 10^{7.688\text{-pH}}))) \times 1.45 \bullet 10^{0.028 \bullet (25 - \text{MAX}(T,7))}$

it the present or future beneficial uses the water body should be supporting (MTDEQ 2012). 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 2013) and closely follow federal standards. Rivers and streams within BICA (in 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).

Wyoming's 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).

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 2014 Final Water Quality Integrated Report (MTDEQ 2014a) and Wyoming Water Quality Assessment and Impaired Waters List published in 2014 (WYDEQ 2014).

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.

The 2012 Montana 305(b)/303(d) Integrated Report (MTDEQ 2012) included 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 was listed as only partially supporting for aquatic life and cold water fisheries because of elevated total nitrogen concentrations (MTDEQ 2012). In the 2014 Montana Integrated Report, the 70.85 km of the Bighorn River from Yellowtail Dam to the Crow Indian Reservation Boundary was removed as these waters belong under the jurisdiction of the Crow Tribe (MTDEQ 2014a).

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 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 quarterly for river sites: Bighorn River at Kane, Wyoming; Bighorn River at St. Xavier, Montana; and the Shoshone River at Lovell, Wyoming in 2014 (Figure 3).

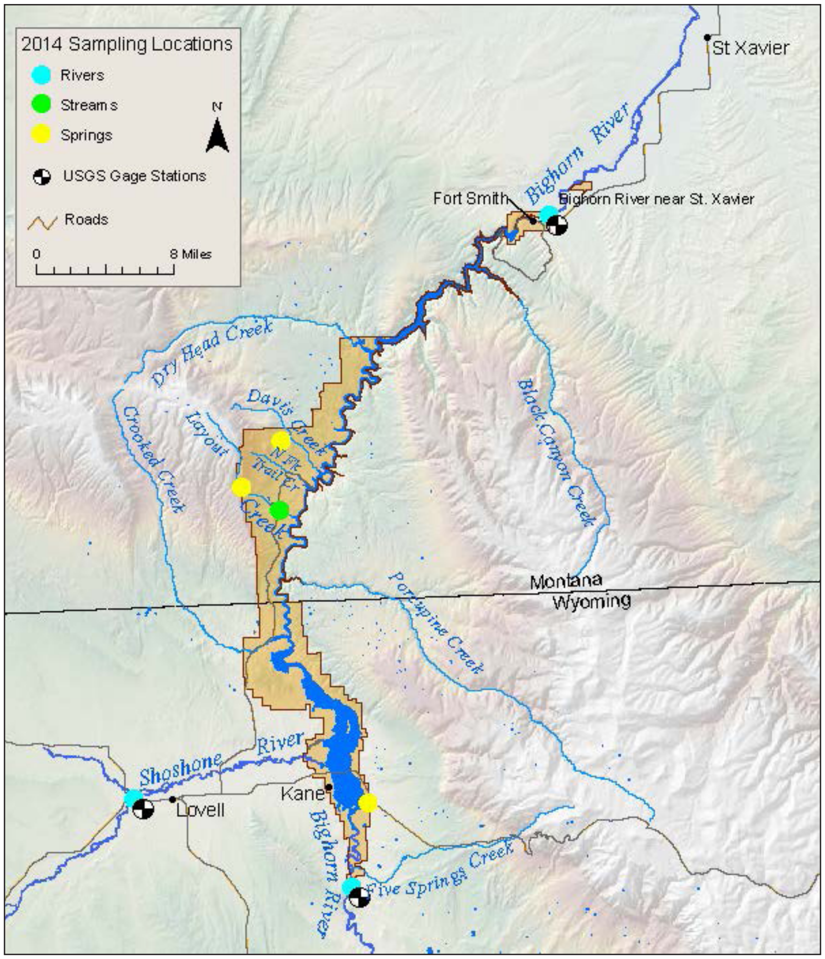


Figure 3. Sampling locations for rivers, streams, and springs sampled in Bighorn Canyon National Recreation Area in calendar year 2014.

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 556 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 using a DH-81 Sampler (Federal Interagency Sedimentation Project, Vicksburg, Mississippi) affixed to a 1-m wading rod. A three liter polypropylene bottle was used with the DH-81 sampler. The bottle was filled at multiple points among wadeable portions of a cross section of the river. When full, the 3L bottle was emptied into an 8L polyethylene churn splitter to facilitate a larger composite water sample that is more representative of the stream conditions. The churn homogenizes the collected water before subsamples are retrieved. All bottles necessary for laboratory analysis are filled from the churn.

The 3L collection bottle and churn splitter were triple rinsed with deionized water between samples to prevent cross contamination. Bottles used for lab analysis were triple rinsed with sample water before filling.

Bacterial samples were collected 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). 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) and 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 electro-magnetic Marsh McBirney velocity meter affixed to a graduated, stainless-steel, top-setting wading rod (Nolan and Shields 2000).

Results

Discharge of Bighorn and Shoshone Rivers

Hydrographs for the Bighorn River vary according to location, but traditionally 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 2014, daily flows in the Bighorn River near Kane, Wyoming were between the mean and the 75th percentile of daily flows for the period of record; peak flow occurred earlier in the year than historic peak flows (1928-2014; 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). Despite this variation, 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 show 2014 flows from March through June well exceeded the 75th percentile of daily flows for this location. From mid to late June, flows were drastically reduced at the dam for management reasons (Figure 5). Similar to the Bighorn River near Kane, the hydrograph at Bighorn River near St. Xavier experienced higher than average flows in early spring. 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) but remained elevated above baseflow

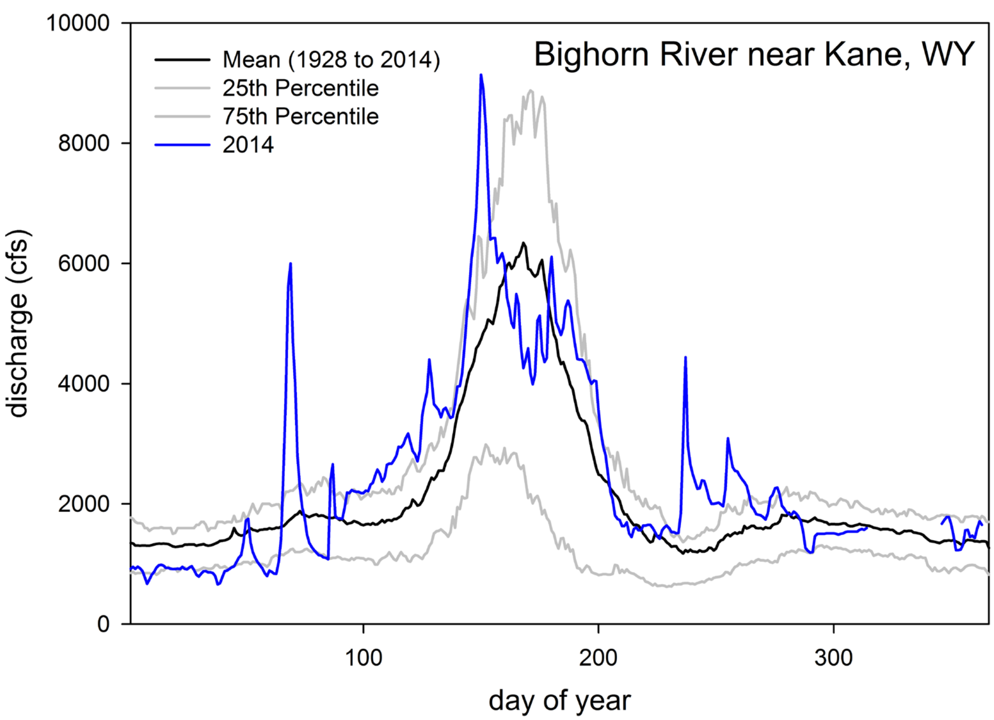


Figure 4. Long-term summary of average daily discharge (in cfs) at the Bighorn River near Kane, Wyoming (USGS Gage 06279500). River flows are presented by day of year where day 1 refers to January 1st of each calendar year. The period of record summarized for this gage extends from 1928 to 2014. Mean daily discharge for the period of record is shown in black and the 25th and 75th percentiles of daily flows are shown in gray. A summary of 2014 (blue) is also presented.

