



Mojave Desert Network Inventory and Monitoring Streams and Lakes Protocol

2009 and 2010 Pilot Data

Natural Resource Data Series NPS/MOJN/NRDS—2013/448



ON THE COVER

Stella Lake, Great Basin National Park

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

Data in this report were collected and analyzed using methods based on established, peer-reviewed protocols and were analyzed and interpreted within the guidelines of the protocols. This report received informal peer review by subject-matter experts who were not directly involved in the collection, analysis, or reporting of the data.

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Executive Summary

The Mojave Desert Inventory and Monitoring Network (MOJN I&M) began pilot testing its Streams and Lakes protocol in the summer of 2009. The protocol was revised based on the results of the 2009 tests, and a full field season of monitoring was carried out in the summer of 2010. The field work was conducted primarily by the staff of Great Basin National Park (GRBA) and MOJN I&M cooperators. Discharge data on Lehman Creek was collected by the United States Geological Survey (USGS).

The MOJN I&M Streams and Lakes monitoring protocol has three components: monitoring the regulatory status of water bodies in and adjacent to GRBA and Lake Mead National Recreation Area (LAKE); monitoring water quality, discharge, and benthic macroinvertebrate assemblages in GRBA streams; and monitoring water quality, water level, lake clarity, and ice-free period in GRBA lakes.

The regulatory status review revealed that four streams in GRBA are considered to be Class A waters by the state of Nevada. There are four water bodies near LAKE considered to be impaired by the state of Nevada (the Muddy River, the Virgin River, Las Vegas Wash, and the Colorado River), and the Colorado River from Hoover Dam to Lake Mohave is considered to be impaired by the state of Arizona.

The water quality in GRBA streams is generally excellent, with the measured concentrations of most constituents present at concentrations far below regulatory limits. The available discharge data exhibit a pattern typical of snowmelt-fed headwater streams. The benthic macroinvertebrate assemblages observed in the streams are consistent with healthy ecosystems.

The water quality in GRBA lakes is generally excellent, with low measured concentrations of all constituents. The acid neutralizing capacity of the lakes is relatively low, indicating that they could potentially be sensitive to acid deposition. The lakes were frozen-over from early November 2009 until late May to early June 2010.

The first two years of monitoring have provided valuable baseline data on the health of aquatic ecosystems and enabled the testing and development of robust field methods. The 2009 and 2010 data in this report will be analyzed extensively in a quadrennial trend analysis report following the 2013 field season.

Acknowledgments

The data in this report was collected thanks to the efforts of numerous GRBA and MOJN I&M staff. In particular, Mark Pepper, Jonathan Reynolds, and Stephanie Olind collected the bulk of the water quality and discharge data.

Analytical data were provided by the Cooperative Chemical Laboratory established by Memorandum Of Understanding no. PNW-82 between the U.S. Forest Service Pacific Northwest Research Station and the Department of Forest Ecosystems and Society, Oregon State University.

The Lehman Creek discharge data were collected, processed, and published by the U.S. Geological Survey.

Introduction

The Mojave Desert Network (MOJN) includes seven units of the National Park system: Death Valley National Park (DEVA), Great Basin National Park (GRBA), Joshua Tree National Park (JOTR), Lake Mead National Recreation Area (LAKE), Manzanar National Historic Site (MANZ), Mojave National Preserve (MOJA), and Grand Canyon-Parashant National Monument (PARA). Collectively, these parks comprise 3.3 million hectares or 9.7% of the total land area managed by the NPS. However, the MOJN I&M Streams and Lakes protocol is only concerned with LAKE and GRBA because stream and lake habitats are limited or absent in the other parks.

LAKE encompasses 229 km of the Colorado River and is centered on two large reservoirs, Lake Mead and Lake Mojave. In addition to the Colorado River, LAKE is fed by the Virgin River and the Muddy River to the north and treated wastewater channeled through Las Vegas Wash to the west (Figure 1). Millions of visitors engage in water recreation at LAKE each year, so water quality is a very high priority for park managers. The water quality of the rivers and reservoirs in LAKE is monitored intensively by several different agencies (Turner et al. 2010). Therefore, MOJN I&M does not actively monitor these water bodies, but instead reports on their regulatory status.

GRBA lies within the South Snake Range of east-central Nevada, and receives the most precipitation of the MOJN parks. GRBA contains 10 perennial streams and 6 small subalpine lakes (Figure 2). These streams and lakes are fed primarily by snowmelt, so they are vulnerable to changes in precipitation patterns due to climate change. In addition, some of the streams have been identified as vulnerable to proposed groundwater withdrawals in the Snake Valley (Elliott et al. 2006). The MOJN I&M Streams and Lakes protocol is focused on monitoring the regulatory status, water quality, discharge, and benthic macroinvertebrate assemblages in streams, and the water quality, water level, lake clarity, and ice-free period in GRBA lakes.

303 (d) Impaired Water Bodies at Lake Mead NRA

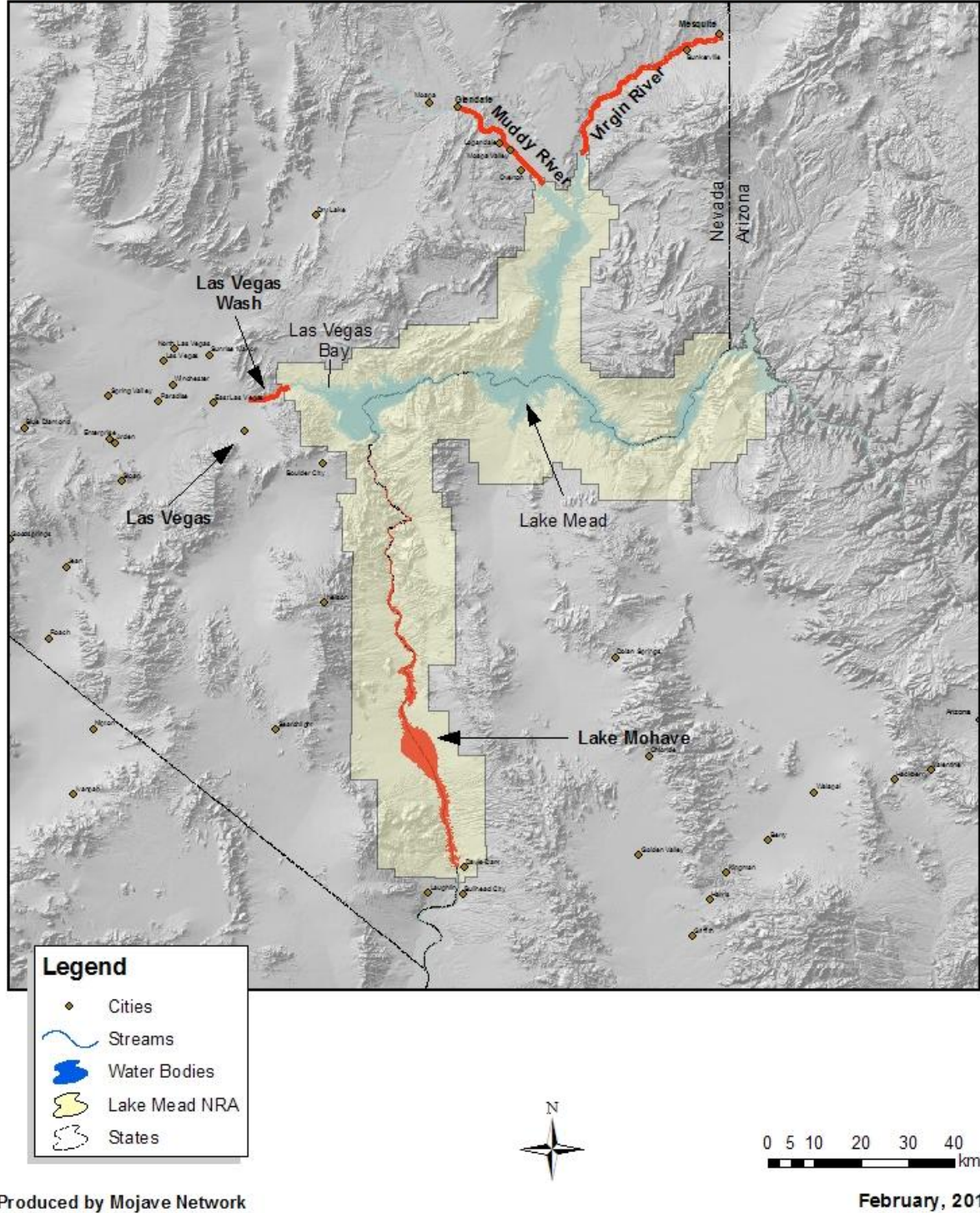


Figure 1. Water bodies in and adjacent to LAKE.

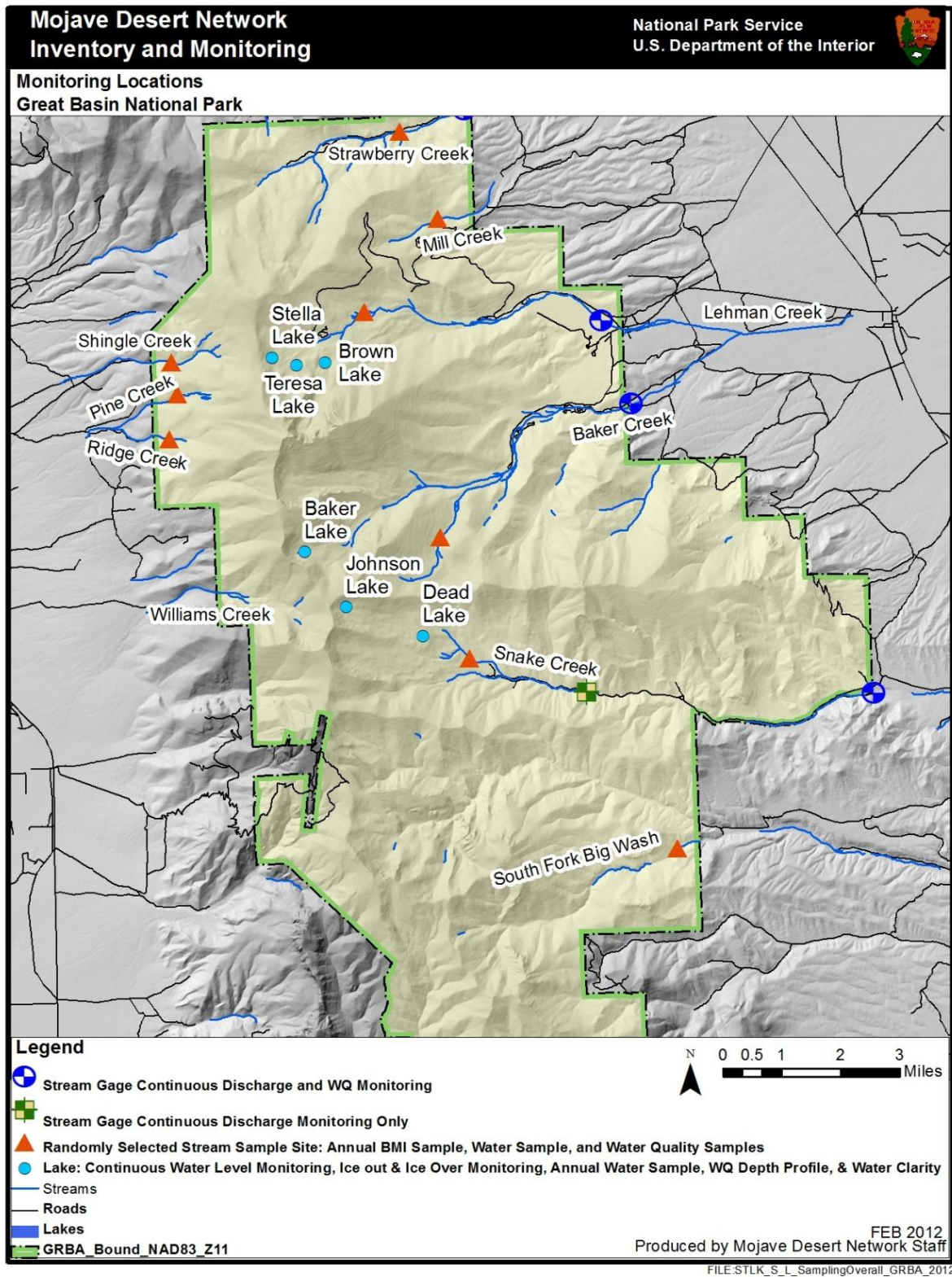


Figure 2. Streams, lakes, and monitoring locations in GRBA.

Methods

The methods used in the 2009 pilot data season and the 2010 monitoring season are fully described in the MOJN Streams and Lakes protocol narrative and SOPs (Caudill et al. 2012). The methods are briefly summarized here.

Regulatory Status

The state of Nevada lists its Class A waters in the Nevada Administrative Code (NAC) 445A.124. The NAC can be accessed at <http://www.leg.state.nv.us/nac/>.

There are three sources for information regarding the 303(d) status of the waters in the MOJN parks: the EPA, the state of Arizona, and the state of Nevada. The EPA's water quality information portal is the Watershed Assessment, Tracking, and Environmental Results (WATERS) system. WATERS can be accessed at <http://www.epa.gov/waters/ir/index.html>. The current and historical 303(d) reports for Arizona and Nevada can be accessed from this site. However, this site only links to the final, EPA-approved reports, so it is necessary to review the reports on the state agencies' websites as well. The Arizona Department of Environmental Quality reports are available at <http://www.azdeq.gov/envIRON/water/assessment/assess.html>. The Nevada Division of Environmental Protection reports are available at <http://ndep.nv.gov/bwqp/standard.htm>. The three websites should be reviewed annually at the time of report preparation.

Streams

The MOJN I&M Streams and Lakes protocol contains four stream monitoring components: stream discharge, continuous water quality monitoring, stream water chemistry, and benthic macroinvertebrate sampling. All monitoring locations are shown on Figure 2.

Stream discharge is monitored by GRBA staff at four gages (Strawberry Creek, Baker Creek, upper Snake Creek, and lower Snake Creek) and by the USGS at one gage (Lehman Creek). These sites are shown on Figure 2. The discharge data collected by GRBA staff are being processed for eventual inclusion in the National Water Information System (NWIS). At the time of this report, only the data from Lehman Creek are available on NWIS for 2009 and 2010.

Continuous water quality data are collected from early June to late September at the five sites (Strawberry Creek, Baker Creek, Lehman Creek, upper Snake Creek, and lower Snake Creek) shown on Figure 2. The records are collected using sondes (data-logging instruments deployed in the streams) that are recalibrated approximately every two weeks. The sondes record hourly measurements of temperature, specific conductance, dissolved oxygen, and pH. The data from the two week deployments are processed, graded, and joined using the Aquarius software package. With the exception of the upper Snake Creek site, the water quality sondes are located adjacent to the stream gages. In the 2009 pilot season, only one sonde was available, and it was rotated between streams approximately every two weeks. In 2010, data were collected from all five sites.

Stream water chemistry is determined through laboratory analysis of water samples. Annual samples were collected in late summer of 2009 and 2010 from nine of GRBA's 10 permanent streams (the tenth stream, Williams Canyon, was determined to be too inaccessible for annual

monitoring) and analyzed for nutrients, major ions, and acid neutralization capacity. A handheld multimeter was used to measure temperature, dissolved oxygen, specific conductance, and pH at the time of sampling. The water samples were collected from randomly-selected sites that will be visited each year (Figure 2). In the 2009 pilot season, the Baker Creek and Lehman Creek samples were collected from the stream gages instead of the random sites.

Benthic macroinvertebrate (BMI) samples are collected at the same time and location as the water samples. Samples were collected in 2009 and 2010 using the EPA's Environmental Monitoring and Assessment Program (EMAP) method (Peck et al. 2006), which involves collecting samples from 11 evenly-spaced reaches and compositing them. In the 2009 pilot season, the Baker Creek and Lehman Creek samples were collected from the stream gages instead of at the random sites.

Lakes

The MOJN I&M Streams and Lakes protocol contains three lake monitoring components: lake level and ice-free period, lake water chemistry, and lake clarity. All lakes are visited annually in a late-September index period. In 2009, four lakes (Stella, Teresa, Baker, and Johnson) were visited. In 2010, all six lakes were visited.

