National Park Service
U.S. Department of the Interior

Natural Resource Program Center

# Greater Yellowstone Network Water Quality Monitoring Annual Report

*October 2005–December 2006*

Natural Resource Technical Report NPS/GRYN/NRTR—2009/204

**ON THE COVER**
Water bodies in the Greater Yellowstone Network, clockwise from top left: Bighorn River downsream of Afterbay Dam, Bighorn Canyon National Recreation Area; Yellowstone Lake, Yellowstone National Park; and Jackson Lake, Grand Teton National Park. National Park Service photos.

# Greater Yellowstone Network Water Quality Monitoring Annual Report

*October 2005–December 2006*

Natural Resource Technical Report NPS/GRYN/NRTR–2009/204

**Authors**
Susan O'Ney
Grand Teton National Park
PO Drawer 170
Moose, WY 83012

Jeff Arnold
Yellowstone National Park
PO Box 168
Yellowstone National Park, WY 82190

Cassity Bromley
Bighorn Canyon National Recreation Area
20 Highway 14A East
Lovell, WY 82431

**Editing and Design**
Emily Yost

April 2009

U.S. Department of the Interior
National Park Service
Natural Resource Program Center
Fort Collins, Colorado

Printed copies of reports in this series may be produced in limited quantity, and are only available as long as the supply lasts. You may send a request to:

Greater Yellowstone Network
AJM Johnson Hall
Bozeman, MT 59717

This report is also available electronically from the Greater Yellowstone Network website, http://www.nature.nps.gov/im/units/GRYN/, and the Natural Resource Publications Management website, http://www.nature.nps.gov/publications/NRPM/.

Please cite this publication as:

O'Ney, S., J. Arnold, and C. Bromley. 2009. Greater Yellowstone Network water quality monitoring annual report: October 2005–December 2006. Natural Resource Technical Report NPS/GRYN/NRTR—2009/204. National Park Service, Fort Collins, Colorado.

NPS D-1399, April 2009

# Contents

NPS

Water resources are especially important in the Greater Yellowstone Network because of the Outstanding Natural Resource Water designation for Yellowstone National Park and Grand Teton National Park (above). These important places are headwaters to the Yellowstone River and Snake River watersheds.

## 1. Introduction and Background

The Greater Yellowstone Network (GRYN) was established by the National Park Service Inventory and Monitoring (I&M) Program in 2000 to help enhance the scientific basis for stewardship and management of natural resources in Bighorn Canyon National Recreation Area, Grand Teton National Park (including John D. Rockefeller, Jr. Memorial Parkway), and Yellowstone National Park. It is one of 32 I&M units nationwide that group some 270 national parks into networks based on geographic similarities, common natural resources, and resource protection challenges. Water resources are especially important in the GRYN because of the Outstanding Natural Resource Water designation for Yellowstone and Grand Teton. These important places are headwaters to the Yellowstone River and Snake River watersheds. Water resources also provide important public recreational opportunities in Bighorn Canyon, critically important plant and wildlife habitat, and unique scenic vistas within all three network parks.

Aquatic resources across the GRYN face numerous and varied threats, including atmospheric deposition, altered hydrology, mining, agriculture, pollution from boats, nonnative species, erosion, leaking underground storage tanks, improper sewage plant or drain field operations, and stormwater runoff. Water quality monitoring to assess the effects of these threats has been underway for more than 50 years, though not as a coordinated, comprehensive program focused on ecosystem health.

In 2005, the GRYN began monitoring water bodies identified as water-quality impaired by the states of Montana and Wyoming. Monitoring activities followed the network's Regulatory Water Quality Monitoring (O'Ney 2006). The identified water-quality impaired water bodies include Soda Butte and Reese creeks in Yellowstone and the Bighorn and Shoshone rivers in Bighorn Canyon. Standard operating procedures were established for measuring core parameters (water temperature, pH, dissolved oxygen [DO], conductivity) and discharge, metals in both water and sediment, nutrients, *Escherichia coli,* and benthic macroinvertebrates. In 2006, GRYN parks began monitoring water chemistry and benthic macroinvertebrates at fixed monitoring sites as part of the GRYN vital signs monitoring program.

### *1.1 Justification for Monitoring*

Water quality of park rivers and streams is important to fisheries and adds significantly to visitors' enjoyment of river and lake experiences. In addition, the Wyoming Department of Environmental Quality (DEQ) has designated the surface waters in both Grand Teton and Yellowstone as Class 1 Outstanding Resource Waters, meaning that no further degradation of these waters is allowed. Given the increased public use of areas like Bighorn Canyon, Grand Teton, and Yellowstone, and the overall population increase in the West, pressure on park water resources is likely to continue to increase. Recreational activities such as camping, hiking, floating, snowmobiling, and horseback riding can result in detectable water quality degradation in heavily used areas (Mott 1998). Visitor facilities produce seasonally large volumes of wastewater. Cattle, horses, and wild ungulates can elevate sediment, bacterial, and nutrient loads in park streams and

reduce streambank strength due to trampling and intense grazing levels. Increasing sources of atmospheric deposition, such as oil and gas development, must also be considered as threats to park waters. Melting of contaminated snowpacks can result in changes to soil processes and alterations in surface water chemistry, which can in turn affect aquatic biota in high elevation lakes and streams. There are also concerns about atmospheric deposition of toxic elements, especially mercury and pesticides.

Water quality monitoring is a fundamental tool in the management of freshwater resources. The chemical, physical, and biological health of waters are considered to be of national value and are protected by the Federal Water Pollution Control Act. This act is designed to ensure that Americans have clean water for domestic, agricultural, commercial, and recreational uses. Water quality monitoring helps ensure that a water body is suitable for its determined use. It can also be used for protective purposes to prevent degradation or to upgrade conditions. Both water chemistry and benthic macroinvertebrates are being monitored in the GRYN.

Water chemistry data are critical for interpreting the biotic condition and ecological processes of aquatic resources and helping us to understand the combined influences of atmospheric deposition, climate, geology, and geothermal activity on surface water chemistry and biota. Chemical stressors can result in impaired functioning, loss of a sensitive species, or a change in community structure. Water chemistry also affects the bioavailability of contaminants and the metabolism of aquatic species. For example, ionic conditions affect osmo-regulation (Hoar and Randall 1969) and contaminant uptake (Sinley, Goetti, and Dacies 1974; Luoma 1989; Spry and Weiner 1991), and dissolved oxygen and temperature affect metabolic rate (Hoar and Randall 1969). Successful reproduction requires the appropriate chemical conditions for fertilization and development of eggs and larvae (Holtze and Hutchinson 1989).

The use of macroinvertebrates as indicators of aquatic ecosystem health developed out of observations that specific taxa were restricted under certain environmental conditions (Richardson 1925, 1928; Gaufin 1958). The presence of a mixed population of healthy aquatic insects usually indicates that water quality has been good for some time. Changes in the macroinvertebrate community may indicate impacts (episodic events) on water quality missed in routine water chemistry monitoring. Changes in the abundance or richness of macroinvertebrates may indicate changes in food web dynamics that may impact both aquatic and terrestrial ecosystems.

## *1.2 Objectives*

The development of measurable objectives is a critical element of any monitoring program. The basic objective for regulatory water quality monitoring is to determine whether parameters exceed state standards. In addition to determining whether these standards are being exceeded, the GRYN plans to determine whether the Government Performance and Results Act (GPRA) goal of improved water quality is being achieved (National Park Service 2000); examine long-term data for water quality trends; and provide the parks and the states with credible data that may help with management decisions. The GRYN objectives for water quality monitoring are as follows:

- Determine the status and long-term trends in water chemistry (major ions and nutrients), conductivity, DO, pH, water temperature, and discharge in perennial rivers and streams at fixed stations in all GRYN parks and in Yellowstone and Jackson lakes
- Determine the status and trends in the biological conditions of wadeable rivers and streams (second-order and above), based on aquatic macroinvertebrate metrics, at fixed stations and other targeted sites.


NPS

About five percent of Yellowstone National Park is covered by water, including more than 220 lakes and 1,000 streams. Yellowstone Lake, which lies at an elevation of 2,356 m, is the largest lake at high elevation in North America. Park Aquatic Biologist Jeff Arnold conducts winter water sampling in the Yellowstone River at the outlet of Yellowstone Lake at Fishing Bridge.

## 2. Design and Sampling

The GRYN is using a “targeted” sampling design for monitoring water chemistry and aquatic macroinvertebrates. This design reflects the need to continue historical trend data from the USGS (U.S. Geological Survey) and to meet budget constraints. Fixed monitoring sites were selected that target specific waters of concern and/or act as integrator sites (i.e., located at outlets of drainage basins with relatively homogeneous land-use and physiographic conditions, intended to reflect conditions within that basin). Many of these sites have sufficient access to enable year-round monitoring, and are co-located with USGS gaging stations that have long-term records useful to the interpretation of water quality data. As such, these are important data sources to the parks, which have placed high value on maintaining their continued monitoring.

In 2006, eight fixed monitoring sites at Bighorn Canyon were sampled quarterly for major cations, major anions, and nutrients. Six monitoring sites at Grand Teton were sampled based on flow regime for major cations, major anions, nutrients, total suspended solids, and alkalinity. Ten fixed monitoring sites at Yellowstone were sampled monthly for major cations, major anions, nutrients, turbidity, and total suspended solids. Certain sites within the GRYN will also be sampled for dissolved and total metals, metals in sediment, pesticides, *E. coli*, and macroinvertebrates.

### *2.1 Study Areas*

The diverse water resources of Bighorn Canyon, located in southeastern Montana and north-central Wyoming, include Bighorn Lake (the reservoir created by Yellowtail Dam in 1966), 8–16 km of the Bighorn River, and 3–5 km of the Shoshone River above the pool of Bighorn Lake; several small ponds constructed in the Yellowtail Wildlife Habitat Management Area and in other park locations for wildlife and water management; the extreme lower reaches of several small streams that flow into the east and west sides of Bighorn Lake; a small number of seeps and springs primarily located at the base of the Pryor Mountains in the western portion of the park; and the wetland and riparian areas associated with these systems. The Bighorn River and its tributaries are part of the Bighorn-Wind River Basin of the Missouri River Basin. Most of the park is contained within the Bighorn Lake hydrologic unit (fig. 1), with a small portion in the Lower Bighorn. The Shoshone hydrologic unit provides additional surface water inputs. Bighorn Lake winds through approximately 113 km of spectacular, sheer canyons carved by the Bighorn River. The Yellowtail Dam, operated by the Bureau of Reclamation and located near the northern edge of the park, dominates Bighorn Canyon’s hydrology and aquatic resources.