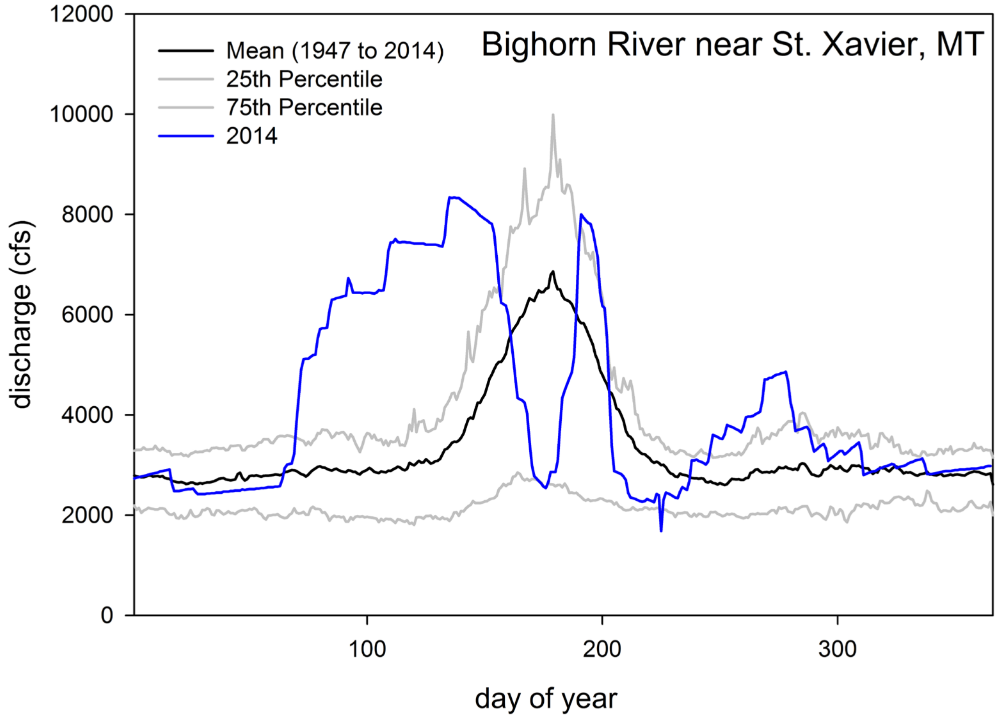


Figure 5. Long-term summary of average daily discharge (in cfs) at the Bighorn River near St. Xavier, Montana (USGS Gage 06287000). River flows are presented by day of year where day 1 refers to January 1st of each calendar year. The period of record summarized for this gage extends from 1947 to 2014. Mean daily discharge for the period of record is shown in black and the 25th and 75th percentiles of daily flows are shown in gray. A summary of 2014 (blue) is also presented.

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

The 2014 calendar year hydrograph for the Shoshone River at Lovell, Wyoming depicts average spring flows exceeding the 75th percentile (April-June), this is a similar trend as is seen at Bighorn River near St. Xavier site (Figure 5). The high spring flows are likely attributed to higher than average precipitation values in February of 2014 where, Lovell, WY experienced 800% of average precipitation (Figure 9). After peak runoff in July, the 2014 hydrograph follows a similar pattern to historic flows. However, flows in the Fall still remain elevated above the 75th percentile. This pattern may be explained by the above average precipitation and cooler weather in August and November (Figure 9). Like previous years, there is evidence in the hydrograph of flow manipulation and irrigation/withdrawals and/or diversions (Figure 10). 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 11).

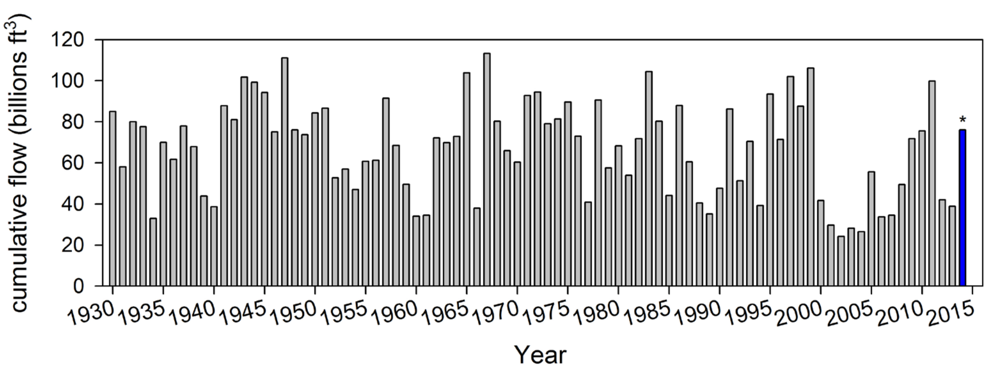
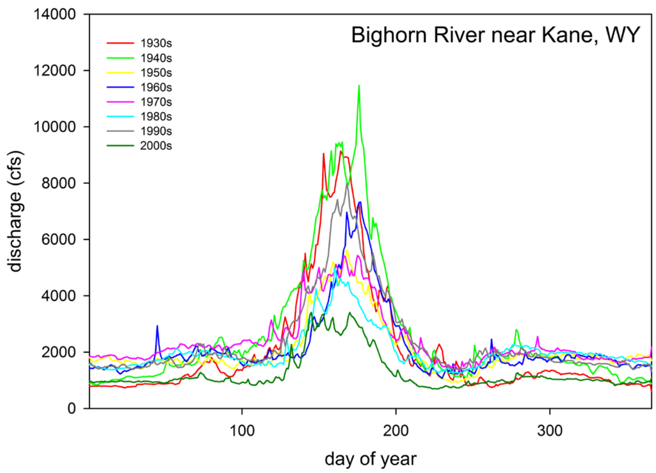


Figure 6. Histogram of annual river flow (in billion ft^3) at the Bighorn River near Kane, Wyoming USGS Gage (06279500). Years 1930 to 2014 are summarized and show year fluctuations in annual river flow. Asterisk denotes flows were estimated during periods with ice.



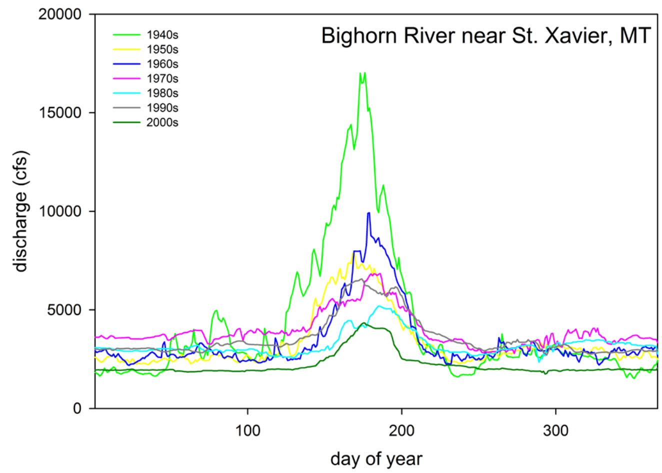
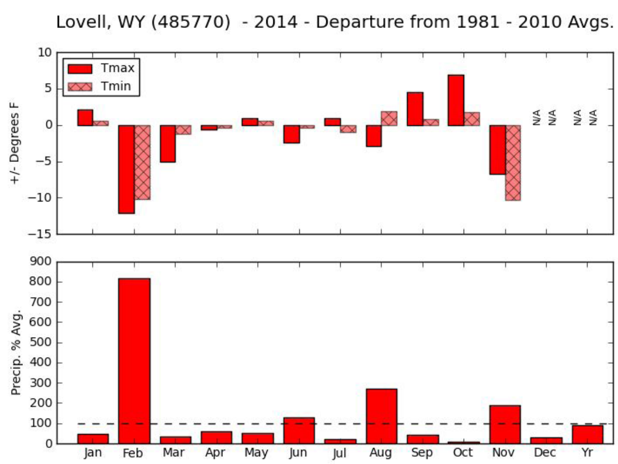


Figure 7. Decadal hydrographs for the Bighorn River near Kane, Wyoming (USGS Gage 06279500). River flows are presented by day of year where day 1 refers to January 1st each year. Years included in this summary span from 1930 to 2010.

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.



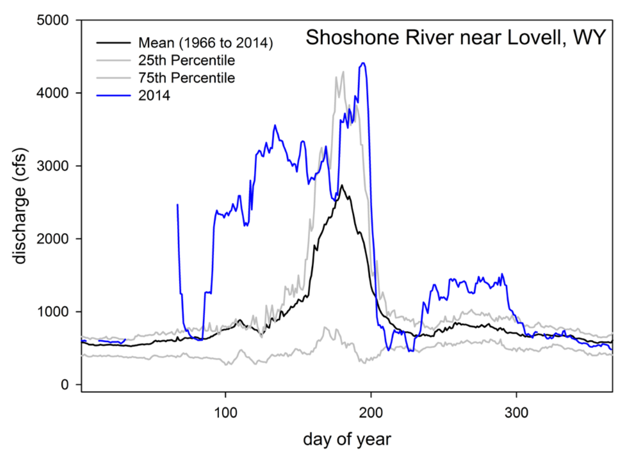


Figure 9. 2014 temperature (˚F) and precipitation departure from 30 year average at Lovell, WY (climateanalyzer.org [accessed March 26, 2015]).