Lake level and ice-free period are monitored using data-logging pressure transducers and temperature sensors. At each annual visit, the lake level is compared to the elevation of fixed benchmarks using the line level method (e.g. Hoffman et al. 2005). The lake-bottom pressure transducer record is converted to a lake level record using the measured elevations and an atmospheric pressure record collected using a separate transducer. The lake level record and the temperature record are then used to infer the dates of ice-over and ice-out. Records are available for the 2010 Water Year for the four lakes where loggers were deployed in September 2009 and retrieved in September 2010.

Lake water chemistry is monitored by laboratory analysis of water samples and depth profiles of water chemistry. Each year, a single water sample is collected by hand-dipping from the deepest area of each lake and analyzed for nutrients, major ions, and acid neutralization capacity. At the same time, a handheld multimeter is used to measure temperature, dissolved oxygen, specific conductance, and pH at several depths from the lake surface to the lake bed.

Lake clarity is assessed by lowering a Secchi disk until it is no longer visible, then recording the depth. The disk is then raised until it becomes visible, and a second depth is recorded. This process is repeated three times, and the average of the six depths is the Secchi depth. In practice, the lakes of GRBA are shallow and clear, so the disk was visible on the bottom at every lake visited in 2009 and 2010.

Regulatory Status

All of the regulatory status information reported in this section is current as of December 2011.

The state of Nevada lists four stream reaches in GRBA as Class A Waters (Table 1). These streams are treated as Outstanding Natural Resource Waters (ORNWs) under the Clean Water Act.

Table 1. Nevada Class A Waters in GRBA.

Name	Description
Baker Creek	From its origin to the national forest boundary
Lehman Creek	From its origin to the national forest boundary
Pine Creek	From its origin to the first point of diversion, near the west line of section 17, T. 13 N., R. 68 E., M.D.B. & M
Ridge Creek	From its origin to the first point of diversion, near the west line of section 17, T. 13 N., R. 68 E., M.D.B. & M

States are required to submit a list of impaired waters (the state's 303(d) report) to the EPA every two years. The most recent 303(d) report submitted to the EPA by the state of Nevada is for 2006. However, the report has not yet been approved by the EPA. The report lists five water bodies in or adjacent to LAKE as impaired by different constituents (Table 2).

The most recent 303(d) report submitted to the EPA by the state of Arizona is for 2010. However, the report has not yet been approved by the EPA. The report lists two water bodies in or adjacent to LAKE as impaired by selenium (Table 2).

In reading Table 2, it should be noted that the state of Nevada considers Lake Mohave's inlet to be 16 river miles downstream of the Hoover Dam, while the state of Arizona considers Lake Mohave's inlet to be 40.4 river miles downstream. This difference may result in some sampling points that would be considered part of the Colorado River by Arizona being considered part of Lake Mohave by Nevada.

Table 2. 303 (d) listed waters in and adjacent to LAKE.

Arizona Listings						
Waterbody Name	Reach Description	Existing TMDLs	2004 List (EPA-Approved)	2006 List (EPA-Approved)	2008 List (EPA-Approved)	2010 List (Submitted to EPA)
Colorado River	Hoover Dam to Lake Mohave (40.4 miles)	None	Selenium	Selenium	Selenium	Selenium
Lake Mohave	-	None	None	None	None	Selenium
Nevada Listings						
Waterbody Name	Reach Description	Existing TMDLs	2002 List (EPA-Approved)	2004 List (EPA-Approved)	2006 List (Submitted to EPA)	
Las Vegas Wash	Telephone Line Rd to Lake Mead	Total ammonia, Phosphorus (total)	Iron (total) Total Suspended Solids	Iron (total) Selenium	Iron Molybdenum	
Virgin River	Mesquite to Lake Mead	Draft TMDL for Boron	Boron (total) Iron (total) Temperature Phosphorus (total)	Boron (total) Iron (total) Temperature Phosphorus (total) Selenium	Manganese Iron Temperature Phosphorus (total)	
Muddy River	Glendale to Lake Mead	None	Boron (total) Iron (total) Temperature	Boron (total) Iron (total) Temperature	Boron Iron Temperature Manganese Molybdenum	
Colorado River	Lake Mohave Inlet to CA State Line	None	pH	Temperature	Temperature	
Colorado River	Hoover Dam to Lake Mohave Inlet (16 miles)	None	pH	Zinc (total)	Dissolved Oxygen Temperature	

Precipitation and Snowpack

Year-to-year variations in precipitation and snowpack are expected to cause variations in many of the monitored parameters. This section discusses the precipitation measured at National Weather Service Cooperative (NWS Coop) Station Number 263340 (located behind the Lehman Caves Visitor Center) and the snowpack measured at Baker Creek Snowcourse # 3 (USDA Natural Resources Conservation Service Station 14L03). These index sites were chosen so that the results in a given year could be compared to the longest possible historical record (Figures 3 and 4). The intent of this section is not to provide a complete discussion of the year's precipitation in GRBA, but to provide context for the streams and lakes monitoring data.

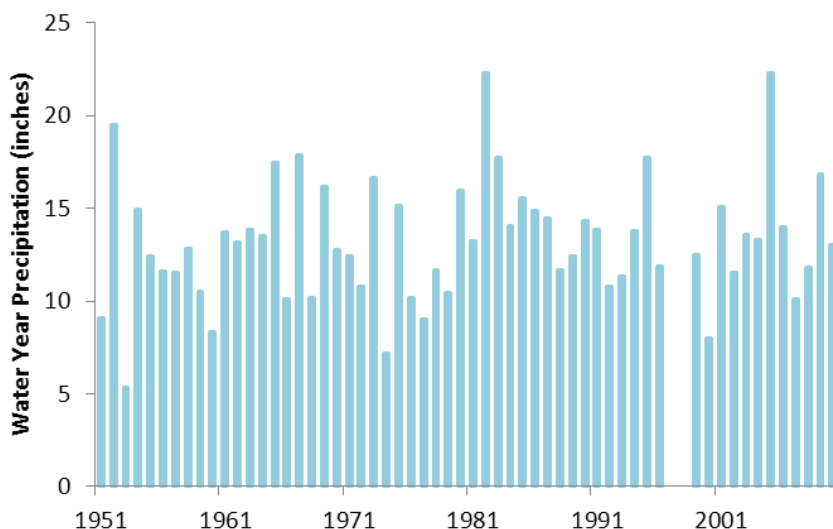


Figure 3. Annual precipitation by water year (October 1 to September 30) recorded at the NWS COOP weather station in Baker Flats.

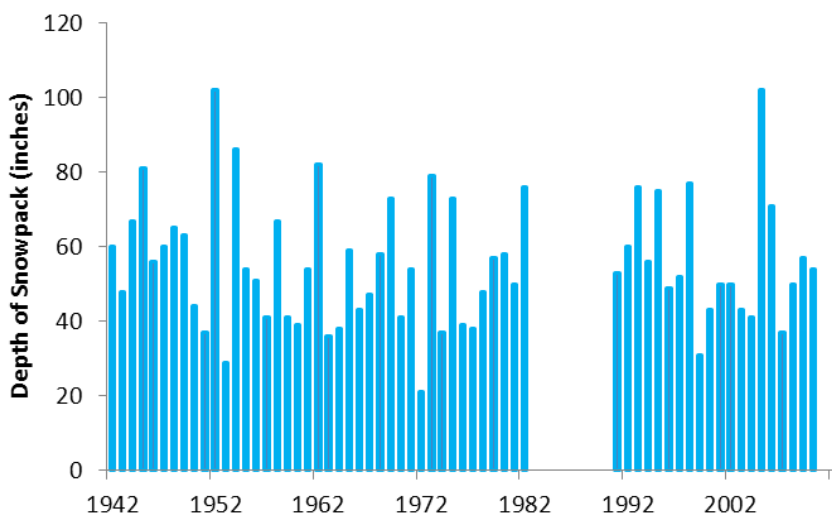


Figure 4. NRCS depth-of-snowpack data collected at Baker Creek Snowcourse #3 near April 1 of each year.

Water Year 2009

NWS Coop Station 263340 recorded 16.82 inches of precipitation in WY2009, slightly greater than the 1951-2010 average of 13.2 inches. Precipitation events were distributed throughout the year, with the most significant storms occurring in January and February (Figure 5).

The April 1 depth of the snowpack at the snow course site for 2009 (actually measured on March 29) was 57 inches, very close to the 1942-2010 average on 55.4 inches.

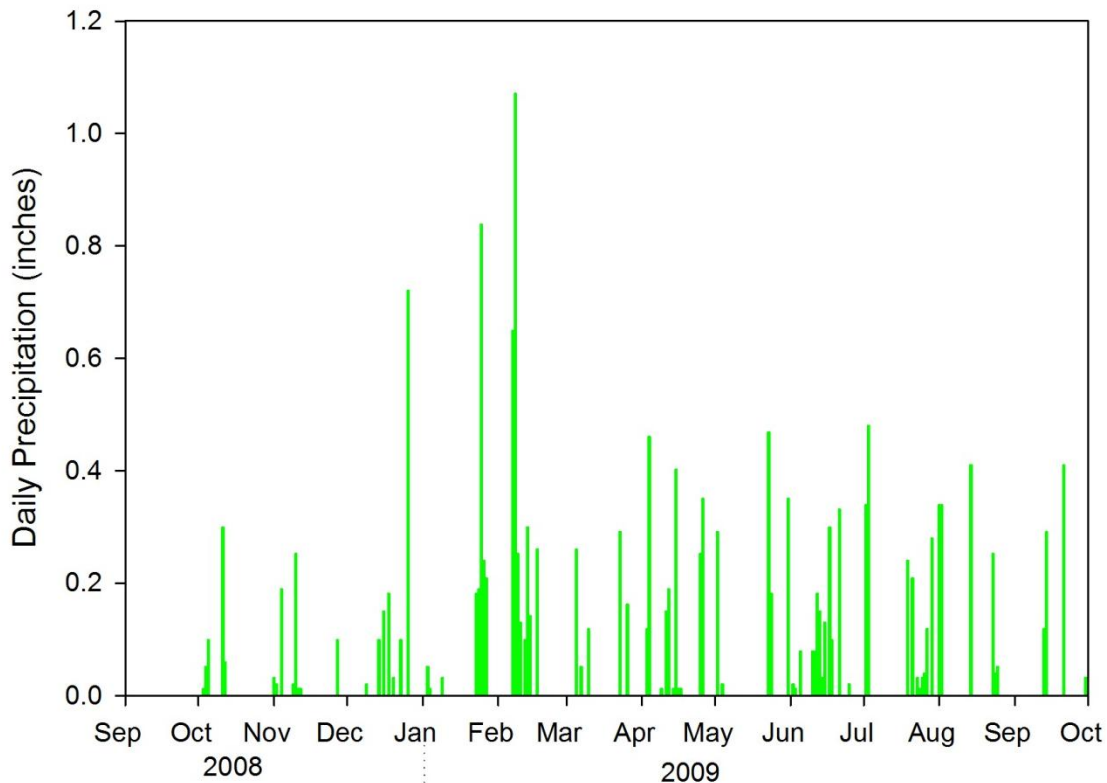


Figure 5. Daily precipitation recorded at NWS Coop Station 263340 in Water Year 2009.

Water Year 2010

NWS Coop Station 263340 recorded 13.02 inches of precipitation in WY2010, very close to the 1951-2010 average of 13.2 inches. The wettest months were January, February, and April (Figure 6). The summer was relatively dry, with the only significant storm occurring July 27-30.

The April 1 depth of the snowpack at the snowcourse site for 2010 (actually measured on March 30) was 54 inches, very close to the 1942-2010 average on 55.4 inches.

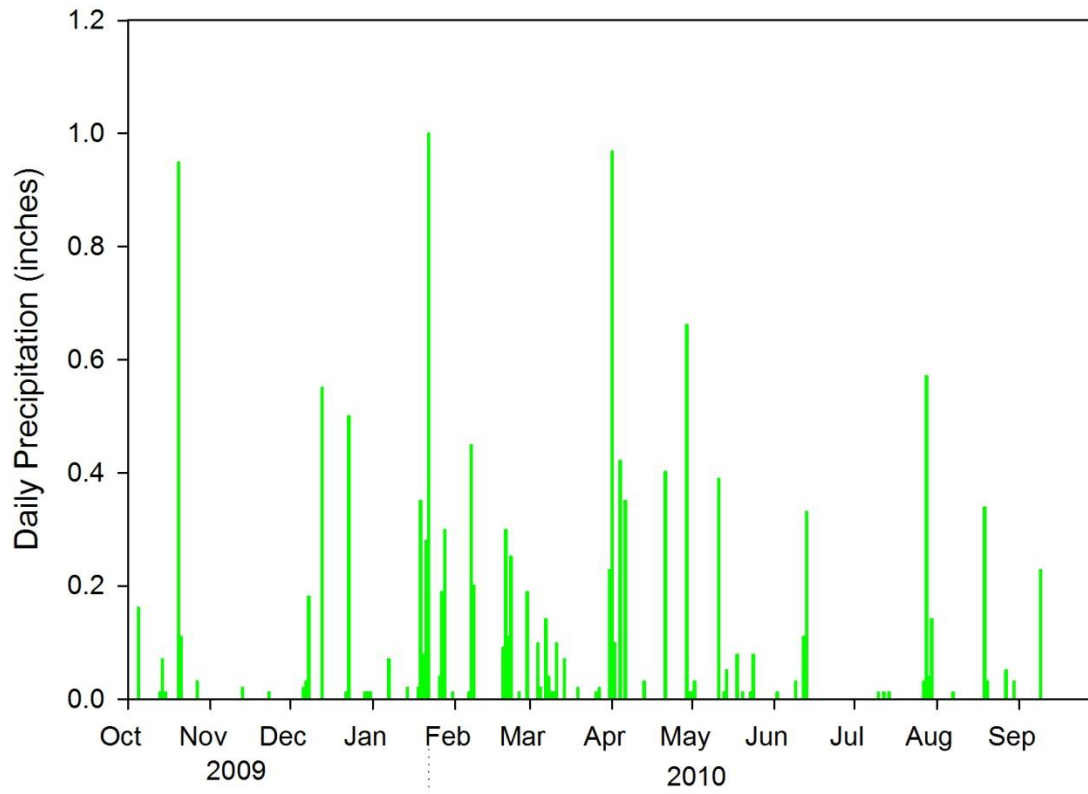


Figure 6. Daily precipitation recorded at NWS Coop Station 263340 in Water Year 2010.

Streams Monitoring Results

The results of stream discharge monitoring, continuous water quality monitoring, stream water chemistry monitoring, and benthic macroinvertebrate sampling activities conducted in the 2010 field season are summarized below. More detailed information regarding these data may be obtained by contacting the Mojave Desert Network.

Stream Discharge

GRBA is currently having an outside contractor process the WY2009 and WY2010 stream discharge data, which will be made available through the USGS National Water Information System (NWIS). While WY2010 discharge and stream stage data were collected for all of the second-order streams, at this time only the USGS-collected Lehman Creek data are available on NWIS. Discharge results for the other monitored streams will be included in future Streams and Lakes Protocol Annual Reports.

Lehman Creek

The Lehman Creek gage is located on the main stem of Lehman Creek near the park boundary (Figure 2). The UTM coordinates for the gage are 741152 E, 4321829 N (zone 11S, NAD83). The historical monthly means for the Lehman Creek gage are given in Table 3.

Table 3. Monthly mean discharge (in m³/s) for Lehman Creek. 1947-1955, 1992-1997, and 2002-2010. Data collected by the USGS and downloaded from NWIS.