Approximately 10% or 125 $km^2$ of Grand Teton is covered by surface water, most of which is contained in six piedmont lakes along the eastern front of the Teton Range, with Jackson Lake Reservoir being the largest. About 100 alpine lakes (varying from 0.004 to 0.24 $km^2$) are within the Teton Range, mostly above 304.5 m elevation. Approximately 75 pothole ponds of less than 0.0002 to more than 0.14 $km^2$ occur in the glacial-drift area south and east of Jackson Lake. Seven streams originating in the Teton Range drain eastward into Jackson Lake; six others drain into Cottonwood Creek and the Snake River near Moose, Wyoming; and three drain the southern portion of the Teton Range into

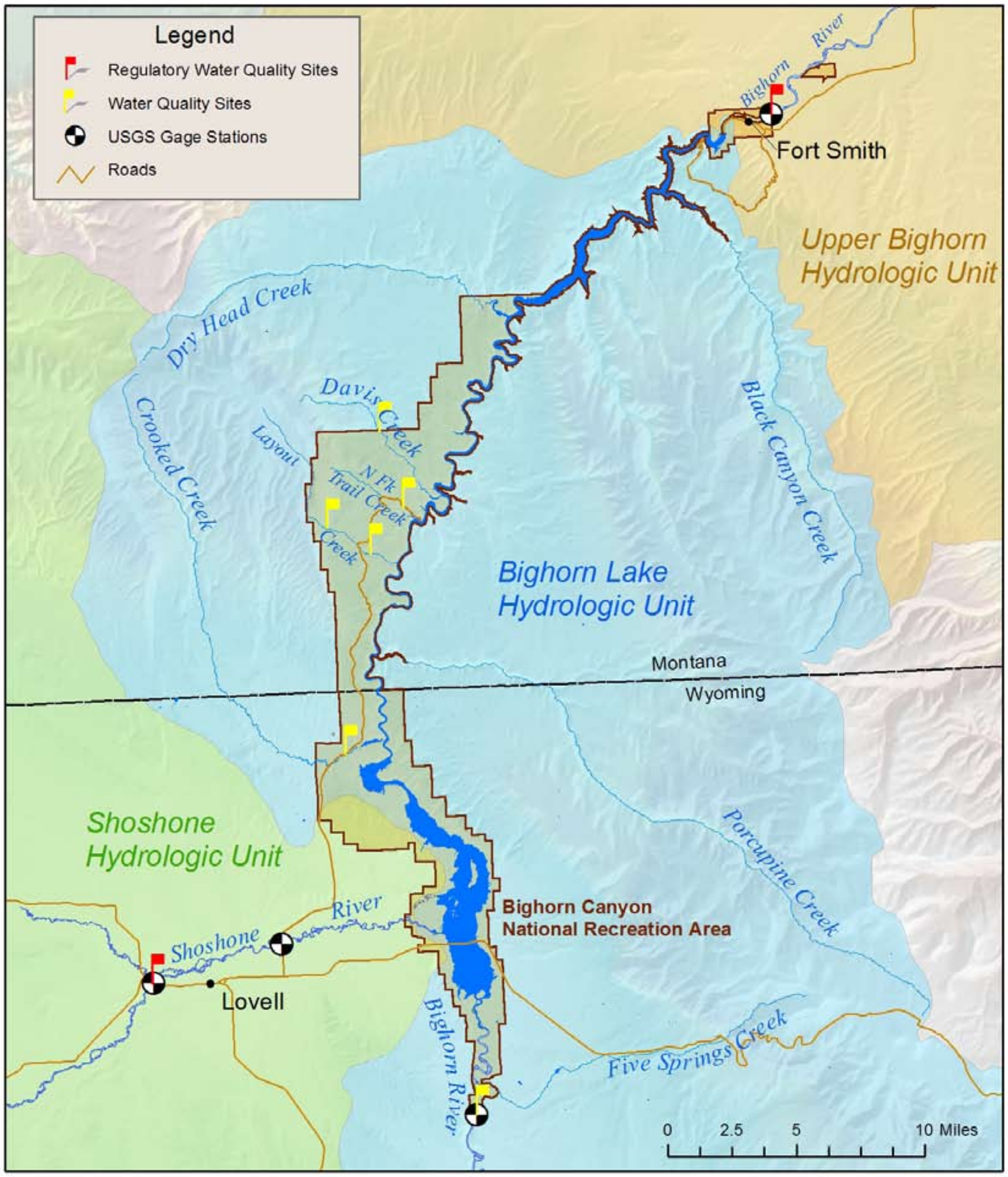



Figure 1. Water quality monitoring sites sampled in 2006 at Bighorn Canyon National Recreation Area.

Lake and Fish Creeks, which flow into the Snake River south of the park. Eight major streams drain highlands in the Bridger-Teton National Forest north and east of the park and flow into Jackson Lake or the Snake River within the park. All surface and groundwater in the park drains into the Snake River, which originates in highlands of the Teton Wilderness Area, flows north and west through part of Yellowstone, south through the parkway, and into Jackson Lake in the park. From Jackson Lake, the Snake River flows east and then south for about 40 km before crossing the park's south boundary. The entire park is part of the Snake River hydrologic unit (fig. 2).

Yellowstone encompasses approximately 9,065 km$^2$ of watersheds that preserve one of the most significant, near-pristine aquatic environments in the U.S. and contribute to two of the nation's farthest-reaching drainages: the Missouri and Columbia rivers. About five percent of the park is covered by water, including more than 220 lakes and 1,000 streams. Yellowstone Lake, which lies at an elevation of 2,356 m, covers 352 km$^2$ and is 122 m deep,

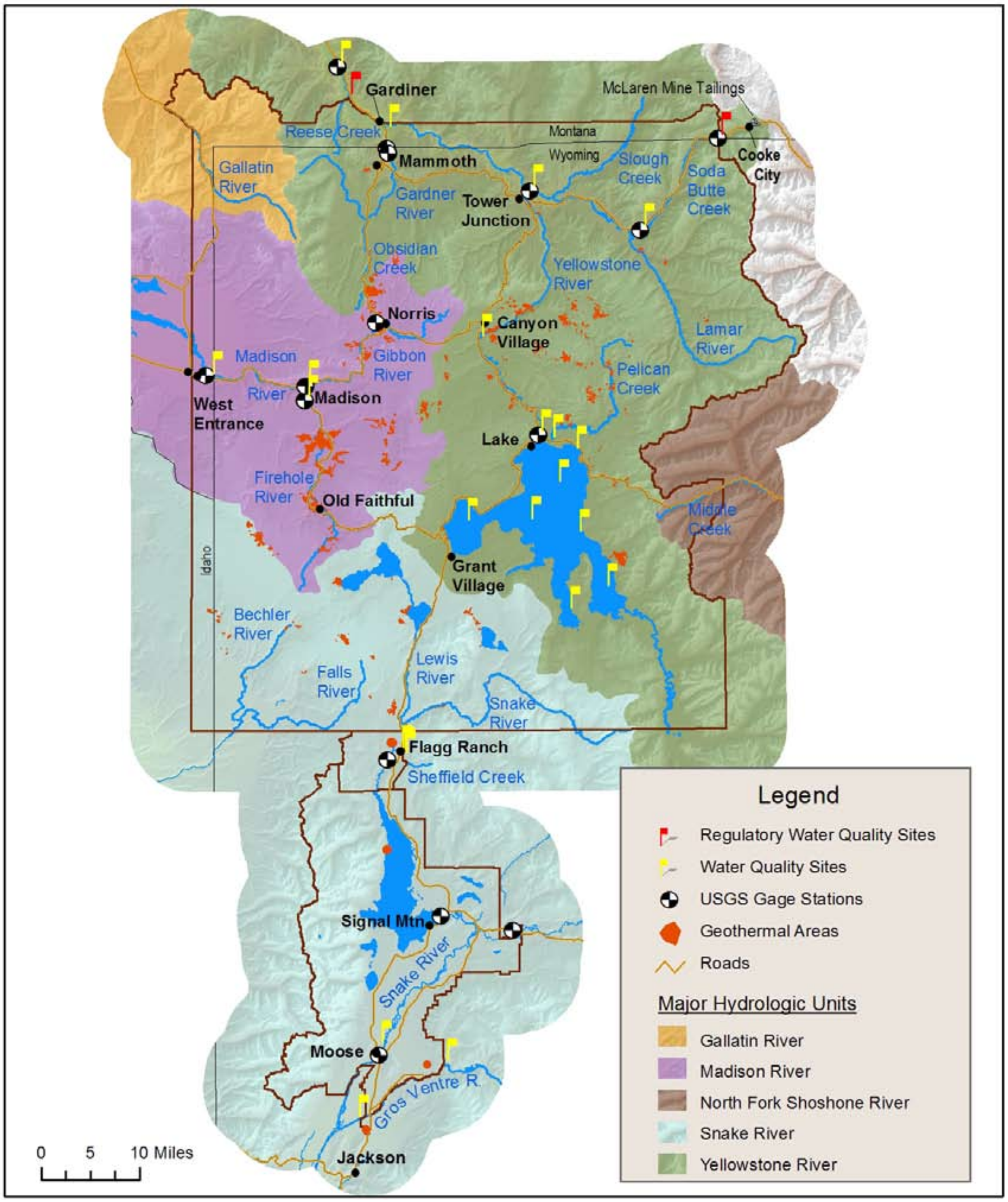



Figure 2. Water quality monitoring sites sampled in 2006 at Grand Teton and Yellowstone national parks.

is the largest lake at high elevation in North America. As a result of both natural topography and early preservation actions, the headwaters of five major river systems (Fall, Gallatin, Madison, Snake, and Yellowstone) are either in or just upstream from the park. More than 50% of the park's surface waters are located within the Yellowstone Headwaters hydrologic unit (fig. 2). Other hydrologic units within park boundaries are the Madison, Snake Headwaters, Upper and Lower Henrys, North Fork Shoshone, and the Gallatin.

NPS

Bighorn Canyon expanded water quality monitoring activities in 2006 to include a total of eight stream and river sites in and around the park that were sampled on a quarterly basis.

## 3. Results and Discussion

The following is a summary of the results and preliminary data analyses for water quality sampling conducted for the GRYN between October 2005 and December 2006. Water quality data were entered in the NPSTORET database, and data verification and validation were performed. Routine data summaries were performed and evaluated.

### *3.1 Bighorn Canyon National Recreation Area*

Bighorn Canyon expanded water quality monitoring activities in 2006, to include a total of eight stream and river sites in and around the park that were sampled on a quarterly basis. Two sampling sites located at USGS gage stations were monitored for regulatory (303[d]) purposes: the Shoshone River near Lovell, Wyoming, and the Bighorn River near St. Xavier, Montana (fig. 1). Five smaller, spring-fed stream sites were added to the monitoring plan: Crooked Creek, upper and lower Layout Creek, Davis Creek, and Trail Creek. Located near the southern boundary of the park, Crooked Creek is impacted by agricultural and industrial activities. Upper and lower Layout and Davis creeks bisect the interior of the South District. Their sampling examines the effects of activities such as cattle trailing and grazing on park hydrology. Paralleling a campground, the Trail Creek site monitors recreational inputs. A final sampling site was added at the Bighorn River upstream of the reservoir near Kane, Wyoming, in order to evaluate the quality and composition of water entering Bighorn Lake.

