



Water Quality Summary for the Lamar River, Yellowstone River, and Madison River in Yellowstone National Park

Preliminary Analysis of 2014 Data

Natural Resource Report NPS/GRYN/NRR—2016/1235



ON THE COVER

Sampling the Madison River near West Yellowstone, June 2014.

Photography by: NPS

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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. Views, statements, findings, conclusions, recommendations, and data in this report do not necessarily reflect views and policies of the National Park Service, U.S. Department of the Interior. Mention of trade names or commercial products does not constitute endorsement or recommendation for use by the U.S. Government.

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Contents

	Page
Figures	iv
Tables	iv
Photographs	v
Appendices	v
Executive Summary	vi
Acknowledgments	vii
Introduction	1
Overview of Yellowstone NP Water Resources	1
Potential Threats to Water Resources	3
Focal Waters	3
Lamar River near Tower Ranger Station	4
Yellowstone River – Corwin Springs	4
Madison River near West Yellowstone	5
Water Quality Standards That Apply to Yellowstone National Park	5
Federal Water Quality Criteria	5
Montana Water Quality Standards and Water Classification System	5
Wyoming Water Quality Standards and Water Classification System	6
Monitoring Objectives	6
Methods	7
River Sampling	7
Results	8
Lamar River, Yellowstone River, and Madison River Climate, Discharge, and Water Chemistry	8
Climate Station Summaries	8
2014 Temperature and Precipitation	9
Discharge	10
Water Chemistry	13
Discussion	17
Literature Cited	19

Figures

Page

Figure 1. Water quality sampling locations and associated U.S. Geological Survey gaging stations in Yellowstone National Park.	2
Figure 2. Calendar year 2014 monthly temperature (maximum and minimum) and precipitation summaries for the Tower Falls COOP station 489025 (elevation 1910 m)	8
Figure 3. Calendar year 2014 monthly temperature (maximum and minimum) and precipitation summaries for the Yellowstone Park Mammoth COOP station 489905 (elevation 1899 m)	9
Figure 4. Calendar year 2014 monthly temperature (maximum and minimum) and precipitation summaries for the Old Faithful COOP station 486845 (elevation 2243 m)	10
Figure 5. Summary of average daily discharge (in cfs) in the Lamar River near Tower Ranger Station, WY (USGS 06188000), Yellowstone at Corwin Springs, MT (USGS 06191500), and Madison River near West Yellowstone, MT (USGS 06037500).	11
Figure 6. Summary of annual peak discharge and date of peak discharge at the Lamar River monitoring site near Tower Ranger Station, WY (USGS 06188000).	12
Figure 7. Proportion of monthly nutrient samples collected in 2014 from Lamar River (LMR), Madison River (MDR), and Yellowstone River at Corwin Springs (YRCS) monitoring stations that produced non-detectable levels for ammonia (NH ₃), nitrite + nitrate (NO ₂ +NO ₃), and ortho-phosphorus (ortho-P).	13
Figure 8. Rating curves showing the relationship between log-transformed discharge, ortho-phosphorus, total phosphorus, total suspended solids, sulfate, total arsenic, total sodium, and total calcium at the Lamar River (USGS6188000) sampling location.	15
Figure 9. Red line indicates daily discharge (in cfs) in the Lamar (11A; USGS6188000), Madison (11B, 6037500) and Yellowstone (9C; USGS6191500) rivers.	16
Figure C-1. 2014 Reese Creek Stream flow measurements.	C-2
Figure C-2. 2014 Royal Teton Ranch (RTR) and National Park Service (NPS) allotments vs. actual flow.	C-3

Tables

	Page
Table 1. Summary of discharge metrics for the Lamar River near Tower Ranger Station, WY (USGS Gage 06188000)	10
Table 2. Summary of discharge metrics for the Yellowstone River at Corwin Springs, MT (USGS Gage 06191500)	13
Table 3. Summary of discharge metrics for the Madison River at West Yellowstone, MT (USGS Gage 06191500)	13
Table A-1. Environmental Protection Agency (EPA) recommended water quality criteria.	A-1
Table B-1. Monthly water quality lab results and core parameters from the field for Lamar River near Tower Ranger Station, WY.	B-1
Table B-2. Monthly water quality lab results and core parameters from the field for Yellowstone River at Corwin Springs, MT.	B-2
Table B-3. Monthly water quality lab results and core parameters from the field for Madison River at West Yellowstone, MT.	C-3

Photographs

	Page
Photo 1. River sampling is accomplished using a bridge board, reel, and churn splitter during high flows and within large rivers (e.g., Yellowstone River at Corwin Springs, MT).	4
Photo 2. River sampling at the Madison River sampling location. Width- and depth-integrated techniques are used and collected water is composited with an 8L polyethylene churn splitter to produce a representative sample of river conditions.	5
Photo 3. River sampling is accomplished with a DH-81 Sampler affixed to a 1-m wading rod with 3L bottle during wadeable conditions.	7

Appendices

	Page
Appendix A	A-1
Appendix B	B-1
Appendix C	C-1

Executive Summary

The Greater Yellowstone Inventory and Monitoring (I&M) Network is a National Park Service (NPS) program charged with monitoring ecological vital signs in three national park units in Wyoming, Montana, and Idaho. This report focuses on monitoring efforts in Yellowstone National Park and summarizes discharge and water quality monitoring data for the Lamar River, Yellowstone River, and Madison River for calendar year 2014. Monitoring activities for Soda Butte Creek, a 303(d)-listed stream that is a tributary to the Lamar River, for calendar year 2014 will be included in a separate report. Reese Creek, another 303(d)-listed (for dewatering) stream, was monitored during 2014 and the monitoring report prepared by Yellowstone National Park is included as Appendix C.

Results for the Lamar River, Yellowstone River, and Madison River that are presented in this report include annual and long-term discharge summaries and an evaluation of chemical and suspended sediment conditions relative to state and federal water quality standards. Sampling locations on the Lamar River and Yellowstone River are located at U.S. Geological Survey (USGS) streamflow gages. The Madison River sampling location is located at the Montana Hwy 191 bridge crossing downstream of the USGS streamflow gage. These results are considered provisional, and therefore, may be subject to change.

River Discharge

Hydrographs for the Lamar River near Tower Ranger Station, Yellowstone River at Corwin Springs, and Madison River near West Yellowstone exhibit a general pattern of high early summer flows and lower baseflows occurring in late summer and extending into fall. The hydrographs for the Lamar River and Yellowstone River are indicative of snow-melt driven systems while the hydrograph for the Madison River suggests greater contributions from groundwater. In 2014, flows often exceeded the historic mean at each station. The daily flows at the Lamar River and Yellowstone River stations were above the historic median at peak flows and generally through the remainder of the year. Daily flows at the Madison River station were similar to historic median flows, with peak flows exceeding historic median flows.

Water quality monitoring

Water quality at sampling locations exhibited seasonal variability over the sampling period. Specifically, total suspended solids peaked during high flows. Total phosphorus peaked during high flows at Lamar River and Yellowstone River. In the Madison River, total phosphorus was at minimum levels during peak flows. Greater total phosphorus present during non-runoff periods is suggestive of Madison River receiving greater groundwater contributions relative to the other monitored waters. Across all sites arsenic, calcium, chloride, and sodium concentrations were generally at minimum levels during high flows.

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Introduction

Yellowstone National Park was established in 1872 as the first national park. Spanning approximately 890,000 hectares (2.2 million acres) in the northwest corner of Wyoming and including parts of Montana and Idaho (Figure 1), Yellowstone is the second largest national park in the lower 48 states. Nearly 167 million visitors have been recorded since 1904 with over 3.5 million visitors in 2014 alone (NPS 2015a). This iconic park captivates visitors from around the world with rare natural resources that have remained relatively unchanged due, in part, to early protection.

Yellowstone National Park was established primarily to protect geothermal features. Half of the world's active geysers are contained within the park. In addition, there are over 10,000 hydrothermal features and 300 geysers. Much of the water in Yellowstone National Park and the Northern Rockies originates from mountain snowpacks. Melt of these snowpacks contributes disproportionately to river flows over a three to four month window (Gardner et al. 2010). These snowpacks in Yellowstone National Park and neighboring Grand Teton National Park also serve as headwaters to two major river systems (Yellowstone and Snake rivers). Combined, these rivers support an abundance of fish and wildlife, provide numerous recreational opportunities, and offer a lifeline for downstream agricultural users and municipalities.

The climate in Yellowstone National Park is complex, in part due to its mountainous topography, but also because it rests at the boundary of two major precipitation regimes (Tercek et al. 2012). Historically, northern parts of Yellowstone received most of their precipitation during late spring and early summer (April, May, and June). In contrast, southern parts of the park and neighboring Grand Teton National Park experience the greatest precipitation in winter months (December, January, and February; Tercek et al. 2012). Precipitation is greatly influenced by the moisture channel formed by the Snake River Plain to the west that was originally formed by the passing of the North American Plate over the belt of volcanism or 'hotspot' that currently exists beneath modern day Yellowstone National Park (Pierce and Morgan 1992). Orographic effects and elevational gradients are also at work. In general, lower elevations are warmer and higher elevations colder. High elevation areas are classified as humid continental according to

Köppen-Geiger climate classification.

The long history of science in the Greater Yellowstone Ecosystem has revealed evidence of a changing climate (Westerling et al. 2011). Recent increases in temperatures (Sepulveda et al. 2015) and declines in snowpack (Pederson et al. 2011) have been documented. Changing whitebark pine (Shanahan et al. 2016) and cutthroat trout populations (Koel et al. 2012), drying of wetlands (Schook and Cooper 2014), and altering river hydrographs (Leppi et al. 2012) are areas of active study characterizing responses to a changing climate.

Given the complexity of climate throughout Yellowstone National Park, we provide summaries from climate stations located closest to river monitoring stations on the Lamar, Yellowstone, and Madison rivers. For more detailed information on climate in Yellowstone National Park and across the Greater Yellowstone Ecosystem see Millsbaugh et al. (2000), Tercek et al. (2012), Romme and Turner (2015), and Sepulveda et al. (2015).

Overview of Yellowstone NP Water Resources

Yellowstone National Park contains a diversity of surface water features: over 600 lakes and ponds, approximately 4,000 kilometers (2,500 miles) of streams and rivers, and ephemeral wetland habitats that alone make up roughly three percent of the landscape (NPS 2015). Major lakes include Yellowstone Lake, Shoshone Lake, Lewis Lake and Heart Lake; smaller lakes are common and documented in Pierce (1987). Water has been monitored in Yellowstone for over a century. For example, the U.S. Geological Survey (USGS) has been collecting stream discharge measurements since 1889 on the Yellowstone River. The records for the Lamar, Yellowstone, and Madison rivers began in 1923, 1889, and 1913, respectively. These long-term records provide unique opportunities to examine how hydrographs in the region may be responding to documented changes in air temperatures and snowpacks (*sensu* Luce and Holden 2009).

The Greater Yellowstone Ecosystem contains the headwaters of seven important rivers flowing to the Pacific Ocean, the Gulf of California, and the Gulf of Mexico. These rivers, which include the Missouri

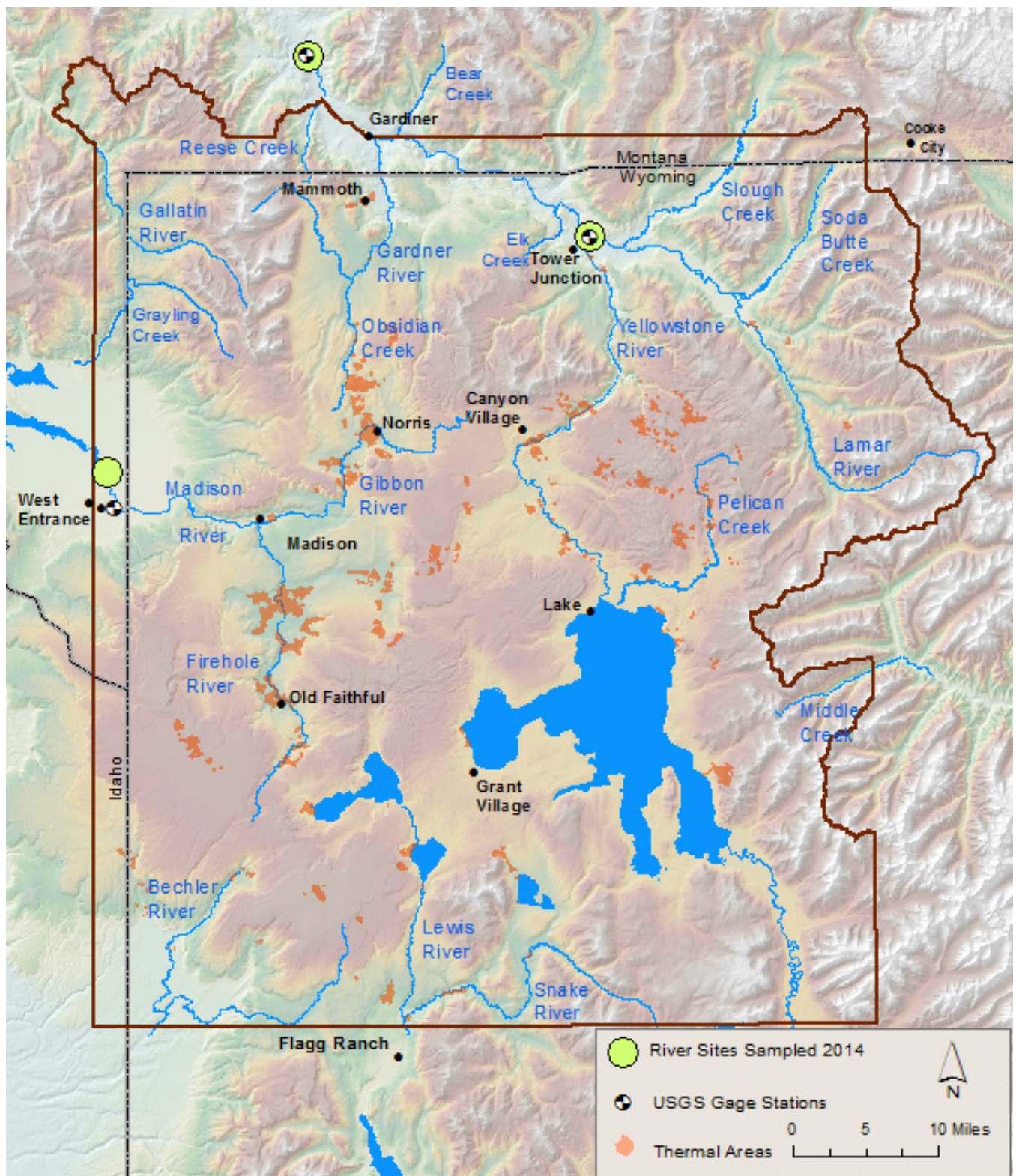


Figure 1. Water quality sampling locations and associated U.S. Geological Survey gaging stations in Yellowstone National Park.