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1947										0.062	0.059	0.054
1948	0.048	0.043	0.043	0.079	0.223	0.368	0.236	0.153	0.097	0.073	0.058	0.046
1949	0.040	0.043	0.077	0.127	0.292	0.620	0.388	0.167	0.094	0.078	0.057	0.050
1950	0.044	0.036	0.036	0.052	0.154	0.337	0.216	0.108	0.078	0.070	0.058	0.050
1951	0.041	0.031	0.033	0.039	0.151	0.345	0.224	0.179	0.098	0.062	0.047	0.038
1952	0.035	0.035	0.048	0.147	0.592	0.920	0.609	0.365	0.173	0.099	0.066	0.051
1953	0.047	0.038	0.029	0.037	0.052	0.119	0.139	0.111	0.059	0.045	0.040	0.037
1954	0.023	0.025	0.034	0.089	0.399	0.348	0.286	0.128	0.084	0.065	0.055	0.043
1955	0.035	0.036	0.040	0.042	0.149	0.572	0.377	0.306	0.144			
1992										0.050	0.050	0.045
1993	0.027	0.021	0.033	0.047	0.447	0.541	0.345	0.172	0.128	0.095	0.069	0.051
1994	0.034	0.033	0.033	0.059	0.233	0.360	0.191	0.146	0.108	0.101	0.060	0.045
1995	0.037	0.043	0.050	0.082	0.227	1.110	1.232	0.510	0.238	0.105	0.073	0.067
1996	0.053	0.049	0.049	0.073	0.182	0.309	0.211	0.124	0.100	0.074	0.063	0.046
1997	0.050	0.043	0.044	0.063	0.334	0.459	0.266	0.152	0.122			
2002								0.103	0.090	0.060	0.047	0.032
2003	0.028	0.027	0.032	0.037	0.148	0.496	0.203	0.135	0.123	0.069	0.056	0.048
2004	0.044	0.035	0.036	0.056	0.214	0.222	0.196	0.119	0.080	0.065	0.063	0.046
2005	0.047	0.051	0.060	0.090	0.912	1.733	0.906	0.490	0.170	0.089	0.069	0.052
2006	0.040	0.033	0.032	0.059	0.445	0.527	0.300	0.175	0.108	0.085	0.064	0.048
2007	0.042	0.033	0.038	0.047	0.149	0.157	0.104	0.097	0.074	0.067	0.053	0.023
2008	0.023	0.024	0.034	0.034	0.123	0.257	0.201	0.097	0.076	0.053	0.052	0.035
2009	0.023	0.023	0.030	0.036	0.331	0.501	0.379	0.167	0.093	0.083	0.066	0.018
2010	0.020	0.028	0.033	0.051	0.095	0.524	0.263	0.131	0.065			
Avg.	0.037	0.034	0.040	0.065	0.278	0.510	0.340	0.187	0.110	0.074	0.059	0.045

Water Year 2009: Lehman Creek reached its maximum discharge for WY2009 on May 22, 2009, when the daily mean discharge was $0.57 \text{ m}^3/\text{s}$ (Figure 7). Discharge remained high (greater than $0.5 \text{ m}^3/\text{s}$) until the end of June. The minimum discharge of $0.021 \text{ m}^3/\text{s}$ occurred December 30-31, 2008. The monthly summary statistics for Lehman Creek discharge are compared to the historical record in Table 3. The monthly mean discharges in the winter months (October 2008 to April 2009) were slightly below normal, but the monthly mean discharges for May 2009 to September 2009 were near their historical averages. The average flow in Water Year 2009 (October 1, 2008-September 30, 2009) was $0.144 \text{ m}^3/\text{s}$, close to the long-term average of $0.148 \text{ m}^3/\text{s}$. None of the summer 2009 precipitation events appear to have substantially affected the discharge record.

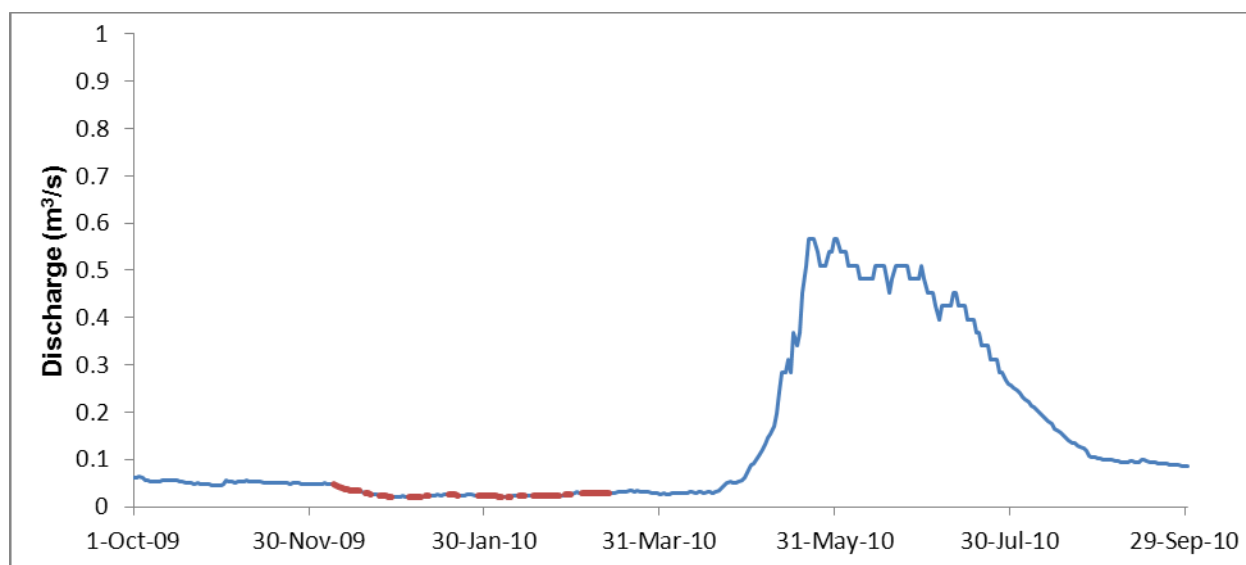


Figure 7. USGS discharge record for Lehman Creek in Water Year 2009. The thick red line segments represent estimated data.

Water Year 2010: Lehman Creek's discharge peaked on June 11, 2010, when the daily mean discharge was $0.85 \text{ m}^3/\text{s}$ (Figure 8). The sharp peak in early June reflects a delayed start of runoff due to a colder than average May (NWS Coop Station 263340 recorded a mean daily maximum of 14.2°C in May 2010; the long term average is 19.3°C). The minimum discharge of $0.013 \text{ m}^3/\text{s}$ occurred December 18-20, 2009. The monthly summary statistics for Lehman Creek discharge are compared to the historical record in Table 3. The mean discharge in June 2010 was near the historical average, but flows in most of the other months were slightly below normal. The average flow in Water Year 2010 (October 1, 2009-September 30, 2010) was $0.114 \text{ m}^3/\text{s}$, 23% below the long-term average of $0.148 \text{ m}^3/\text{s}$. The late July 2010 precipitation event (0.75 inches) did not have a measureable impact on the discharge at the gaging station. The August 19 precipitation event briefly raised the mean daily discharge from $0.11 \text{ m}^3/\text{s}$ to $0.13 \text{ m}^3/\text{s}$, a 15% increase.

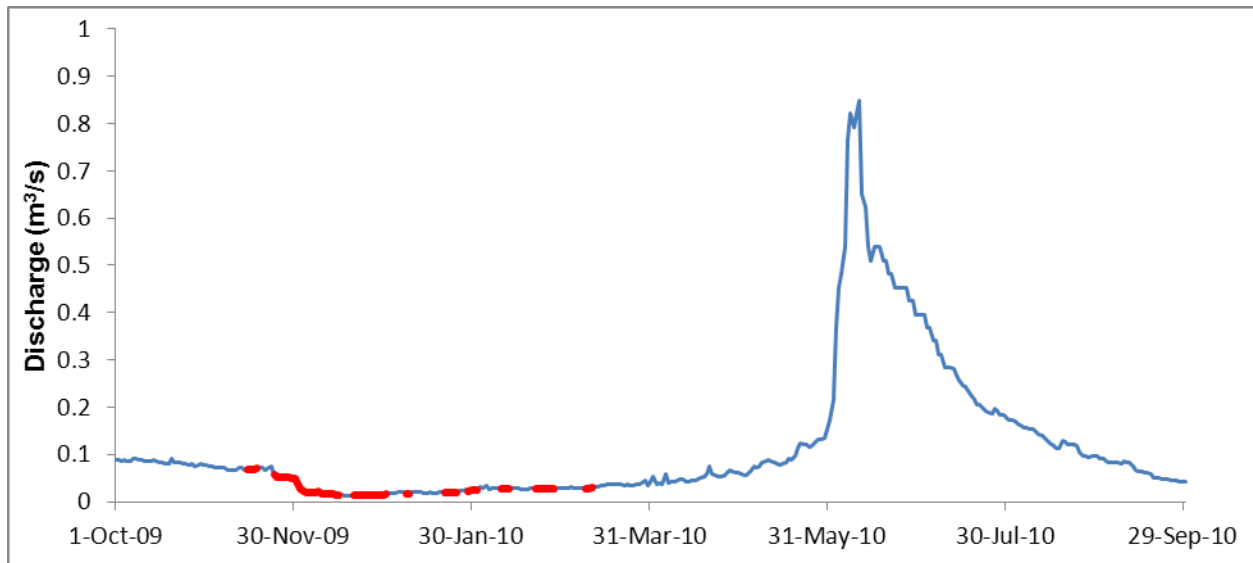


Figure 8. USGS discharge record for Lehman Creek in Water Year 2010. The thick red line segments represent estimated data.

Continuous Water Quality

Continuous water quality data was collected near the stream-gages on the four second-order streams in GRBA, with sondes deployed in both the upper and lower portions of Snake Creek (gage locations are shown in Figure 2 and given in Table 4).

Water Year 2009: In the 2009 field season, one water quality sonde was rotated between streams at approximately two-week intervals, with data collected every 15 minutes. No data was collected in Upper Snake Creek. Due to their limited scope, the 2009 data are not discussed or presented graphically in this report, but the average values during the applicable index periods are included in the summary tables (Tables 5 to 9).

Water Year 2010: In the 2010 field season, hourly water quality data was collected using separate sondes for each creek. These data are presented below. Many of the WY2010 records were impacted by a late July precipitation event (Figure 6). From July 28 to July 30, 2010, NWS Coop Station 263340 recorded 0.75 inches of rain. The only other significant rain event (0.34 inches on August 19, 2010) had a much less noticeable impact on stream water quality.

Table 4. UTM coordinates (NAD 83, Zone 11S) for continuous water quality monitoring locations.

Gaged Stream	Easting (m)	Northing (m)
Baker Creek	742,027	4,319,535
Lehman Creek	741,152	4,321,829
Lower Snake Creek	748,657	4,311,656
Upper Snake Creek		
Strawberry Creek	733,483	4,327,499

Baker Creek

In 2010, a sonde was deployed in Baker Creek from July 12 to September 23 (the deployment was delayed due to high discharge). No data were collected from August 14 to August 16, as a decrease in discharge left the sonde above the water. The average values of each parameter in five index periods are presented in Table 5. The daily average, minimum, and maximum values of each parameter are plotted in Figures 9a to 9d.

Table 5. Average water quality parameter values in Baker Creek, 2009-2010.

Parameter	Year	July 1-15	July 16-31	August 1-15	August 16-31	September 1-15
Mean Temperature, °C	2009	-	11.7 ^b		-	-
	2010	-	12.5	13.4 ^a	13.2 ^a	10.5
Mean DO, % saturation	2009	-	81.0 ^b		-	-
	2010		82.9	80.9 ^a	79.0 ^a	77.9
Median pH, standard units	2009		7.47 ^b			
	2010		7.70	7.68 ^b	7.59 ^a	7.57
Mean SpCond, µS/cm	2009		32 ^b			
	2010		40	46 ^a	40 ^a	41

a. Average calculated with 1-2 days of data missing

b. Average calculated with 3-5 days of data missing

Baker Creek's water temperature (Figure 9a) increased in July, reached a maximum temperature of 17.7 °C on August 4, and began to decrease in late August.

The dissolved oxygen saturation of Baker Creek (Figure 9b) decreased steadily over the field season, from approximately 83% in mid-July to approximately 78% in late September.

The pH of Baker Creek (Figure 9c) generally decreased over the field season, from approximately 7.65 in mid-July to approximately 7.45 in late September. The stream's pH increased during the late July precipitation event, with a maximum pH value of 8.54.

The overall trend in the specific conductance of Baker Creek (Figure 9d) was a slight increase from approximately 35 µS/cm in mid-July to approximately 45 µS/cm in late-September. The daily mean specific conductance did not respond strongly to the late July rain event, but some high values were recorded for brief periods. The maximum observed specific conductance was 78 µS/cm on July 29.

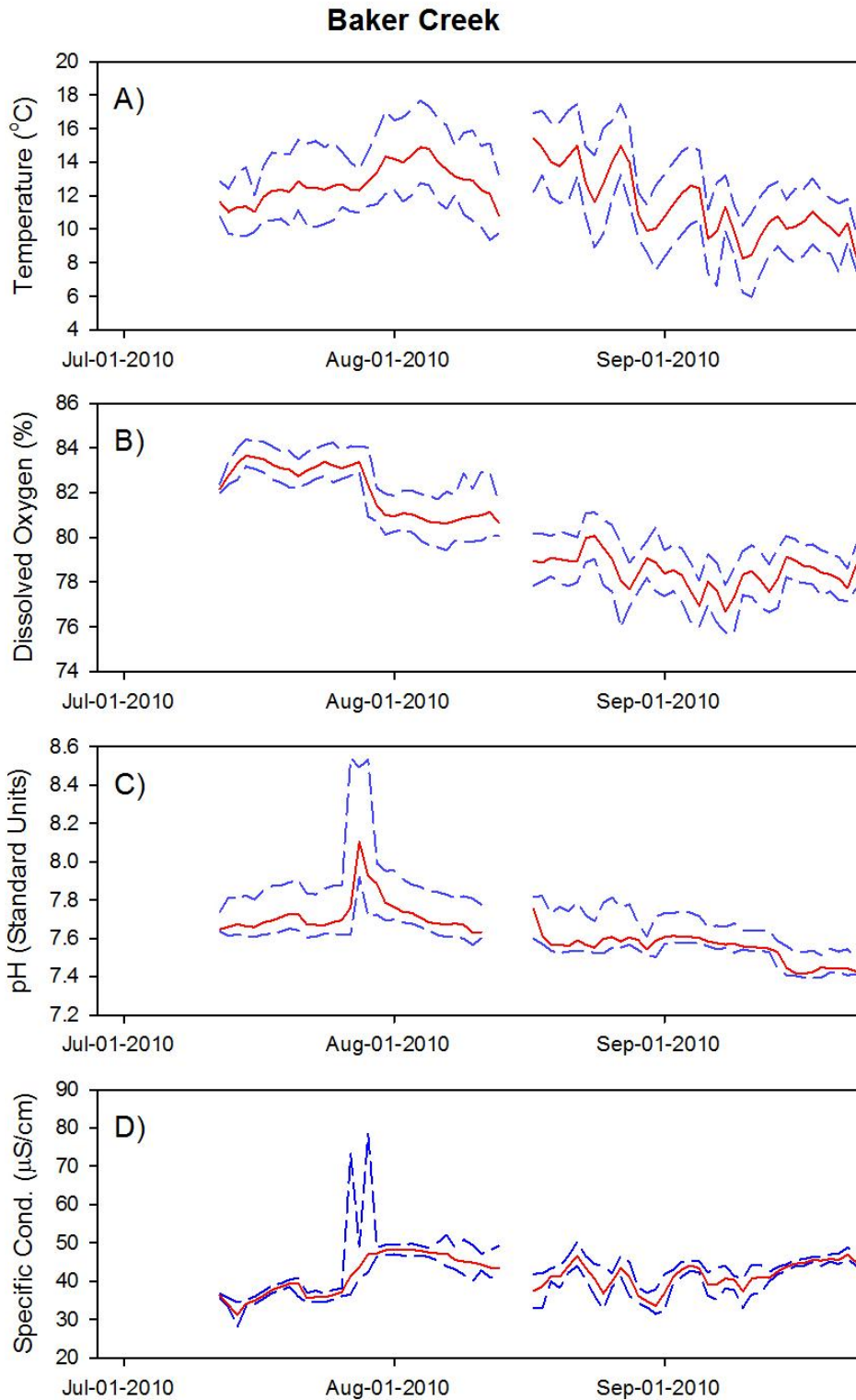


Figure 9. Baker Creek water quality data from the 2010 field season. The sonde was dry from August 14-16. A. Daily mean, minimum, and maximum temperature values. B. Daily mean, minimum, and maximum dissolved oxygen saturation values. C. Daily median, minimum, and maximum pH values. D. Daily mean, minimum, and maximum specific conductance values.

Lehman Creek

In 2010, a sonde was deployed in Lehman Creek from August 17 to September 23 (the deployment was delayed due to sonde malfunction). The average values of each parameter in five index periods are presented in Table 6. The daily average, minimum, and maximum values of each parameter are plotted in Figures 10a to 10d.

Table 6. Average water quality parameter values in Lehman Creek, 2009-2010.