Core parameters measured at each site included pH, water and air temperature, DO, conductivity, and discharge. Additional variables sampled included concentrations of major cations, anions, and nutrients, as well as levels of turbidity. *E. coli* samples were taken from all eight sites in June 2006. Sampling at the Davis Creek site was only possible in June because the site was completely dry in both September and December.

#### 3.1.1 303(d) Quality-Impaired Streams

##### *3.1.1.1 Bighorn River Near St. Xavier, Montana*

The Bighorn River site near St. Xavier, Montana, is located in the North District of Bighorn Canyon. Sampling is conducted within a reach listed as impaired on the Montana 303(d) list. From January to July, monthly samples for nitrogen were collected and analyzed using method 300.0 (Hautman, Munch, and Pfaff 1997). During this period, no exceedances of the regulatory standard (10 mg/L) were detected. Sampling was then scaled back to a quarterly schedule for the remainder of the year.

Required field parameters remained within ranges normal for the Yellowstone River Basin. Water temperatures varied from 3.12°C to 13.72°C throughout the sampling year. Mean pH at the sampling site was slightly alkaline (7.458 ±0.333). Average DO and conductivity were 11.76 ±1.613 mg/L and 819.6 ±67.85 µSiemens/cm (µS/cm), respectively. Water composition within the Bighorn River site was calcium-sodium-magnesium-bicarbonate. Nutrients, *E. coli*, and turbidity measurements all remained within acceptable ranges, with no levels exceeding EPA (Environmental Protection Agency) standards.

Monthly nitrogen samples were analyzed by Energy Laboratories, Inc., of Billings, Montana, and quarterly samples taken during September and December were analyzed by Environmental Testing & Consulting, Inc., of Memphis, Tennessee,

both using method 300.0. All results were well below EPA limits (10 mg/L). Future samples will be analyzed using method E353.3 (Hautman, Munch, and Pfaff 1997). The change to this method resulted from concerns for the ability of field crews to ship and ensure that the samples were received by the laboratory within the limited time (48 hours) before which samples must be analyzed in order to meet quality assurance/quality control requirements, as well as the safety hazards associated with the addition of acid as a preservative in the field.

Analysis was completed for aquatic benthic macroinvertebrates collected in September 2005 using a D-frame kick net. Stream invertebrate samples were collected in November 2006, using a slack sampler kit with a 0.25-$m^2$ sampling square, a slight variation from the 2005 method. In addition, a habitat assessment was performed at the site. Results from the 2006 sampling have not yet been received, and will be included in the 2007 report. September 2005 results were analyzed according to the most current revision of Montana DEQ protocols (Montana DEQ 2006). In this revision, rather than using the Aquatic Life Threshold, impairment is determined using a multi-metric index (MMI) developed by Jessup, Hawkins, and Stribling (2006). An MMI was calculated for the sample to determine the Montana impairment score.

The MMI is an average of metric scores calibrated for different site classes (Mountains, Low Valleys, and Plains). The Bighorn River site was classified as a Plains site; however, it is important to note that this site is located primarily in the Wyoming Basin (ecoregion 18; Omernik and Bailey 1997), which was not included in any of the three site-class descriptions. Labeling the site as a "plain" is thus an approximation. Invertebrate results were entered and MMI calculations completed using the Ecological Data Application System (EDAS; Tetra Tech 2006), a data management and analysis program downloaded from the Montana DEQ. The Montana DEQ cut-off for severe impairment in plains ecosystems is a score of 27.0. The MMI result for the Bighorn River site was below 28.

This less-than-severe impairment score was most likely due to the high richness of midge, crustacean, and mollusk taxa within the macroinvertebrate sample population. Macroinvertebrate species diversity at the Bighorn River sample site was measured using a variety of diversity indices. The Shannon-Weiner diversity index, which accounts for subspecies richness and proportion of each subspecies within a zone, score for biodiversity was 2.22. Species evenness, a measure of the similarity in the abundances of different species, was fairly moderate, at 0.65. Thus, while the number of taxa recorded for the Bighorn River was not extremely low (27), the low abundance of certain groups, such as Ephemeroptera, Plecoptera, and Trichoptera (EPT) taxa, *Tanypodinae*, and predators, indicate impairment at the site. Macroinvertebrate diversity, evenness, and impairment scores will be more useful when they can be compared to future results.

##### *3.1.1.2 Shoshone River Near Lovell, Wyoming*

In 2006, the Shoshone River sampling site was moved from the bridge crossing on Road 37 (a historical USGS water-quality sampling site) to its current location off of U.S. Highway 14A just outside of Lovell, Wyoming (USGS site 06285100). This change facilitates discharge measurements by using the data from the USGS gauging station at this location. Regulatory *E. coli* monitoring continued (monthly, week-long sampling during the recreation season) in addition to quarterly sampling procedures. Week-long *E. coli* sampling was completed in June, August, and September.

Field parameters measured at the Shoshone River were similar to those in the Bighorn River. The pH of the river was slightly alkaline, ranging from 7.57 to 8.66. Water temperatures varied from 2.62°C to 19.93°C. Dissolved-oxygen concentrations averaged at 9.341 ±1.099 mg/L and conductivity 672.6 ±126.3 µS/cm. Water composition at the Shoshone River was calcium-sodium-magnesium-bicarbonate, possibly reflecting the input of river sediments from the Absaroka Volcanic Subgroup (Lageson and Spearing 2004).

Concentrations of ions such as sulfate and nitrogen remained well below EPA limits. Mean phosphorus concentration (0.236 ±0.132 mg/L) exceeded the EPA goal for minimizing nuisance plant growth. Excessive phosphorus concentrations in aquatic systems can lead to negative processes such as eutrophication, the process in which a water body becomes rich in organic nutrients that promote the growth of algae and impede the survival of other species. Phosphorus concentrations will be closely monitored in future sampling. The single turbidity (cloudiness) measurement of 78 nephlometric turbidity units (NTU), taken in September 2006, exceeded the EPA high-limit standard of 50 NTU. Although high turbidity is not a direct health risk, increased silt levels can promote the growth of pathogens by providing shelter for microbes (EPA 1999). Excessive turbidity in aquatic ecosystems may also reduce photosynthesis of aquatic plant species and inhibit respiration of fish and invertebrates.

The geometric mean of *E. coli* concentrations (measured in colony forming units [cfu]) sampled from the Shoshone River was 567.7 cfu/100 ml. Overall, 93% of samples taken exceeded EPA high-limit standards of 126 cfu/100ml. It is logical that *E. coli* concentrations would be high in the Shoshone, a regulated river system adjacent to multiple populated areas. Probable sources of *E. coli* include sewage, agricultural and domestic waste, wildlife waste, and septic systems. The presence of *E. coli* can be dangerous to human health. The Shoshone River will continue to be monitored in June, July, August, and September of future sampling years.

### 3.1.2 Waters of Management Interest in Bighorn Canyon

Field parameters measured in park streams remained within a normal range, but varied greatly between different sites and sampling dates. Water temperatures ranged from 0.12°C to 19.59°C. The pH of the samples was again slightly basic, with a mean of 7.858. DO averaged 9.041 ±1.508 mg/L, and conductivity averaged 236 ±405.6 µS/cm.

Water composition varied slightly among the six non-regulatory sampling sites within the park, with an average composition of

calcium-magnesium-sodium-sulfate. The chemical composition of park surface waters is most likely due to the weathering of Cretaceous- and Tertiary-period sedimentary rocks underlying the basin. Differences in water composition reflect the diverse topography and geology of the region. For instance, a predominance of calcium-bicarbonate at the upper Layout Creek site is possibly due to its higher elevation, in addition to deposits from the Madison limestone formation.

Stream concentrations of phosphorus within the park varied greatly, ranging from 0.025 to 1.32 mg/L. The average concentration of total phosphorus was 0.2148 ±0.394 mg/L, exceeding the EPA goal of 0.1 mg/L for minimizing nuisance plant growth. Three water-quality parameters were above EPA standards. Concentrations of sulfate within park streams exceeded the EPA drinking water standard of 250 mg/L in 60% of samples collected, with an average concentration of 402.4 ±402.2 mg/L. Excess sulfate contributions were most likely derived from natural, not anthropogenic sources. Interestingly, 40% of turbidity measurements within the park exceeded the EPA high-limit value of 50 NTU, with a mean of 271.6 ±559.2 NTU. Turbidity levels were extremely high at the Bighorn River near Kane, Wyoming (1,270 NTU).

*E. coli* concentrations within park streams varied greatly, ranging from 23 to 309 cfu/100 ml with a geometric mean of 66.21 cfu/100 ml. Twenty-nine percent of values exceeded the EPA high-limit standard of 126 cfu/100ml. Crooked Creek was the only nonregulatory sampling site within the park to exceed the EPA limit, averaging 237 ±72 cfu/100ml. It is logical that *E. coli* concentrations might be high at the site, located near the entrance to the park; the creek travels through both agricultural and mining areas before reaching it.

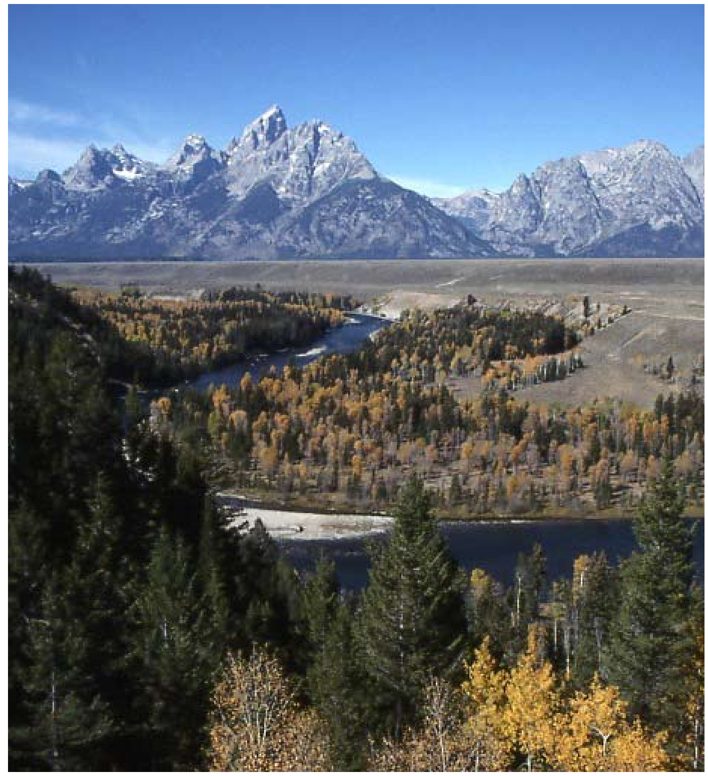
Water quality results from the 2006 monitoring period provide a baseline for future data comparison. It will be useful to compare and contrast results from subsequent sampling years, and to extrapolate trends in water composition and quality.

