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Natural Resource Stewardship and Science

Water Quality Summary for the Snake River and Alpine Lakes in Grand Teton National Park and the John D. Rockefeller, Jr. Memorial Parkway

Preliminary Analysis of 2013 Data

Natural Resource Report NPS/GRYN/NRR—2016/1228

ON THE COVER
Depth and width integrated sampling in the Snake River at Moose—April 2014

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

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

Data in this report were collected and analyzed using established methods based on peer-reviewed U.S. Geological Survey and National Park Service protocols and interpreted relative to relevant water quality standards. This report received informal and formal peer review by subject-matter experts who were not directly involved in the collection, analysis, or reporting of the data, and whose background and expertise put them on par technically and scientifically with the authors of the information.

This report is available from the Greater Yellowstone Network website (http://science.nature.nps.gov/im/units/gryn/), and the Natural Resource Publications Management website (http://www.nature.nps.gov/publications/nrpm/) on the Internet. To receive this report in a format optimized for screen readers, please email irma@nps.gov.

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Executive Summary

This report summarizes discharge and water quality monitoring data for the Snake River and water quality monitoring data for representative alpine lakes in Grand Teton National Park and the John D. Rockefeller, Jr. Memorial Parkway for calendar year 2013. Results presented include annual and long-term discharge summaries and an evaluation of chemical conditions relative to state and federal water quality standards. These results are considered provisional, and therefore may be subject to change.

River discharge. Hydrographs for the Snake River at Flagg Ranch and Moose exhibit a general pattern of high early summer flows and lower baseflows occurring in late summer. During much of 2013, flows at the Flagg Ranch monitoring location were similar to the 25th percentile of daily flows at that site. Peak flows were higher (similar to the 75th percentile), occurred earlier in the year compared to the long-term average, but quickly dropped below long-term average flows. Daily flows at the Moose monitoring station were similar to average daily mean flows. During summer months, the unnatural hydrograph at Moose exhibited signs of flow regulation associated with the management of Jackson Lake.

Water quality monitoring in the Snake River. Water quality in the Snake River exhibited seasonal variability over the sampling period. Specifically, total iron peaked during high flows. In contrast, chloride, sulfate, dissolved sodium, total magnesium, and total calcium levels were at their annual minimum during runoff. During peak flows, total iron levels exceeded the Wyoming Chronic Aquatic Life Criterion for total recoverable iron.

Water quality monitoring of alpine lakes. Water quality in three monitored lakes (Amphitheater, Delta, and Surprise Lakes) varied by lake and sampling date. Amphitheater Lake had total nitrogen and total phosphorus levels below the EPA reference condition for the Middle Rockies Ecoregion. Delta Lake had the highest total nitrogen and total phosphorus levels and exceeded EPA reference condition criteria for these nutrients. Detectable levels of ammonium were documented in Amphitheater Lake during the July sampling.

Acknowledgments

The authors would like to acknowledge and thank the Grand Teton National Park and Greater Yellowstone Inventory and Monitoring staff for their logistical support and with reviews of prior versions of this report. Special thanks to Sue Consolo-Murphy, who has been extremely helpful and supportive of water monitoring in Grand Teton National Park and John D. Rockefeller, Jr. Memorial Parkway. We thank Mary Levandowski and Kristin Legg for comments on earlier versions of this manuscript.

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Field work was completed by Grand Teton National Park staff. Laboratory work was conducted by Chemtech-Ford Laboratories in Sandy, Utah, and the Kiowa Environmental Chemistry Laboratory, University of Colorado, Boulder, Colorado.

Introduction

Grand Teton National Park (Fig. 1) encompasses 133,547 ha (330,000 acres) located in western Wyoming. The park was created in 1929 to "protect the scenic and geological values of the Teton Range and Jackson Hole, and to perpetuate the Park's indigenous plant and animal life" (NPS 1995). Grand Teton NP also administers the 9,622 ha (23,776 acres; included in acreage estimate above) John D. Rockefeller, Jr. Memorial Parkway, established in 1972 to honor the contributions of its namesake to the conservation movement.

Grand Teton NP is famous for its topography, including 12 peaks above 3,660 m (12,000 ft), which developed along the north–south Teton Fault. Subsequent glacial activity further sculpted the Teton Range, and perennial glaciers and ice fields occupy some protected recesses within the range. Approximately 10% of Grand Teton NP is covered by surface water. The park contains more than 100 alpine lakes, with surface areas ranging from 0.5 to 24 ha (1 to 60 acres), and many above 2,743 m (9,000 ft) in elevation. Surface and groundwater in the park ultimately connect with the Snake River. Jackson Lake Dam is operated by the Bureau of Reclamation, which retains exclusive control of the flow and use of water in Jackson Lake, except water reserved for Snake River fisheries (280 cfs minimum; O'Ney and Gipson 2006). The National Park Service (NPS) and Wyoming Game and Fish Department cooperatively manage fisheries within the park. Several lakes are stocked with native cutthroat trout (*Oncorhynchus clarkii*) as part of a sport fisheries program, but the stocking of Jackson Lake with nonnative lake trout (*Salvelinus namaycush*) ceased in 2006 to help facilitate natural lake processes.

The climate at Grand Teton NP varies from north to south and from its high peaks to it sagebrush flats. Near the Flagg Ranch, WY, and Moose, WY, monitoring sites, climate is classified as high elevation continental climate, with warm, dry summers (Dsb—Köppen Climate Classification System). The climate is strongly influenced by the Teton Range and to a lesser extent by the Absaroka Range to the east (particularly in the northern regions of the park). These ranges receive disproportionately more precipitation than other regions of the park, with much of it delivered as snow. The Teton Range also creates a rain shadow effect at lower elevations.

The Snake River, WY, COOP weather station (elevation 2098 m), located near Flagg Ranch on the boundary between John D. Rockefeller, Jr. Memorial Parkway and Yellowstone National Park, receives >50% (approx. 42 cm) of annual moisture between November and March. Historically, the greatest amount of precipitation at Flagg Ranch came in December and January and the least amount came in August and September (Fig. 2). Average (1981 to 2010) January maximum and minimum temperatures are -2.8 °C (27.0 °F) and -18.1 °C (-0.62 °F). Average (1981 to 2010) July maximum and minimum temperatures are 24.9 °C (76.8 °F) and 3.1 °C (37.6 °F). The maximum temperature recorded at this station was 36 °C (97 °F) in July 1951. The minimum temperature of -43 °C (-46 °F) occurred in December 1978.

At the Moose, WY, COOP station (elevation 1964 m), located near Grand Teton NP headquarters, approximately 50% (28 cm) of annual moisture is delivered between November and March (Fig. 3). Historically, August was the driest month, contributing only 5.9% (3.2 cm) of the annual precipitation. Average (1981 to 2010) January maximum and minimum temperatures are -3.2 °C (26.2 °F) and -17.6 °C (0.3 °F). Average (1981 to 2010) July maximum and minimum temperatures are 26.8 °C (80.2 °F) and 5.5 °C (41.9 °F). The maximum temperature recorded at this station was 36 °C (97 °F) in July 2002 and August 2003. The minimum temperature of -43 °C (-46 °F) occurred in January 1979.

Overview of Grand Teton NP Water Resources

Nearly three million people visit Grand Teton NP each year (2.7 million in 2013; NPS 2015). Visitors are drawn to the park's stunning mountain scenery, wilderness lakes, and abundant wildlife. Surface water resources (including Jackson Lake, numerous high alpine lakes, and the Snake River and tributary streams) provide visitors with exceptional opportunities to enjoy their recreational and aesthetic qualities. Focused studies (Woods and Corbin 2003; Clark et al. 2004; Clark et al. 2007) indicate that the park's surface waters are of outstanding quality. Fishing in the Snake River is considered unrivaled, and for this reason, the upper Snake River has been considered a destination for native cutthroat trout (Snake River fine spotted cutthroat trout; *O. clarkii behnkei*) by anglers and enthusiasts (Ostresh et al. 1990). In fact, river reaches above Jackson Hole, Wyoming, are estimated to support more than 95,000 angler-days per year (Loomis 2006). Part of the appeal of this location is the presence of a morphologically distinct population of native cutthroat trout (Gresswell 2011); this native salmonid occupies cold, high quality, and upper elevation mainstem reaches and tributaries of the upper Snake River (Harper and Farag 2004). These uppermost reaches of the Snake River in Wyoming are

Figure 1. Water quality sampling locations for Grand Teton National Park and John D. Rockefeller, Jr. Memorial Parkway.

