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Natural Resource Program Center

Baseline Water Quality Inventory of Great Basin National Park

Natural Resource Technical Report NPS/NRPC/WRD/NRTR—2009/201

ON THE COVER
Williams Creek, Great Basin National Park, Nevada
NPS Photo

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Acronyms

ANOVA	Analysis of Variance
EPA	Environmental Protection Agency
EPT	Ephemeroptera, Plecoptera, and Trichoptera
GRBA	Great Basin National Park
NPS	National Park Service
NTU	Nephelometric Turbidity Units
QA	Quality Assurance
QC	Quality Control
SD	Standard Deviation
TDS	Total Dissolved Solids
WRD	Water Resources Division

Conversion Factors

Multiply	**By**	**To obtain**
Length		
inch (in.)	25.40	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
Area		
acre	0.0040	square kilometer (km2)
square foot (ft^2)	0.09294	square meter (m2)
square mile (mi^2) 2.590		square kilometer (km2)
Volume		
gallon (gal)	3.785	liter (L)
gallon (gal)	0.003785	cubic meter (m^3)
cubic foot (ft^3)	0.02832	cubic meter (m^3)
Flow rate		
gallon per minute (gal/min) 3.785		liter per minute (L/min)
cubic foot per second (ft3/s) 0.02832		cubic meter per second (m^3/s)
Mass		
ounce, avoirdupois (oz)	28.35	gram (g)
pound avoirdupois (lb)	0.4535	kilogram (kg)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:
°F= (1.8×°C) +32.

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:
°C= (°F-32)/1.8.

Chemical concentrations and volumes of water collected for analyses are reported in SI units.

Specific conductance is given in microsiemens per centimeter at 25 degrees Celsius (µS/cm at 25oC).

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88).

Horizontal coordinate information is referenced to North American Datum of 1983 (NAD 83).

Executive Summary

A baseline water quality inventory was initiated in 2006 to obtain data about Great Basin National Park's water sources. This inventory was needed due to several development proposals outside the park that could potentially affect water sources, including a large ground-water pumping and exportation project in both valleys adjacent to the park and two, new, coal-fired power plants.

Sixty-seven sites were sampled from December 2006 to October 2007, including six lakes, 35 springs, four caves, and 20 stream sampling locations. A three-pronged approach was used, with field measurements of standard water quality parameters, grab samples analyzed by a water quality lab for additional parameters, and macroinvertebrate samples taken from a sub-set of sites.

Results of the field measurements showed all the lakes have similar parameters, with mean summer temperatures from 10.4 to 13.5°C. Most notable is the low specific conductance of all the lakes (19 to 42 µS/cm/25°C), which indicates they could be susceptible to changes in pH due to deposition from coal-fired power plants. Springs and streams showed a greater range of water quality parameters, largely based on their underlying substrate. Springs and streams underlain by metamorphic rock had lower pH and conductivity values than those underlain by carbonate rock. Caves had the highest conductivity and pH and the lowest dissolved oxygen mean values, which was expected due to the larger influence of groundwater.

The lab analyses of additional parameters showed total dissolved solids are weakly correlated by elevation, with lower values at higher elevations. Anthropogenic impacts were highest at Squirrel Springs, Lehman Caves, and Can Young 20; notably, these are all cave systems, indicating that the watersheds above the cave systems are impacting the water in the ground below. Three metals–iron, manganese, and copper–exceeded EPA criteria for drinking or fresh water aquatic life in some of the samples collected. The charge balance for cations and anions did not balance for the majority of the lab samples, indicating some error in lab analyses.

Macroinvertebrates were sampled at 27 locations, and a total of 157 taxa were found. The most abundant taxa was Diptera (Family Chironomidae, Subfamily Orthocladiinae), making up 30 percent of the samples. In total, the top ten taxa accounted for about 64 percent of the samples, while 67 taxa had a relative abundance of less than 0.1 percent. Overall, increased complexity of the aquatic system resulted in higher abundance and richness, with the fewest taxa in caves and the most in lower-elevation stream areas.

The findings of this project indicate that the water resources in Great Basin National Park are nearly pristine, with only a few exceptions. Continued sampling over time, especially following implementation of any air- or water-related projects near the park, is needed to determine if water quality is changing.

Acknowledgements

This project was made possible through funding from the National Park Service (NPS) Water Resources Division (WRD) and the NPS Inventory and Monitoring (I&M) Program. Fieldwork and data collection were accomplished by Student Conservation Association interns Patrick O'Brien and Kelley Garrison, along with Great Basin National Park staff members Ben Roberts, Loren Reinhold, and Billie O'Doan. We are grateful to Mark Grover of Southern Utah University, Chris Caudill of the University of Idaho, and Bob Truitt of the NPS Mojave Desert I&M Network for reviewing the report and providing insightful comments. Thanks to Pat Wiese, NPS WRD, for assisting with the final review and formatting the manuscript. And finally, Gary Rosenlieb, NPS WRD, made this report possible by helping obtain funding, reviewing protocols and reports, and assisting with publication.

Introduction

Great Basin National Park (GRBA) is currently facing several threats to its water sources that could significantly impact water quality. Proposed groundwater pumping in adjacent valleys by the Southern Nevada Water Authority (SNWA) could potentially have impacts on park water sources in Lehman, Baker, Pine/Ridge, and Snake watersheds (Elliott et al. 2006). These impacts could include a reduction of water quantity, which may in turn affect water quality and aquatic organisms. Another threat is the potential construction of two, coal-fired power plants within the next five to ten years less than 100 miles from the park. Because the park's six sub-alpine lakes are known to have low buffering capacity, atmospheric deposition could have detrimental effects on the lakes by increasing their acidity.

In response, a level one baseline water quality inventory of park water sources (perennial streams, major springs, sub-alpine lakes, and caves with perennial water) was initiated in December of 2006, and data collection was completed in October 2007. Baseline data will provide information about the spatial, chemical, and statistical distributions of water quality in the park and allow for the detection of changes from the current pristine conditions. The inventory is part of a nationwide program by the National Park Service (NPS) Inventorying and Monitoring Program to develop a nominal set of baseline water quality information for key surface water resources in NPS units throughout the United States. Key surface water resources are those that are essential to cultural, historical, or natural resource management themes of the unit or that provide habitats for threatened and endangered species. The project will help the park to better understand the natural cycles and seasonality of its water resources, in addition to contributing to Vital Signs monitoring objectives of the Mojave Desert Network Inventory and Monitoring Program.

The baseline water quality inventory consisted of three components: field sampling, lab analysis, and biological assessment. Field sampling included measuring core water quality parameters at any visit to a water source. These core parameters were water temperature, dissolved oxygen, pH, conductivity, and discharge. In addition to these core parameters, the park decided an additional set of parameters would add useful information to the park's baseline information, including nutrients and basic anions and cations (total dissolved solids, hardness, calcium, magnesium, sodium, potassium, sulfate, chloride, nitrate, total alkalinity, bicarbonate-alkalinity, carbonate-alkalinity, fluoride, arsenic, iron, manganese, copper, zinc, barium, boron, silica, color, turbidity, pH, and conductivity).

Macroinvertebrates are often used to infer water quality because they are sensitive to changing physical, chemical, and biological conditions over multiple spatial and temporal scales. They also exhibit taxon-specific responses to spatial and temporal variation in water quality parameters that are informative when comparing macroinvertebrate assemblages (Barbour et al. 1999; Karr and Chu 1999). Macroinvertebrate samples are also useful in detecting the presence of non-native invertebrate species.

Study Area

Great Basin National Park is located in eastern Nevada in the South Snake Range within the Great Basin Desert. The park's highest mountain, Wheeler Peak, reaches 13,063 feet in elevation, creating a wetter microclimate in the higher elevations. The mountaintops receive more than double the precipitation of the lower lying valleys. With this added moisture, the park contains abundant water resources, including 6 sub-alpine lakes, 10 perennial streams, many ephemeral streams, and over 400 springs. These water sources were divided into 25 watersheds by GIS analysis, of which ten were included in this level one baseline water quality inventory (Figure 1). All ten of these watersheds have perennial water sources, while many of the other watersheds in the park only contain water during spring runoff or exceptionally wet years and were therefore excluded.

Sampling sites included six lakes, 35 springs, four caves, and 20 stream sampling locations along 10 streams for a total of 67 sampling sites (Table 1). Site selection was based on susceptible, outstanding, and important water resources located within the park (Figure 2). Susceptible areas were defined as those areas outlined by Elliot et al. (2006) to have the potential for a loss of water due to groundwater pumping in adjacent valleys. These areas are located near the park boundary in the Lehman, Baker, Can Young, and Snake watersheds. Outstanding water resources were defined as Class A waters recognized by the State of Nevada, namely Baker, Lehman, Pine and Ridge creeks. Important water resources were defined as streams supporting native fishes, springsnails (*Pyrgulopsis kolobensis*), or cave biota.

Lakes

Six sub-alpine lakes are located in the park within three watersheds: Baker (n=1), Lehman (n=3), and Snake (n=2). Johnson Lake is the highest lake at 3,305 m (10,844 ft), and Dead Lake is the lowest at 2,920 m (9,580 ft). Both of these lakes are within the Snake Creek watershed. Only Teresa and Johnson lakes have year-round water sources from perennial springs; all other lakes receive their water from snowmelt.

Springs

Over 425 perennial springs and seeps have been identified within the park (Baker 2004), and 34 were included in the baseline water quality inventory. Springs were chosen based on the amount of discharge, location, and underlying bedrock.

Caves

Four caves were included in the baseline water quality survey; all contain perennial water that fluctuates seasonally. Model Cave and Wheeler's Deep are located within the Baker Creek System and are connected to surface water from Baker Creek and possibly ground water. Wheeler's Deep contains a stream; Model Cave is in contact with the water table, which rises during spring run-off. Squirrel Springs Cave is located in the Snake Creek watershed and is connected to the water table. During the dryer months, more of the cave is accessible as the water level recedes. During spring runoff on normal to wet years, the water level rises sufficiently that water flows out of the cave. Lehman Cave contains pools from percolation of overlying water, but known cave passages do not have flowing water or intercept the water table.

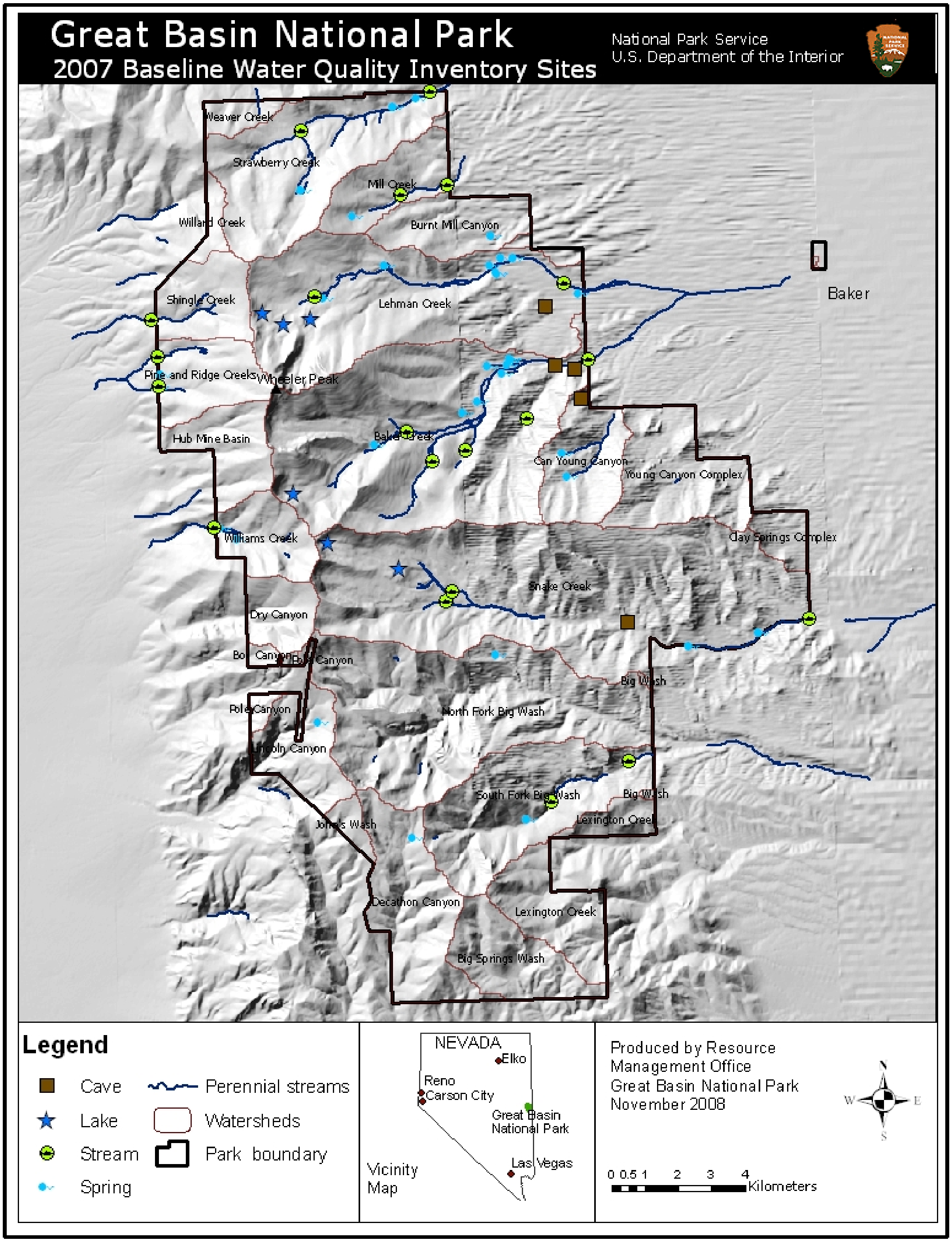


Figure 1. Sampling stations for 2007 baseline water quality inventory and watersheds in Great Basin National Park.

Table 1. Sampling sites for 2007 baseline water quality inventory in Great Basin National Park. Coordinates are in NAD83 Zone 11.