## *3.2 Grand Teton National Park*

### 3.2.1 Outstanding Natural Resource Waters

In 2006, Grand Teton began monitoring park rivers and streams as part of the GRYN vital signs monitoring program. The objective of this monitoring is to determine the status and long-term trends in surface water chemistry and discharge in selected perennial rivers and streams. This monitoring focuses on assessing physical and chemical characteristics (including suspended sediment, dissolved solids, major ions and metals, nutrients, and dissolved pesticides), and relating these characteristics to hydrologic conditions (discharge), sources, and transport. Discharge measurements are critical for interpreting data and assessing trends in stream-water chemistry that are sensitive to streamflow differences.

A review of historical data shows that many of the rivers and streams in Grand Teton have been sampled by the USGS using the National Water-Quality Assessment (NAWQA) protocols. By continuing this type of targeted, fixed-station sampling, the GRYN will collect data comparable to the historical USGS data.



These two sites on the main stem of the Snake River will be monitored annually: Flagg Ranch and Moose. Both of these sites are colocated with existing USGS gage stations.

The sampling design for Grant Teton adds an “above-and-below” approach (in which a stream or river is sampled at two fixed sites, one above some perceived or potential threat and the second below that same threat) to the basic USGS fixed-site monitoring strategy. By adding this component, Grant Teton will be able to identify reach segments that are degrading. Changes in water chemistry may indicate the need for further synoptic studies to determine the cause of the change. The target population for sampling water quality in Grant Teton is limited to the water quality at the sampling site. No inferences will be made to “all the flowing waters of the park,” as park resource managers have asked for a more targeted approach that could describe the quality of park waters at specific locations which are of interest to the general public.

Most of the major water bodies in Grant Teton have been sampled many times for water quality; however, most locations have only been sampled periodically, or were sampled intensively for just one or two years or for just one or two parameters; thus, these data are of limited value for determining the status and trends in park water quality. Woods and Corbin (2003) reviewed existing water quality data and determined that Grant Teton water quality is generally very high, and has been little impacted by human activity in the park and in upstream watersheds. Water quality sampling conducted by the USGS on five eastern tributaries during 2002 and 2003 (Clark, Sadler, and O’Ney 2004) indicates that water chemistry, including nutrients, varies in response to the geologic terrain.

In 2006, Grand Teton field crews made a total of three site

visits to each of six locations and collected approximately 149 water quality samples for laboratory analysis. The 2006 water quality monitoring stations in Grand Teton are shown in figure 2. The Snake River was monitored at two locations: Snake River at Flagg Ranch and Snake River at Moose. Both of these sites are colocated with existing USGS gage stations. Samples were collected three times: at high flow, low flow, and somewhere in between. For each sampling event, in addition to collecting the five required field parameters (temperature, pH, DO, specific conductivity and discharge), samples were collected and analyzed for alkalinity, major anions, major cations, metals, nutrients, and total suspended solids. These two sites on the main stem of the Snake River will be monitored every year.

Sampling was also conducted on two tributaries of the Snake River. Sheffield Creek and the Gros Ventre River were sampled at "above-and-below" locations. Samples were collected as for the Snake River, described above. These tributary sites will be re-sampled approximately every five years.

Preliminary results support those found in previous studies—the water quality (as measured at fixed sites) in Grand Teton is generally high. Major-ion chemistry varies between basins and from north to south, probably as a result of geologic differences between the tributary basins. Samples taken from the Snake River at Moose exhibit a dilution of major ions when compared to samples taken at Flagg Ranch.

In 2007, Grand Teton plans to target three known high-risk alpine lakes to determine the status and trend in their acid-neutralizing capacity and estimate the rate at which high-alpine water chemistry is changing over time in the park. In future years, monitoring will include the status and long-term trends in surface water chemistry of selected lakes, including Jackson Lake.

## *3.3 Yellowstone National Park*

### 3.3.1 303(d) Quality-Impaired Streams

#### *3.3.1.1 Soda Butte Creek*

Soda Butte Creek is located in the northeast corner of Yellowstone. A section of this creek, outside of park boundaries, is listed as impaired by the State of Montana on its 303(d) list. Instream metals contamination in Soda Butte Creek is a result of historic mining in the vicinity of Cooke City, Montana, which is approximately eight kilometers from the park boundary. Mine tailings still persist within the floodplain of Soda Butte Creek, and contribute to the listing of the portion of this stream as impaired and only partially supporting of aquatic life and coldwater fisheries. During 2006, water quality measurements were collected as part of Yellowstone's long-term water quality monitoring program and the GRYN monitoring program.

Field parameters from this site, collected on one day each month between January and December, included water temperature, DO, pH, specific conductivity, and turbidity. Water samples were taken to the field laboratory of Yellowstone's Fisheries and Aquatic Science staff for analysis of total suspended solids (TSS) and volatile suspended solids (VSS) (table 1). In addition, water and sediment samples were analyzed for metals (arsenic, copper, iron, and selenium) during both high- and low-flow conditions, which occur in June and September, respectively (table 2). In 2005, water and sediment samples were analyzed by Energy Laboratories, Inc. In 2006, the GRYN contracted with Environmental Testing & Consulting, Inc. To allow for data comparability between the two sample years, the network decided that both analytical laboratories would analyze Soda Butte Creek metal samples in 2006.

All required field parameters were within ranges expected of high-elevation, coldwater streams (table 1). As expected, natural variations were observed in field parameters depending upon the time of day and month sampled. Mean water temperature was 4.3°C (range -0.2°C–11.9°C). DO concentrations (range 9.2–13.6 mg/L) tended to correspond with changes in water temperature, with higher concentrations being recorded during the cold, winter months and lower concentrations being recorded during the warmer periods of July and August. The pH of Soda Butte Creek was slightly basic, ranging between 7.4 and 8.5—considerably higher than pH values consistent with acid mine drainage (table 1). Values for specific conductance, turbidity, TSS, and VSS tended to be directly related to flow. In general, specific conductance (range 85–266 $\mu Scm^{-1}$) was lower during the spring high-flow period, while turbidity, TSS, and VSS tended to be higher (table 1). By contrast, the low-flow fall and winter periods produced higher specific conductance and lower turbidity, TSS, and VSS values (table 1).

Results for metals analysis are presented in table 2. Dissolved and total metals in water (arsenic, copper, and selenium) were below the analytical detection limit for all sample events, with the exception of dissolved copper on 15 June (0.0004 mg/L). This value is barely above the detection limit and still below acute and chronic aquatic-life standards for the State of Montana. Chronic levels for iron in water are 1 mg/L; there is no standard for acute levels of iron in water. Levels of both dissolved and total iron concentration in water did not exceed State of Montana aquatic-life standards for any sample event. Highest levels of dissolved and total iron concentration in water were 0.65 mg/L and 0.77 mg/L, both of which occurred on 15 June, at 1943 and 0815, respectively (table 2). Total hardness did not exceed 50 mg/L.

Concentrations of arsenic and copper in sediments were well below the probable effect concentrations listed by MacDonald and Ingersoll (2002): 33 mg/kg and 149 mg/kg, respectively. There are no recognized standards for iron and selenium in sediments. Concentrations of iron in sediment varied depending on the analytical laboratory. For samples analyzed by Energy Laboratories, Inc., iron concentration in sediments was 18,100 and 15,800 mg/kg in June and September, respectively. For samples analyzed by Environmental Consulting & Testing, Inc., iron concentration in sediments was 25,500 and 21,000 mg/kg in June and September, respectively (table 2). Concentration of selenium in sediments was below detection limits for both analytical laboratories and both sample events.

Aquatic macroinvertebrate sampling was conducted in August 2005 and 2006, to assess the overall stream health of Soda Butte Creek at the Yellowstone boundary. Results for the 2005 samples have been analyzed and compared to State of

**Table 1. Annual summary of physical measurements at established stream water-quality sites in Yellowstone National Park, calendar year 2006**

| Sample location | Statistic | Water temperature (°C) | DO (mg/L) | pH | Specific conductance (µS $cm^{-1}$) | Turbidity (NTU) | TSS (mg/L) | VSS (mg/L) |
|---|---|---|---|---|---|---|---|---|
| Firehole River[a] (YELL_FH001.8C) | Mean | 14.3 | 8.7 | 8.2 | 471.0 | 2.7 | 4.9 | 2 |
| | Median | 14.5 | 8.8 | 8.3 | 528.0 | 2.2 | 3.8 | 1.2 |
| | Minimum | 6.2 | 7.3 | 7.7 | 207.0 | 0.7 | 0.5 | 0.6 |
| | Maximum | 22.1 | 10.1 | 8.5 | 639.0 | 8.0 | 19.4 | 7.5 |
| | Std. dev | 1.3 | 0.2 | 0.1 | 41.7 | 0.6 | 1.4 | 0.5 |
| | N Obs. | 14 | 12 | 14 | 14 | 14 | 14 | 14 |
| Gardner River[a] (YELL_GN002.9M) | Mean | 13.8 | 9.6 | 8.3 | 609.2 | 19.5 | 19.2 | 3.7 |
| | Median | 13.3 | — | 8.3 | 735.0 | 4.6 | 5.7 | 1.5 |
| | Minimum | 9.2 | 8.5 | 7.9 | 168.0 | 1.4 | 2.2 | 0.8 |
| | Maximum | 23.0 | 10.6 | 8.5 | 909.0 | 117.0 | 102.0 | 13.3 |
| | Std. dev | 1.2 | 0.3 | 0.0 | 73.6 | 10.4 | 8.6 | 1.3 |
| | N Obs. | 12 | 8 | 12 | 12 | 12 | 12 | 12 |
| Gibbon River[a] (YELL_GB000.2M) | Mean | 11.4 | 9.3 | 7.0 | 419.4 | 4.5 | 5.9 | 1.7 |
| | Median | 11.0 | 9.1 | 7.1 | 488.0 | 3.5 | 4.8 | 1.4 |
| | Minimum | 3.8 | 7.9 | 6.6 | 139.0 | 1.0 | 0.7 | 0.6 |
| | Maximum | 19.3 | 10.6 | 7.2 | 614.0 | 15.4 | 27.1 | 5.7 |
| | Std. dev | 1.4 | 0.3 | 0.1 | 42.9 | 1.0 | 1.8 | 0.3 |
| | N Obs. | 14 | 11 | 14 | 14 | 14 | 14 | 14 |
| Lamar River (YELL_LM000.5M) | Mean | 6.1 | 11.6 | 7.9 | 172.2 | 8.5 | 11.4 | 1.9 |
| | Median | 6.8 | 11.6 | 8.0 | 196.0 | 2.6 | 2.9 | 1.2 |
| | Minimum | 0.0 | 9.7 | 6.1 | 71.0 | 0.9 | 1.1 | 0.7 |
| | Maximum | 17.2 | 14.6 | 8.8 | 271.0 | 50.8 | 70.0 | 7.4 |
| | Std. dev | 1.8 | 0.5 | 0.2 | 19.3 | 3.8 | 5.4 | 0.5 |
| | N Obs. | 13 | 10 | 13 | 13 | 13 | 13 | 13 |
| Madison River[a] (YELL_MD133.2T) | Mean | 11.7 | 9.5 | 7.9 | 462.3 | 3.5 | 6.5 | 1.9 |
| | Median | 12.1 | 9.6 | 7.9 | 520.0 | 2.5 | 3.7 | 1.4 |
| | Minimum | 3.3 | 8.0 | 7.5 | 176.0 | 0.7 | 0.7 | 0.6 |
| | Maximum | 20.4 | 11.9 | 8.3 | 619.0 | 16.6 | 38.7 | 8.5 |
| | Std. dev | 6.1 | 1.1 | 0.3 | 151.2 | 4.2 | 10.0 | 2.1 |
| | N Obs. | 13 | 10 | 13 | 13 | 13 | 13 | 13 |
| Pelican Creek[a] (YELL_PC000.4M) | Mean | 5.6 | 9.2 | 7.2 | 378.1 | 22.4 | 23.5 | 5.5 |
| | Median | 0.3 | 9.4 | 7.1 | 434.0 | 13.1 | 13.1 | 4.9 |
| | Minimum | -0.2 | 7.3 | 6.8 | 64.0 | 8.3 | 10.8 | 0.1 |
| | Maximum | 18.6 | 10.6 | 7.7 | 588.0 | 71.1 | 81.2 | 12.2 |
| | Std. dev | 7.1 | 1.1 | 0.3 | 173.6 | 22.8 | 25.0 | 3.1 |
| | N Obs. | 11 | 10 | 13 | 11 | 11 | 12 | 12 |