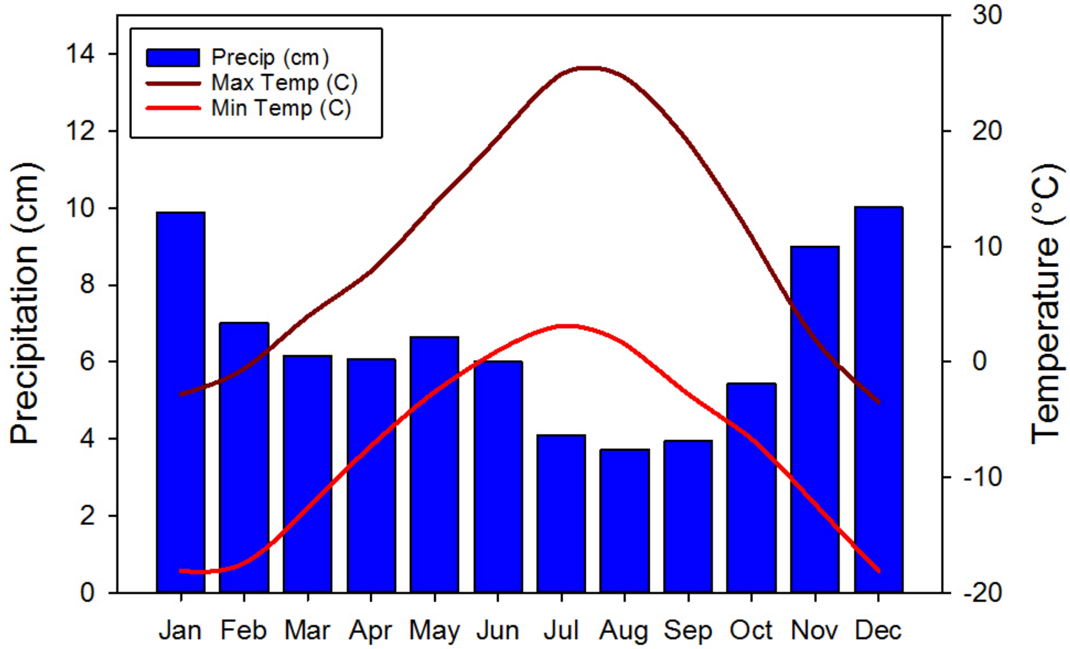

Figure 2. Climograph constructed from climate data from the Snake River COOP Station 488315 near Flagg Ranch, Wyoming (elevation 2098 m). Average (1981–2010) monthly precipitation (cm; blue bars) and average monthly minimum (light red) and maximum (dark red) temperatures are shown.

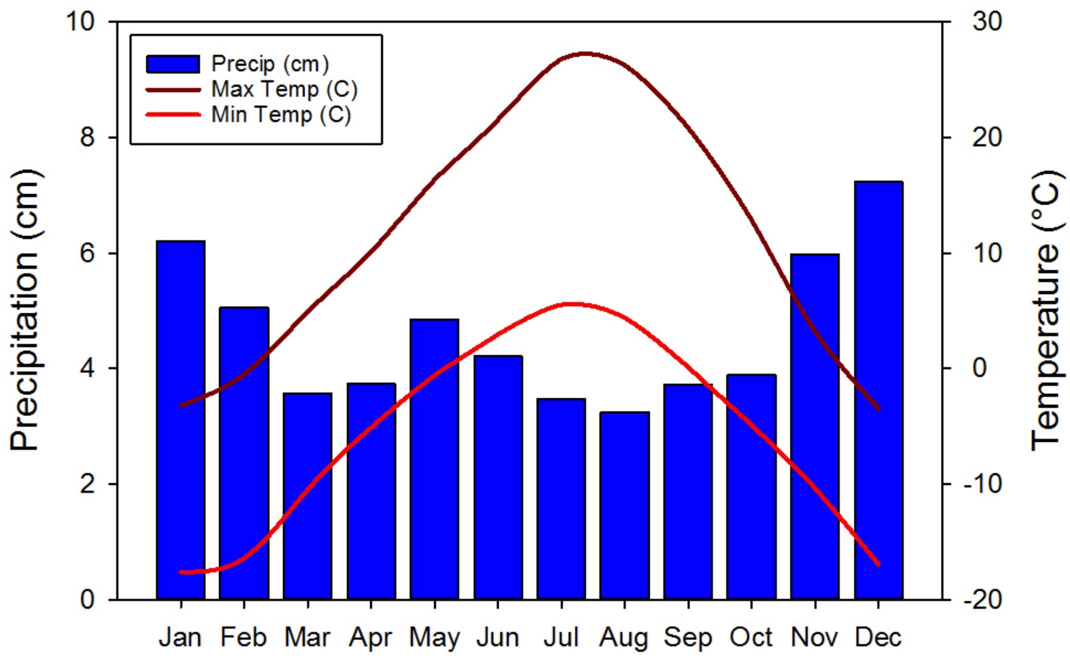

Figure 3. Climograph constructed from climate data from COOP Station 486428 near Moose, Wyoming (elevation 1964 m). Average (1981–2010) monthly precipitation (cm; blue bars) and average monthly minimum (light red) and maximum (dark red) temperatures are shown.

characterized by good water quality, with relatively low levels of dissolved nutrients and other anthropogenic compounds (e.g., pesticides; Clark et al. 2004). Good water quality and the presence of native fish, including cutthroat trout, are not surprising given that the headwaters of the Snake River include parts of Grand Teton and Yellowstone National Parks.

Maintenance of high quality waters and continued support of native freshwater assemblages rank among the highest management objectives for Grand Teton NP (Mott 1998; Clark et al. 2004; O'Ney et al. 2009). The State of Wyoming also recognizes and values this important resource and has designated the upper Snake River and all surface waters within Grand Teton NP as Outstanding or Class 1 waters. Class 1 waters are recognized for their exceptional quality, and therefore "no further water quality degradation by point source discharges other than from dams will be allowed" (WYDEQ 2001). Wyoming's classification also corresponds with the U.S. Environmental Protection Agency's Outstanding Natural Resource Waters (ONRWs) designation, giving the Snake River within Grand Teton NP the highest level of protection from degradation (USEPA 1994). Despite these designations, the recent Wild and Scenic River designation (Snake River Headwaters Legacy Act, 2009) established additional policy to honor, preserve, and protect the quality of the Snake River headwaters' outstanding natural, cultural, and recreational values for the enjoyment of present and future generations (Wild and Scenic Rivers Act, October 2, 1968).

Potential Threats to Water Resources

Threats to the water resources of Grand Teton NP were discussed extensively in a water resources scoping report (Mott 1998). In place (in some form) since 1907, Jackson Lake Dam changed the hydrologic regime, sediment transport processes, and channel dynamics within the Snake River. Issues associated with the dam included: unnatural fluctuations in shoreline elevations in Jackson Lake, altered riparian community structure and function, and creation of a heavily regulated and unnatural hydrograph. For these reasons, the release schedule of Jackson Lake Dam was changed greatly in 1957. The new release schedule caused a 32% reduction in the magnitude of peak flows relative to pre-1957 conditions, but post-1957 peak flows were timed to coincide with the timing of natural high flows on downstream tributaries (Marston et al. 2005).

Grazing by cattle and native ungulates affects deciduous woody vegetation in riparian areas around Grand Teton NP's water resources. In addition, cattle, horse, and wild ungulate access to small streams can contribute to sediment, bacterial, and nutrient loads and affect streambank integrity. Park facilities, bridges, streamside campgrounds, boat accesses, and irrigation headgates individually and collectively have some impact on water resources and change the visual appearance of park resources.

Recreational activities such as camping, hiking, floating, snowmobiling, and horseback riding may also contribute to water quality degradation, especially in heavily used areas. Similarly, some visitor facilities produce seasonally large volumes of wastewater.

Issues related to water withdrawal are tied to water rights and irrigation. These permitted withdrawals arise from local and regional water allocations. Locally, water is withdrawn from the Snake River and its tributaries to meet irrigation needs inside and outside the park and to accommodate water use practices from governmental, municipal, commercial, and residential users.

Headwater lakes in Grand Teton NP are potentially sensitive to the atmospheric deposition of sulfur and nitrogen compounds. Increased urbanization of the western United States has caused a dramatic increase in atmospheric deposition of anthropogenically produced compounds in recent years (Neff et al. 2008). Increased coal burning in the western United States has raised the potential for sulfur and mercury (Peterson et al. 2007) deposition. Local sources of air pollution, such as snowmobile exhaust, can result in greater loadings of organics and nitrogen and sulfur depositions to snowpacks (Ingersoll 1999). Snowpack surveys have shown consistent "hotspots" of inorganic nitrogen deposition downwind of agricultural and industrial activities in Idaho (Turk et al. 2001; Clow et al. 2002). In 2013, the Garnet Canyon snow chemistry monitoring station showed that ammonium and nitrate concentrations in snow from this location ranked 2nd and 20th, respectively, out of 58 Rocky Mountain monitoring sites (Sexstone 2015). Runoff from melting contaminated snowpacks can alter surface water chemistry, which can, in turn, affect aquatic biota in high elevation lakes and streams (Neff et al. 2008). Unique high-alpine streams within this region are known to support rare and potentially endemic aquatic organisms (e.g., Lednia tetonica; Baumann and Call 2012). For these reasons, alpine lake monitoring has become a component of the NPS Inventory and Monitoring Program. Alpine lakes are regularly monitored because they integrate landscape and atmospheric changes and because their unique chemistries appear quite responsive to environmental change or other perturbations (Williamson et al.

2009; Hundley et al. 2014).

Long-term monitoring of high elevation lakes and streams in Rocky Mountain National Park, Colorado, indicated increased levels of atmospheric deposition and increased sensitivity to acidification in park waters (Mast et al. 1990; Baron 1992; Campbell et al. 1995; Baron and Campbell 1997; Peterson and Sullivan 1998; Campbell et al. 2000; Sueker et al. 2000; Williams and Tonnessen 2000; Cosby and Sullivan 2001). Concern about results prompted more recent investigations in Grand Teton NP (Corbin and Woods 2004; Nanus et al. 2005). Moreover, monitoring of select lakes in Grand Teton NP strongly suggests influences from anthropogenic nitrogen sources (Spaulding et al. 2011). Combined, this work helped target sensitive lakes (Amphitheater, Delta, and Surprise Lakes) appropriate for long-term monitoring.