Parameter	Year	July 1-15	July 16-31	August 1-15	August 16-31	September 1-15
Mean Temperature, °C	2009	-	-	-	10.9 ^a	-
	2010	-	-	-	11.7 ^a	9.8
Mean DO, % saturation	2009	-	-	-	79.9 ^a	-
	2010	-	-	-	79.3 ^a	79.5
Median pH, standard units	2009	-	-	-	7.53 ^a	-
	2010	-	-	-	7.53 ^a	7.55
Mean SpCond, µS/cm	2009	-	-	-	35 ^a	-
	2010	-	-	-	36 ^a	36

a. Average calculated with 1-2 days of data missing

The water temperature in Lehman Creek (Figure 10a) decreased from approximately 13 °C in mid-August to approximately 10 °C in late September. The highest recorded temperature was 16.7 °C during the rain event on August 19.

The dissolved oxygen saturation in Lehman Creek (Figure 10b) remained steady over the period of the deployment, with values fluctuating between 77% and 80%.

Lehman Creek's pH record (Figure 10c) exhibited very little variation over the period of the deployment, with most values near 7.5.

The specific conductance of Lehman Creek (Figure 10d) remained steady over the period of the deployment, with the highest values (a maximum of 45 µS/cm) occurring shortly after the August 19 rain event.

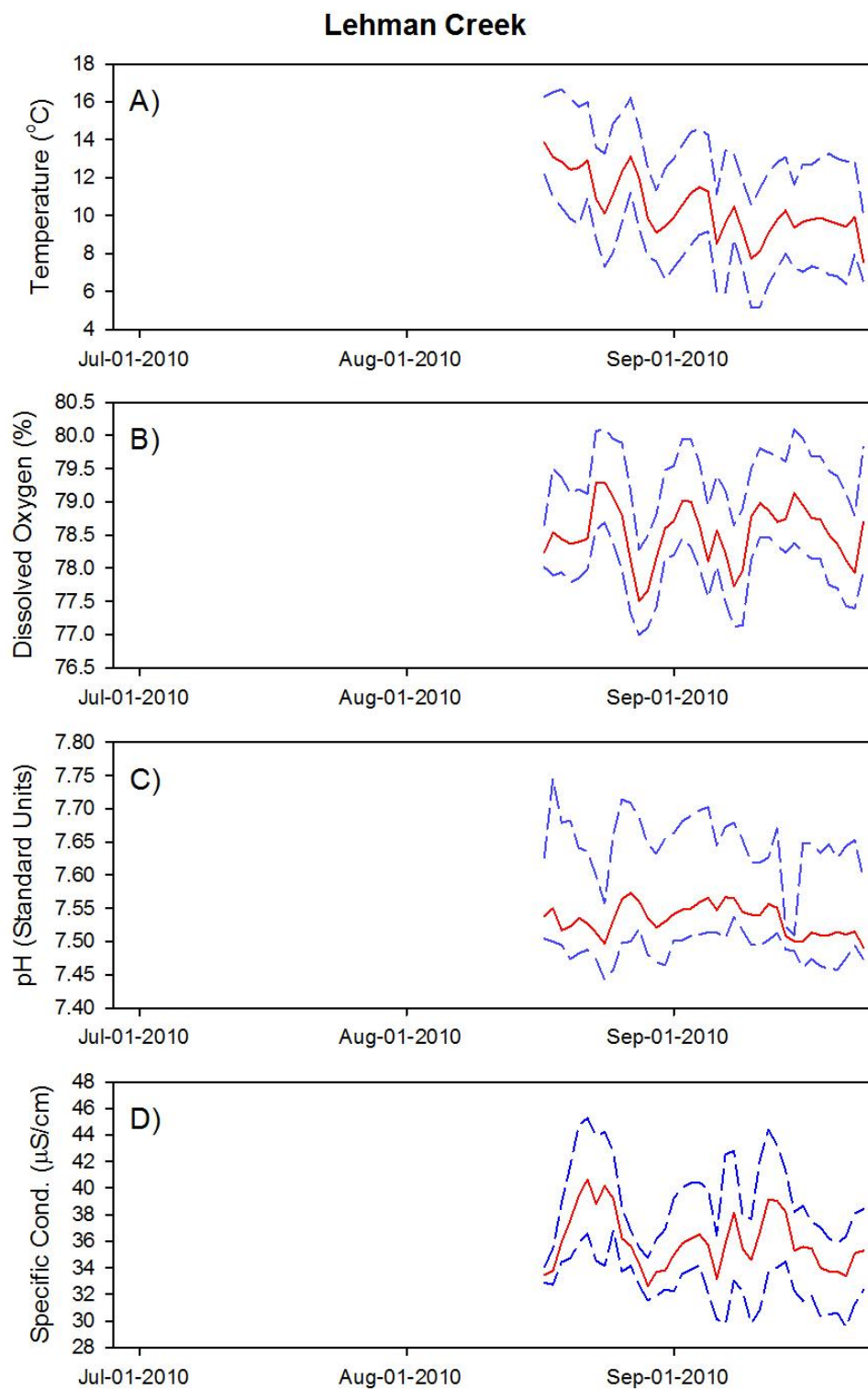


Figure 10. Lehman Creek water quality data from the 2010 field season. The deployment was delayed to August 17 by sonde malfunction. A. Daily mean, minimum, and maximum temperature values. B. Daily mean, minimum, and maximum dissolved oxygen saturation values. C. Daily median, minimum, and maximum pH values. D. Daily mean, minimum, and maximum specific conductance values.

Lower Snake Creek

In 2010, a sonde was deployed in Lower Snake Creek from June 29 to September 23. The average values of each parameter in five index periods are presented in Table 7. The daily average, minimum, and maximum values of each parameter are plotted in Figures 11a to 11d.

Lower Snake Creek generally runs dry in late summer. In 2009, the water level first receded below the conductance sensor on September 9. In 2010, the water level first receded below the conductance sensor level on September 14.

Table 7. Average water quality parameter values in Lower Snake Creek, 2009-2010.

Parameter	Year	July 1-15	July 16-31	August 1-15	August 16-31	September 1-15
Mean	2009	11.1	-	-	-	-
Temperature, °C	2010	11.6	13.6	13.5	12.5	10.7
Mean DO, % saturation	2009	81.1	-	-	-	-
	2010	83.1	82.8	82.1	82.9	83.1 ^a
Median pH, standard units	2009	8.23	-	-	-	-
	2010	8.36	8.41	8.39	8.35	8.37 ^a
Mean SpCond, µS/cm	2009	148	-	-	-	-
	2010	175	214 ^a	174	186	209 ^a

a. Average calculated with 1-2 days of data missing

The water temperature in lower Snake Creek (Figure 11a) generally increased from the beginning of the record until it reached a maximum of 17.8 °C on August 3. It then declined for the remainder of the field season.

The dissolved oxygen saturation in lower Snake Creek (Figure 11b) remained steady over the period of the deployment, with most values between 82% and 84%. Dissolved oxygen saturation declined slightly following the late July rain event, and exhibited slightly greater variability from late August until the stream dried up.

The pH values recorded in lower Snake Creek (Figure 11c) were generally between 8.3 and 8.5, which were significantly higher than in the other streams. The elevated pH values are likely due to exchange between the stream and the underlying carbonate aquifer (Elliott et al. 2006). The lowest observed pH value (8.20) was recorded on July 30 during the late July rain event.

The specific conductance of lower Snake Creek (Figure 11d) peaked on July 23 at 244 µS/cm, showed a sharp decrease during the late July rain event, and then increased steadily over the rest of the field season.

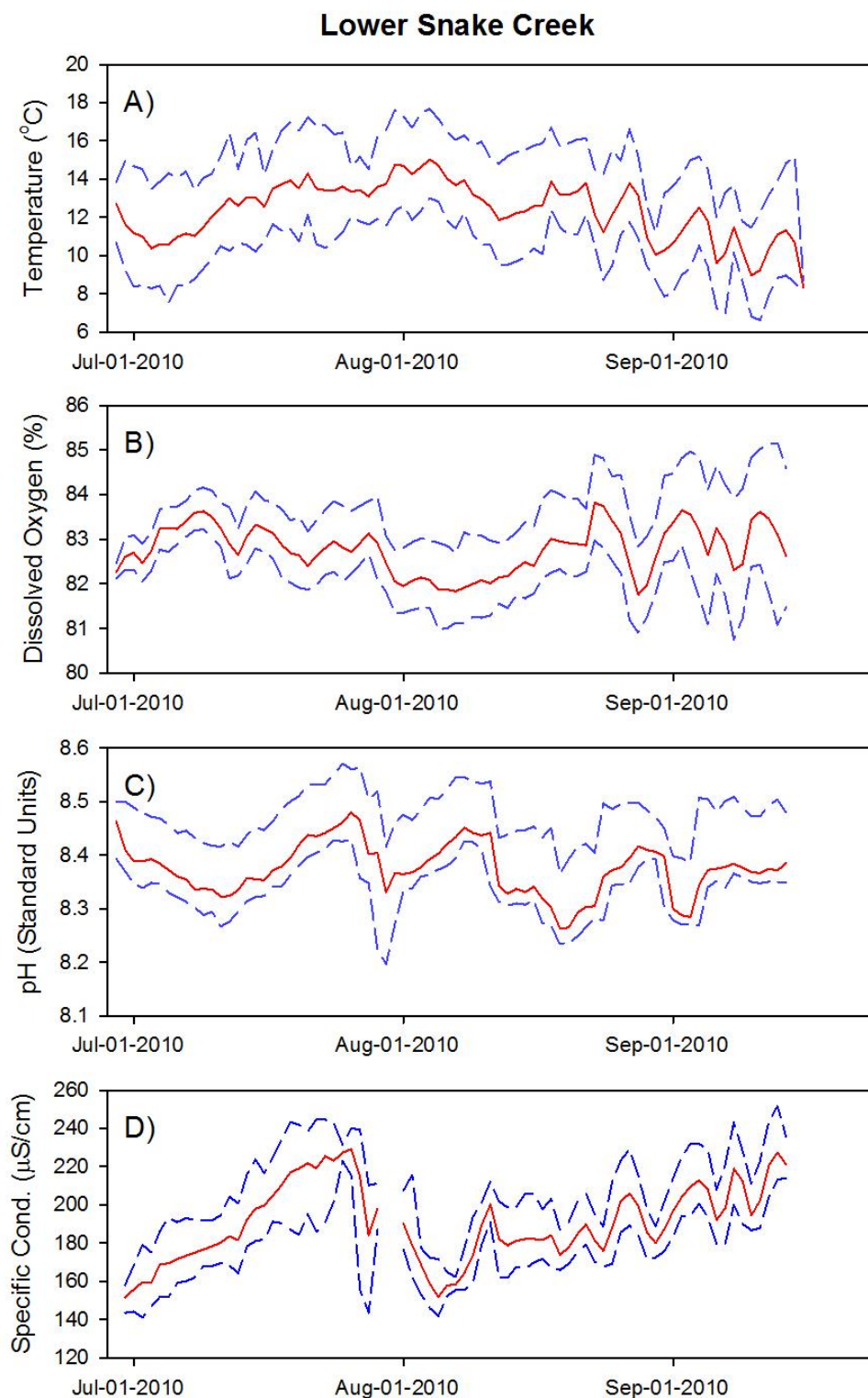


Figure 11. Lower Snake Creek water quality data from the 2010 field season. A. Daily mean, minimum, and maximum temperature values. B. Daily mean, minimum, and maximum dissolved oxygen saturation values. C. Daily median, minimum, and maximum pH values. D. Daily mean, minimum, and maximum specific conductance values.

Upper Snake Creek

In 2010, a sonde was deployed in upper Snake Creek from June 29 to August 17 (the sonde was moved to Lehman Creek on August 17 to replace a malfunctioning sonde). The average values of each parameter in five index periods are presented in Table 8. The daily average, minimum, and maximum values of each parameter are plotted in Figures 12a to 12d.

Table 8. Average water quality parameter values in Upper Snake Creek, 2010.

Parameter	Year	July 1-15	July 16-31	August 1-15	August 16-31	September 1-15
Mean Temperature, °C	2010	7.6	9.5	9.5	-	-
Mean DO, % saturation	2010	75.8	75.9	73.2	-	-
Median pH, standard units	2010	7.57	7.60	7.57	-	-
Mean SpCond, µS/cm	2010	48	47	-	-	-

The water temperature in upper Snake Creek (Figure 12a) increased slightly from the beginning of the record until it reached a maximum of 12.6 °C on July 30. It then declined for the remainder of the deployment. While the 2010 deployment period for upper Snake Creek was short, it encompassed the time periods when the other streams reached their maximum temperatures. The temperature is lower for upper Snake Creek than the other streams because it is at a higher elevation (approximately 2500 m above mean sea level).

The dissolved oxygen saturation in upper Snake Creek (Figure 12b) varied between 75% and 77% prior to the late July rain event and between 72% and 74% afterwards.

The pH values recorded in upper Snake Creek (Figure 12c) were generally between 7.5 and 7.7, with a minimum observed pH value (7.37) recorded on July 29 during the late July rain event.

The specific conductance of upper Snake Creek (Figure 12d) varied between 40 and 55 µS/cm in early July, then increased to a maximum of 61 µS/cm during the late July rain event. The specific conductance record was unusable after August 1, likely due to either partial burial or partial drying of the sensor.

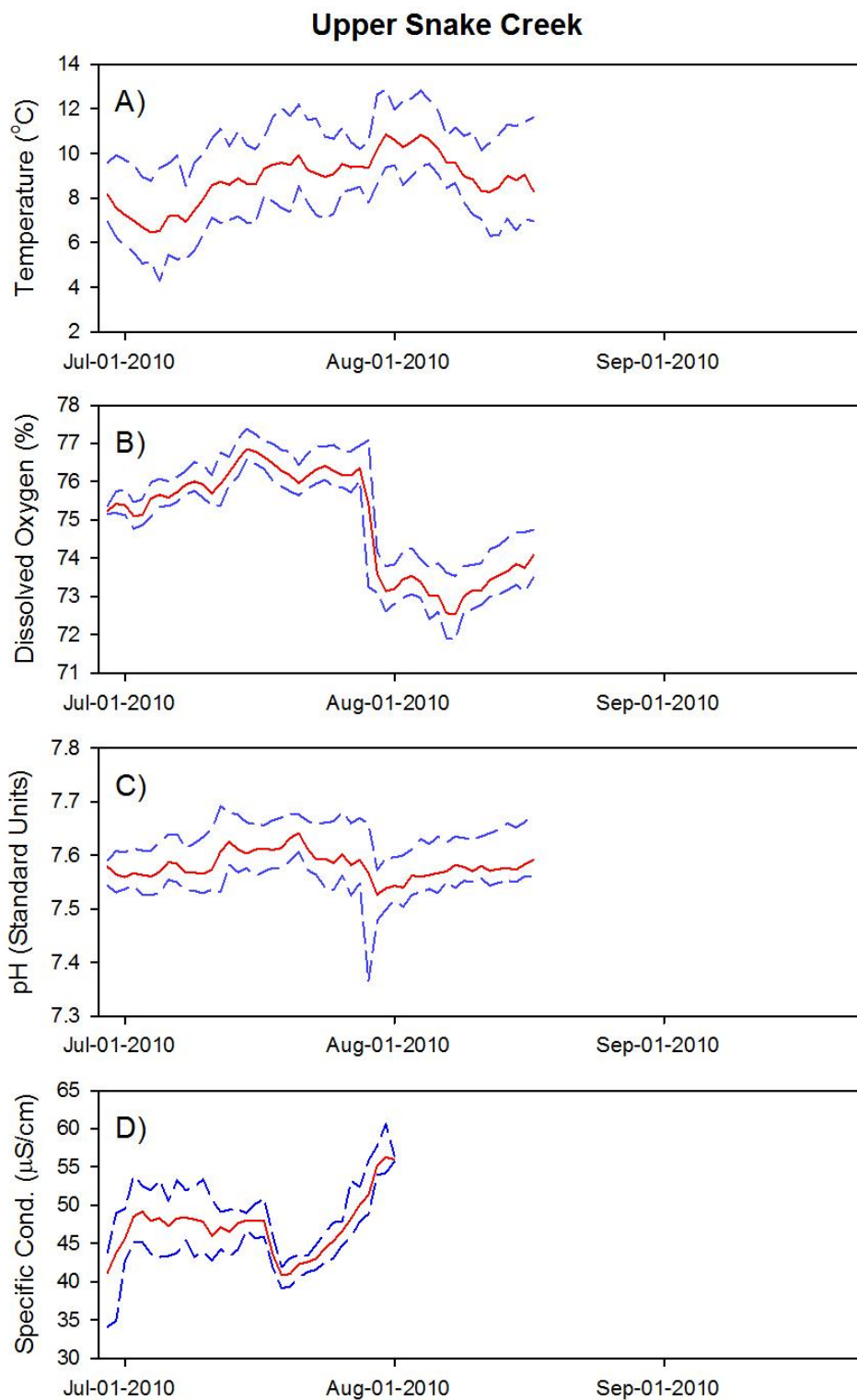


Figure 12. Upper Snake Creek water quality data from the 2010 field season. The sonde was moved to Lehman Creek on August 17. A. Daily mean, minimum, and maximum temperature values. B. Daily mean, minimum, and maximum dissolved oxygen saturation values. C. Daily median, minimum, and maximum pH values. D. Daily mean, minimum, and maximum specific conductance values.