*Note*: NPSTORET station ID is given in parentheses. DO = dissolved oxygen; µS $cm^{-1}$ = µSiemens $cm^{-1}$; NTU = nephlometric turbidity units; TSS = total suspended solids; VSS = volatile suspended solids.

[a]Stream sites with major thermal contributions.

[b]Stream sites with little thermal contributions.

**Table 1 *(continued)***

| Sample location | Statistic | Water temperature (°C) | DO (mg/L) | pH | Specific conductance (µS cm$^{-1}$) | Turbidity (NTU) | TSS (mg/L) | VSS (mg/L) |
|---|---|---|---|---|---|---|---|---|
| Soda Butte Creek, lower (YELL_SB001.5M) | Mean | 6.1 | 10.0 | 7.3 | 244.8 | 5.8 | 8.9 | 1.5 |
| | Median | 5.3 | — | 7.5 | 272.5 | 2.2 | 2.1 | 0.9 |
| | Minimum | 0.8 | 8.3 | 6.6 | 116.0 | 1.0 | 1.1 | 0.6 |
| | Maximum | 15.1 | 11.2 | 7.9 | 343.0 | 28.5 | 47.4 | 5.1 |
| | Std. dev | 5.1 | 0.9 | 0.4 | 72.7 | 9.3 | 16.0 | 1.5 |
| | N Obs. | 12 | 8 | 12 | 12 | 12 | 12 | 12 |
| Soda Butte Creek, upper (YELL_SB015.7A) | Mean | 4.3 | 10.4 | 8.0 | 185.6 | 4.6 | 6.7 | 1.2 |
| | Median | 4.9 | 10.0 | 8.0 | 206.5 | 3.0 | 2.9 | 1.1 |
| | Minimum | -0.2 | 9.2 | 7.4 | 85.0 | 1.2 | 0.8 | 0.5 |
| | Maximum | 11.9 | 13.6 | 8.5 | 266.0 | 18.2 | 26.8 | 2.7 |
| | Std. dev | 3.9 | 1.1 | 0.3 | 66.6 | 4.6 | 7.9 | 0.6 |
| | N Obs. | 16 | 13 | 16 | 16 | 16 | 16 | 16 |
| Yellowstone River at Fishing Bridge (YELL_YS616.4M) | Mean | 7.1 | 9.5 | 7.7 | 99.1 | 1.3 | 1.1 | 0.8 |
| | Median | 4.4 | 9.7 | 7.5 | 93.0 | 1.2 | 1.0 | 0.8 |
| | Minimum | 0.8 | 7.9 | 7.0 | 87.0 | 0.4 | 0.2 | <0.2 |
| | Maximum | 17.9 | 11.0 | 8.5 | 123.0 | 2.8 | 2.5 | 1.2 |
| | Std. dev | 1.6 | 0.2 | 0.1 | 3.6 | 0.2 | 0.2 | 0.1 |
| | N Obs. | 15 | 14 | 15 | 15 | 15 | 15 | 15 |
| Yellowstone River at Canyon[b] (YELL_YS600.5M) | Mean | 7.3 | 9.5 | 6.8 | 130.3 | 3.1 | 3.5 | 1.5 |
| | Median | 9.8 | — | 7.1 | 137.0 | 2.9 | 2.6 | 1.2 |
| | Minimum | -0.2 | 7.2 | 5.4 | 82.0 | 1.0 | 1.1 | 0.8 |
| | Maximum | 16.3 | 12.4 | 7.5 | 183.0 | 8.2 | 8.1 | 3.1 |
| | Std. dev | 2.2 | 0.6 | 0.2 | 11.9 | 1.0 | 0.8 | 0.2 |
| | N Obs. | 10 | 8 | 10 | 10 | 10 | 11 | 11 |
| Yellowstone River at Corwin Springs[b] (YELL_YS549.7M) | Mean | 8.5 | 11.4 | 8.0 | 221.1 | 16.0 | 24.8 | 2.9 |
| | Median | 6.4 | — | 8.0 | 249.5 | 3.8 | 4.2 | 1.2 |
| | Minimum | 2.0 | 10.1 | 7.3 | 71.0 | 1.8 | 2.2 | 0.9 |
| | Maximum | 18.5 | 12.3 | 8.8 | 343.0 | 122.0 | 203.4 | 16.7 |
| | Std. dev | 6.2 | 0.9 | 0.4 | 91.1 | 34.0 | 57.3 | 4.5 |
| | N Obs. | 12 | 8 | 12 | 12 | 12 | 12 | 12 |

*Note*: NPSTORET station ID is given in parentheses. DO = dissolved oxygen; µS cm$^{-1}$ = µSiemens cm$^{-1}$; NTU = nephlometric turbidity units; TSS = total suspended solids; VSS = volatile suspended solids.

[a]Stream sites with major thermal contributions.

[b]Stream sites with little thermal contributions.

Montana impairment scores; the 2006 invertebrate sample is still being processed. Aquatic macroinvertebrates are excellent biological indicators of stream health because they are sensitive to environmental changes, relatively sedentary, and long-lived (1–2 years). In 2005, there were 34 invertebrate taxa, 20 of which were EPT taxa, collected at Soda Butte Creek (table 3). Total abundance was estimated at 1,740 invertebrates/m$^2$ and 1,583 EPT taxa/m$^2$, and the Hilsenhoff biotic index was calculated at 2.91 (table 3). State of Montana impairment scores for streams are expressed as a range from 0 to 1 (0 = most impaired, 1 = least impaired) (table 4). The 2005 metric scoring for Soda Butte Creek is 0.85 (table 5). When these data are compared with the suggested State of Montana impairment score, Soda Butte Creek at the Yellowstone boundary rates as a stream that is fully supportive of aquatic life, with no evidence of impairment.

**Table 2. Concentrations of select metal concentrations on Soda Butte Creek at northeast park boundary between June and September 2006**

| Date | Matrix | Analysis | Time (MDST) | Hardness | Measured analyte | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | Arsenic | Copper | Iron | Selenium |
| Laboratory analysis conducted by Energy Laboratories, Inc. | | | | | | | | |
| 15 Jun | Aqueous (mg/L) | Dissolved metals | 0815 | — | <0.008 | <.003 | 0.77 | <0.02 |
| | | | 1943 | — | <0.008 | 0.004 | 0.65 | <0.02 |
| | | Total metals | 0815 | 39 | <0.008 | <0.003 | 0.12 | <0.02 |
| | | | 1943 | 40 | <0.008 | <0.003 | 0.12 | <0.02 |
| 20 Sep | Aqueous (mg/L) | Dissolved metals | 0957 | — | <0.008 | <0.003 | 0.23 | <0.02 |
| | | | 1633 | — | <0.008 | <0.003 | 0.26 | <0.02 |
| | | Total metals | 0957 | 100 | <0.008 | <0.003 | <0.03 | <0.02 |
| | | | 1633 | 96 | <0.008 | <0.003 | <0.03 | <0.02 |
| 20 Jun | Sediment (mg/kg) | Total metals | 1017 | — | <5 | 32 | 18,100 | <5 |
| 20 Sep | Sediment (mg/kg) | Total metals | 0957 | — | <5 | 17 | 15,800 | <5 |
| Laboratory analysis conducted by Environmental Testing & Consulting, Inc. | | | | | | | | |
| 15 Jun | Aqueous (mg/L) | Dissolved metals | 0815 | 42.5 | <0.01 | <0.005 | 0.11 | <0.01 |
| | | | 1943 | 38.1 | <0.01 | <0.005 | 0.115 | <0.01 |
| | | Total metals | 0815 | 43.4 | <0.01 | <0.005 | 0.592 | <0.01 |
| | | | 1943 | 40.7 | <0.01 | <0.005 | 0.591 | <0.01 |
| 20 Sep | Aqueous (mg/L) | Dissolved metals | 0957 | 101 | <0.01 | <0.005 | <0.1 | <0.01 |
| | | | 1633 | 97.3 | <0.01 | <0.005 | <0.1 | <0.01 |
| | | Total metals | 0957 | 105 | <0.01 | <0.005 | 0.292 | <0.01 |
| | | | 1633 | 102 | <0.01 | <0.005 | 0.312 | <0.01 |
| 20 Jun | Sediment (mg/kg) | Total metals | 1017 | — | 2.58 | 36.9 | 25,500 | <1 |
| 20 Sep | Sediment (mg/kg) | Total metals | 0957 | — | 1.56 | 22.9 | 21,000 | <5 |

It is recommended that water quality monitoring on Soda Butte Creek at the park boundary be continued to establish seasonal and annual trends regarding basic field parameters, metal concentrations, dissolved anions, dissolved cations, nutrients, and benthic macroinvertebrate communities. Although total metal concentrations appear to be minimal, Soda Butte Creek is still at risk from upstream contamination during an extreme flood event. Currently, state and federal agencies are participating in a long-term plan to remove the McLaren mine tailings from the streambed. Continued monitoring of Soda Butte Creek is imperative to evaluate current water quality conditions and to monitor changes, both favorable and adverse, that may occur in the event that the McLaren mine tailings are removed from the streambed.