Water Quality Standards That Apply to Grand Teton National Park

Federal Water Quality Criteria

The Environmental Protection Agency (USEPA 2012) aquatic life water quality standards were examined along with Wyoming water quality criteria (WYDEQ 2013) to assess whether the Snake River in Grand Teton NP and the John D. Rockefeller, Jr. Memorial Parkway were meeting water quality standards. Water resource monitoring in the national park and memorial parkway does not include constituents on EPA's national priority pollutants (http://www.epa.gov/eg/toxic-and-priority-pollutants-under-clean-water-act#priority); however, federal criteria for non-priority pollutants are based on EPA National Recommended Water Quality Criteria guidance (http://www.epa.gov/wqc/national-recommended-water-quality-criteria-aquatic-life-criteria-table). Federal and state water quality standards are presented in Appendix A.

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 Grand Teton NP and the John D. Rockefeller, Jr. Memorial Parkway have been classified as Outstanding or Class 1 waters. Class 1 waters are those surface waters known to support fish or supply drinking water (or surface waters where those uses are believed to be attainable) and 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:

1. Summarize annual discharge and water quality conditions of the Snake River within Grand Teton National Park and the John D. Rockefeller, Jr. Memorial Parkway.
2. Characterize water quality conditions in three alpine lakes: Amphitheater, Delta, and Surprise Lakes.

Methods

River Sampling

We collected depth-integrated water samples monthly (Appendix B) between May and October 2013 from two Snake River monitoring sites: Flagg Ranch, Wyoming (Photo 2), and Moose, Wyoming (cover photo).

In addition to water samples, we characterized core field water quality parameters (i.e., temperature, specific conductivity, dissolved oxygen (DO), and pH) in situ using an In-Situ handheld multiparameter instrument at a representative location on the river cross-section (O'Ney et al. 2009).

We collected water samples in wadeable depths across a range of flow conditions using a DH-81 Sampler (Federal Interagency Sedimentation Project, Vicksburg, Mississippi) affixed to a 1 m wading rod. A 1 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. All bottles necessary for laboratory analysis were filled from the DH-81. We rinsed the 1 L sample bottle with deionized water between samples to prevent contamination.

Discharge estimates for river sites were taken from U.S. Geological Survey (USGS) maintained stations for the Snake River (USGS Gage 13010065 for Flagg Ranch, Wyoming, and USGS Gage 13013650 for Moose, Wyoming).

All water samples collected from the Snake River were shipped overnight to Chemtech-Ford Laboratories in Sandy, Utah.

Alpine Lake Sampling

Lake samples were collected twice (July and September) from three lakes: Amphitheater, Delta, and Surprise Lakes (Photos 4, 5, and 6). Core field water quality parameters (i.e.,

Photo 2. Snake River at the Flagg Ranch, Wyoming, monitoring station—August 2014.

temperature, specific conductivity, DO, and pH) were also characterized in situ using a handheld multiparameter water quality instrument from well-mixed water that was representative of the lake (i.e., the outlet of the lake; Photo 3 upper photo). Samples were collected by immersing presterilized 250 ml brown, nonreactive HDPE bottles with a gloved hand approximately 10 cm beneath the water. The mouth of immersed bottles was oriented in a manner that was upstream of the outlet flows (O'Ney et al. 2009; Photo 3 lower photo). Duplicate and blank samples were collected along with raw samples to evaluate the reproducibility of the lab results and to characterize contamination potential.

Water samples from alpine lakes were shipped overnight to Kiowa Environmental Chemistry Laboratory at the University of Colorado in Boulder, Colorado.

Photo 3. Alpine lake sampling consisted of collecting core field water quality parameters (i.e., temperature, specific conductivity, DO, pH) using a handheld multiparameter water quality instrument from the outlet of the lake (upper photo). Grab samples were collected by immersing presterilized 250 ml brown nonreactive HDPE bottles with a gloved arm approximately 10 cm beneath the water (lower photo).

Photo 4. Amphitheater Lake, Grand Teton National Park.

Photo 5. Delta Lake, Grand Teton National Park.

Photo 6. Surprise Lake, Grand Teton National Park.

Results

Snake River Climate, Discharge, and Water Chemistry

We present air temperature and precipitation, river discharge, and water chemistry data from two monitoring sites on the Snake River in 2013.

Temperature and Precipitation

At the Flagg Ranch station, the 2013 average annual maximum temperatures were approximately 1 °C (2 °F) below the 30-year average, and the average annual minimum temperatures were similar to the long-term average (Fig. 4). At the Moose station, average annual minimum temperatures were nearly 1.5 °C (2.7 °F) cooler than the 30-year average (Fig. 5). Total annual precipitation in 2013 was similar to the 30-year average at Flagg Ranch; however, the annual precipitation at Moose was just 80% of the long-term average (Figs. 4 and 5). At both stations, a disproportionate amount of precipitation fell in September relative to the long-term records. At the Flagg Ranch monitoring station, above-average precipitation was also recorded in March, April, and August (Fig. 4). Precipitation at Moose had large deviances from the average in January, February, June, August, and September (Fig. 5).

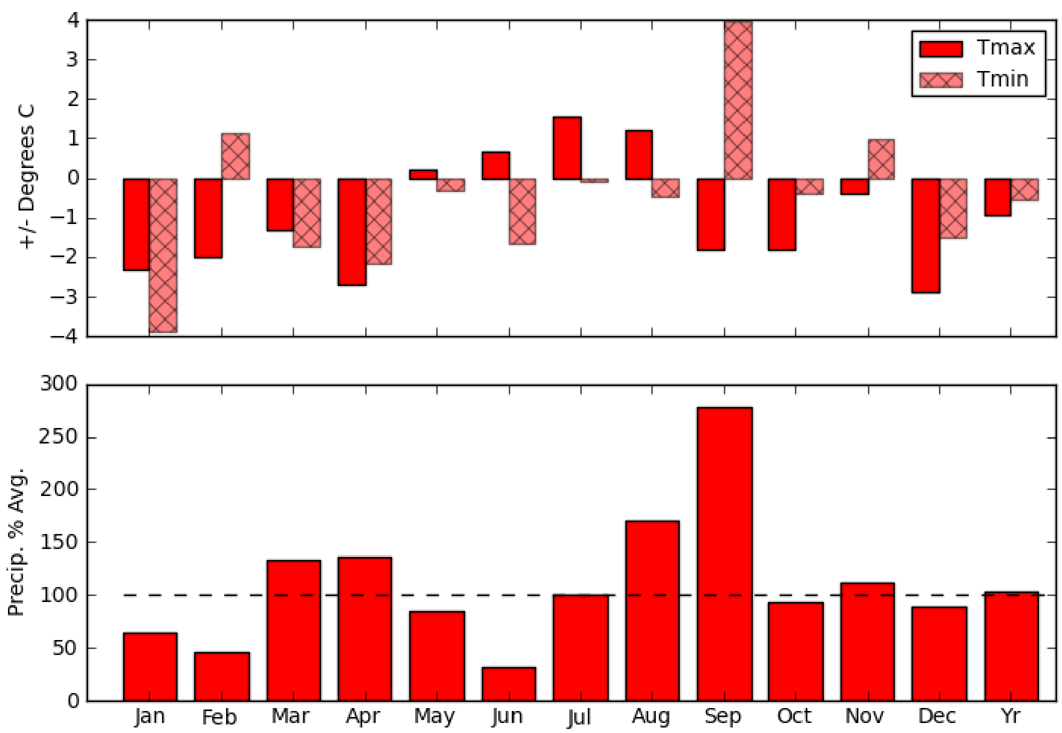

Figure 4. Calendar year 2013 monthly temperature (maximum and minimum) and precipitation summaries for the Snake River COOP Station 488315 near Flagg Ranch, Wyoming (elevation 2098 m). Monthly and year end departures from the 30-year (1981–2010) average are shown.

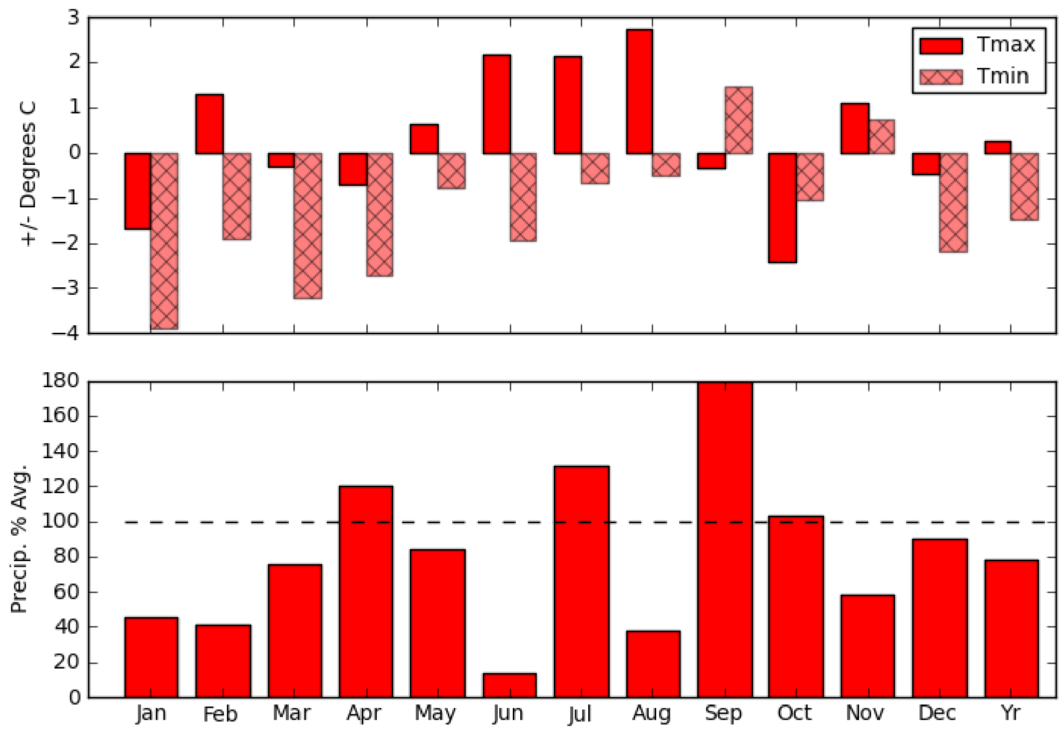

Figure 5. Calendar year 2013 monthly temperature (maximum and minimum) and precipitation summaries for the Snake River COOP Station 486428 at Moose, Wyoming (elevation 1964 m). Monthly and year end departures from the 30-year average are shown.