and Columbia, provide essential water to the western and midwestern United States. The headwaters of the Lamar River, Yellowstone River, and Madison River are within the park boundaries or within protected areas and are minimally affected by human activities. Under the Clean Water Act, the surface waters in Yellowstone are classified as Outstanding National Resource Waters. Additionally, these Outstanding National Resource Waters (ONRW) located wholly within national park boundaries are designated as Outstanding Resource Waters (MTDEQ 2012) or Class 1 Outstanding Natural Resource Waters (WYDEQ 2013) by the states of Montana and Wyoming, respectively. In Wyoming, this designation indicates that high quality waters are known to support fish or supply drinking water and no further water quality degradation by point source discharges other than from dams will be allowed (WYDEQ 2013).

The quality of water in Yellowstone National Park is high, but the chemistry of these waters is nearly as varied as the geologic terrain. It is also based largely on the degree to which a water body is influenced by geothermal sources or the seasonal effects (i.e., snowmelt and runoff) that also result in a dynamic hydrograph (NPS 2013b). Total arsenic levels are high across Yellowstone National Park (Planer-Friedrich et al. 2007) and exceeded the state standards at the Yellowstone River upstream of Corwin Springs and at Madison River near West Yellowstone. These exceedances are likely natural in origin as both rivers or their tributaries are heavily influenced by geothermal activity (NPS 1994).

Potential Threats to Water Resources

The waters in Yellowstone National Park are classified as Outstanding National Resource Waters and are considered relatively unaffected by anthropogenic sources. There are several anthropogenic threats to the water quality in Yellowstone National Park. In October 2003, a report to the World Heritage Committee identified high visitation, outdated waste treatment plants, lift stations, underground lines, single wall fuel tanks, and spills as threats to mitigate (NPS 2003). Chemical spills may occur from traffic accidents along roads near streams, rivers, or lakes. Road construction, dewatering, atmospheric deposition, runoff from mining sites outside the park boundary, and climate change are cited as water quality threats in the Yellowstone Resources Handbook (NPS 2015b). Waters are threatened by various symptoms of the

changing climate including changes in the hydrological cycle resulting from less precipitation as snow and earlier snow melt (Barnett et al. 2005). The effects of these changes have been documented or are predicted in water processes throughout the park as the frequency of low flow conditions increases (Leppi et al. 2012). These low flow conditions and elevated air temperatures also influence water temperatures. Water temperature is expected to increase between 0.8 and 1.8 °C (1.4-3.2°F) by 2069 (Al-Chokhachy et al. 2013). Combined changes in discharge patterns and water temperature may influence how visitors experience the park. For example, the park has issued seasonal fishing closures on rivers with high water and air temperatures to protect temperature-stressed fish during the hottest days of the season (NPS 2013a). Temperature increase may trigger additional ecological changes including shifting biological communities and increased opportunities for the establishment of invasive species (Woodward et al. 2010).

A number of aquatic invasive species have already been documented in waters within Yellowstone National Park. Whirling disease (*Myxobolus cerebralis*), New Zealand mud snails (*Potamopyrgus antipodarum*), and lake trout (*Salvelinus namaycush*) are present in various areas. New Zealand mud snails, which can grow to overwhelming numbers (300,000 snails per m²), alter nutrient flows, and potentially outcompete native species, have been studied on the Madison River (Hall et al. 2003). Lake trout are present in Yellowstone Lake harming native cutthroat species that are a necessary food source for large vertebrates (Ruzycki et al. 2003; Koel et al. 2005). Native fish species are also affected by whirling disease which has been documented in the Yellowstone River and the Madison River (Koel et al. 2005; Kruegar et al. 2006).

Focal Waters

Site selection and sampling design are described in the approved Greater Yellowstone Network Regulatory Water Quality Monitoring Protocol (O’Ney 2006) and can be found at http://science.nature.nps.gov/im/units/gryn/monitor/water_resources.cfm.

In brief, water quality monitoring sites included in the Greater Yellowstone Network’s water resource monitoring program were those that met the program objectives, have spatial and temporal variability, or are stream reaches that are 303(d)-listed. Sites were also selected to be near existing permanent USGS stream

gaging stations because discharge readings can be used to measure the relationships between streamflow and water quality; generally, long-term flow records are also available for the permanent stream gages. In Yellowstone, selected sites included Lamar River near Tower Ranger Station, WY; Yellowstone River at Corwin Springs, MT; Madison River near West Yellowstone, MT; and Soda Butte Creek, MT which is not reported here. Reese Creek is also monitored collaboratively with Yellowstone National Park and reported on separately (see Appendix C). Although, these sites do not reflect all of the waters in the park, they do offer insight on the major river systems in and exiting Yellowstone National Park. The Snake River, which has headwaters in Yellowstone National Park, is also monitored by the Greater Yellowstone Network (Ray et al. 2015). The rationale for testing nutrients and suspended solids can be found in the approved Greater Yellowstone Network Regulatory Water Quality Monitoring Protocol (O’Ney et al. 2006).

Lamar River near Tower Ranger Station

The Lamar River is a major tributary of the Yellowstone River. Much of the Lamar River watershed is protected with the boundaries of Yellowstone National Park. Soda Butte Creek joins the Lamar River before connecting with the Yellowstone River.

The Lamar River has not been listed previously; however, a tributary to the Lamar River (Soda Butte Creek) is one of only three 303(d)-listed waters identified within the park. While Soda Butte is monitored by the Greater Yellowstone Inventory and Monitoring Network, results from 2014 monitoring will be included in a separate report.

Yellowstone River – Corwin Springs

The Yellowstone River is the longest (1,080 km [671 mi]) undammed river in the lower 48 states. The river begins on Younts Peak, WY; flows northwest through Yellowstone Lake; and exits the park near Gardiner, MT. The monitoring site at Corwin Springs is located downstream from Gardiner, MT. A 14-km (8.68 mi) segment of the Yellowstone River within the park from the Wyoming border to Yellowstone National Park boundary and a 7.7-km (4.79 mi) segment from the park boundary to Reese Creek were listed on Montana’s 303(d)-list in 2014. The 14-km segment was listed for ammonia, copper, nitrates (i.e., $\text{NO}_2 + \text{NO}_3\text{-N}$), sediment, and arsenic levels that exceed drinking water standards. The 8.4-km segment from the park boundary to Reese Creek was listed for non-pollutant impairment (EPA 2014a). Both listed segments are upstream of the sampling location. Yellowstone River at Corwin Springs has historically had high arsenic



Photo 1. River sampling is accomplished using a bridge board, reel, and churn splitter during high flows and within large rivers (e.g., Yellowstone River at Corwin Springs, MT).



Photo 2. River sampling at the Madison River sampling location. Width- and depth-integrated techniques are used and collected water is composited with an 8-L polyethylene churn splitter to produce a representative sample of river conditions.

levels. High levels of arsenic may be natural in origin and associated with geothermal influences (NPS 2013b)

Madison River near West Yellowstone

The monitoring site for the Madison River drainage near West Yellowstone, MT has a hydrograph that is characteristic of a groundwater influenced system (Gardner et al. 2010). Therefore, surface water pH and arsenic levels in the Madison River may be affected by the local geology and geothermal activity in the area (Thompson 1979). In fact, many of the park's geyser basins drain into the Firehole River which joins the Gibbon River to form the Madison River. Due to access issues during winter months, monitoring in 2014 was completed approximately 7 km (4.5 mi) downstream of the USGS gage at the Montana Highway 191 bridge crossing (Figure 1).

Water Quality Standards That Apply to Yellowstone National Park

Federal Water Quality Criteria

The Environmental Protection Agency (EPA 2012) aquatic life water quality standards were examined along with Wyoming water quality criteria (WYDEQ

2013) and Montana water quality criteria (MTDEQ 2012) to assess whether the Lamar River, Yellowstone River, and Madison River are meeting current water quality standards. Water resource monitoring in the national park and just outside of the park boundary does not include constituents on EPA's national priority pollutants (<https://water.epa.gov/scitech/methods/cwa/pollutants.cfm>); however, federal criteria for non-priority pollutants are based on EPA National Recommended Water Quality Criteria guidance (<https://www.epa.gov/wqc/national-recommended-water-quality-criteria-aquatic-life-criteria-table#table>). Federal and state water quality standards are presented in Appendix A.

Montana Water Quality Standards and Water Classification System

Montana's Department of Environmental Quality (MTDEQ) water quality standards are described in the Montana numeric water quality standards, Circular DEQ-7 (MTDEQ 2012) and Montana base numeric nutrient standards, Circular DEQ-12 (MTDEQ 2014). Water bodies within Yellowstone are classified as Outstanding Resource Waters (ORW) by Montana. Four stream segments on the northern border of Yellowstone National Park were listed as

303(d) impaired by Montana: upper Soda Butte Creek near Cooke City, MT; Reese Creek from the park boundary to Yellowstone River near Gardiner, MT; and Yellowstone River from the Wyoming border to the Yellowstone National Park boundary.

The Yellowstone River upstream of Corwin Spring was listed on Montana's 303(d) list (see above). The following probable causes of impairment for 2014 were listed by MTDEQ: 1) Highway/Road/Bridge Runoff (Non-construction Related) for sediment; 2) impacts from abandoned mine lands (inactive) for arsenic and copper; 3) natural sources for ammonia, arsenic, nitrite + nitrate, and sediment; 4) subsurface (hardrock) mining for arsenic and copper; 5) surface mining for arsenic and copper; and 6) unknown sources for ammonia, un-ionized arsenic and copper, and nitrite + nitrate (EPA 2014b).

While not reported here, Soda Butte Creek is listed for copper, iron, lead, and manganese and Reese Creek for dewatering/habitat modification.

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 agency's plan for developing

and implementing nutrient criteria is 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 Yellowstone National Park have been classified as Outstanding or Class 1 waters, those surface waters known to support fish or supply drinking water (or where those uses are believed to be attainable) in which no further water quality degradation by point source discharges other than from dams will be allowed (WYDEQ 2013).

Monitoring Objectives

Our specific objectives for the purposes of annual reporting are to summarize annual and long-term discharge patterns and characterize water quality conditions of the Lamar River, Yellowstone River, and Madison River from 2014 monitoring efforts.

Methods

River Sampling

We collected depth-integrated water samples monthly (Appendix B) between April and October 2014 from three river monitoring sites: Lamar River near Tower Ranger Station, WY; Yellowstone River at Corwin Springs, MT; and Madison River near West Yellowstone, MT.

In addition to water samples, we characterized core field water quality parameters (i.e., temperature, specific conductivity, dissolved oxygen, pH, and turbidity) *in situ* using a YSI handheld multi-parameter instrument and a Hach benchtop turbidimeter at a representative location on the river cross-section.

Following the Greater Yellowstone Network's approved protocol, we collected water samples in wadeable depths across a range of flow conditions using a DH-81 Sampler (Federal Interagency Sedimentation Project, Vicksburg, Mississippi) affixed to a 1-m wading rod. A 3-L polypropylene bottle was used with the DH-81 sampler to collect river water. Water was collected at multiple locations along the cross-section using vertically integrated sampling techniques. When full, the 3-L bottle was emptied into an 8-L polyethylene churn splitter to facilitate

a larger composite water sample that is more representative of river conditions. The churn homogenizes the collected water before a subsample is retrieved. All bottles necessary for laboratory analysis are filled from the churn. We rinsed the 3-L sample bottle and churn splitter three times with deionized water between samples to prevent contamination. All water samples collected from the Lamar River, Yellowstone River, and Madison River were shipped overnight to Chemtech-Ford Laboratories in Sandy, UT. The approved Greater Yellowstone Network Regulatory Water Quality Monitoring Protocol (O'Ney 2006) can be found at http://science.nature.nps.gov/im/units/gryn/monitor/water_resources.cfm.