Sampling site	Watershed	Type of waterbody	UTMX	UTMY	Elevation (m)
Baker 53	Baker	Spring	739700	4319506	2250
Baker57	Baker	Spring	739725	4319455	2234
Baker59	Baker	Spring	739641	4319323	2242
Baker94	Baker	Spring	738319	4317892	2477
Baker130	Baker	Spring	738756	4318209	2378
Baker136	Baker	Spring	739500	4319048	2241
Baker137	Baker	Spring	739034	4319296	2314
Baker200	Baker	Spring	735657	4316941	2862
Baker Lake	Baker	Lake	733111	4315460	3237
Baker Creek Lower	Baker	Stream	741946	4319459	2066
Model Cave	Baker	Cave	741559	4319175	2080
Pole Canyon Creek	Baker	Stream	740109	4317689	2288
South Fork Baker Creek	Baker	Stream	737259	4316396	2695
Timber Creek	Baker	Stream	738270	4316739	2587
Baker Upper	Baker	Stream	736502	4317293	2745
Wheelers Deep	Baker	Cave	740970	4319268	2147
Burnt Mill Spring	Burnt Mill	Spring	739151	4323201	2208
Can Young 9	Can Young	Spring	741442	4315949	2521
Can Young 17	Can Young	Spring	741284	4316660	2480
Can Young 20	Can Young	Spring	741737	4318297	2280
Decathon 1	Decathon	Spring	736792	4305116	3109
Decathon Spring	Decathon	Spring	736297	4298911	2511
Rowland Spring	Lehman	Spring	741772	4321459	2004
Lehman 004	Lehman	Spring	739440	4322537	2201
Lehm006	Lehman	Spring	739808	4322542	2182
Lehm013	Lehman	Spring	739117	4322304	2223
Lehman 25	Lehman	Spring	734079	4321329	2972
Lehman 52	Lehman	Spring	735933	4322299	2695
Cave Springs	Lehman	Spring	739289	4322108	2218
Brown Lake	Lehman	Lake	733614	4320695	3125
Cave Springs2	Lehman	Spring	739327	4322061	2217
Lehman Cave	Lehman	Cave	740652	4321053	2096
Lehman Creek Lower	Lehman	Stream	741200	4321768	2036
Stella Lake	Lehman	Lake	732167	4320867	3180
Teresa Lake	Lehman	Lake	732802	4320535	3130
Lehman Creek Upper	Lehman	Stream	733739	4321359	3000
Lincoln 1	Lincoln	Spring	733936	4308588	3107
Mill Creek 3	Mill	Spring	734969	4323792	2864
Mill Creek Lower	Mill	Stream	737731	4324727	2312
Mill Creek Upper	Mill	Stream	736325	4324425	2507
NFBW6	North Fork Big Wash	Spring	739296	4310605	2520
PIRI008	Pine/Ridge	Spring	729137	4318641	2488
PIRI010	Pine/Ridge	Spring	729216	4319043	2555
Pine Creek	Pine/Ridge	Stream	728993	4319548	2485

Sampling site	Watershed	Type of waterbody	UTMX	UTMY	Elevation (m)
Ridge Creek	Pine/Ridge	Stream	729027	4318676	2481
SFBW5	South Fork Big Wash	Spring	740232	4305683	2441
SFBW Lower	South Fork Big Wash	Stream	743175	4307388	2141
SFBW Upper	South Fork Big Wash	Stream	740848	4306190	2382
Shingle Creek	Shingle	Stream	728819	4320655	2407
Outhouse Spring	Snake	Spring	747212	4311294	1949
Outlet Spring	Snake	Spring	745110	4310865	2067
Dead Lake	Snake	Lake	736267	4313183	2920
Johnson Lake	Snake	Lake	734132	4313965	3305
Snake Creek Lower	Snake	Stream	748589	4311685	1903
South Fork Snake Creek	Snake	Stream	737665	4312215	2527
Squirrel Springs	Snake	Cave	743129	4311590	2188
Snake Creek Upper	Snake	Stream	737861	4312493	2563
Strawberry 002	Strawberry	Spring	736886	4327341	2112
Straw007	Strawberry	Spring	736218	4327083	2159
Strawberry 50	Strawberry	Spring	733422	4324557	2810
Strawberry Lower	Strawberry	Stream	737179	4327502	2091
Strawberry Creek Upper	Strawberry	Stream	733338	4326352	2402
WILM004	Williams	Spring	731015	4314402	2579
Williams 5	Williams	Spring	731531	4314098	2694
Williams Creek	Williams	Stream	730706	4314417	2525

This is the only cave with a developed tour route, including cement walkways, railings, stairs, a lighting system and daily cave tours. For over a century Lehman Caves has been impacted by development from -improvements for tourist access.

All four caves are close in elevation, lying between 2,080 and 2,188 m (6,821 - 7,180 ft) in elevation. Lehman Cave, Model Cave, and Wheeler's Deep Cave are all within the same geologic layer, Pole Canyon Limestone. Squirrel Springs Cave lies on the margin between the Fish Haven and Laketown Dolomite and Pole Canyon Limestone in the Snake Creek drainage.

Streams

Ten permanent streams originate in the park between 1,890 and 3,353 m (6,200 - 11,000 ft) elevation, and all ten were included in the baseline water quality inventory. The streams are first and second order headwater streams with an average length of 8 km (5 mi) within the park. Six streams (Strawberry, Mill, Lehman, Baker, Snake, and South Fork Big Wash) flow eastward into Snake Valley and the Bonneville Basin. The other four streams (Shingle, Pine, Ridge, and Williams) flow westward into Spring Valley and were originally fishless. Outside park boundaries the majority of these streams are used for irrigation; some water evaporates or percolates into the alluvium before reaching the valley bottom.

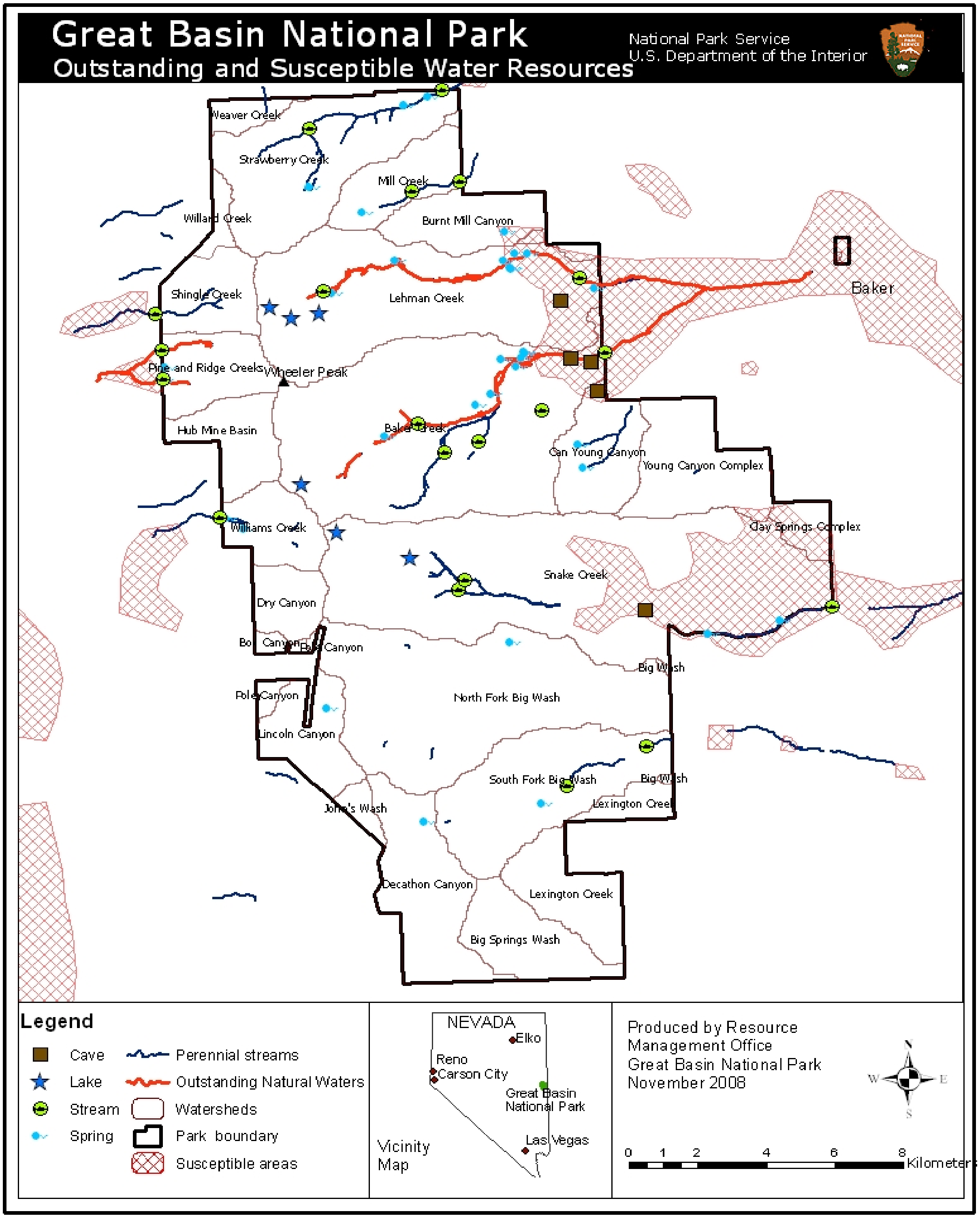


Figure 2. Outstanding and susceptible water resources in Great Basin National Park. Outstanding natural waters are considered to be waters that the State of Nevada has classified as Class A waters. Susceptible areas are shown in hatch marks and are taken from Elliott et al. (2004).

Methods

Water chemistry, water quantity, and macroinvertebrate samples were collected from a total of 67 sites, including six lakes, 35 springs, four caves, and 20 stream locations. A total of 186 samples were collected, including 26 replicate quality assurance samples. The protocol was to sample seasonally in December, March, June, and September, but several sites, including the sub-alpine lakes and higher elevation sites, were inaccessible during the winter months. Basic water quality parameters and water samples were taken in June and September at Brown Lake and Dead Lake and taken in June, July, August, and September at Baker, Stella, Teresa, and Johnson lakes.

Basic Water Chemistry Sampling

Basic water quality parameters, including water temperature, dissolved oxygen, specific conductance, and pH were measured *in situ* using a YSI® 85 dissolved oxygen and conductivity meter and an OAKTON® pH testr2 meter.

In streams and springs, water parameters were measured in the middle of a riffle area. In lakes, water quality was measured from the deepest location at the surface, at mid-depth, and then at the bottom just above the substrate. In caves, water quality was measured in a riffle if available. If no running water was available, the water was taken in the most accessible location at the water's edge.

Discharge measurements were made at each stream and spring sampling visit using a pygmy meter when possible and following NPS Water Resources Division protocols (Stednick and Gilbert 1998) for taking measurements. If water levels or accessibility prevented use of a pygmy meter, a discharge estimate was made by measuring width, average depth, and average surface velocity by timing a buoyant object carried by the current over a known distance.

Secchi disk readings were conducted on lakes to determine clarity following EPA Lake and Reservoir Bioassessment and Biocriteria protocol (Gerritsen et al. 1998).

Laboratory Water Chemistry Analysis

Water samples were collected at each site for lab analyses. For quality assurance purposes, approximately twenty percent of the samples were immediately re-sampled with a second set of samples collected. Turbidity was measured within 24 hours of collection using a SMART colorimeter in the Resource Management Laboratory at Great Basin National Park.

Collected samples were shipped via express mail to a Nevada state licensed water quality lab for analysis using protocols established by the EPA and adequate quality assurance measures. Due to contracting restraints, samples collected from December to March were sent to Sierra Environmental Monitoring, in Nevada, and from April to October to Biochem Testing, Inc., in West Virginia. Each lab conducted testing for total dissolved solids, hardness, calcium, magnesium, sodium, potassium, sulfate, chloride, nitrate, total alkalinity, bicarbonate-alkalinity, carbonate-alkalinity, fluoride, arsenic, iron, manganese, copper, zinc, barium, boron, silica, color, turbidity, pH, and conductivity. See Appendix B for additional explanations of each of these parameters.

Macroinvertebrate Sampling

Macroinvertebrate samples were sampled at selected lake, stream, spring, and cave sites following modified EPA protocols (Barbour et al. 1999). Both quantitative and qualitative samples of macroinvertebrates were obtained from streams. One quantitative sample was taken at each of four riffle locations (8 quantitative samples total) within a reach using a dip net with a 500 micron mesh net. During each sample, an area of roughly the same dimensions as the mouth of the net was disturbed directly in front of the net by roiling the substrate with hands and feet for 30 seconds and allowing the invertebrates and detritus to wash downstream into the net. The samples from the four riffle locations were composited to make a sample of approximately 0.744 m^2 for each location.

Qualitative surveys were collected from representative habitats in each body of water sampled using a 500 micron mesh dip net. Following the collection of a sample, one-person hour was spent picking live macroinvertebrates and putting them into a Nalgene bottle. All macroinvertebrates collected were preserved in 95% ethyl alcohol and sent for identification to the National Aquatic Monitoring Center (Buglab) using U.S. Geological Survey general procedures (Cuffney et al. 1993) with slight modifications (Vinson and Hawkins 1996). The Buglab reported all taxa found at each site, along with generating indices to help summarize the data. The indices reported include:

Abundance – The abundance, density, or number of aquatic macroinvertebrates per unit area, reported as number of individuals per square meter for quantitative samples and the number of individuals collected in each qualitative sample. This is an indicator of habitat availability and fish food abundance.

EPT – The insect Orders Ephemeroptera, Plecoptera, and Trichoptera (EPT) are commonly considered sensitive to pollution. A summary of the EPT taxonomic abundance and richness is reported.

Richness – Taxa richness, or the number of distinct taxa, is a component and estimate of community structure and stream health. Taxa richness normally decreases with decreasing water quality.

Families – Number of distinct families. This is another way to report richness, and is more useful for comparing different datasets than taxa richness due to using the same taxonomic level. Comparing numbers of distinct families is a good way to assess higher-level taxonomic diversity and evaluate how many groups with distinct ecological habitats are present. Decreasing numbers of families indicates decreasing water quality.

Shannon Diversity Index – A measure of community structure defined by the relationship between the number of distinct taxa and their relative abundances (Shannon and Weaver 1949). Higher values indicate more diversity and/or more evenness within the community.

Statistical Analysis

As an initial check on the laboratory analytical results, we calculated charge balance in an aqueous solution. Comparisons were done between results from sample splits for Quality

Assurance and presented as maximum percent error. In addition to reporting the minimum, maximum, and median values, we calculated sample means and standard deviations. We found sample histograms to be strongly skewed towards lower values except for pH, suggesting that parametric statistical tests may not be appropriate. For testing correlations, such as between concentration and elevation, we used the Spearman Rank Correlation statistic. In order to minimize confounding spatial, temporal, sampling, and analytical error sources of variability, we used the average value when more than one sample came from a given sampling station. To compare categories we used the Mann-Whitney U test for pairs, such as groundwater versus surface water, and the Kruskal-Wallis test for multiple comparisons, such as varying geology. Although these non-parametric rank statistics do not assume normality, independence and homogeneity of variance are still assumed. For significance we used a level of $\alpha = 0.05$.

Piper diagrams were constructed to examine general aqueous geochemistry. We tested for silica saturation and alkalinity as a function of pH. Lastly, we tested for evidence of groundwater evolution as a function of residence time using elevation as a proxy for flow path length.

Data Management

All water quality data, including field data and lab analyzed data, are stored in the NPStoret database following NPS protocols. Data has undergone quality assurance checks and will be downloaded to the main database for final storage. Hard copies of data are on file in the Resource Management office at GRBA. Macroinvertebrate samples and data are stored at the Utah State University Buglab with Mark Vinson.

Results by Type of Water Body

Between December 4, 2006, and October 25, 2007, a total of 186 samples, including 26 samples for Quality Assurance (QA), were collected from 67 sampling sites.

Lakes

Mean lake water temperature showed little variation among lakes, ranging from 10.4 to 13.5° C (Table 2). Likewise, mean dissolved oxygen also varied little, from 5.2 to 7.8 mg/L. All lakes are located on metamorphic rock and had corresponding low mean specific conductance values, ranging from 19.1 to 42.3 µS/cm/25°C. The mean pH for all lakes was high, from 8.2 to 8.9.

Table 2. Mean values and standard deviation for measurements of basic water quality parameters at sub-alpine lakes (n=6), 2007.

Sampling Station (Watershed)	Water Temperature (°C)			Dissolved Oxygen (mg/L)			Specific Conductance (µS/cm/25°C)			pH		
	Mean	SD	#	Mean	SD	#	Mean	SD	#	Mean	SD	#
Baker Lake (Baker)	13.5	1.6	4	6.4	0.6	4	19.1	1.1	4	8.6	0.7	4
Brown Lake (Lehman)	12.0	0.9	2	5.2	1.0	2	41.1	31	2	8.6	0.1	2
Stella Lake (Lehman)	12.3	5.4	4	6.4	0.9	4	33.2	4.6	4	8.8	0.4	4
Teresa Lake (Lehman)	10.7	2.1	4	6.2	1.0	4	21.2	1.9	4	8.4	0.2	4
Dead Lake (Snake)	10.4	8.1	2	7.8	1.0	2	24.2	5.1	2	8.9	0.6	2
Johnson Lake (Snake)	12.5	2.9	4	5.5	2.0	4	42.3	5.2	4	8.2	0.2	4

Turbidity for the lakes ranged between 2 and 12 NTU. The EPA standard for drinking water is less than 1 unit, or less than 5 units for special circumstances. Dead Lake had the highest turbidity value (12 NTU) while Baker Lake and Johnson Lake had the lowest values of 2 NTU (Figure 3). A Secchi disk was also used to measure the clarity of the lakes. The Secchi disk was visible to the substrate at each lake; however, some lakes have depths of less than 0.7 m (2 ft) in the autumn.