Figure 10. 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 2014. Mean daily discharge for the period of record is shown in black and the 25th and 75th percentiles of daily flows are shown in gray. A summary of 2014 (blue) is also presented.

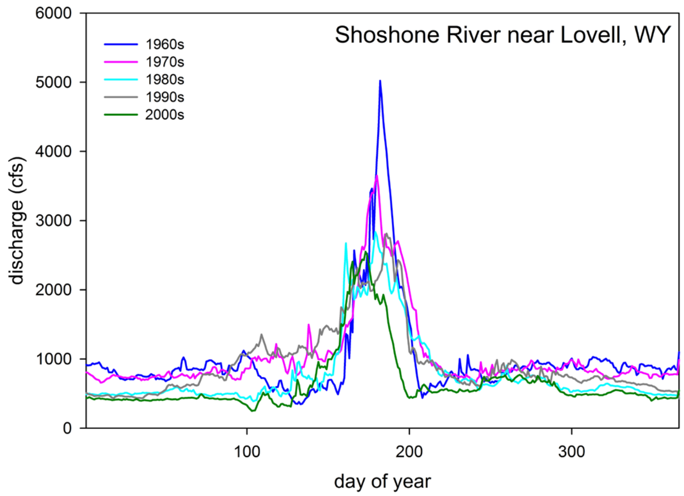


Figure 11. Decadal hydrographs for the Shoshone River near Lovell, Wyoming (USGS Gage 06285100) River flows are presented by day of year where day 1 refers to January 1st each year. Years included in this summary span from 1966 to 2010.

Water Quality of Bighorn and Shoshone Rivers

The ionic composition of BICA's large rivers (Bighorn and Shoshone) were summarized using quarterly sampling in 2014 using 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 (Figure10). Similar to 2013, 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 Bighorn River near St. Xavier, Montana (Table 2).

Median concentrations of nitrogen (NO_2 + NO_3) were greater in the Shoshone River than at either location in the Bighorn River (Figure 12) and concentrations were 0.9 mg/L and 1 mg/L in the Shoshone River during the September and December sampling dates in 2014. Mean total phosphorus (TP) was greatest at the Bighorn River near Kane, WY. The highest TP concentration measured during our 2014 quarterly sampling was in the Bighorn River near Kane, WY (1.6 mg/L TP in March 2014). This was the highest measured value of TP since 2011.

Variation in both primary nutrients was greatest in the Shoshone River and Bighorn at Kane (see Figure 12). The highest TP levels at the Shoshone River and at the Bighorn River at Kane were both during the March event when flows at both sites were above the 75th percentile (Figure 4, Figure 10) and the total suspended solids measurements were elevated (1,560 mg/L TSS and 2,030 mg/L TSS, respectively).

Despite its partial support designation for aquatic life and coldwater fisheries, the Bighorn River below Yellowtail Dam had a quarterly mean NO_2+$NO_{3\text{-}}$N concentration of 0.4 mg/L (Figure 12) and $NH_{3\text{-}}$N was always below detection (<0.2 mg/L). Although the Bighorn River near St. Xavier is not under state regulation for meeting Montana's Water Quality standards, in 2014, the waters met the criterion for wadeable streams for Total N (0.440 mg/L Total N; MTDEQ 2014b).

Table 2. Concentrations (mean ± 1 standard deviation of quarterly samples) 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).

	Cations (mg/L)				Anions (mg/L)			
Site	**Ca**	**K**	**Mg**	**Na**	**HCO_3**	**CO_3**	**Cl**	**SO_4**
Bighorn River, Kane, WY*	80.2 ± 17.2	7.7 ± 5.4	27.2 ± 8.7	58.0 ± 24.3	166.7 ± 24.8	5.0 ± 2.9	11.7 ± 5.5	180.3 ± 80.6
Bighorn River, St. Xavier, MT	62.1 ± 12.5	3.4 ± 0.7	21.2 ± 4.8	56.4 ± 14.8	199.0 ± 27.4	5.0 ± 2.8	9.2 ± 2.5	190.6 ± 58.4
Shoshone River Lovell, WY	69.4 ± 33.3	4.9 ± 3.5	23.1 ± 11.6	48.7 ± 21.0	210.3 ± 73.0	5.7 ± 3.5	5.3 ± 3.2	146.8 ± 82.4

*Represents the average of three samples from this site.

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 of BICA 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 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 the fecal coliform bacterium *E. coli* are more stringent during summer months (see Table 1) for waters designated for primary contact recreation. Figure 13 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 and during any consecutive 60-day period (WYDEQ 2013).

In 2014, *E. coli* levels from individual samples collected from the Shoshone River outside the park boundary were elevated

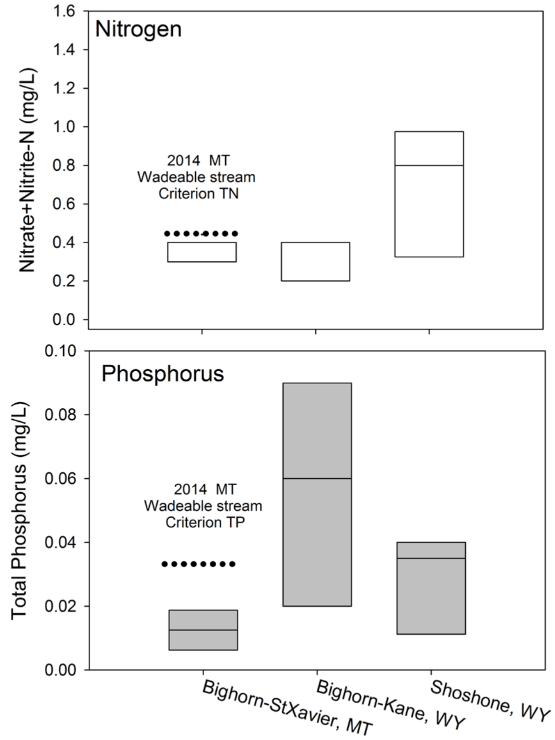


Figure 12. Box plots summarizing nitrogen (expressed as $NO_2 + NO_3$-N) and total phosphorus concentrations in surface waters collected from the Bighorn River (at St. Xavier, Montana and Kane, Wyoming) and the Shoshone River (near Lovell, Wyoming) in 2014. Boxes represent the upper and lower quartiles of the dataset; internal lines indicate the medians. Boxed summaries represent a minimum of three observations. The 2014 total nitrogen (TN) and total phosphorus (TP) for Montana's Pryor-Bighorn Foothills (43v) Ecoregion is shown. The period when the criteria applies is 16 June to 30 September (MTDEQ 2014a).

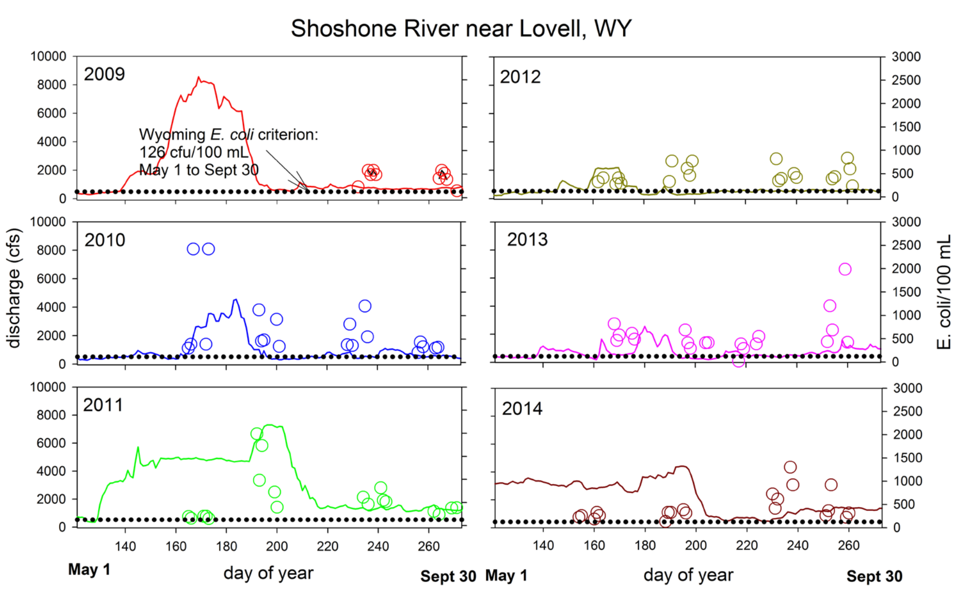


Figure 13. *Escherichia coli* levels (circles) in the Shoshone River near Lovell, Wyoming. *E. coli* levels (colonies/100 mL) are plotted by calendar day along with river discharge (solid line) for years 2009 to 2014. The period of the calendar year (May 1 to September 30) is displayed and corresponds to the Wyoming numeric standard for *E. coli* (126 colonies/100 mL; shown as a dotted line) for waters designated for primary contact recreation.

but variable during summer months (Figure 13). The 5-day geometric mean *E. coli* concentration for all months sampled across 2014 (range from 247 cfu/100 mL [June 2014] to 740 cfu/100 mL [August 2014]) exceeded the Wyoming State Standards for primary contact recreation (126 cfu/100 mL). These exceedances now represent six calendar years (2009 to 2014) of exceedances of the Wyoming State Standard (range in 5-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 2014 mean daily discharge and *E. coli* concentrations collected on that same day. Consistent with previous years, *E. coli* concentrations were lower at high discharge levels, however, in 2014 *E. coli* were most variable at low discharge (Figure 14).