Strawberry Creek

In 2010, a sonde was deployed in Strawberry Creek from June 29 to September 23. The average values of each parameter in five index periods are presented in Table 9. The daily average, minimum, and maximum values of each parameter are plotted in Figures 13a to 13d.

Table 9. Average water quality parameter values in Strawberry Creek, 2009-2010.

Parameter	Year	July 1-15	July 16-31	August 1-15	August 16-31	September 1-15
Mean Temperature, °C	2009	-	-	11.97 ^a	-	-
	2010	10.79	13.19	13.02	12.38	10.10 ^a
Mean DO, % saturation	2009	-	-	78.2 ¹	-	-
	2010	79.1 ^b	80.7	78.1	78.9	78.9
Median pH, standard units	2009	-	-	8.05 ^a	-	-
	2010	8.00 ^a	8.02	7.93	8.07	8.06
Mean SpCond, µS/cm	2009	-	-	120 ^a	-	-
	2010	94	108	177	131	124

¹ Average calculated with 1-2 days of data missing

² Average calculated with 3-5 days of data missing

The water temperature Strawberry Creek (Figure 13a) increased in early July, reached a maximum temperature of 17.3 °C on August 3, and then slowly decreased for the remainder of the field season. The highest temperatures were observed during and shortly after the late July rain event.

The dissolved oxygen saturation of Strawberry Creek (Figure 13b) varied over a small range, from approximately 79% to approximately 81%. There was a small decrease during the late July rain event.

The pH of Strawberry Creek (Figure 13c) remained relatively invariant at 8.0 for the entire field season with the exception of a decrease during and after the late July rain event. The minimum pH of 7.07 was recorded on July 30, the fourth day of rain. The maximum recorded pH value of 8.51 was recorded on August 23 at 7:00 PM. The 8:00 PM pH value was also unusually high (8.23). These atypical values may represent a brief period of sensor malfunction (potentially fouling) or a brief perturbation of the stream's chemistry.

The specific conductance of Strawberry Creek (Figure 13d) increased steadily over the field season, from approximately 90 µS/cm in late June and early July to approximately 140 µS/cm in mid-September. A strong response to the late July rain event was superimposed on this trend. Specific conductance rose sharply on July 31 (the last day of rain), reached a maximum of 283 µS/cm on August 3, and then decreased until August 10.

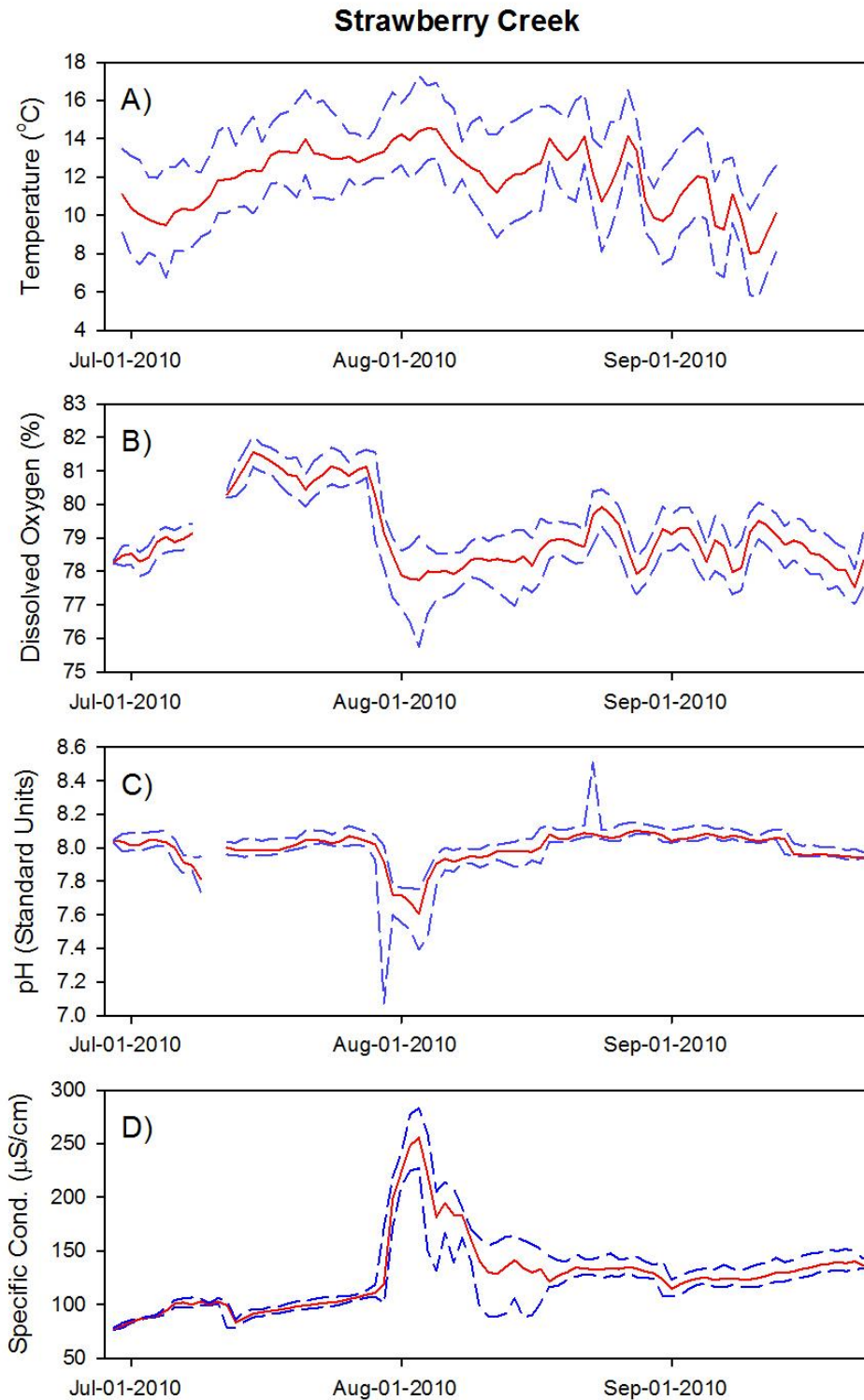


Figure 13. Strawberry Creek water quality data from the 2010 field season. A. Daily mean, minimum, and maximum temperature values. B. Daily mean, minimum, and maximum dissolved oxygen saturation values. C. Daily median, minimum, and maximum pH values. D. Daily mean, minimum, and maximum specific conductance values.

Stream Water Chemistry

Stream water samples were collected from nine streams at the locations given in Table 10 and shown on Figure 2. The sites were chosen randomly to ensure that the results were representative of aquatic habitat condition across the park. Care should be taken in comparing values between streams, as some samples were collected at higher elevations in tributaries while other samples were collected at lower elevations on the main channel (Figure 2).

The water samples were analyzed for basic chemistry and nutrient concentrations at the Cooperative Chemical Analysis Facility (CCAL) in Corvallis, Oregon. The results of these analyses, water quality data measured at the time of the sampling, and pilot data from the 2009 field season are described in this section.

The bottles containing the 2009 filtered samples for Mill Creek and Shingle Creek were overfilled, so they cracked during freezing (the water samples are frozen before being shipped to the laboratory). As a result, some data are missing for Mill Creek and Shingle Creek in 2009.

In 2009, the water samples for Baker Creek and Lehman Creek were collected at the stream gages instead of at random sites. We have included the results from these samples in this report with the understanding that they are not directly comparable to samples collected in 2010 and later.

Water Quality Parameters

Four water quality parameters were measured at each site during the 2009 and 2010 field seasons: temperature, dissolved oxygen (DO), pH, and specific conductance (SpCond). In order to assess mixing, these parameters were measured near each bank and at the center of the channel. All of the streams were found to be well mixed each year, and the median of the three measurements is reported here. During the 2009 field season, formal field recording and data management procedures had not been established, so much of the 2009 water quality has been lost.

The state of Nevada has established water quality standards for Class A Waters for pH (between 6.5 and 9.0), DO (greater than or equal to 6.0 mg/l), and temperature (less than or equal to 20°C). All of the measured values meet these standards.

Table 10. Water quality parameters in GRBA streams. Each value is the median of three measurements.

Stream	UTM Coordinates Zone 11S, NAD83 m	Visit Date	Temperature °C	Dissolved Oxygen mg/l	pH S.U.	Specific Conductivity µS/cm
Snake	737569, 4326941	8/1/2009	8.3	9.52	8.4	45.5
		9/7/2010	6.8	9.31	8.08	55
Baker	736781, 4315879	8/31/2010	4.9	9.2	7.59	41.9
Lehman	734703, 4322017	8/30/2010	4.4	8.33	7.92	30.3
Pine	729600, 4319780	8/26/2010	7.9	9.25	7.6	29.8
Ridge	729383, 729383	8/26/2010	6.8	9.95	7.57	36.9
S. Fk. Big Wash	743243, 4307414	9/2/2010	8.8	9.45	7.99	398.2
Mill	736689, 4324562	9/7/2010	8.3	8.92	7.91	49.7
Shingle	729424, 4320644	8/18/2009	7.0	-	8.0	66.2
		9/1/2010	6.7	9.71	8.01	70
Strawberry	735651, 4326941	7/31/2009	12.9	7.08	7.9	103
		8/24/2010	12.2	8.58	8.13	112

Nutrients

The nutrient concentrations measured in the stream water samples are all very low (Table 11). The highest Total Nitrogen (TN) and total Phosphorus (TP) values (0.45 mg/l and 0.074 mg/l, respectively) were observed in Mill Creek in 2009. All TP values were below the Nevada water quality standard for Class A Waters of ≤ 0.10 mg/l.

The Total Dissolved Nitrogen (TDN) values were greater than the TN values in nine of the stream samples. As discussed in Appendix 1, all but two of these anomalies fall within the range of expected variability. In the other two samples, TDN exceeds TN by an amount that is outside the expected range of variability, indicating that either the samples were contaminated during filtration or contaminated bottles were used. In 2011, additional care was taken in crew training to emphasize the importance of wearing gloves and using tweezers to handle the filters.

Table 11. Nutrient concentrations in GRBA streams

Stream	Sampling Date	Total N mg/l	Total Dissolved N mg/l	Nitrate + Nitrite mg/l as N	Total P mg/l	Total Dissolved P mg/l
Snake	9/2/2009	0.05	0.06	0.002	0.013	0.011
	9/7/2010	0.05	0.06	0.003	0.007	0.005
Baker	8/27/2009 ^a	0.15	0.15	0.051	0.017	0.016
	8/31/2010	0.13	0.15	0.091	0.008	0.009
Lehman	8/27/2009 ^a	0.20	0.24	0.158	0.020	0.015
	8/30/2010	0.24	0.24	0.191	0.010	0.007
Pine	8/28/2009	0.12	0.17 ^b	0.092	0.013	0.012
	8/26/2010	0.21	0.19	0.130	0.015	0.012
Ridge	8/28/2009	0.44	0.33	0.264	0.027	0.019
	8/26/2010	0.31	0.38 ^b	0.248	0.020	0.016
S. Fk. Big Wash	9/2/2009	0.12	0.13	0.080	0.005	0.004
	9/2/2010	0.10	0.12	0.070	0.002 ^c	0.003
Mill	7/31/2009	0.45	-	-	0.074	-
	9/7/2010	0.18	0.12	0.003	0.024	0.019
Shingle	8/18/2009	0.22	-	-	0.030	-
	9/1/2010	0.08	0.11	0.008	0.010	0.009
Strawberry	9/28/2009	0.16	0.13	0.005	0.031	0.020
	8/24/2010	0.10	0.06	0.004	0.020	0.013

a. Sample collected at stream gage.

b. TDN value greater than TN value with the difference outside the expected range of variability, indicating contamination of sample.

c. Concentration is above the method detection limit (MDL) but below the minimum level of quantification (ML).

In June 2010, CCAL switched to an automated method to measure TP. In order to avoid the accumulated bias, the water samples collected in 2010 were analyzed using both the old and the new methods. As discussed in Appendix 1, the concentrations measured with the new method are slightly lower than the concentrations produced by the old method (a mean difference of 0.0054 mg/l).

Major Ions and Acid Neutralization Capacity

The 2009 and 2010 water samples were analyzed for sodium, potassium, calcium, magnesium, sulfate, and chloride (Table 12). Systematic changes in the concentrations of these ions over time may be useful in determining changes in the source of water to the streams.

In addition, the acid neutralization capacity (ANC) of each stream was measured. ANC is expressed in milliequivalents per liter (meq/l), that is, the number of millimoles of H⁺ ions (acid) that can be neutralized by a liter of the water without a change in the pH. As ANC decreases, the sensitivity of the water body to acidification increases. Decreases in ANC may be an indication of acid deposition. The high ANC values in South Fork Big Wash may indicate that the late-summer discharge at the monitoring site is dominated by springflow.

Table 12. Major ion concentrations and acid neutralization capacity in GRBA streams.

Stream	Sampling Date	Sodium mg/l	Potassium mg/l	Calcium mg/l	Magnesium mg/l	Sulfate mg/l as S	Chloride mg/l	ANC µeq/l
Snake	9/2/2009	3.21	0.52	6.29	0.74	0.66	0.82	485
	9/7/2010	3.32	0.50	6.29	0.75	0.68	0.69	497
Baker	8/27/2009 ^a	1.78	0.43	4.42	0.78	0.67	0.71	296
	8/31/2010	2.60	0.41	4.32	0.67	0.52	0.64	362
Lehman	8/27/2009 ^a	1.46	0.33	3.96	0.76	0.40	0.60	314
	8/30/2010	1.08	0.27	3.71	0.78	0.36	0.39	268
Pine	8/28/2009	1.82	0.22	3.43	0.70	0.49	0.65	270
	8/26/2010	1.16	0.23	3.42	0.74	0.51	0.40	254
Ridge	8/28/2009	1.65	0.43	4.10	0.88	0.61	0.66	124
	8/26/2010	1.33	0.49	4.25	0.95	0.62	0.69	308
S. Fk. Big Wash	9/2/2009	3.21	0.49	58.70	16.26	2.45	2.93	3774
	9/2/2010	3.08	0.45	62.57	14.55	3.11	2.76	3586
Mill	7/31/2009	-	-	-	-	-	-	396
	9/7/2010	2.54	0.50	5.18	1.29	0.73	1.37	417
Shingle	8/18/2009	-	-	-	-	-	-	616
	9/1/2010	2.07	0.32	9.84	1.85	0.66	0.65	657
Strawberry	9/28/2009	4.73	0.77	12.37	3.15	1.19	2.42	964
	8/24/2010	4.44	0.66	15.29	3.33	1.16	2.10	953

a. Sample collected at stream gage.

Stream Benthic Macroinvertebrates

Benthic macroinvertebrate (BMI) samples were collected from nine streams at the locations given in Table 10 at the same time that water samples were collected. The sampled macroinvertebrates were identified and enumerated by the Utah State University National Aquatic Monitoring Center (the BugLab) in Logan, Utah. The complete results of the analysis are available from MOJN. Four common population metrics are reported in Table 13.

Abundance (the total number of specimens in each sample), taxon richness (the total number of taxa observed in each sample), and percent dominant taxon (the percentage of the counted individuals in the most abundant taxon) are measures of the diversity of the BMI community in

the streams. In general, the BMI communities in impaired streams are less diverse than those in healthy streams. EPT taxa richness is the number of taxa of the orders Ephemeroptera (mayflies), Plecoptera (stoneflies), and Trichoptera (caddisflies). These insects are generally sensitive to ecosystem stressors, so the EPT taxa richness would be expected to decrease in response to any degradation of water quality.