Discharge estimates for river sites were taken from USGS maintained stations for the Lamar River (USGS Gage 06188000 near Tower Ranger Station, WY), Yellowstone River (USGS Gage 06191500 at Corwin Springs, MT), and Madison River (USGS Gage 06037500 near West Yellowstone, MT). Note that water sampling for the Madison River near West Yellowstone, MT was completed approximately 7 km downstream of the USGS Gage to accommodate year-round access.



Photo 3. River sampling is accomplished with a DH-81 Sampler affixed to a 1-m wading rod with 3-L bottle during wadeable conditions. Photo from the Lamar River near Tower Ranger Station, WY.

Results

Lamar River, Yellowstone River, and Madison River Climate, Discharge, and Water Chemistry

We present air temperature and precipitation, river discharge, and water chemistry data from three monitoring sites within and around Yellowstone National Park. We summarize information using a single site for each of the following: Lamar River, Yellowstone River, and Madison River.

Climate Station Summaries

The Tower Falls COOP weather station (elevation 1910 m [6,266 ft]) located near Tower Ranger Station, WY is approximately 4.0 km (2.5 mi) from Lamar River sampling station and received 54.4 cm (21.4 in) of precipitation in 2014. More than half of the annual precipitation (approx. 27.4 cm [10.8 in]) is delivered from August to December. The greatest amount of annual precipitation at Tower Falls (17.5%) occurred in August (approx. 9.6 cm [3.8 in]), and the least amount (4.5%) in July (approx. 2.4 cm [0.9 in]; Figure 2). The long-term average (1981 to 2013) January maximum temperature is -3.3°C (26°F) with an average January minimum temperature of -17.3°C

(0.86°F). The average long-term July maximum temperature (1981 to 2013) is 22.9°C (73.2°F) with an average July minimum temperature of 2.4°C (36.3°F). The maximum temperature recorded at Tower Falls COOP station was 36.7°C (98°F) in July 2002. The minimum temperature, -43.3°C (-46°F), occurred in January 1997.

The Mammoth COOP weather station (elevation 1899 m [6,230 ft]) located in Mammoth, WY approximately 17 km (10.5 mi) from the Yellowstone River at Corwin Springs received 41.7 cm (16.4 in) of precipitation in 2014. More than half of the annual precipitation (approx. 21.2 cm [8.3 in]) is delivered from August to December. The greatest contribution to annual precipitation at Mammoth (17.4%) occurred in August (approx. 7.4 cm [2.9 in]), and the least amount (<1%) in May (approx. 0.96 cm [0.4 in]; Figure 3). The long-term average (1981 to 2013) January maximum temperature is -0.6°C (31°F) with an average January minimum temperature of -11.1°C (12°F). The long-term average (1981 to 2013) July maximum temperature is 25°C (77°F) with an average July minimum temperature of 8.3°C (47°F). Maximum temperature recorded at Mammoth COOP station was 37.2°C

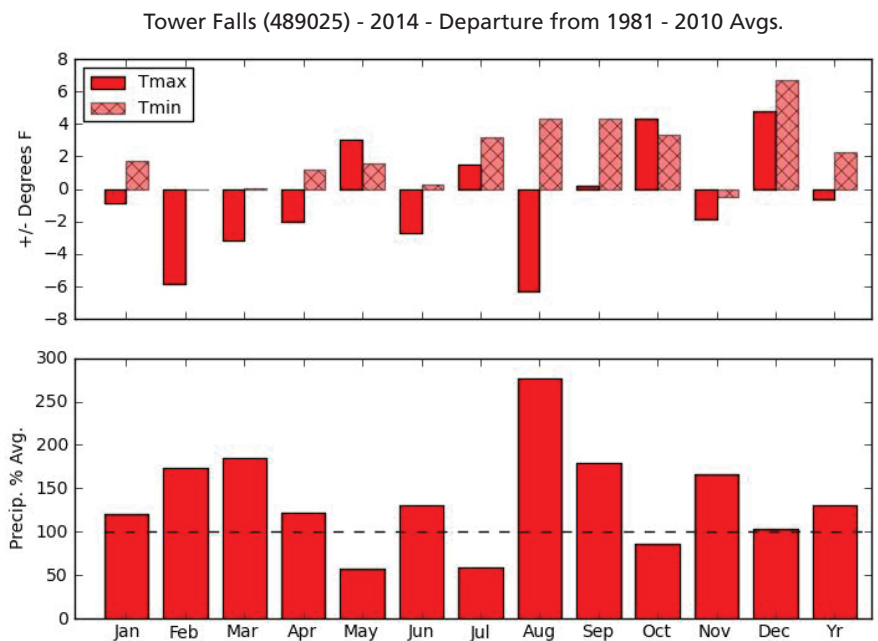


Figure 2. Calendar year 2014 monthly temperature (maximum and minimum) and precipitation summaries for the Tower Falls COOP station 489025 (elevation 1910 m) approximately 4 km from Lamar River monitoring site. Monthly and year end departures from the 30-year average are shown.

(99°F) in July 2002. Minimum temperature, -7.2°C (-35°F), occurred February 1989 and December 1990.

The West Yellowstone SNOTEL station (elevation 2042 m [6,700 ft]) located in West Yellowstone, MT approximately 2.6 km (1.6 mi) from the Madison River monitoring station received 77.2 cm (30.4 in) of precipitation in 2014. More than half of the annual precipitation (approx. 40.3 cm [15.9 in]) is delivered from December to May. The greatest amount of annual precipitation at West Yellowstone (15.8%) occurred in March (approx. 2.9 cm [1.1 in]), and the least amount (1.3%) in July (approx. 1.6 cm [0.6 in]). The long-term average (1981 to 2013) January maximum temperature is -9.9°C (14.2°F) with an average January minimum temperature of -14.7°C (5.5°F). The long-term average (1981 to 2013) July maximum temperature is 27°C (80.6°F) with an average July minimum temperature of 4.8°C (40.6°F). Maximum temperature recorded at West Yellowstone SNOTEL station was 35°C (95°F) in July 2002, August 2003, and October 2003. Minimum temperature -43.3°C (-46°F) occurred in December 1998.

2014 Temperature and Precipitation

Temperatures in 2014 were near 30-year averages at all

three monitoring locations. At Lamar River (summarized using the Tower Falls COOP station; Figure 2), the average annual maximum temperatures were approximately 0.4°C (0.7°F) below the 30-year average, and the average annual minimum temperatures were above the long-term average (approximately 1.2°C [2.2°F]). At Yellowstone River (summarized using the Mammoth COOP station; Figure 3), the average annual maximum temperatures were approximately 0.6°C (1°F) below the 30-year average, and the average annual minimum temperatures were approximately 0.6°C (1°F) above the 30-year average. At Madison River (summarized using the Old Faithful COOP station; Figure 4), the average annual maximum temperatures were similar to the 30-year average, but the average annual minimum temperatures were above the 30-year average (approximately 0.6°C [1°F]).

Total annual precipitation in 2014 was higher than the 30-year average at stations near all three monitoring locations. A disproportionate amount of precipitation fell in August relative to the long-term record (over 270% of 30-year average) at all COOP stations used to summarize conditions at the three monitoring locations. The greatest precipitation departure

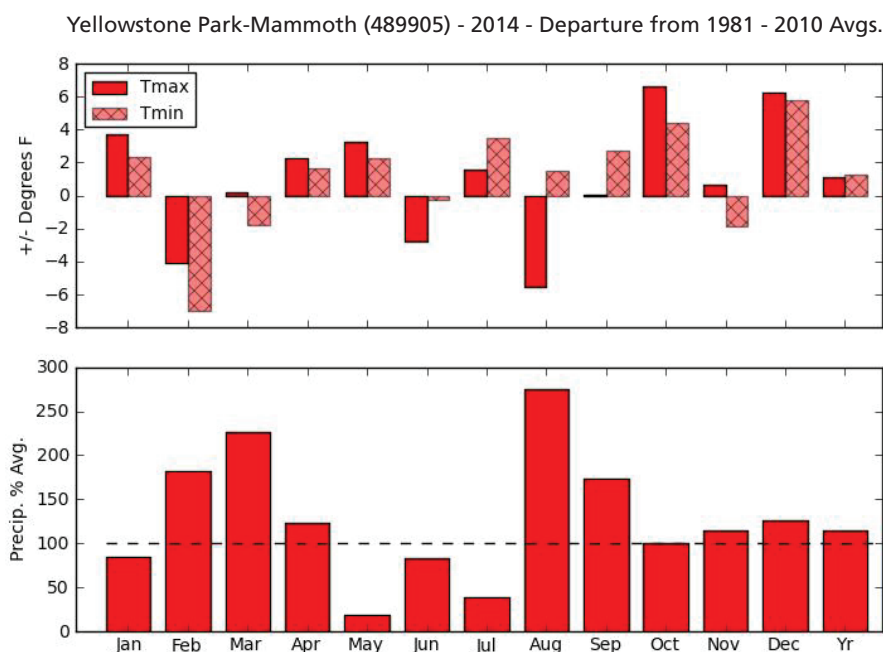


Figure 3. Calendar year 2014 monthly temperature (maximum and minimum) and precipitation summaries for the Yellowstone National Park Mammoth COOP station 489905 (elevation 1899 m) approximately 17 km from the Yellowstone River monitoring site. Monthly and year end departures from the 30-year average are shown.

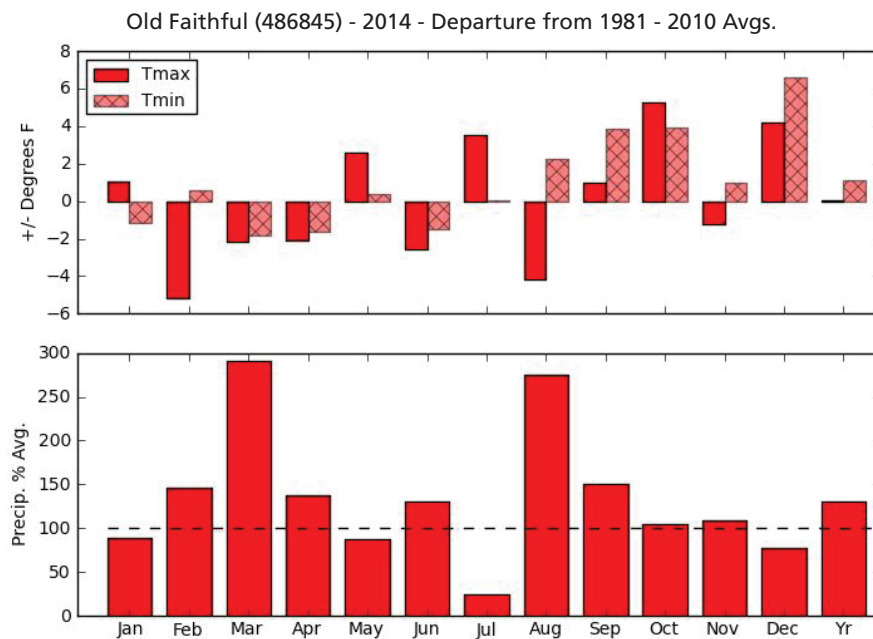


Figure 4: Calendar year 2014 monthly temperature (maximum and minimum) and precipitation summaries for the Old Faithful COOP station 486845 (elevation 2243 m) approximately 35 km from Madison River monitoring site. Monthly and year end departures from the 30-year average are shown.

from long-term average occurred at Old Faithful in March (291% of 30-year-average). Additionally, above-average precipitation was also recorded at Tower Falls in February, March, April, September, November, and December. Above-average precipitation was also recorded at Mammoth COOP station in February, March, April, September, November, and December. Above-average precipitation was recorded at Old Faithful in February, March, April, June, and September.

Discharge

Discharge is reported for the calendar year 2014. Hydrographs for monitored rivers within Yellowstone National Park exhibit a general pattern of high early summer flows and lower baseflows occurring in late summer and extending into fall and winter (Figure 5). The hydrograph for the Lamar River monitoring site is characteristic of a snowmelt-driven system. The peak discharge at the Lamar River in 2014 was 11,700 cubic feet per second (cfs) on May 28th (148th day of the year), more than 3,500 cfs greater than the long-term average (from 1924-2013, the average discharge was 8,218 cfs). The long-term average peak flow at the Lamar River occurs on June 3rd (154th day of the year) and approximately one week later than the peak flow in 2014. Total volume of flow was similar in 2014

compared with the long-term average, however, there were five more days of estimated ice cover in 2014 compared to the long-term average of 139 days (Table 1). Days of estimated ice cover are retrieved from USGS estimations. The discharge associated with peak flows in the Lamar River is increasing approximately 300 cfs per decade (Figure 6a). Additionally, the date of peak flows is shifting in the Lamar River at a rate of approximately one day earlier per decade (Figure 6b). In 2014, the peak flow was the 5th highest out of 71 available annual years (note, years 1969 to 1988 are missing from record).