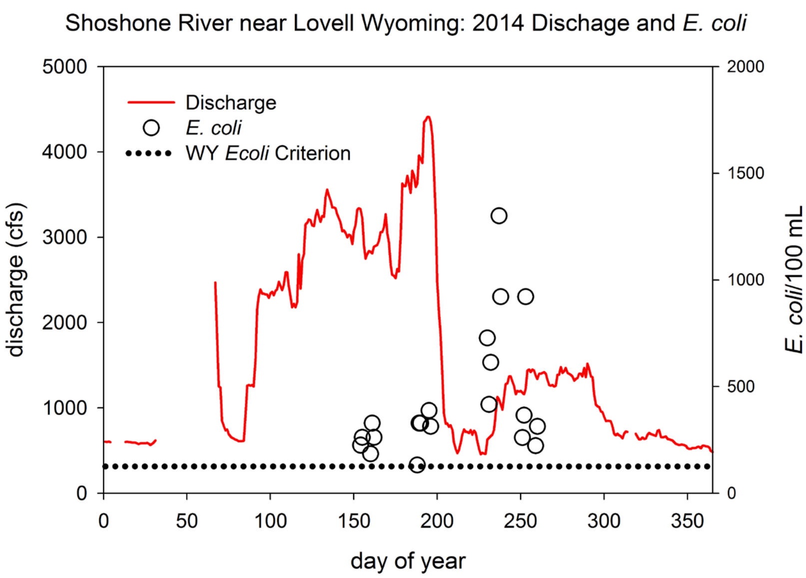


Figure 14. *Escherichia coli* levels (circles) in the Shoshone River near Lovell, Wyoming. *E. coli* levels (colonies/100 mL) are plotted by calendar day along with river discharge (solid red line) for calendar year 2014. Discharge for the entire year is shown along with the Wyoming numeric standard for *E. coli* (126 colonies/100mL; shown as a dotted line) that applies from May 1 to September 30.

Discharge Patterns of Representative Springs and Streams

Continuous discharge monitoring of springs in BICA began in 2011 (see Sigler 2011, 2012) and continued through 2014 (Figure 15). As with river hydrographs, spring and stream discharge varies markedly among years at some locations. For example, in Layout Creek (measured at upper Layout Creek [LayoutSpr1] and lower Layout Creek [LCR2]) measured and modeled discharge was dramatically higher in 2011 and 2014 compared to 2012 and 2013 (Figure 15).

The headwaters of Layout Creek begin in steep limestone walls in a deep canyon within the east Pryor Mountains. Layout Creek quickly descends in a restricted channel of limestone and large boulders out of the canyon and into the Tensleep Sandstone formations that are characterized by fine to medium grained, rounded, well-sorted, porous sandstone materials which are susceptible to movement and erosion (KellerLynn 2011). The upper Layout Creek (LayoutSpr1) site is located high in the canyon. The lower Layout Creek (LCR2) site is located in an often dry channel approximately 4.2 km (2.6 miles) downstream. The channel morphology and geology of the two sites are quite different; the lower channel where LCR2 is located has substrates that are more susceptible to alterations due to high flows.

During calendar year 2014, Layout Creek (at both sites) saw elevated peak flows that were similar to flows in 2011 (Figure 15.) Although discharge during maximum flows was not measured using manual techniques, flows for 2014 were estimated using a rating curve from 2011-2014. At upper Layout Creek (LayoutSpr1), the maximum modeled discharge was estimated to be 30 cubic feet per second (cfs) on May 30, 2014. A point discharge measurement was not collected during the May sampling trip (on May 28th) as it was unsafe to enter the water due to extremely high flow levels.

The empirically derived rating curve used to model flows in upper Layout Creek was statistically significant (R^2=0.859; n = 18). Using data from a four year period indicates

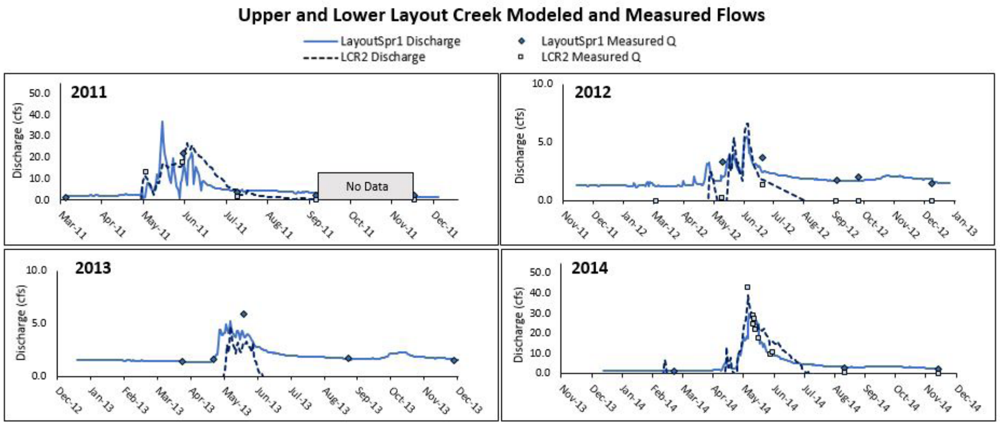


Figure 15. Measured and modelled discharge at upper Layout Creek (LayoutSpr1) and lower Layout Creek (LCR2). Note the different y-axis for the 2011 and 2014 figures. Discharge calculations for Layout Spring were based on rating curves incorporating data from years 2011-2014. Discharge calculations for lower Layout Creek were based on the rating curve for individual years.

a stable, multi-year relationship between stage and discharge at this site.

The maximum modeled discharge at lower Layout Creek (LCR2) was estimated to be 39 cfs on May 29, 2014 and maximum measured discharge occurred on May 28, 2014 (43 cfs). The difference between the measured and modeled discharge on May 28th and 29th suggest the model used to estimate discharge may only conservatively estimate high flow levels. The TruTrack water level data logger location at LCR2, which measures water height (i.e., stage), is also more likely to support debris jams on the upstream side of the stilling well; collection of this material could impact the stage/discharge relationship. Due to the seasonal and yearly variations at the lower Layout Creek site (LCR2), it was more appropriate to use a rating curve for the current year (2014) rather than a rating curve combining across all four years. Hence, only 2014 data were used in the rating curve for lower Layout Creek (LCR2) (R^2=0.906; n=10). Fortunately, in 2014 a large number of discharge measurements were taken (n=10) compared to past years (average 2011 to 2013, 2-3 measurements per year). This increase in the number of discharge measurements, specifically the increase in the number of measurements (n=7) during the falling limb of the hydrograph, helped to produce a strong rating curve for 2014.