*3.3.1.2 Reese Creek*

Discharge measurements on Reese Creek were collected during 13 site visits between 15 May and 12 October 2006, by Yellowstone's resource management staff (table 6). Discharge measurements were collected from two locations: (1) just above the uppermost flume and (2) stream water flowing through the upper diversion ditch. The difference between these two readings will equal the amount of water entering the main channel of Reese Creek from the uppermost flume (table 6). The adjudicated water right stipulated that Reese Creek was to have a minimum flow of 0.037 m$^3$/sec between 15April 15 and October during any given year. During 2006, discharge on Reese Creek ranged from 0.017 to 0.156 m$^3$/sec (table 6). Minimum flow requirements were not met on four of the eight days when both the upper flume and the diversion ditch were measured.

Water use and water rights issues surrounding Reese Creek continue to be a concern to park resource managers. A minimum streamflow of 0.037 m$^3$/sec is required to maintain healthy fish and aquatic invertebrate populations. These low flows seem to be of particular concern after spring runoff and during the heavy irrigation seasons of July and August, and could ultimately affect the overall survival of resident fishes in Reese Creek. Continued

**Table 3. Summary of metrics for Soda Butte Creek at northeast park boundary for 2005 macroinvertebrate collection**

| | Number of taxa | Abundance | % of group |
|---|---|---|---|
| Taxonomic group | | | |
| Non-insect | 3 | 32 | 1.9 |
| *Ephemeroptera* (mayflies) | 10 | 1,215 | 69.8 |
| *Plecoptera* (stoneflies) | 2 | 100 | 5.7 |
| *Trichoptera* (caddisflies) | 8 | 268 | 15.5 |
| Misc. *Diptera* (true flies) | 3 | 11 | 0.6 |
| *Chironomidae* (midges) | 8 | 114 | 6.5 |
| *Total* | 34 | 1,740 | 100 |
| Feeding group | | | |
| Predator | 7 | 160 | 9.3 |
| Parasite | 2 | 29 | 1.7 |
| Collector-gatherer | 15 | 1,017 | 58.3 |
| Scraper | 8 | 458 | 26.3 |
| Shredder | 1 | 65 | 3.7 |
| Omnivore | 1 | 11 | 0.7 |
| *Total* | 34 | 1,740 | 100 |
| Dominant taxa (of all taxa classified) | | | |
| *Drunella doddsi* | — | 560 | 32.2 |
| *Baetis tricaudatus* | — | 253 | 14.6 |
| *Cinygmula* | — | 124 | 7.1 |
| *Glossosoma* | — | 124 | 7.1 |
| *Rhthrogena* | — | 97 | 5.6 |
| *Total* | — | 1,158 | 66.6 |
| Summary | | | |
| Hilsenhoff Biotic Index | 2.91 | | |
| EPT abundance | 1,583 | | |
| Number of EPT taxa | 20 | | |
| % EPT | 90.9 | | |

*Note*: Abundance converted to m$^2$.

monitoring of discharge during the summer months is important to conserve the stream's native fish population and biological integrity.

### 3.3.2 Outstanding Natural Resource Waters

Yellowstone forms the core of the Greater Yellowstone Ecosystem, which is the largest intact ecosystem in the lower 48 states. All Wyoming water bodies within Yellowstone are classified as Outstanding Natural Resource Waters and designated as Class 1 waters by the State of Wyoming. There are approximately 11,216 km of streams and 43,706 ha of lakes in Yellowstone (Varley and Schullery 1998). Yellowstone and adjacent wilderness areas form the headwaters of three major rivers: the Yellowstone, Madison and Snake (fig. 2). In addition, Yellowstone contains >10,000 geothermal features, including geysers, hot springs, fumaroles and mud pots. These thermal features not only affect water temperatures, but also vary in acidity, and are natural sources

**Table 4. Suggested State of Montana aquatic-life use support/standards violations thresholds, expressed as a score range from 0 to 1**

| Score | Status |
|---|---|
| >0.75 | Full support: standards not violated |
| 0.25–0.75 | Partial support: standards violated; moderate impairment |
| <0.25 | Non-support: standards violated; severe impairment |

**Table 5. Provisional criteria for metric scoring for wadeable streams in Montana mountain regions**

| Score | 3 | 2 | 1 | 0 | Soda Butte Creek |
|---|---|---|---|---|---|
| Taxa richness | >28 | 28–24 | 24–19 | <19 | 3 |
| EPT richness | >19 | 19–17 | 17–15 | <15 | 3 |
| Biotic index | <3 | 3–4 | 4–5 | >5 | 3 |
| % dominant | <25 | 25–35 | 35–45 | >45 | 2 |
| % collectors (gatherer and filterer) | <60 | 60–70 | 70–80 | >80 | 3 |
| % scrapers and shredders | >55 | 55–40 | 40–25 | <25 | 1 |
| % EPT | >70 | 70–55 | 55–40 | <40 | 3 |
| | | | | Total | 18 |
| Site metric score/maximum possible score: 18 ÷ 21 = | | | | | 0.857143 |

*Note*: EPT = Ephemeroptera, Plecoptera, and Trichoptera taxa.

**Table 6. Streamflow measurements on Reese Creek between May and October 2006**

| | (m$^3$/sec) | | |
|---|---|---|---|
| Date | Upper flume | Upper diversion ditch | Reese Creek discharge |
| 15 May | 0.201 | 0.095 | 0.106 |
| 30 May | 0.287 | 0.131 | 0.156 |
| 1 Jun | 0.283 | — | — |
| 19 Jun | 0.246 | 0.140 | 0.105 |
| 27 Jun | 0.231 | — | — |
| 17 Jul | 0.160 | — | — |
| 19 Jul | 0.119 | 0.101 | 0.017* |
| 26 Jul | 0.147 | — | — |
| 8 Aug | 0.130 | 0.108 | 0.021* |
| 21 Aug | 0.118 | 0.083 | 0.035* |
| 28 Aug | 0.113 | 0.080 | 0.033* |
| 5 Sep | 0.112 | 0.068 | 0.044 |
| 12 Oct | 0.126 | — | — |

*Flows were below the minimum required flow of 0.037 m$^3$/sec.

of mercury, arsenic, and other chemicals that affect surface water composition.

During the 2006 calendar year, water samples were collected on one day each month from 11 established stream water-quality sites in Yellowstone (fig. 2). Basic water-quality parameters were collected from each site visit, including water temperature, DO, pH, specific conductivity, and turbidity. Water samples were also taken to the Yellowstone Fisheries and Aquatic Sciences field laboratory for TSS and VSS analysis. Beginning in June, additional water-quality parameters were added to the sampling protocol, including analysis of dissolved anions (chloride, sulfate, and total alkalinity), dissolved cations (calcium, magnesium, potassium, and sodium), and nutrients (nitrate, nitrite, ammonia, total phosphorus, and ortho-phosphate) from 10 water-quality sites. Water samples for chemical analysis were sent to Environmental Testing & Consulting, Inc.

Physical and chemical water quality data are directly related to seasonal changes, elevation, precipitation events, and presence or absence of thermal features. Water temperature and DO have a close relationship. As water temperature decreases, the solubility of oxygen in water increases (i.e., colder water holds more oxygen); conversely, as water temperature increases, the solubility of oxygen in water decreases (i.e., warmer water holds less oxygen). As expected, water temperature and DO are most closely related to seasonal changes, elevation, and proximity to geothermal areas. Warmer, summer months bring about warmer water temperatures and lower DO concentrations, while cool, winter months result in low water temperatures and higher DO concentrations. Similarly, small streams located at high elevations are colder (because of snowmelt and elevation) in summer than larger streams at lower elevations.

In 2006, water temperatures ranged between -0.2°C and 23°C. Lowest mean water temperatures were recorded for the Lamar River, upper Soda Butte Creek, and lower Soda Butte Creek. The coldest measurements were recorded at the Yellowstone River at Canyon, the Lamar River, Pelican Creek, and upper Soda Butte Creek (table 1). The latter four streams are ice-covered during winter months, which contributed largely to the low water temperatures observed. Upper Soda Butte Creek, a small, high-elevation stream located near the park's northeast entrance, had the lowest mean water temperature of 4.3°C (range -0.2°C–11.9°C). Conversely, highest mean water temperatures were recorded for the Gardner, Firehole, Gibbon, and Madison rivers (table 1). These four rivers are located within basins that have considerable geothermal activity (fig. 2). The highest water temperature (23°C) was recorded at the Gardner River on 8August 2006, while the highest mean temperature (14.3°C, range 6.2°C–22.1°C) occurred on the Firehole River (table 1). DO concentrations recorded in 2006 ranged between 7.2 and 14.6 milligrams per liter (mg/L), with the Yellowstone River at Canyon and the Lamar River having the lowest and highest DO readings, respectively (table 1). The Firehole River had the lowest mean DO concentration (8.7 mg/L, range 7.3–10.1 mg/L). The Lamar River had the highest mean DO concentration (11.55 mg/L, range 9.7–14.6 mg/L) (table 1).

Acidity of surface water is evaluated by measuring pH. In Yellowstone, the pH of surface waters can vary considerably; ranges between 2.0–9.0 are common, with most surface waters having a pH that is near neutral (pH 6.5–7.5) to slightly basic (pH 7.5–8.5). The pH of surface waters in Yellowstone is influenced by several factors, including water source, local geology, atmospheric deposition, and geothermal contributions. Within-site variation of pH is quite low, with most differences occurring between sites. This is best illustrated within the Madison River drainage. The Madison River receives water from the Firehole and Gibbon rivers, both of which are influenced by thermal activity. Mean pH for the Firehole River was 8.2 (range 7.7–8.5). This is the second-highest mean pH of all sites sampled, with the Gardner River having the highest mean pH (8.26, range 7.9–8.5). By contrast, the Gibbon River had a more neutral pH, with a mean of 6.96 (range 6.6–7.2). The lowest mean pH (6.76, range 5.4–7.5) was recorded at the Yellowstone River at Canyon (table 1). Geothermal water that is very acidic flows into both the Gibbon River and the Yellowstone River at Canyon, thus contributing to the lower pH values observed at these two sites (fig. 2).

Specific conductance, turbidity, and TSS are directly related to stream flow. Specific conductance is a measure of resistance of a solution to electrical flow. The resistance of water to electrical current will decline with increasing ion content (i.e., anions and cations). Hence, the purer the water, the lower the specific conductance value (Wetzel 2001). For all sites, specific conductance is lower during high-flow periods of May and June and higher during low-flow periods of late summer and winter. For example, the Gardner River experienced its highest flow from mid-May to mid-June. This coincided with the lowest specific conductivity readings for the entire year. During high flow, the volume of water increases due to snowmelt and spring rains. This, in effect, dilutes dissolved material in the water, resulting in lower conductivity readings. During low-flow periods of late summer and winter, dissolved materials in water are more concentrated, resulting in higher conductivity readings. The lowest mean specific conductance was 98 $\mu S\ cm^{-1}$, recorded for the Yellowstone River at Fishing Bridge (range 87–123 $\mu Scm^{-1}$). The highest mean specific conductance value (598 $\mu S\ cm^{-1}$, range 168–909 $\mu S$ cm-$^{1}$) was recorded at the Gardner River (table 1).

