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Natural Resource Stewardship and Science

Greater Yellowstone Network Water Quality Monitoring Annual Report

January 2009–December 2009

Natural Resource Data Series NPS/GRYN/NRDS—2011/310

ON THE COVER
Clockwise: Alpine lake in Grand Teton National Park; water quality sampling in Yellowstone National Park; Hillsboro Spring, Bighorn Canyon National Recreation Area; and Crooked Creek, Bighorn Canyon National Recreation Area
Photos courtesy of NPS and Adam Sigler (*bottom left*)

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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 of interest and applicability to a broad audience in the National Park Service and others in natural resource management, including scientists, conservation and environmental constituencies, and the public.

The Natural Resource Data Series is intended for the timely release of basic data sets and data summaries. Care has been taken to assure accuracy of raw data values, but a thorough analysis and interpretation of the data has not been completed. Consequently, the initial analyses of data in this report are provisional and subject to change.

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

Data in this report were collected and analyzed using methods based on established, peer-reviewed protocols and were analyzed and interpreted within the guidelines of the protocols.

This report is available at the Greater Yellowstone Network offices in Bozeman, Montana, and the Natural Resource Publications Management website (http://www.nature.nps.gov/publications/nrpm/).

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Executive Summary

The Greater Yellowstone Network includes Bighorn Canyon National Recreation Area (NRA), Grand Teton National Park and John D. Rockefeller Memorial Parkway, and Yellowstone National Park (NP). In 2005, the Greater Yellowstone Network began monitoring water bodies identified by the states of Montana and Wyoming as “water quality impaired.” By 2009, monitoring activities included water quality of impaired waters in Bighorn Canyon NRA and Yellowstone NP, outstanding natural resource waters in Grand Teton NP and Yellowstone NP, high alpine lakes in Grand Teton NP, and arid seeps and springs in Bighorn Canyon NRA.

Results of the water quality monitoring program in the Greater Yellowstone Network are compared to federal and state standards (appendix A) to identify potential water quality degradation issues in network parks. Land uses and geology within and upstream of each park present specific concerns with regard to potential water quality impacts and likely sources of contamination. Specific locations where water quality did not meet applicable standards were identified for each park.

- Overall, water chemistry data collected on the four 2009 Bighorn Canyon NRA project visits are compliant with most national and state standards with the exception of the Montana draft nutrient standards. Nitrate detections above Montana draft standards in springs with no obvious sources of impairment suggest that geology may be partially responsible for elevated nutrients at some sample sites within Bighorn Canyon NRA. Many sites exhibited sulfate concentrations that did not meet the Environmental Protection Agency (EPA) standard for culinary water supplies, however these sulfate concentrations are also likely related to site-specific geology. All samples for *Escherichia coli* (*E. coli*) in Bighorn Canyon NRA failed to meet state and national standards. The source of the *E. coli* is unknown, but is assumed to be related to agricultural activities, septic systems, and animal waste contaminated runoff upstream of the monitoring sites.

- Several water quality samples collected in Grand Teton NP did not meet state and/or national standards for arsenic. Observed concentrations are likely related to the site-specific geology. Several field pH values at Amphitheatre, Surprise, and Delta lakes were outside of the range recommended for natural waters in Wyoming. However, the pH of these water bodies is within acceptable ranges for sensitive alpine headwater lakes.

- Waters within Yellowstone NP continue to be of high quality. The water quality standards that were not met were due to local geology and thermal inputs to nearby streams. Minimum instream flows for the lower portions of Reese Creek continue to be a concern for park resource managers and will continue to be monitored on an annual basis.

List of Acronyms

ANC	Acid Neutralizing Capacity
BICA	Bighorn Canyon National Recreation Area
cfs	cubic feet per second
cfu	colony forming unit
DEQ	Department of Environmental Quality
FSS	Fixed Suspended Solids
EPA	Environmental Protection Agency
ETC	Environmental Testing and Consulting
GRTE	Grand Teton National Park
GRYN	Greater Yellowstone Network
I&M	Inventory and Monitoring
NP	National Park
NPS	National Park Service
NRA	National Recreation Area
NRDS	Natural Resources Data Series
NTU	n turbidity units
ONRW	Outstanding Natural Resource Waters
QA/QC	Quality Assurance/Quality Control
SOP	Standard Operating Procedures
STORET	Storage and Retrieval
TMDL	Total Maximum Daily Load
TSS	Total Suspended Solids
µg/L	micrograms per liter
µS/cm	microsiemens per centimeter
USFS	United States Forest Service
USGS	United States Geological Survey
VSS	Volatile Suspended Solids
WQ	Water Quality
WRD	Water Resources Division
YELL	Yellowstone National Park

Introduction

Ecosystem "vital signs" are key to the National Park Service's (NPS) Inventory and Monitoring Program (I&M). A summary of vital signs monitoring is provided in *An Overview of Vital Signs Monitoring and its Central Role in Natural Resource Stewardship and Performance Management* (National Park Service n.d.). Through the NPS I&M program, 270 national park units were organized into 32 networks. The Greater Yellowstone Network includes Bighorn Canyon National Recreation Area (NRA), Grand Teton National Park and John D. Rockefeller Memorial Parkway, and Yellowstone National Park (NP). The significance of water resources within the Greater Yellowstone Network is reflected in the network's ranking of freshwater quality as third among all of the potential vital signs identified and prioritized by the Greater Yellowstone Network.

Background

In 2005, the Greater Yellowstone Network began monitoring water bodies identified by the states of Montana and Wyoming as "water quality impaired." Monitoring activities gradually expanded to focus not only on quality impaired waters, but also on the outstanding natural resource waters in Grand Teton NP and Yellowstone NP; high alpine lakes in Grand Teton NP; and waters of management concern and arid seeps and springs in Bighorn Canyon NRA. In 2009, the monitoring protocol was revised (O'Ney et al. 2009a [under review]) to combine the regulatory protocol (O'Ney 2006)—aimed at monitoring state 303(d)/305(b) listed rivers and streams—with the network's other water resource monitoring needs. This expanded protocol may be found at http://science.nature.nps.gov/im/monitor/VitalSigns/BrowseProtocol.aspx.

Study Areas

A detailed description of the study areas (Bighorn Canyon NRA, Grand Teton NP, and Yellowstone NP) can be found in the Greater Yellowstone Network 2007/2008 water quality monitoring annual report (O'Ney et al. 2009b). In the Greater Yellowstone Network, water quality is being monitored at fixed sites in each of the three parks. Waters being monitored include the Outstanding Natural Resource Waters in Grand Teton NP and Yellowstone NP, the "impaired water bodies" (e.g., appear on state 303d/305b reports) in Bighorn Canyon NRA and Yellowstone NP, and waters of management concern in Bighorn Canyon NRA. As part of the I&M program, special emphasis is given to streams included in state 303d/305b reports. Included in the report are listings of waters that are fully supporting all beneficial uses (Category 1); waters where available data and information indicate that some but not all of the beneficial uses are supported (Category 2A); waters where available data and information indicate that a water quality standard is exceeded because of an apparent natural source in the absence of any identified anthropogenic sources (Category 2B); waters that have not been assessed or have insufficient data to evaluate their use support levels (Category 3); waters where one or more beneficial uses have been assessed as impaired or threatened; however, all necessary total maximum daily loads (TMDLs) either have been completed (Category 4A) or are not required (Category 4C); and waters where one or more applicable beneficial uses have been assessed as being impaired or threatened, and a TMDL is required to address the factors causing the impairment or threat (Category 5). A TMDL specifies the amount of a particular pollutant that may be present in a water body, allocates allowable pollutant loads among sources, and provides the basis for attaining or maintaining water quality standards. Category 5 waters are those included on the state's 303(d) list. Both Category 4 and Category 5 waters have failed to meet

water quality standards and, as a result, are unable to attain their designated uses and are given a priority for monitoring.

Bighorn Canyon National Recreation Area Rivers/Streams on State 303d/305b Reports
In Wyoming, the Shoshone River (Category 5), from its confluence with Bighorn Lake upstream to an undetermined distance has been on Wyoming's 303(d) list since 2002. The cause of the listing stems from fecal coliform contamination. Crooked Creek (Category 4C) flows into Wyoming from Montana, and then flows into Bighorn Lake. A 3.8 mile section of Crooked Creek appears in Wyoming's 303(d)/305(b) report as impaired due to flow alterations but no TMDL is required and it is not included on the 303(d) list. Reductions of flow in this section inhibit aquatic life to the extent that cold water fisheries and aquatic life uses are affected (Wyoming DEQ 2008).