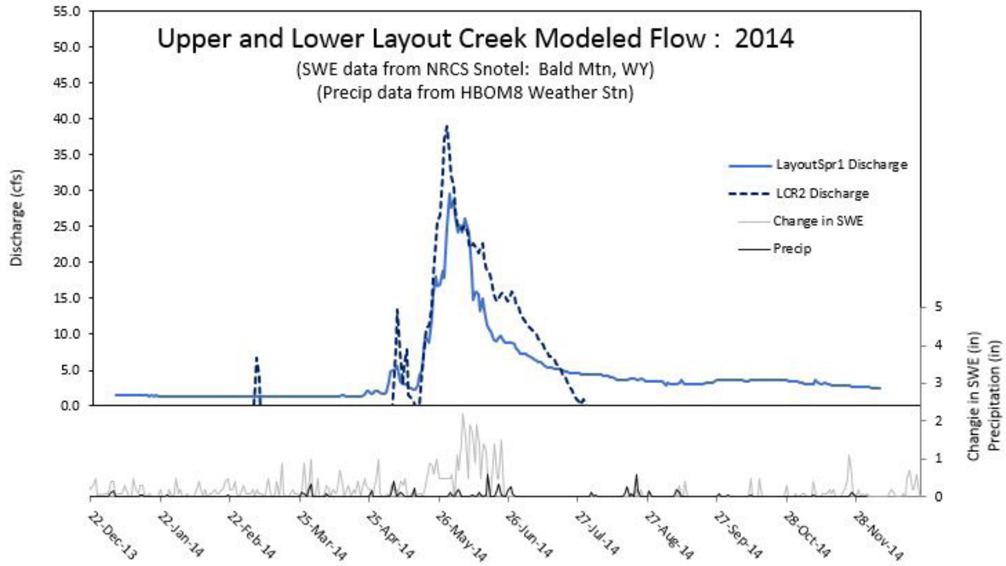
Interestingly, modeled peak flow at lower Layout Creek (LCR2) was estimated to be 9 cfs higher than max modeled flows at upper Layout Creek (LayoutSpr1; Figure 16). This may have occurred due to a weakness in our model, or it could also indicate increased contributions from subsurface flow or ephemeral tributaries to the Layout Creek channel as soils may have been saturated due to melting snow and precipitation events.

Maximum discharges at upper Layout Creek in 2011 and 2014 as shown in Figure 15 should be viewed carefully since the stage/discharge relationship above these discharge levels could not be confirmed. However, 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 flow. Using stage data collected through the loggers, lower Layout Creek was predicted to be dry 83% of the year in 2012, 66% of the year in 2013, and only 25% of the time in 2014.

Modelled 2014 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 snotel courtesy of NRCS; Figure 16). These summaries suggest that flows in Layout Creek are groundwater derived except possibly during large precipitation events and/or rain on snow events where water may reach the spring orifice and upper Layout Creek during overland flow (Figure 16).

Unlike variations in discharge documented in upper and lower Layout Creek, Lockhart Stockpond Spring water table levels display only small variations between 2011 and 2014 (Figure 17). One notable exception was a dramatic change in water level in late

Figure 16. Discharge at upper Layout Creek (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.



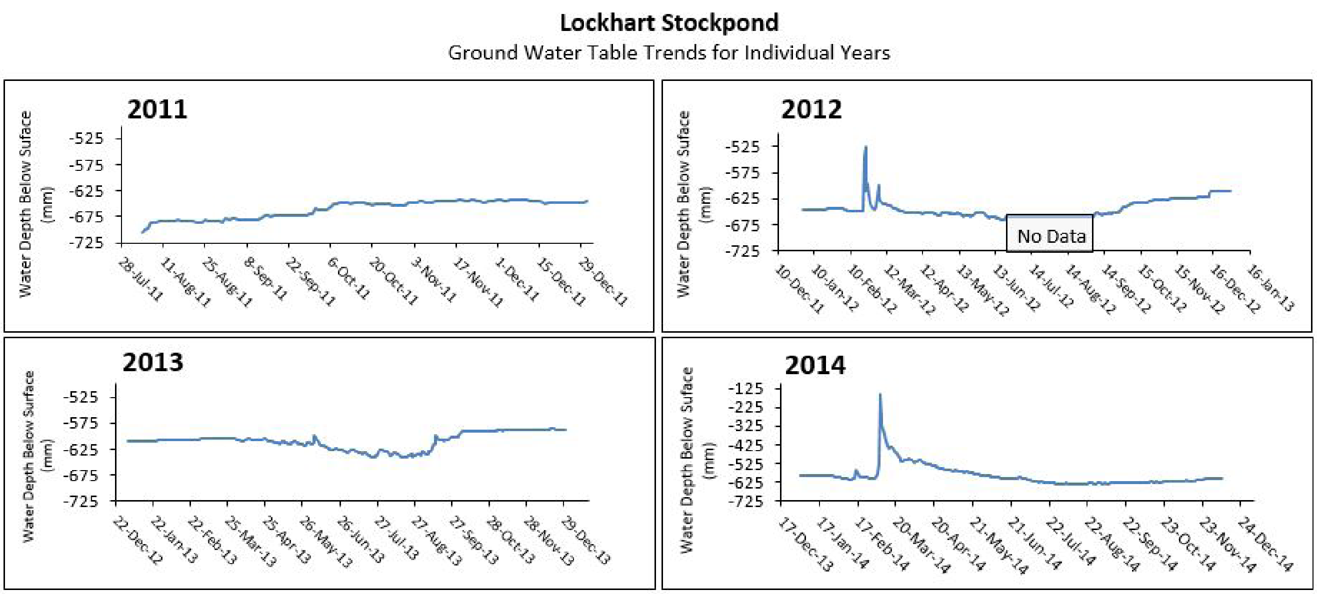
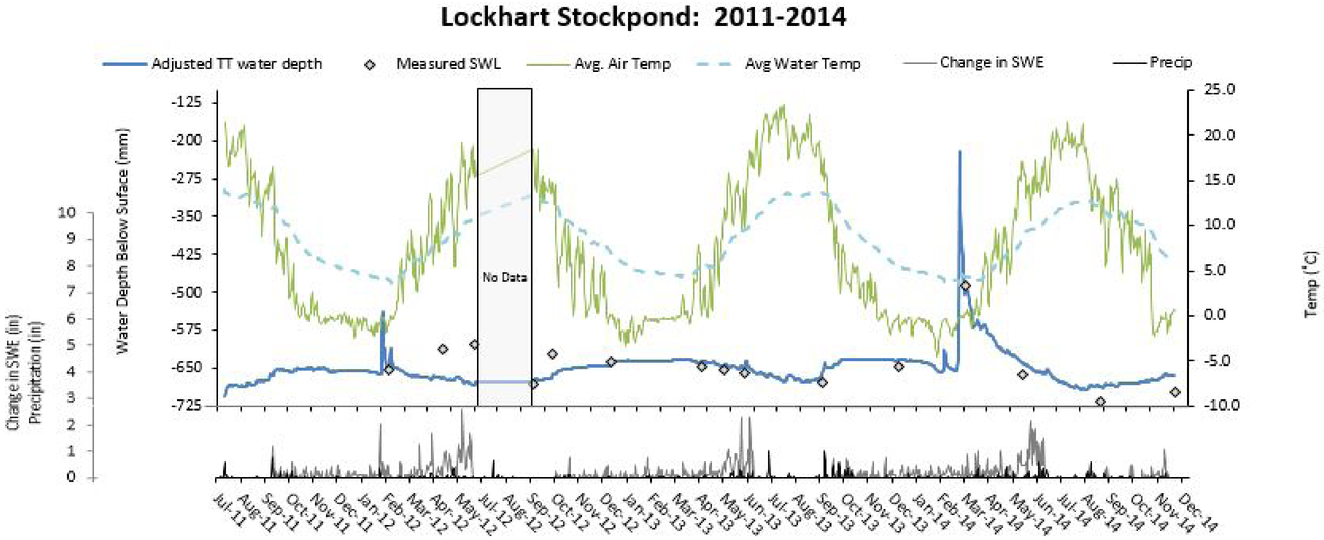


Figure 17. Water table levels (depth below the surface) for each year 2011-2014 at Lockhart Stockpond Spring. Note: 2011 records start in August.

Dense vegetation at Lockhart Stockpond Spring during the September visit.

February in 2012 and early March in 2014. The dramatic water level change in 2014 does not correspond with changes in SWE from nearby snotel site (Bald Mountain, Wyoming), indicating the peak may be due to more localized effects associated with snow accumulation and melting directly up-gradient from the spring (Figure 18).

Water levels measured at Lockhart Stockpond do not appear to be influenced by regional precipitation and snowmelt (SWE) (Figure 18). Instead, water levels generally show yearly declines during the growing



season. These declines may be linked with increased evapotranspiration as the spring outfall supports dense vegetative stands during the growing season (Figure 17). A notable increase in water levels occurring in the Fall may likewise be, in part, the result of reduced evapotranspiration rates following plant senescence.

In 2014, the TruTrack water level data logger was checked for accuracy. The zero line was off by 3cm and the 1 meter line was off by 7 cm. Based on the documented drift, a correction factor was applied to the TruTrack water level data logger to decrease the effect of the drift (Appendix E shows difference between raw and corrected readings). While the adjusted TruTrack water levels are closer to the manually measured static water levels during 2013-2014, the difference between the two readings ranged from 1-8cm (mean 4cm) across site visits and the source of the error is uncertain (Figure 18). This error might be a combination of instrumentation and human error.

