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Natural Resource Stewardship and Science

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

## *Preliminary Analysis of 2015 Data*

Natural Resource Report NPS/GRYN/NRR—2017/1389

ON THE COVER
Sampling location on the Lamar River near Tower Ranger Station, WY - August 2015.
Photography by NPS

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

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# Contents

# Figures

# Tables

Page



# Appendices

Page

# Executive Summary

The Greater Yellowstone Inventory and Monitoring Network (GRYN I&M) is a National Park Service (NPS) program charged with monitoring ecological vital signs in four national park units in Wyoming, Montana, and Idaho. This report focuses on discharge and water quality monitoring efforts in the Lamar, Yellowstone, and Madison rivers in and surrounding Yellowstone National Park for calendar year 2015. Monitoring activities for Soda Butte Creek, a 303(d)-listed stream that is a tributary to the Lamar River, will be included in a separate report for calendar year 2015. Reese Creek, identified for impairment due to a fish-passage barrier, was monitored during 2015 and the monitoring report prepared by Yellowstone National Park is included as Appendix C.

Results for the Lamar, Yellowstone, and Madison rivers 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 and Yellowstone rivers are co-located with 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 and Yellowstone rivers are indicative of snow-melt driven systems while the hydrograph for the Madison River suggests greater contributions from groundwater. In 2015, flows were below the historic mean at each station for a majority of days. The daily flows at the Lamar and Yellowstone rivers were above the historic mean at peak flows and generally below historic average flows the remainder of the year. Daily flows at the Lamar River were above the historic average flows until early May but flows, including peak flows, for the remainder of the year were near or below the $25^{th}$ percentile of long-term flows.

## Water Quality Monitoring

Water quality at sampling locations exhibited seasonal variability over the sampling period. Across all sites, total arsenic, calcium, chloride, and sodium concentrations were generally at minimum levels during high flows. Total arsenic levels in the Madison River at West Yellowstone exceeded the state of Montana's chronic life criteria during all but one sampling occasion. Arsenic in the Madison River is likely naturally occurring from geothermal geology in the watershed. Other water quality results also suggest Madison River is receiving greater groundwater contributions relative to the other monitoring waters.

# Acknowledgments

The authors would like to acknowledge and thank the Yellowstone National Park and Greater Yellowstone Inventory & Monitoring staff for their logistical support and with reviews of prior versions of this report. Special thanks to Ann Rodman who has been extremely helpful and supportive of water monitoring in Yellowstone National Park. We would also like to thank Stacey Sigler and Sarah Haas for assistance with research permits, and Zach Wilson, Megan Podolinsky, and Ann Rodman for reviews of prior versions of this report.

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# Introduction

Yellowstone National Park was established in 1872 as America's 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. Over 170 million visitors have been recorded since 1904 with over 4 million visitors in 2015 alone (NPS 2016). The 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. 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 from 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 receive 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 minimum and maximum 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), wetland drying (Schook and Cooper 2014) and the associated impacts to wetland dependent species (McMenamin et al. 2008; Ray et al. 2016a), and changing river hydrographs (Leppi et al. 2012; Levandowski et al. 2016; Al-Chokhachy et al., 2017) are areas of active study characterizing responses to a changing climate.

Given the complexity of climate throughout Yellowstone National Park, we provide 2015 meteorological and 30-year climate 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 Millspaugh 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 km (2,500 mi) of streams and rivers, and ephemeral wetland habitats that alone make up roughly three percent of the landscape (NPS 2015b). Major lakes include Yellowstone, Shoshone, Lewis, and Heart lakes; smaller lakes are common and documented in Pierce (1987). Water has been monitored in Yellowstone National Park for over a century. For example, the U.S. Geological Survey 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

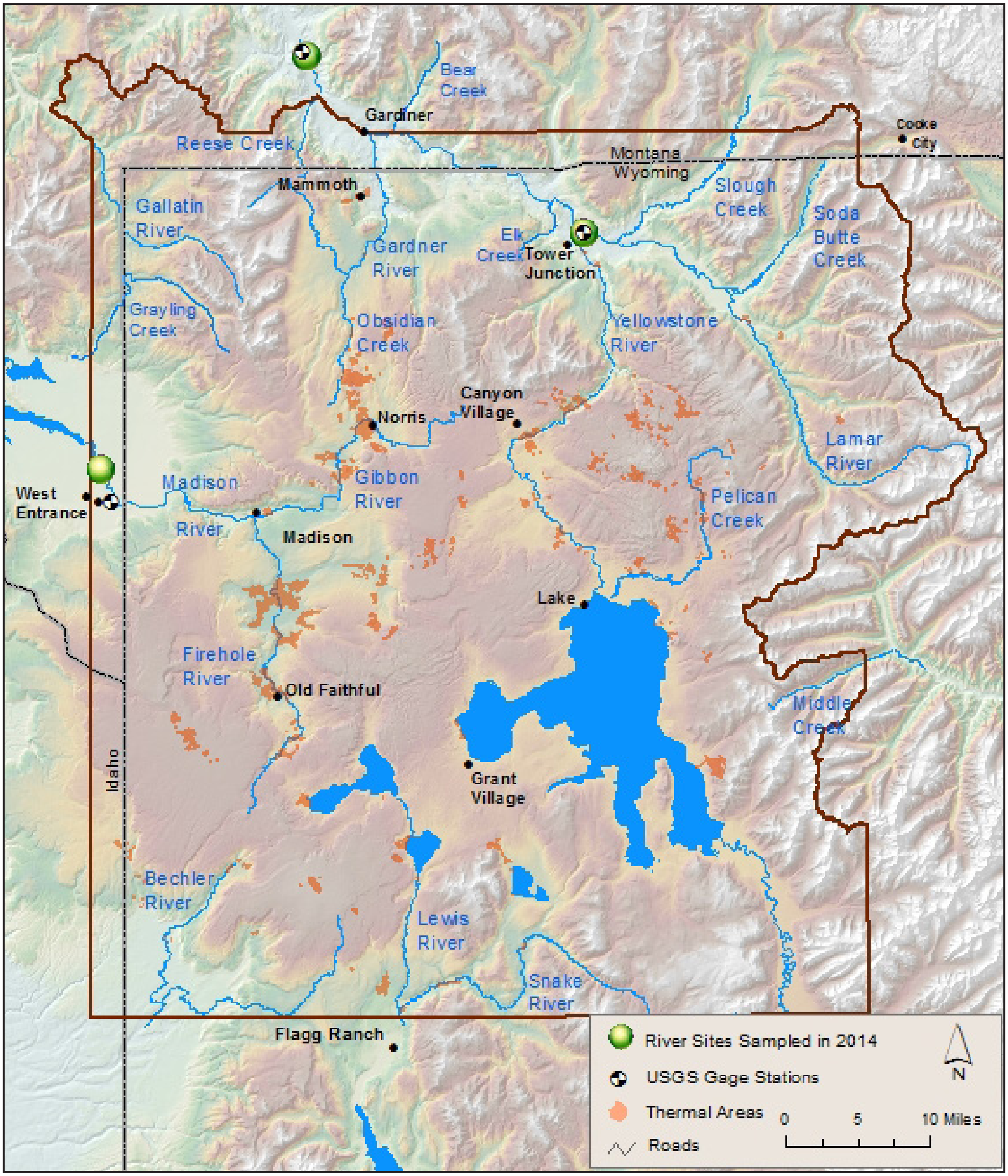



**Figure 1.** Water quality sampling locations and associated U.S. Geological Survey gaging stations in and surrounding Yellowstone National Park.

Pacific Ocean, the Gulf of California, and the Gulf of Mexico. These rivers, which include the Missouri and Columbia, provide essential water to the western and midwestern United States. The headwaters of the Lamar, Yellowstone, and Madison rivers are within the park boundaries or within neighboring protected areas and are minimally affected by human activities. Under the Clean Water Act, the surface waters in Yellowstone National Park are classified as Outstanding National Resource Waters. Additionally, these Outstanding National Resource Waters, 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 generally high, but the chemistry of these waters is nearly as varied as the geologic terrain. Water quality is based largely on the degree to which a water body is influenced by geothermal sources and by seasonal effects (i.e., snow-melt and runoff) that influence discharge patterns (NPS 2013). Total arsenic levels are high across Yellowstone National Park (Planer-Friedrich et al. 2007) and regularly exceeded the Montana chronic aquatic life criteria of 0.15 mg/L at the Madison River near West Yellowstone, MT in 2014 (Levandowski et al. 2016). These exceedances are likely natural in origin as the tributaries of the Madison River 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. Still, there are several anthropogenic threats to the water quality in Yellowstone National Park. In 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 (UNESCO 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 additional water quality threats in the Yellowstone Resources Handbook (NPS 2015b).

Waters are also threatened by various symptoms of the changing climate including changes in the hydrologic 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; Al-Chokhachy et al. 2017). 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 2015a). Temperature increase may trigger additional ecological changes including shifting biological communities and increased opportunities for the establishment of invasive species (Woodward et al. 2010). In 2016, a decision to close 294.5 km (183 mi) of the Yellowstone River downstream of the park occurred as a result of a documented large mountain whitefish (*Prosopium williamsoni*) die-off. This die-off and the subsequent closure may portend the novel threats facing water resources as record low flows combine with increasing air temperatures.

A number of aquatic invasive species have already been documented in waters within Yellowstone National Park. Whirling disease (*Myxobolus cerebralis*), New Zealand mud snail (*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 $m^2$), 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 and brook trout (*Salvelinus fontinalis*) are present in some tributaries and smaller lakes potentially 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; Krueger 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 or co-located with existing permanent USGS stream gaging stations because discharge readings can be used to develop rating curves that characterize the relationships between streamflow and water quality. At most USGS stations, long-term flow records are also available and provide an opportunity to describe annual and long-term patterns of streamflow, ice-cover, and timing of important hydrologic events (e.g., timing of peak and baseflows; see Levandowski et al. 2016). In Yellowstone, selected sites included the Lamar River near Tower Ranger Station, WY; the Yellowstone River at Corwin Springs, MT; the Madison River near West Yellowstone, MT; and Soda Butte Creek near Silvergate, MT; Soda Butte Creek work completed by the Greater Yellowstone Network in 2015 is not reported here. Reese Creek is also monitored collaboratively with Yellowstone National Park and reported separately (see Appendix C). Although these sites do not reflect all of the waters in the Yellowstone National Park, they do offer insight on some of 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. 2016b; Yoder et al. 2016). The rationale for testing nutrients and suspended solids can be found in the approved Greater Yellowstone Network Regulatory Water Quality Monitoring Protocol (O'Ney 2006).

### *Lamar River near Tower Ranger Station, WY*

The Lamar River is a major tributary of the Yellowstone River. Much of the Lamar River watershed is protected within the boundaries of Yellowstone National Park. Soda Butte Creek joins the Lamar River before connecting with the Yellowstone River. The Lamar River has no documented impairments; however, a tributary to the Lamar River (Soda Butte Creek) is one of only three current or formerly 303(d)-listed waters identified within the park. While Soda Butte Creek is monitored by the Greater Yellowstone Network, results from 2015 monitoring will be included in a separate report.