Montana's 2008 303(d) list (Montana DEQ 2009) includes 6.9 miles of the Bighorn River (Class B-1) from the Yellowtail Dam to the Crow Indian Reservation Boundary (Montana DEQ 2009). This portion of the river is listed as only partially supporting for aquatic life and cold water fisheries because of elevated total nitrogen concentrations, stemming from the supersaturation of dissolved gases on the fishery of the Bighorn River downstream of the Yellowtail Afterbay dam.

Grand Teton National Park Rivers/Streams on State 303d/305b Reports
Surface waters within Grand Teton NP are contained wholly within the state of Wyoming. No Grand Teton NP streams appear on Wyoming's 2008 303(d)/305(b) report as impaired.

Yellowstone National Park Rivers/Streams on State 303d/305b Reports
In 2009, three stream segments on the border of Yellowstone National Park were listed as 303(d) impaired by the state of Montana and monitored as regulatory streams. These are (1) upper Soda Butte Creek near Cooke City, Montana; (2) Yellowstone River upstream of Corwin Springs, Montana; and (3) Reese Creek on the park's northern boundary near Gardiner, Montana.

Figures 1, 2, and 3 and Table 1 identify the 51 fixed monitoring sites visited in 2009.

Figure 1. Water quality monitoring sites in Bighorn Canyon NRA.

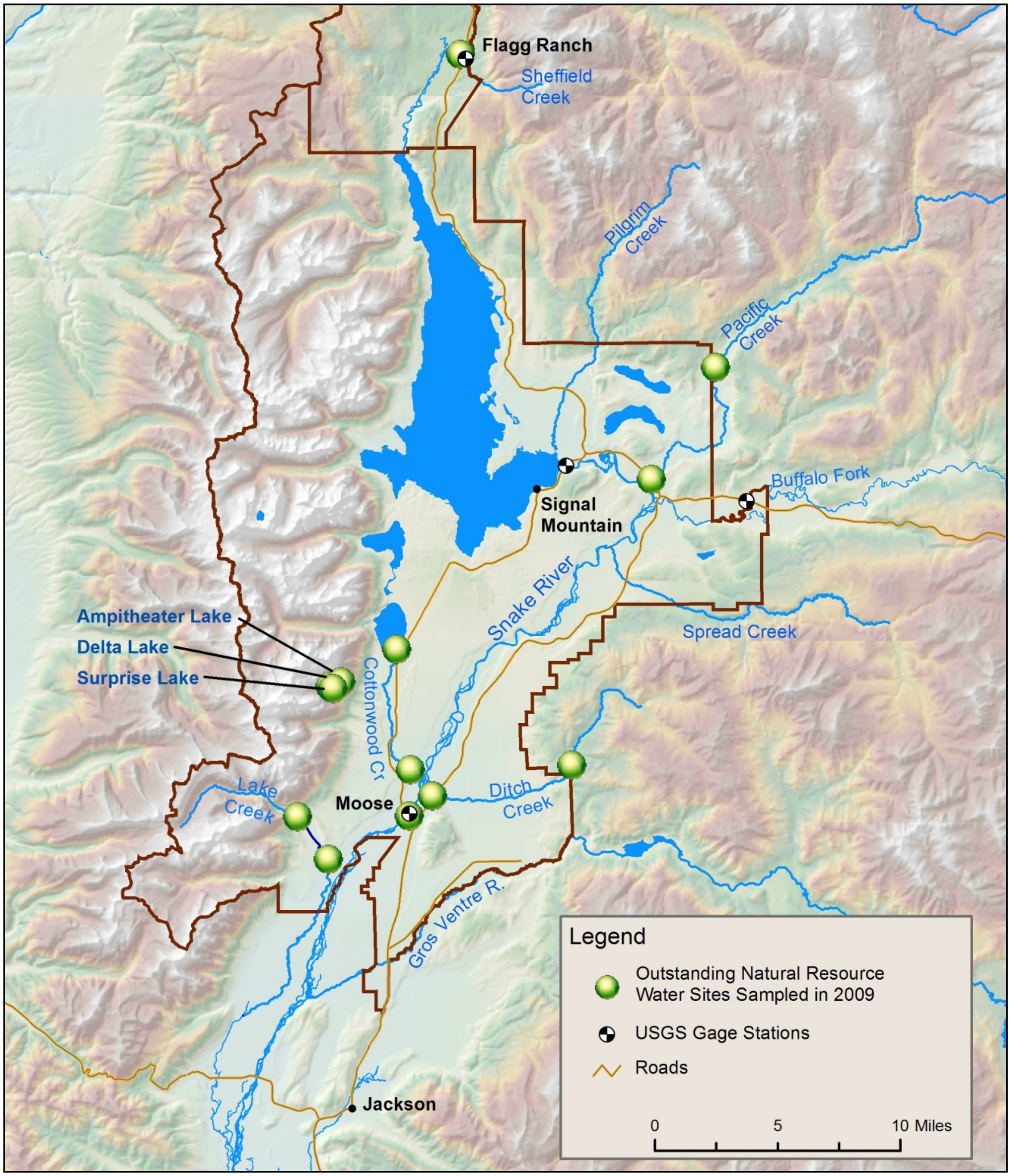

Figure 2. Water quality monitoring sites in Grand Teton NP and John D. Rockefeller Memorial Parkway.

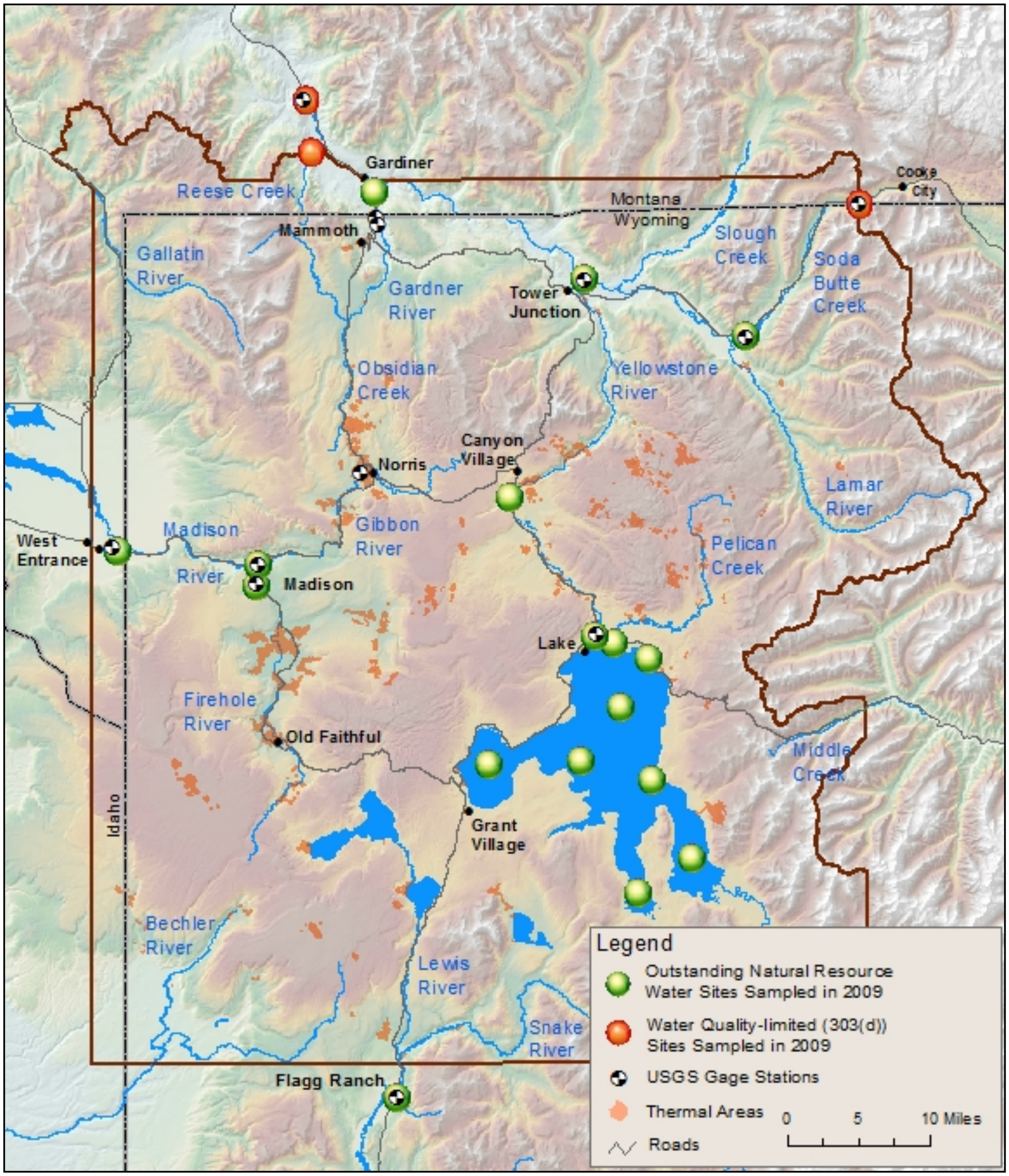

Figure 3. Water quality monitoring sites in Yellowstone NP.