Total dissolved solid (TDS) concentrations were measured for the lakes and were within acceptable limits for park water sources with concentrations between 9 and 40 mg/l; however, because of extended shipping times, twenty percent of the samples were not analyzed within the appropriate holding time for TDS.

Springs

Thirty-three springs from 13 watersheds were sampled for the baseline water quality survey. All springs surveyed had lower water levels as the water year progressed; however, one spring in the Strawberry Creek watershed was already dry at its second sampling visit in June. Five springs were sampled four times (December, March, June, and September). Ten springs were sampled twice. The remaining springs were sampled once.

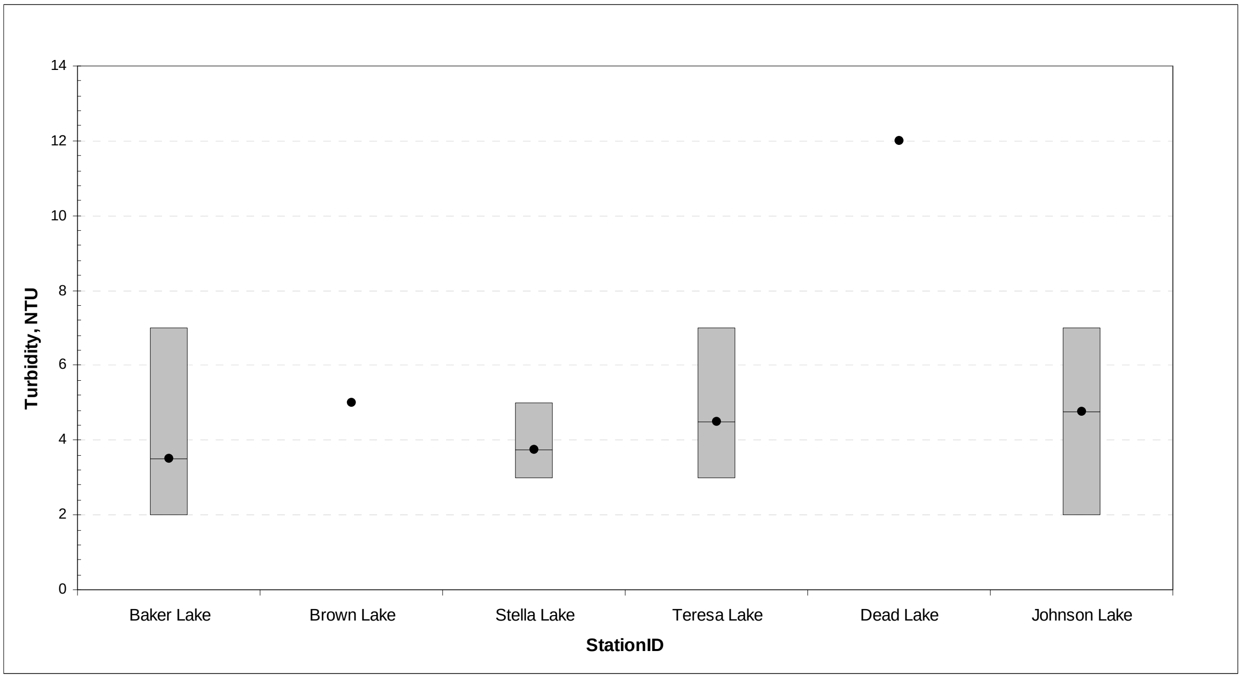


Figure 3. Minimum, maximum, and mean turbidity for sub-alpine lakes in Great Basin National Park, 2007. Only one turbidity measurement was made for Brown and Dead Lakes.

Water temperatures from sampled springs ranged from 0.3 °C to 13.6 °C (Table 3). The coldest water temperature was recorded at Lehman 052 in December of 2006. The highest water temperatures were recorded at two locations, Burnt Mill Spring and Snake 056 in the summer during low water levels (Figure 4). The water temperatures of the sampled springs were several degrees higher than the streams measured in the survey, indicating their groundwater source and the greater influence of snowmelt on streams. The springs also had less seasonal temperature variation than streams. The mean water temperature was 8.0 °C with the lowest water temperatures recorded during the winter months and at the higher elevation spring sites.

The springs surveyed had high variation in specific conductance values (17.3-613 µS/cm/25°C). The highest specific conductance values were recorded for Decathon Spring (613 µS/cm/25°C), Decathon 001 (392.1 µS/cm/25°C), Can Young 001 (375.7 µS/cm/25°C), and springs in Snake Creek and South Fork of Big Wash (Figure 5). All but one of the springs with high specific conductance values (Strawberry 002) are located in the southern part of the park, which is dominated by karst. Strawberry 002, which is located in the northern portion of the park, had a specific conductance value of 320.7 µS/cm/25°C recorded in December of 2006. Total dissolved solids had similar values as specific conductance (Table 4).

Discharge measurements for the sampled springs were minimal and exhibited little seasonal variation when compared to the discharge measurements for the stream sites. Four of the sampled spring sites were metered discharge measurements. The maximum discharge was measured at Lehman 025 (5.3 cfs) in June, and the lowest discharge was measured at North Fork of Big Wash 006 (0.0015 cfs) in September. The mean discharge for all sampled springs was 0.7 cfs.

Table 3. Mean water quality parameters for sampled springs (n=33) by watershed, 2006-07. Western range includes Pine, Ridge, Shingle, and Williams Creeks. Southern range includes Big Wash and Decathon watersheds. Burnt Mill Spring and a second location at Cave Springs were not included.

	Water Temperature (°C)			Dissolved Oxygen (mg/l)			pH			Specific Conductance (μS/cm)		
Watershed (# of sites)	Mean	SD	#	Mean	SD	#	Mean	SD	#	Mean	SD	#
Baker (8)	8.9	2.4	12	6.9	1.8	12	7.2	0.5	12	73.0	39.1	12
Lehman (7)	8.2	4.5	13	6.4	1.8	13	7.9	0.5	13	104	66.2	12
Can Young (3)	6.7	1.3	5	5.6	2.4	4	8.4	0.2	5	225.	113	5
Strawberry (3)/Mill (1)	7.4	3.6	8	6.9	1.7	8	7.9	0.5	8	135	102	8
Snake (2)	10	2.4	8	6.2	0.7	8	7.9	0.3	8	265	35.5	8
Western range (5)	5.5	2.1	7	8.4	1.5	7	8.0	0.5	7	68.4	55.3	7
Southern range (4)	6.5	1.6	4	6.2	1.2	3	7.9	7.9	4	372	179	4
Mean	8.0	3.1	61	6.8	1.7	59	7.9	0.5	61	150	129	60

	Discharge (cfs)			Turbidity (NTU)		
Watershed (# of sites)	Mean	SD	#	Mean	SD	#
Baker (8)	0.2	0.5	12	4.5	2.3	10
Lehman (7)	0.9	1.5	17	6.3	4.0	8
Can Young (3)	0.1	0.1	3	4.6	0.9	5
Strawberry (3)/Mill (1)	0.3	0.6	6	8.1	7.0	7
Snake (2)	1.1	1.6	8	7.7	2.6	4
Western range (5)	1.6	1.7	6	3.6	2.2	7
Southern range (4)	0.1	0.1	2	8.3	6.4	3
Mean	0.7	1.3	56	6.0	4.1	44

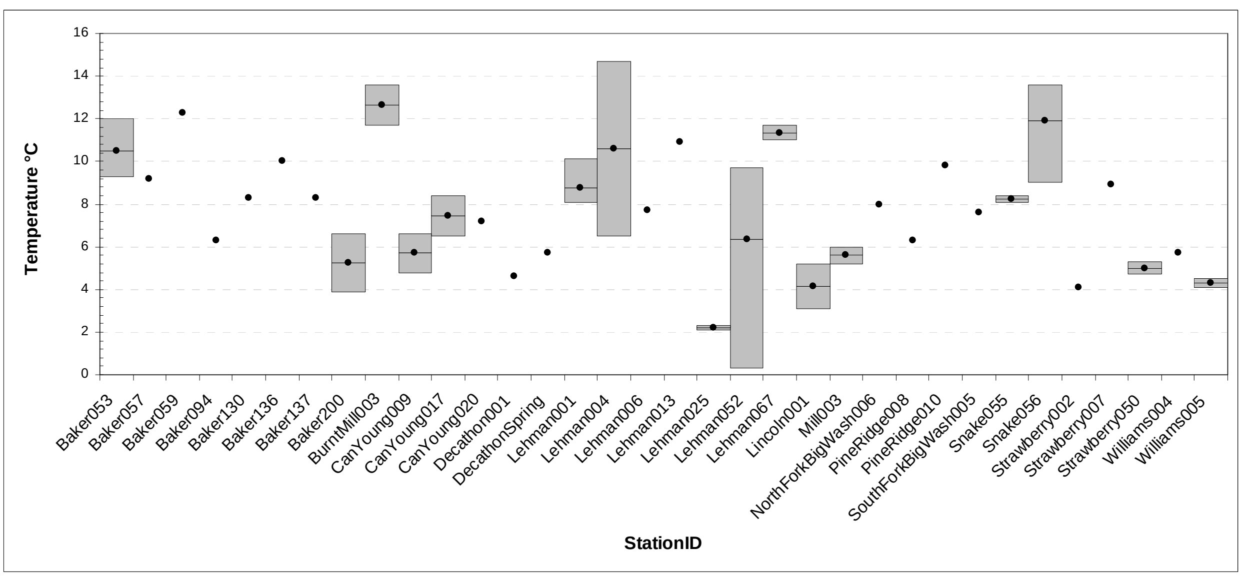


Figure 4. Minimum, maximum, and mean water temperatures for sampled springs, 2006-07.

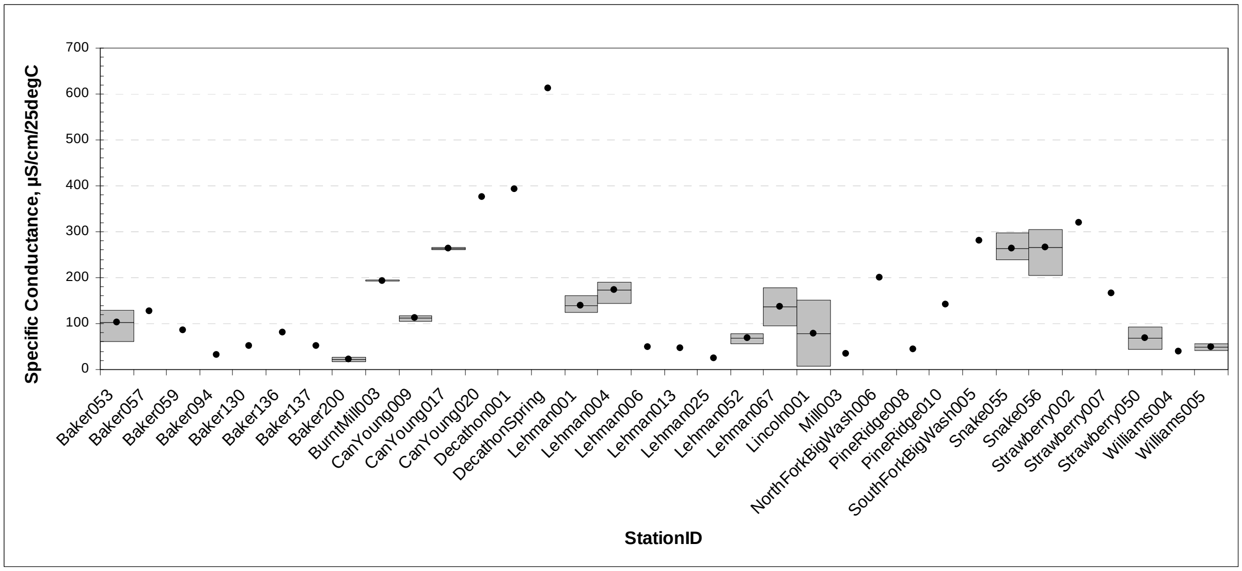


Figure 5. Minimum, maximum, and mean specific conductance for sampled springs, 2006-07.

Table 4. Maximum specific conductance and total dissolved solid (TDS) concentrations for sampled springs, 2006-07. Decathon 001, Decathon Spring, and Can Young 020 records are just over of the seven day holding time for TDS analysis. The EPA standard for TDS is 500 mg/l.

Spring	Specific Conductance (µS/cm/25°C)	TDS (mg/l)
Decathon 001	392	237
Decathon Spring	613	341
Can Young 017	266	172
Can Young 020	376	243
Snake 055	298	161
Snake 056	304	168
Strawberry 002	321	250

Caves

The average water temperature for sampled caves was 9.1°C (Table 5). Wheeler’s Deep had the lowest recorded water temperature for caves sampled (3.8 °C). The highest water temperature was recorded in Squirrel Springs Cave (11.8 °C). Both Model Cave and Wheeler’s Deep had comparatively lower water temperatures than either Lehman Cave or Squirrel Springs Cave. Model and Wheeler’s Deep are both in contact with surface water from Baker Creek, which is heavily influenced by snowmelt during spring run-off and diurnal air temperature fluctuations. The water temperatures from Model and Wheeler’s Deep are more similar to the average water temperatures for Baker Creek stream sites than to Lehman Cave or Squirrel Springs Cave (Figure 6), supporting the idea that water from Baker Creek is affecting water temperature and water chemistry in those caves.

Table 5. Mean water quality parameters for water temperature, dissolved oxygen, specific conductance, and pH for sampled caves with mean, standard deviation, and sample number, 2006-07.