### *Yellowstone River at Corwin Springs, MT*

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 the 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, nitrate + nitrite as nitrogen (i.e., $NO_3$ + $NO_2$ as N), sediment, and arsenic levels that exceed drinking water standards. Both listed

**Photo.** River sampling at the Lamar 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 (NPS).

**Photo.** River sampling is accomplished with DH-95 suspension sampler with 1-L collection bottle lowered with a reel and bridge board during high flow conditions (Yellowstone River at Corwin Springs, MT; NPS).

segments of the Yellowstone River are upstream of the sampling location. The Yellowstone River at Corwin Springs, MT has historically had high arsenic levels. High levels of arsenic may be natural in origin and associated with geothermal influences (NPS 2013)

### *Madison River near West Yellowstone, MT*

The monitoring site for the Madison River 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 (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 2015 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 Montana water quality criteria (MTDEQ 2012) and Wyoming water quality criteria (WYDEQ 2013) to assess whether the Lamar, Yellowstone, and Madison rivers 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 (http://water.epa.gov/scitech/swguidance/standards/criteria/current/index.cfm). 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 National Park are classified as Outstanding Resource Waters (ORW) by Montana. Four stream segments on the northern border of Yellowstone National Park were formerly 303(d)-listed by MTDEQ: 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 Springs, MT was present 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, copper, and lead; 3) natural sources for ammonia, arsenic, copper, and nitrate + nitrite as nitrogen; 4) subsurface (hardrock) mining for arsenic, copper, and lead; 5) surface mining for arsenic, copper, and lead; 6) unknown sources for ammonia, un-ionized arsenic, copper, lead, and nitrate + nitrite as nitrogen (EPA 2014).

While not discussed in detail here, Soda Butte Creek is listed for copper, iron, lead, and manganese. Reese Creek was historically listed for dewatering/habitat modification. An 8.4-km (5.2 mi) segment of Reese Creek from the Wyoming border to the Yellowstone River was previously identified on Montana's 2000 and 2002 303(d)-lists (MTDEQ 2000, 2002). The 303(d)-list includes waters within Water Quality Assessment Category 5. Category 5 waters are those where the impairment of beneficial uses has been identified and a total maximum daily load (TMDL) is required to address those identified impairments or contributing factors. Since that time, Reese Creek has been moved to Water Quality Assessment Category 4C (MTDEQ 2016; Category 4C indicates that the identified threat or impairment (fish–passage barrier) is a result of habitat modification or hydrologic alteration – impairments due to pollution not caused by a pollutant). With its 4C categorical designation, a TMDL is not required to address the impairments in Reese Creek.

Recent guidance by the EPA on Water Quality Assessment Category 4C (EPA 2015) waters indicates that there is a growing need nationally to identify, understand, and restore waters where impairments are not caused by a pollutant (4C waters). EPA's justification for this recent shift in focus acknowledges that hydrologic alteration and habitat modification are significant threats to waters of the U.S. and that these alterations could interact with changing climatic conditions (e.g., increasing air temperatures) to further impair Reese Creek and other 4C waters. For this and other reasons, Yellowstone National Park scientists are working closely with private landowners, public land managers, partners, and water right holders in the Reese Creek watershed to document annual and seasonal flow patterns and discuss options to minimize the effects of hydrologic alteration particularly during periods of low flow when these effects exacerbate conditions (i.e., warm water temperatures) that are already stressful to aquatic life.

### *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, Yellowstone, and Madison rivers based on 2015 monitoring efforts.

# Methods

## River Sampling

We collected depth-integrated water samples monthly (Appendix B) between April and November 2015 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.

Under wadeable conditions, we used a DH-81 hand-held 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.

During non-wadeable flows at the Yellowstone and Madison rivers, samples were collected from a bridge using a bridge-board, reel, and DH-95 suspension sampler. A 1-L polypropylene bottle was used with the DH-95 sampler to collect river water. The vertical transit rate for the line suspension sampler was adjusted based on flows present to avoid overfilling the sampler when representing the entire stream depth. When full, the 1-L bottle was emptied into a polyethylene churn splitter.

Once full, the churn splitter was used to homogenize water collected from each cross-section. All laboratory-provided bottles used for shipping and laboratory analysis were filled from the churn. All water samples collected from the Lamar, Yellowstone, and Madison rivers were shipped overnight to Chemtech-Ford Laboratories in Sandy, UT or Energy Laboratories in Casper, WY and Billings, MT.

After sampling, all equipment is rinsed with distilled water to prevent contamination between samples. In brief, the 3-L (used with DH-81) and 1-L (used with DH-95) sample bottles, as well as the churn splitter, were triple-rinsed.

Replicate and blank samples were submitted along with ambient samples for field quality control. Replicates can be "sequential replicates" (samples taken one immediately after the other, separated only by the actual time required to fill the sample container) or "replicate splits" (subsamples drawn from the same initial volume of matrix [i.e., taken from the same churn splitter]). Field blanks are samples of blank matrix, certified inorganic free deionized water (CIFDW) provided by the laboratory, and prepared in the field under identical conditions, processed the same, and included for analysis as a regular sample. Field blanks are a quality control check to identify potential problems with water handling, bottle contamination, or other errors in the field.

In addition to water samples, we characterized core water quality parameters (i.e., temperature, specific conductivity, dissolved oxygen (DO), pH, and turbidity) *in situ* using a handheld multi-parameter instrument and a benchtop turbidimeter at a representative

**Photo.** Sampling at Madison River near West Yellowstone, MT is accomplished by wading during low flows (shown) or using a bridge board and reel during high flows (NPS ).

location on the river cross section. Collection of water samples and core parameters is described in the approved Greater Yellowstone Network Regulatory Water Quality Monitoring Protocol (O'Ney 2006).

All field and laboratory data are entered into NPSTORET, a database application developed and supported by the NPS Water Resource Division (WRD). After a final review by technical staff, the data are made available to WRD for approval. Upon approval from the WRD, these data are imported to the EPA National STORET (STOrage and RETrieval) Data Warehouse. Data from 2015 are anticipated to be available in EPA National STORET by late 2017. Data management is described in the approved Greater Yellowstone Regulatory Water Quality Monitoring Protocol (O'Ney 2006).

Discharge estimates for river sites were taken from USGS maintained stations for the Lamar River (USGS 06188000 near Tower Ranger Station, WY), Yellowstone River (USGS 06191500 at Corwin Springs, MT), and Madison River (USGS 06037500 near West Yellowstone, MT). Note that water sampling for the Madison River near West Yellowstone, MT was completed approximately 7 km (4.3 mi) downstream of the USGS gage to accommodate year round access. We used USGS records of daily discharge to summarize calendar year 2015 and long-term discharge metrics (e.g., date of peak discharge, total volume, and days with ice) for each monitoring station.

For comparative purposes, we also summarized calendar year 2015 and long-term discharge patterns for four additional rivers in the region (USGS 06191000 Gardner River near Mammoth, MT; USGS 13046995 Fall River at Yellowstone Canal near Squirrel, ID; USGS 06043500 Gallatin River near Gallatin Gateway, MT; and USGS 06207500 Clarks Fork Yellowstone River near Belfry, MT). These rivers were not selected randomly; rather they were selected for the following reasons: 1) the presence of a USGS gage and associated long-term discharge record, 2) their recognized regional importance to fish and wildlife, in-stream recreation, and downstream water users, and 3) their distinct physiographic settings. These rivers originate and the leave the park at distinct locations. For example, the Gardner River flows north, exiting the park's north boundary before joining the Yellowstone River near Gardiner, MT. In contrast, Fall River originates in the Bechler Region in Yellowstone's southwest corner and the Clarks Fork Yellowstone River flows east from its headwaters in the Beartooth Mountains just outside Yellowstone's northeast entrance.

# 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 or at the boundaries of 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 the Lamar River monitoring station and received a total of 43.0 cm (16.9 in) of precipitation in 2015. Approximately half of the annual precipitation (approx. 21.5 cm [8.5 in]) was delivered from August to December. The greatest amount of annual precipitation at Tower Falls, 19.3% (approx. 8.3 cm) occurred in May and the least amount, 1.6% (approx. 0.7 cm; Figure 2), in March. The long-term average (1948 to 2014) January maximum temperature is -4.1°C (25°F) with an average January minimum temperature of -17.4°C (0.6°F). The average long-term July maximum temperature is 24.3°C (76°F) with an average July minimum temperature of 2.6°C (36.7°F). The maximum temperature recorded at the Tower Falls COOP station was 36.7°C (98°F) in July 2002. The minimum temperature -45°C (-49°F) occurred in December 1964.

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, MT received 38.4 cm (15.1 in) of total precipitation in 2015. More than half of the annual precipitation in 2015 (approx. 22.1 cm [8.7 in]) was delivered from December to July. The greatest contribution to annual precipitation in 2015 at Mammoth, 20.1% (approx. 3.0 cm), occurred in May and the least amount, 2% (approx. 0.8 cm; Figure 3), in January. The long-term average (1894 to 1903, 1942 to 2014) January maximum temperature is 1.6°C (29.2°F) with an average January minimum temperature of -11.9°C (10.6°F). The long-term average (1894 to 1903, 1942 to 2014) July maximum temperature is 26.7°C (80.1°F) with an average July minimum temperature of 8.5°C (47.3°F). The maximum temperature recorded at the Mammoth COOP station was 37.2°C (99°F) in July 2002. The minimum temperature -37.2°C (-36°F) occurred in the month of January in 1951 and 1963, respectively.

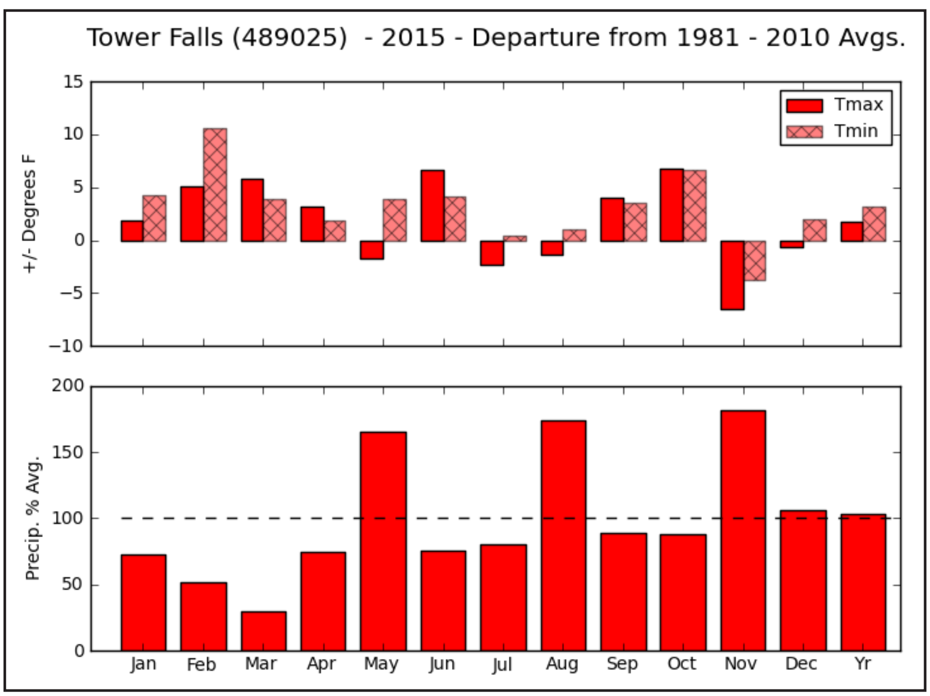



**Figure 2.** Calendar year 2015 monthly temperature (maximum and minimum) and precipitation summaries for the Tower Falls COOP station 489025 (elevation 1910 m) approximately 4 km from the Lamar River monitoring site. Monthly and year-end departures from the 30-year average are shown.