Table 1. Water resource monitoring stations sampled in 2009 (highlighted streams appear on state 303d/305b reports)

Location	Drainage Basin	Station ID	Station Name
Bighorn Canyon National Recreation Area (BICA)	Lower Bighorn Drainage	BICA_BHR1	Bighorn River near St. Xavier
	Bighorn Lake Drainage	BICA_BHR2	Bighorn River at Kane
		BICA_CCR1	Crooked Creek
		BICA_DACR1	Davis Creek
		BICA_LCR2	Layout Creek below road
		BICA_LAYOUTSPR1	Layout Spring
		BICA_PICKETSPR1	Pickett's Wall Seep
		BICA_PENTAGSPR1	Pentagon Spring
		BICA_HILLARYSPR1	Hillary Spring
		BICA_TRC1	North Trail Creek
		BICA_MASLOVSPR1	Mason-Lovell Spring
		BICA_HLSBMNSPR1	Hillsboro Main Spring
		BICA_NDAVISPR1	North Davis Spring
		BICA_LOCKPNDSPR1	Lockhart Stockpond Spring
		BICA_LCKSOSPR1	South Lockhart Spring
		BICA_HAILSPR1	Hailstorm Spring
	Shoshone River Drainage	BICA_SHR2	Shoshone River near Lovell, Wyoming
Grand Teton National Park (GRTE)	Snake River Drainage	GRTE_SNR01	Snake River at old Flagg Ranch 1,000 feet below bridge
		GRTE_SNR02	Snake River below site of new visitor center
		GRTE_AMP01	Amphitheatre Lake
		GRTE_SUR01	Surprise Lake
		GRTE_DEL01	Delta Lake
		GRTE_COC01	Cottonwood Creek at Jenny Lake
		GRTE_COC02	Lower Cottonwood Creek near Snake River
		GRTE_DIC01	Ditch Creek above Teton Science School
		GRTE_DIC02	Ditch Creek at Hwy 89
		GRTE_LAC01	Lake Creek at inlet to Phelps Lake
		GRTE_LAC02	Lake Creek at Moose-Wilson Road
		GRTE_PAC01	Pacific Creek at USFS Campground
		GRTE_PAC02	Pacific Creek at Hwy 89
Yellowstone National Park (YELL)	Yellowstone River Drainage	YELL_YS616.4M	Yellowstone River at Yellowstone Lake outlet
		YELL_YS549.7M	Yellowstone River at Corwin Springs, Montana
		YELL_YS600.5M	Yellowstone River at Canyon
		YELL_PC000.4M	Pelican Creek at Yellowstone Lake
		YELL_SB015.7A	Soda Butte Creek at park boundary
		YELL_SB001.5M	Soda Butte Creek near Lamar Ranger Station
		YELL_LM000.5M	Lamar River near Tower Ranger Station
		YELL_GN002.9M	Gardner River near Gardiner, Montana
		YELL_RC000.9A	Reese Creek lower diversion

Location	Drainage Basin	Station ID	Station Name
		YELL_RC000.9B	Reese Creek upper discharge mainstem
		YELL_YL001.0M	Yellowstone Lake site 1
		YELL_YL002.0M	Yellowstone Lake site 2
		YELL_YL003.0M	Yellowstone Lake site 3
		YELL_YL004.0M	Yellowstone Lake site 4
		YELL_YL005.0M	Yellowstone Lake site 5
		YELL_YL006.0M	Yellowstone Lake site 6
		YELL_YL007.0M	Yellowstone Lake site 7
	Snake River Drainage	YELL_SN999.9M	Snake River at old Flagg Ranch
	Madison River Drainage	YELL_FH001.8C	Firehole River near Madison Junction
		YELL_GB000.2M	Gibbon River near Madison Junction
		YELL_MD133.2T	Madison River near park boundary

Objectives

The objective of this report is to summarize water quality results from the previous calendar year. The summary report presented here covers 2009 plus any lab data not previously reported. This report will

1. Summarize monitoring activities and data. For each park, a description of the number of samples taken and analyses conducted is provided.
2. Describe the current condition of the resource relative to state and/or EPA criteria.
3. Highlight notable events and observations.
4. Discuss recommendations, including modifications to the monitoring program and where the need for special studies is indicated.
5. Provide a basis for communication within the park and network.

The target audiences include park managers, resource managers in the park and network, and state water quality managers.

Methods

Field Methods

Two-thousand-nine was a transition year for the water quality monitoring program. During this period, a new protocol was being developed that combined the Regulatory Monitoring Protocol (O'Ney 2006) with the Seeps and Springs Monitoring Protocol (Schmitz et al. 2007). Water samples were collected following procedures described in both of these documents. Both of these protocols were used in 2009.

Following the manufacturers written guidelines, multiparameter probes (Hydrolab minisonde 4a, Troll 9500 professional) were used to collect field parameters (pH, conductivity, water temperature, and dissolved oxygen) from each site location. In Yellowstone NP, a HACH turbidity meter 6100P was used to collect turbidity and water samples were collected from each site for suspended solids analysis.

Analytical Methods

Environmental Testing and Consulting, Inc. (ETC) of Memphis, Tennessee, was contracted to conduct laboratory analysis of water quality samples from all locations except the alpine lakes in Grand Teton NP. In Yellowstone NP and Grand Teton NP, samples were chilled and shipped overnight to ETC at the end of each sampling day. Samples collected in Bighorn Canyon NRA were chilled in a laboratory refrigerator and sent overnight to ETC on the Monday following collection. Alpine lake samples were sent to the USFS/USGS Water & Soils Laboratory in Fort Collins, Colorado. Table 2 outlines the analytes and the corresponding analytical method employed.

Table 2. Analytical methods for samples collected in the Greater Yellowstone Network

Analyte	Method	Laboratory
Acid Neutralizing Capacity (Alpine Lake)	Gran Titration	USFS/USGS
Arsenic, Calcium, Copper, Hardness as $CaCO_3$, Iron, Magnesium, Potassium, Selenium, Sodium	200.7	ETC
Ammonia	4500NH3D	ETC
Ammonium	Ion Chromatography	USFS/USGS
Bicarbonate Alkalinity, Carbonate Alkalinity, Total Alkalinity	2320 B	ETC
Chloride, Fluoride, Nitrate-N, Nitrite-N, Phosphorus, Orthophospate (as P), Sulfate	300.0	ETC
Conductivity, Dissolved Oxygen, Temperature, pH, Alkalinity*	**	--
Escherichia coli	Colilert	Performed on-site (Bighorn Canyon NRA)
Phosphate	4500 PB5	ETC

*Alkalinity measured as field alkalinity at spring sites in Bighorn Canyon NRA.

**Field parameters collected via method described in Gibs et al. 2007. Use of multiparameter instruments for routine field measurements.

ETC = Environmental Testing and Consulting, Inc.; USFS = United States Forest Service; USGS = United States Geological Survey; NRA = National Recreation Area

Aquatic Biology Associates in Corvallis, Oregon, performed macroinvertebrate identification.

Field parameters (pH, conductivity, temperature, and dissolved oxygen) were collected at each site using a multi-parameter instrument such as the In-Situ Troll 9500 (or equivalent).

Quality Assurance/Quality Control (QA/QC)

All data collected for the Greater Yellowstone Network water quality monitoring program are verified and validated for quality assurance and quality control purposes. Data verification is a systematic process that evaluates data collection performance for completeness, correctness, and consistency. Data validation is the process used to qualify the data and reject or accept the information with no conditions or qualifications. During the validation review, any deviations from SOPs must be documented and their potential effect on the usability and quality of the monitoring data must be evaluated and discussed. Data verification and validation reports (Hershberger 2010a and 2010b, O'Ney 2010a and 2010b, O'Ney et al. 2010a and 2010b, Arnold 2010a and 2010b) are available at the Greater Yellowstone Network offices in Bozeman, Montana. After QA/QC procedures are completed, results from Greater Yellowstone Network's water quality monitoring program will be uploaded to the Environmental Protection Agency's national water quality database, EPA STORET (EPA STOrage and RETrieval) http://www.epa.gov/storet/.

Water Quality Criteria

Results of the water quality monitoring program in the Greater Yellowstone Network are compared to national and state standards to identify potential water quality degradation issues in network parks. The results discussed in this report were compared to published standards from various sources, including the Montana Department of Environmental Quality (Montana DEQ 2010), United States Environmental Protection Agency (US EPA 1987, 2000, and 2009), and Wyoming Department of Environmental Quality (Wyoming DEQ 2008). In many cases, the water quality of network parks is better than existing standards.