According to the manually measured SWL at Lockhart Stockpond, water levels during 2014 appear to be slightly decreasing. Due to this noted instrumentation drift, it is not possible to fully assess multi-year changes in water table levels through time.

Water temperatures in Lockhart Stockpond varied between 5 and 15°C over the period of record 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.

Figure 18. Adjusted water table levels (depth below the surface), air, and water temp at Lockhart Stockpond. Precipitation and daily change in snow water equivalent (SWE) are summarized from nearby monitoring stations.

Time series photos of mass wasting slope above the Mason Lovell stilling well. The well was installed in 2011.

Over the past three years, the slope upgradient of the well at Mason Lovell Spring has experienced mass wasting. Although the sloughing does not appear to have changed the well position or increase the sediment inside the well, it is not certain how this changing environment is impacting water table levels and the quality of water level measurements. Again, in 2014, the accuracy of the TruTrack water level data logger was checked at Mason Lovell and about 3.5 cm of drift at the zero line and almost 9 cm of drift at the 1 meter mark were documented. The TruTrack water level logger measurements at Mason Lovell were adjusted based on the slope of the drift, similar to the adjustments made to the Lockhart Stockpond Spring data (Figure 19). While the adjusted TruTrack water levels are closer to the manually measured static water levels during 2011-2014, the difference between the two readings ranged from 1 to 6.5cm (mean 2.3 cm; see Appendix E for raw and adjusted values) and the source of the error is uncertain (Figure 19). Error may be combination of instrumentation and human error. Figure 19 shows the TruTrack and the measured static water table levels slowly increasing from November 2011 to December 2014.

Discharge measurements taken from an improved pipe just downslope of the stilling well do not show a consistent trend in discharge through time. However, discharge measurements at this location may also be influenced by evapotranspiration from the vegetative growth around the spring and may not be a good representation of water table height change. Similar to Lockhart Stockpond Spring, the greatest increases in water table level in 2011-2014 occurred in late September through 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 appeared to be relatively unresponsive to seasonal precipitation events and annual precipitation totals (Figure 19). 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 in air temperatures by nearly two months (Figure19).

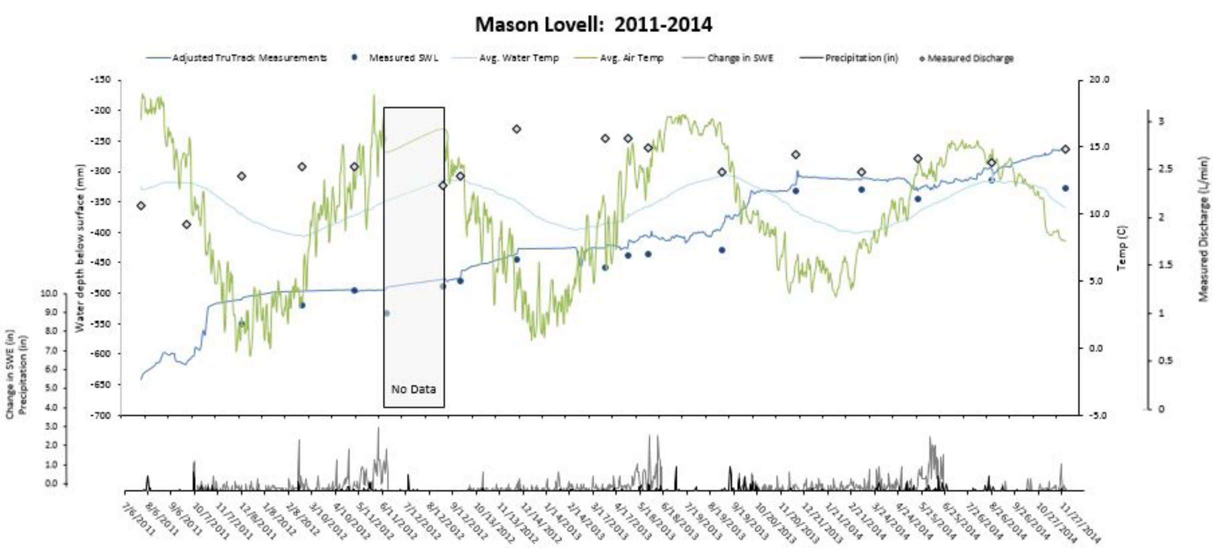


Figure 19. Adjusted water table levels from the TruTrack water level logger, measured static water level (with a tape) and measured discharge, air and water temperatures recorded at Mason Lovell Spring. Daily change in snow water equivalent (SWE) and precipitation were measured from nearby snotel and weather stations.

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 the visitor recreation experiences as well as their perceptual evaluations of the NRAs aesthetic features (*sensu* Burmil et al. 1999). During the 2014 calendar year, ongoing monitoring activities further characterized water quality and discharge patterns in BICA's rivers, streams, and springs. These summaries will contribute to the understanding of the variability of water resources in BICA but also reveal whether these resources are meeting state and federal water quality standards.

Discharge patterns in the Bighorn and Shoshone rivers vary strongly among calendar years. Flows at all river locations in 2014 were very similar to the 75th 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, MT exhibited little variability over the sampling period. In contrast, the Shoshone River near Lovell, WY 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 5-day geometric mean *E. coli* concentration for all months sampled across six calendar years (2009 to 2014) exceeded Wyoming state standards. Although *E. coli* levels were consistently high, the highest values were documented during August 2014.

Discharge patterns in three springs and one stream (Layout Creek) were characterized in 2014 creating what is now a four-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 monitoring springs show very different responses to precipitation or snow-water equivalent 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 year 2014 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). 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 2014 at two locations (Bighorn River at St. Xavier and Crooked Creek). We are working with our cooperators to summarize laboratory results (for 2011 to 2014), but macroinvertebrate assemblage data may provide further information on the condition of BICA's water resources.

Based on results presented from the 2014 monitoring summarized within this report, the GRYN recommends the following:

- Continued monitoring of major cations and anions, growth limiting nutrients, alkalinity, and total suspended solids in the Bighorn (Kane, WY and St. Xavier, MT) and Shoshone rivers. Monitoring sites quarterly should provide an understanding of the within year variation at these sites. We recommend collecting greater than four TSS samples (if possible) to better quantify TSS trends in the Bighorn and Shoshone rivers and TSS loading to Bighorn Lake. GRYN could provide training for BICA staff and other GRYN field crews (e.g., vegetation crews) and necessary sampling materials (e.g., equipment and bottles) that would permit collection of additional TSS samples during peak flows and throughout the year.

- At the Bighorn River near St. Xavier site, below the Yellowtail Afterbay Dam, we recommend collecting samples from both the left and right bank to allow for a more complete cross-sectional representation of water composition from the Bighorn River. This can be achieved by wading in from the left and right bank as far as safely possible. Collected water should be composited in a churn splitter to allow for a homogenized composite water sample.

- Continued monitoring of *E. coli* in the Shoshone River at Lovell, Wyoming. Monitoring of *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 especially during high flows. Access to the Shoshone River at State Highway 37 by entering through BLM lands and accessing the river from the north may provide a suitable alternative location.

- Consider an alternative location for the Bighorn River at Kane, Wyoming monitoring site. Private ownership of the property may not support access to the historic monitoring site. Potential alternatives include accessing the river from the west side or accessing the river further downstream from the Wildlife Habitat area off Crystal Creek Road. Road access from the Wildlife Habitat area can be challenging if the roads are wet or snow covered.

- It is recommended to record the drift of the TruTrack dataloggers once (in March) or twice (March and September) each year. If drift is documented each year, the data can be adjusted accordingly which will assist in determining groundwater level trends through time.

- 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 per field season including a minimum of three measurements during peak flows (mid-April to mid-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. GRYN could work with BICA staff to collect spring samples and submit them to a commercial or university laboratory for trace gas characterization and recharge age determination.

- 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.

- It is recommended to stabilize the slope above Mason- Lovell Spring PVC standpipe that houses a groundwater-level logger. Stabilization is needed due to sloughing and unstable slopes above the standpipe. In 2014, the slope continued to slough soil around the standpipe and the standpipe is almost completely buried. Caution should be heeded when attempting to remove soil away from the PVC standpipe. It is very important not to damage the PVC standpipe or alter the vertical position of the enclosed logger.

- Establish permanent photo points at all monitoring sites. GRYN will establish and begin using permanent photo points in 2015.

- Establish a set of protocols for measuring water depths in wells.