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 a total of 61.0 cm (24 in) of precipitation in 2015. Nearly 40% of annual precipitation (29.2 cm [11.5 in]) was delivered in three months (May, November, and December. The greatest amount of annual precipitation at West Yellowstone, MT 19.2% (approx. 11.7 cm), occurred

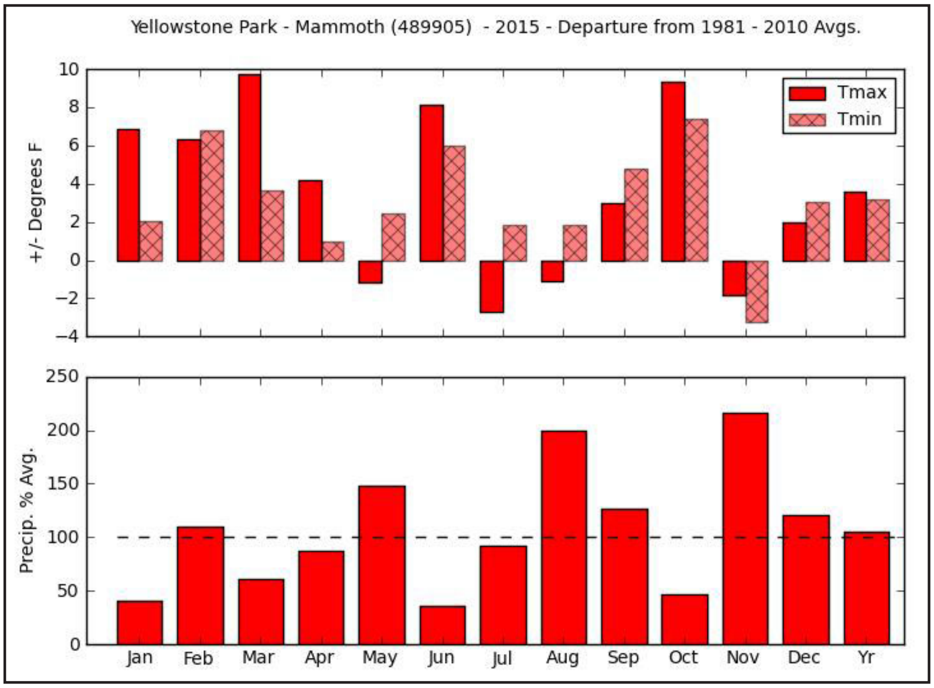



**Figure 3.** Calendar year 2015 monthly temperature (maximum and minimum) and precipitation summaries for the Yellowstone Park Mammoth COOP station 489905 (elevation 1899 m) approximately 17 km from the Yellowstone River monitoring site. Monthly and year-end departures from the 30-year average are shown.

in May and the least amount, 2.1% (approx. 1.27 cm), in March. The long-term average (1998 to 2014) January maximum temperature is -0.8°C (30.5°F) with an average January minimum temperature of -14.8°C (5.3°F). The long-term average July maximum temperature is 26.8°C (80.3°F) with an average July minimum temperature of 4.8°C (40.6°F). The maximum temperature recorded at the West Yellowstone SNOTEL station was 35°C (95°F) in July 2002, August 2003, and October 2003. The minimum temperature at this station was -43.3°C (-46°F) and occurred in December 1998.

### *2015 Temperature and Precipitation*

Temperatures in 2015 were above the 30-year averages (1981 to 2010) at all three monitoring locations. At the Lamar River (summarized using the Tower Falls COOP station; Figure 2), the average annual maximum temperature was approximately 1.1°C [2°F] above the 30-year average, and the average annual minimum temperature was nearly 3°C (5.4°F) above the long-term average. At Yellowstone River (summarized using the Mammoth COOP station; Figure 3), the average annual maximum temperature was approximately 1.6°C [3°F] above the 30-year average, and the average annual minimum temperature was approximately 1.8°C [3.2°F] above the 30-year average. At Madison River (summarized using the Old Faithful COOP station; Figure 4), the average annual maximum temperature was approximately 1.4°C [2.6°F] above the 30-year average. The average annual minimum temperature at Madison River was also above the 30-year average (approximately 1.3°C [2.4°F]).

Total annual precipitation in 2015 was similar to the 30-year average at stations near all three monitoring locations. A disproportionate amount of precipitation fell in November relative to the long-term record (over 175% of 30-year average) at the Tower Falls and Mammoth COOP stations. The greatest precipitation departure from long-term average occurred at Mammoth in November (over 200% of 30-year-average). Additionally, above-average precipitation was recorded at Tower Falls in May, at the Mammoth COOP station in February, May, August, September, and December and at Old Faithful in May, July, August, and September.

The high relative temperatures in February and March at Lamar River (Figure 2) and Yellowstone River (Figure 3) are notable. Hydrographs at all three sampling locations demonstrate earlier runoff; it is likely that warmer winter temperatures (e.g., February 2015 minimum temperatures at Tower Ranger Station were nearly 6°C [>10°F] higher than the 30-year average) contributed to this pattern. Peak flows also occurred earlier than the historic peak flows at all three monitoring locations (Figure 5). The 2015 peak flows are lower than the historic average at the Yellowstone and Madison rivers.

### *Discharge*

Discharge is reported for the calendar year 2015. Hydrographs for monitored rivers within Yellowstone National Park exhibited a general pattern of an early

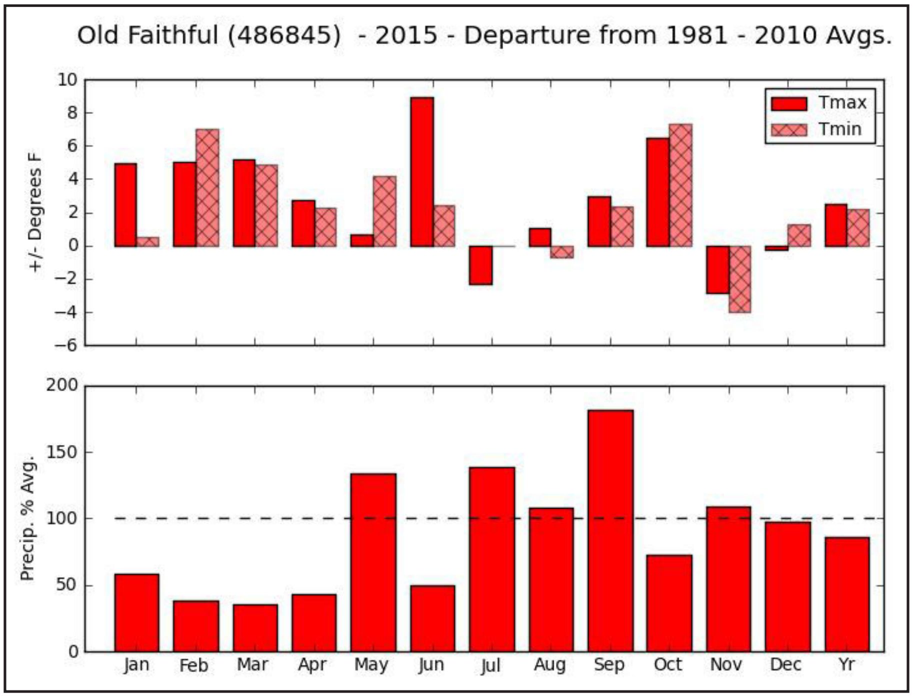



**Figure 4.** Calendar year 2015 monthly temperature (maximum and minimum) and precipitation summaries for the Old Faithful COOP station 486845 (elevation 2243 m) approximately 35 km from the Madison River monitoring site. Monthly and year-end departures from the 30-year average are shown.

runoff period relative to historic flows followed by a more prominent early summer peak (Figure 5). In addition, the onset of baseflows occurred several days earlier than the long-term average and extended into fall and winter (Figure 5).