Snake River Discharge

Hydrographs for the Snake River vary according to location (Figs. 6 and 7) but exhibit a general pattern of high early summer flows and lower baseflows occurring in late summer and extending into fall and winter. There is also a conspicuously unnatural hydrograph at the Moose site that is associated with the operation of the Jackson Lake Dam (Fig. 7). The effect of river regulation on the hydrograph is easily viewed by comparing the two Snake River hydrographs: Flagg Ranch, Wyoming (upstream of Jackson Lake; Fig. 6), and Moose, Wyoming (downstream of Jackson Lake Dam; Fig. 7). Regardless of dam operations, hydrographs in the Snake River generally peak in late May and early June, with the months of April through June coinciding with snowmelt at higher elevations and high flows.

From 1984 to 2012, peak flows at the Snake River near Flagg Ranch monitoring site averaged 6,880 cfs and typically occurred during the last week of May (Table 1). In 2013, peak discharge was 6,160 cfs, and it occurred on May 14, nearly two weeks earlier than the long-term average. The peak discharge in 2013 ranked as the 11th highest recorded peak flow in the 31 years of annual records. The magnitude of peak flows and the date of peak flows for the Flagg Ranch station exhibit considerable annual variation but show no overall pattern over the period of record (Fig. 8).

During 2013, daily flows in the Snake River near Flagg Ranch, Wyoming, were similar to the 25th percentile of daily flows at that site. Peak flows were higher (similar to 75th percentile), occurred earlier in the year compared to the long-term average, but quickly dropped below long-term average flows (period of record 1984–2012) for the remainder of the calendar year (Fig. 6). A relatively high level of among year variation in annual river flow has been documented for this location; however, long-term inferences are limited by a relatively short period of record at this station. The estimated number of days with ice in 2013 was more than twice (84 days) the average number of days estimated with ice for this station (32 days; Table 1). This may be a reflection of colder minimum temperatures in January, March, and April that supported longer ice cover at this station.

At the Snake River, Moose, Wyoming, gage, daily flows at the Moose monitoring station were similar to average daily mean flows (1996–2012; Fig. 7). Augmented flows at this site showed a significant drop in discharge between June 1 and June 7, 2013. During this period flows dropped more than 1,000 cfs and averaged 3,500 cfs less than the long-term average for this period (Fig. 7).

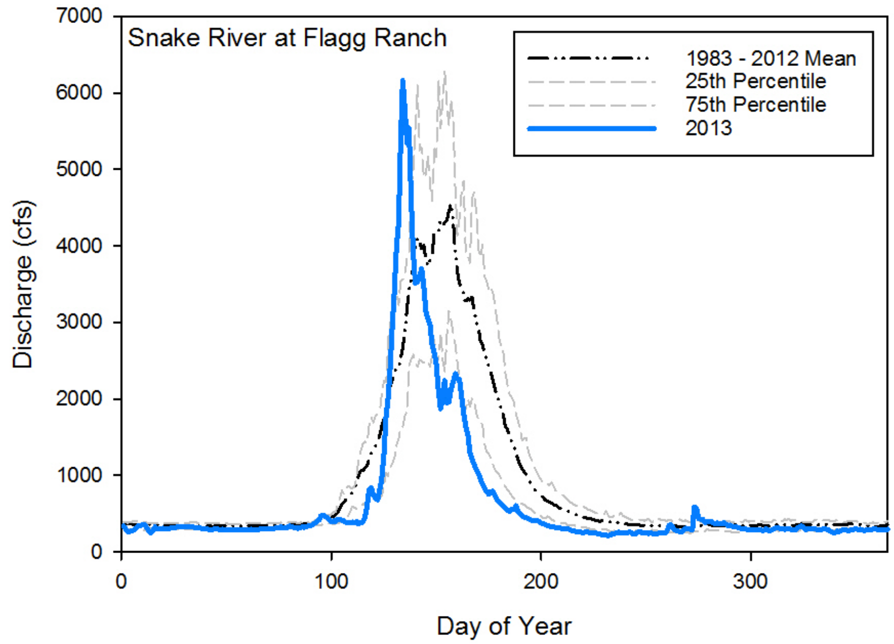

Figure 6. Summary of average daily discharge (in cfs) in the Snake River near Flagg Ranch, Wyoming (USGS Gage 13010065). River flows are presented by day of year where day 1 refers to January 1 of each calendar year. The period of record for this gage is 1983 to 2013. Mean daily discharge for the period of record is shown in black and the 25th and 75th percentiles of daily discharge are shown in grey. A summary of 2013 (blue) is also presented.

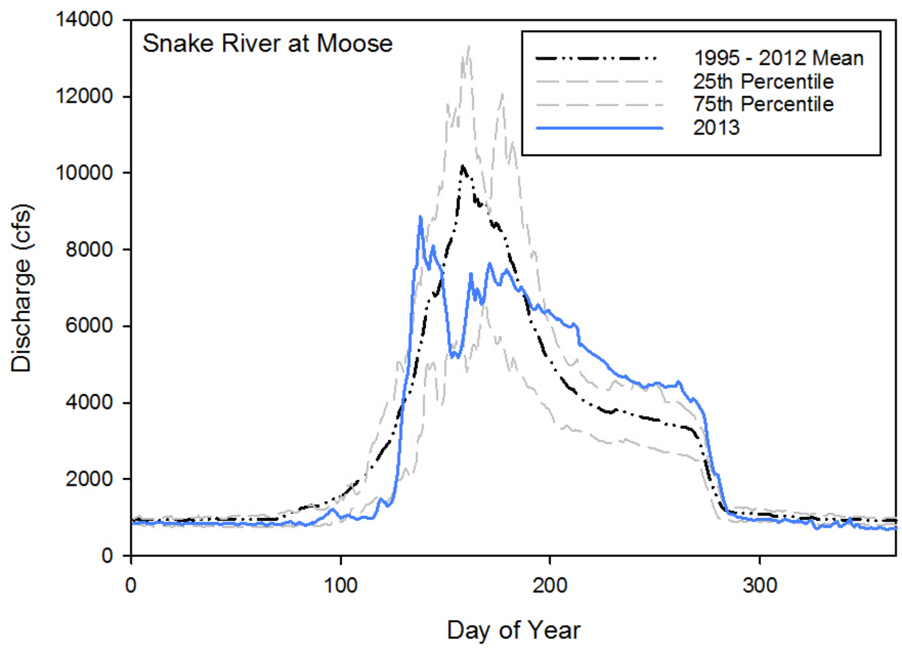

Figure 7. Summary of average daily discharge (in cfs) in the Snake River near Moose, Wyoming (USGS Gage 13013650). River flows are presented by day of year where day 1 refers to January 1 of each calendar year. The period of record for this gage is 1995 to 2013. Mean daily discharge for the period of record is shown in black, and the 25th and 75th percentiles of daily discharge are shown in grey. A summary of 2013 (blue) is also presented.

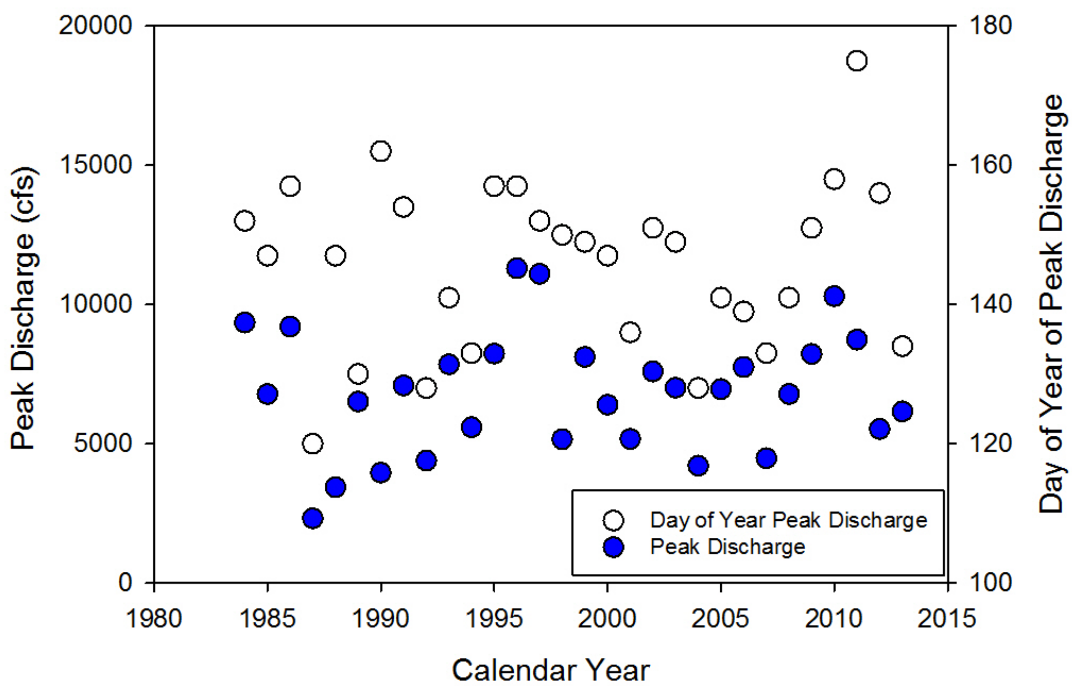

Figure 8. Peak discharge and the day of year that peak discharge occurred for the Snake River near Flagg Ranch, Wyoming, gaging station (USGS Gage 13010065). Peak discharge is shown on a log-transformed scale. Day of year 1 refers to January 1 of each calendar year.