- Collaborate with the Buffalo Bill Center of the West in hosting an educational event and developing materials for school age groups to learn about BICA water resources. In August 2015, GRYN will coordinate with BICA staff and educators from the Buffalo Bill Center of the West to discuss the importance of long-term water quality monitoring and share results from the last five years of monitoring. Participating students will also have the opportunity to assist GRYN field crews with the collection of water quality data on the Bighorn River.

Literature Cited

Akashi, Y. 1988. Riparian vegetation dynamics along the Bighorn River, Wyoming. M.S. Thesis, University of Wyoming, Laramie, Wyoming.

Burmil, S., T. C. Daniel, and J. D. Hetherington. 1999. Human values and perceptions of water in arid landscapes. *Landscape and Urban Planning* 44:99-109.

Eagles-Smith, C. A., J. J. Willacker, and C. M. Flanagan Pritz. 2014. Mercury in fishes from 21 national parks in the Western United States—Inter and intra-park variation in concentrations and ecological risk: U.S. Geological Survey Open-File Report 2012-1051, 54 p.

Gore, J. A. 1996. Discharge measurements and streamflow analysis. Pages 53-74 in F. R. Hauer and G. A. Lamberti, editors. Methods in stream ecology, Academic Press, San Diego, California.

Jacobs R. W., T. Peters, and D. Sharrow. 1996. Water Resources Management Plan, Bighorn Canyon National Recreation Area. Greater Yellowstone Inventory & Monitoring Program, National Park Service, Bozeman, Montana.

KellerLynn, K. 2011. Bighorn Canyon National Recreation Area: geologic resources inventory report. Natural Resource Report NPS/NRSS/GRD/NRR—2011/447. National Park Service, Fort Collins, Colorado, USA.

Komp, M. R., A. J. Nadeau, E. Iverson, L. Danzinger, S. Amberg, K. Kilkus, J. Sopcak, C. Jean, M. Myers, and B. Drazkowski. 2012. Bighorn Canyon National Recreation Area Natural Resource Condition Assessment. Natural Resources Report NPS/BICA/NRR—2012/554. Fort Collins, Colorado. 267 pp.

Ladenburger, C. G., A. L. Hild, D. J. Kazmer, and L. C. Munn. 2006. Soil salinity patterns in Tamarrix invasions in the Bighorn Basin, Wyoming, USA. *Journal of Arid Environments* 65:111-128.

Manga, M. 2001. Using springs to study groundwater flow and active geologic processes. *Annual Review of Earth and Planetary Science* 29:201-228.

Montana Department of Environmental Quality (MTDEQ). 2012. Montana 2012 Final Water Quality Integrated Report. Montana Department of Environmental Quality, Helena, Montana.

Montana Department of Environmental Quality (MTDEQ). 2014a. Montana 2014 Final Water Quality Integrated Report. Montana Department of Environmental Quality, Helena, Montana.

Montana Department of Environmental Quality (MTDEQ). 2014b. Montana Base Numeric Nutrient Standards. Circular DEQ-12A. Montana DEQ, Water Quality Planning Bureau, Water Quality Standards Section, Helena, Montana.

Myers, M. and V. Resh. 2002. Trichoptera and other macroinvertebrates in springs of the Great Basin: species composition, richness, and distribution. *Western North American Naturalist* 62:1-13.

Nolan, K. M. and R. R. Shields. 2000. Measurement of stream discharge by wading: U.S. Geological Survey Water-Resources Investigations Report 00-4036.

O'Ney, S., J. Arnold, C. Bromley, R. Daley, and C. Jean. 2009. Greater Yellowstone Network Water Resource Monitoring Protocol. Natural Resource Report DRAFT –September 2009.

Peterson, D. A. and G. K. Boughton. 2000. Organic compounds and trace elements in fish tissue and bed sediment from streams in the Yellowstone River basin, Montana and Wyoming, 1998. U.S. Geological Survey Water Resources Investigations Report: 00-4190. U.S. Geological Survey, Cheyenne, Wyoming.

Ray, A., M. K. Kleehammer, and W. A. Sigler. 2013. 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. National Park Service, Fort Collins, Colorado.

Schmitz, D. 2007. Data summary for baseline monitoring of springs in Bighorn Canyon National Recreation Monitoring. Report submitted the Greater Yellowstone Network. Montana State University Land Resources and Environmental Sciences. 46 pp.

Sigler, W. A. 2011. BICA 2011 spring well and level logger install summary. Report submitted the Greater Yellowstone Network. Montana State University Extension Water Quality. 10 pp.

Sigler, W. A. 2012. BICA continuous monitoring pilot project summary. Report submitted the Greater Yellowstone Network. Montana State University Extension Water Quality. 4 pp.

Springer, A. E. and L. E. Stevens. 2009. Spheres of discharge in springs. *Hydrogeology Journal* 17:83-93.

Soil Conservation Service. 1994. Big Horn River Basin surface water quality study. Final Report and Recommendations, Wyoming Cooperative River Basin Study no. 4376. U.S. Department of Agriculture, Soil Conservation Service, Casper, Wyoming.

Stagliono, D. 2008. Aquatic macroinvertebrate inventory & assessment of springs and seeps within Bighorn Canyon National Recreation Area (BICA). Montana Natural Heritage Program, Helena, Montana.

U.S. Army Corps of Engineers (USACOE). 2010. Bighorn Lake sediment management study. Final Report submitted to the U.S. Bureau of Reclamation March 2010. Omaha District Corps of Engineers, Hydrologic Engineering Branch. Omaha, Nebraska.

U.S. Bureau of Reclamation (BOR). 2012. Internet information on Yellowtail Dam. Available at: ww.usbr.gov/projects/Facility.jsp?fac_Name=Yellowtail%20Dam (accessed 12 March 2013).

U.S. Environmental Protection Agency (EPA). 2000. Ambient Water Quality Criteria Recommendations - Information Supporting the Development of State Tribal Nutrient Criteria - Rivers and Streams in Nutrient Ecoregion III. U. S. Environmental Protection Agency Office of Water, Washington D. C. EPA 822-B-00-016.

U.S. Environmental Protection Agency (EPA). 2012. National recommended water quality criteria. U.S. EPA, Office of Water, Washington, D.C. Available at: http://water.epa.gov/scitech/swguidance/standards/criteria/current/index.cfm (accessed 25 October 2012).

von Fumetti, S. and P. Nagel. 2012. Discharge variability and its effect on faunistic assemblages in springs. *Freshwater Science* 31:647-656.

Western Regional Climate Center. 2015. Cooperative Climatological Data Summaries. Available at: http://www.wrcc.dri.edu/cgi-bin/cliMAIN.pl?wy5770 (accessed 23 April 2015).

Wyoming Department of Environmental Quality (WYDEQ). 2008. Wyoming Nutrient Criteria Development Plan. Wyoming Department of Environmental Quality, Cheyenne, Wyoming.

Wyoming Department of Environmental Quality (WYDEQ). 2012. Wyoming water quality assessment and impaired waters list (2012 Integrated 305(b) and 303(d) Report). Wyoming Department of Environmental Quality, Cheyenne, Wyoming.

Wyoming Department of Environmental Quality. 2013. Water quality rules and regulations. Chapter 1 in Water Quality Division rules and regulations.

Online. Available at: http://soswy.state.wy.us/Rules/RULES/9176.pdf (accessed 22 December 2014).

Wyoming Department of Environmental Quality (WYDEQ). 2014. Wyoming water quality assessment and impaired waters list (2014 Integrated 305(b) and 303(d) Report). Wyoming Department of Environmental Quality, Cheyenne, Wyoming.

Yeardley, R. B., J. M. Lazorchak, and S.G. Paulsen. 1998. Elemental fish tissue contamination in the northeastern, U.S. lakes: evaluation of an approach to regional assessment. *Environmental Toxicology and Chemistry* 17:1875-1894.

Appendix A: *E. coli* at the Shoshone River at Lovell, Wyoming

Table A1. 2011-2014 monthly five-day geometric mean of *Escherichia coli* at the Shoshone River at Lovell, Wyoming.

	***E.coli* geometric mean - 5 samples within 60 day period**				
	2010	**2011**	**2012**	**2013**	**2014**
June	358	179	338	579	247
July	600	995	560	426	280
August	593	498	471	217	740
September	317	405	457	787	407

Appendix B: Water Quality Laboratory Results

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 = carbonate, CO_2 = carbon dioxide, OH = hydroxide, $NH_{3-}N$ = ammonium nitrogen, NO_3+NO_2 = combined result for nitrate + nitrate, SO_4 = sulfate, Ortho-P = ortho-phosphate, P = phosphorus, TSS = total suspended solids.

Table B1. Water quality lab results for the Bighorn River at St. Xavier, Montana.