For turbidity and TSS, the reverse is true; faster-flowing water carries more suspended material (i.e., sand, silt, clay) than slower-moving water, resulting in more-turbid (cloudy) conditions during high-flow periods and less-turbid conditions (clearer) during low-flow periods. Turbidity readings and TSS concentrations tend to mirror each other. The Yellowstone River at Fishing Bridge had the lowest mean turbidity (1.3 nephelometric turbidity units [NTU], range 0.4–2.8 NTU) and had the lowest mean TSS concentration (1.1 mg/L, range 0.2–0.2.5 mg/L). The Yellowstone River at Fishing Bridge site is located at the Yellowstone Lake outlet (fig. 1). Suspended material entering Yellowstone Lake has adequate time to settle from the water column before reaching the lake outlet. This accounts for low turbidity and TSS values at this site. Pelican Creek had the highest mean turbidity (22.43 NTU, range 8.3–71.1 NTU) (table 1), while Pelican Creek (23.5 mg/L, range 10.8–81.2 mg/L) and the Yellowstone River at Corwin Springs, Montana (24.8 mg/L, range 2.2–203.4 mg/L), had the highest

**Table 7. Annual summary of chemical measurements at established stream water-quality sites in Yellowstone National Park, June–December 2006**

| Sample location | Statistic | mg/L | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Anions | | | Cations | | | | Nutrients | | | | |
| | | Dissolved chloride | Dissolved sulfate | Total alkalinity | Dissolved calcium | Dissolved magnesium | Dissolved potassium | Dissolved sodium | Nitrate-Nitrogen | Nitrite- Nitrogen | Ammonia-Nitrogen | Total phosphorus | Ortho-phosphate |
| Firehole River[a] (YELL_FH001.8C) | Mean | 67.43 | 12.45 | 107.6 | 5.513 | 0.4902 | 8.337 | 92.08 | 0.05 | 0.05 | 0.05 | 0.1797 | 0.1 |
| | Median | — | — | — | — | — | — | — | — | — | — | — | — |
| | Minimum | 59.4 | 10.8 | 99 | 5.23 | 0.444 | 7.8 | 88 | <0.05 | <0.05 | <0.05 | 0.092 | <0.1 |
| | Maximum | 73.1 | 14.2 | 116 | 5.86 | 0.604 | 8.82 | 96.9 | <0.05 | <0.05 | <0.05 | 0.251 | <0.1 |
| | Std. dev. | 5.206 | 1.487 | 6.066 | 0.2298 | 0.0577 | 0.338 | 3.847 | 0 | 0 | 0 | 0.0615 | 0 |
| | N. Obs. | 6 | 6 | 5 | 6 | 6 | 6 | 6 | 6 | 6 | 7 | 7 | 6 |
| Gardner River[a] (YELL_GN002.9M) | Mean | 26.86 | 100 | 156.4 | 65.62 | 17.47 | 10.91 | 27.55 | 0.05 | 0.05 | 0.05 | 0.0654 | 0.1233 |
| | Median | — | — | — | — | — | — | — | — | — | — | — | — |
| | Minimum | 5.75 | 25.7 | 130 | 46.9 | 11.6 | 5.99 | 15.1 | <0.05 | <0.05 | <0.05 | 0.034 | <0.1 |
| | Maximum | 38 | 148 | 168 | 79.8 | 21.8 | 14.3 | 36.8 | <0.05 | <0.05 | <0.05 | 0.136 | 0.24 |
| | Std. dev. | 12.34 | 44.51 | 15.32 | 11.51 | 3.608 | 3.004 | 7.882 | 0 | 0 | 0 | 0.0357 | 0.0572 |
| | N. Obs. | 7 | 7 | 5 | 6 | 6 | 6 | 6 | 6 | 6 | 7 | 7 | 6 |
| Gibbon River[a] (YELL_GB000.2M) | Mean | 52.98 | 24.03 | 98.1 | 8.75 | 1.297 | 10.73 | 73.03 | 0.05 | 0.05 | 0.05 | 0.1377 | 0.1 |
| | Median | — | — | — | — | — | — | — | — | — | — | — | — |
| | Minimum | 36 | 17.7 | 92 | 8.53 | 1.23 | 8.27 | 52.2 | <0.05 | <0.05 | <0.05 | 0.086 | <0.1 |
| | Maximum | 65.5 | 30.2 | 105 | 9.24 | 1.36 | 13 | 88.6 | <0.05 | <0.05 | <0.05 | 0.198 | <0.1 |
| | Std. dev. | 12.23 | 6.225 | 5.505 | 0.2542 | 0.0513 | 1.846 | 13.57 | 0 | 0 | 0 | 0.0466 | — |
| | N. Obs. | 6 | 6 | 5 | 6 | 6 | 6 | 6 | 6 | 6 | 7 | 7 | 6 |
| Lamar River (YELL_LM000.5M) | Mean | 0.05 | 5.638 | 95.12 | 20.8 | 6.936 | 1.544 | 8.14 | 0.05 | 0.05 | 0.05 | 0.0527 | 0.1 |
| | Median | — | — | — | — | — | — | — | — | — | — | — | — |
| | Minimum | <0.05 | 1.63 | 84.5 | 15.3 | 5.06 | 1.21 | 5.33 | <0.05 | <0.05 | <0.05 | <0.0125 | <0.1 |
| | Maximum | <0.05 | 7.71 | 106 | 24.7 | 8.2 | 1.85 | 9.98 | <0.05 | <0.05 | <0.05 | 0.115 | <0.1 |
| | Std. dev. | 0 | 2.485 | 10.48 | 3.637 | 1.237 | 0.2694 | 1.859 | 0 | 0 | — | 0.0378 | — |
| | N. Obs. | 6 | 6 | 4 | 5 | 5 | 5 | 5 | 5 | 5 | 7 | 7 | 5 |
| Madison River[a] (YELL_MD133.2T) | Mean | 59.82 | 14.77 | 106.7 | 6.553 | 0.7218 | 8.88 | 87.08 | 0.05 | 0.05 | 0.05 | 0.1798 | 0.1 |
| | Median | — | — | — | — | — | — | — | — | — | — | — | — |
| | Minimum | 51.7 | 10.9 | 92.5 | 6.25 | 0.649 | 7.96 | 78.1 | <0.05 | <0.05 | <0.05 | 0.093 | <0.1 |
| | Maximum | 64.1 | 19.9 | 115 | 6.82 | 0.789 | 9.71 | 98.7 | <0.05 | <0.05 | <0.05 | 0.269 | <0.1 |
| | Std. dev. | 5.017 | 3.61 | 9.338 | 0.225 | 0.0499 | 0.7797 | 7.162 | 0 | 0 | — | 0.0672 | — |
| | N. Obs. | 6 | 6 | 5 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| Pelican Creek[a] (YELL_PC000.4M) | Mean | 25.55 | 91.52 | 76.8 | 18.22 | 12.03 | 11.34 | 42.03 | 0.1422 | 0.1 | 0.2405 | 0.1002 | 0.1 |
| | Median | — | — | — | — | — | — | — | — | — | — | — | — |
| | Minimum | 14.8 | 57.8 | 65 | 14.3 | 8.9 | 7.77 | 27.2 | 0.05 | <0.05 | <.05 | 0.032 | <0.1 |
| | Maximum | 32.1 | 108 | 86 | 20.9 | 14.2 | 13 | 49.6 | 0.284 | <0.05 | 0.689 | 0.172 | <0.1 |
| | Std. dev. | 6.025 | 17.38 | 9.23 | 2.247 | 1.764 | 2.039 | 8.486 | 0.0887 | 0 | 0.2982 | 0.0581 | 0 |
| | N. Obs. | 6 | 6 | 5 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 |

Note: NPSTORET station ID is given in parentheses. N. Obs. = number of observations.

[a]Stream sites with major thermal contributions.

**Table 7 (*continued*)**

| | | mg/L | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Anions | | | Cations | | | | Nutrients | | | | | |
| Sample location | Statistic | Dissolved chloride | Dissolved sulfate | Total alkalinity | Dissolved calcium | Dissolved magnesium | Dissolved potassium | Dissolved sodium | Nitrate-Nitrogen | Nitrite- Nitrogen | Ammonia-Nitrogen | Total phosphorus | Ortho-phosphate |
| Soda Butte Creek, lower (YELL_SB001.5M) | Mean | 0.5143 | 6.489 | 130 | 31.25 | 10.04 | 1.717 | 4.295 | 0.05 | 0.05 | 0.05 | 0.0711 | 0.1 |
| | Median | — | — | — | — | — | — | — | — | —- | — | — | — |
| | Minimum | <0.05 | 3.16 | 119 | 22.2 | 6.76 | 1.1 | 3.58 | <0.05 | <0.05 | <0.05 | 0.0125 | <0.1 |
| | Maximum | 1.05 | 8.1 | 140 | 35.4 | 11.4 | 2.29 | 5.14 | <0.05 | <0.05 | <0.05 | 0.198 | <0.1 |
| | Std. dev. | 0.2897 | 1.86 | 9.772 | 4.86 | 1.716 | 0.3896 | 0.5205 | 0 | 0 | 0 | 0.0625 | 0 |
| | N. Obs. | 7 | 7 | 5 | 6 | 6 | 6 | 6 | 6 | 6 | 7 | 7 | 6 |
| Soda Butte Creek, upper (YELL_SB015.7A) | Mean | 0.4357 | 7.084 | 94.4 | 23.36 | 5.354 | 0.5323 | 4.472 | 0.05 | 0.05 | 0.05 | 0.0439 | 0.1 |
| | Median | — | — | — | — | — | — | — | — | — | — | — | — |
| | Minimum | <0.05 | 3.68 | 82 | 11 | 2.56 | 0.455 | 4.02 | <0.05 | <0.05 | <0.05 | <0.0125 | <0.1 |
| | Maximum | 0.5 | 9.68 | 110 | 30.6 | 6.78 | 0.701 | 4.73 | <0.05 | <0.05 | <0.05 | 0.103 | <0.1 |
| | Std. dev. | 0.1701 | 2.178 | 10.21 | 7.638 | 1.649 | 0.095 | 0.2512 | 0 | 0 | 0 | 0.0336 | 0 |
| | N. Obs. | 7 | 7 | 5 | 10 | 10 | 6 | 6 | 6 | 6 | 7 | 7 | 6 |
| Yellowstone River at Fishing Bridge (YELL_YS616.4M) | Mean | 4.852 | 7.76 | 31.4 | 5.505 | 2.477 | 1.808 | 9.497 | 0.05 | 0.05 | 0.05 | 0.0402 | 0.1 |
| | Median | — | — | — | — | — | — | — | — | — | — | — | — |
| | Minimum | 4.16 | 7.23 | 25 | 5.1 | 2.28 | 1.76 | 9.02 | <0.05 | <0.05 | <0.05 | <0.0125 | <0.1 |
| | Maximum | 5.35 | 8.67 | 35 | 5.97 | 2.62 | 1.89 | 10.2 | <0.05 | <0.05 | <0.05 | 0.125 | <0.1 |
| | Std. dev. | 0.4756 | 0.5357 | 4.099 | 0.342 | 0.1476 | 0.0512 | 0.4068 | 0 | 0 | 0 | 0.0402 | 0 |
| | N. Obs. | 6 | 6 | 5 | 6 | 6 | 6 | 6 | 6 | 6 | 7 | 7 | 6 |
| Yellowstone River at Corwin Springs[a] (YELL_YS549.7M) | Mean | 9.561 | 24.84 | 64.6 | 16 | 5.077 | 4.223 | 19.08 | 0.1173 | 0.05 | 0.0723 | 0.0717 | 0.1318 |
| | Median | — | — | — | — | — | — | — | — | — | — | — | — |
| | Minimum | 2.85 | 8.09 | 53 | 10.6 | 3.7 | 2.54 | 11.1 | <0.05 | <0.05 | <0.05 | <0.0125 | <0.1 |
| | Maximum | 13.9 | 39.4 | 74.5 | 21.3 | 6.51 | 5.62 | 25.5 | 0.238 | <0.05 | 0.143 | 0.198 | 0.291 |
| | Std. dev. | 4.349 | 11.35 | 9.147 | 3.818 | 1 | 1.104 | 4.935 | 0.0794 | 0 | 0.039 | 0.0624 | 0.078 |
| | N. Obs. | 7 | 7 | 5 | 6 | 6 | 6 | 6 | 6 | 6 | 7 | 7 | 6 |

Note: NPSTORET station ID is given in parentheses. N. Obs. = number of observations.