Table 1. Summary of discharge metrics for the Snake River at Flagg Ranch, Wyoming (USGS Gage 13010065).

Discharge Metric	Mean for Period of Record 1984–2012	2013
Peak discharge (cfs)	6880	6160
Day of year of peak discharge (calendar date)	146 (May 25)	134 (May 14)
25th percentile discharge*	310 cfs	175 days*
Total volume (in billions ft^3)	28.17	20.77
Day of year of half volume (calendar date)	153 (June 2)	144 (May 4)
Days with ice**	32	84

*Number of days in 2013 that were below the 25th percentile discharge for the 1984–2012 period.

**Days with ice were estimated as the number of days between 10/1 and 4/30 that are noted as 'e', or estimated by the USGS.

Table 2. Summary of discharge metrics for the Snake River at Moose, Wyoming (USGS Gage 13013650).

Discharge Metric	Mean for Period of Record 1996–2012	2013
Peak discharge (cfs)	12,712	8860
Day of year of peak discharge (calendar date)	160 (June 9)	138 (May 18)
25th percentile discharge*	920 cfs	141 days*
Total volume (in billions ft^3)	92.17	91.34
Day of year of half volume (calendar date)	179 (June 28)	188 (July 6)

*Number of days in 2013 that were below the 25th percentile discharge for the 1996–2012 period.

On average, peak discharge is nearly double at Moose than it is at Flagg Ranch. In 2013, peak discharge at Moose was only 1.4 times peak discharge at Flagg Ranch. Interestingly, the total volume of water passing the Flagg Ranch site was 20.8 billion ft^3 in 2013 or 74% of the long-term average. The total volume of water at the Snake River at Moose gaging station was similar to the long-term average (Table 2). In addition, the total volume of water that passed the Moose monitoring site was more than four times that passing through the channel at the Flagg Ranch monitoring station (Tables 1 and 2). Major tributaries introducing flows between these locations include, but are not limited to, Pilgrim Creek, Pacific Creek, Buffalo Fork, and Spread Creek.

Snake River Water Chemistry

Nutrients

In 2013, water chemistry in the Snake River was indicative of high quality waters and contained low levels of dissolved nutrients. Non-detectable results predominated for nitrate nitrogen. Ortho-phosphorus levels were consistently low (commonly 0.01 mg/L at both monitoring sites). Not surprisingly, DO levels ranged from 8.3 to 10.3 mg/L when documented.

Trace Metals

Trace metals (i.e., arsenic, copper, and selenium) have been detected in the watershed and are often naturally present at measurable concentrations (Clark et al. 2004). In general, these metals exist at levels below the State of Wyoming's aquatic life criteria. In 2013, dissolved and total fractions of arsenic, copper, iron, and selenium (see Appendix B) were estimated from monthly sampling events. Both forms of copper and selenium were generally low and below detection levels at both Snake River monitoring sites and throughout the sampling period. Total iron levels were greatest during elevated discharge, and during these flows exceeded the Wyoming Chronic Aquatic Life Criterion for total recoverable iron (see Figs. 9 and 10). In contrast, total arsenic was inversely related to discharge at each monitoring site; arsenic concentrations were an order of magnitude higher at Flagg Ranch (0.026 ± 0.010 mg/L; mean ± 1 SD) than Moose (0.004 ± 0.002 mg/L). Arsenic levels in the Snake River at Flagg Ranch were below Wyoming's Chronic Aquatic Life Criterion.

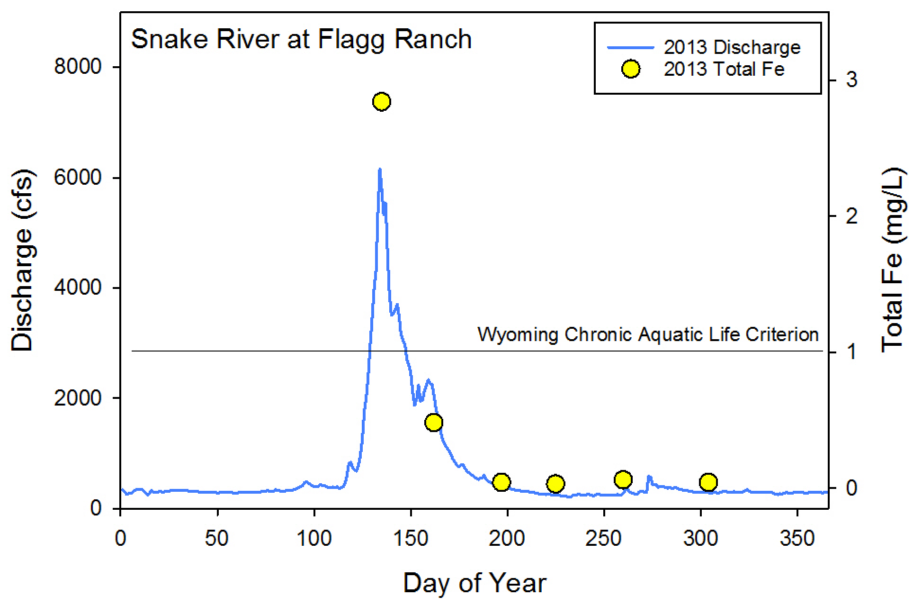

Figure 9. Daily discharge (in cfs; blue line) in the Snake River near Flagg Ranch, Wyoming (USGS Gage 13010065). Also shown are concentrations of total iron (yellow circles) summarized from water collected during monthly sampling at this station. The Wyoming Chronic Aquatic Life Criterion (1 mg/L total extractable iron) is also shown.

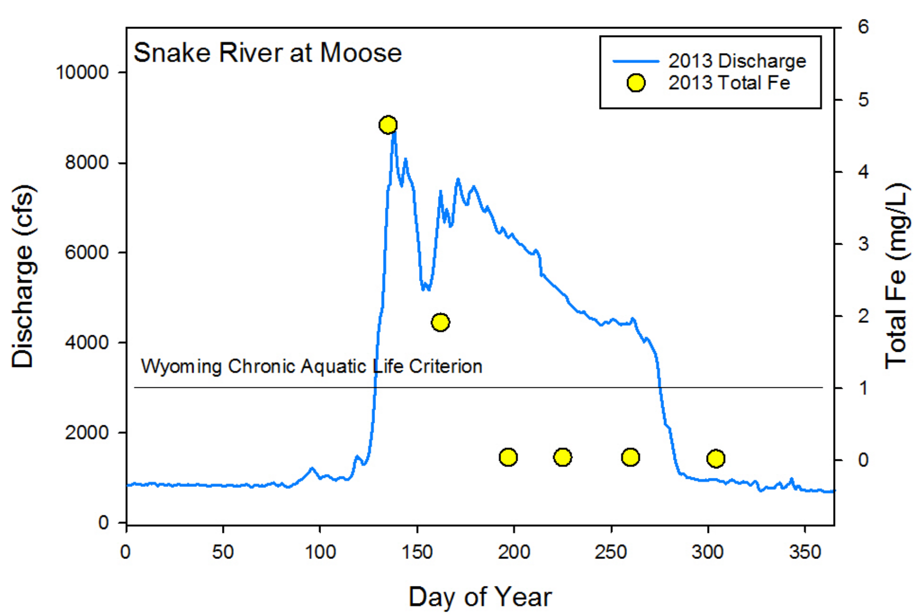

Figure 10. Daily discharge (in cfs; blue line) in the Snake River near Moose, Wyoming (USGS Gage 13013650). Also shown are concentrations of total iron (yellow circles) summarized from water collected during monthly sampling at this station. The Wyoming Chronic Aquatic Life Criterion (1 mg/L total extractable iron) is also shown.

Water Quality of Alpine Lakes

In Grand Teton NP, monitoring of three alpine lakes (Amphitheater, Delta, and Surprise Lakes) began in 2006 and continued in 2013 with sampling events in July and September. Results from 2013 indicate that nitrogen and phosphorus concentrations vary by lake and sampling date (Appendix C). Amphitheater Lake had total nitrogen (TN) levels below the EPA Reference Condition for the Middle Rockies Ecoregion (0.160 mg TN/L; USEPA 2000). Total nitrogen and total dissolved nitrogen (TDN) levels in Delta Lake were highest in July and near or above EPA reference condition levels. In September, TN levels in Surprise Lake were at or above EPA reference levels for TN (Appendix C). In addition, detectable levels of ammonium (NH_4) were documented in Amphitheater Lake (0.009 mg/L) during the July sampling. Lake samples from Amphitheater and Surprise Lakes had total phosphorus (TP) concentrations that were below the EPA Reference Condition (0.0175 mg/L; USEPA 2000) levels for this region. Delta Lake had levels that exceeded EPA's Reference Condition for TP in September 2013.

Results from blank samples suggest that low, but measurable, levels of calcium, magnesium, sodium, sulfate, fluoride, phosphorus, and nitrite were present (Appendix C). The source of these compounds could not be determined, but their detection indicates that results from alpine lake monitoring should be viewed with caution.