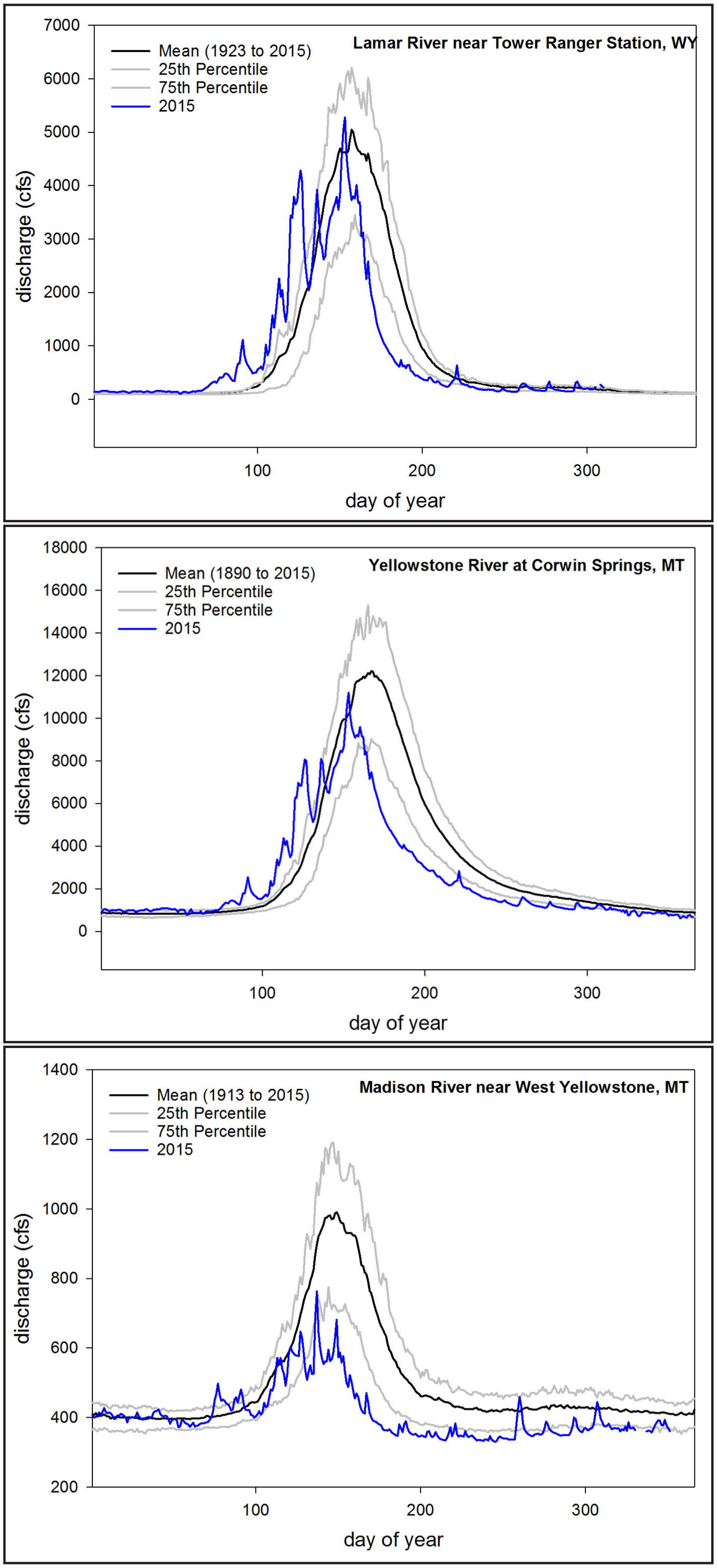
Peak discharge at the Lamar River in 2015 was 5,280 cubic feet per second (cfs) and occurred on June 2nd (153th day of the year). This peak flow is 2,910 cfs lower than the long-term average (from 1923 to 1968 and 1989 to 2014, the average peak discharge was 8,190 cfs) and ranked 2015 as 67th highest out of 73 years of available records (note, years 1969 to 1984 are missing from record with partial data sets from 1985 to 1988). The long-term average peak flow at the Lamar River typically occurred on June 3rd (154th day of the year). In 2015, the date of peak flow was similar to the long-term average (June 2nd), but the hydrograph in 2015 shows flows increasing in late February and early March. These late winter increases in flow coincide with above average air temperatures in February and March (Figure 2) that likely contributed to earlier melting and the subsequent onset of runoff compared with the historic average. Total volume of flow was similar in 2015 compared with the long-term average, however, there were 26 fewer days of estimated ice cover in 2015 compared to the long-term average of 142 days (Table 1). Note that days of estimated ice cover are retrieved from USGS estimations and data shown are considered provisional.

Similar to the Lamar River, flow in the Yellowstone River is characteristic of a snow-driven system (Figure 5). In the Yellowstone River at Corwin Springs, MT, peak flows historically occurred at the beginning of June, coinciding with snowmelt at higher elevations; high seasonal flows typically persist from April through June. Runoff flows in the Yellowstone River began earlier and were, on average, lower in 2015 than the long-term average (1890 to 1892, 1911 to 2014) and were below the 25th percentile of flows for this station 173 days of the year. These flows at the Yellowstone River monitoring site ranked 96th highest out of 109 annual records (note that years 1894 to 1909 are missing from the record with partial data sets in 1893 and 1910). The peak flow in 2015 was 11,200 cfs and occurred on June 2nd (153th day of the year), 7 days earlier and >5,000 cfs lower than the long-term average of 16,875 cfs. The total volume of flow in the Yellowstone River was 19.7 billion cubic feet lower than the long-term average. Ice cover in

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

| Discharge Metric | Mean for Period of Record (1923 to 1968, 1989 to 2014) | 2015 |
|---|---|---|
| Day of year of peak discharge (calendar date) | 154 (June 3) | 153 (June 2) |
| Total volume (in billions $ft^3$) | 27.5 | 24.3 |
| Days with ice ** | 142 (1989 to 2014) | 116 |

**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. Discharge metrics for additional river sites in the region are included as Appendix D.




2015 had 13 fewer days of ice 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). The long-term (1913 to 1973, 1989 to 2014) peak flows at the Madison River monitoring site averaged 1,325 cfs and typically occurred on May 25$^{th}$ (145$^{th}$ day of the year; Table 3). In 2015, peak discharge was 763 cfs and occurred 8 days earlier on May 17$^{th}$ (137$^{th}$ day of the year). In 2015, peak discharge ranked 88$^{th}$ highest out of the 93 years of available annual records (note, years 1975 to 1987 are missing from record with partial data sets in 1974 and 1988). Daily flows in the Madison River near West Yellowstone, MT in 2015 were generally at or below the 25th percentile of long-term daily flows. The total volume of flow in the Madison River in 2015 was 57.5% of the long-term average. There were two fewer days with ice cover than the long-term average (18 days with ice on average from 1989 to 2014; Table 3).

Although there is considerable among-year variation, peak flows in the Lamar River are, on average, increasing 300 cfs per decade and the timing of peak flows is occurring approximately 1 day earlier

**Figure 5.** Summary of average daily discharge (in cfs) in the Lamar River near Tower Ranger Station, WY (USGS 06188000); Yellowstone River 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$^{st}$ of each calendar year. The periods of record for these gages are 1923 to 2015 at the Lamar River, 1890 to 2015 at the Yellowstone River, and 1913 to 2015 at the Madison River. Mean daily discharge for the period of record is shown in black and the 25$^{th}$ and 75$^{th}$ percentiles of daily discharge are shown in grey. A summary of 2015 (blue) is also presented.

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

| Discharge Metric | Mean for Period of Record (1890 to 1892, 1911 to 2014) | 2015 |
|---|---|---|
| Day of year of peak discharge (calendar date) | 160 (June 9) | 153 (June 2) |
| Total volume (in billions $ft^3$) | 98.5 | 78.8 |
| Days with ice ** | 18 (1986 to 2014) | 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. Discharge metrics for additional river sites in the region are included as Appendix D.

**Table 3.** Summary of discharge metrics for the Madison River at West Yellowstone, MT (USGS 06037500).

| Discharge Metric | Mean for Period of Record (1913 to 1973, 1989 to 2014) | 2015 |
|---|---|---|
| Day of year of peak discharge (calendar date) | 145 (May 25) | 137 (May 17) |
| Total volume (in billions $ft^3$) | 15.0 | 12.8 |
| Days with ice ** | 18 (1989 to 2014) | 16 |

**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. Discharge metrics for additional river sites in the region are included as Appendix D.

per decade (Figure 6). 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.

Patterns of earlier peak flows and lower annual flow volumes were also apparent at four additional rivers in the region (USGS 06191000 Gardner River near Mammoth, MT; USGS 13046995 Fall River at Yellowstone Canal near Squirrel, ID; USGS 06043500 Gallatin River near Gallatin Gateway, MT; and USGS 06207500 Clarks Fork Yellowstone River near Belfry, MT) See Appendix D for 2015 and long-term discharge summaries from these four gages.

### *Water Chemistry*

#### Nutrients and Suspended Solids

In 2015, water chemistry at the Lamar, Yellowstone, and Madison rivers monitoring locations were indicative of high water quality with low levels of dissolved nutrients. Nitrogen and phosphorus were low at all monitoring sites and non-detectable results predominated for ammonia-nitrogen ($NH_3$), nitrate + nitrite as nitrogen ($NO_3 + NO_2$ as N), and ortho-phosphorus (ortho-P; Figure7). Note that two different labs were used for chemical analysis during the 2015 season;

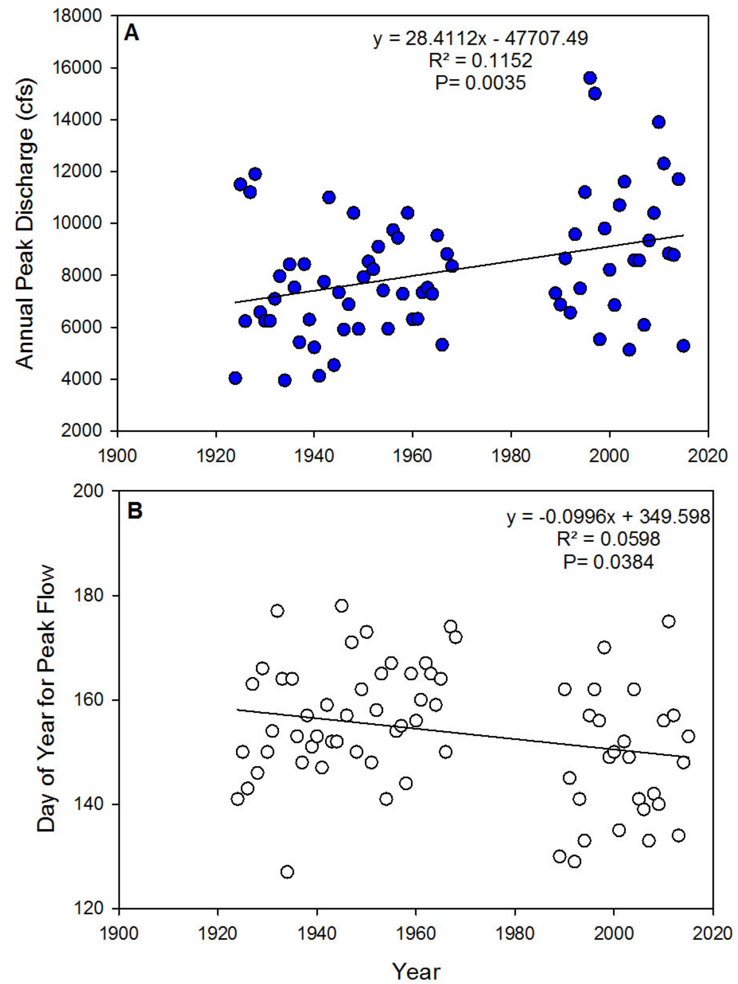



**Figure 6.** Summary of annual peak discharge and date of peak discharge at the Lamar River monitoring site near Tower Ranger Station, WY (USGS 06188000). At this location, the magnitude of peak flow has increased from 1924 to 2015 (A) and the date of peak flow is occurring 1 day sooner every decade (B).

Chemtech Ford Laboratories (Sandy, UT) completed analysis from April to October 2015 and Energy Laboratories (Casper, WY and Billings, MT) completed analysis in October and November 2015. Because of this transition, laboratory splits were included in our monitoring at two sites in October 2015.

In 2015, water chemistry in the Lamar River contained relatively low levels of dissolved nutrients. Ammonia-nitrogen was below detection levels at all sampling occasions. $NO_3$ + $NO_2$ as N levels were below detection levels for all sampling events. Ortho-phosphorus levels ranged from non-detectable results to 0.04 mg/L. Total phosphorus (total P) and total suspended solids (TSS) varied through the sampling season (see Table B-1, Appendix B). Total P ranged from 0.03 to 0.08 mg/L and TSS ranged from <4 mg/L to 23 mg/L; both constituents had maximum levels recorded in October (Figures 8A and 8E). These high levels during the October sampling likely coincided with a 1.5 cm (0.59 in) rain event that occurred two days prior to the October 22nd sampling visit.