Both Montana and Wyoming are moving towards the adoption of the EPA's Ambient Water Quality Criteria Recommendations (US EPA 2000a and 2000b). These ecoregion based criteria are intended to provide starting points for states to develop (with assistance from EPA) more refined nutrient criteria based on actual data from reference streams. They recommend using the 25^{th} percentile from an entire region (aggregate) as a surrogate for a reference population (US EPA 2000a). In Montana, the draft criteria (Montana DEQ 2008b) will only apply seasonally. This is because low temperatures in winter and high flow events during spring runoff tend to mute the local effects of eutrophication (plant growth slows dramatically in winter, and spring high-flow events prevent nuisance algal mats from developing). Therefore, the criteria have been set for the time period when eutrophication problems are most likely to occur (July 1–Sept. 30).

Table 3 summarizes the draft nutrient criteria recommended by the state of Montana and the EPA. Appendix A summarizes the water quality criteria used by the Greater Yellowstone Network.

Table 3. Draft nutrient criteria (EPA and Montana)

Ecoregion	Total P (mg/L)	Total N (mg/L)	NO_{2+3} (mg/L)	Turbidity (NTU)	Park (s) (state)	Comment	Source
Wyoming Basin	0.124	1.358	0.076	N/A	Bighorn Canyon NRA (Montana)	Criteria apply July1–Sept. 30	Montana DEQ 2008b
Middle Rockies	0.048	0.320	0.100	N/A	Yellowstone NP (Montana)	Criteria apply July1–Sept. 30	Montana DEQ 2008b
Western Forested Mountains (aggregate)	10.0	.012	0.014	1.3	Grand Teton NP, Yellowstone NP (Wyoming, Montana)		US EPA 2000a
Xeric West (aggregate)	21.88	0.377	0.025	1.84	Bighorn Canyon NRA (Wyoming, Montana)		US EPA 2000b

US EPA = United States Environmental Protection Agency; DEQ = Department of Environmental Quality; NRA = National Recreation Area; NP = National Park

Results and Discussion

Bighorn Canyon National Recreation Area

River Monitoring

The water quality at Bighorn Canyon NRA was sampled quarterly at eight fixed monitoring sites in 2009. Basic water quality parameters, including water temperature, dissolved oxygen, pH, and specific conductivity were collected *in situ* at each site. Turbidity was also collected at each site. Water samples were analyzed in the laboratory for additional chemical parameters:

- dissolved anions (chloride, sulfate, and total alkalinity);
- dissolved cations (calcium, magnesium, potassium, and sodium); and
- nutrients (nitrate, nitrite, and ortho-phosphate).

In addition, two sampling rounds were conducted for *Escherichia coli (E. coli)* at the Shoshone River near Lovell. Normally sampling would have been conducted June, July, August, and September. However, Bighorn Canyon NRA's two incubators failed and the decision was made to switch to the Colilert system for sample analysis. The Colilert equipment was not operational until August. For each *E. coli* sampling round, samples were collected on five consecutive days for analysis.

The 2009 water quality sampling effort in Bighorn Canyon NRA comprised 40 visits, 297 activities, and data entry for 1,223 results into NPSTORET (for 8 sites). Results include field observations, multiprobe measurements, and laboratory analysis.

Bighorn Lake Basin.—The Bighorn Lake basin includes six of the eight river/stream sites monitored in Bighorn Canyon NRA. In Crooked Creek, the maximum temperature threshold was exceeded for one sample event. Samples from four sites (Bighorn River at Kane, Crooked Creek, Layout Spring, and North Trail Creek) exceeded Montana's draft nutrient criteria for nitrate as N during the summer sampling event. Several sampling events show exceedances of EPA's sulfate concentration standard for domestic water supplies (US EPA 1987) at the Big Horn River at Kane, Crooked Creek, and the North Trail Creek sites. These sulfate levels are of little concern as they are most likely from natural geologic sources (table 4).

Table 4. The 2009 water quality sampling locations in the Bighorn Lake basin of Bighorn Canyon NRA where constituent concentrations did not meet applicable (including draft) standards

Site	Parameter	Standard[1]	Units	# of Exceedance/ # of Observations	Range of Values
Bighorn River at Kane	Sulfate	250	mg/L	1/4	235–312
	Nitrate as N	0.076 July 1–Sept. 30	mg/L	1/1	0.204
Crooked Creek	Sulfate	250	mg/L	4/4	276–485
	Nitrate as N	0.076 July 1–Sept. 30	mg/L	1/1	0.358
North Trail Creek	Sulfate	250	mg/L	4/4	757–840
	Nitrate as N	0.076 July 1–Sept. 30	mg/L	1/1	0.109

[1] See references, appendix A and table 3. mL = milliliter; mg = milligram

Lower Bighorn Basin.—The Bighorn River at St. Xavier is the single sample site in the Bighorn Canyon NRA project located within the Lower Bighorn basin. See figure 2 for sample site locations. The site is just downstream from the Yellowtail dam at the head of a popular trout fishing section of the Big Horn River. Water quality results were within standards for all parameters analyzed, except for nitrate as N that exceeded Montana's draft nutrient criteria for the summer sampling event (table 5).

Table 5. The 2009 water quality sampling locations in the Lower Bighorn basin of Bighorn Canyon NRA where constituent concentrations did not meet applicable (including draft) standards

Site	Parameter	Standard[1]	Units	# of Exceedance/ # of Observations	Range of Values
Bighorn River at Xavier	Nitrate as N	0.076 July 1–Sept. 30	mg/L	1/1	0.294

[1] See references, appendix A and table 3.

Shoshone River Basin.—The Shoshone near Lovell is the single sample site in the Bighorn Canyon NRA project located within the Shoshone River basin. See figure 2 for sample site locations. The site is just west of Lovell and was selected to represent the quality of the Shoshone River entering Bighorn Canyon NRA. Water quality results were within existing Wyoming standards for all chemical parameters, except for nitrate as N that exceeded Montana's draft nutrient criteria for the summer sampling event.

The Shoshone River was also monitored for *E. coli*. In order to meet state standards for contact recreation, the geometric mean of five consecutive sampling days should not exceed 126 CFU of *E. coli* per 100 mL. Geometric means from all 2009 samples did not meet this standard (table 6). 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.

Table 6. The 2009 water quality sampling locations in the Shoshone River basin of Bighorn Canyon NRA where constituent concentrations did not meet applicable (including draft) standards

Site	Parameter	Standard[1]	Units	# of Exceedance/ # of Observations	Range of Values
Shoshone River near Lovell	*E. coli*	126/100 mL	cfu	10/10	372–401
	Nitrate as N	0.076 July 1–Sept. 30	mg/L	1/1	0.979

[1] See references, appendix A and table 3.

cfu = colony forming unit; mL = milliliter; mg = milligram

Spring Monitoring

A total of nine seep and spring monitoring stations were visited twice (May and December) during 2009. Hailstorm Spring (BICA_HAILSPR1) was dry during both station visits. Hillary's Spring was sampled once in May of 2009 but was not visited in December. All seeps/springs were located in the Bighorn Lake basin. Data were collected according to Data Collection of Water Quality SOP #5 (Schmitz et al. 2007) and analyzed according to the Data Analysis SOP #9 (Schmitz et al. 2007).

Two lines of evidence, the calcium: magnesium molar ratios and Piper plots, indicate that the chemical signatures of Bighorn Canyon NRA springs are stable. No spring bicarbonate levels were below the minimum recommended standard for aquatic life of 20 mg/L. All of the samples from Hillary's, Lockhart South, Lockhart Stockpond, Mason-Lovell South, North Davis Springs, and Pickett's Wall Seep did not meet sulfate standards for domestic water supplies. These sulfate levels are most likely from geologic sources. Because the springs were not sampled during the summer season, results were not compared to Montana draft nutrient standards.

Grand Teton National Park

Sampling in Grand Teton occurs June through October. A total of 1,520 results for 13 stations were entered into NPSTORET in 2009. These results included field observations, duplicate multiprobe measurements, and the results for laboratory analyses of 175 water samples.

Water samples for rivers and streams were collected and shipped overnight on ice for analysis at Environmental Testing and Consulting, Inc., Memphis, Tennessee. The following list of analyses was conducted:

- dissolved anions (chloride, sulfate, and total alkalinity)
- dissolved cations (calcium, magnesium, potassium, and sodium)
- nutrients (nitrate, nitrite, and ortho-phosphate)
- dissolved metals (arsenic, copper, iron, and selenium)
- total metals (arsenic, copper, iron, selenium and carbonate hardness)

The USFS/USGS Water & Soils Laboratory in Fort Collins, Colorado, analyzed water samples for alpine lakes for the following parameters: pH, acid neutralizing capacity (ANC), conductivity, sodium, ammonium, potassium, magnesium, calcium, fluoride, chloride, nitrate, phosphate, and sulfate.