Analytes	3/13/2014 (Left bank)	3/13/2014 (Right bank)	5/27/2014	9/3/2014	12/10/2014
Total Ca	72.1	69	67.4	41	61
Total K	3.8	3.6	4.2	2.3	3.2
Total Mg	25.5	24.1	22.7	13.2	20.3
Total Na	68.4	65.3	63.1	32	53.4
Total Alk as $CaCO_3$	192	186	166	127	163
HCO_3	226	214	203	154	198
CO_3	4	6	<1.0	<1.0	<1.0
CO_2	169	164	147	113	143
OH	<1.0	<1.0	<1.0	<1.0	<1.0
$NH_{3-}N$	<0.2	<0.2	<0.2	<0.2	<0.2
Cl	11	11	10	5	9
NO_3 + NO_2	0.5	0.5	0.3	0.4	0.3
SO_4	244	241	191	101	176
Ortho-P	0.02	0.01	0.01	0.02	0.01
Total P	0.02	0.02	0.03	0.03	0.02
TSS	<4.0	<4.0	<4.0	<4.0	4

Table B2. Water quality lab results for Bighorn River at Kane, Wyoming.

Analytes	3/13/2014	5/27/2014	9/3/2014
Total Ca	100	71.2	69.4
Total K	13.9	4.6	4.5
Total Mg	37.2	21.5	22.9
Total Na	80.7	32.3	60.9
Total Alk as $CaCO_3$	143	114	161
HCO_3	174	139	187
CO_3	<1.0	<1.0	5
CO_2	126	101	142
OH	<1.0	<1.0	<1.0
$NH_{3-}N$	<0.200	<0.200	<0.200
Cl	17	6	12
$NO_3 + NO_2$	0.4	0.2	0.4
SO_4	259	98	184
Ortho-P	0.06	0.09	0.02
Total P	1.6	0.6	0.14
TSS	2030	822	186

Table B3. Water quality lab results for Shoshone River at Lovell, Wyoming.

Analytes	3/14/2014	5/27/2014	9/4/2014	12/9/2014
Total Ca	103	30.3	54	90.1
Total K	9.9	2	3	4.5
Total Mg	35.1	9.6	17.6	29.9
Total Na	65.9	21.8	42.4	64.8
Total Alk as $CaCO_3$	223	105	150	240
HCO_3	255	128	172	286
CO_3	8	<1.0	6	3
CO_2	195	93	132	211
OH	<1.0	<1.0	<1.0	<1.0
$NH_{3-}N$	<0.200	<0.200	<0.200	<0.200
Cl	8	2	3	8
$NO_3 + NO_2$	0.7	0.2	1	0.9
SO_4	182	46	121	238
Ortho-P	0.03	0.04	0.04	<0.01
Total P	1.1	0.17	0.18	0.07
TSS	1560	1280	147	63

Appendix C: Measured and Modeled Flow Comparison Tables

Table C1. 2014 Upper Layout Creek measured and modeled flow.

Date	Stage (mm)	Measured Discharge (cfs)	Modeled Discharge (cfs)	%RPD
5/28/2014	Not measured; water too high			
9/4/2014	558	2.72	2.7	0%
3/14/2014	475	1.38	1.3	3%
12/9/2014	532	2.2	2.5	6%

Table C2. 2014 Lower Layout Creek measured and modeled flow.

Date	Stage (mm)	Measured Discharge (cfs)	Modeled Discharge (cfs)	%RPD
5/28/2014	253	43.0	37	15%
6/2/2014	192	25.0	27.2	8%
6/3/2014	178	29.0	25	15%
6/4/2014	178	27.7	25	10%
6/5/2014	175	22.2	24.5	10%
6/8/2014	163	17.6	22.6	25%
6/20/2014	113	10.0	14.6	37%
6/22/2014	119	10.9	15.6	35%
9/4/2014	-4	0.5	-4.4	-248%
12/9/2014	8	8	-2.4	371%

Appendix D: Max Stage Measurements

Table D1. Upper Layout Creek max stage measurements, 2011-2014.

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
2014	5/30/2014	764	29.7

Table D2. Lower Layout Creek max stage measurements, 2011-2014.

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 Sept 1 - Dec 12, 2011		
2012	6/5 - 6/6/2012	90	3.7	62	303	83%
2013	5/24/2013	68	4.69	37	328	66%
2014	5/29/2014	265	39.1	272	93	25%

Appendix E: Water Level Data

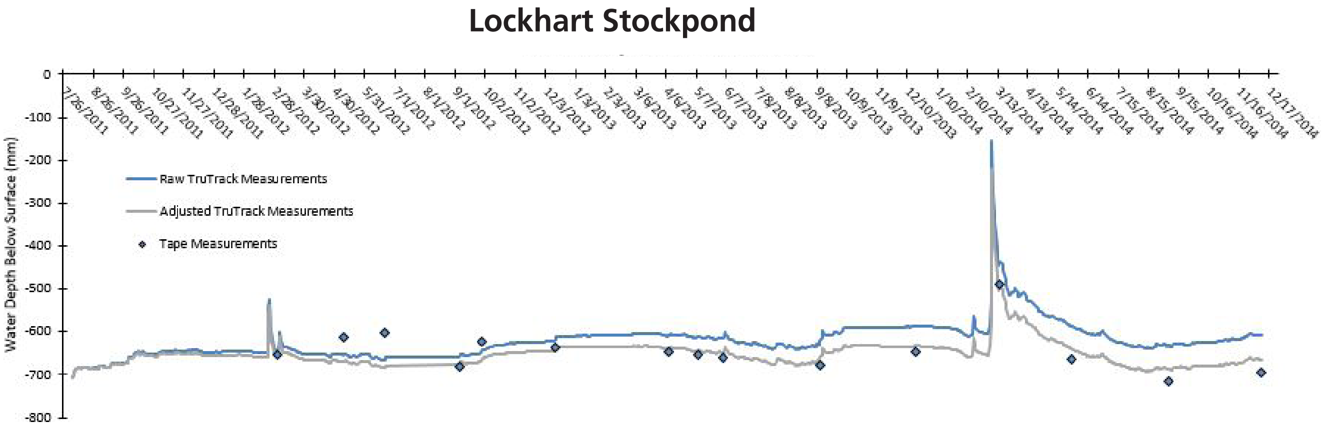


Figure E1. Raw and correction factor-adjusted water table levels from the TruTrack water level logger (depth below the surface), manually measured static water level (with a tape) at Lockhart Stockpond, 2011-2014.

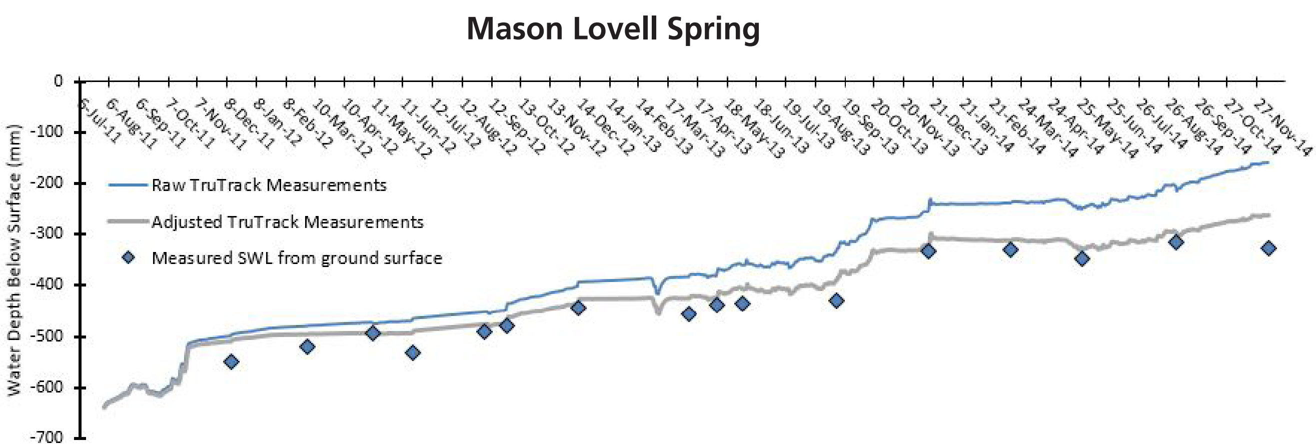


Figure E2. Raw and correction factor-adjusted water table levels from the TruTrack water level logger (depth below the surface), manually measured static water level (with a tape) at Mason Lovell Spring, 2011-2014.

NPS 617/129077, July 2015

National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science
1201 Oak Ridge Drive, Suite 150
Fort Collins, Colorado 80525

www.nature.nps.gov