Sampling Station (Watershed)	Water Temperature (°C)			Dissolved Oxygen (mg/L)			Specific Conductance (µS/cm/25°C)			pH		
	Mean	SD	#	Mean	SD	#	Mean	SD	#	Mean	SD	#
Lehman Cave (Lehman)	11	0.2	4	4.9	2.1	4	421	47	4	8.2	0.5	4
Model Cave (Baker)	7.7	2.1	4	5.4	1.8	4	107	8.6	4	8.2	0.5 6	4
Wheeler's Deep Cave (Baker)	6.0	1.5	4	6.5	4.3	4	108	54.	4	8.1	0.5	4
Squirrel Springs Cave (Snake)	12	0.3	4	4.2	0.3	4	552	54	4	7.7	0.2	4

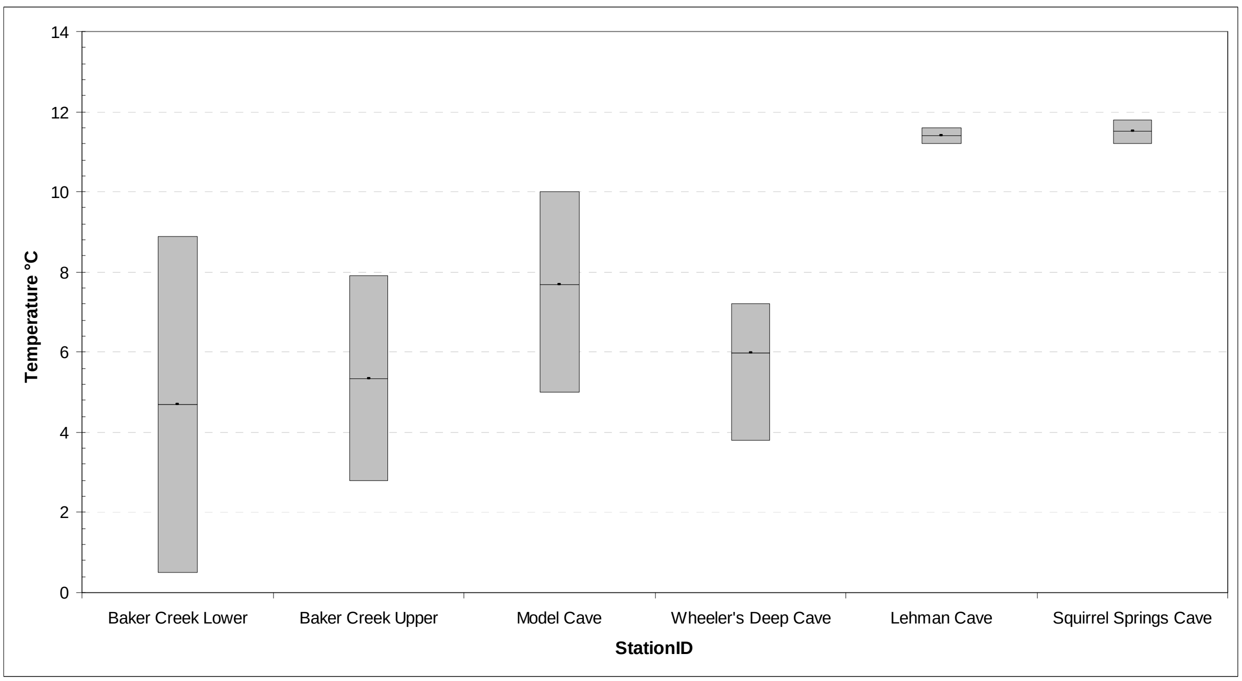


Figure 6. Minimum, maximum, and mean water temperature for Model, Wheeler's Deep, Lehman, and Squirrel Springs Caves, along with data for Baker Creek Lower and Baker Creek Upper stream sampling sites, 2007.

The ranges in water temperature for Model Cave are from 5 to 10 °C, and ranges for air temperatures are 13 to 16 °C. Comparatively, the range in water temperature for Lehman Cave is 11.5 to 14 °C (Figure 6) and air temperature 11.2 to 11.6 °C.

Squirrel Springs Cave had the highest recorded specific conductance (551.8 µS/cm/25°C), and Model Cave and Wheeler's Deep had the lowest specific conductance values (106.8 and 107.5 µS/cm/25°C, respectively). Lehman Cave and Squirrel Springs Cave are influenced by ground water as reflected by the high specific conductance values. The water sources in Model Cave and

Wheeler's Deep are charged by water from Baker Creek and have lower specific conductance values indicating a surface water source rather than a ground water source. Figure 7 illustrates the similarity of the water samples taken from Lehman Cave and Squirrel Springs Cave, which are not in contact with surface water but are true ground water sources, and the similarity of the samples taken from Model Cave and Wheeler's Deep Cave, which are heavily influenced by surface water.

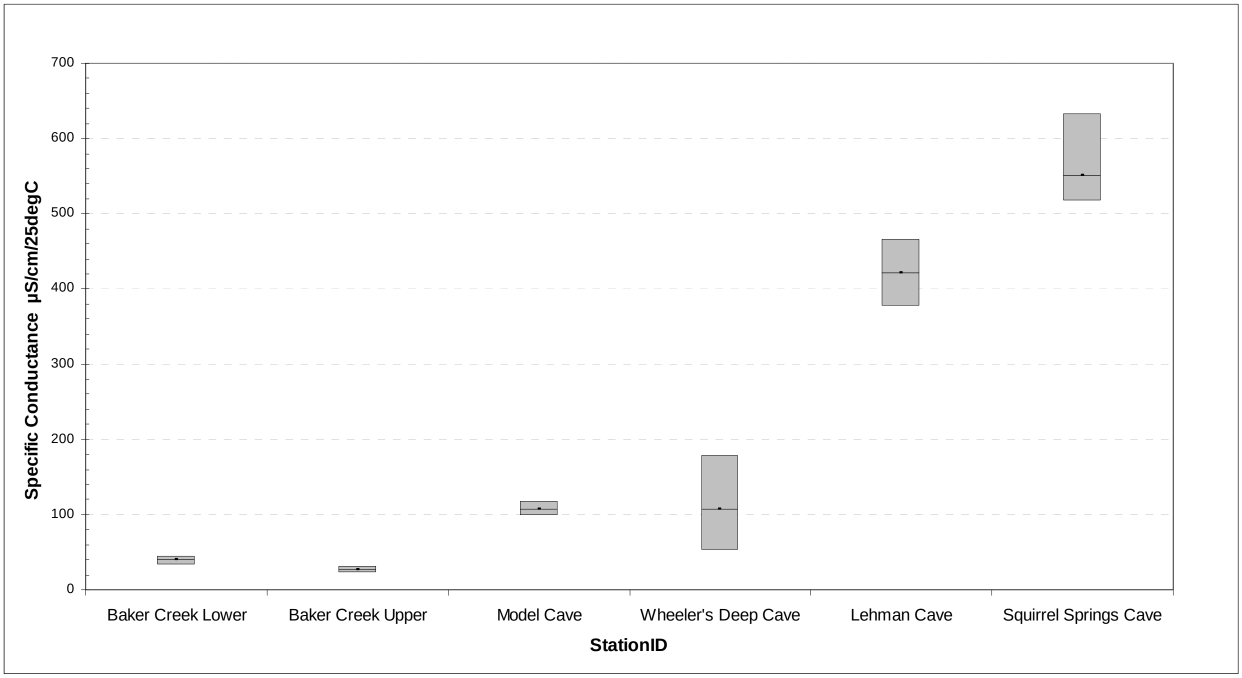


Figure 7. Minimum, maximum, and mean specific conductance for sampled caves and Baker Creek stream sites, 2006-07.

Total dissolved solids concentrations for Lehman Cave (466 mg/l) and Squirrel Springs Cave (633 mg/l) were higher than the concentrations found in the Baker Creek system caves, Model and Wheeler's Deep Cave. The lowest TDS concentrations were recorded in Wheeler's Deep Cave (53.3 mg/l). Like with specific conductance values, the TDS concentrations for Model Cave and Wheeler's Deep were more closely related to Baker Creek stream sites than to the other two cave sampling sites (Figure 8). Model Cave and Wheeler's Deep TDS concentrations were lower than Lehman Cave or Squirrel Springs Cave because of the surface water input from Baker Creek. Lehman and Squirrel Springs Cave are in contact with ground water, which typically has higher concentrations of dissolved solids.

Streams

Six larger streams within the park were sampled at two points, one upper and one lower elevation site. Smaller streams were sampled at only one site, and all sampled streams were sampled at least twice during the water year. The elevation of each site affected water temperature and turbidity. The lower elevation sites had higher turbidity because of their downstream location and higher sediment input from the accumulation of particles as stream length increased. The Baker Creek watershed had the greatest number of survey sites (n=5)

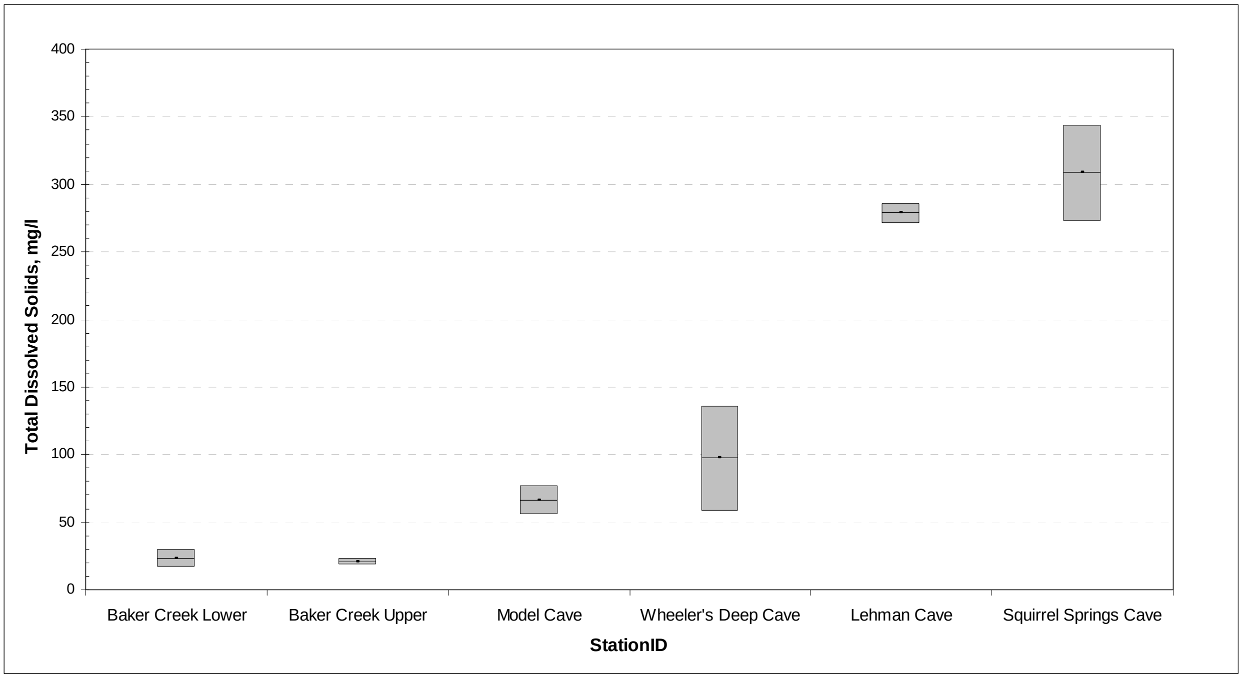


Figure 8. Minimum, maximum, and mean total dissolved solids concentrations for sampled caves and Baker Creek Lower and Baker Creek Upper stream sites for comparison, 2006-07.

because of the number of tributaries in this watershed. The other nine watersheds contained between one and three sampling stations depending on size and accessibility.

Because of the extended shipping times for laboratory analysis for the samples collected between June and October of 2007, several water chemistry parameters were not within the established holding times for accurate analysis. None of the samples were received within holding time for color, turbidity (lab analyzed), and pH (lab analyzed), and twenty percent of the samples were not within the appropriate holding time for total dissolved solids.

The water temperatures of the surveyed streams ranged from -0.1 °C to 14.7 °C depending on when the sample was taken and the elevation of the site. The mean water temperature for all streams was 5.9 °C (SD=4.0), with the coldest temperatures recorded at the lower elevation site on Lehman Creek in December and the warmest temperatures measured in June along the South Fork of Baker Creek (Table 5). The greatest range of temperatures was also recorded at the lower elevation site along Lehman Creek (-0.1°C to 13.9 °C). Despite the large ranges in water temperature, the recorded temperatures for the surveyed streams are within their natural range. The mean dissolved oxygen for the streams was 8.9 mg/l (SD=1.9). The highest concentrations of dissolved oxygen were measured at the lower elevation sites on Baker, Lehman Pine, and Ridge creeks. The lowest concentrations were recorded at the lower site on South Fork of Big Wash (Figure 9, Table 6). All the measurements for dissolved oxygen were within the normal limits for water sources within the park and adequate for sustaining aquatic organisms with high dissolved oxygen requirements.

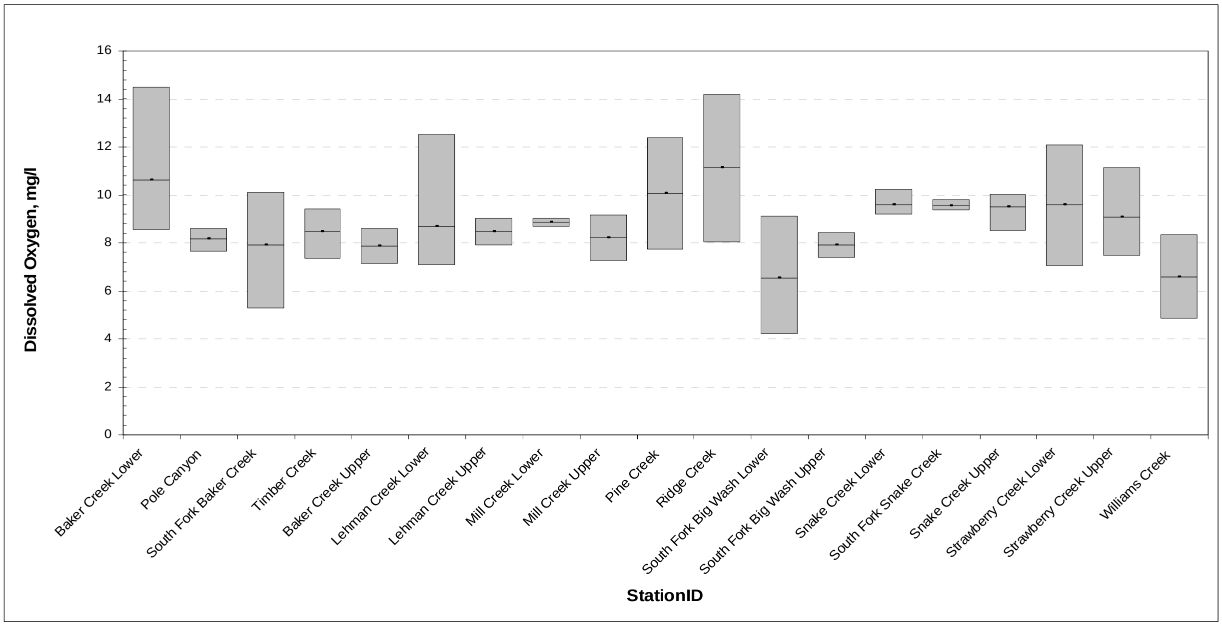


Figure 9. Minimum, maximum, and mean dissolved oxygen concentrations for sampled park streams, 2006-07.

Table 6. Mean basic water quality for park streams, 2007. Six of the park's perennial streams were sampled at an upper and lower elevation site. Additional stream sites were sampled at the park boundary or at upper elevation sites along a perennial tributary stream. # is the number of samples taken at each site during the sampling period, November to October, and SD is the standard deviation.