Water chemistry in the Yellowstone River contained low levels of dissolved nutrients. Ammonia-nitrogen was below detection levels on all sampling occasions except on November 19th, 2015 when a concentration of 0.09 mg/L was detected. $NO_3$ + $NO_2$ as N levels were below detection levels except in June, September, October, and November when $NO_3$ + $NO_2$ as N was between 0.1 and 0.3 mg/L. Ortho-phosphorus was low (ranging from 0.01 to 0.03 mg/L) when detected. Total P and TSS did not exhibit a strong relationship with discharge, however, both tended to be higher with higher flows. TSS concentrations were highest during the July 9th sampling and total P concentrations were at annual maxima on April 28th and May 26th (see Table B-2, Appendix B).

The Madison River also contained low levels of dissolved nitrogen. Ammonia-nitrogen and nitrate + nitrite as nitrogen levels were below detection levels on all sampling occasions. In contrast, ortho-phosphorus levels were detectable during all sampling events and levels ranged from 0.02 to 0.1 mg/L; ortho-phosphorus levels showed no apparent trend with discharge. The patterns at Madison River for total P differed from the Yellowstone River and the Lamar River. Total P increased with decreasing discharge and the highest concentration of total P in the Madison River occurred during the August 24th and October 15th, 2015 sampling dates. Between April and September 2015, TSS levels in the Madison River ranged from 4 to 8 mg/L. The highest levels of TSS occurred during the May 15th sampling event.

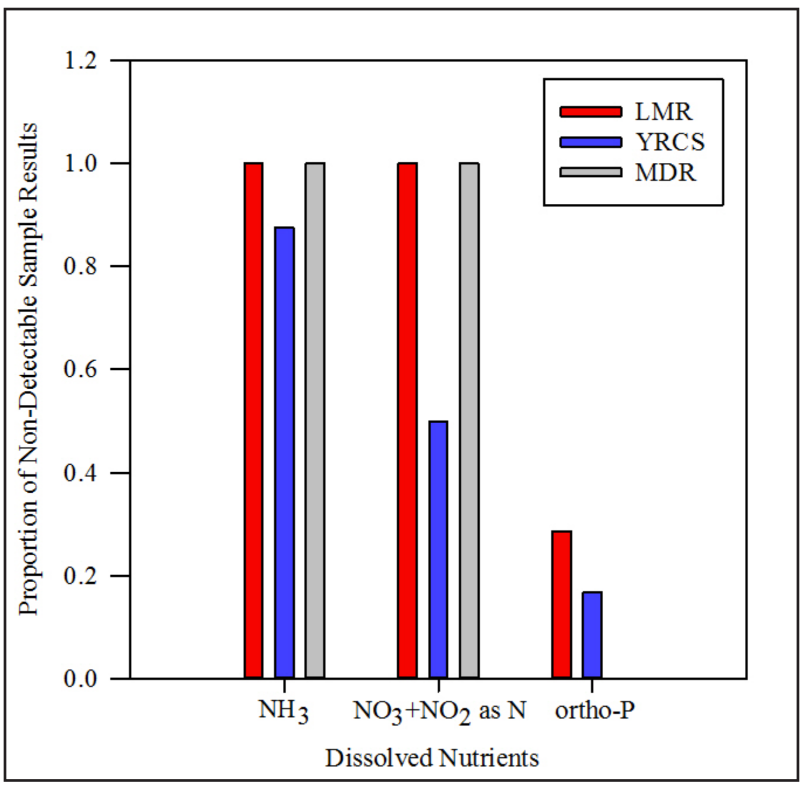



**Figure 7.** Proportion of monthly nutrient samples collected in 2015 from Lamar River (LMR), Yellowstone River at Corwin Springs (YRCS), Madison River (MDR) monitoring stations that produced non-detectable levels for ammonia (NH3), nitrate + nitrite as nitrogen (NO3 + NO2 as N), and ortho-phosphorus (ortho-P). A complete summary of water quality results are provided in Appendix B.

## Trace Metals

Trace metals (i.e., arsenic, zinc, mercury, lead) have been detected in the 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 2015. Additionally, total arsenic, sodium, and calcium (Figures

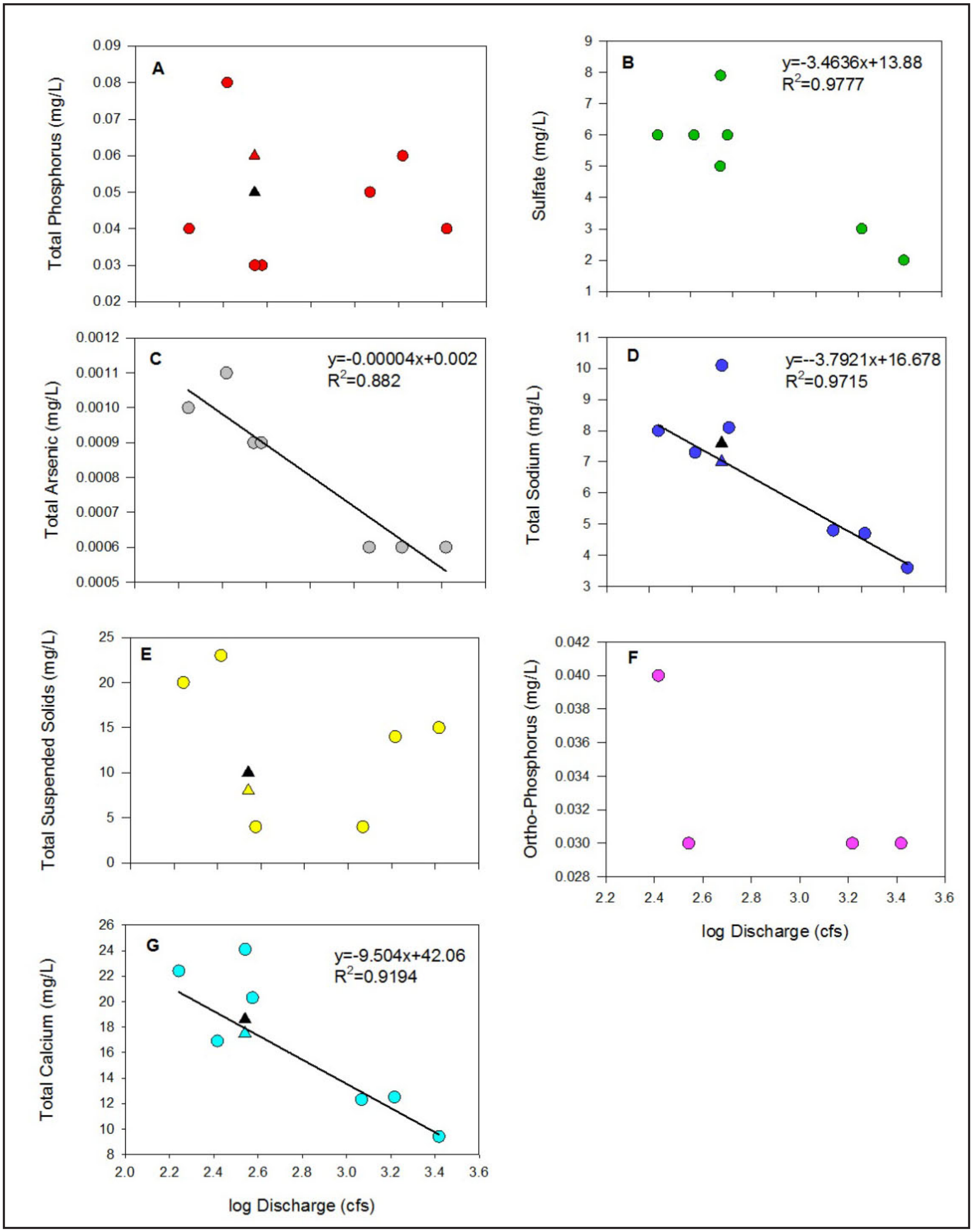



**Figure 8.** Rating curves show the relationship between log-transformed discharge and total phosphorus (8A), sulfate (8B), total arsenic (8C), total sodium (8D), total suspended solids (8E), ortho-phosphorus (8F), and total calcium (8G) at the Lamar River (USGS 06188000) sampling location. Duplicate results that differ from the original sample are represented with black triangles, the corresponding original sample is represented with a colored triangle.

8C, 8D, and 8G) 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, MT reveals an inverse relationship with arsenic and discharge (Figure 9D). Similarly, sulfate, sodium, and calcium levels generally declined as discharge increased.

Surface water from the Madison River near West Yellowstone, MT exceeded the State of Montana's chronic aquatic life criteria (0.15 mg/L; Appendix A) for total arsenic during all sampling events. 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 the Madison River monitoring station did not reveal any strong relationships between trace metals and discharge.