Similar to the Lamar River, flow in the Yellowstone River at Corwin Springs is characteristic of

Table 1. Summary of discharge metrics for the Lamar River near Tower Ranger Station, WY (USGS Gage 06188000)

Discharge Metric	Mean for Period of Record (1924-2013)	2014
Day of year of peak discharge (calendar date)	154 (June 3)	148 (May 28)
Total volume (in billions ft ³)	26.96	27.47
Days with ice **	139	144

** Days with ice were estimated as the number of days that are coded as 'e' indicating the flow value was estimated in the gaging station record due to ice affecting stream gage.

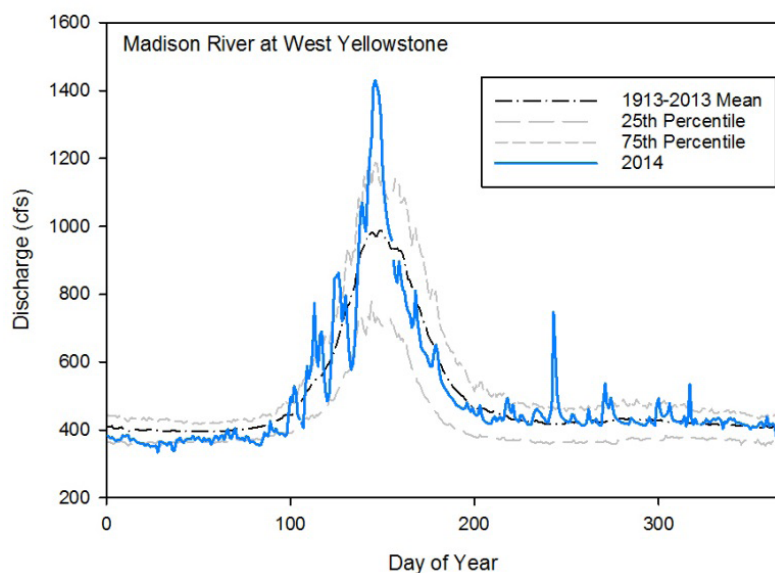
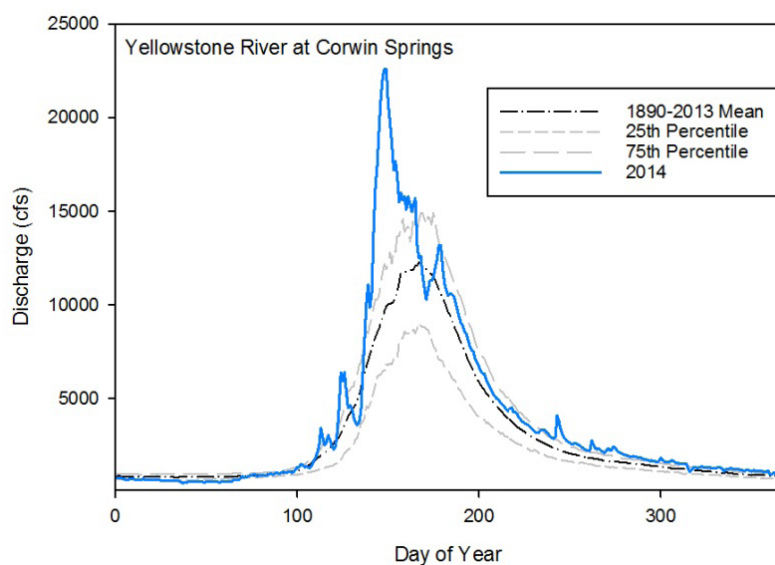
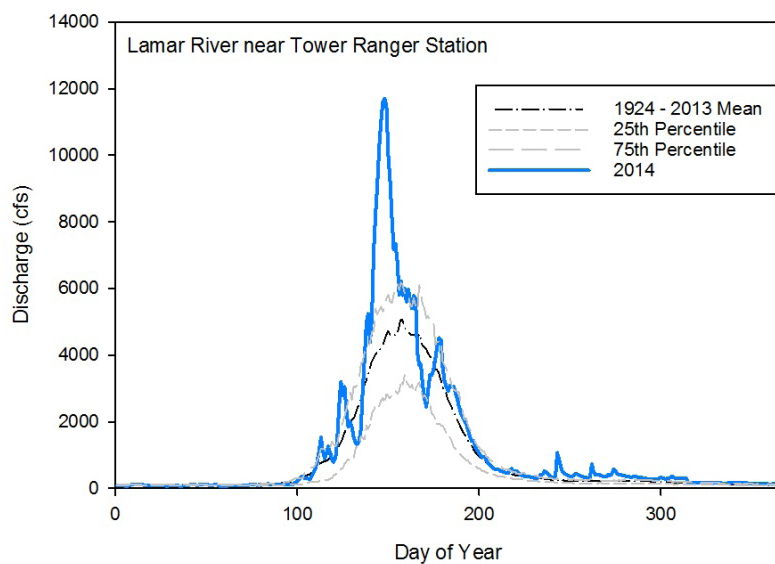


Figure 5. Summary of average daily discharge (in cfs) in the Lamar River near Tower Ranger Station, WY (USGS 06188000), Yellowstone at Corwin Springs, MT (USGS 06191500), and Madison River near West Yellowstone, MT (USGS 06037500). River flows are presented by day of year where day 1 refers to January 1 of each calendar year. The periods of record for these gages are 1924-2014 at the Lamar River, 1890-2014 at the Yellowstone River, and 1913 to 2014 at the Madison River. Mean daily discharge for the period of record is shown in black and the 25th and 75th percentiles of daily discharge are shown in grey. A summary of 2014 (blue) is also presented

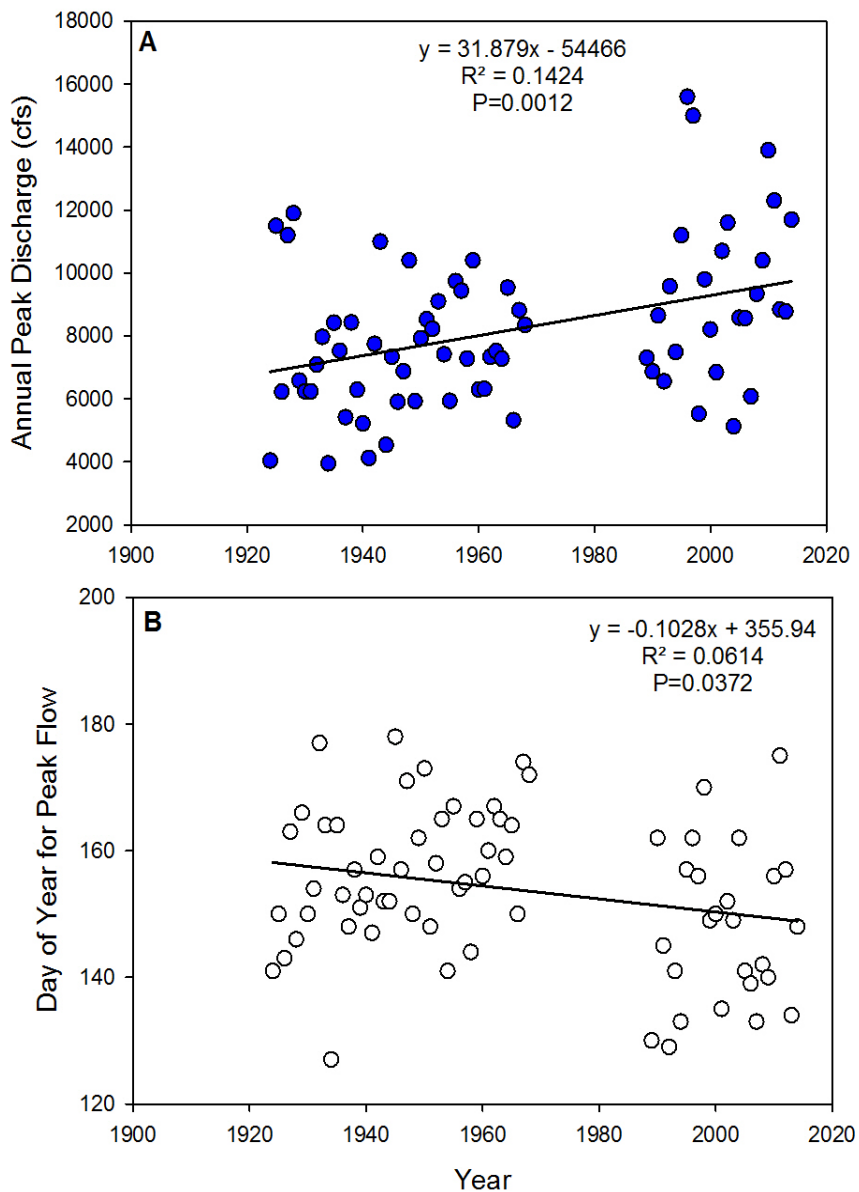


Figure 6. Summary of annual peak discharge and date of peak discharge at the Lamar River monitoring site near Tower Ranger Station, WY (USGS 06188000). At this location, the magnitude of peak flow has increased from 1924 to 2014 (A) and the date of peak flow is occurring one day sooner every decade (B).

a snow-driven system (Figure 5). The peak flows occurred at the end of May, coinciding with snowmelt at higher elevations; higher flows persisted from April through June. Peak flow in the Yellowstone River was higher in 2014 than the long-term average (1890-2013) and exceeded the 75th percentile of flows for this station. These flows at the Yellowstone River monitoring site ranked the 14th highest out of 102 annual records. In addition, the peak in 2014 occurred on May 28th (148th day of the year), 11 days

earlier than the long-term average (Table 2). The total volume of flow in the Yellowstone River was notably higher than the long-term average and ice cover lasted only 10 days compared to the long-term average of 18 days (Table 2).

The hydrograph for the Madison River monitoring site is characteristic of a ground-water fed system (Figure 5). From 1913 to 2013, peak flows at the Madison River monitoring site averaged 1,324 cfs and

Table 2. Summary of discharge metrics for the Yellowstone River at Corwin Springs, MT (USGS Gage 06191500)

Discharge Metric	Mean for Period of Record (1913-2013)	2014
Day of year of peak discharge (calendar date)	159 (June 8)	148 (May 28)
Total volume (in billions ft ³)	98.05	121.96
Days with ice **	18	10

** Days with ice were estimated as the number of days that are coded as 'e' indicating the flow value was estimated in the gaging station record due to ice affecting stream gage.

Table 3. Summary of discharge metrics for the Madison River at West Yellowstone, MT (USGS Gage 06191500)

Discharge Metric	Mean for Period of Record (1913-2013)	2014
Day of year of peak discharge (calendar date)	148 (May 27)	146 (May 25)
Total volume (in billions ft ³)	15.03	15.61
Days with ice **	18	5

** Days with ice were estimated as the number of days that are coded as 'e' indicating the flow value was estimated in the gaging station record due to ice affecting stream gage.

typically occurred in late May (148th day of the year; Table 3). In 2014, peak discharge was 1,430 cfs on May 25th (146th day of the year). In 2014, peak discharge ranked 31st highest out of 92 years of available annual records. Daily flows in the Madison River near West Yellowstone, MT in 2014 closely tracked the long-term average daily flows. The total volume of flow in the Madison River was similar to the long-term average. Notably, there were 13 fewer days with ice cover than the long term average (18 days with ice on average from 1913-2013; Table 3).

Water Chemistry

Nutrients and Suspended Solids

In 2014, water chemistry at the Lamar River, Yellowstone River, and Madison River, monitoring locations were indicative of high water quality with low levels of dissolved nutrients. Ammonia-nitrogen and phosphorus were low at all monitoring sites and non-detectable results predominated for ammonia-nitrogen (NH₃), nitrite + nitrate (NO₂+NO₃), and ortho-phosphorus (ortho-P; Figure.7).

In 2014, water chemistry in the Lamar River contained relatively low levels of dissolved nutrients.

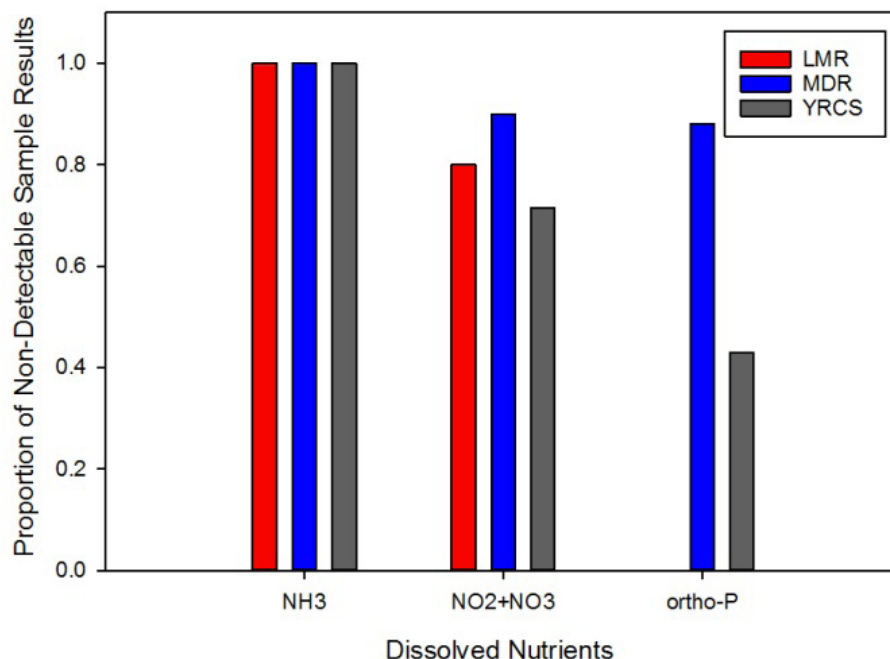


Figure 7. Proportion of monthly nutrient samples collected in 2014 from Lamar River (LMR), Madison River (MDR), and Yellowstone River at Corwin Springs (YRCS) monitoring stations that produced non-detectable levels for ammonia (NH₃), nitrite + nitrate (NO₂+NO₃), and ortho-phosphorus (ortho-P). A complete summary of water quality results are provided in Appendix B.