[a]Stream sites with major thermal contributions.

mean TSS concentrations, respectively. Pelican Creek is a slow-moving stream that flows into the northern portion of Yellowstone Lake, has a drainage area of approximately 19,047 ha, and has numerous thermal features that contribute various anions, cations, and nutrients to its overall chemical composition (fig. 2). The slow-moving water, coupled with the chemical elements, promotes growth of phytoplankton, which most likely contributes to the higher turbidity and TSS observed at this site.

Descriptive statistics for chemical composition of 10 water-quality sites are presented in table 7. Overall, chemical composition of water in Yellowstone is influenced by precipitation, local geology, atmospheric deposition and proximity to geothermal features. Mean dissolved-chloride concentrations were highest in the Firehole (67.43 mg/L), Gibbon (52.98 mg/L), and Madison (59.82 mg/L) rivers of the Madison River drainage. Mean dissolved-sulfate concentrations where highest at two sites in the Yellowstone River drainage: Gardner River (100 mg/L) and Pelican Creek (91.52 mg/L). Although these rivers have considerable geothermal activity, the chemical composition is apparently quite different between watersheds (table 7).

Similar comparisons were also noted for dissolved cations (calcium, magnesium, potassium, and sodium) and nutrients (nitrate, nitrite, ammonia, total phosphorus, and ortho-phosphate). The Gardner River had the highest mean concentrations of dissolved calcium (65.62 mg/L) and dissolved magnesium (17.47 mg/L), and the second-highest mean concentration of dissolved potassium (10.91 mg/L). Pelican Creek had the highest mean dissolved potassium (11.34 mg/L) (table 7). Both nitrate and ammonia were detected from only two locations: Pelican Creek and the Yellowstone River at Corwin Springs. Pelican Creek had the highest mean concentration for nitrate (0.1422 mg/L) and ammonia (0.2405 mg/L) (table 7). Sources for nitrate and ammonia at both sites are not known; however, ammonia is produced by some geothermal features in Yellowstone, and oxidization of ammonia produces nitrate (Fournier 1989; Miller, Clark, and Wright 2005). Ammonia is produced by the leaching of organic-rich sedimentary rocks at depth by the high temperatures and subsequent surface discharge of geothermal features (Love and Good 1970; Miller, Clark, and Wright 2005). The water quality sites at both Pelican Creek and the Yellowstone River at Corwin Springs are located downstream of geothermal features that could serve as the source for nitrate and ammonia.

Nitrite was below detection limits for all sites during the 2006 sample period (June–December). Similar to chloride concentrations, mean total phosphorus concentrations were highest at the three sites in the Madison River drainage: Firehole River (0.1797 mg/L), Gibbon River (0.1377 mg/L) and Madison River (0.1798 mg/L) (table 7). Ortho-phosphate was detected from only two water-quality sites, with mean concentrations of 0.1233 mg/L on the Gardner River and 0.1318.mg/L at the Yellowstone River at Corwin Springs (table 7).

## 4. Acknowledgements

We would like to acknowledge our field assistants (and others), without whom this work could never have been accomplished. At Bighorn Canyon, special thanks to Dana Thomas, Ryan Felkins, and Laura Meyers for their help in gathering and managing water quality data. At Grand Teton, many thanks to John Clune, Brian Villalobos, Andrew Bishop, and Damian Stoy for their excellent field work, and to Kelly McCloskey for her continued willingness to provide assistance. At Yellowstone, thanks to Nicole Legere, Jeremy Erickson, Hunter Hutchinson, and Hilary Billman for their outstanding dedication in collecting and maintaining quality data. Thanks also to Rob Daley and Dean Tucker for providing us with much-needed guidance and support in data management and NPSTORET.

## 5. Literature Cited


Clark M. L., W. J. Sadler, and S. E. O'Ney. 2004. *Water-quality characteristics of the Snake River and five tributaries in the upper Snake River basin, Grand Teton National Park, Wyoming, 1998-2002*. Scientific Investigations Report 2004-5017. Reston, VA: U.S. Geological Survey.

[EPA.] U.S. Environmental Protection Agency. 1999. *Guidance manual for compliance with the interim enhanced surface water treatment rule: Turbidity provisions*. EPA 815-R-99-010. Environmental Protection Agency, Office of Water. Available online at http://www.epa.gov/OGWDW/mdbp/mdbptg.html.

Fournier, R. O. 1989. Geochemistry and dynamics of the Yellowstone National Park hydrothermal system. *Annual Review of Earth Planetary Sciences* 17:13–53.

Gaufin, A. R. 1958. The effects of pollution on a midwestern stream. *Ohio Journal of Science* 58 (4): 197–208.

Hautman, D. P.,D. J. Munch, and J. D. Pfaff. 1997. *US EPA Method 300.1: Determination of inorganic anions in drinking water by ion chromatography*. Revision 1.0. Cincinnati, OH: U.S. Environmental Protection Agency National Exposure Research Laboratory. Available online at http://www.epa.gov/waterscience/methods/method/files/300_1.pdf.

Hoar, W. S. and D. J. Randall, eds. 1969. *Excretion, ionic regulation, and metabolism*. Volume 1 of *Fish physiology*. New York: Academic Press.

Holtze, K. E., and N. J. Hutchinson. 1989. Lethality of low pH and Al to early life stages of six fish species inhabiting Precambrian shield waters in Ontario. *Canadian Journal of Fisheries and Aquatic Sciences* 46 (7): 1188–1202.

Jessup, B., C. Hawkins, and J. Stribling. 2006. *Biological indicators of stream condition in Montana using benthic macroinvertebrates*. Prepared for Montana Department of Environmental Quality, Helena, MT.

Lageson, D. R., and D. R. Spearing. 2004. *Roadside Geology of Wyoming*. 2nd ed. Missoula, MT: Montana Press Publishing Company.

Love, J. D., and J M. Good. 1970. *Hydrocarbons in thermal areas, northwestern Wyoming*. Professional Paper 644-B. U.S. Geological Survey.

Luoma, S. N. 1989. Can we determine the biological availability of sediment-bound trace elements? *Hydrobiologia* 176–177 (1): 379–396.

MacDonald, D. D., and C. G. Ingersoll. 2002. *Interpretation of the results of sediment quality investigations*. Volume 3 of *A guidance manual to support the assessment of contaminated sediments in freshwater ecosystems*. Report EPA-905-B02-001-C. Chicago: U.S. Environmental Protection Agency, Great Lakes National Program Office.

Miller, K. A., M. L. Clark, and P. R. Wright. 2005. *Water-quality assessment of the Yellowstone River Basin, Montana and Wyoming: water quality of fixed sites, 1999-2001*. Scientific Investigations Report 2004-5113. Reston, VA: U.S. Geological Survey.

[Montana DEQ.] Montana Department of Environmental Quality. 2006. Sampling collection, sorting, and taxonomic identification of benthic macroinvertebrates: Water Quality Planning Bureau standard operation procedure WQPBWQM-009. Helena, MT: Montana Department of Environmental Quality.

Mott, D. N. 1998. *Grand Teton National Park, Wyoming, water resources scoping report*. Technical Report NPS/NRWRS/NRTR-98/154. CO: National Park Service.

National Park Service. 2000. National Park Service Strategic plan for FY 2001–2005. Washington, DC: National Park Service. Available online at http://planning.nps.gov/document/NPS_strategic_plan.pdf.

O'Ney, S. E. 2006. *Regulatory water quality monitoring protocol*. Version 2.0. Bozeman, MT: National Park Service, Greater Yellowstone Network.

Omernik, J. M., and R. G. Bailey. 1997. Distinguishing between watersheds and ecoregions. *Journal of American Water Resources Association* 33:935–49.

Richardson, R. E. 1925. Illinois River bottom fauna in 1923. *Bulletin of the Illinois Natural History Survey* 15 (6): 391–422.

Richardson, R. E. 1928. The bottom fauna of the Middle Illinois River, 1913-1925: Its distribution, abundance, valuation, and index value in the study of stream pollution. *Bulletin of the Illinois Natural History Survey* 17 (12):387–475.

Sinley, J. R., J. P. Goetti, and P. H. Davies. 1974. The effects of zinc on rainbow trout (*Salmo gairdneri*) in hard and soft water. *Bulletin of Environmental Contamination and Toxicology* 12 (2): 193–201.

Spry, D. J. and J. G. Weiner. 1991. Metal bioavailability and toxicity to fish in low-alkalinity lakes: A critical review. *Environmental Pollution* 71: 243–304.

Tetra Tech. Ecological Data Application System (EDAS). Version MT 3.3.2k. 2006. Available from: http://www.deq.state.mt.us/wqinfo/QAProgram/index.asp (accessed 1 April 2007).

Varley, J. D., and P. Schullery. 1998. *Yellowstone fishes: Ecology, history, and angling in the park*. Mechanicsburg, PA: Stackpole Books.

Wetzel, R. G. 2001. *Limnology: Lake and river ecosystems*. 3rd ed. New York: Academic Press.

Woods, S. W., and J. Corbin. 2003. *Vital signs water quality monitoring for the Greater Yellowstone Network: Grand Teton National Park*. Final technical report. Bozeman, MT: National Park Service, Greater Yellowstone Network.

NPS D-1399, April 2009

National Park Service
U.S. Department of the Interior

**Natural Resource Program Center**
1201 Oak Ridge Dr., Suite 150
Fort Collins, CO 80525

www.nature.nps.gov

**EXPERIENCE YOUR AMERICA™**