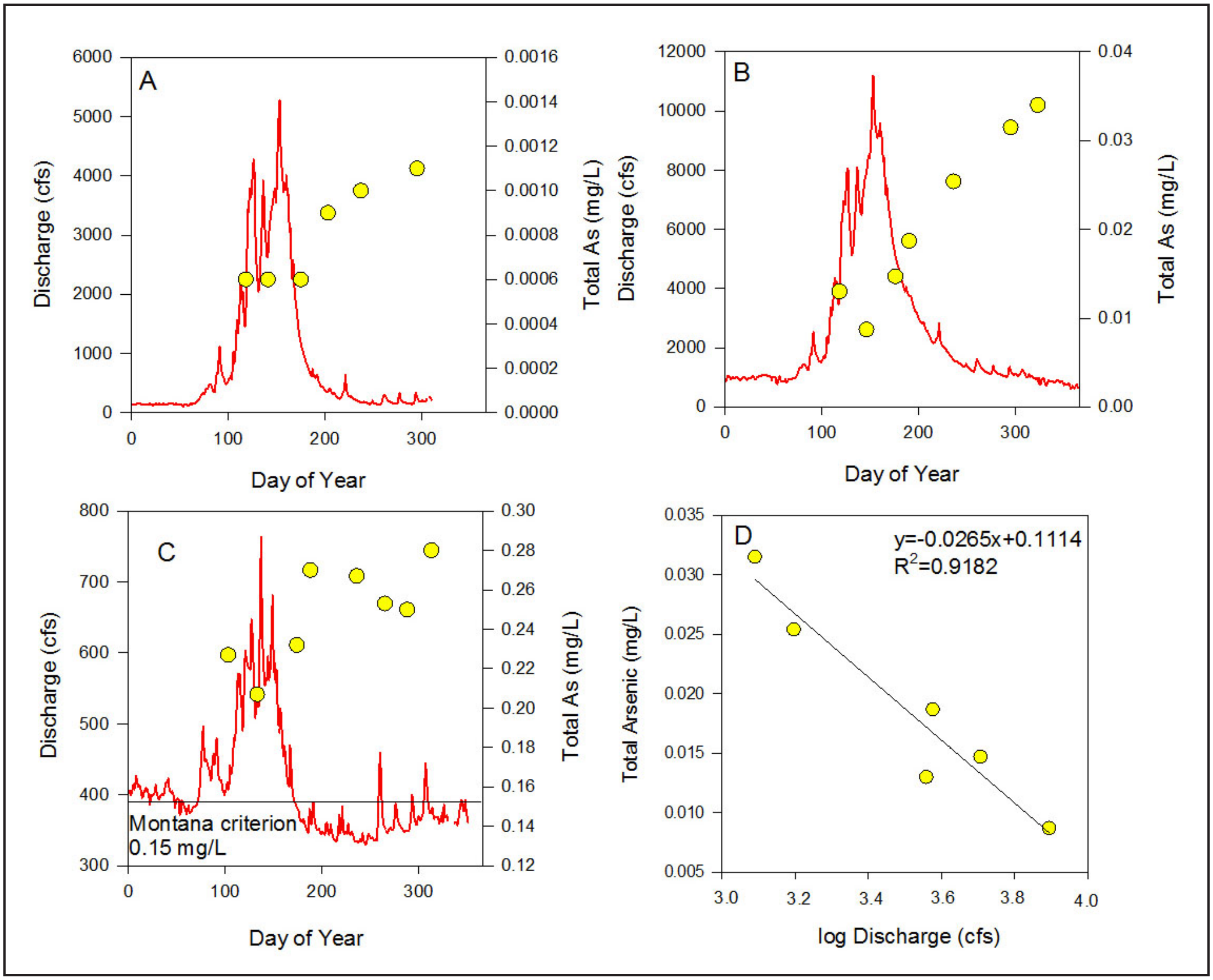



**Figure 9.** Daily discharge (in cfs; solid red line) in the Lamar (9A; USGS 06188000), Yellowstone (9B; USGS 06191500) and Madison (9C; USGS 06037500) rivers. Also shown are concentrations of total arsenic (yellow circles) summarized from water collected during monthly sampling events. The Montana chronic aquatic life criterion (same criterion for Wyoming; 0.15 mg/L) is represented by the solid black line in 9C. The rating curve of total arsenic for the Yellowstone River (9D) shows an inverse relationship between arsenic and 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 visitor recreational experiences and their perceptual evaluations of natural features (*sensu* Burmil et al. 1999) within NPS units. 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 the NPS including Yellowstone National Park. During the 2015 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 precipitation and snowpack 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 2015, peak flows in the Madison River were 1.7 times baseflow levels. In contrast, the Lamar River ranged between 5,280 cfs in early May to 100 cfs on February 22nd indicating peak flows were 52.8 times higher than baseflows. In the Yellowstone River, peak flows were approximately 18 times higher than baseflows in 2015; flows ranged from 11,200 cfs in early May to 612 cfs in late December.

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 National Park's rivers, shifts in the timing and magnitude of peak flows have already been detected (Figure 6). The Lamar River has shown a significant shift over the period of record with the magnitude of peak flows increasing and the date of peak flow occurring earlier. Compared with other rivers in the region (Gallatin River, Fall River, Gardner River, and Clarks Fork Yellowstone River) it is apparent that long-term hydrologic shifts are occurring across study sites. For the other rivers, we documented a general decrease in the total volume and earlier peak flows, however, the slope varied between sites.

Not unexpectedly, water quality in Yellowstone National Park'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 and exceeded the Montana chronic aquatic life criterion (0.15 mg/L) on all but one sampling occasion. 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, however, still below the Montana chronic aquatic life criterion.

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

[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*.'

Madison River, dissolved and total phosphorus levels were highest in August and October when baseflow conditions occurred, though levels were relatively consistent across monitoring occasions. These levels support the conclusion that phosphorus-rich groundwater is contributing disproportionately to phosphorus levels in the Madison River (Gardner et al. 2010).

Water quality in Yellowstone National Park exhibited the greatest variability during high flows (May 2015). For example, sulfate, sodium, and arsenic levels were generally lower in the Lamar and Yellowstone rivers during high flows relative to other times sampled. Total suspended solids (TSS) and total phosphorus (total P) levels were highest during high flows in the Yellowstone River. These seasonal patterns for total P and TSS were less clear in the Lamar and Madison rivers during 2015 and may have been obscured by the relatively variable, and sometimes flashy, flow patterns documented for these two rivers in 2015.

Currently, the WYDEQ and MTDEQ have no standard for primary nutrients in our focal systems (see WYDEQ 2013 and MTDEQ 2012). The Yellowstone River at Corwin Springs, MT is below the numeric nutrient criterion for lower portions of the Yellowstone River downstream of the monitoring site (0.655 mg/L TN and 0.055 mg/L total P; MTDEQ 2014). 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 2015 suggests that monitored resources are meeting state and federal water quality criteria for most constituents. Based on the 2015 monitoring results summarized in 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.
- Continued exploration of discharge summaries to characterize long-term discharge trends in the Lamar, Yellowstone, and Madison rivers, as well as, other gage rivers in the region.
- Use of large river sampling equipment for sampling the Yellowstone and Madison rivers during non-wadeable flows.
- 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), Montana DEQ, and Wyoming DEQ Water Quality Criteria

**Table A-1.** Environmental Protection Agency (EPA), Montana DEQ, and Wyoming DEQ Water Quality Criteria

| Parameter | 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 (2013)[e] |
|---|---|---|---|---|---|
| **Ammonia** | Acute criteria/pH and temperature dependent; one-hour[f] and 30-day[g] criterion 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; from pH 6.5–9.0, acute values for $NH_3$-N plus NH4-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[f] and continuous concentrations[g] are shown below. |
| **Arsenic** | Freshwater (Acute) = 340 µg/L<br>Freshwater (Chronic) = 150 µg/L<br>Human Health consumption of water plus organism = 0.018 µg/L<br>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.<br>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 |

**Table A-1 (continued).** Environmental Protection Agency (EPA), Montana DEQ, and Wyoming DEQ Water Quality Criteria

| Parameter | 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 (2013)[e] |
|---|---|---|---|---|---|
| **Chloride** | Freshwater (Acute) = 860,000 µg/L<br>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)[h] 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 = 3.79 µg/L at 25 mg/L hardness (12) Aquatic Life Standard/ Chronic = 2.85 µg/L at 25 mg/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, cold water 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, cold water criteria, the water column concentration recommended to achieve inter-gravel DO concentration/1-day minimum = 4,000 µg/L. | For early life stages, cold water 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.<br>For other life stages, cold water 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, cold water 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).<br>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, cold water 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, cold water criteria, the water column concentration recommended to achieve inter-gravel DO concentration/ 1-day minimum = 4.0 mg/L. |

**Table A-1 (continued).** Environmental Protection Agency (EPA), Montana DEQ, and Wyoming DEQ Water Quality Criteria

| Parameter | 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 (2013)[e] |
|---|---|---|---|---|---|
| **Nitrate + Nitrite as Nitrogen** | not found | Domestic water supplies = 10,000 µg/L | 40 µg/L[i] | Nitrate + Nitrite as Nitrogen is recognized as a 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[i] | 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).<br>Yellowstone Plateau (17j) Ecoregion: 0.03 mg/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 (continued).** Environmental Protection Agency (EPA), Montana DEQ, and Wyoming DEQ Water Quality Criteria

| Parameter | 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 (2013)[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* (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 1ºF maximum increase above naturally occurring water temperature is allowed within the range of 32ºF to 66ºF; within the naturally occurring range of 66ºF to 66.5ºF, no discharge is allowed which will cause the water temperature to exceed 67ºF; and where the naturally occurring water temperature is 66.5ºF or greater, the maximum allowable increase in water temperature is 0.5ºF. A 2ºF per-hour maximum decrease below naturally occurring water temperature is allowed when the water temperature is above 55ºF. A 2ºF per-hour maximum decrease below naturally occurring water temperature is llowed when the water temperature is above 55ºF. | 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 60ºF 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 discharged in amounts which will result in an increase of more than 2º (1.1ºC) in existing temperatures. |

**Table A-1 (continued).** Environmental Protection Agency (EPA), Montana DEQ, and Wyoming DEQ Water Quality Criteria

| Parameter | 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 (2013)[e] |
|---|---|---|---|---|---|
| **Water Temperature, cont.** | | | — | 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) 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 discharged in amounts which will result in an increase of more than 4°F (2.2°C) in existing temperatures.<br>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 |

[a]Source: Environmental Protection Agency (EPA). 2012. National recommended water quality criteria. U.S. EPA, Office of Water, Washington, D.C. Available from http://water.epa.gov/scitech/swguidance/standards/criteria/current/index.cfm.

[b]Source: Environmental Protection Agency (EPA). 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.

[c]Source: 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.

[d]Source: Montana Department of Environmental Quality (MTDEQ). 2012. Montana numeric water quality standards. Circular DEQ-7. Montana DEQ, Planning, Prevention, and Assistance Division, Helena, Montana.

[e]Source: Wyoming Department of Environmental Quality (WYDEQ). 2013. Water quality rules and regulations. Chapter 1 in Water Quality Division rules and regulations. Available at https://www.epa.gov/sites/production/files/2014-12/documents/wy-chapter1.pdf.

[f]One-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))

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

hSource: Environmental Protection Agency (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.

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

# Appendix B: 2015 Laboratory Results from Monthly Monitoring of the Lamar, Yellowstone, and Madison Rivers

The following tables present laboratory results and core field parameters for three river monitoring sites: Lamar River (Tables B-1 and B-2), Yellowstone River (Tables B-3 and B-4), and Madison River (Tables B-5 and B-6). Water sample results were produced by ChemTech Ford Laboratory in Sandy, UT and Energy Laboratory in Billlings, MT and Casper, WY. Total hardness as $CaCO_3$ = water hardness as calcium carbonate, ammonia as N = $NH_3$ - N, nitrate + nitrite as nitrogen = $NO_3$ + $NO_2$ as N (total content of N associated with nitrate and nitrite), ortho-P = ortho phosphate, total P = total phosphorus, sulfate = $SO_4$, TSS = total suspended sediment, As = arsenic, Ca = calcium, Mg = magnesium, K = potassium, Na = sodium, Cu = copper, Fe = iron, Pb = Lead, Mn = Manganese, Se = selenium, Zn = Zinc, '-' = missing values, "ND" = Non-detect (below detection levels).