Ammonia-nitrogen was below detection levels at all sampling occasions. Nitrate-nitrogen (expressed as $\text{NO}_2 + \text{NO}_3\text{-N}$) levels were below detection levels for all but one sampling event (August 5, 2014; $\text{NO}_2 + \text{NO}_3\text{-N}$ was 0.1 mg/L). Ortho-phosphorus levels ranged from 0.02 to 0.04 mg/L and showed no apparent trend with discharge (Figure 8A). Total phosphorus (total P) and total suspended solids (TSS) increased with increasing discharge, peaking during the June 4th sampling (Figures 8B and 8C).

Water chemistry in the Yellowstone River contained low levels of dissolved nutrients. Patterns for ortho-P, total P, and TSS resembled patterns at Lamar River. Ammonia-nitrogen was below detection levels on all sampling occasions. Nitrate-nitrogen levels were below detection levels except on August 20, 2014 when $\text{NO}_2 + \text{NO}_3\text{-N}$ was 0.1 mg/L and October 23, 2014 when $\text{NO}_2 + \text{NO}_3\text{-N}$ was 0.2 mg/L. Ortho-phosphorus was low (range 0.01 to 0.02 mg/L) when detected and below detection levels in September 2014 showing no apparent trend with discharge. Total phosphorus and TSS increased with increasing discharge, peaking during the June 5th sampling.

Madison River also contained low levels of dissolved nutrients. Ammonia-nitrogen was below detection levels at all sampling occasions. Nitrate-nitrogen levels were below detection levels except on August 20, 2014 when $\text{NO}_2 + \text{NO}_3\text{-N}$ was 0.2 mg/L. Ortho-phosphorus levels were detectable during all sampling events and levels ranged from 0.02 to 0.08 mg/L and showed no apparent trend with discharge. The patterns at Madison River for total P differed from Yellowstone River and Lamar River. Total phosphorus decreased with increasing discharge; the lowest concentration occurred during the highest flow on June 4, 2014.

Similarly, the highest levels of TSS occurred during the June 4th sampling event. Between April and August 2014, TSS levels in the Madison River ranged from 4 to 12 mg/L.

Trace Metals

Trace metals (i.e., arsenic, zinc, mercury, lead) have been detected in waters of Yellowstone National Park and are often naturally present at measurable concentrations (Elliott and Hektner 2000). Most metals occur below state standards for aquatic life criteria. Measured analytes in the Lamar River did not exceed water quality criteria in 2014. Additionally, total arsenic, sodium, and calcium (Figures 8E, 8G, and 8F) showed an inverse relationship with discharge. Unlike levels documented at the Madison River sampling location, total arsenic levels in the Lamar and Yellowstone rivers did not exceed the Montana or Wyoming acute or chronic aquatic life criteria. A rating curve of total arsenic at Yellowstone River at Corwin Springs reveals an inverse relationship with arsenic and discharge (Figure 9D). Similarly, sulfate, sodium, and calcium levels generally declined as discharge decreased.

Surface water from the Madison River near West Yellowstone, MT also exceeded the State of Montana's aquatic life criteria for total arsenic during all sampling events except one in June. Surface water and groundwater contributing to the Madison River inside the park boundary are influenced by geothermal features. Accordingly, arsenic in the Madison River is likely naturally occurring from the geothermal geology in the watershed. Rating curves for water chemistry at Madison did not reveal any strong relationships between trace metals and discharge.

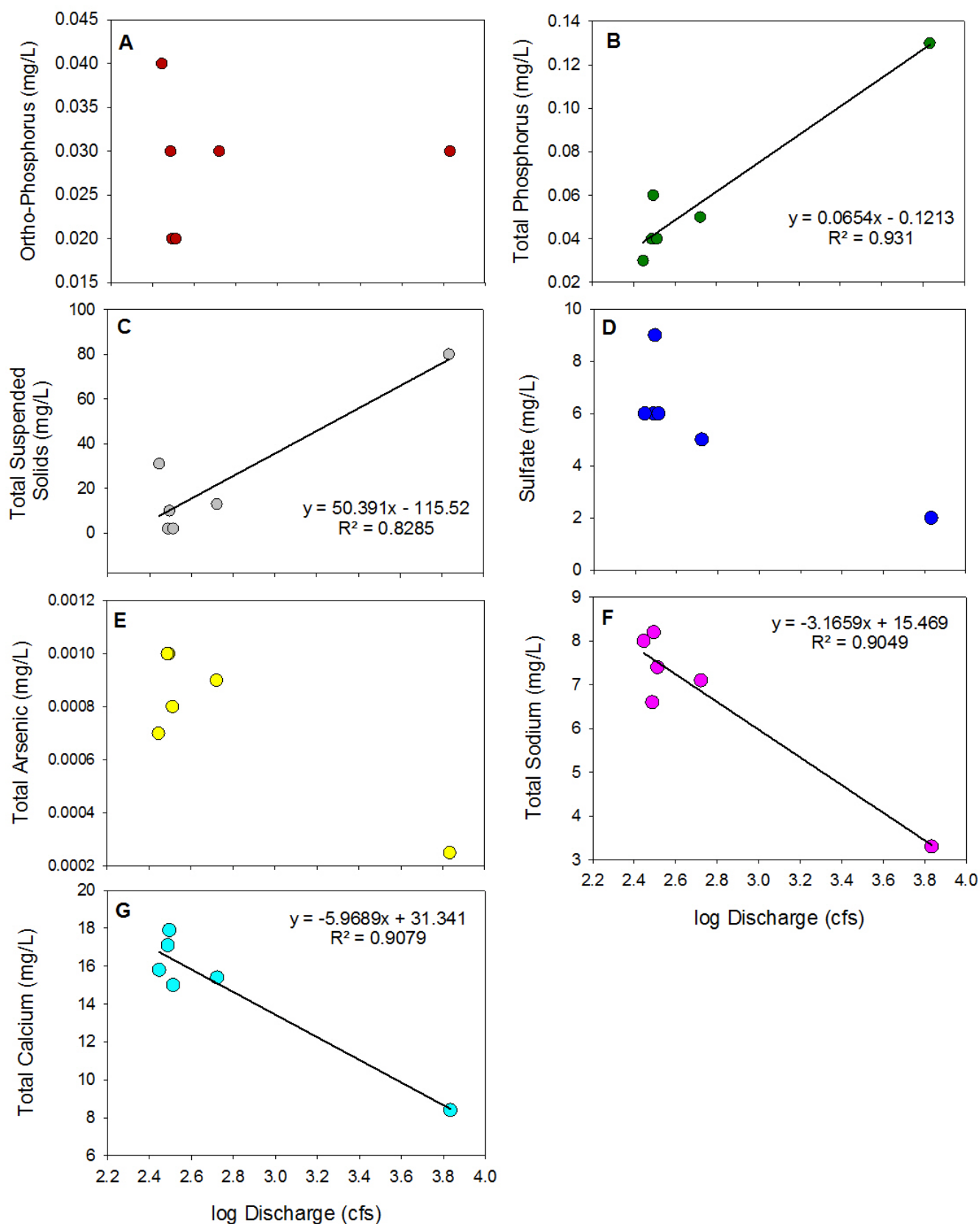


Figure 8. Rating curves showing the relationship between log-transformed discharge, ortho-phosphorus, total phosphorus, total suspended solids, sulfate, total arsenic, total sodium, and total calcium at the Lamar River (USGS6188000) sampling location.

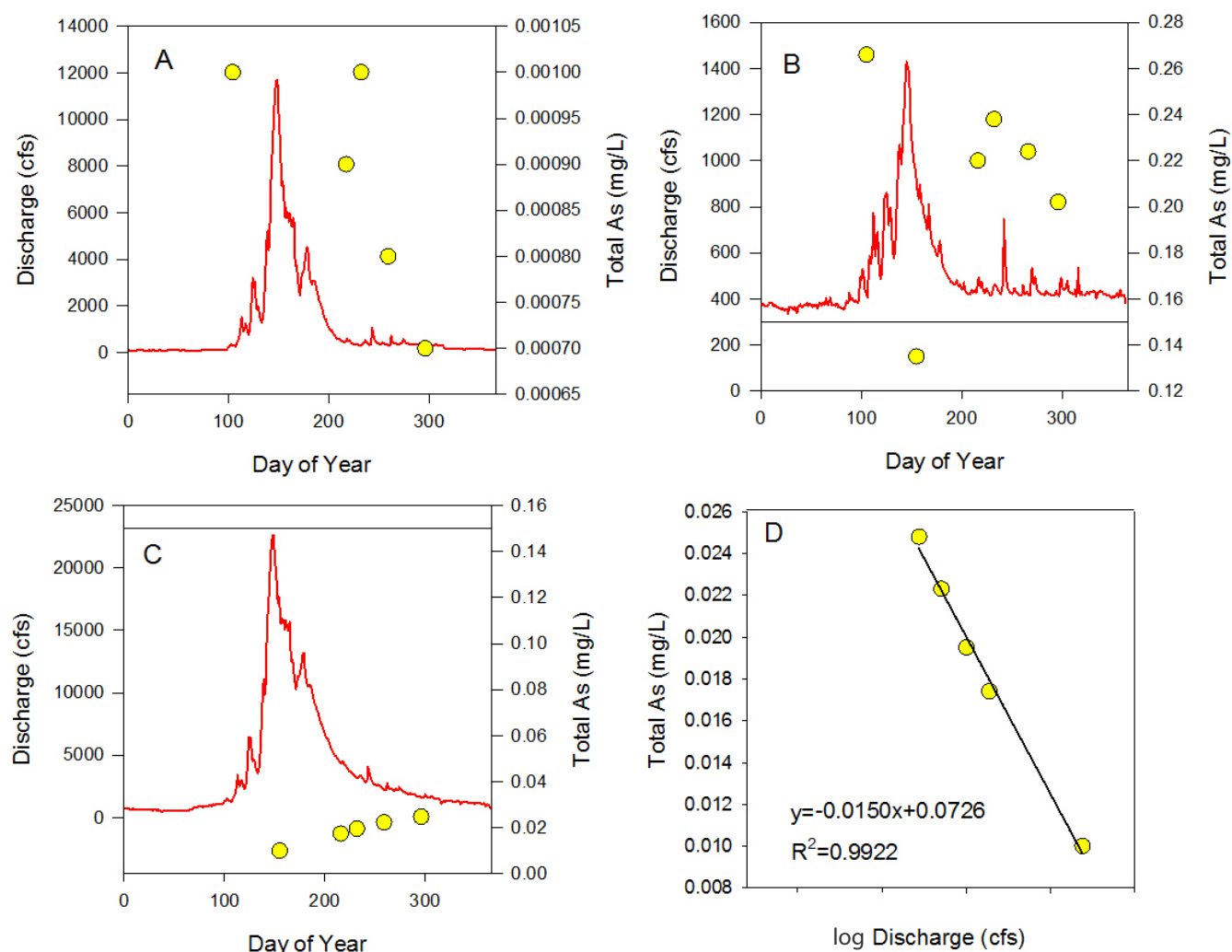


Figure 9. Red line indicates daily discharge (in cfs) in the Lamar (11A; USGS6188000), Madison (11B, 6037500) and Yellowstone (9C; USGS6191500) rivers. Also, concentrations of total arsenic (total As), represented as yellow circles, are summarized from water collected during monthly sampling. The Montana chronic aquatic life criterion (same criterion for Wyoming; 0.15 mg/L total As) is represented by the black line in 9B and 9C. The rating curve of total As at Yellowstone River (9D) shows an inverse relationship with discharge.

Discussion

Water resources are critical to the health and productivity of semi-arid landscapes like those found within Yellowstone National Park. In addition, water resources are important to the recreational experiences of visitors and their perceptual evaluations of natural features (*sensu* Burmil et al. 1999) within national parks. Consistent with the National Park Service Organic Act of 1916, maintenance of high quality waters and continued conservation of native freshwater assemblages for the ‘enjoyment of future generations’¹ are important management objectives for NPS including Yellowstone National Park. During the 2014 calendar year, ongoing monitoring activities assisted in further characterizing water quality and discharge patterns in the Lamar, Yellowstone, and Madison rivers. These summaries will contribute to the improved understanding of the variability and aid in trend monitoring of important water resources in Yellowstone National Park. Importantly, this work also aids in determining whether these aquatic resources are meeting state and federal water quality criteria.