	Water Temperature (°C)			Dissolved Oxygen (mg/l)			pH			Specific Conductance (µS/cm/25°C)		
Stream	Mean	SD	#	Mean	SD	#	Mean	SD	#	Mean	SD	#
Baker Lower	4.7	4.7	4	10.6	2.8	4	8.2	0.3	4	39.5	6.9	2
Baker Upper	5.3	3.6	2	7.9	1.0	2	8.2	0.1	2	27.0	5.2	2
South Fork Baker	8.3	6.8	3	7.9	2.4	3	7.9	0.2	3	43.7	9.1	2
Lehman Lower	7.1	7.2	4	8.7	2.6	4	8.3	0.1	4	41.3	1.7	2
Lehman Upper	5.6	2.1	2	8.5	0.8	2	8.0	0.1	2	36.8	1.6	2
Mill Lower	6.9	2.9	2	8.9	0.3	2	8.2	0.1	2	72.5	6.6	
Mill Upper	5.9	1.8	2	8.2	1.3	2	7.9	0.4	2	36.7	3.8	2
Pine	5.6	3.1	2	10.1	3.3	2	7.9	0.14	2	41.6	2.6	2
Pole Canyon	7.5	4.4	4	8.2	0.4	4	8.1	0.3	4	245	48	4
Ridge	6.2	1.1	2	11.1	4.3	2	8.2	0.1	2	35.0	15	2
Shingle	5.2	4.5	4	9.7	1.6	4	7.9	0.9	4	84.5	5.5	3
Snake Lower	5.2	3.9	3	9.6	0.6	3	8.5	0.3	3	175	30	2
Snake Upper	4.4	4.4	5	9.5	0.7	5	8.5	0.6	5	57.7	7.8	2
South Fk Snake	4.0	2.7	4	9.5	0.2	4	8.5	0.3	4	106	0.5	2
SFBW Lower	8.3	0.6	3	6.5	2.5	3	7.6	0.2	3	421	49	3
SFBW Upper	7.1	0.3	2	7.9	0.7	2	7.6	0.1	2	411	24	2
Strawberry Low	6.1	6.4	4	9.6	2.6	4	8.4	0.1	4	172	18	2
Strawberry Up	5.5	5.6	4	9.1	1.5	4	8.1	0.2	4	83.3	1.7	2
Timber	5.4	3.3	3	8.5	1.1	3	7.9	0.3	3	129	15	2
Williams	6.9	1.6	2	6.6	2.5	2	7.9	0.14	2	44.4	4.7	2
Mean All streams	5.9	4.0	61	8.9	1.9	61	8.1	0.4	61	127	124.4	61

Specific conductance values for the surveyed streams varied widely, with the highest values recorded at the low elevation site along the South Fork of Big Wash (464.1 µS/cm/25°C). The lowest value for specific conductance was recorded at the upper elevation site on Baker Creek (23.4 µS/cm/25°C). The mean specific conductance for the streams was 127.2 µS/cm/25°C. The sites with the highest specific conductance values (Upper and Lower South Fork of Big Wash) are located in the southern end of the park where the dominant rock type is limestone. The northern and western areas of the park are dominated by alluvium, quartzite, granite, talus, and glacial deposits (Figure 10). The watersheds with underlying limestone geology have higher specific conductance values because of the composition of the rock and the permeability of these layers to water.

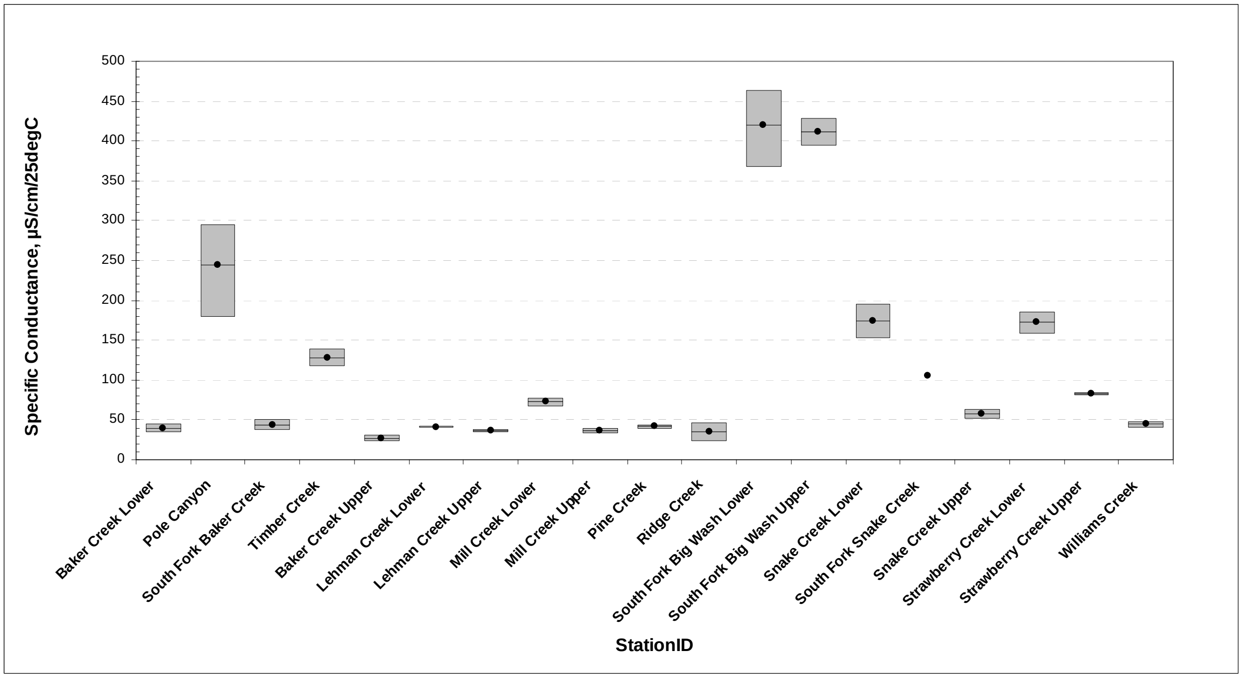


Figure 10. Minimum, maximum, and mean specific conductance for sampled park streams, 2006-07.

The highest turbidity values were measured in Mill Creek. The lower elevation site on Mill Creek had a turbidity value of 22 NTU, and the higher elevation site measured 12 NTU. All other surveyed streams were below 10 units except for the higher elevation site on Strawberry Creek (12 NTU). The mean turbidity for surveyed stream was 5.1 NTU. Four of the streams surveyed with an upper and lower elevation survey site had higher turbidity values at the lower elevation sites. However, Snake and Strawberry Creeks turbidity was higher in the higher elevation sites (Figure 11).

The mean discharge for sampled streams was 1.5 cubic feet per second (cfs). The greatest discharge (14.7 cfs) was measured at Baker Creek in June, and the lowest discharge measurement (0.005 cfs) was taken in Timber Creek in October. Eleven of the 20 sampled streams were measured using a pygmy current meter. Discharge for the other streams was measured by estimating surface velocities, measuring stream width and depth, and calculating a discharge estimate. In semi-arid environments like the Great Basin, stream discharge is extremely dependent on season and the timing of high water from snowmelt. There was a greater variance in discharge in the larger drainages because of increased discharge during spring run-off and also the greater number of tributaries in these streams.

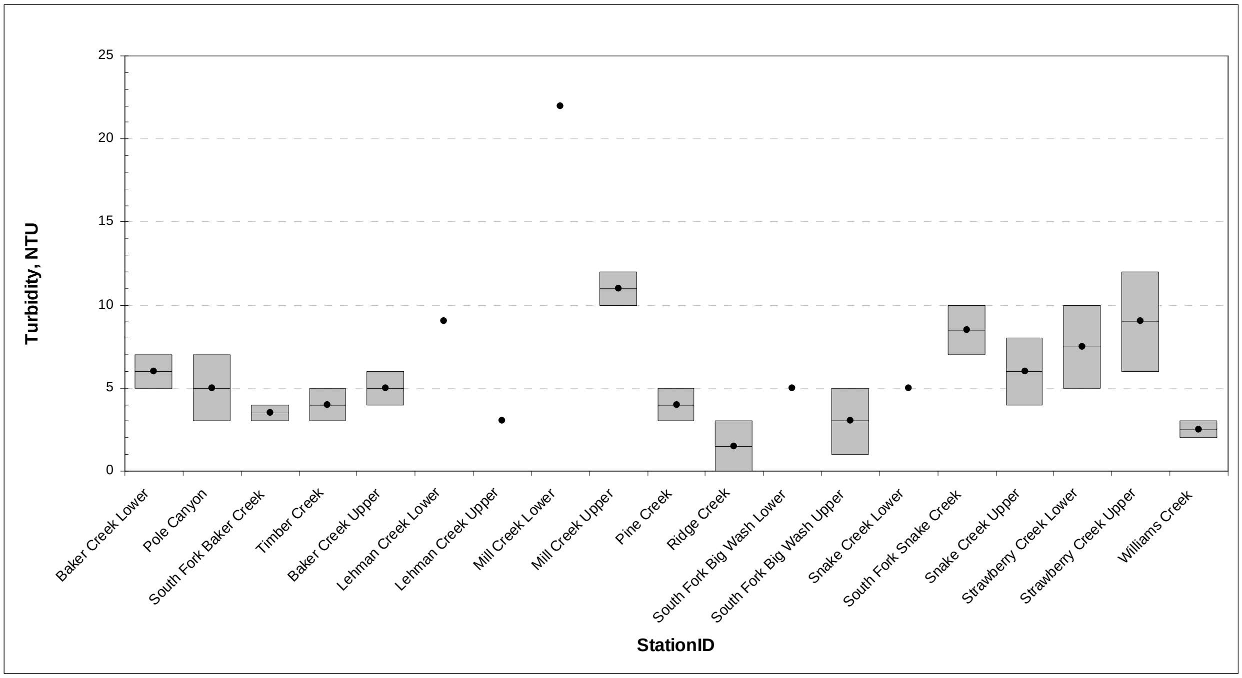


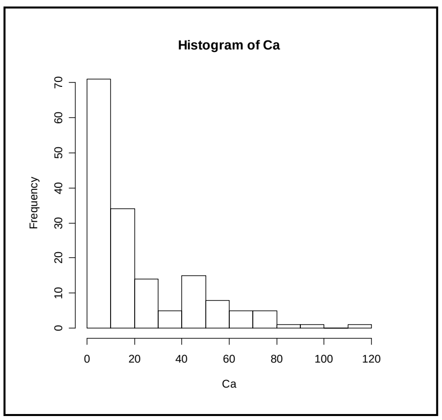
Figure 11. Minimum, maximum, and mean turbidity for sampled park streams, 2006-07.

Results by Parameter

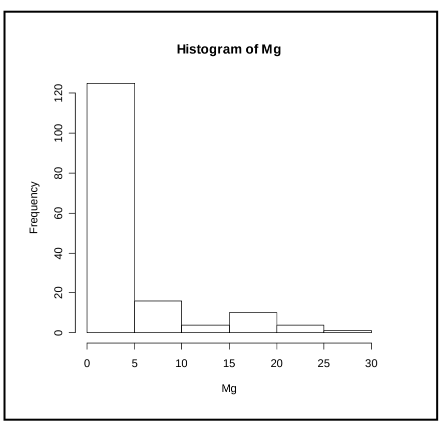
During the project, 186 water samples, including 26 duplicates for quality assessment, were sent to and analyzed by water quality laboratories: Sierra Environmental Monitoring from December to March and Biochem Testing from April through October. We eliminated QA samples from the following analyses.

Distributions of Major and Minor Ions

Frequency distributions show the frequencies of values from water bodies across the park (Figure 12). Central tendency is expressed by the mean and scatter by the standard deviation. Mostly these data are strongly skewed towards smaller values, with many results below the detection limit. Sample locations of maximum values for laboratory water quality parameters are shown in Table 7.

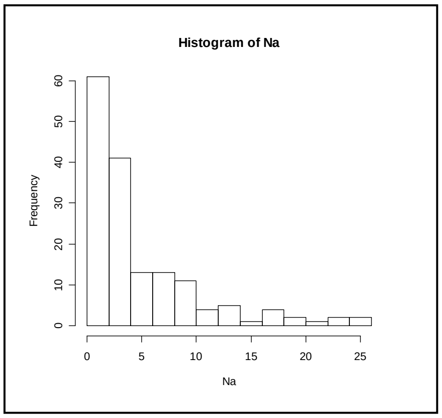


Ca (Calcium)
n = 160
Not Detected = 0
Mean = 21.7 mg/l
Median = 12.5 mg/l
Maximum = 114 mg/l
Standard Deviation = 22.5 mg/l

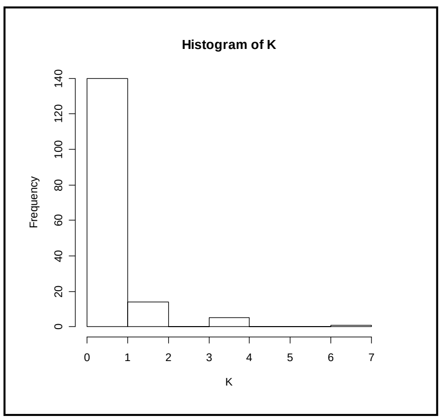


Mg (Magnesium)
n = 160
Not Detected = 0
Mean = 4.4 mg/l
Median = 2.3 mg/l
Maximum = 27.6 mg/l
Standard Deviation = 5.6 mg/l

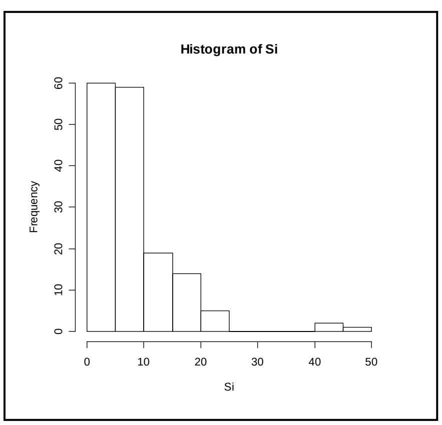
Figure 12. Frequency histograms of major and minor ions found in Great Basin National Park water quality samples, 2007.



Na (Sodium)
n = 160
Not Detected = 10
Mean = 4.9 mg/l
Median = 2.7 mg/l
Maximum = 25.0 mg/l
Standard Deviation 5.4 mg/l

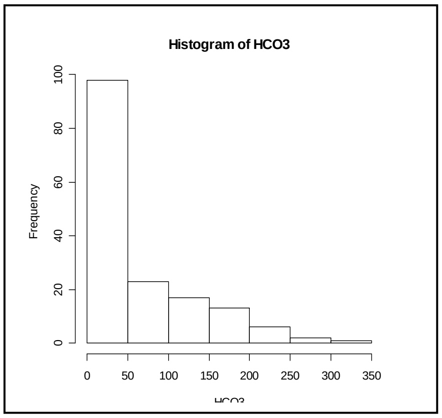


K (Potassium)
n = 160
Not Detected = 86
Mean = 0.5 mg/l
Median = 0 mg/l
Maximum = 6.4 mg/l
Standard Deviation 0.9 mg/l

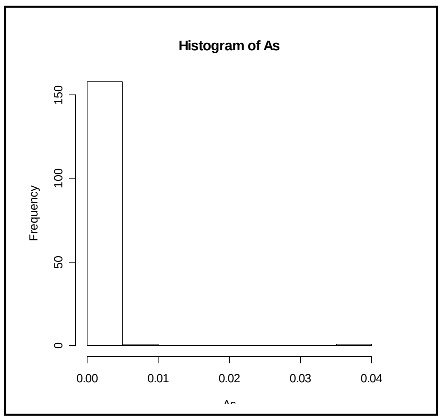


Si (Silicon)
n = 160
Not Detected = 3
Mean = 8.3 mg/l
Median = 6.7 mg/l
Maximum = 48.0 mg/l
Standard Deviation 7.3 = mg/l

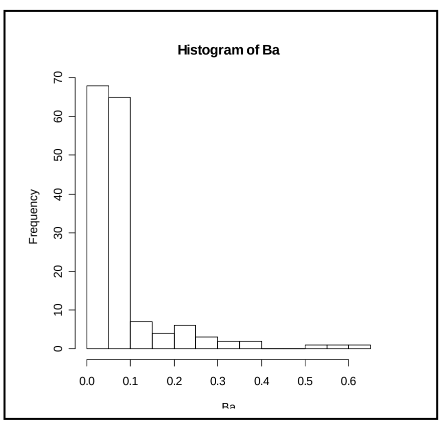
Figure 12 (continued). Frequency histograms of major and minor ions found in Great Basin National Park water quality samples, 2007.