Snake River Drainage

All sample locations in Grand Teton NP are in the Snake River drainage basin (table 7).

Table 7. The 2009 water quality sampling locations in Grand Teton NP where constituent concentrations did not meet applicable (including draft) standards

Site	Parameter	Standard[1]	Units	# Exceedance/ #Observations	Range of Values
Snake River at Flagg Ranch	Total and dissolved arsenic	0.01	mg/L	8/8	0.018–0.038
Upper Cottonwoood	pH	6.5–9	--	1/4	6.4–7.48
Surprise Lake	pH	6.5–9	--	1/2	4.02–6.81
Amphitheatre Lake	pH	6.5–9	--	1/1	5.71
Delta Lake	pH	6.5–9	--	1/2	6.45–6.88

[1] See references, appendix A.

mg/L = milligrams per liter

Snake River Gaging Station at Moose, Wyoming

The Moose gage, operated by the United States Geological Survey and funded by the Greater Yellowstone Network, Grand Teton NP, and the Teton Conservation District, is located on the Snake River adjacent to park headquarters in Moose, Wyoming. The US Geological Survey has collected and completed quality assurance and quality checks (QA/QC) on discharge data at this location since 1995, and on real-time temperature, pH, dissolved oxygen, and specific conductivity data since 2002.

Median daily discharge at Moose for the period of record is compared with 2009 data in figure 4. Spring flows in 2009 had two peaks in comparison with the median flow record. Timing, magnitude, and duration of peak flows may affect spawning cues for migratory fish, the evolution of life history strategies, as well as other behavioral mechanisms. Flows at Moose also differ from the typical hydrograph in that there are “shoulder” flows during August and September due to the operations of Jackson Lake dam.

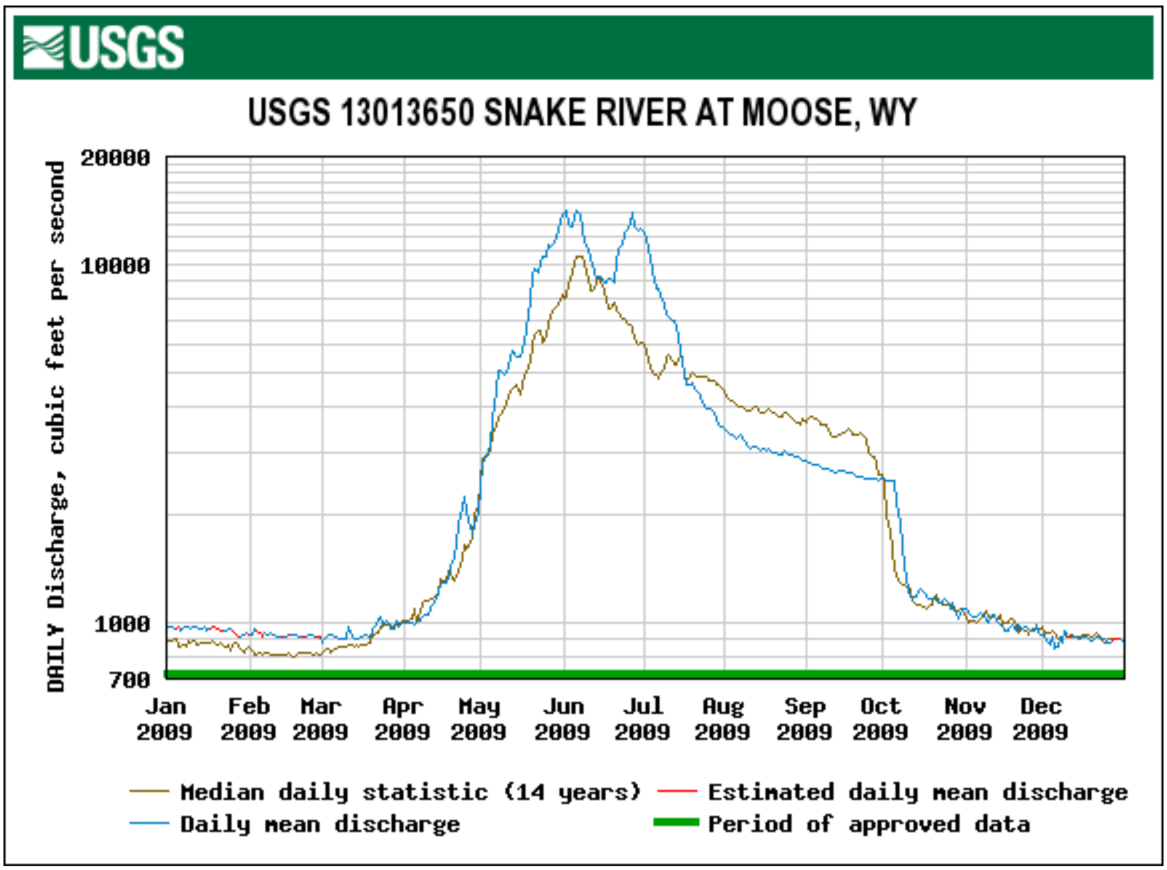

Figure 4. Mean daily discharge at Moose for calendar year 2009 compared with median values.

Yellowstone National Park

During the 2009 calendar year, water samples were collected one day each month from 12 long-term stream water quality monitoring sites from January to October, 7 sites on Yellowstone Lake from June to October, and 2 sites on Reese Creek that measures stream discharge (fig. 1 and table 2). All water bodies in Yellowstone NP are classified as Outstanding Natural Resource Waters by the states of Montana and Wyoming. Basic water quality parameters were collected

from each site visit, including water temperature, dissolved oxygen, pH, specific conductivity, and turbidity. Water was also collected and processed for TSS (total suspended solids), VSS (volatile suspended solids), and FSS (fixed suspended solids). Additional chemical parameters collected from 9 stream sites include analysis of dissolved anions (chloride, sulfate, and total alkalinity), dissolved cations (calcium, magnesium, potassium, and sodium), and nutrients (nitrate, nitrite, ammonia, and total phosphorus).

In 2009, three stream segments on the border of Yellowstone NP were listed as 303(d) impaired by the state of Montana and monitored as regulatory streams. These are (1) upper Soda Butte Creek near Cooke City, Montana; (2) Yellowstone River upstream of Corwin Springs, Montana; and (3) Reese Creek on the park's northern boundary near Gardiner, Montana (fig. 1). At the upper Soda Butte Creek site water and sediment samples were analyzed for metals (i.e., arsenic, copper, iron, and selenium) between May and October. In-stream metals contamination in Soda Butte Creek is a result of historic mining in the vicinity of Cooke City, Montana, which is approximately 8 km from the Yellowstone NP boundary. Mine tailings still persist within the floodplain of Soda Butte Creek, and contribute to the listing of a portion of this stream as impaired and only partially supporting of aquatic life and coldwater fisheries. The upper Soda Butte Creek regulatory water quality site is collocated with the park's long-term water quality site that is sampled monthly. The Yellowstone River upstream of Corwin Springs, Montana, was listed on Montana's 303(d) list in 2006 for sedimentation and arsenic levels that exceed drinking water standards. Very little supporting data were given for this listing but is primarily based on a USGS report that summarized data collected from 1999 to 2001(Miller 2004). In addition to routine parameters, total and dissolved arsenic, copper, iron, and selenium were collected from this site between July and October 2009 to obtain current information regarding the status of this stream segment. The lower portion of Reese Creek is on Montana's 303(d) list because irrigation practices from adjacent land owners often leave too little water in the stream to sustain healthy resident fish populations during the critical summer months of July and August. Discharge measurements on Reese Creek were collected during 17 site visits between May 28 and September 17, 2009, by Yellowstone NP's resource management staff to calculate instream flows during this critical period.

Aquatic invertebrates were sampled at five stream locations near long-term water quality monitoring sites to supplement physical and chemical data. Within the Yellowstone River drainage these include two sites on Soda Butte Creek and one site each on the Gardner River and Reese Creek; within the Madison River drainage invertebrates are collected from the one location on the lower portion of Gibbon River.

Yellowstone River Drainage

In 2009, 10 of 15 sites monitored in the Yellowstone River drainage of Yellowstone NP met or surpassed national/state water quality standards for all parameters on all collection days. These include the 7 sites on Yellowstone Lake, Yellowstone River at Fishing Bridge, Gardner River, and Lamar River. Five of 15 sites monitored did not meet the standards (table 8) outlined by the EPA or state for at least one parameter. Three sites did not meet water quality standards for pH and include Yellowstone River at Canyon (7 site visits), and Pelican and lower Soda Butte Creeks (2 site visits each). The low pH values are most likely attributed to natural seasonal variation within the watersheds and contributions from thermal sources. The upper Soda Butte Creek regulatory site exceeded EPA/state standards for total iron and drinking water standards (1

site visit) and aquatic life criteria (14 site visits) (table 8 and fig. 5). Yellowstone River regulatory site upstream of Corwin Springs exceeded human health surface water standard for arsenic on all site visits (4 samples; July–October) and is most likely cause by thermal contributions along the Yellowstone River.