Discharge patterns in Yellowstone National Park’s rivers vary among calendar years depending on annual snow pack levels and seasonal and annual temperatures. Flow volumes and hydrograph patterns also vary considerably among monitored rivers. For example, the Lamar River shows a characteristic snow-driven hydrograph, where peak flows can be two orders of magnitude (100 times) higher than baseflows. In contrast, the hydrograph of the Madison River (and its tributaries) exhibits characteristics of a river influenced to a much greater extent by groundwater contributions (Gardner et al. 2010). For example, peak flows in the Madison River are only 2 to 4 times higher than baseflows. In 2014, peak flows in the Madison River were 3.5 times baseflow levels. In contrast, the Lamar River ranged between 11,700 cfs in late May to 60 cfs in January indicating peak flows were 195 times higher than baseflows. In the Yellowstone River, peak flows were approximately 45 times higher than baseflows in 2014; flows ranged from 22,600 cfs in late May to 500 cfs in February.

Warming conditions in snow-dominated regions are predicted to alter river discharge patterns and, in particular, produce earlier peak flows (Barnett et al. 2005, Palmer et al. 2009). In some of Yellowstone’s rivers, shifts in the timing and magnitude of peak flow have already been detected (Figure 6). In the Lamar River, both the timing and magnitude of peak flows have shown a significant shift over the period of record. Although there is considerable among-year variation, peak flows are, on average, increasing 300 cfs per decade and the timing of peak flows is occurring approximately 1 day earlier per decade. In the Madison River, peak flows are, on average, increasing 200 cfs per decade with peak flows occurring approximately 1.75 days earlier per decade. In the Yellowstone River, peak flows are, on average, decreasing 148 cfs per decade with peak flows occurring approximately 4 days earlier per decade. Note there are considerable variations among years at all sites.

Not unexpectedly, water quality in Yellowstone’s rivers reflects that of high quality river conditions, as well as, unique chemical signatures associated with geothermally influenced rivers. For example, arsenic levels are high in the Madison River near West Yellowstone, MT. These high levels exceeded the Montana chronic aquatic life criterion (0.15 mg/L) on all but one sampling occasion (June 4, 2014). Arsenic has been shown to be high in the Madison River (Thompson 1979) and these elevated levels have been attributed to high concentrations of arsenic from geothermal sources (e.g., geothermal springs; Webster and Nordstrom 2003) like those found in the Firehole and Gibbon drainages of Yellowstone National Park (Thompson 1979). Other elements characteristic of geothermal influence include mercury, fluoride, and selenium (Webster and Nordstrom 2003). Arsenic levels in the Yellowstone River at Corwin Springs, MT were twice those documented in the Lamar River, but below the Montana chronic aquatic life criterion.

Dissolved nitrogen concentrations were low in all waters surveyed. Dissolved phosphorus was lowest in the Lamar and Yellowstone rivers. In the Madison

¹ NPS Organic Act of 1916 states, “...to conserve the scenery and the natural and historic objects and the wild life therein and to provide for the enjoyment of the same in such manner and by such means as will leave them unimpaired for the enjoyment of future generations.”

River, dissolved and total phosphorus levels were highest in April, September, and October when baseflow conditions occurred. These levels support the conclusion that phosphorus-rich groundwater is contributing disproportionately to phosphorous levels in the Madison River (Gardner et al. 2010).

Water quality in Yellowstone National Park exhibited the greatest variability during high flows (June 2014). During high flows total phosphorus, suspended solids, and iron levels were high and sulfate, sodium, and arsenic levels were lower than other months sampled. Currently, WYDEQ and MTDEQ have no standard for primary nutrients (see WYDEQ 2008 and MTDEQ 2012 for assessing the status of phosphorus in our focal systems). The Yellowstone River at Corwin Springs is below the numeric nutrient criterion recommended (0.655 mg/L TN and 0.055 mg/L TP) for lower portions of the Yellowstone River (see Flynn and Suplee 2013). High quality conditions described here are not unexpected given that watersheds for the three sampling sites are largely undeveloped. The high levels documented for arsenic and other trace metals are believed to be naturally occurring (NPS 1994).

Water quality monitoring of select water resources of Yellowstone National Park during calendar year

2014 suggests that most monitored resources are meeting state and federal water quality criteria. Based on results presented from the 2014 monitoring and summarized with this report, the Greater Yellowstone Network recommends the following:

- Continued monitoring of major cations and anions, growth limiting nutrients, trace metals, and total suspended solids in the Lamar, Yellowstone, and Madison rivers.
- Use of large river sampling equipment for sampling the Yellowstone River and Madison River during non-wadeable flows.
- Establish permanent photo points at all monitoring sites.
- Consider integration of other measures of riverine function (e.g., gross primary production and ecosystem metabolism; see Marcarelli et al. 2010) into the river monitoring program. Although changes in river chemistry are not anticipated within the protected boundaries of Yellowstone National Park, ecosystem metabolism may be strongly influenced by observed and future changes in discharge patterns.

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Appendix A:

Environmental Protection Agency (EPA) Recommended Water Quality Criteria

Table A-1. Environmental Protection Agency (EPA) recommended water quality criteria.

	EPA National Recommended Water Quality Criteria (2012) ^a	EPA Gold Book (1987) ^b	EPA Ambient Water Quality Criteria (2000) ^c	Montana Circular DEQ-7 (October 2012) ^d	Wyoming Department of Environmental Quality Water Quality Rules and Regulations (2007) ^e
Arsenic	Freshwater (Acute) = 340 µg/L Freshwater (Chronic) = 150 µg/L Human Health consumption of water plus organism = 0.018 µg/L Human health for consumption of organism only = 0.14 µg/L	Freshwater aquatic organisms and their uses should not be affected unacceptably if the 4-day average concentration of arsenic does not exceed 190 µg/L more than once every 3 years on the average and if the 1-hour average concentration does not exceed 360 µg/L more than once every 3 years on the average. For the maximum protection of human health from the potential carcinogenic effects due to exposure of arsenic through ingestion of contaminated water and contaminated aquatic organisms, the ambient water concentration should be zero based on the non-threshold assumption for this chemical. However, zero level may not be attainable at the present time. Therefore, the levels which may result in incremental increase of cancer risk over the lifetime are estimated at and the corresponding criteria are 0.022 µg/L, 0.0022 µg/L, and 0.00022 µg/L, respectively. If the above estimates are made for consumption of aquatic organisms only, excluding consumption of water, the levels are 0.175 µg/L, 0.0175 µg/L, and 0.00175 µg/L, respectively.	—	Aquatic Life Standard/Acute = 340 µg/L; Aquatic Life Standard/Chronic = 150 µg/L; Human Health surface water = 10 µg/L	Aquatic Life/Acute = 340 µg/L; Aquatic Life/Chronic = 150 µg/L; Human Health value fish and drinking water = 10 µg/L; Human Health value fish only = 10 µg/L
Ammonia	Acute criteria/pH and temperature dependent; one-hour ^g and 30-day ^h criterion are based on the calculations (provided below) ^f that are specific to waters that support or lack salmonids or early life stages of fish.	Acute criteria/pH and temperature dependent; from pH 6.5–9.0, acute values for NH ₃ -N plus NH ₄ -N ranges from 885 to 32,600 µg/L for coldwater/ salmonids present and from 1,320 to 48,800 µg/L salmonids absent.	—	Acute criteria/pH and temperature dependent; 1-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 885 to 32,600 µg/L for coldwater/ salmonids present and from 1,320 to 48,800 µg/L salmonids absent. The chronic criterion for ammonia are dependent on whether early life stages of fish or salmonids (of any life stage) are present. Calculations for maximum concentration ^g and continuous concentrations ^h are shown below.

Table A-1. Environmental Protection Agency (EPA) recommended water quality criteria, cont.

	EPA National Recommended Water Quality Criteria (2012)^a	EPA Gold Book (1987)^b	EPA Ambient Water Quality Criteria (2000)^c	Montana Circular DEQ-7 (October 2012)^d	Wyoming Department of Environmental Quality Water Quality Rules and Regulations (2007)^e
Chloride	Freshwater (Acute) = 860,000 µg/L Freshwater (Chronic) = 230,000 µg/L	Domestic water supplies = 250,000 µg/L	—	not found in any MT guidance documents	Aquatic Life/Acute = 860,000 µg/L; Aquatic Life/Chronic = 230,000 µg/L
Copper	Biotic Ligand Model (BLM) ^f was developed to more carefully characterize copper toxicity in freshwater environments (EPA 2009). This new approach to modeling copper toxicity recognizes “that toxicity is not simply related to total aqueous concentrations, but that both metal-ligand complexation and metal interaction with competing cations at the site of action of toxicity” are needed to develop acute and chronic criteria. Human health for consumption of water + organism = 1,300 µg/L	Freshwater aquatic organisms = at a hardness of 100,000 µg/L as CaCO ₃ , the 4-day average concentration is 12 µg/L and the 1-hour average concentration is 18 µg/L Human health = for controlling undesirable taste and odor quality of ambient water, the estimated level is 1,000 µg/L	—	Aquatic Life Standard/Acute=3.79µg/L at 25mg/L hardness (12) Aquatic Life Standard/Chronic=2.85µg/L at 25mg/L hardness (12); Human Health surface water and ground water= 1300 µg/L	Aquatic Life/Acute = 13.4 µg/L; Aquatic Life/Chronic = 9.0 µg/L at a CaCO ₃ hardness of 100,000 µg/L; Human Health value fish and drinking water = 1,000 µg/L
Dissolved Oxygen (DO)	For early life stages, coldwater criteria, the water column concentration recommended to achieve inter-gravel DO concentration/ 1-day minimum = 8,000 µg/L; 5,000 µg/L for early life stages exposed directly to the water column For other life stages, coldwater criteria, the water column concentration recommended to achieve inter-gravel DO concentration/1-day minimum = 4,000 µg/L.	For early life stages, coldwater criteria, the water column concentration recommended to achieve inter-gravel DO concentration/1-day minimum = 8,000 µg/L; 5,000 µg/L for early life stages exposed directly to the water column. For other life stages, coldwater criteria, the water column concentration recommended to achieve inter-gravel DO concentration/1-day minimum = 4,000 µg/L.	—	Freshwater aquatic life standards recommended to achieve inter-gravel DO concentration/ 1-day minimum = 8.0 mg/L; 5.0 mg/L for early life stages exposed directly to the water column; for other life stages, coldwater criteria, the water column concentration recommended to achieve inter-gravel DO concentration/ 1-day minimum = 4.0 mg/L (for A-1, B-1, B-2, C-1, and C-2 waters). Freshwater aquatic life standards for B-3, C-3, and I waters requires a 1-day DO minimum concentration = 5.0 mg/L for early life stages; for other life stages a 1-day minimum DO concentration = 3.0 mg/L is required.	For early life stages, coldwater criteria, the water column concentration recommended to achieve inter-gravel DO concentration/ 1-day minimum = 8.0 mg/L; 5.0 mg/L for early life stages exposed directly to the water column; For other life stages, coldwater criteria, the water column concentration recommended to achieve inter-gravel DO concentration/ 1-day minimum = 4.0 mg/L.

Table A-1. Environmental Protection Agency (EPA) recommended water quality criteria, cont.

	EPA National Recommended Water Quality Criteria (2012) ^a	EPA Gold Book (1987) ^b	EPA Ambient Water Quality Criteria (2000) ^c	Montana Circular DEQ-7 (October 2012) ^d	Wyoming Department of Environmental Quality Water Quality Rules and Regulations (2007) ^e
Nitrite + Nitrate	not found	Domestic water supplies = 10,000 µg/L	40 µg/L ^f	Nitrite + Nitrate 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). Human health standard/Surface water = 10,000 µg/L	Human health value/fish and drinking water = 10,000 µg/L
pH	Freshwater = 6.5–9.0	Freshwater Aquatic Life = 6.5–9.0	—	For A-1, B-1, and C-1 waters, induced variation of hydrogen ion concentration (pH) within the range of 6.5 to 8.5 must be less than 0.5 pH unit. Natural pH maintained without change. Natural pH above 7.0 must be maintained above 7.0. For B-2, B-3, C-2, and C-3 waters, induced variation of hydrogen ion concentration (pH) within the range of 6.5 to 9.0 must be less than 0.5 pH unit. Natural pH maintained without change. Natural pH above 7.0 must be maintained above 7.0 (from 17-30-6 MTDEQ). From ARM 17.30.6.	Aquatic Life Chronic value = 6.5 - 9.0
Phosphorus	no standard	no standard	15 µg/L ^f	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). Yellowstone Plateau (17j) Ecoregion: 0.03mg/L, Absorka-Gallatin Volcanic Mountains (17i) (July 1 to September 30; MTDEQ 2014	not found in any WY guidance documents
Ortho-phosphate	no standard	no standard	—	Ortho-phosphate is recognized as a plant nutrient that, in excessive amounts, may cause violations of Administrative Rules of Montana (ARM) 17.30.637 (1)(e).	not found in any WY guidance documents
Selenium	Freshwater (Chronic) = 5.0 µg/L Human health consumption of water + organism = 170 µg/L; Human health for consumption of organism only = 11,000 µg/L	Freshwater Aquatic life/acute = 260 µg/L	—	Aquatic Life standard/Acute = 20 µg/L; Aquatic Life Standard/Chronic = 5 µg/L. Human health standard/Surface water = 50 µg/L	Aquatic Life/Acute = 20 µg/L; Aquatic Life/Chronic = 5 µg/L. Human health value/fish and drinking water = 50 µg/L; Human health value fish only = 4,200 µg/L

Table A-1. Environmental Protection Agency (EPA) recommended water quality criteria, cont.