HCO_3 (Bicarbonate)
n = 160
Not Detected = 2
Mean = 65.7 mg/l
Median = 40.3 mg/l
Maximum = 305 mg/l
Standard Deviation 66.7 = mg/l

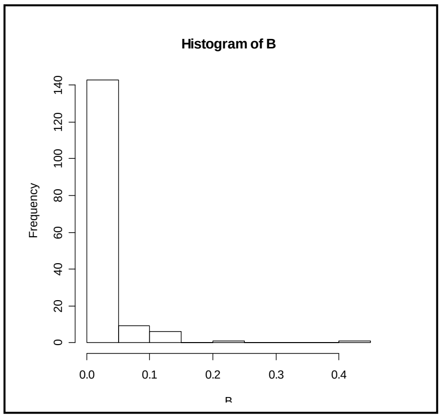


As (Arsenic)
n = 160
Not Detected = 155
Mean = 0.0004 mg/l
Median = 0 mg/l
Maximum 0.04 mg/l
Standard Deviation = 0.003 mg/l

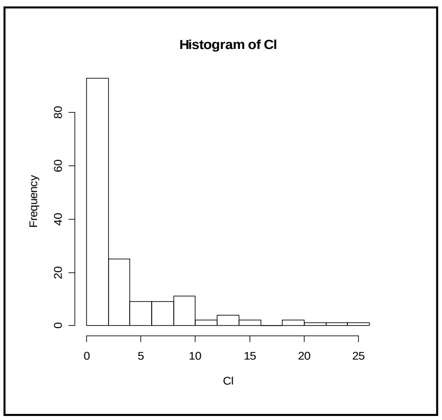


Ba (Barium)
n = 160
Not Detected = 0
Mean = 0.084 mg/l
Median = 0.059 mg/l
Maximum = 0.601 mg/l
Standard Deviation = 0.099 mg/l

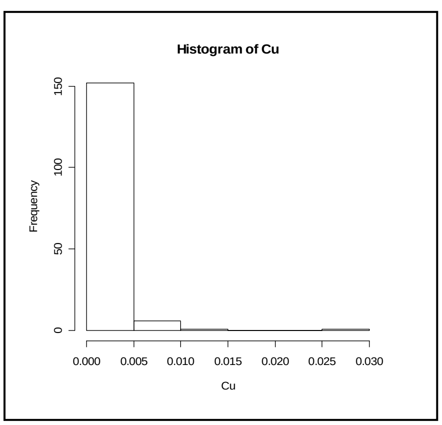
Figure 12 (continued). Frequency histograms of major and minor ions found in Great Basin National Park water quality samples, 2007.



B (Boron)
n = 160
Not Detected = 35
Mean = 0.02 mg/l
Median = 0.008 mg/l
Maximum = 0.45 mg/l
Standard Deviation = 0.05 mg/l

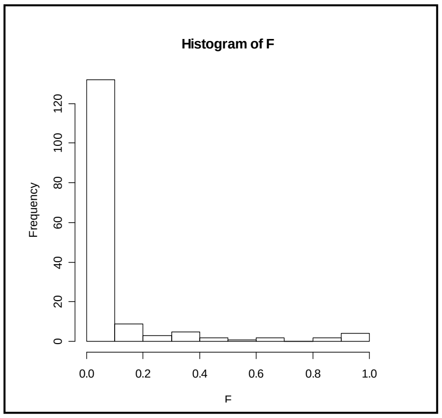


Cl (Chlorides)
n = 160
Not Detected = 46
Mean = 3.6 mg/l
Median = 2 mg/l
Maximum = 25 mg/l
Standard Deviation = 5 mg/l

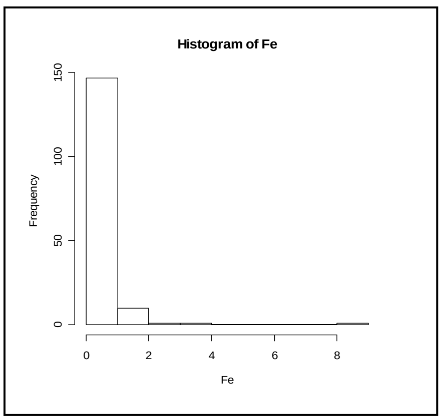


Cu (Copper)
n = 160
Not Detected = 135
Mean = 0.0009 mg/l
Median = 0 mg/l
Maximum = 0.027 mg/l
Standard Deviation = 0.003 mg/l

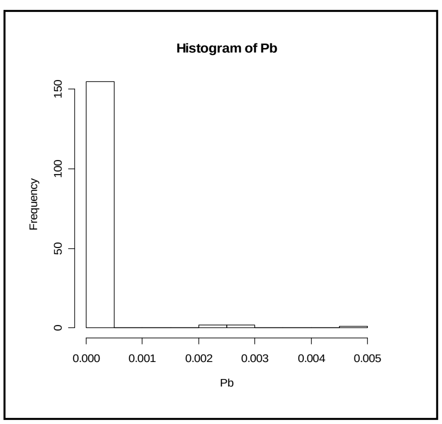
Figure 12 (continued). Frequency histograms of major and minor ions found in Great Basin National Park water quality samples, 2007.



Fl (Fluoride)
n = 160
Not Detected = 120
Mean = 0.1 mg/l
Median = 0 mg/l
Maximum = 1 mg/l
Standard Deviation = 0.2 mg/l

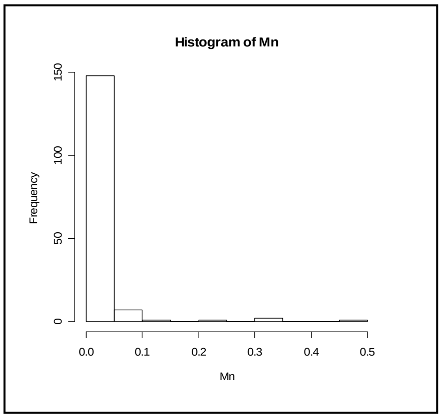


Fe (Iron)
n = 160
Not Detected = 14
Mean = 0.37 mg/l
Median = 0.12 mg/l
Maximum = 8.04 mg/l
Standard Deviation = 0.78 mg/l

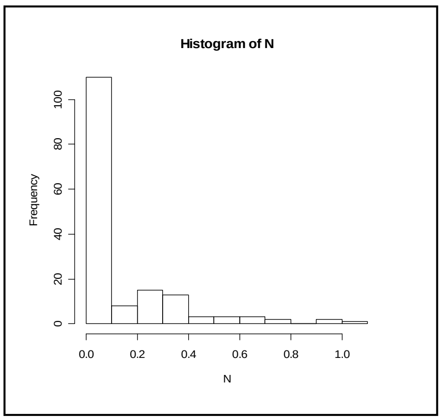


Pb (Lead)
n = 160
Not Detected = 155
Mean = 9.4e-05 mg/l
Median = 0 mg/l
Maximum = 0.005 mg/l
Standard Deviation = 0.0006 mg/l

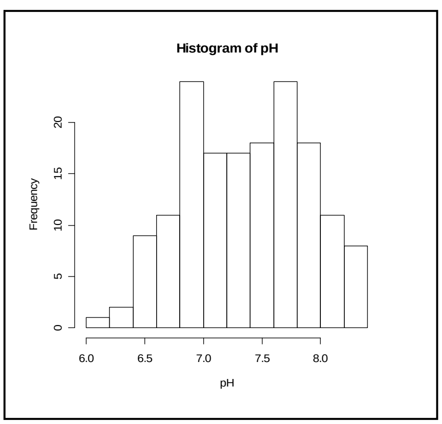
Figure 12 (continued). Frequency histograms of major and minor ions found in Great Basin National Park water quality samples, 2007.



Mn (Manganese)
n = 160
Not Detected = 44
Mean = 0.02 mg/l
Median = 0.006 mg/l
Maximum = 0.48 mg/l
Standard Deviation = 0.057 mg/l

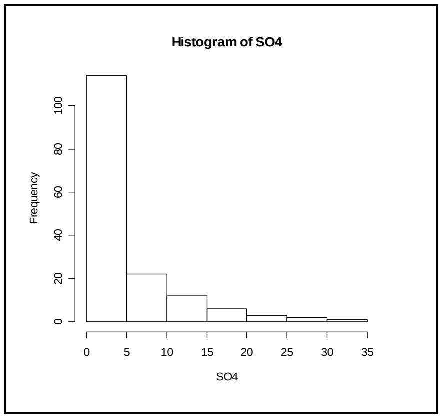


N (Nitrate + Nitrite)
n = 160
Not Detected = 106
Mean = 0.13 mg/l
Median = 0 mg/l
Maximum = 1.1 mg/l
Standard Deviation = 0.23 mg/l

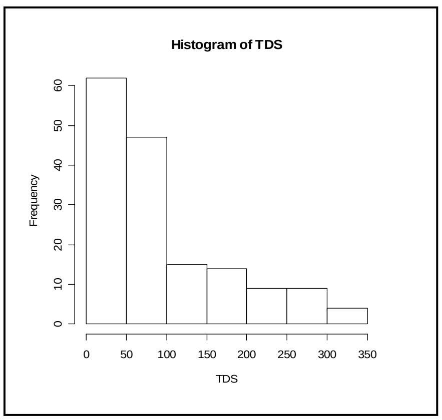


pH
n = 160
Not Detected = 0
Mean = 7.38
Median = 7.39
Maximum = 8.4
Standard Deviation = 0.52

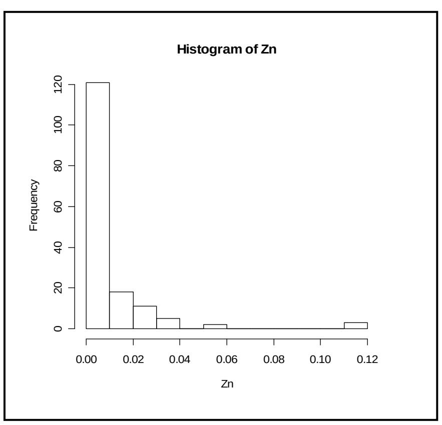
Figure 12 (continued). Frequency histograms of major and minor ions found in Great Basin National Park water quality samples, 2007.



SO4 (Sulfate)
n = 160
Not Detected = 92
Mean = 4.0 mg/l
Median = 0 mg/l
Maximum = 31 mg/l
Standard Deviation = 6.4 mg/l



Total Dissolved Solids
n = 160
Not Detected = 5
Mean = 95 mg/l
Median = 64 mg/l
Maximum = 344 mg/l
Standard Deviation = 84 mg/l



Zn (Zinc)
n = 160
Not Detected = 95
Mean = 0.009 mg/l
Median = 0 mg/l
Maximum = 0.117 mg/l
Standard Deviation = 0.019 mg/l

Figure 12 (continued). Frequency histograms of major and minor ions found in Great Basin National Park water quality samples, 2007.

Table 7. Sample locations of maximum values for laboratory water quality parameters in Great Basin National Park, 2006-07.

Species	Maximum Value	Sample Number and Station	
Ca (Calcium)	114 mg/l	187	DecathonSpring
Mg (Magnesium)	27.6 mg/l	113	Lincoln1
Na (Sodium)	25.0 mg/l	8	Strawberry002
K (Potassium)	6.4 mg/l	187	DecathonSpring
Si (Silicon)	48.0 mg/l	31	LehmanCave
HCO_3 (Bicarbonate)	305 mg/l	187	DecathonSpring
As (Arsenic)	0.04 mg/l	184	CaveSprings2
Ba (Barium)	0.601 mg/l	126	BurntMill
B (Boron)	0.45 mg/l	32	RowlandSpring
Cl (Chlorides)	25 mg/l	33	SquirrelSprings
Cu (Copper)	0.027 mg/l	121	LehmanCave
Fl (Fluoride)	1 mg/l	19, 45	PoleCanyonCreek
Fe (Iron)	8.04 mg/l	184	CaveSprings2
Pb (Lead)	0.005 mg/l	33	SquirrelSprings
Mn (Manganese)	0.48 mg/l	9	Strawberry002
N (Nitrate + Nitrite)	1.1 mg/l	121	LehmanCave
pH highest	8.4	12	LehmanCave
pH lowest	6.15	75	Baker200
SO4 (Sulfate)	31 mg/l	33	SquirrelSprings
Total Dissolved Solids	344 mg/l	63	SquirrelSprings
Zn (Zinc)	0.117 mg/l	165	Straw007

Total Dissolved Solids as a Function of Elevation

Many factors, such as the groundwater component of flow and the nature of geologic material, affect total dissolved solids (TDS), but generally, TDS should be inversely correlated with elevation because precipitation tends to increase with elevation, precipitation has a low TDS, and runoff dissolves solutes with increasing flow distance, thus increasing TDS with decreasing elevation (Figure 13).

Significant variability can be seen in the repeated sampling at some sampling stations (error bars), so to avoid comingling sampling error and temporal variability with spatial variability, the average value at each sampling station is plotted in Figure 13. Higher elevations were somewhat less variable in TDS than the downstream elevations, excluding the two points in the upper right (Decathon 1 and Lincoln 1 [2 samples]). TDS measurements at elevations below about 2500 m could have been more scattered because of increasing anthropogenic influence at lower elevations and increasing variability in flow path. Generally, TDS is weakly correlated with elevation ($r^2 = 0.23$, $p = 0.00004$) by the Spearman rank correlation test.

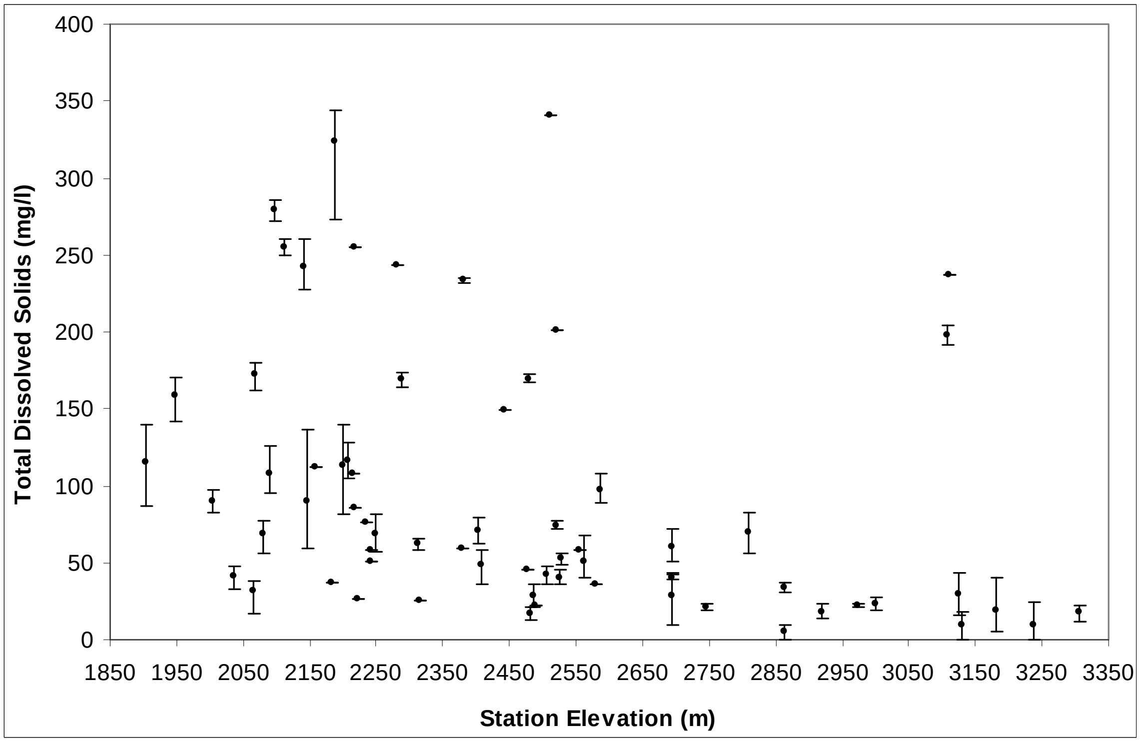


Figure 13. 160 samples of TDS (not including QA samples) from Great Basin National Park, 2006-07.