Table 8. Water quality sampling stations in the Yellowstone River drainage where constituent concentrations did not meet applicable standards

Site	Parameter	Standard	Units	Exceedance/ # of visits	Range of values
Soda Butte Creek at park boundary	Total iron	1.00*	mg/L	1/36	ND–1.12
	Total iron	0.30**	mg/L	14/36	ND–1.12
Yellowstone River at Corwin Springs	Total arsenic	0.01***	mg/L	4/4	0.014–0.029
Pelican Creek at Yellowstone Lake	Ammonia	0.885–32.6	mg/L	1/9	ND–0.942
	pH (low)	6.5–9.0	-	2/9	6.1–7.5
Soda Butte Creek near Lamar Ranger Station	pH (low)	6.5–9.0	-	2/11	6.3–7.3
Yellowstone River at Canyon	pH (low)	6.5–9.0	-	7/9	5.3–6.7

*primary standard for total iron (aquatic life).

**secondary standard for total iron (water supply).

*** human health surface water standard (Montana Circular 2008a).

ND = not detected; mg/L = milligram per liter

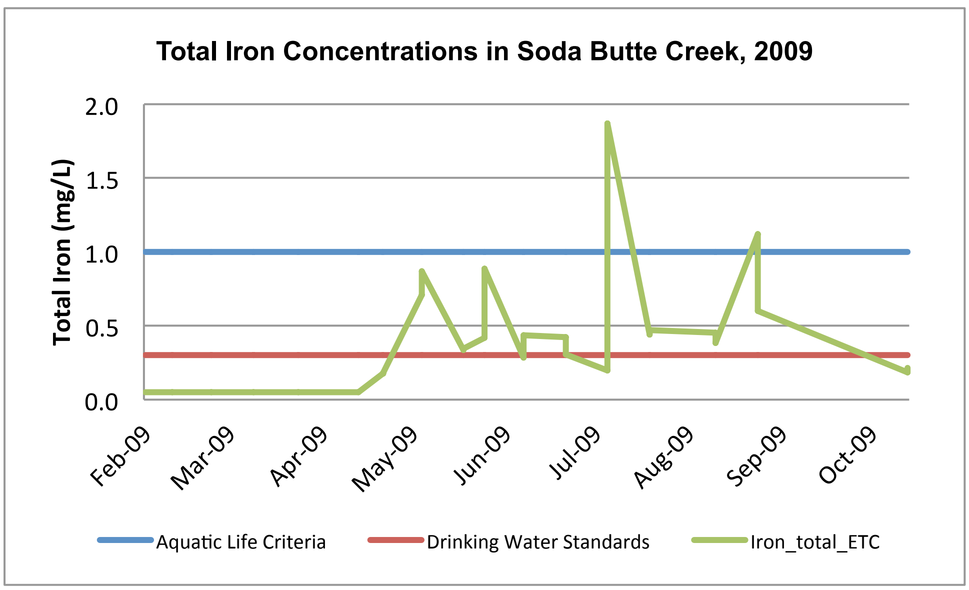

Figure 5. Total iron concentrations in Soda Butte Creek compared to aquatic life and drinking water standards.

Water-use and water-rights issues surrounding Reese Creek continue to be a concern to park resource managers. On Reese Creek, 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 equals the amount of water entering the main channel of Reese Creek from the uppermost flume. The adjudicated water rights stipulate that Reese Creek is to have a minimum flow of 1.306 ft^3/sec between April 15 and October 15 during any given year. During 2009, discharge on Reese Creek ranged from 4.25 to 21.75 ft^3/sec (fig. 6). Continued monitoring of discharge during the summer months is important to conserve the stream's native fish populations and biological integrity.

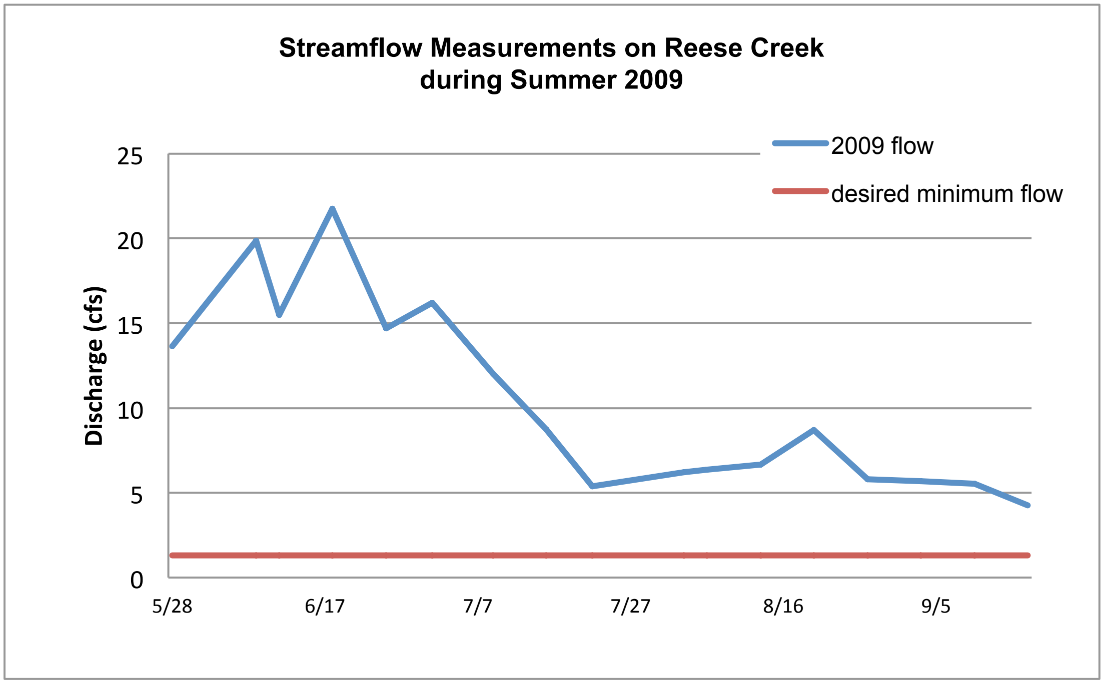

Figure 6. Stream discharge on Reese Creek, 2009.

Aquatic invertebrate sampling was conducted during the fall of 2009 at four locations in the Yellowstone River drainage. State of Montana impairment scores for streams are expressed as a range from 0 to 1 (0 = most impaired, 1 = least impaired) (table 9). Both sites on Soda Butte Creek rated very high indicating the stream is fully supporting of aquatic life with no water quality standards being violated (table 10). Impairment scores for the sites on Gardner River and Reese Creek, however, indicate that current water quality is only partially supporting of aquatic life with moderate impairment (table 10). The invertebrate sampling site on the Gardner River is located approximately 3 km below the Boiling River, a thermal area that discharges approximately 25 ft^3/sec daily to the Gardner River. Flow within Reese Creek is often altered during summer months for irrigating adjacent lands outside Yellowstone National Park. Both the thermal contribution to Gardner River and low stream flows on Reese Creek could increase water temperatures and affect aquatic communities living within the stream. Closer monitoring of the invertebrate communities on these two stream sections is needed to establish a baseline for future evaluation of stream water quality.

Table 9. 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 10. Provisional criteria for metric scoring for wadeable streams in Montana mountain regions (Yellowstone River drainage)

Score	3	2	1	0	Soda Butte Ck. (upper)	Soda Butte Ck. (lower)	Gardner River	Reese Creek
Taxa richness	>28	28–24	24–19	<19	3	3	3	3
EPT richness	>19	19–17	17–15	<15	3	3	2	3
Biotic Index	<3	3–4	4–5	>5	2	1	0	1
Percent dominant	<25	25–35	35–45	>45	3	2	2	3
Percent collectors (gather + filterer)	<60	60–70	70–80	>80	3	3	3	1
Percent scrapers and shredders	>55	55–40	40–25	<25	3	3	2	0
Percent EPT	>70	70–55	55–40	<40	3	3	3	1
Total					20	18	15	12
Site metric score/maximum possible score:					**0.95238**	**0.85714**	**0.71429**	**0.57143**

Madison River Drainage

One of three sites monitored in the Madison River drainage of Yellowstone NP in 2009 met or surpassed water quality standards. This site was on the Madison River. Two of three sites monitored did not meet the standards as outlined by the EPA or state (table 11) for at least one parameter and are discussed below.