Discussion

Water resources are critical to the health and productivity of semiarid landscapes like those found within Grand Teton National Park and the John D. Rockefeller, Jr. Memorial Parkway. In addition, water resources are important to visitor recreation experiences and their perceptual evaluations of natural features (*sensu* Burmil et al. 1999) within NPS units. For these and other reasons, maintenance of high quality waters and continued support of native freshwater assemblages (e.g., fish) are critical management objectives for Grand Teton NP (Mott 1998; Clark et al. 2004). During the 2013 calendar year, ongoing monitoring activities assisted in further characterizing water quality and discharge patterns in the Snake River and water quality in three alpine lakes. These summaries should improve understanding of variability and aid in trend monitoring of the Snake River and representative alpine lakes within Grand Teton NP and the John D. Rockefeller, Jr. Memorial Parkway. Importantly, this work also helps determine whether these aquatic resources are meeting state and federal water quality criteria.

Snake River Discharge

Discharge patterns in the Snake River vary among calendar years depending on annual snow pack levels and seasonal and annual temperatures. Flows differed between river locations in 2013. Flows for much of the 2013 calendar year at the Flagg Ranch gage were similar to the 25th percentile of daily flows at that site. Peak flows were higher and occurred earlier in the year compared to the long-term average, but quickly dropped below long-term average flows. Flows at the Moose station were similar to average daily mean flows, but a regulated hydrograph at this location was evident. This observation is not unexpected given the management of flows behind Jackson Lake Dam. Despite management of the hydrograph, peak flows in 2013 below the dam exceeded historical regulated flows (e.g., between 1955 and 1975; Marston et al. 2005) at this location. Maintenance and timing of high peak flows is important for maintaining both hydrologic and ecologic integrity (Van Kirk and Benjamin 2001). Maintenance of peak flows ensures that habitat forming flows of the hydrograph occur; these flows facilitate sediment transport and scour spawning habitat for native trout. The regulated, descending portion of the hydrograph does not currently mimic a natural recession rate that facilitates recruitment of woody riparian vegetation. But, the delayed recession rate does provide higher summer flows, resulting in increased opportunities for boating and fishing enthusiasts (Marston et al. 2005).

Snake River Water Quality

Water quality in the Snake River exhibited the greatest variability during high flows (June 2013). During high flows total iron levels were high, and sulfate, sodium, and arsenic levels were lower than other months sampled. Currently, the WYDEQ has no standard for primary nutrients in streams and rivers (see WYDEQ 2008) for assessing the status of phosphorus in the Snake River, but total iron levels exceeded the State of Wyoming's Chronic Aquatic Life Criterion (1.0 mg/L) during one of the six sampling visits at Flagg Ranch, and two of the visits at Moose. Because most of the watershed in the upper Snake River is undeveloped, it is believed that iron and other trace metals are naturally occurring (Clark et al. 2004) and that natural fluctuations in iron levels are driven by elevated discharge during runoff.

Alpine Lakes Water Quality

Water quality results for lakes varied among lakes and between sampling dates. Delta Lake has consistently had the highest levels of nitrogen (2008 to 2013) compared with other monitored lakes. In 2013, total nitrogen levels were similar to those measured in 2012 for Delta Lake. Delta Lake results were approximately 2X the levels reported for Amphitheater and Surprise Lakes in July 2013 and for Surprise Lake in September 2013. Delta Lake has high levels of suspended glacial flour and is influenced by glacial ice (Spaulding et al. 2011). The presence of glacier ice in alpine watersheds of the American Rocky Mountains has been shown to strongly influence nitrogen concentrations in high-elevation lake ecosystems, and glacier ice alone is a better predictor of nitrogen presence than geomorphic or biogeographic lake characters (Saros et al. 2010). Results for Delta Lake exceeded EPA's Reference Condition Criteria for the Middle Rockies Ecoregion for total phosphorus in September 2013. As with other studies (see Spaulding et al. 2011), our water quality results for Amphitheater Lake and Surprise Lake showed very low levels of total phosphorus relative to other monitored lakes. Most monitored alpine lakes in Grand Teton NP have been characterized as phosphorus limited; however, Surprise Lake may shift to nitrogen limited during July and August (Spaulding et al. 2011).

Recommendations

Water quality monitoring of select water resources of Grand Teton NP and the John D. Rockefeller, Jr. Memorial Parkway during calendar year 2013 suggests that most monitored resources are meeting state and federal water quality criteria.

Based on results presented from the 2013 monitoring and summarized in this report, the Greater Yellowstone Network recommends the following:

- Continued monitoring of major cations and anions, growth limiting nutrients, and trace metals in the Snake River. Future monitoring should consider inclusion of total suspended solids in the Snake River.
- Use of large river sampling equipment for sampling the Snake River during non-wadeable flows.
- Continued monitoring of major cations and anions and growth limiting nutrients at Amphitheater, Delta, and Surprise Lakes.
- Focused attention on QA/QC protocols during alpine lake sampling. Detection of multiple analytes in blank water samples and considerable variation in duplicate samples suggest that contamination of lake samples is likely affecting results.
- Use of standardized (e.g., USGS) protocols for alpine lake monitoring in Grand Teton National Park should be considered.
- Establishment of permanent photo points at all monitoring sites.

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Appendix A: Relevant Environmental Protection Agency (EPA) Recommended Water Quality Criteria and Wyoming DEQ Water Quality Criteria for Grand Teton National Park Waters

	EPA National Recommended Water Quality Criteria (2012)[a]	EPA Gold Book (1987)[b]	EPA Ambient Water Quality Criteria (2000)[c]	Wyoming Department of Environmental Quality Water Quality Rules and Regulations (2013)[d]
Arsenic	Freshwater (Acute) = 340 µg/L Freshwater (Chronic) = 150 µg/L Human Health consumption of water plus organism = 0.018 µg/L Human health for consumption of organism only = 0.14 µg/L.	Freshwater aquatic organisms and their uses should not be affected unacceptably if the 4-day average concentration of arsenic does not exceed 190 µg/L more than once every 3 years on the average and if the 1-hour average concentration does not exceed 360 µg/L more than once every 3 years on the average. For the maximum protection of human health from the potential carcinogenic effects due to exposure of arsenic through ingestion of contaminated water and contaminated aquatic organisms, the ambient water concentration should be zero based on the non-threshold assumption for this chemical. However, zero level may not be attainable at the present time. Therefore, the levels which may result in incremental increase of cancer risk over the lifetime are estimated at and the corresponding criteria are 0.022 µg/L, 0.0022 µg/L, and 0.00022 µg/L, respectively. If the above estimates are made for consumption of aquatic organisms only, excluding consumption of water, the levels are 0.175 µg/L, 0.0175 µg/L, and 0.00175 µg/L, respectively.	—	Aquatic Life/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.
Alkalinity	Freshwater (Chronic) = not less than 20,000 µg/L	Freshwater aquatic life = not less than 20,000 µg/L as $CaCO_3$ except where natural concentrations are less	—	not found in any WY guidance documents
Ammonia	Acute criteria/pH and temperature dependent; one-hour ** and 30-day *** 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 NH_4-N ranges from 885 to 32,600 µg/L for coldwater/ salmonids present and from 1,320 to 48,800 µg/L salmonids absent.	—	Acute criteria/pH and temperature dependent; 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** and continuous*** concentrations are shown below.
Cadmium	Freshwater (Acute) = 2.0 µg/L Freshwater (Chronic) = 0.25 µg/L	Freshwater aquatic organisms = at a hardness of 100,000 µg/L as $CaCO_3$, the 4-day average concentration is 1.1 µg/L and the 1-hour average concentration is 3.9 µg/L. Human health =10 µg/L.	—	Aquatic Life/Acute = 2.0 µg/L; Aquatic Life/Chronic = 0.25 µg/L; Human Health value fish and drinking water = 5 µg/L.

	EPA National Recommended Water Quality Criteria (2012)[a]	EPA Gold Book (1987)[b]	EPA Ambient Water Quality Criteria (2000)[c]	Wyoming Department of Environmental Quality Water Quality Rules and Regulations (2013)[d]
Chloride	Freshwater (Acute) = 860,000 µg/L Freshwater (Chronic) = 230,000 µg/L	Domestic water supplies = 250,000 µg/L	—	Aquatic Life/Acute = 860,000 µg/L; Aquatic Life/Chronic = 230,000 µg/L
Chromium (III)	Freshwater (Acute) = 570 µg/L Freshwater (Chronic) = 74 µg/L	Freshwater aquatic organisms and their uses should not be affected unacceptably if at a hardness of 100,000 µg/L as CaCO3, the 4-day average concentration of chromium (III) does not exceed 210 µg/L more than once every 3 years on the average and if the 1-hour average concentration does not exceed 1,700 µg/L more than once every 3 years on the average. For the protection of human health from the toxic properties of Chromium III ingested through water and contaminated aquatic organisms, the ambient water criterion is 170 mg/L; for Chromium III ingested through contaminated organism alone, the ambient water criterion is 3433 mg/L.	—	Aquatic Life/Acute = 569.8 µg/L; Aquatic Life/Chronic = 74.1 µg/L; Human Health value fish and drinking water = 100 µg/L (total).
Chromium (VI)	Freshwater (Acute) = 16 µg/L Freshwater (Chronic) = 11 µg/L	Freshwater aquatic organisms and their uses should not be affected unacceptably if the 4-day average concentration of chromium (VI) does not exceed 50 µg/L more than once every 3 years on the average and if the 1-hour average concentration does not exceed 1,100 µg/L more than once every 3 years on the average. Human health criteria for ingestion of contaminated water and contaminated organisms=50 µg/L.	—	Aquatic Life/Acute = 16 µg/L; Aquatic Life/Chronic = 11 µg/L; Human Health value fish and drinking water = 100 µg/L (total).
Copper	Biotic Ligand Model (BLM)[e] was developed to more carefully characterize copper toxicity in freshwater environments (USEPA 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 CaCO3, 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/Acute = 13.4 µg/L; Aquatic Life/Chronic = 9.0 µg/L at a CaCO3 hardness of 100,000 µg/L; Human Health value fish and drinking water = 1,000 µg/L.
Dissolved Oxygen	For early life stages, coldwater criteria, the water column concentration recommended to achieve inter-gravel DO concentration/ 1-day minimum = 8,000 µg/L; 5,000 µg/L for early life stages exposed directly to the water column. For other life stages, coldwater criteria, the water column concentration recommended to achieve inter-gravel DO concentration/1-day minimum = 4,000 µg/L.	For early life stages, coldwater criteria, the water column concentration recommended to achieve inter-gravel DO concentration/1-day minimum = 8,000 µg/L; 5,000 µg/L for early life stages exposed directly to the water column. For other life stages, coldwater criteria, the water column concentration recommended to achieve inter-gravel DO concentration/1-day minimum = 4,000 µg/L.	—	For early life stages, coldwater criteria, the water column concentration recommended to achieve inter-gravel DO concentration/ 1-day minimum = 8.0 mg/L; 5.0 mg/L for early life stages exposed directly to the water column; For other life stages, coldwater criteria, the water column concentration recommended to achieve inter-gravel DO concentration/ 1-day minimum = 4.0 mg/L.