Correlation between TDS and elevation in the four main watersheds (Baker, Lehman, Snake, and Strawberry) is strongest in Snake ($r^2 = 0.58$, $n = 8$, $p \sim 0.05$) and weakest in Baker ($r^2 = 0.29$, $p = 0.03$).

An approximately linear relationship was also shown spatially (Figure 14) with steep gradients between Dead Lake and Squirrel Springs and up from Lehman Cave.

Categorical Comparisons

Difference between Groundwater and Surface Water

Groundwater is represented by samples from caves and springs while surface water is represented by lakes and streams. Groundwater should be generally higher in concentration of total dissolved solids than surface water.

All species compared in Table 8 showed a significant difference between surface and groundwater. Values of mean and standard deviation are presented for description only as they are not used or compared in the non-parametric Mann-Whitney U test.

Differences between Watersheds

The numbers of samples collected by watershed were: Baker Creek (41), Burnt Mill Canyon (2), Can Young Canyon (5), Decathon Canyon (2), Lehman Creek (39), Lincoln Canyon (2), Mill Creek (6), North Fork Big Wash (1), Pine and Ridge Creek (6), South Fork Big Wash (6),

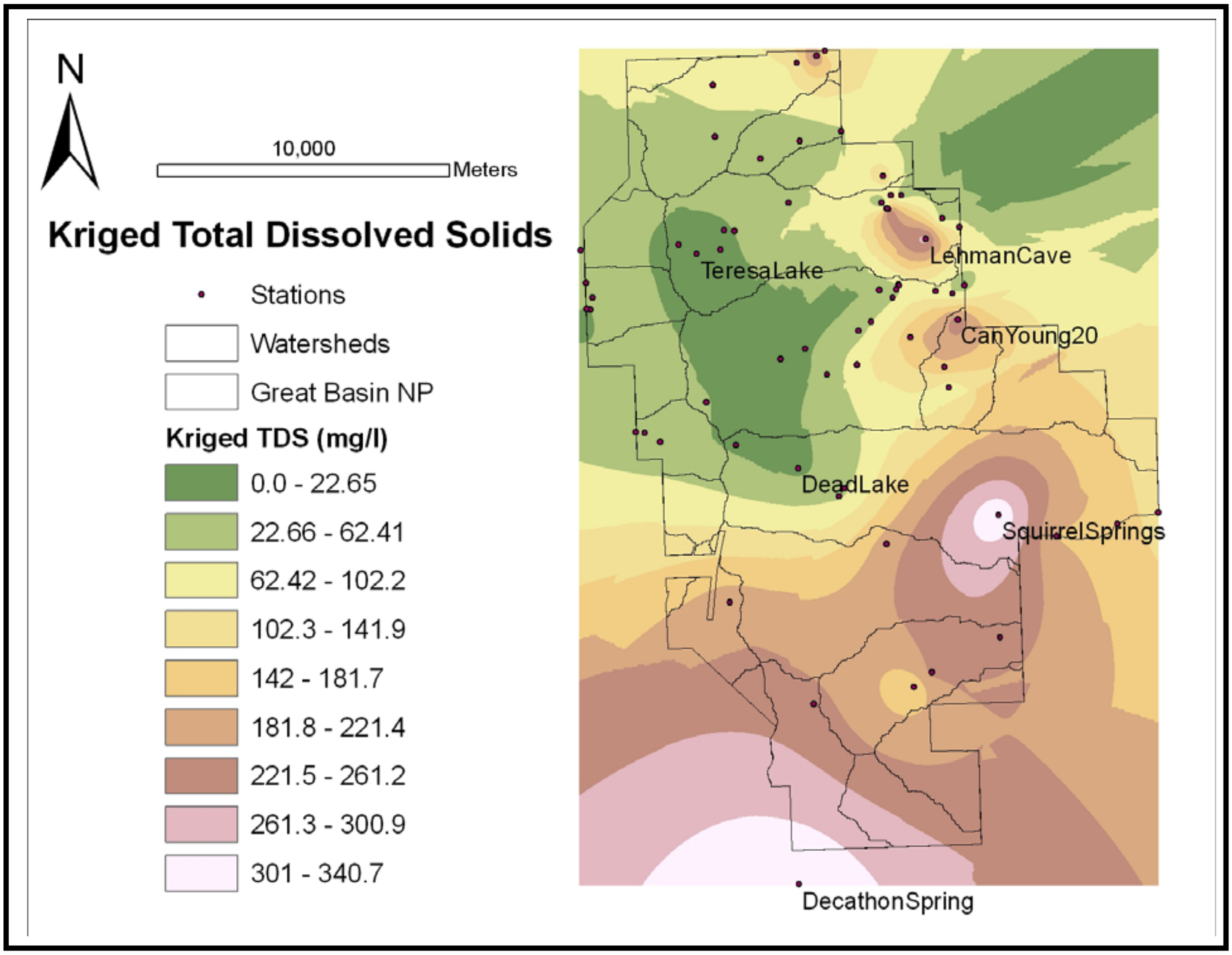


Figure 14. Kriged total dissolved solids from all 186 samples.

Table 8. Surface water groundwater Mann–Whitney U test comparisons of TDS, pH, and major ions.

	Spring and Cave			Stream and Lake			Mann–Whitney U test
Species	Mean	Median	Std dev	Mean	Median	Std dev	p
TDS	125.77	86	91.28	62.61	42	61.88	<.0001
pH	7.52	7.54	0.50	7.23	7.18	0.51	0.0005
HCO3	89.45	65.4	73.45	41.49	20.8	48.56	<.0001
Ca	28.94	19.9	24.59	14.33	6.6	17.51	<.0001
Si	10.09	7.7	8.35	6.54	4.3	5.59	0.0004
N	0.20	0	0.28	0.06	0	0.12	0.0037

Shingle Creek (4), Snake Creek (28), Strawberry Creek (13), and Williams Creek (5). From these numbers of samples, it appeared that comparisons between the Baker Creek, Lehman Creek, Snake Creek, and Strawberry Creek watersheds were possible.

The Kruskal-Wallis test, using an H statistic adjusted for number of ties, for the species shown in Table 9 indicated a significant difference ($\alpha = 0.05$) among all four watersheds except for Na and Si. The Kruskal-Wallis test is appropriate given the non normality of the data. Individual pairwise comparisons were not performed. The median values, however, appeared to indicate more similarities between the Baker and Lehman watershed than the Baker and Snake watersheds, for example.

Table 9. Kruskal-Wallis test comparison of water chemistry for four major watersheds.

Species	Baker median	Lehman median	Snake median	Strawberry median	p
TDS mg/l	58	48	103.5	95	0.0177
Ca mg/l	9.9	8.3	27.6	15.9	0.006
Mg mg/l	1.9	2.0	2.9	3.5	0.0354
Na mg/l	2.7	2.5	5.45	4.3	0.0933
Si mg/l	7.7	5.3	7.8	10.4	0.2793
pH mg/l	7.03	7.21	7.765	7.8	0.0006
N mg/l	0.0	0.0	0.0	0.0	0.031
HCO3 mg/l	25.6	33.5	84.45	66.7	0.006

Differences between Geologic Units

Geologic units were lumped into the six general categories of alluvium (35 stations), moraine (10 stations), metamorphic (9 stations), granite (4 stations), carbonate (9 stations), and shale (no stations) (Figure 15). The numbers of samples, not including QA samples, corresponding to these units were: alluvium (81), moraine (30), metamorphic (19), granite (7), and carbonate (23). The Kruskal-Wallis test, using an H statistic adjusted for number of ties, was used to compare geologic units because of the non normality of the data. Pairwise comparisons were done using the Mann-Whitney U test. All species indicated a significant difference ($\alpha = 0.05$) among all four watersheds (Table 10).

Total dissolved solids were highest in carbonate and lowest in moraine. There was no difference in TDS between granite and alluvium ($p = 0.633$). All other differences were significant at the $\alpha = 0.05$ level.

Calcium was highest in carbonate rocks, as would be expected, and lowest in moraine. There was no difference between alluvium and granite ($p = 0.781$). All other differences were significant at the $\alpha = 0.05$ level.

Magnesium was low in all units and somewhat higher in carbonate rocks, probably from dolomite. There were significant differences between carbonate and all other units. There were also significant differences between alluvium and metamorphic ($p = 0.006$), alluvium and moraine ($p < 0.0001$), granite and moraine ($p = 0.001$), and metamorphic and moraine ($p < 0.0001$). Differences between alluvium and granite and between granite and metamorphic were not significant at the $\alpha = 0.05$ level.

Sodium was comparable in alluvium, carbonate, and granite. Significant differences were found between alluvium and metamorphic ($p = 0.0001$), alluvium and moraine ($p < 0.0001$), carbonate

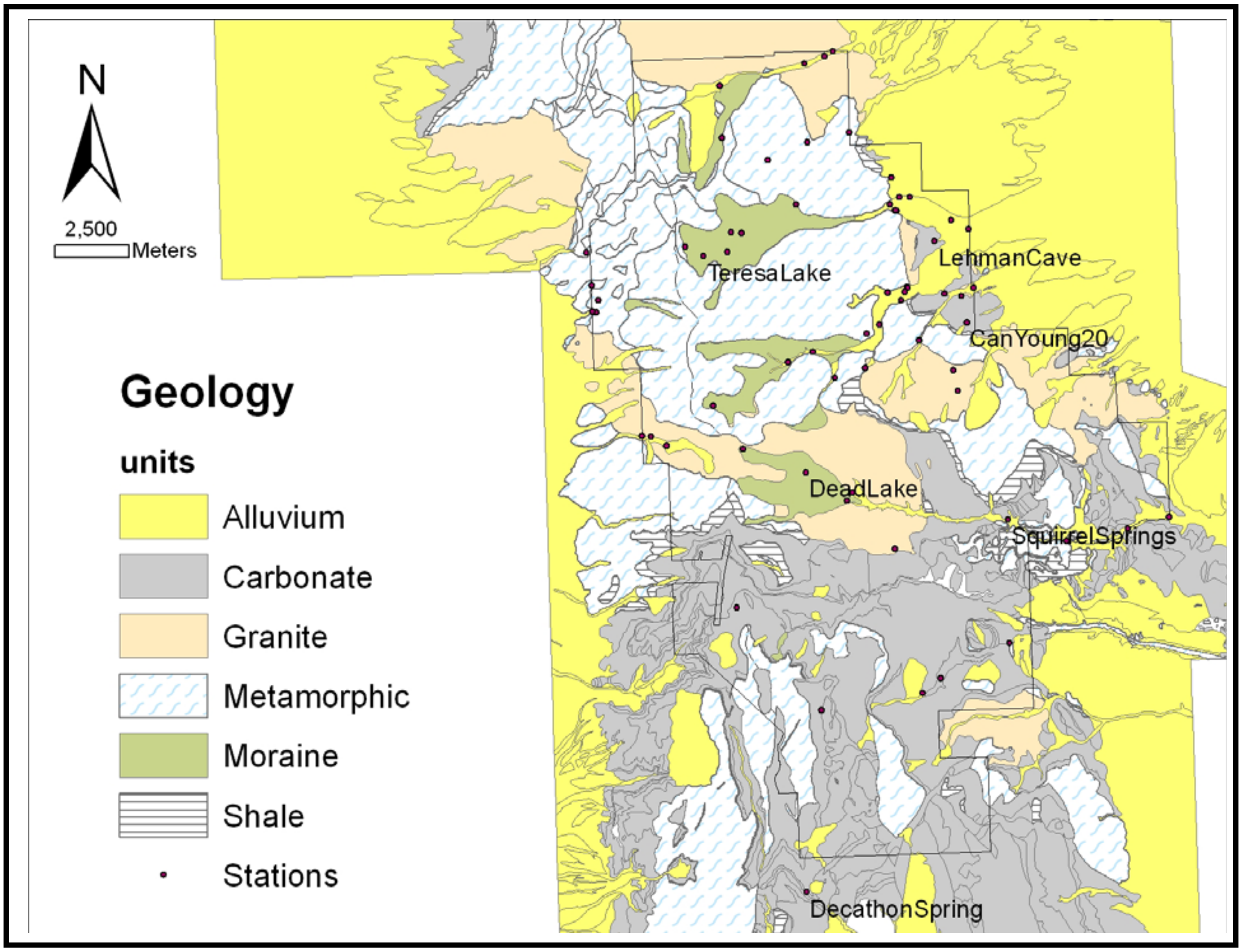


Figure 15. Geologic map of general rock types of Great Basin National Park with sampling sites shown.

Table 10. Kruskal-Wallis test comparison of five geologic units.

Species	Alluvium median	Carbonate median	Granite median	Metamorphic median	Moraine median	p
TDS mg/l	86.0	232	77.0	46.0	21.0	p<0.0001
Ca mg/l	16.8	49.8	16.5	6.0	4.35	p<0.0001
Mg mg/l	3.2	15.0	2.2	1.8	0.6	p<0.0001
Na mg/l	5.2	3.0	4.1	1.8	0.75	p<0.0001
Si mg/l	8.6	7.3	7.8	6.0	1.75	p<0.0001
pH mg/l	7.53	7.80	7.53	7.18	6.86	p<0.0001
N mg/l	0.0	0.3	0.0	0.0	0.0	0.0019
HCO3 mg/l	52.2	184.0	46.5	20.8	13.3	p<0.0001

and metamorphic ($p = 0.002$), carbonate and moraine ($p < 0.0001$), granite and moraine ($p = 0.0007$), and between metamorphic and moraine ($p < 0.0001$).

Silica was fairly uniform in alluvium, carbonate, and granite. Significant differences occurred between alluvium and metamorphic ($p = 0.012$), alluvium and moraine ($p < 0.0001$), carbonate and moraine ($p < 0.0001$), granite and moraine ($p = 0.002$), and between metamorphic and moraine ($p < 0.0001$).

Values of pH were lowest in moraine and highest in carbonate. Significant differences occurred between alluvium and carbonate ($p = 0.019$), alluvium and metamorphic ($p = 0.012$), alluvium and moraine ($p < 0.0001$), carbonate and metamorphic ($p < 0.0001$), carbonate and moraine ($p < 0.0001$), granite and metamorphic ($p = 0.037$), granite and moraine ($p = 0.009$), and between metamorphic and moraine ($p = 0.03$).

Nitrate plus nitrite was highest in carbonate and low in the other units. Significant differences existed between alluvium and carbonate ($p = 0.003$), carbonate and granite ($p = 0.046$), carbonate and metamorphic ($p = 0.004$), and carbonate and moraine ($p = 0.001$). There were no other significant differences at the $\alpha = 0.05$ level.

Bicarbonate was highest in carbonate terrain, as would be expected. The value of 211 mg/l in sample number 169 collected at Lehman 52 seemed anomalously high for moraine. The station was near a contact with metamorphic rock. But sample number 20, also collected at Lehman 52, came in at 34 mg/l, so perhaps sample 169 is simply an outlier. Significance differences occurred between alluvium and carbonate ($p = 0.0001$), alluvium and metamorphic ($p = 0.001$), alluvium and moraine ($p < 0.0001$), carbonate and granite ($p = 0.029$), carbonate and metamorphic ($p < 0.0001$), carbonate and moraine ($p < 0.0001$), granite and moraine ($p = 0.003$), and between metamorphic and moraine ($p = 0.003$).

In general, concentrations tended to be highest in carbonate units and lowest in moraine units.