The significance of interannual variations will be easier to assess when more data are available. The large changes in abundance may be due to inconsistent sampling effort in the field.

Table 13. Population metrics for BMI samples collected in GRBA streams

Stream	Sampling Date	Abundance (per m ²)	Taxon Richness	EPT Taxa Richness	% Dominant Taxon
Snake	9/2/2009	1039	55	19	24
	9/7/2010	858	61	24	12
Baker	8/27/2009 ^a	820	60	24	24
	8/31/2010	3563	41	18	38
Lehman	8/27/2009 ^a	566	54	26	32
	8/30/2010	870	39	18	19
Pine	8/28/2009	1090	51	22	9
	8/26/2010	1973	55	19	14
Ridge	8/28/2009	1891	45	20	12
	8/26/2010	4840	50	19	16
S. Fk. Big Wash	9/2/2009	506	35	11	16
	9/2/2010	1467	41	13	19
Mill	7/31/2009	1252	53	26	27
	9/7/2010	4502	62	26	18
Shingle	8/18/2009	614	57	21	12
	9/1/2010	1062	65	24	11
Strawberry	9/28/2009	311	46	20	12
	8/24/2010	1477	57	23	19

a. Sample collected at stream gage- not comparable to 2010 data.

Lakes Monitoring Results

The results of lake level and temperature monitoring, water quality depth profile collection, lake water chemistry monitoring, and lake water clarity monitoring activities conducted in the 2009 pilot study and the 2010 field season are summarized below. Four lakes (Stella Lake, Teresa Lake, Baker Lake, and Johnson Lake) were monitored in 2009, and all six lakes were monitored in 2010. During the 2009 pilot study, two of the lakes (Stella Lake and Teresa Lake) were monitored outside of the late September index period.

Lake Level and Ice-Free Period

The relative water levels measured at the lakes are given in Table 14. Each lake's water level measurements are reported relative to a lake-specific benchmark (assigned a relative elevation of 100 m), so water levels cannot be compared between lakes. In the 2009 pilot season, lake levels were surveyed using an optical level. In the 2010 field season, levels were measured using the line level method described in the protocol SOPs. All four of the lakes measured in both years had slightly higher water levels in 2010 than in 2009.

Table 14. Measured water levels in GRBA lakes.

Lake	Sampling Date	Relative Lake Level (m) Benchmark = 100 m
Stella	8/27/2009 ^a	97.76
	9/21/2010	98.51
Teresa	8/27/2009 ^a	97.25
	9/21/2010	98.10
Brown	9/21/2010	99.27
Baker	9/25/2009	98.98
	9/22/2010	99.37
Johnson	9/24/2009	98.81
	9/23/2010	98.98
Dead	9/23/2010	99.02

a. Lake monitored outside of the index period.

Lake level and temperature records for the 2010 water year are only available for the four lakes where loggers were deployed during the 2009 pilot testing field season (Stella Lake, Teresa Lake, Baker Lake, and Johnson Lake). As part of the pilot testing, the loggers in Stella Lake and Teresa Lake were set to record pressure and temperature every 15 minutes, so their memory capacity was reached in February 2010, prior to ice-out. Loggers were deployed in all six of GRBA's lakes in 2010, with sampling frequencies ranging from 2 hours to 12 hours.

The water level and temperature records for each lake are shown in Figures 14a to 14d. The water levels in all four lakes slowly declined from the time of deployment until the ice-over. In Baker Lake and Johnson Lake, water levels increased and then decreased rapidly over a period of

several days after ice out. This sharp peak in lake level may be due the same delay in the onset of melting noted in the 2010 Lehman Creek discharge record (Figure 8). Water levels remained high until late June and then declined steadily for the remainder of the summer. In the Johnson Lake record, very slight response (less than 2 cm) can be seen to the late July precipitation event. The maximum and minimum observed lake levels are given in Table 15.

The temperature records cannot be used to monitor overall lake temperature, as they represent the temperature at a single point in the lake that changes slightly from year to year, and the depth of water above them varies over the course of the year. However, they can be used, along with the water level records, to infer the dates of ice over and ice out. Other studies (e.g. Hodgkins et al. 2002, Pierson et al. 2011) have found that the uncertainty associated with these dates is on the order of several days. The methods that will be used to determine ice-over and ice-out have not yet been finalized. The provisional ice-over and ice-out dates, inferred from inspection of the data, are given in Table 15.

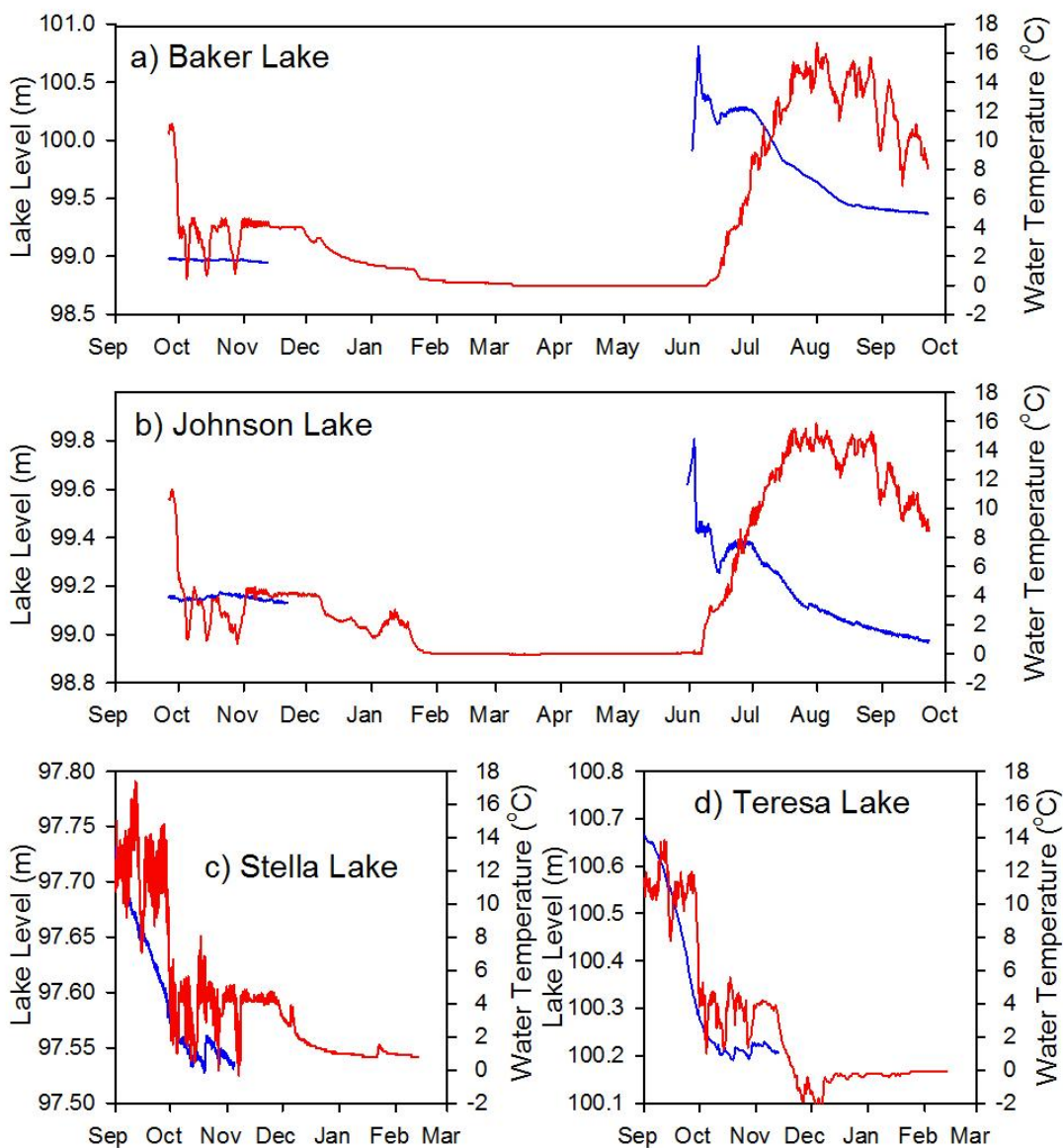


Figure 14. 2010 water level records (blue lines) and temperature records (red lines) for lakes in GRBA.

Table 15. Minimum and maximum lake levels and provisional ice-over and ice-out dates for GRBA lakes.

Lake	Water Year	Minimum Lake Level (m above datum)	Maximum Lake Level (m above datum)	Ice-Over Date	Ice-Out Date
Stella	2010	97.526 (10/19/09)	Not recorded	11/5/09	No data
Teresa	2010	96.747 (10/19/09)	Not recorded	11/13/09	No data
Baker	2010	98.943 (11/12/2009)	100.809 (6/5/2010)	11/13/09	6/2/2010
Johnson	2010	99.129 (11/20/09)	99.808 (6/3/10)	11/13/09	5/31/2010

Lake Water Clarity

Lake water clarity was assessed in the field by measuring Secchi depth. In all cases, the Secchi disk was visible on the bottom of the lake (Table 16). While the lakes at GRBA are likely too shallow to detect small changes in water clarity using this method, these data would allow any major decrease in water clarity (for example, an algal bloom) to be documented.

Table 16 also gives the UTM coordinated (Zone 11S, NAD83 datum) for the deepest point in each lake. Due to the surrounding terrain, these coordinates, which were measured using a handheld GPS unit, are approximate values. In practice, the deepest point is determined by repeated measurements in the vicinity of the reported coordinates.

Table 16. Secchi depth in GRBA lakes.

Lake	Measurement Location (m, Zone 11S NAD83)	Measurement Date	Secchi Depth (m)
Stella	732181, 4320790	8/27/2009 ^a	visible on bottom (0.9 m)
		9/21/2010	visible on bottom (0.7 m)
Teresa	732840, 4320574	8/27/2009 ^a	visible on bottom (1.3 m)
		9/21/2010	visible on bottom (0.8 m)
Brown	733613, 4320656	9/21/2010	visible on bottom (0.5 m)
Baker	733119, 4315483	9/25/2009	visible on bottom (2.1 m)
		9/22/2010	visible on bottom (2.0 m)
Johnson	734180, 4313999	9/24/2009	visible on bottom (4.4 m)
		9/23/2010	visible on bottom (4.2 m)
Dead	736282, 4313195	9/23/2010	visible on bottom (1.4 m)

a. Lake monitored outside of index period

Lake Water Chemistry

Lake water samples were collected from four lakes in 2009 and six lakes in 2010. The samples were collected by hand-dipping near the deepest point in each lake (Table 16). These samples were analyzed for basic chemistry and nutrient concentrations at the Cooperative Chemical Analysis Facility (CCAL) in Corvallis, Oregon.

Nutrients

The nutrient concentrations measured in the lake water samples (Table 17) are generally similar to the concentration measured in the stream water samples. Total nitrogen (TN) ranged from 0.21 to 0.82 mg/l and total phosphorus (TP) ranged from 0.008 to 0.051 mg/l. Total dissolved nitrogen (TDN) values were close to TN values and nitrate+nitrite values were generally lower than TDN values, suggesting the dominant form of N in the lakes in late summer is dissolved organic nitrogen. Total dissolved phosphorus (TDP) concentrations are significantly less than TP concentrations in many of the samples, suggesting both particulate and dissolved P are present in the lakes.

Table 17. Nutrient concentrations in GRBA lakes.

Lake	Sampling Date	Total N mg/l	Total Dissolved N mg/l	Nitrate + Nitrite mg/l (as N)	Total P mg/l	Total Dissolved P mg/l
Stella	8/27/2009 ^a	0.25	0.25	0.002 ^d	0.012	0.007
	9/21/2010	0.27	0.26	0.001 ^d	0.011	0.007
Teresa	8/27/2009 ^a	0.21	0.39 ^b	0.252 ^c	0.012	0.010
	9/21/2010	0.68	0.64	0.014	0.054	0.035
Brown	9/21/2010	0.69	0.63	0.025	0.015	0.009
Baker	9/25/2009	0.26	0.24	0.052	0.025	0.019
	9/22/2010	0.28	0.29	0.068	0.033	0.026
Johnson	9/24/2009	0.20	0.21	0.004	0.008	0.006
	9/23/2010	0.21	0.23	0.004	0.009	0.008
Dead	9/23/2010	0.82	0.95 ^b	0.001 ^d	0.051	0.039

a. Lake sampled outside of index period.

b. TDN value greater than TN value with the difference outside the expected range of variability, indicating contamination of sample.

c. Likely an erroneous value- discussed in text.

d. Concentration is above the method detection limit (MDL) but below the minimum level of quantification (ML).

The TDN values were greater than the TN values in five of the lake samples. As discussed in Appendix 1, all but two of these anomalies fall within the range of expected variability. In the other two samples, TDN exceeds TN by an amount that is outside the expected range of variability, indicating that the either the samples were contaminated during filtration or contaminated bottles were used. In 2011, additional care was taken in crew training to emphasize the importance of wearing gloves and using tweezers to handle the filters.

In the 2009 Teresa Lake sample, TDN exceeds TN by 0.28 mg/l, which is similar in magnitude to the nitrate+nitrite concentration (0.252 mg/l). Therefore, it is likely that the anomalously high nitrate+nitrite concentration in Teresa Lake in 2009 is an artifact of contamination.

Major Ions and Acid Neutralization Capacity

The 2009 and 2010 water samples were analyzed for sodium, potassium, calcium, magnesium, sulfate, and chloride (Table 18). Systematic changes in the concentrations of these ions over time may be useful in determining whether the lake is being affected by atmospheric deposition. The relatively minor year-to-year variations of these concentrations suggest that any future changes will be detectable. In Stella Lake and Teresa Lake, all of the major ions have higher concentrations in the 2010 samples (collected in late September) than in the 2009 samples (collected in late August). This difference could be explained by concentration due to evaporation.

In addition, the ANC of each lake was measured. Lakes with ANC values of less than 100 µeq/l are often considered sensitive to acidification (e.g., Stoddard et al. 2008, Campbell et al 2004, Burtns et al. 2011). By this measure, only the 2009 sample from Teresa Lake would be classified as sensitive to acidic deposition. Both Stella Lake and Teresa Lake have lower ANC values in 2009, when samples were collected in late August, so ANC may increase over the course of the summer.

Table 18. Major ion concentrations and acid neutralization capacity in GRBA lakes.

Lake	Sampling Date	Sodium mg/l	Potassium mg/l	Calcium mg/l	Magnesium mg/l	Sulfate mg/l as S	Chloride mg/l	ANC µeq/l
Stella	8/27/2009 ^a	1.25	0.51	3.87	0.71	0.19	0.50	242
	9/21/2010	1.62	0.57	4.35	0.84	0.23	0.62	335
Teresa	8/27/2009 ^a	0.69	0.34	1.96	0.43	0.34	0.45	92
	9/21/2010	0.87	0.59	2.44	0.64	0.36	0.67	192
Brown	9/21/2010	2.05	1.19	4.08	1.13	0.57	1.76	307
Baker	9/25/2009	0.73	0.33	1.94	0.37	0.41	0.55	144
	9/22/2010	0.70	0.40	1.77	0.43	0.43	0.44	140
Johnson	9/24/2009	1.06	0.29	5.76	0.38	1.15	0.42	293
	9/23/2010	0.96	0.30	5.30	0.40	1.12	0.24	258
Dead	9/23/2010	1.52	0.89	1.80	0.41	0.34	1.04	152

a. Lake sampled outside of index period

Water Quality Depth Profiles

Depth profiles of four water quality parameters (temperature, DO, pH, and SpCond) were measured at four lakes in 2009 and six lakes in 2010. Measurements were made near the deepest point in each lake (Table 16) at the surface, the lake bed, and several points in between. The pH meter used in 2009 and 2010 cannot be deployed at depth, so only surface measurements were collected. In 2009 and 2010, the depth of Johnson Lake was greater than the length of the cord on the water quality instrument, so no measurements were made below the depth of 3.05 m.

The 2009 depth profiles are given in Table 19, and the 2010 depth profiles are given in Table 20. No stratification is apparent in any of the depth profiles. This observation, combined with the variations in the temperature records recorded at depth (Figure 14) likely indicates that the lakes are frequently mixed.