**Table B-1.** Monthly water quality lab results for Lamar River near Tower Ranger Station, WY. All values presented are in mg/L. Columns with dark shading represent "duplicate" samples (same date), "blank" samples using certified inorganic free deionized water, or "laboratory split" (one sample sent to each lab from the same date) as indicated by the header.

| Analyte | 28-Apr | 21-May | 24-June | 22-July (Duplicate) | | 25-Aug (Blank) | | 22-Sept | 22-Oct | 22-Oct[a] (Laboratory Split) | 19-Nov[a] |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Total Hardness as $CaCO_3$ | 49 | 38 | 49 | 78 | 73 | 90 | ND | 84 | 74.5 | 81 | 94 |
| Ammonia as N | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND[b] |
| Chloride | ND | ND | ND | ND | ND | ND | ND | ND | ND | 0.9 | 1.1 |
| Nitrate+Nitrite as Nitrogen | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND[b] |
| Ortho-P | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | ND | ND | ND | 0.04 | ND | -- |
| Total P | 0.06 | 0.04 | 0.05 | 0.06 | 0.05 | 0.04 | ND | 0.03 | 0.08 | 0.11 | 0.03 |
| Sulfate | 3 | 2 | 3 | 5 | 5 | 6 | ND | 6 | 6 | 6.5 | 7.9 |
| TSS | 14 | 15 | 4 | 8 | 10 | 20 | ND | 4 | 23 | 73[b] | ND |
| Dissolved As | 0.0005 | 0.0005 | 0.0005 | 0.0009 | 0.0009 | 0.0009 | ND | 0.0008 | 0.0008 | ND | ND |
| Total As | 0.0006 | 0.0006 | 0.0006 | 0.0009 | 0.0009 | 0.001 | ND | 0.0009 | 0.0011 | ND | ND |
| Dissolved Ca | 11.8 | 9.0 | 11.2 | 17.4 | 17.1 | 20.4 | ND | 20.5 | 16.7 | 20.3 | 24.2 |
| Total Ca | 12.5 | 9.4 | 12.3 | 18.6 | 17.5 | 22.4 | ND | 20.3 | 16.9 | 19.3 | 24.1 |
| Dissolved Mg | 4.4 | 3.0 | 4.0 | 6.3 | 6.2 | 7.9 | ND | 8.1 | 6.5 | 7.24 | 8.22[b] |
| Total Mg | 4.3 | 3.4 | 4.5 | 7.6 | 7.2 | 8.2 | ND | 8.1 | 7.8 | 8.11 | 8.49 |
| Dissolved K | 0.8 | 0.6 | 0.9 | 1.6 | 1.5 | 1.6 | ND | 1.6 | 1.3 | 1.5 | 1.6[b] |
| Total K | 1.3 | 0.6 | 1.1 | 1.6 | 1.5 | 1.7 | ND | 1.5 | 1.5 | 1.82 | 1.74 |
| Dissolved Na | 4.3 | 3.6 | 4.3 | 7.3 | 7.1 | 7.9 | ND | 8.0 | 7.0 | 7.7 | 9.5[b] |
| Total Na | 4.7 | 3.6 | 4.8 | 7.6 | 7.0 | 8.0 | ND | 8.1 | 7.3 | 8.4 | 10.1 |

[a]Energy Laboratory

[b]Suspect value needs review

**Table B-2.** Monthly core field parameters for Lamar River near Tower Ranger Station, WY. All values presented are in mg/L.

| Field Parameter | 28-Apr | 21-May | 24-June | 22-July | 25-Aug | 22-Sept | 22-Oct | 19-Nov |
|---|---|---|---|---|---|---|---|---|
| Water Temp. | 7.0 | 7.0 | 14.0 | 15.4 | 13.51 | 11.1 | 6.03 | 0.02 |
| Specific Conductance | 110.4 | 91 | 108.3 | 92.2 | 208.1 | 206.3 | 180.4 | 226.9 |
| pH | -- | 8.38 | 8.21 | 8.38 | 8.43 | 8.44 | 8.9 | 8.17 |
| Dissolved Oxygen | 8.37 | 9.44 | 7.81 | 7.81 | 9.29 | 10.33 | 10.44 | 11.19 |
| Turbidity | 9.71 | 5.91 | 5.21 | 10.5 | 2.0 | 2.17 | 18.6 | 1.9 |

**Table B-3.** Monthly water quality lab results for Yellowstone River at Corwin Springs, MT. All values presented are in mg/L. Columns with dark gray shading and labeled in the header represent "laboratory split" (one sample sent to each lab from the same date).

| Analyte | 28-Apr | 26-May | 25-June | 9-July | 24-Aug | 22-Sept | 22-Oct | 22-Oct[a] Laboratory Split) | 19-Nov |
|---|---|---|---|---|---|---|---|---|---|
| Total hardness as $CaCO_3$ | 48 | 35 | 37 | 40 | 55 | 60.9 | 65.7 | 70[b] | 73[b] |
| Ammonia as N | ND | ND | ND | ND | ND | ND | ND | ND | 0.09** |
| Chloride | 5 | 3 | 5 | 6 | 10 | 11 | 11 | 11.9 | 13.7 |
| Nitrate+Nitrite as Nitrogen | ND | ND | 0.3 | ND | ND | 0.1 | 0.2 | 0.2[b] | 0.2[b] |
| Ortho-P | 0.02 | 0.03 | 0.02 | 0.01 | ND | 0.01 | 0.03 | -- | -- |
| Total P | 0.05 | 0.05 | 0.04 | 0.04 | 0.03 | 0.03 | 0.04 | 0.03 | 0.02 |
| Sulfate | 14 | 8 | 11 | 15 | 24 | 29 | 30 | 31.6 | 35.6 |
| TSS | 11 | 20 | 6 | 18 | ND | 4 | 7 | 8 | 2 |
| Dissolved As | 0.0107 | 0.0073 | 0.0135 | 0.0162 | 0.0244 | 0.0266 | 0.0245 | 0.027 | 0.031 |
| Total As | 0.0130 | 0.0087 | 0.0147 | 0.0187 | 0.0254 | 0.0289 | 0.0315 | 0.029 | 0.034 |
| Dissolved Ca | 12.8 | 8.8 | 8.7 | 9.1 | 11.9 | 15.3 | 15.6 | 18.3[b] | 19.0[b] |
| Total Ca | 12.8 | 9.0 | 9.0 | 9.5 | 13.7 | 15.1 | 16.2 | 17.1 | 19.1 |
| Dissolved Mg | 4.5 | 2.8 | 3.3 | 3.3 | 4.4 | 5.7 | 5.7 | 5.97[b] | 6.25[b] |
| Total Mg | 4.0 | 3.1 | 3.5 | 3.9 | 5.1 | 5.6 | 6.1 | 5.87 | 6.14 |
| Dissolved K | 2.4 | 1.6 | 2.2 | 2.3 | 3.5 | 4.3 | 4.4 | 4.7[b] | 5.3[b] |
| Total K | 2.9 | 1.8 | 2.4 | 2.8 | 4.0 | 4.2 | 4.6 | 4.9 | 5.6 |
| Dissolved Na | 10.5 | 7.0 | 10.0 | 11.2 | 16.5 | 19.3 | 19.2 | 20.9[b] | 23.6[b] |
| Total Na | 9.4 | 7.1 | 10.3 | 12.2 | 17.8 | 18.5 | 20.1 | 22.1 | 24.6 |

[a]Energy Laboratory

[b]Suspect value needs review

**Table B-4.** Monthly core field parameters for Yellowstone River at Corwin Springs, MT. All values presented are in mg/L.

| Field Parameter | 28-Apr | 26-May | 25-June | 9-July | 24-Aug | 22-Sept | 22-Oct | 19-Nov |
|---|---|---|---|---|---|---|---|---|
| Water Temp. | 8.8 | 8.86 | 17.2 | 18.4 | 18.52 | 16.09 | 10.4 | 2.05 |
| Specific Conductance | 151.4 | 103 | 130.3 | 145.4 | 210 | 235.23 | 237.5 | 272.8 |
| pH | -- | 8.11 | 7.92 | 8.78 | 8.97 | 8.82 | 9.38 | 8.69 |
| Dissolved Oxygen | 8.77 | 10.71 | 7.4 | 7.15 | 11.07 | 11.43 | 9.6 | 13.67 |
| Turbidity | 7.15 | 8.54 | 4.39 | 9.63 | 2.93 | 2.03 | 3.24 | 2.3 |

**Table B-5.** Monthly water quality lab results for Madison River near West Yellowstone, MT. All values presented are in mg/L. Columns with dark gray shading and labeled in the header represent "duplicate" samples (same date).

| Analyte | 13-Apr | 13-May | 23-June | 7-July | 24-Aug | 24-Aug (Duplicate) | 22-Sept | 22-Sept (Duplicate) | 15-Oct | 15-Oct (Duplicate) | 9-Nov[a] |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Total Hardness as $CaCO_3$ | 18 | 16 | 19 | 20 | 20 | 19 | 19.3 | 18.6 | 19.1 | 18.7 | 21 |
| Ammonia as N | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND[b] |
| Chloride | 53 | 45 | 51 | 55 | 57 | 57 | 54 | 54 | 57 | 57 | 62.3 |
| Nitrate+Nitrite as Nitrogen | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND[b] |
| Ortho-P | 0.03 | 0.02 | 0.05 | 0.05 | 0.10 | 0.10 | 0.02 | 0.03 | 0.09 | 0.09 | -- |
| Total P | 0.09 | 0.10 | 0.11 | 0.11 | 0.12 | 0.12 | 0.11 | 0.11 | 0.12 | 0.12 | 0.02 |
| Sulfate | 13 | 12 | 11 | 13 | 12 | 12 | 13 | 13 | 13 | 13 | 15.0 |
| TSS | 5 | 8 | 4 | 5 | ND | ND | 4 | ND | ND | ND | 219[b] |
| Dissolved As | 0.219 | 0.196 | 0.240 | 0.243 | 0.267 | 0.261 | 0.255 | 0.243 | 0.262 | 0.272 | 0.26 |
| Total As | 0.227 | 0.207 | 0.232 | 0.270 | 0.267 | 0.277 | 0.253 | 0.246 | 0.250 | 0.263 | 0.28 |
| Dissolved Ca | 5.4 | 5.0 | 6.2 | 6.2 | 6.4 | 6.1 | 6.8 | 6.6 | 6.4 | 6.4 | 7.0[b] |
| Total Ca | 5.7 | 5.1 | 6.1 | 6.5 | 6.4 | 6.3 | 6.3 | 6.0 | 6.2 | 6.1 | 7.4 |
| Dissolved Mg | 0.7 | 0.7 | 0.9 | 0.8 | 0.8 | 0.8 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9[b] |
| Total Mg | 0.8 | 0.8 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.8 | 0.9 | 0.8 | 1.0 |
| Dissolved K | 7.6 | 6.8 | 8.2 | 8.1 | 9.2 | 8.5 | 9.2 | 9.1 | 8.6 | 8.5 | 9.2[b] |
| Total K | 8.3 | 6.7 | 7.8 | 8.8 | 9.1 | 9.0 | 8.5 | 7.9 | 9.0 | 9.0 | 9.8 |
| Dissolved Na | 77.3 | 65.7 | 81.6 | 80.2 | 84.7 | 81.7 | 86.8 | 84.6 | 86.0 | 86.4 | 94.8[b] |
| Total Na | 81.7 | 64.3 | 79.5 | 85.3 | 90.4 | 90.1 | 81.7 | 79.2 | 92.6 | 82.7 | 96.4 |
| Dissolved Cu | -- | ND | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Total Cu | -- | ND | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Dissolved Fe | -- | 0.10 | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Total Fe | -- | 0.25 | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Dissolved Pb | -- | ND | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Total Pb | -- | ND | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Dissolved Mn | -- | 0.008 | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Total Mn | -- | 0.031 | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Dissolved Se | -- | 0.0008 | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Total Se | -- | 0.0013 | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Dissolved Zn | -- | ND | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Total Zn | -- | ND | -- | -- | -- | -- | -- | -- | -- | -- | -- |

[a]Energy Laboratory

[b]Suspect value needs review

**Table B-6.** Monthly core field parameters for Madison River near West Yellowstone, MT. All values presented are in mg/L.

| Parameter | 13-Apr | 13-May | 23-June | 7-July | 24-Aug | 22-Sept | 15-Oct | 9-Nov |
|---|---|---|---|---|---|---|---|---|
| Water Temp. | 11.2 | 13.2 | 16.3 | 19.0 | 12.91 | 11.95 | 10.03 | 4.86 |
| Specific Conductance | 462.4 | 391.8 | 420.3 | 369.1 | 472.8 | 741.8 | 485.8 | 488.0 |
| pH | -- | -- | 8.21 | 8.17 | 8.24 | 8.09 | 8.3 | 7.95 |
| Dissolved Oxygen | 9.63 | 7.54 | 6.95 | 6.65 | 8.91 | 8.62 | 10.37 | 9.74 |
| Turbidity | 3.11 | 2.80 | 2.09 | 1.77 | 0.5 | 0.5 | 0.4 | 1.3 |

# Appendix C: Reese Creek Monitoring Report

## Reese Creek Flow and Water Use Monitoring

Yellowstone National Park, 2015

Brian Teets, North District Resource Operations

### *Introduction*

In 2015, 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.