	EPA National Recommended Water Quality Criteria (2012)[a]	EPA Gold Book (1987)[b]	EPA Ambient Water Quality Criteria (2000)[c]	Wyoming Department of Environmental Quality Water Quality Rules and Regulations (2013)[d]
E. coli	Based on a statistically sufficient number of samples (generally not less than 5 samples equally spaced over a 30-day period), the geometric mean of the indicated bacterial densities should not exceed one or the other of the following:(') *E. coli* 126 per 100,000 μL.	Based on a statistically sufficient number of samples (generally not less than 5 samples equally spaced over a 30-day period), the geometric mean of the indicated bacterial densities should not exceed one or the other of the following:(') *E. coli* 126 per 100,000 uL.	—	In all waters designated for primary contact recreation, during the summer recreation season (May 1 through September 30), concentrations of *E. coli* bacteria shall not exceed a geometric mean of 126 organisms per 100 milliliters during any 60-day period. During period October 1 through April 30 all waters are protected for secondary contact recreation; concentrations of *E. coli* shall not exceed a geometric mean of 630 organisms per 100 mL during any 60-day period.
Iron	Freshwater (Chronic) = 1000 μg/L Human health for consumption of water + organism = 300 μg/L	Freshwater aquatic life = 1,000 μg/L Domestic water supplies (welfare) = 300 μg/L	—	Aquatic Life/Chronic = 1,000 μg/L; Human Health value fish plus drinking water = 300 μg/L
Lead	Freshwater (Acute) = 65 μg/L Freshwater (Chronic) = 2.5 μg/L	Freshwater aquatic organisms = at a hardness of 100,000 μg/L as CaCO3, the 4-day average concentration is 3.2 μg/L and the 1-hour average concentration is 82 μg/L. Human health = 50 μg/L.	—	Aquatic Life/Acute = 64.6 μg/L; Aquatic Life/Chronic = 2.5 μg/L; Human Health value fish and drinking water = 15 μg/L.
Nitrate as N	Human health consumption of water + organism = 10,000 μg/L	Domestic water supplies = 10,000 μg/L	—	Human health value/fish and drinking water = 10,000 μg/L
Nitrite as N	not found	not found	—	human health value/fish and drinking water = 1,000 μg/L
Nitrite + Nitrate	not found	Domestic water supplies = 10,000 μg/L	40 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	—	Aquatic Life Chronic value = 6.5–9.0
Phosphorus	no standard	no standard	15 μg/L*	not found in any WY guidance documents
Ortho-phosphate	no standard	no standard	—	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/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.
Silver	Freshwater (Acute) = 3.2 μg/L	Freshwater aquatic organisms = at a hardness of 100,000 μg/L as CaCO3, the concentration should not exceed 4.1 μg/L at any time. Available data indicate that chronic toxicity to freshwater aquatic life may occur at concentrations as low as 0.12 μg/L. Human health = 50 μg/L.	—	Aquatic Life/Acute = 1.7 μg/L; Human Health value fish and drinking water = 100 μg/L

	EPA National Recommended Water Quality Criteria (2012)[a]	EPA Gold Book (1987)[b]	EPA Ambient Water Quality Criteria (2000)[c]	Wyoming Department of Environmental Quality Water Quality Rules and Regulations (2013)[d]
Specific Conductance	no standard	no standard	—	not found in any WY guidance documents
Sulfate	no standard	no standard	—	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.	—	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 25th percentile)	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	—	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 discharge in amounts which will result in an increase of more than 2ºF (1.1ºC) in existing temperatures. When ambient temperatures are above 60ºF in all Class 1, 2AB, and 2B waters which are warm water fisheries, effluent attributable to or influenced by the activities of man shall not be discharge in amounts which will result in an increase of more than 4ºF (2.2ºC) in existing temperatures. The maximum allowable stream temperature will be the maximum natural daily stream temperature plus the allowable change, provided that this temperature is not lethal to existing fish life and under no circumstance shall this maximum temperature exceed 68ºF (20ºC) in the case of cold water fisheries and 86ºF (30ºC) in the case of warm water fisheries.

	EPA National Recommended Water Quality Criteria (2012)[a]	EPA Gold Book (1987)b	EPA Ambient Water Quality Criteria (2000)[c]	Wyoming Department of Environmental Quality Water Quality Rules and Regulations (2013)[d]
Zinc	Freshwater (Acute) = 120 µg/L Freshwater (Chronic) = 120 µg/L Human Health consumption of water plus organism = 7,400 µg/L Human health for consumption of organism only = 26,000 µg/L	Freshwater aquatic organisms = at a hardness of 100,000 µg/L as CaCO3, the concentration should not exceed 320 µg/L at any time Human health = for controlling undesirable taste and odor quality of ambient water, the estimated level is 5,000 µg/L	—	Aquatic Life/Acute = 117.2 µg/L; Aquatic Life/Chronic = 118.1 µg/L; Human Health value fish and drinking water = 5,000 µg/L; Human Health value fish only = 26,000 µg/L.

Note: DO = dissolved oxygen

[a]*Source*: U.S. Environmental Protection Agency. 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 (accessed 7 May 2015).

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

[c]*Source*: U.S. Environmental Protection Agency. 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*: Wyoming Department of Environmental Quality. 2013. Water quality rules and regulations. Chapter 1 in Water Quality Division rules and regulations. Online. (http://soswy.state.wy.us/Rules/RULES/9176.pdf) (accessed 7 May 2015).

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

**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))

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

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

Appendix B: 2013 Laboratory Results for Monthly Monitoring of the Snake River Sites

The following tables present laboratory results for two river monitoring sites: Snake River at Flagg Ranch, Wyoming (Tables B-1, B-2), and Snake River at Moose, Wyoming (Tables B-3, B-4). All values presented are in mg/L. Hardness as $CaCO_3$=water hardness as calcium carbonate, Cl=chloride, N=nitrogen, ortho-P=ortho phosphate, SO_4=sulfate, Diss.=dissolved, As=arsenic, Ca=calcium, Co=cobalt, Cu=copper, Fe=iron, Mg=magnesium, K=potassium, Se=selenium, Na=sodium. Water sample results from the Snake River were produced by ChemTech Ford Laboratory in Sandy, Utah. '—' = missing values.

Table B-1. Monthly water quality lab results for Snake River at Flagg Ranch, Wyoming, 2013.

Analyte	15 May	11 June	16 July	13 August	17 September	31 October
Hardness as $CaCO_3$	44.2	36.9	58.1	69.1	65	60.1
Cl	4	4	14	19	20	19
Nitrate as N	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
ortho-P	0.01	0.01	—	0.01	<0.01	0.02
Total P	—	—	—	0.02	—	—
SO_4	<10	9	27	37	36	33
Diss. As	0.0055	0.0102	0.0331	0.0417	0.0434	0.0344
Total As	0.0074	0.0102	0.0313	0.0420	0.0516	0.0383
Diss. Ca	10.1	10.2	17.5	21.0	19.9	18.3
Total Ca	12.6	11.3	18.0	21.2	20.1	18.4
Diss. Cu	0.0062	<0.001	<0.001	<0.001	0.0012	<0.001
Total Cu	0.0023	<0.001	<0.001	<0.001	0.0021	<0.001
Diss. Fe	0.06	0.03	0.03	<0.02	0.05	0.02
Total Fe	2.84	0.48	0.04	0.03	0.06	0.04
Diss. Mg	2.1	1.9	3.2	3.7	3.5	3.3
Total Mg	3.1	2.1	3.2	3.9	3.6	3.4
Diss. K	1.6	1.5	3.9	4.6	4.8	4.5
Diss. Se	<0.0005	<0.0005	<0.0005	<0.0005	0.0006	<0.0005
Total Se	<0.0005	<0.0005	<0.0005	0.0007	0.0013	<0.0005
Diss. Na	5.6	8.5	25.2	32.1	31.7	33.1
Total Co	—	—	<0.0005	—	—	—
Core Parameters from Field						
Temp (°C)	4.83	8.66	16.20	14.38	15.85	5.10
Spec. Cond. (µS/cm)	54.72	78.18	208.8	251.0	264.5	244.9
pH	7.98	7.98	8.09	8.28	8.22	8.11
Diss. Oxygen (mg/L)	10.34	9.13	—	8.46	—	10.03

Table B-2. Monthly water quality lab QA/QC results for Snake River near Flagg Ranch, Wyoming, 2013.