Table 19. Water quality depth profiles for 2009 collected in GRBA lakes.

Lake and Sampling Date	Depth (m)	pH (S.U.)	Dissolved Oxygen (mg/l)	Specific Conductivity (µS/cm)	Temperature (°C)
Stella 8/27/2009	0.00	7.8	5.94	29.0	14.3
	0.46		5.91	28.9	14.6
	0.88		6.76	29.0	15.0
Teresa 8/27/2009	0.00	7.6	6.89	18.6	13.1
	0.30		7.13	18.2	12.3
	0.61		7.03	17.8	11.6
	0.91		7.09	17.4	11.3
	1.31		7.24	18.2	10.9
Baker 9/25/2009	0.00	8.6	7.6	16.7	10.9
	0.61		6.89	16.7	10.6
	1.22		6.6	16.7	10.5
	1.83		7.15	16.8	9.9
Johnson 9/23/2010	0.00	7.9	7.65	37.1	9.9
	0.91		7.67	37.4	8.4
	1.83		7.42	37.4	8.0
	2.74		7.44	37.3	7.9

Table 20. Water quality depth profiles for 2010 collected in GRBA lakes.

Lake and Sampling Date	Depth (m)	pH (S.U.)	Dissolved Oxygen	Specific Conductivity	Temperature (°C)
Stella 9/21/2010	0.00	8.13	8.32	35.4	6.6
	0.67		2.31	49.2	10.2
Teresa 9/21/2010	0.00	7.74	7.69	21.7	8.6
	0.38		7.50	21.6	8.5
	0.76		7.55	21.5	8.5
Brown 9/21/2010	0.00	7.88	8.61	42.0	11.5
	0.46		8.21	42.1	11.5
Baker 9/22/2010	0.00	7.99	8.20	16.8	8.4
	0.30		8.20	16.8	8.1
	0.61		7.80	16.9	8.1
	0.91		8.20	16.9	8.1
	1.22		8.10	16.8	8.1
	1.52		8.15	16.8	8.1
	1.83		7.93	16.8	8.1
Johnson 9/23/2010	0.00	7.51	6.73	36.5	9.9
	0.61		7.38	35.8	8.4
	1.22		6.03	36.0	8.0
	2.13		5.92	35.9	7.9
	3.05		7.54	35.6	7.8
Dead 9/23/2010	0.00	7.50	6.80	18.9	14.9
	0.30		6.20	18.8	12.8
	0.61		6.30	18.7	11.8
	0.91		6.50	18.5	11.6
	1.22		6.50	18.4	11.4

Quality Assurance and Quality Control

The MOJN Streams and Lakes protocol Quality Assurance Project Plan (SOP 15) describes the extensive quality assurance and quality control (QA/QC) procedures undertaken to ensure that the quality of the data collected meets the needs of the protocol. The key findings of the QA/QC program are summarized below:

- Many of the QA/QC procedures described in SOP 15 were developed during the 2009 and 2010 pilot field seasons, so the QA/QC reports will be more complete in future years.
- A head-to-head comparison of the water quality instruments showed that the handheld pH sensors appear to read slightly higher values than those recorded by the more reliable sondes. Thus, the data from these pHTestr pH meters may not be appropriate for long-term trend analysis. No other problems with the water quality instruments were observed.
- All of the tested streams were found to be well-mixed. The significance of this finding is that it is difficult to collect representative continuous water quality data in poorly mixed streams (Wagner et al. 2006).
- The testing laboratory used to analyze the water samples changed the method it used to measure P between the 2009 and 2010 field seasons. MOJN had its 2010 samples analyzed using both methods, and found a small but systematic difference in the results. The 2009 data should be transformed to correct for this difference when performing long term trend analyses.
- Several of the TDN and TDP values measured by the laboratory are slightly greater than the corresponding TN and TP values. MOJN is working to identify the source of these problems, and the importance of avoiding contamination has been emphasized to field personnel.
- In 2009 and 2010, the laboratory performed 52 duplicate analyses to test the precision of their methods. All of the duplicate analyses met the quality objectives outlined in SOP 15.
- The 2009 field season was incomplete, as many of the methods and sampling plans were still under development. The 2010 field season met most of the protocol's data collection goals. The exceptions were in continuous water quality (one of the sondes malfunctioned), lake level monitoring (incomplete due to incomplete deployment in the 2009 field season), and lake pH measurements (only surface measurements were made due to the type of pH meter used).

The measurements made for QA/QC purposes are reported and discussed in greater detail in the Appendix to this report. The key recommendations for future years based on these measurements are that care should be taken to avoid contamination of water samples and that it would be desirable to use a higher quality pH meter capable of making measurements at depth.

Discussion

All of the streams in GRBA classified as Class A Waters by the state of Nevada meet the water quality requirements specified in the Nevada Administrative Code. These streams are considered ONRWs under the terms of the Clean Water Act, and the park is required to prevent any degradation in their water quality.

The state of Nevada's 303(d) list for 2006 classifies Las Vegas Wash, the Muddy River, the Virgin River, and the Colorado River (from the Hoover Dam to the California state line) as impaired. The state of Arizona's 303(d) list for 2010 includes the Colorado River from the Hoover Dam to Lake Mohave and Lake Mohave. The water quality problems in the Colorado River and its tributaries and reservoirs are the focus of an intensive interagency monitoring program (Turner et al. 2010).

Both the snowpack depth and total precipitation in GRBA were close to their long-term averages in Water Years 2009 and 2010. As a result, the stream discharges recorded for Lehman Creek were also near their long term averages for those years. Lehman Creek experienced a sharp peak in discharge in June 2010 due to a delayed start of runoff because of a colder than average May. This delayed runoff resulted in a higher maximum flow in 2010 ($0.85 \text{ m}^3/\text{s}$) than in 2009 ($0.57 \text{ m}^3/\text{s}$). The effect of summer precipitation events on the discharge records was generally not detectable, although the mean daily discharge of Lehman Creek increased by 15% after the August 19 2010 storm..

The streams in GRBA have low nutrient concentrations, high pH values, low temperatures, and high levels of oxygen saturation. Stream water quality responded quickly to major precipitation events, but generally recovered to previous levels within days. The observed BMI communities are consistent with unimpaired water quality, although specific reference conditions have not been determined. Over all, the water quality measurements show that the streams provide excellent habitat for the trout species found in the park, which reflects the relatively pristine conditions of the watershed.

The available lake level records for GRBA's subalpine lakes show a slow decline in water levels in from September 2009 until freezing over in November. Ice-off occurred in late May and early June 2010, when there was a sharp peak in lake levels which may be caused by the same delayed melting that caused a sharp peak in 2010 stream discharge. Lake levels then declined slowly over the course of the summer, with slight (less than 2 cm) increases due to precipitation events.

Water quality and chemistry measurements made in GRBA's subalpine lakes indicate that the lakes have low nutrient concentrations, high pH values, low temperatures, and high concentrations of dissolved oxygen. The lack of variability observed in the depth profiles and the frequent temperature changes recorded at depth indicate that the lakes are well mixed. The clarity of the lakes is such that the secchi disk could be seen on the lake bottom at every measurement in the 2009 and 2010 seasons. One potential concern is the low ANC values of the lakes. While the values are naturally low because the lakes are extremely dilute, the lakes could be vulnerable to the impacts of any future acidic deposition.

The pilot program discussed in this report was successful in developing the methods used in the MOJN Streams and Lakes protocol (Caudill et al. 2012). In the future, additional care should be taken to avoid contamination of water samples, and a pH meter capable of collecting measurements at depth should be used in the lakes.

Literature Cited

- Burns, D. A., J. A. Lynch, B. J. Cosby, M. E. Fenn, J. S. Baron, and U.S. EPA Clean Air Markets Division. 2011. National Acid Precipitation Assessment Program Report to Congress 2011: An Integrated Assessment. U.S. Geological Survey New York Water Science Center, Troy, New York. Available online: <http://ny.water.usgs.gov/projects/NAPAP/>. Accessed 8 October 2012.
- Campbell, D. H., E. Muths, J. T. Turk, and P. S. Corn. 2004. Sensitivity to acidification of subalpine ponds and lakes in north-western Colorado. *Hydrological Processes* 18:2817–2834.
- Caudill, C. C., G. J. M. Moret, A. Chung-MacCoubrey, G. Baker, N. Tallent, D. Hughson, J. Burke, L. A. H. Starcevich, and R. K. Steinhorst. 2012. Mojave Desert Network Inventory and Monitoring streams and lakes monitoring protocol: Protocol narrative. Natural Resource Report NPS/MOJN/NRR—2012/593. National Park Service, Fort Collins, Colorado.
- Elliott, P. E., D. A. Beck, and D. E. Prudic. 2006. Characterization of surface-water resources in the Great Basin National Park area and their susceptibility to ground-water withdrawals in adjacent valleys White Pine County, Nevada. U.S. Geological Survey Scientific Investigations Report 2006-5099. U.S. Geological Survey, Reston, Virginia. Available online: <http://pubs.water.usgs.gov/sir2006-5099>. Accessed 8 June 2010.
- Hodgkins, G. A., I. C. James, and T. D. Huntingdon. 2002. Historical changes in lake ice-out dates as indicators of climate change in New England, 1850-2000. *International Journal of Climatology* 22:1819-1827.
- Hoffman, R. L., T. J. Tyler, G. L. Larson, M. J. Adams, W. Wente, and S. Galvan. 2005. Sampling protocol for monitoring abiotic and biotic characteristics of mountain ponds and lakes: U.S. Geological Survey Techniques and Methods 2-A2.
- Peck, D. V., A. T. Herlihy, B. H. Hill, R. M. Hughes, P. R. Kaufmann, D. Klemm, J. M. Lazorchak, F. H. McCormick, S. A. Peterson, P. L. Ringold, T. Magee, and M. Cappaert. 2006. Environmental Monitoring and Assessment Program-Surface Waters western pilot study: Field operations manual for wadeable streams. EPA/620/R-06/003. U.S. Environmental Protection Agency, Washington, D.C.
- Pierson, D. C., G. A. Weyhenmeyer, L. Arvola, B. Benson, T. Blenckner, T. Kratz, D. M. Livingstone, H. Markensten, G. Marzec, K. Pettersson, and K. Weathers. 2011. An automated method to monitor lake ice phenology. *Limnology and Oceanography: Methods* 9:74-83.
- Stoddard, J. L., C. T. Driscoll, J. S. Kahl, and J. H. Kellogg. 1998. A regional analysis of lake acidification trends for the Northeastern U.S., 1982-1994. *Environmental Monitoring and Assessment* 51:399-413.
- Turner, K., J. M. Miller, and C. J. Palmer. 2010. Long-term limnological and aquatic resource monitoring and research plan for Lakes Mead and Mohave. Approved Working Document

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Appendix 1: QA/QC Measurements

This appendix reports on the results of all QA/QC measurements made in the field and the laboratory. Many of the QA/QC measurements described in the protocol QAPP were under development during the 2010 field season, so the testing reported below is less complete than it will be in future years.

Instrument Testing

The laboratory-based instrument comparison procedures described in the protocol QAPP had not been developed at the beginning of the 2010 field season. Instead, readings were collected for all instruments near the Lehman Creek stream gage. The results of this head-to-head comparison are given below (Table A-1). Sondes A-D are YSI 6920 multiprobes. Handhelds 1-5 are YSI 63 multiprobes. The pH meters (2,3, and A) are pHTestr pH meters.

Table A-1. June 29, 2010 head-to-head instrument comparison in Lehman Creek.

Instrument	pH (Standard units)	Specific Conductivity ($\mu\text{S}/\text{cm}$)	Temperature ($^{\circ}\text{C}$)	Dissolved Oxygen (mg/l)
Sonde A	8.28	145	12.39	8.98
Sonde B	8.31	134	12.53	9.40
Sonde C	8.40	141	12.49	8.82
Sonde D	8.24	143	12.37	9.32
Handheld 1	-	163.8	12.6	5.30
Handheld 2	-	151.2	12.7	9.38
Handheld 3	-	160.7	12.7	8.32
Handheld 4	-	150.0	12.7	8.32
Handheld 5	-	148.5	12.7	9.26
pH Meter 2	8.5	-	-	-
pH Meter 3	8.6	-	-	-
pH Meter A	9.7	-	-	-

As the readings were not simultaneous, the water quality values may have changed slightly over the course of the procedure (for example, it is likely that the temperature rose over the course of the testing). Two sensors appear to have been malfunctioning: the DO sensor on handheld instrument 1 and the pH sensor on pH meter A (neither of these instruments was used for measurements reported in this document). The inexpensive handheld pH sensors appear to read slightly higher values than those recorded by the more reliable sondes. Thus, the data from these pHTestr pH meters may not be appropriate for long-term trend analysis.

AMS+ is a metric of measurement sensitivity in an ambient condition such as a well-mixed flowing stream. It is affected by instrument noise and natural heterogeneity. Seven repeated measurements are made in rapid succession in situ. AMS+ is then calculated as:

$$AMS+ = t \times s ,$$

where:

s = sample standard deviation of the 7 in-situ measurement values, and

$t = 3.708$, the 99% confidence middle (two-sided) t-value for a sample size of 7.

The seven readings needed to calculate AMS+ were collected for sonde C only in Lower Snake Creek near the stream gage. As Table A-2 shows, all of the sensors were very stable.

Table A-2. AMS+ data for sonde C in Lower Snake Creek on June 29, 2010.

Reading	pH (Standard units)	Specific Conductivity ($\mu\text{S}/\text{cm}$)	Temperature ($^{\circ}\text{C}$)	Dissolved Oxygen (mg/l)
1	8.39	141	12.51	8.79
2	8.39	141	12.52	8.79
3	8.39	141	12.53	8.78
4	8.39	141	12.53	8.79
5	8.39	141	12.54	8.78
6	8.39	141	12.55	8.78
7	8.39	141	12.56	8.78
AMS+	0 (< readout precision)	0 (< readout precision)	0.06	0.02

Stream Cross-Section Data

Water quality cross-section surveys were collected on June 29, 2010 for Lower Snake Creek, Upper Snake Creek, and Strawberry Creek. Handheld instrument 5 was used for all measurements. At each site, the streams were sufficiently shallow that measurements were recorded at a single depth. Five evenly-spaced measurements were made in Lower Snake Creek and Upper Snake Creek. There were two narrow channels at the Strawberry Creek site, so three evenly-spaced measurements were made in each channel. As Table A-3 shows, temperature and specific conductance were relatively invariant within each stream, suggesting that a sonde deployed anywhere in the channel would record water quality data representative of the entire stream.

Table A-3. 2010 water quality cross-section surveys.

Lower Snake Creek						
	1	2	3	4	5	
Sp. Cond. (μS/cm)	149.9	150.5	150.8	150.9	151.1	
Temperature (°C)	13.4	13.3	13.2	13.2	13.2	
Upper Snake Creek						
	1	2	3	4	5	
Sp. Cond. (μS/cm)	41.4	41.8	41.8	41.8	41.4	
Temperature (°C)	9.9	9.9	9.8	9.8	9.9	
Strawberry Creek						
	Left Channel			Right Channel		
	1	2	3	1	2	3
Sp. Cond. (μS/cm)	79.6	79.6	79.6	79.6	79.5	78
Temperature (°C)	13.4	13.4	13.4	13.4	13.4	13.4

Cumulative Bias Avoidance

In 2010, CCAL began the transition to a new method of phosphorus analysis. CCAL used manual spectrophotometry (Method 4500-P E) for TP and TDP analyses of MOJN's 2009 samples. Going forward, automated spectrophotometry (Method 4500-P F) will be used. In 2010, MOJN had the lab perform both types of analyses on Streams and Lakes protocol samples. The paired measurements are shown in Table A-4. In general, the concentrations measured with the new method are slightly lower than the concentrations produced by the old method with an average difference (new – old) of -0.0054 mg/L and a standard deviation of 0.004 mg/L. However, the data appear to indicate that the offset varies linearly as a function of P concentration (Figure A-1), with separate linear trends for the streams and the lakes. These biases should be removed from the 2009 P concentrations prior to their inclusion in long-term trend analyses.

Table A-4. CCAL measurements of phosphorus made using the old and new methods.