### *2015 ACTIVITIES*

Yellowstone National Park field personnel measured stream flows in Reese Creek approximately once per week from May 21, 2015 until September 21, 2015. 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 ½ to ¾ 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 2015 irrigation season, the USFS periodically diverted their water rights. Measurements were not taken by NPS staff at the USFS diversion.

Un-diverted main stem discharge at the upper site reached its peak on June 1, 2015 at 14.28 cubic feet per second (cfs). By the end of July, discharge in Reese Creek had leveled off, averaging 7.26 cfs for the remainder of the irrigation season. The lowest recorded stream flow was 3.88 cfs taken on August 20, 2015.

During the irrigation season of 2015, these water rights were not met on three occasions. The RTR exceeded their allotment on eight occasions; however these events only resulted in the NPS water flow becoming lower than their allotment on three occasions.

The details of these events are outlined below:

**July 30, 2015:**

- Upper Flume - 5.678cfs
- Lower Flume (RTR ditch) – 4.81cfs
- Remaining water in stream (NPS) - 0.87cfs

Allotments based on 2006 stipulated agreement at 5.70 cfs:

- NPS - 1.25 cfs
- USFS - 0.76 cfs
- CUT - 3.02 cfs
- Mikolich - 0.25 cfs
- Hotchkiss (Beede) - 0.42 cfs

**August 20, 2015:**

- Upper Flume – 3.88 cfs
- Lower Flume (RTR ditch) – 3.58 cfs
- Remaining water in stream (NPS) - 0.30 cfs

Allotments based on 2006 stipulated agreement at 3.90 cfs:

- NPS - 1.25 cfs
- USFS - 0.45 cfs
- CUT – 1.79 cfs
- Mikolich - 0.25 cfs
- Hotchkiss (Beede) - 0.16 cfs

**September 3, 2015:**

- Upper Flume – 4.59 cfs
- Lower Flume (RTR ditch) – 3.38 cfs
- Remaining water in stream (NPS) – 1.21 cfs* (*not reported to RTR)

Allotments based on 2006 stipulated agreement at 4.60 cfs:

- NPS - 1.25 cfs
- USFS - 0.57 cfs
- CUT – 2.27 cfs
- Mikolich - 0.25 cfs
- Hotchkiss (Beede) - 0.26 cfs

In each instance where the RTR was significantly overdrawing (July 30, 2015 and August 20, 2015) Ann Rodman (NPS) was notified and contacted the RTR representative and they reduced their take. North District Resource Ops staff did not take action on the September 3, 2015 overdraw event as the amount of water overdrawn was within the accepted margin of error of our measuring equipment. It should also be noted that the solar powered fish barrier installed just above the upper diversion continues to be out of order. 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.

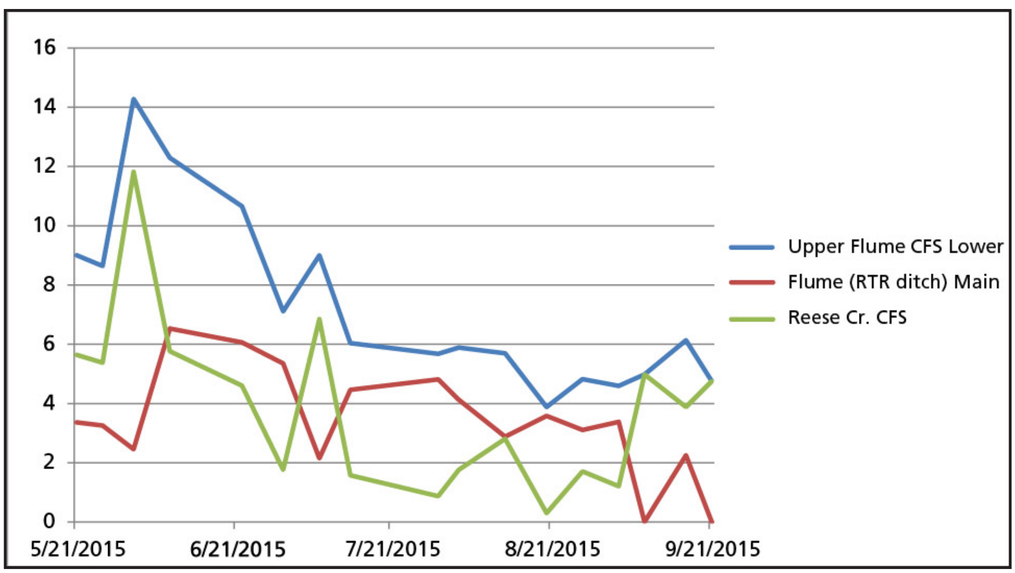


**Figure C-1.** 2015 Reese Creek stream flow measurements. Upper Flume CFS represents the stream flow of Reese Creek above all diversions. Lower Flume represents the amount of water diverted from Reese Creek into the RTR irrigation ditch. Main Reese Cr. represents the total water remaining in Reese Creek below the RTR diversion.

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 2015 and found it to be in good working order.

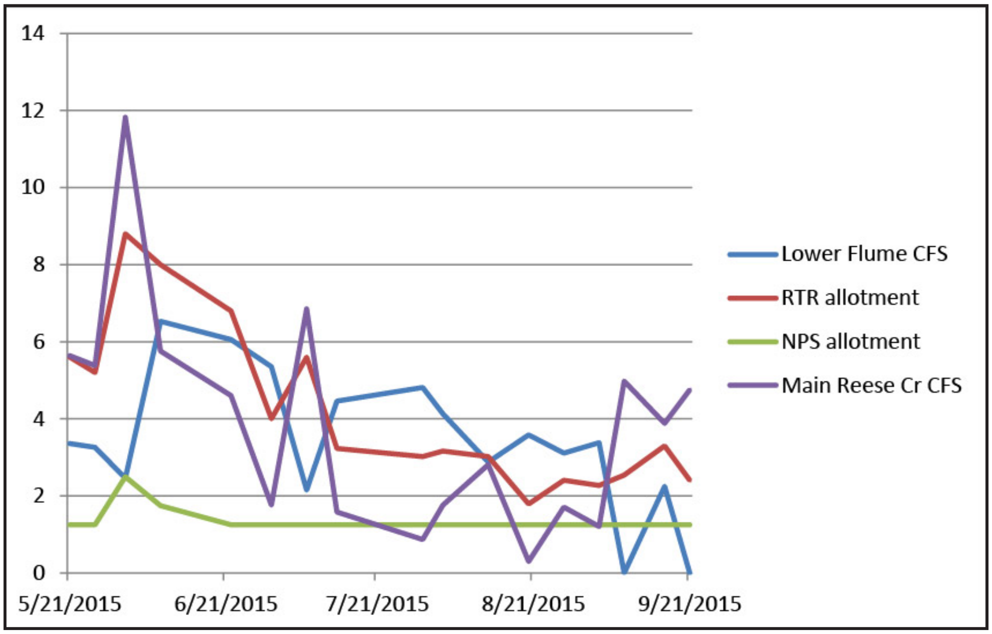


**Figure C-2.** 2015 RTR and NPS allotments vs. actual flow. Lower Flume represents the amount of water diverted from Reese Creek into the RTR irrigation ditch. Main Reese Cr. represents the total water remaining in Reese Creek below the RTR diversion. RTR allotment refers to the amount of water (CFS) 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.

# Appendix D: Discharge Summaries of Regional Rivers

**Table D-1.** Summary of discharge metrics for the Gardner River near Mammoth, WY (USGS 06191000).

| Discharge Metric | Mean for Period of Record (1938 to 2014) | 2015 |
|---|---|---|
| Day of year of peak discharge (calendar date) | 158 (June 4) | 153 (June 2) |
| Total volume (in billions $ft^3$) | 6.6 | 4.8 |
| Days with ice ** | 3.5 (1984 - 2014) | 2 |

**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 D-2.** Summary of discharge metrics for the Fall River at Yellowstone Canal near Squirrel, ID (USGS 13046995).

| Discharge Metric | Mean for Period of Record (1993 to 2014) | 2015 |
|---|---|---|
| Day of year of peak discharge (calendar date) | 154 (June 3) | 137 (May 17) |
| Total volume (in billions $ft^3$) | 26.7 | 19.2 |
| Days with ice ** | 83 | 32 |

**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 D-3.** Summary of discharge metrics for the Gallatin River near Gallatin Gateway, MT (USGS 06043500).

| Discharge Metric | Mean for Period of Record (1930 to 1981, 1985 to 2014) | 2015 |
|---|---|---|
| Day of year of peak discharge (calendar date) | 158 (June 7) | 152 (June 1) |
| Total volume (in billions $ft^3$) | 25.0 | 20.6 |
| Days with ice ** | 15 (1988 - 2014) | 4 |

**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 D-4.** Summary of discharge metrics for the Clarks Fork Yellowstone River near Belfry, MT (USGS 6207500).

| Discharge Metric | Mean for Period of Record (1921 to 2014) | 2015 |
|---|---|---|
| Day of year of peak discharge (calendar date) | 162 (June 11) | 162 (June 11) |
| Total volume (in billions $ft^3$) | 29.3 | 27.6 |
| Days with ice ** | 28 (1986 -2014) | 12 |

**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.

The Department of the Interior protects and manages the nation's natural resources and cultural heritage; provides scientific and other information about those resources; and honors its special responsibilities to American Indians, Alaska Natives, and affiliated Island Communities.

NPS 101/136266, February 2017

**National Park Service**
**U.S. Department of the Interior**

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