	Duplicates			Blanks	
Date	**Analyte**	**Result**	**Duplicate Result**	**Analyte**	**Blank Result**
15 May	Hardness as $CaCO_3$	44.2	44.9	Diss. Ca	<0.2
	Total As	0.0074	0.0075	Diss. Mg	<0.5
	Total Ca	12.6	12.8	Diss. K	<0.5
	Total Cu	0.0023	0.0023	Diss. Na	<0.5
	Total Fe	2.84	2.87	—	—
	Total Mg	3.1	3.2	—	—
	Total Se	<0.0005	<0.0005	—	—
11 June	Diss. Ca	10.2	10.7	Cl	<1
	Diss. Mg	1.9	2.0	Nitrate as N	<0.1
	Diss. K	1.5	1.6	ortho-P	<0.01
	Diss. Na	8.5	9.0	SO_4	<1
16 July	Diss. Ca	17.5	17.2	Hardness as $CaCO_3$	<1.3
	Diss. Mg	3.2	3.1	Total As	<0.0005
	Diss. K	3.9	3.8	Diss. Ca	<0.2
	Diss. Na	25.2	24.6	Total Cu	<0.001
	—	—	—	Total Fe	<0.02
	—	—	—	Total Mg	<0.2
	—	—	—	Total Se	<0.0005
13 August	Hardness as $CaCo_3$	69.1	73	Diss. Ca	<0.2
	Total As	0.042	0.0438	Diss. Mg	<0.2
	Total Ca	21.2	22.4	Diss. K	<0.5
	Total Cu	<0.001	<0.001	Diss. Na	<0.5
	Total Fe	0.03	0.03	—	—
	Total Mg	3.9	4.1	—	—
	Total Se	0.0007	0.0010	—	—
17 September	Diss. Mg	3.5	3.5	Diss. Ca	<0.2
	Diss. K	4.8	4.6	Diss. Mg	<0.2
	Diss. Na	31.7	31	Diss. K	<0.5
	Diss. Ca	19.9	19.6	Diss. Na	<0.5
31 October	Hardness	60.1	58.7	Cl	<1
	Total As	0.0383	0.0388	Nitrate as N	<0.1
	Total Ca	18.4	18.0	Nitrite as N	<0.1
	Total Cu	<0.001	<0.001	ortho-P	<0.01
	Total Fe	0.04	0.04	SO_4	<1
	Total Mg	3.4	3.4	—	—
	Total Se	<0.0005	<0.0005	—	—

Table B-3. Monthly water quality lab results for Snake River at Moose, Wyoming, 2013.

Analyte	15 May	11 June	16 July	13 August	17 September	31 October
Hardness as $CaCO_3$	77.8	49.8	48.4	52.6	56.4	75.2
Cl	3	2	4	5	6	4
Nitrate as N	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
ortho-P	0.03	0.02	--	<0.01	0.01	0.01
Total P	—	—	—	0.02	—	—
SO_4	<10	5	9	10	11	10
Diss. As	0.0022	0.0030	0.0076	0.0093	0.0098	0.0042
Total As	0.0034	0.0035	0.0073	0.0098	0.0108	0.0043
Diss. Ca	14.3	11.9	13.7	14.8	17.6	21.0
Total Ca	21.3	14	14.5	15.5	16.7	21.9
Diss. Cu	0.0010	<0.001	<0.001	<0.001	<0.001	<0.001
Total Cu	0.0042	0.0084	<0.001	<0.001	0.0015	<0.001
Diss. Fe	0.03	0.02	<0.02	<0.02	<0.02	<0.02
Total Fe	4.65	1.91	0.04	0.04	0.04	0.02
Diss. Mg	2.9	2.4	2.9	3.1	3.6	4.6
Total Mg	5.9	3.6	3.0	3.3	3.5	5.0
Diss. K	1.2	1.3	1.7	1.9	2.2	1.8
Diss. Se	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
Total Se	<0.0005	<0.0005	<0.0005	0.0006	0.0006	<0.0005
Diss. Na	4	4.6	8.4	9.8	11	7.5
Total Co	—	—	<0.001	—	—	—
Core Parameters from Field						
Temp (°C)	8.73	12.41	16.68	17.98	15.36	5.50
Spec. Cond. (µS/cm)	82.65	77.72	123.0	134.8	135.4	191.3
pH	8.39	8.14	8.39	8.65	8.56	9.04
Diss. Oxygen (mg/L)	9.32	8.35	—	—	—	—

Table B-4. Monthly water quality lab QA/QC results for Snake River at Moose, Wyoming, 2013.

		Duplicates	
Date	**Analyte**	**Result**	**Duplicate Result**
15 May	Cl	3	3
	Nitrate as N	<0.1	<0.1
	ortho-P	0.03	0.02
	SO_4	<10	<10
11 June	Diss. As	0.0030	0.0029
	Diss. Cu	<0.001	<0.001
	Diss. Fe	0.02	0.02
	Diss. Se	<0.0005	<0.0005
16 July	Diss. As	0.0076	0.0074
	Diss. Cu	<0.001	<0.001
	Diss. Fe	<0.02	<0.02
	Diss. Se	<0.0005	<0.0005
13 August	Cl	5	5
	Nitrate as N	<0.1	<0.1
	ortho-P	<0.01	<0.01
	Total P	**0.02**	**0.02**
	SO_4	10	10
17 September	Diss. As	0.0098	0.0098
	Diss. Cu	<0.001	<0.001
	Diss. Fe	<0.02	0.03
	Diss. Se	<0.0005	<0.0005
30 October	Cl	4	4
	Nitrate as N	<0.1	<0.1
	ortho-P	0.01	0.01
	SO_4	10	10

Appendix C: 2013 Laboratory Results for Monitoring of Alpine Lakes: Amphitheater Lake, Delta Lake, and Surprise Lake

The following tables present laboratory results for alpine lake monitoring sites: Amphitheater Lake (Table C-1), Delta Lake (Table C-2) and Surprise Lake (Table C-3). All values presented are in mg/L. Ca=calcium, Mg=magnesium, Na=sodium, K=potassium, Li=lithium, NH_4=ammonium, Cl=chloride, NO_3= nitrate, SO_4=sulfate, Br=bromide, F=fluoride, NO_2=nitrite, TN=total nitrogen, TDN=total dissolved nitrogen, TP= total phosphorus, TDP=total dissolved phosphorus. Water sample results from alpine lakes were produced by Kiowa Environmental Chemistry Laboratory at the University of Colorado in Boulder, Colorado. Columns with dark shading represent either duplicate samples on the same date or blank samples using certified inorganic free deionized water, as indicated by header.

Table C-1. Water quality lab results for Amphitheater Lake in Grand Teton National Park, Wyoming, 2013.

Analyte	15 July	15 July (Duplicate)	15 July (Blank)	16 Sept
Ca	0.641	0.634	0.017	0.613
Mg	0.118	0.118	0.004	0.122
Na	0.298	0.298	0.009	0.317
K	0.169	0.179	0.013	0.058
Li	<0.007	<0.007	<0.007	<0.007
NH_4	0.009	<0.005	0.006	<0.005
Cl	0.103	0.118	0.010	0.121
NO_3	0.126	<0.001	<0.001	0.039
SO_4	0.291	0.293	<0.005	0.293
Br	<0.003	<0.003	<0.003	<0.003
F	<0.006	<0.006	<0.006	<0.006
NO_2	0.0014	0.0015	<0.0007	0.0009
TN	0.071	0.087	0.020	0.076
TDN	0.057	0.062	<0.008	0.031
TP	0.0021	0.0022	0.0014	0.0064
TDP	<0.0012	<0.0012	<0.0012	<0.0012

Table C-2. Water quality lab results for Delta Lake in Grand Teton National Park, Wyoming, 2013.

Analyte	15 July	16 Sept	16 Sept (Duplicate)
Ca	0.848	0.947	0.940
Mg	0.166	0.182	0.184
Na	0.317	0.294	0.296
K	0.368	0.399	0.402
Li	<0.007	<0.007	<0.007
NH_4	<0.005	<0.005	<0.005
Cl	0.082	0.010	0.139
NO_3	0.688	<0.001	<0.001
SO_4	0.455	0.014	0.320
Br	<0.003	<0.003	<0.003
F	0.014	0.016	0.017
NO_2	0.0015	0.0016	0.0017
TN	0.153	<0.008	0.122
TDN	0.170	0.013	0.092
TP	0.0173	0.0261	0.0127
TDP	0.0026	0.0017	0.0021

Table C-3. Water quality lab results for Surprise Lake in Grand Teton National Park, Wyoming, 2013.

Analyte	15 July	16 Sept	16 Sept (Blank)
Ca	0.608	0.594	0.013
Mg	0.118	0.129	<0.001
Na	0.306	0.329	0.004
K	0.143	0.179	0.017
Li	<0.007	<0.007	<0.007
NH_4	<0.005	<0.005	<0.005
Cl	0.102	0.108	0.115
NO_3	0.132	0.670	0.662
SO_4	0.290	0.556	0.559
Br	<0.003	<0.003	<0.003
F	<0.006	<0.006	<0.006
NO_2	0.0017	<0.007	0.009
TN	0.082	0.126	0.073
TDN	0.050	0.163	0.203
TP	0.0047	0.0078	<0.0012
TDP	<0.0012	<0.0012	<0.0012

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