	EPA National Recommended Water Quality Criteria (2012)^a	EPA Gold Book (1987)^b	EPA Ambient Water Quality Criteria (2000)^c	Montana Circular DEQ-7 (October 2012)^d	Wyoming Department of Environmental Quality Water Quality Rules and Regulations (2007)^e
Specific Conductance	no standard	no standard	—	not found in any MT guidance documents	not found in any WY guidance documents
Sulfate	no standard	no standard	—	not found in any MT guidance documents	not found in any WY guidance documents
Total Suspended Solids	Freshwater fish and other aquatic life: settleable and suspended solids should not reduce the depth of the compensation point for photosynthetic activity by more than 10% from the seasonally established norm for aquatic life	Freshwater fish and other aquatic life: settleable and suspended solids should not reduce the depth of the compensation point for photosynthetic activity by more than 10% from the seasonally established norm for aquatic life	—	No increases are allowed above naturally occurring concentrations of sediment or suspended sediment which will or are likely to create a nuisance or render the waters harmful, detrimental or injurious to public health, recreation, safety, welfare, livestock, wild animals, birds, fish or other wildlife	In all Wyoming surface waters, floating and suspended solids attributable to or influenced by the activities of man shall not be present in quantities which could result in significant aesthetic degradation, significant degradation of habitat for aquatic life, or adversely affect public water supplies, agricultural or industrial water use, plant life or wildlife.
Turbidity	Freshwater fish and other aquatic life: settleable and suspended solids should not reduce the depth of the compensation point for photosynthetic activity by more than 10% from the seasonally established norm for aquatic life	Freshwater fish and other aquatic life: settleable and suspended solids should not reduce the depth of the compensation point for photosynthetic activity by more than 10% from the seasonally established norm for aquatic life	0.5 NTU ^f (based on less than 4 streams to calculate 25 th percentile)	No increase above naturally occurring turbidity or suspended sediment is allowed (A-1 waters); no increase above naturally occurring greater than 5 NTUs (B-1, C-1); no increase above naturally occurring greater than 10 NTUs (B-2, B-3, C-2, C-3). From ARM 17.30.6	In all cold water fisheries and drinking water supplies (classes 1, 2AB, 2A, and 2B) the discharge of substances attributable to or influenced by the activities of man shall not be present in quantities which would result in a turbidity increase of more than ten (10) NTUs
Water Temperature	species specific criteria	species specific criteria	—	A 1°F maximum increase above naturally occurring water temperature is allowed within the range of 32°F to 66°F; within the naturally occurring range of 66°F to 66.5°F, no discharge is allowed which will cause the water temperature to exceed 67°F; and where the naturally occurring water temperature is 66.5°F or greater, the maximum allowable increase in water temperature is 0.5°F. A 2°F per-hour maximum decrease below naturally occurring water temperature is allowed when the water temperature is above 55°F. A 2°F maximum decrease below naturally occurring water temperature is allowed within the range of 55°F to 32°F (A-1, B-1, B-2, C-1, C-2).	For Class 1, 2, and 3 waters, effluent attributable to or influenced by the activities of man shall not be discharged in amounts which change ambient water temperatures to levels which result in harmful acute or chronic effects to aquatic life, or which would not fully support existing and designated uses. When ambient temperatures are above 60°F in all Class 1, 2AB, and 2B waters which are cold water fisheries, effluent attributable to or influenced by the activities of man shall not be discharge in amounts which will result in an increase of more than 2°F (1.1°C) in existing temperatures.

Table A-1. Environmental Protection Agency (EPA) recommended water quality criteria, cont.

	EPA National Recommended Water Quality Criteria (2012)^a	EPA Gold Book (1987)^b	EPA Ambient Water Quality Criteria (2000)^c	Montana Circular DEQ-7 (October 2012)^d	Wyoming Department of Environmental Quality Water Quality Rules and Regulations (2007)^e
Water Temperature, cont.	species specific criteria	species specific criteria	—	A 3°F maximum increase above naturally occurring water temperature is allowed within the range of 32°F to 77°F; within the naturally occurring range of 77°F to 79.5°F, no thermal discharge is allowed which will cause the water temperature to exceed 80°F; and where the naturally occurring water temperature is 79.5°F or greater, the maximum allowable increase in water temperature is 0.5°F. A 2°F per-hour maximum decrease below naturally occurring water temperature is allowed when the water temperature is above 55°F. A 2°F maximum decrease below naturally occurring water temperature is allowed within the range of 55°F to 32°F (B-3, C-3).	When ambient temperatures are above 60°F in all Class 1, 2AB, and 2B waters which are warm water fisheries, effluent attributable to or influenced by the activities of man shall not be discharge in amounts which will result in an increase of more than 4°F (2.2°C) in existing temperatures. The maximum allowable stream temperature will be the maximum natural daily stream temperature plus the allowable change, provided that this temperature is not lethal to existing fish life and under no circumstance shall this maximum temperature exceed 68°F (20°C) in the case of cold water fisheries and 86°F (30°C) in the case of warm water fisheries.

^aSource: 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>.

^bSource: Environmental Protection Agency. 1987. Quality criteria for water 1986 [The Gold Book]. EPA 440/5-86-001. U.S. EPA, Office of Water Regulations and Standards, Washington, D.C.

^cSource: Environmental Protection Agency (EPA). 2000. Ambient water quality criteria recommendations: Information supporting the development of state and tribal nutrient criteria for rivers and streams in nutrient ecoregion 2. EPA 822-B-00-015. U.S. EPA, Office of Water, Washington, D.C.

^dSource: Montana Department of Environmental Quality (DEQ). 2012. Montana numeric water quality standards. Circular DEQ-7. Montana DEQ, Planning, Prevention, and Assistance Division, Helena, Montana.

^eSource: Wyoming Department of Environmental Quality. 2007. Water quality rules and regulations. Chapter 1 in Water Quality Division rules and regulations. Available at <http://http://soswy.state.wy.us/Rules/RULES/9176.pdf>.

^fReference conditions for level III ecoregion 17; 25th Percentiles based on all seasons data for the Decade

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

^h30-day chronic ammonia-N criterion (in mg/L) is $CCC = ((0.0577/(1 + 10^{7.688-pH})) + (2.487/(1 + 10^{pH-7.688}))) \times \text{MIN}(2.85, 1.45 \cdot 10^{0.028 \cdot (25 - \text{MAX}(T, 7)))}$ (when early life stages of fish are present) or $CCC = ((0.0577/(1 + 10^{7.688-pH})) + (2.487/(1 + 10^{pH-7.688}))) \times 1.45 \cdot 10^{0.028 \cdot (25 - \text{MAX}(T, 7))}$

ⁱSource: U.S. EPA. 2009. The Biotic Ligand Model: technical support document for its application to the evaluation of water quality criteria for Copper. U.S. EPA, Office of Science and Technology Health and Ecological Criteria Division, Washington, D.C.

Appendix B:

2014 Laboratory Results from Monthly Monitoring of Lamar River, Yellowstone River, and Madison River

The following tables present laboratory results for three river monitoring sites: Lamar River (Table B-1), Yellowstone River (Table B-2), and Madison River (Table B-3). Water samples results from the Lamar River, Madison River, and Yellowstone River were produced by ChemTech Ford Laboratory in Sandy, UT. ‘-’=missing values.

Table B-1. Monthly water quality lab results and core parameters from the field for Lamar River near Tower Ranger Station, WY. All values presented are in mg/L. Hardness as CaCO_3 = water hardness as calcium carbonate, $\text{NH}_3\text{-N}$ = ammonium nitrogen, Cl = chloride, $\text{NO}_2\text{+NO}_3\text{-N}$ = combined result for nitrite + nitrate, ortho-P = ortho phosphate, TP = total phosphorus, SO_4 = sulfate, TSS = total suspended sediment, Diss. = dissolved, As = arsenic, Ca = calcium, Cu = copper, Fe = iron, O = oxygen, Mg = magnesium, K = potassium, Se = selenium, Na = sodium. ‘-’=missing values.

Analyte	14-April	4-June	5-August	16-September	23-October
Hardness as CaCO_3	74.5	36.2	62	64	65
$\text{NH}_3\text{-N}$	<0.2	<0.2	<0.2	<0.2	<0.2
Cl	<1	<1	<1	<1	<1
$\text{NO}_2 + \text{NO}_3\text{-N}$	<0.1	<0.1	0.1	<0.1	<0.1
ortho-P	0.02	0.03	0.03	0.02	0.04
TP	0.06	0.13	0.05	0.04	0.03
SO_4	9	2	5	6	6
TSS	10	80	13	<4	31
Diss. As	0.0007	<0.0005	0.0008	0.0009	0.0007
Total As	0.001	<0.0005	0.0009	0.0008	0.0007
Diss. Ca	17.3	7.4	14.1	16.1	17.1
Total Ca	17.9	8.4	15.4	15.0	15.8
Diss. Mg	6.5	2.7	5.0	5.8	6.1
Total Mg	7.2	3.7	5.8	6.0	6.2
Diss. K	1.2	0.7	1.1	1.2	1.2
Total K	1.3	1.1	1.4	1.2	1.3
Diss. Na	7.8	2.8	5.7	7.5	7.9
Total Na	8.2	3.3	7.1	7.4	8.0
Total Cu	-	0.0037	-	-	-
Total Se	-	<0.0005	-	-	-
Water Temp.*	1.85	6.25	13.57	9.48	3.88
Spec. Cond.*	174.7	40.7	146.0	165.0	164.0
pH*	8.07	7.77	8.12	7.76	7.66
Diss. O*	12.99	10.54	9.36	10.03	11.81
Turbidity*	8.05	29.7	2.19	1.82	1.78

*Core parameters from the field

Table B-2. Monthly water quality lab results and core parameters from the field for Yellowstone River at Corwin Springs, MT. All values presented are in mg/L. Hardness as CaCO₃ = water hardness as calcium carbonate, NH₃-N = ammonium nitrogen, Cl = chloride, NO₂+NO₃-N = combined result for nitrite + nitrate, ortho-P = ortho phosphate, TP = total phosphorus, SO₄ = sulfate, TSS = total suspended sediment, Diss. = dissolved, As = arsenic, Ca = calcium, Cu = copper, Fe = iron, O = oxygen, Mg = magnesium, K = potassium, Se = selenium, Na = sodium. Columns with dark shading represent either duplicate samples on the same date or blank samples using certified inorganic free deionized water, as indicated by header. '-'=missing values.

Analyte	14-April (Blank)		5-June	4-August (Duplicate)		16-September (Duplicate)		23-October
Hardness as CaCO ₃	64.1	<1.3	33.9	36	49	42	45	48
NH ₃ - N	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
Cl	11	<1	3	6	6	8	8	9
NO ₂ + NO ₃ -N	0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.2
ortho-P	0.02	<0.01	0.02	0.01	<0.01	<0.01	<0.01	0.01
TP	0.05	<0.01	0.11	0.03	0.03	0.03	0.03	0.02
SO ₄	35	<1	7	14	14	19	20	24
TSS	10	<4	86	6	6	<4	<4	<4
Diss. As	0.0221	<0.0005	0.0065	0.015	0.015	0.0196	0.0196	0.0233
Total As	0.0295	<0.0005	0.0100	0.0174	0.0167	0.0223	0.0208	0.0248
Diss. Ca	15.6	<0.2	6.9	8.2	8.3	10.4	11.2	12.8
Total Ca	15.9	<0.2	7.9	9.1	12.2	10.6	11.3	12
Diss. Mg	5.7	<0.2	2.6	3.2	3.3	4.0	4.2	4.9
Total Mg	5.9	<0.2	3.4	3.3	4.6	4.1	4.5	4.5
Diss. K	4.4	<0.5	1.5	2.3	2.3	2.9	3.2	3.5
Total K	4.5	<0.5	1.9	2.4	2.4	3.1	3.4	3.6
Diss. Na	19.6	<0.5	6.0	11.2	11.2	13.8	14.8	16.4
Total Na	20.0	<0.5	6.5	11.3	11.6	14.8	15.9	16.6
Total Cu	-	-	0.0027	-	-	-	-	-
Total Se	-	-	<0.0005	-	-	-	-	-
Water Temp.*	7.51		7.16	17.08		14.08	13.97	8.09
Spec. Cond.*	235		89.7	122		175	175	196.7
pH*	8.32		7.75	8.04		8.52	8.51	8.35
Diss. O*	11.05		9.7	8.56		10.67	10.39	12.49
Turbidity*	5.98		33.2	2.08		1.87	1.99	1.74

*Core parameters from the field

Table B-3. Monthly water quality lab results and core parameters from the field for Madison River at West Yellowstone, MT. All values presented are in mg/L. Hardness as CaCO₃ = water hardness as calcium carbonate, NH₃-N = ammonium nitrogen, Cl = chloride, NO₂+NO₃-N = combined result for nitrite + nitrate, ortho-P = ortho phosphate, TP = total phosphorus, SO₄ = sulfate, TSS = total suspended sediment, Diss. = dissolved, As = arsenic, Ca = calcium, Cu = copper, Fe = iron, O = oxygen, Mg = magnesium, K = potassium, Se = selenium, Na = sodium. Columns with dark shading represent either duplicate samples on the same date or blank samples using certified inorganic free deionized water, as indicated by header. '-'=missing values.