Table 11. Water quality sampling stations in the Madison River drainage of Yellowstone NP where constituent concentrations did not meet applicable standards

Site	Parameter	Standard	Units	Exceedance/ # of visits	Range of values
Firehole River at Madison Junction	Water Temperature	<22.7	^{o}C	1/10	8.9–24.4
Gibbon River at Madison Junction	pH (low)	6.5–9.0	-	5/10	6.2–6.6

The Madison River drainage in the western portion of the park is dominated by geothermal activity. As a result, water entering this drainage varies considerably in acidity and temperature. The pH values observed in both the Firehole and Gibbon rivers (which did not meet national /state standards) are likely a result of local geology and thermal activity in this region of the park. Because of this, aquatic life has evolved with these conditions and should be minimally impacted

by seasonal temperature changes and subtle changes in pH. Since these conditions are naturally occurring, there will likely be no long-term, negative effect to water quality, aquatic biota, or recreational use within this portion of the park.

Using the metric scoring criteria for Montana streams, the site on the Gibbon River rated only partial support of aquatic life (0.6666). Thermal areas along the lower 21 km of the stream heavily influence water quality at this site. These thermal features contribute greatly to increased water temperatures and chemical component of stream water. Additionally, the site selected on the Gibbon River is not an ideal invertebrate collection site due to unstable substrate, which is composed primarily of sand and fine gravel. Because of the stream’s thermal areas, the Montana scoring criteria is not an appropriate use for this stream and a more appropriate index is needed.

Conclusion

Waters within Grand Teton NP and Yellowstone NP continue to be of high quality. The water quality standards that were not met in Grand Teton NP were due to geologic sources. Water quality standards that were not met in Yellowstone NP were due to local geology and thermal inputs to nearby streams. Although measurements on Reese Creek show stream flows above the minimum required, minimum instream flows for the lower portions of Reese Creek continue to be a concern for park resource managers and will continue to be monitored on an annual basis. Waters within Bighorn Canyon NRA have been affected by anthropogenic forces, most of which are outside the control of resource managers. Draft nutrient criteria may affect the number of water bodies on state 303(d)/305(b) lists. Water quality sampling is slated to continue at slightly reduced levels in 2010 due to budgetary constraints. Trend analysis for parameters of concern (to be determined) is scheduled to begin in 2011.

Literature Cited

Arnold, J. 2010a. 2009 Yellowstone National Park water quality data validation report. National Park Service, Greater Yellowstone Network, Bozeman, Montana.

———. 2010b. 2009 Yellowstone National Park water quality data verification report. March 2010. National Park Service, Greater Yellowstone Network, Bozeman, Montana.

Gibs, J., F. D. Wilde, and H. A. Heckathorn. 2007. Use of multiparameter instruments for routine field measurements (ver. 1.1): U.S. Geological Survey Techniques of Water-Resources Investigations, book 9, chap. A6, section 6.8, August. Accessed August 4, 2010, online only from http://pubs.water.usgs.gov/twri9A/.

Hershberger, K. 2010a. 2009 Bighorn Canyon National Recreation Area water quality data validation report for seeps, springs, rivers and streams. March 2010. National Park Service, Greater Yellowstone Network, Bozeman, Montana.

———. 2010b. 2009 Bighorn Canyon National Recreation Area water quality data verification report for seeps, springs, rivers and streams. March 2010. National Park Service, Greater Yellowstone Network, Bozeman, Montana.

Montana Department of Environmental Quality (Montana DEQ). 2008a. Montana numeric water quality standards. Montana Department of Environmental Quality. Report nr Circular DEQ-7. Montana Department of Environmental Quality, Helena, Montana.

———. 2008b. Scientific and technical basis of the numeric nutrient criteria for Montana's wadeable streams and rivers. Michael Suplee, Ph.D, Montana Department of Environmental Quality; Vicki Watson, Ph.D, University of Montana; Arun Varghese and Josh Cleland, ICF International. Accessed July 5, 2010, from http://deq.mt.gov/wqinfo/standards/PDF/WhitePaper_FNL3_Nov12-08.pdf.

———. 2009. Final water quality integrated report. Prepared in accordance with requirements of Sections 303d and 305b of the federal Clean Water Act. Montana Department of Environmental Quality, Water Quality Planning Bureau, Helena, Montana. Accessed August 4, 2010, from http://cwaic.mt.gov/wqrep/2008/2008Final_MT_WQ_IntegratedReport.pdf.

———. February 2010. Montana numeric water quality standards. Montana Department of Environmental Quality. Report nr Circular DEQ-7.

National Park Service. n.d. An overview of vital signs monitoring and its central role in natural resource stewardship and performance management. National Park Service, Fort Collins, Colorado. Accessed August 30, 2011, from http://science.nature.nps.gov/im/monitor/docs/Vital_Signs_Overview.doc.

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

O'Ney, S. E., J. Arnold, C. Bromley, R. Daley, C. Jean, and S. Ostermann-Kelm. 2009a (under review). Greater Yellowstone Network water resource monitoring protocol: Version 1.0. Natural Resource Report NPS/GRN/NRR—2009/XXX. National Park Service, Fort Collins, Colorado.

O'Ney, S. E., J. Arnold, C. Bromley, S. Carrithers, E. B. Faivre, D. Schmitz, and H. Sessoms. 2009b. Greater Yellowstone Network water quality monitoring annual report: January 2007–December 2008. Natural Resource Data Series NPS/GRYN/NRDS—2009/XXX. National Park Service, Fort Collins, Colorado.

O'Ney, S. E. 2010a. 2009 Grand Teton National Park water quality data validation report. May 2010. National Park Service, Greater Yellowstone Network, Bozeman, Montana.

———. 2010b. 2009 Grand Teton National Park water quality data verification report. May 2010. National Park Service, Greater Yellowstone Network, Bozeman, Montana.

O'Ney, S. E., C. Bromley, and L. Savage. 2010a. 2009 Bighorn Canyon National Recreation Area water quality data validation report for *Escherichia coli*. May 2010. National Park Service, Greater Yellowstone Network, Bozeman, Montana.

———. 2010b. 2009 Bighorn Canyon National Recreation Area water quality data verification report for *Escherichia coli*. May 2010. National Park Service, Greater Yellowstone Network, Bozeman, Montana.

Schmitz, D, B. L. McGlynn, and D. T. Patten. 2007. Bighorn Canyon aridland springs monitoring protocol. National Park Service, Greater Yellowstone Network, Bozeman, Montana.

Sigler, W. 2010. Bighorn Canyon National Recreation Area 2009 water quality report. July 2010. National Park Service, Greater Yellowstone Network, Bozeman, Montana.

U.S. Environmental Protection Agency (US EPA). 1987. Water quality criteria for 1986. USEPA, Washington, D.C. Report nr EPA 440/5-86-001.

———. 2000a. Ambient water quality criteria recommendations. Rivers and Streams in Nutrient Ecoregion II. Office of Water 4304. EPA 822-B-00-015. December 2000.

———. 2000b. Ambient water quality criteria recommendations. Rivers and Streams in Nutrient Ecoregion III. Office of Water 4304. EPA 822-B-00-016. December 2000.

———. 2006. National recommended water quality criteria. Environmental Protection Agency.

———. 2009. National recommended water quality criteria. Environmental Protection Agency.

Wyoming Department of Environmental Quality (Wyoming DEQ). 2007. Water quality rules and regulations. Chapter 1. Wyoming surface water quality standards: Wyoming Department of Environmental Quality, Water Quality Division, April 25, 2007. Accessed March 12, 2009, from http://deq.state.wy.us/wqd/WQDrules/Chapter_01.pdf.

———. 2008. Wyoming's 2008 integrated water quality assessment report (305(b) Report). Wyoming Department of Environmental Quality, Cheyenne, Wyoming.