	TP- New (mg/l)	TP- Old (mg/l)	TDP- New (mg/l)	TDP- Old (mg/l)
Baker Creek	0.008	0.017	0.009	0.019
Baker Lake	0.033	0.036	0.026	0.029
Brown Lake	0.015	0.016	0.009	0.011
Dead Lake	0.051	0.057	0.039	0.044
Johnson Lake	0.009	0.008	0.008	0.008
Lehman Creek	0.010	0.013	0.007	0.011
Mill Creek	0.024	0.039	0.019	0.030
Pine Creek	0.015	0.020	0.012	0.018
Ridge Creek	0.020	0.031	0.016	0.023
Shingle Creek	0.010	0.018	0.009	0.015
Snake Creek	0.007	0.017	0.005	0.012
South Fork Big Wash	0.002	0.007	0.003	0.007
Stella Lake	0.011	0.009	0.007	0.008
Strawberry Creek	0.020	0.029	0.013	0.020
Teresa Lake	0.054	0.058	0.035	0.037

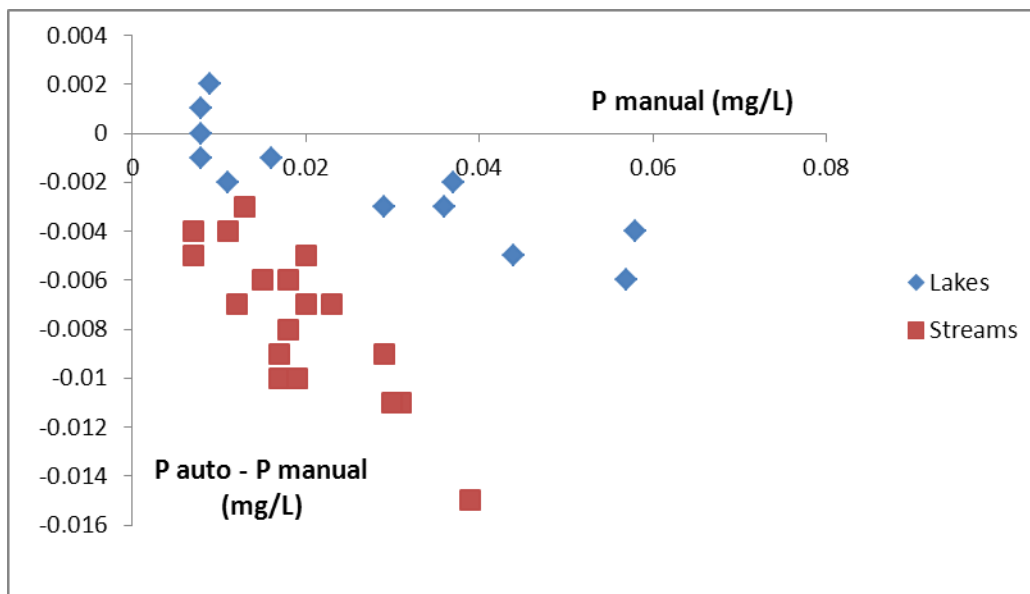


Figure A-1. Difference between P concentrations measured with the new method (P auto) and the old method (P manual) as a function of P concentrations for streams and lakes in 2010.

Laboratory QA/QC

The discussion below summarizes QA/QC checks and procedures for laboratory analytical data collected during 2009 and 2010. All analyses were performed by the Cooperative Chemical Analytical Laboratory (CCAL).

Laboratory Detection Limits and Quantitation Limits

CCAL met the desired measurement quality objectives (MQOs) for detection limits. Several analytical results were between the detection limit (MDL) and the quantitation limit (ML), meaning that the analytes were detected, but their concentrations could not be quantified. These data have been flagged, and they should not be used in long term trend analyses without careful consideration.

Dissolved Concentrations Exceeding Total Concentrations

One observed problem with the laboratory data was that fourteen of the total dissolved nitrogen (TDN) values were greater than their corresponding total nitrogen (TN) values. As shown in Table A-5 and Table A-6, the laboratory performed duplicate and triplicate analyses on many of the samples where the discrepancy was observed.

Table A-5. Summary of 2009 laboratory analyses with TDN > TN.

	Total Nitrogen (mg/l)	Total Dissolved Nitrogen (mg/l)
Lehman Creek	0.20	0.24
Duplicate Analysis	0.22	0.24
Triplicate Analysis	0.22	0.21
Lab Report: "...within the expected normal variability... data are analytically equal in concentration."		
Pine Creek	0.12	0.17
Duplicate Analysis	0.09	0.18
Triplicate Analysis	-	0.19
Lab Report: "...outside of the expected normal variability range... anomalous results"		
Teresa Lake	0.21	0.39
Duplicate Analysis	0.25	0.39
Lab Report: "...outside of the expected normal variability range... anomalous results"		
Snake Creek	0.05	0.06
Duplicate Analysis	0.04	-
Lab Report: "...within the expected normal variability... data are analytically equal in concentration."		
Johnson Lake	0.20	0.21
Lab Report: "...within the expected normal variability... data are analytically equal in concentration."		
South Fork Big Wash	0.12	0.13
Duplicate Analysis	0.12	
Lab Report: "...within the expected normal variability... data are analytically equal in concentration."		

For nine of the samples, CCAL concluded that the TN values "fall to within the normal variability for the total nitrogen procedure (+/- 0.01 mg/l), but the dissolved nitrogen data calculate to a greater value. This is a statistical anomaly where the dissolved nitrogen data calculate to be greater in concentration than the total nitrogen data, while the data are analytically equal in concentration." These nine TDN values are reported without flags.

For one of the samples (Shingle Creek 2010), CCAL concluded that the TN and TDN results were "only slightly outside normal expected variability for the analysis and could be considered as essentially equal in concentration but at the outside limit." The TDN value from this sample is also reported without a flag.

For four samples (Pine Creek 2009, Teresa Lake 2009, Dead Lake 2010, and Ridge Creek 2010, CCAL concluded that the data "fall outside of the expected normal variability range for the nitrogen procedure (+/- 0.01 mg/l) and the anomalous results should be carefully scrutinized." The TDN results for these samples have been flagged in Table 11 and Table 17.

Table A-6. Summary of 2010 laboratory analyses with TDN > TN.

	Total Nitrogen (mg/l)	Total Dissolved Nitrogen (mg/l)
Baker Creek	0.13	0.15
Duplicate Analysis	0.13	0.15
Lab Report: "...within the expected normal variability... data are analytically equal in concentration."		
Baker Lake	0.28	0.29
Lab Report: "...within the expected normal variability... data are analytically equal in concentration."		
Dead Lake	0.82	0.95
Lab Report: "...outside of the expected normal variability range... anomalous results"		
Johnson Lake	0.21	0.23
Lab Report: "...within the expected normal variability... data are analytically equal in concentration."		
Ridge Creek	0.31	0.38
Lab Report: "...outside of the expected normal variability range... anomalous results"		
Shingle Creek	0.08	0.11
Duplicate Analysis		0.11
Lab Report: "slightly outside normal expected variability...could be considered as essentially equal in concentration"		
Snake Creek	0.05	0.06
Lab Report: "...within the expected normal variability... data are analytically equal in concentration."		
South Fork Big Wash	0.10	0.12
Lab Report: "...within the expected normal variability... data are analytically equal in concentration."		

In 2010 there were two samples with total dissolved phosphorus (TDP) values greater than their total phosphorus (TP) values (Table A-7). In both cases, CCAL concluded that the TDP and TP results "fall to within the expected normal variability for the phosphorous procedure (+/- 0.002 mg/l), with the dissolved phosphorous data being greater. The data are analytically equal in concentration." The TDP data from these samples are reported without flags.

Table A-7. Summary of 2010 laboratory analyses with TDP > TP.

	Total Phosphorus (mg/l)	Total Dissolved Phosphorus (mg/l)
Baker Creek	0.008	0.009
Duplicate Analysis	0.007	0.008
Lab Report: "...within the expected normal variability... data are analytically equal in concentration."		
South Fork Big Wash	0.002	0.003
Lab Report: "...within the expected normal variability... data are analytically equal in concentration."		

Duplicate Analyses

In 2009, CCAL performed 27 duplicate analyses on nine samples. In 2010, CCAL performed 25 duplicate analyses on seven samples. In both years, at least one duplicate analysis was performed for each of the measured parameters.

The analytical results for the duplicate samples are compared using Relative Percent Difference (RPD). The RPD for each pair of measurements is calculated as

$$RPD = \left[\frac{S_1 - S_2}{(S_1 + S_2)/2} \right] \times 100 \quad ,$$

where:

S_1 = the larger test result value, and

S_2 = the smaller test result value.

The results of the duplicate analyses and RPD calculations are given in Table A-8 (2009 analyses) and Table A-9 (2010 analyses). In the cases where three measurements were available, we have calculated the RPD using the maximum and minimum of the three values. None of the calculated RPD values exceed the laboratory precision MQO of 30% specified in the QAPP. In 2009, two duplicate analyses had RPD values greater than 20%, but in both cases, (TN in Pine Creek and TN in Snake Creek) the magnitude of the difference was small (0.03 mg/l and 0.01 mg/l respectively). In 2010, none of the RPD values exceeded 20%.

Table A-8. 2009 duplicate laboratory analyses and relative percent difference (RPD) values

Sample	Analysis	Original Result	Duplicate	Triplicate*	RPD
Lehman Creek	TN (mg/l)	0.20	0.22	0.22	10%
	TDN (mg/l)	0.24	0.24	0.21	13%
Pine Creek	TN(mg/l)	0.12	0.09	-	29%
	TDN (mg/l)	0.17	0.18	0.19	11%
Stella Lake	TN (mg/l)	0.25	0.25	-	0
	Na (mg/l)	1.25	1.24	-	1
	K (mg/l)	0.51	0.51	-	0%
	Mg (mg/l)	0.71	0.71	-	0%
Teresa Lake	TN (mg/l)	0.21	0.25	-	17%
	TDN (mg/l)	0.39	0.39	-	0%
	Ca (mg/l)	1.96	1.97	-	1%
	SO4 (mg-S/l)	0.34	0.34	-	0%
	Cl (mg/l)	0.45	0.45	-	0%
Snake Creek	TN (mg/l)	0.05	0.04	-	22%
	Mg (mg/l)	0.74	0.75	-	1%
	SO4 (mg-S/l)	0.66	0.67	-	2%
	Cl (mg/l)	0.82	0.81	-	1%
Strawberry Creek	Na (mg/l)	4.73	4.72	-	0.2%
	K (mg/l)	0.77	0.78	-	1%
	Mg (mg/l)	3.15	3.05	-	3%
Johnson Lake	ANC (µeq/l)	293	296	-	1%
	Ca (mg/l)	5.76	5.72	-	1%
	Mg (mg/l)	0.38	0.37	-	3%
Baker Lake	TDP (mg/l)	0.019	0.019	-	0%
	NO3+NO2 (mg-N/l)	0.052	0.053	-	2%
	Mg (mg/l)	0.38	0.37	-	3%
S. Fk. Big Wash	TN (mg/l)	0.12	0.12	-	0%

*When three values are available, RPD is calculated using the maximum and minimum values.

Table A-9. 2010 duplicate laboratory analyses and relative percent difference (RPD) values.

Sample	Analysis	Original Result	Duplicate	RPD
Baker Creek	TN(mg/l)	0.13	0.13	0%
	TDN (mg/l)	0.15	0.15	0%
	TP(mg/l)	0.008	0.007	13%
	TDP(mg/l)	0.009	0.008	12%
	NO3+NO2 (mg-N/l)	0.091	0.091	0%
	Na (mg/l)	2.60	2.63	1%
	K (mg/l)	0.41	0.41	0%
	Ca (mg/l)	4.32	4.26	1%
	Mg (mg/l)	0.67	0.67	0%
	SO4 (mg-S/l)	0.52	0.53	2%
	Cl (mg/l)	0.64	0.67	5%
Johnson Lake	ANC (µeq/l)	258	256	1%
Mill Creek	TN(mg/l)	0.18	0.17	6%
	TP(mg/l)	0.024	0.023	4%
Shingle Creek	TDN (mg/l)	0.11	0.11	0%
	TDP(mg/l)	0.009	0.008	12%
Snake Creek	Na (mg/l)	3.32	3.33	0.3%
	K (mg/l)	0.50	0.51	2%
	Ca (mg/l)	6.29	6.27	0.3%
	Mg (mg/l)	0.75	0.75	0%
	SO4 (mg-S/l)	0.68	0.69	1%
	Cl (mg/l)	0.69	0.69	0%
Strawberry Creek	TDN (mg/l)	0.06	0.06	0%
	TDP(mg/l)	0.013	0.013	0%
Teresa Lake	TN(mg/l)	0.68	0.69	1%

Effectiveness and Completeness

Effectiveness, E, is calculated as

$$E = (U / N) \times 100 \quad ,$$

where:

U = number of usable parameter values, and

N = number of parameter values collected, including low-quality data that cannot be used in future analyses.

Completeness, C, is calculated as

$$C = (U / P) \times 100 \quad ,$$

where:

P = number of potential parameter values that would have been collected had the field season proceeded as envisioned in the sampling plan.

Stream Discharge

The effectiveness and completeness of the stream discharge monitoring cannot be evaluated at this time, as the bulk of the 2010 data (the data from Baker Creek, Snake Creek, and Strawberry Creek) are still being processed for eventual inclusion in the USGS NWIS system.

Continuous Water Quality

The effectiveness and completeness statistics for the continuous water quality monitoring are summarized in Table A-10.

The effectiveness values are 95% or greater for all of the monitored parameters except for the specific conductance record in Upper Snake Creek, which included 16 days of unusable data. The overall effectiveness was 97%.

The overall completeness for the continuous water quality data was 75%. The primary reason for this was the failure of one of the sondes, which resulted in incomplete records for Upper Snake Creek and Lehman.

Table A-10. Effectiveness and completeness statistics for 2010 continuous water quality monitoring.

Stream	Parameter	Days of Data	Usable Days	Effectiveness	Completeness (P = 77 days)
Baker	Temperature	66	63	95%	82%
	DO	66	63	95%	82%
	SpCond	66	63	95%	82%
	pH	66	61	92%	79%
	Average	66	62.5	95%	81%
Lehman	Temperature	30	30	100%	39%
	DO	30	30	100%	39%
	SpCond	30	30	100%	39%
	pH	30	30	100%	39%
	Average	30	30	100%	39%
Lower Snake	Temperature	76	76	100%	99%
	DO	76	76	100%	99%
	SpCond	76	74	97%	96%
	pH	76	76	100%	99%
	Average	76	75.5	99%	98%
Upper Snake	Temperature	48	48	100%	62%
	DO	48	48	100%	62%
	SpCond	48	32	67%	92%
	pH	48	48	100%	62%
	Average	48	44	92%	57%
Strawberry	Temperature	77	75	97%	97%
	DO	77	74	96%	96%
	SpCond	77	77	100%	100%
	pH	77	75	97%	97%
	Average	77	75.3	98%	98%
Overall Average		59.4	57.4	97%	75%

Stream Water Chemistry and BMI

All nine of the random stream sites were visited, and water quality data, water samples, and BMI samples were collected at each site. The only unusable data are the TDN data discussed in the Laboratory QA/QC section, above.

Lake Level and Water Temperature Loggers

All six lakes were visited in September 2010. However, data could only be downloaded for lakes where pressure transducers were deployed in 2009. In 2009, loggers were deployed in four lakes. As part of the method development and testing process, two of those loggers were deployed with a 15 minute sample interval, and recorded the maximum number of samples that could be held in logger memory in early spring. As Table A-11 shows, the overall completeness of the lake level data was 48%. This relatively low rate is due to the fact that the protocol had not been fully developed in 2009. All of the collected lake level and temperature data was usable.

Table A-11. Completeness of water year 2010 lake level records.

	Deployment Date	Retrieval Date	Last Day of Data	Completeness
Baker Lake	9/24/2009	9/22/2010	9/22/2010	100%
Johnson Lake	9/25/2009	9/23/2010	9/23/2010	100%
Dead Lake	NA	NA	NA	0%
Stella Lake	8/27/2009	9/21/2010	2/12/2010	43%
Teresa Lake	8/28/2009	9/21/2010	2/13/2010	44%
Brown Lake	NA	NA	NA	0%
Overall Average				48%

Lake Water Chemistry and Clarity

All six of the lakes were visited in 2010, and water samples, clarity readings, and depth profile data were collected at each lake. The only unusable analytical chemistry data are the TDN data discussed in the Laboratory QA/QC section, above. Only surface pH data were collected, as the available pH meter could not be deployed at depth. Thus, only six of 24 possible pH measurements were made, a completeness value of 25%.