Analyte	15-April (Duplicates)		24-June (Duplicates)		20-August (Blank)		23-September	29-October
Hardness as CaCO ₃	19.3	18.4	13.6	13.3	18	<1.3	19	18
NH ₃ - N	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
Cl	62	62	27	27	48	<1	54	56
NO ₂ + NO ₃ -N	<0.1	<0.1	<0.1	<0.1	0.2	<0.1	<0.1	<0.1
ortho-P	0.06	0.08	0.02	0.02	0.02	<0.01	0.07	0.03
TP	0.13	0.13	0.07	0.08	0.09	<0.01	0.11	0.11
SO ₄	17	17	8	7	11	<1	13	14
TSS	8	8	12	12	<4	<4	-	4
Diss. As	0.261	0.256	0.114	0.115	0.231	<0.0005	0.242	0.231
Total As	0.266	0.289	0.135	0.126	0.238	<0.0005	0.224	0.202
Diss. Ca	6.2	6.1	4.3	4.3	5.9	<0.2	6	6.3
Total Ca	6.3	6	4.3	4.2	6.2	<0.2	6.1	5.8
Diss. Mg	0.8	0.8	0.7	0.7	0.9	<0.2	0.9	0.9
Total Mg	0.9	0.8	0.7	0.7	0.8	<0.2	0.8	0.8
Diss. K	9	8.8	5.2	4.9	7.8	<0.5	8.4	9.0
Total K	9	8.6	5.1	5	7.9	<0.5	8.3	7.8
Diss. Na	84.4	84.4	44	42.5	74.4	<0.5	79.8	84.9
Total Na	86.8	80.3	44.8	43.3	76.4	<0.5	75.1	80.0
Total Cu	<0.001	<0.001	<0.001	<0.001	-	-	-	-
Total Se	0.0009	0.0009	<0.0005	<0.0005	-	-	-	-
Total Fe	0.32	0.31	-	-	-	-	-	-
Water Temp.*	8.81	8.81	14.05	14.15	15.5		15.14	8.21
Spec. Cond.*	454.7	458.0	142.7	142.3	406		4.9	421
pH*	7.9	7.92	7.85	7.76	7.93		8.12	7.77
Diss. O*	9.27	9.31	8.01	8.00	7.84		7.85	10.95
Turbidity*	3.52	3.63	4	4.14	1.34		3.12	1.24

*Core parameters from the field

Appendix C:

Reese Creek Monitoring Report

Reese Creek Flow and Water Use Monitoring

Yellowstone National Park, 2014

October 23, 2014

BRIAN TEETS, NORTH DISTRICT RESOURCE OPERATIONS

In 2014, Yellowstone National Park, North District Resource Operations staff monitored seasonal stream flow in Reese Creek, a tributary of the Yellowstone River that forms a portion of the park boundary north of Gardiner, Montana. Reese Creek has been of interest to Yellowstone National Park staff because it is the only stream in the park which maintains a water use agreement and has stream flow utilized periodically for private irrigation use adjacent to the park. In addition, this stream supports a population of resident native Yellowstone cutthroat trout and contains suitable spawning habitat for migratory fish species from the Yellowstone River.

Existing water rights claims have made Reese Creek an over-appropriated stream, similar to many other western streams. Since the early 1980s, National Park Service (NPS) and the other water rights claimants have been involved in negotiations to reach a water usage agreement to appropriate water use for this stream where the demand may exceed the available water. By 1992, a stipulated agreement was reached that provided for some usage by the primary claimants—Royal Teton Ranch (RTR), NPS, and other water right users. The amount of water allocated to each user is a flow-dependent variable percentage of the total discharge estimated at a Parshall flume (Upper Flume) located several hundred yards upstream from the uppermost point of diversion. The agreement is divided into irrigation (April 15 to October 15) and non-irrigation seasons (remainder of the year); this report only examines the active irrigation season.

The water use agreement contains provisions for primary as well as additional water usage by other minor claimants during periods of higher stream flow. About a decade after this cooperative usage process was begun, the U.S. Forest Service (USFS) initiated additional agreements with RTR in conjunction with land acquisitions and exchanges associated with ungulate winter range objectives. As a result, the USFS secured its own water rights on Reese Creek and has become a cooperator in maintaining stream flows there.

2014 ACTIVITIES

Yellowstone National Park field personnel measured stream flows in Reese Creek approximately once per week from May 15, 2014 until September 25, 2014. Stream discharge was computed by the mid-section method with velocities determined with a Marsh-McBirney flow meter. On each sample occasion, discharge was measured at the upper irrigation ditch (Lower Flume) and adjacent to the upper main-stem flume (Upper Flume). A typical discharge measurement requires one-half to three-quarters of an hour to complete; however, we assumed that the proximity of the flow sites allows for “instantaneous” comparisons of the volume of water in different sections of Reese Creek. Staff plates located in the Parshall flume and the irrigation head-gate were read to yield additional data that can be used as a flow index at these sites. Weather conditions were also recorded during the sample period.

The difference between the estimated discharge at the upper flume and the measured stream flow in the irrigation ditch represented the amount of water remaining in Reese Creek to meet NPS and USFS water rights. During the 2014 irrigation season, the USFS was not shown to divert their water rights and allowed their respective allotment to remain in Reese Creek down to the confluence with the Yellowstone River.

Un-diverted main stem discharge at the upper site reached its peak on May 29, 2013 at 25.52 cubic feet per second (cfs). By the end of July, discharge in Reese Creek had leveled off, averaging 7.83 cfs for the remainder of the irrigation season. The lowest recorded stream flow was 6.32 cfs taken on September 25, 2014 (Figure C-1).

During the irrigation season of 2014, these water rights were met on most occasions. Occasionally the RTR would take a surplus of their allotment; however these events never resulted in the NPS water flow becoming lower than their allotment (Figure C-2). On one occasion (July 16, 2014) the water flow at the upper diversion was within 0.3 cfs of diverting extra water to the point of leaving the NPS allotment short of the 1.25 cfs required at that time. Otherwise all parties operated well within the stipulated agreement. Due to above average snow pack and consistent rainfall throughout the summer months of 2014, stream flows remained at a sustainable amount for all parties to receive adequate water from Reese Creek.

It should also be noted that the solar powered fish barrier installed just above the upper diversion has failed. Due to exposure to the elements and regular wear and tear, the solar barrier is no longer operational. To ensure that as few fish as possible enter the irrigation diversion, North District Resource Management staff manually clear a stationary screen above the diversion to keep small fish from entering the diversion ditch, while allowing water to enter the diversion ditch.

In an attempt to allow spawning fish species from the Yellowstone River to better use the habitat of lower Reese Creek, North District Resource Management staff improved the fish ladder located near the middle diversion in 2013. The improvements would allow fish of breeding size to access additional habitat between the middle diversion and the fish dam located near the upper diversion. North District resource management staff checked the fish ladder occasionally during summer 2014 and found it to be in good working order.

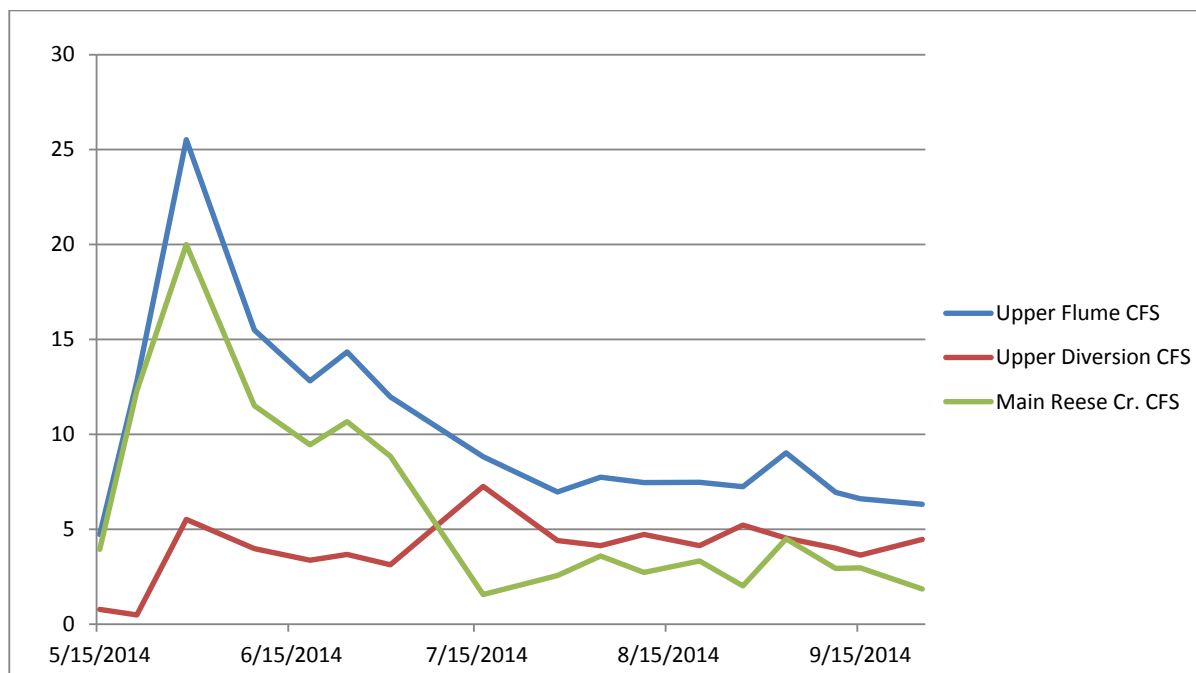


Figure C-1. 2014 Reese Creek Stream flow measurements. Upper Flume CFS represents the stream flow of Reese Creek above all diversions. Upper Diversion represents the amount of water diverted from Reese Creek into the Royal Teton Ranch (RTR) irrigation ditch. Main Reese Cr. represents the total water remaining in Reese Creek below the RTR diversion.

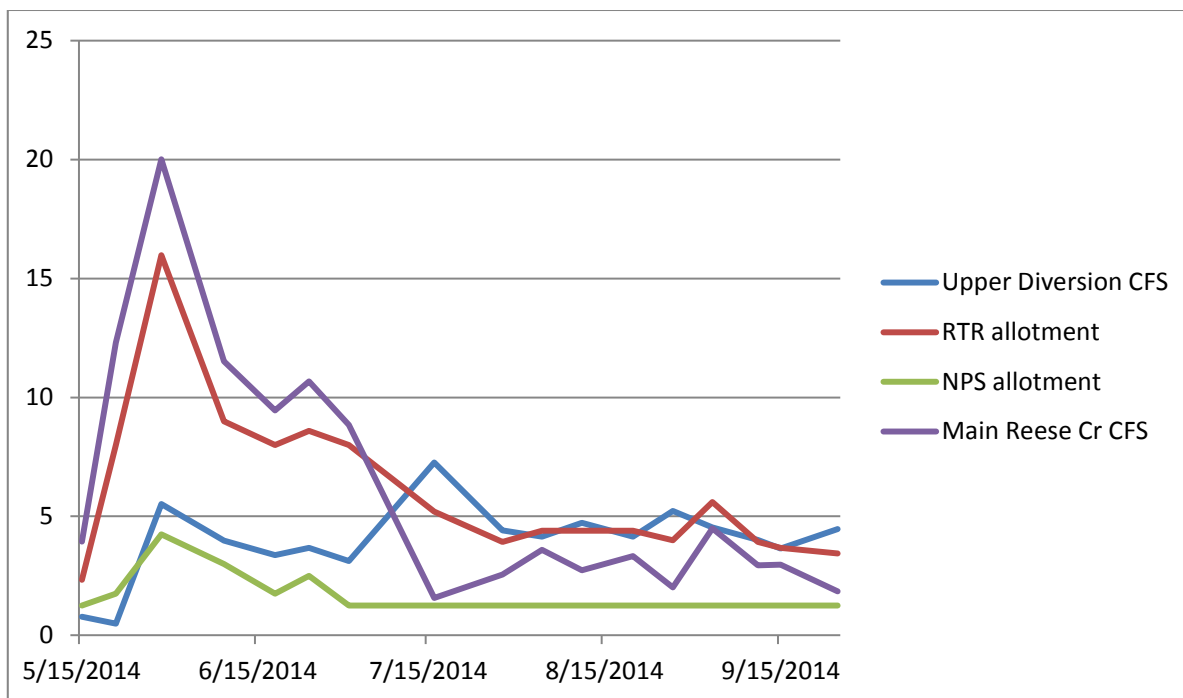


Figure C-2. 2014 Royal Teton Ranch (RTR) and National Park Service (NPS) allotments vs. actual flow. Upper Diversion represents the amount of water diverted from Reese Creek into the RTR irrigation ditch. Main Reese Cr. represents the total water remaining in Reese Creek below the RTR diversion. RTR allotment refers to the amount of water (cfs) allotted to the Royal Teton Ranch per the stipulated agreement. NPS allotment refers to the amount of water (cfs) allotted to the National Park Service per the stipulated agreement based on Upper Flume discharge rate.

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