Appendix A. Water Quality Standards

	EPA National Recommended Water Quality Criteria (2006)	EPA Goldbook (1987)	EPA Ambient Water Quality Criteria (2000)	Montana Circular DEQ-7 (February 2008)	Wyoming DEQ Water Quality Rules and Regulations (2007)
Arsenic	Freshwater/Acute = 340 µg/L; Freshwater/Chronic = 150 µg/L; Human Health consumption of water plus organism = 0.018 µg/L; Human Health consumption of organism only = 0.14 µg/L	Freshwater aquatic organisms and their uses should not be affected unacceptably if the 4-day average concentration of arsenic does not exceed 190 µg/L more than once every 3 years on the average and if the 1-hour average concentration does not exceed 360 µg/L more than once every 3 years on the average; For the maximum protection of human health from the potential carcinogenic effects due to exposure of arsenic through ingestion of contaminated water and contaminated aquatic organisms, the ambient water concentration should be zero based on the non-threshold assumption for this chemical. However, zero level may not be attainable at the present time. Therefore, the levels which may result in incremental increase of cancer risk over the lifetime are estimated at and the corresponding criteria are 0.022 µg/L, 0.0022 µg/L, and 0.00022 µg/L, respectively. If the above estimates are made for consumption of aquatic organisms only, excluding consumption of water, the levels are 0.175 µg/L, 0.0175 µg/L, and 0.00175 µg/L, respectively.		Aquatic Life Standard/Acute = 340 µg/L; Aquatic Life Standard/Chronic = 150 µg/L; Human Health surface water = 10 µg/L	Aquatic Life/Acute = 340 µg/L; Aquatic Life/Chronic = 150 µg/L; Human Health value fish and drinking water = 10 µg/L; Human Health value fish only = 10 µg/L
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 Montana guidance documents	Not found in any Wyoming guidance documents

Appendix A. Water Quality Standards (*continued*)

	EPA National Recommended Water Quality Criteria (2006)	EPA Goldbook (1987)	EPA Ambient Water Quality Criteria (2000)	Montana Circular DEQ-7 (February 2008)	Wyoming DEQ Water Quality Rules and Regulations (2007)
Ammonia	Acute criteria/pH and temperature dependent; from pH 6.5 to 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 to 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 to 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 to 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
Chloride	Freshwater/Acute = 860,000 µg/L; Freshwater/Chronic = 230,000 µg/L	Domestic Water Supplies = 250,000 µg/L		Not found in any Montana guidance documents	Aquatic Life/Acute = 860,000 µg/L; Aquatic Life/Chronic = 230,000 µg/L
Copper	Freshwater/Acute = 13 µg/L; Freshwater/Chronic = 9.0 µg/L at a $CaCO_3$ hardness of 100,000 µg/L; Human Health for consumption of water plus organism = 1,300 µg/L	Freshwater aquatic organisms = at a hardness of 100,000 µg/L as $CaCO_3$, the 4-day average concentration is 12 µg/L and the 1-hour average concentration is 18,000 µg/L; Human Health = for controlling undesirable taste and odor quality of ambient water, the estimated level is 1,000 µg/L		Aquatic Life Standard/Acute = 3.79 µg/L; Aquatic Life Standard/Chronic = 2.85 µg/L; at a $CaCO_3$ hardness of 25 mg/L; Human Health surface water = 1,300 µg/L	Aquatic Life/Acute = 13.4 µg/L; Aquatic Life/Chronic = 9.0 µg/L at a $CaCO_3$ hardness of 100,000 µg/L; Human Health value fish and drinking water = 1,000 µg/L
Dissolved Oxygen	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 = 8,000 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

Appendix A. Water Quality Standards (*continued*)

	EPA National Recommended Water Quality Criteria (2006)	EPA Goldbook (1987)	EPA Ambient Water Quality Criteria (2000)	Montana Circular DEQ-7 (February 2008)	Wyoming DEQ Water Quality Rules and Regulations (2007)
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 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 the following: *E. coli* 126 per 100,000 µL		Not applicable	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 100,000 microliters based on a minimum of not less than 5 samples obtained during separate 24 hour periods for any 30-day period
Iron	Freshwater/Chronic = 1,000 µg/L; Human Health for consumption of water plus organism = 300 µg/L	Freshwater aquatic life = 1,000 µg/L; 300 µg/L for domestic water supplies (welfare)		Aquatic Life Standard/Chronic = 1,000µg/L; Human Health standard = The concentration of iron must not reach values that interfere with the uses specified in the surface and ground water standards (17.30.601 et seq. and 17.30.1001 et seq.) The Secondary Maximum Contaminant Level of 300 micrograms per liter which is based on aesthetic properties such as taste, odor, and staining may be considered as guidance to determine the levels that will interfere with the specified uses.	Aquatic Life/Chronic = 1,000 µg/L; Human Health value fish plus drinking water = 300 µg/L
Nitrate as N	Human health consumption of water + organism = 10,000 µg/L	Domestic water supplies = 10,000 µg/L		Human health standard/Surface water = 10,000 µg/L	Human health value/fish and drinking water = 10,000 µg/L
Nitrite as N	Not found	Not found		Human health standard/Surface water = 1,000 µg/L	Human health value/fish and drinking water = 1,000 µg/L
Nitrite + Nitrate	Not found	Domestic water supplies = 10,000 µg/L	60 µg/L*	Human health standard/Surface water = 10,000 µg/L	Human health value/fish and drinking water = 10,000 µg/L
pH	Freshwater = 6.5–9.0	Freshwater Aquatic Life = 6.5–9.0		Induced variation of hydrogen ion concentration (pH) within the range of 6.5 to 8.5 must be less than 0.5 pH unit. Natural pH maintained without change. Natural pH above 7.0 must be maintained above 7.0 (from 17-30-6 Montana DEQ).	Aquatic Life Chronic value = 6.5–9.0

Appendix A. Water Quality Standards (*continued*)

	EPA National Recommended Water Quality Criteria (2006)	EPA Goldbook (1987)	EPA Ambient Water Quality Criteria (2000)	Montana Circular DEQ-7 (February 2008)	Wyoming DEQ Water Quality Rules and Regulations (2007)
Phosphorus	No standard	No standard	10,000 µg/L*	Not found in any Montana guidance documents	Not found in any Wyoming guidance documents
Ortho-phosphate	No standard	No standard		Not found in any Montana guidance documents	Not found in any Wyoming guidance documents
Selenium	Freshwater/Chronic = 5.0 µg/L	Freshwater Aquatic life/acute = 260 µg/L		Aquatic Life standard/Acute = 20 µg/L; Aquatic Life Standard/Chronic = 5 µg/L	Aquatic Life/Acute = 20 µg/L; Aquatic Life/Chronic = 5 µg/L
Specific Conductance	No standard	No standard		Not found in any Montana guidance documents	Not found in any Wyoming guidance documents
Sulfate	No standard	No standard		Not found in any Montana guidance documents	Not found in any Wyoming 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		No increases are allowed above naturally occurring concentrations of sediment or suspended sediment which will or are likely to create a cuisance or render the waters harmful, detrimental or injurious to public health, recreation, safety, welfare, livestock, wild animals, birds, fish or other wildlife	In all Wyoming surface waters, floating and suspended solids attributable to or influenced by the activities of man shall not be present in quantities which could result in significant aesthetic degradation, significant degradation of habitat for aquatic life, or adversely affect public water supplies, agricultural or industrial water use, plant life or wildlife
Turbidity		Freshwater fish and other aquatic life: settleable and suspended solids should not reduce the depth of the compensation point for photosynthetic activity by more than 10% from the seasonally established norm for aquatic life	0.5 NTU (based on less than 4 streams to calculate 25th percentile)*	No increase above naturally occurring turbidity or suspended sediment is allowed (A-1); no increase above naturally occurring greater than 5 NTUs (B-1)	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

Appendix A. Water Quality Standards (*continued*)

	EPA National Recommended Water Quality Criteria (2006)	EPA Goldbook (1987)	EPA Ambient Water Quality Criteria (2000)	Montana Circular DEQ-7 (February 2008)	Wyoming DEQ Water Quality Rules and Regulations (2007)
Water Temperature	Species specific	Species specific		A-1: A 1ºF maximum increase above naturally occurring water temperature is allowed within the range of 32ºF to 66ºF; within the naturally occurring range of 66ºF to 66.5ºF, no discharge is allowed which will cause the water temperature to exceed 67ºF; and where the naturally occurring water temperature is 66.5ºF or greater, the maximum allowable increase in water temperature is 0.5ºF. A 2ºF-per-hour maximum decrease below naturally occurring water temperature is allowed when the water temperature is above 55ºF. A 2ºF maximum decrease below naturally occurring water temperature is allowed within the range of 55ºF to 32ºF; B-1: A 1ºF maximum increase above naturally occurring water temperature is allowed within the range of 32ºF to 66ºF; within the naturally occurring range of 66ºF to 66.5ºF, no discharge is allowed which will cause the water temperature to exceed 67ºF; and where the naturally occurring water temperature is 66.5ºF or greater, the maximum allowable increase in water temperature is 0.5ºF. A 2ºF per-hour maximum decrease below naturally occurring water temperature is allowed when the water temperature is above 55ºF. A 2ºF maximum decrease below naturally occurring water temperature is allowed within the range of 55ºF to 32ºF.	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

Sources: US EPA 2000, 2006, 2007; Montana DEQ 2008a; Wyoming DEQ 2007.

* Reference conditions for level III ecoregion 17; 25th percentiles based on all seasons data for the decade.