Piper Diagrams and Types of Waters

Piper diagrams show the percent proportions of cations in the lower left triangle and anions in the lower right corner in units of percent meq/l. Because there were no anions detected in samples 74 and 75 from Baker Lake and Baker 200, this plot is undefined for those two samples. As shown in Figure 16, the cations in the lower left triangle are Ca, Mg, and Na combined with K. Anions plotted in the lower right triangle are bicarbonate plus carbonate, sulfate, and chloride. These plots are then projected upwards to their intersection on the upper diamond. On the upper diamond the apex represents a solution rich in Ca and Mg, Cl and sulfate while the bottom vertex is an accumulation of carbonates plus Na and K. Each vertex represents 100% of the indicated species.

Not surprisingly, the results showed calcium carbonate waters in GRBA typical of limestone karst. There was a hint of Mg, probably from dolomite or Mg-calcite, but many samples showed undetectable Na and K. Only a few sampling stations (e.g., Squirrel Springs, Strawberry 002, and Lehman Cave) had much sulfate. Sample 172 from SFBW Upper had the greatest relative proportion of sulfate anion. From this we concluded that all sampled waters in GRBA were generally of the same type in contact with carbonate rocks, primarily limestone.

Silica Saturation

Dissolution of quartz proceeds as represented by the reaction $Si0_2 + 2H_2O \rightarrow H_4SiO_4$ with an equilibrium constant of $1x10^{-4}$ (Drever 1988). Dissolved silica in these chemical analyses is given as mg/l Si. A mole of Si is equivalent to a mole of H_4SiO_4, and activity coefficients are assumed to be unity. Thus, any activity of Si above $1x10^{-4}$ is supersaturated with respect to quartz. At a pH above about 8, however, H_4SiO_4 disassociates into two ionized species, and the total dissolved silica concentration is the sum of the ionized and un-ionized species (Drever 1988). Thus, solubility of quartz increases sharply above a pH of about 9.

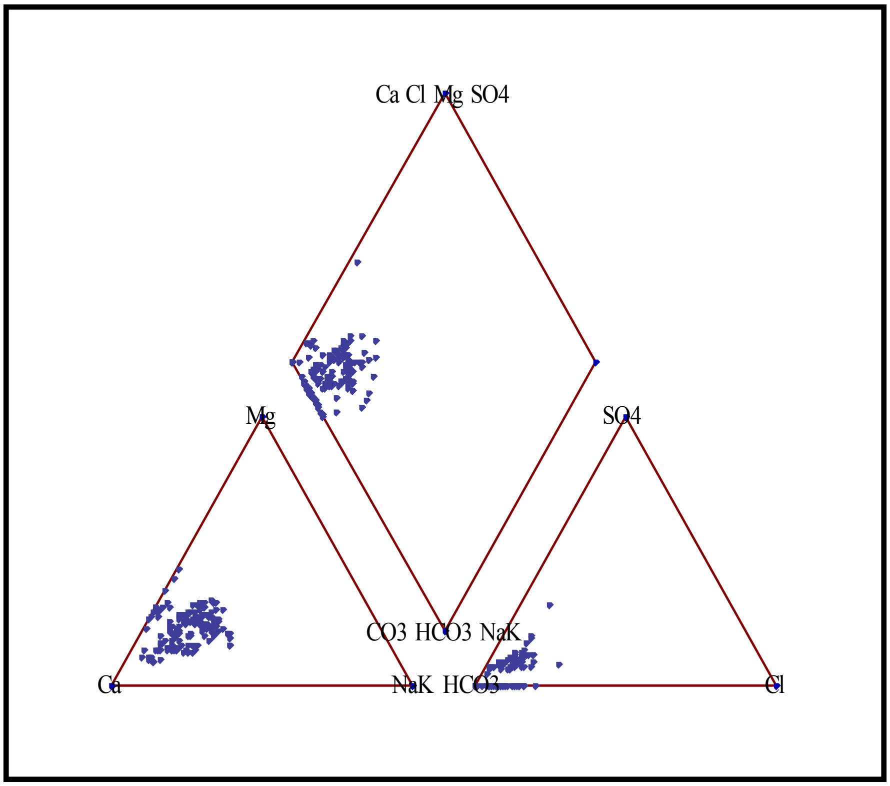


Figure 16. Piper diagram of 158 samples.

In order to avoid confounding spatial and temporal variability and error, samples were averaged over time at stations where multiple samples were collected (Figure 17). Three samples (numbers 109 and 120 from Stella Lake and 118 from Brown Lake) had no detectable Si, but the averages at these sites were greater than zero. Of the 157 non QA samples with Si values above the detection limit, 110 were basic (pH > 7). Theoretically, we expected to see an increase in dissolved Si with increasing pH, and in fact, dissolved log molal silica was correlated with pH (r^2=0.29, $p < 0.0001$). A group of samples (e.g., numbers 65 South Fork Snake Creek, 148 Dead Lake, 103 Stella Lake, and 67 Brown Lake) were undersaturated with respect to Si. Otherwise, the scatter in these data was probably error as indicated by Appendix C.

Alkalinity

Alkalinity in these waters is the sum of bicarbonate plus hydroxide minus hydrogen since carbonate is essentially zero (Domenico and Schwartz 1990). Thus, alkalinity in the data should have been proportional to bicarbonate plus the constant sum of hydrogen ion plus hydroxide. The

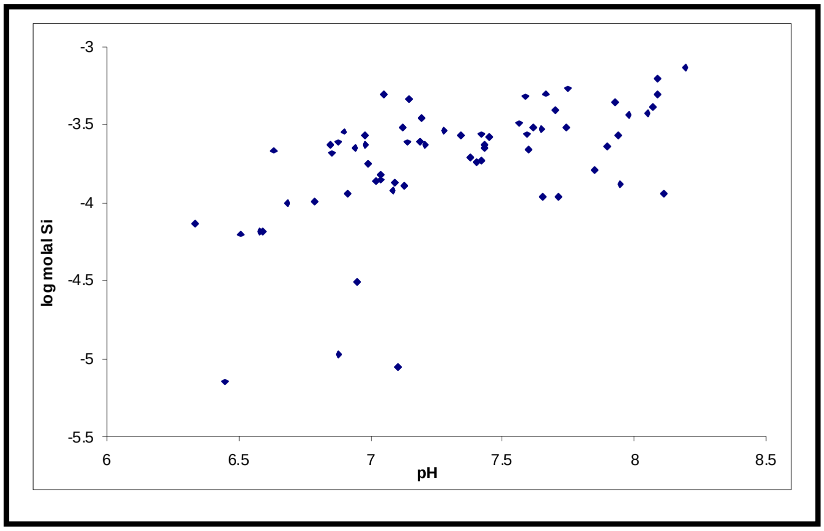


Figure 17. Dissolved Si plotted as a function of pH.

one to one correlation between alkalinity and the bicarbonate ion was found to be $r^2 = 0.9999$, ($p<0.0001$) (Figure 18a).

As pH increases, so should bicarbonate. Below a pH of about 7, carbonic acid forms and bicarbonate drops off. The relationship appeared curvilinear with increasing scatter at higher pH ($r^2 = 0.82$, $p<0.0001$) (Figure 18b).

Samples were averaged over time at stations where multiple samples were collected.

Anthropogenic Impact

As shown in the Piper diagram (Figure 16), waters at Great Basin National Park are pristine, composed primarily of calcium and bicarbonate with some magnesium, likely from Mg-calcite or dolomite. In this environment, nitrate, sulfur, chloride, potassium, and sodium are derived mostly from human activity. Here we look at the top ten sampling stations ranked in terms of these species (Table 11).

Notably, Squirrel Springs, Lehman Cave, and Can Young 20 appeared on the top ten list for all six anthropogenic indicators. These stations were also three of the four high points in TDS (Figure 14). Despite this, even the highest in nitrite plus nitrate concentration, found in Lehman Cave, met drinking water standards (10 mg/l) by almost a factor of ten.

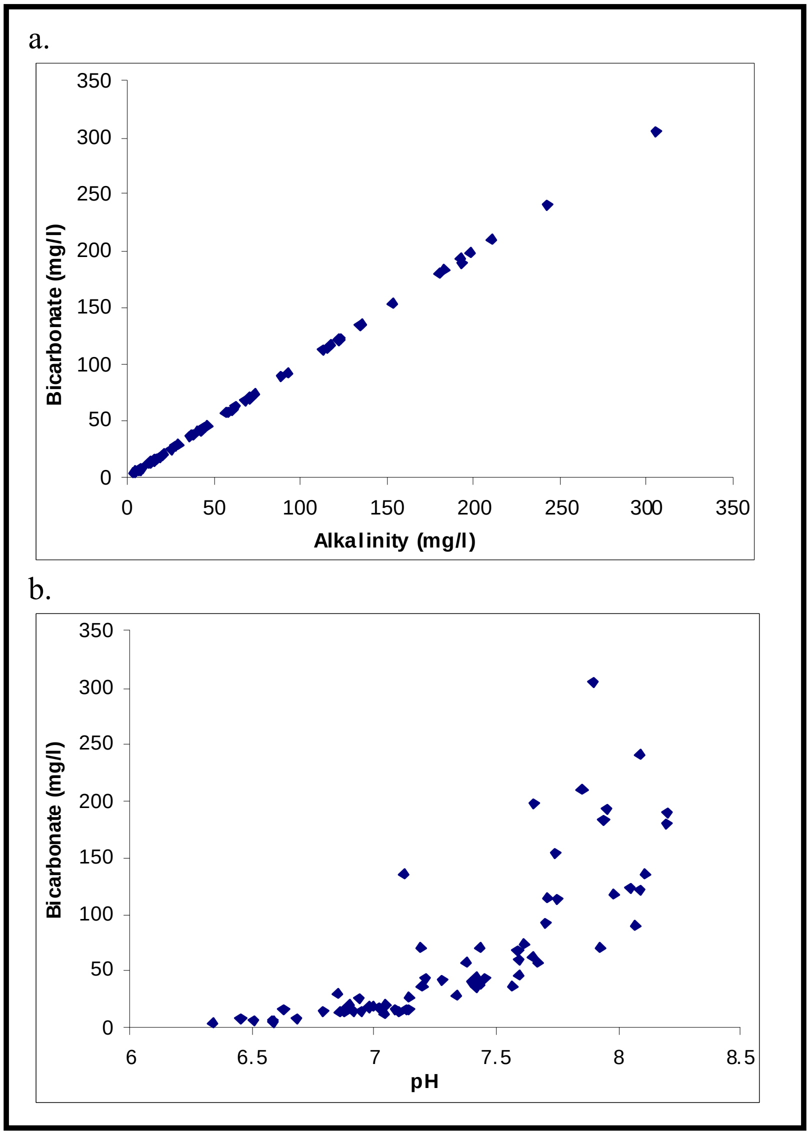


Figure 18a. Bicarbonate in relationship with alkalinity for park water bodies, 2006-07.
Figure 18b. Bicarbonate in relationship with pH for park water bodies, 2006-07.

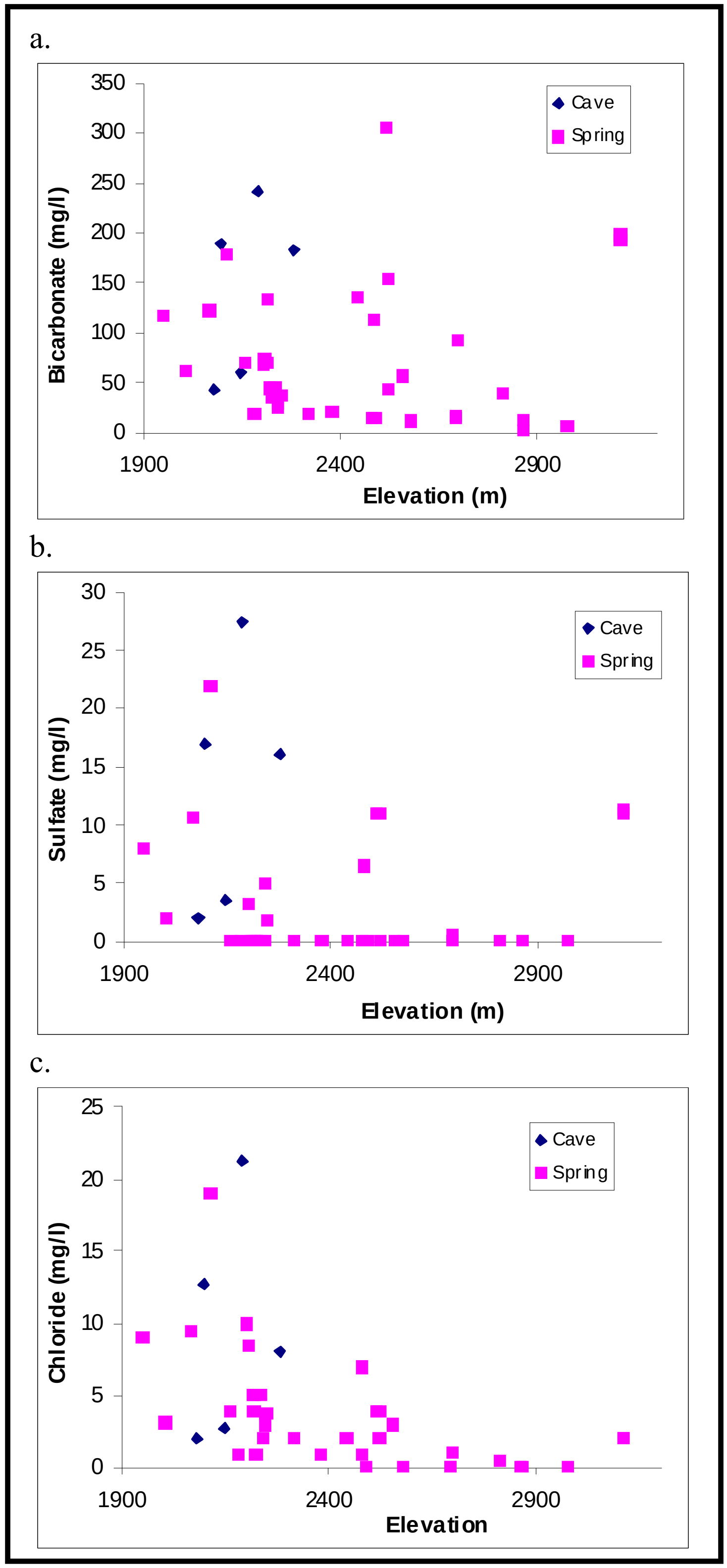
Table 11. Top ten sampling stations ranked in order of likely anthropogenic species.

Na (mg/l)		K (mg/l)		NO2+NO3 (mg/l)		SO4 (mg/l)		Cl (mg/l)	
Strawberry002	25	DecathonSpring	6.4	LehmanCave	1.1	SquirrelSprings	31	SquirrelSprings	25
SquirrelSprings	23	LehmanCave	3.7	SquirrelSprings	0.7	Strawberry002	22	Strawberry002	19
LehmanCave	19	SquirrelSprings	1.9	CanYoung20	0.7	LehmanCave	18	Lehman004	16
PoleCanyonCreek	14.7	NFBW6	1.7	Baker94	0.7	CanYoung20	16	LehmanCave	13
CanYoung17	14	CanYoung20	1.4	Lehman25	0.6	SFBWLower	13	OuthouseSpring	11
CanYoung20	11.9	BrownLake	1.3	WheelersDeep	0.5	Lincoln1	13	OutletSpring	10
Lehman004	11	OutletSpring	1.2	BakerUpper	0.5	SFBWUpper	12	PoleCanyonCreek	9
BurntMill	10.3	BurntMill	1.1	TeresaLake	0.5	DecathonSpring	11	BurntMill	9
NFBW6	10.1	LehmanCreekLower	1	CaveSprings	0.4	NFBW6	11	CanYoung20	8
OutletSpring	10	ModelCave	0.9	Baker136	0.4	OutletSpring	11	SnakeCreekLower	7

Chebotarev Sequence

Groundwater tends to evolve chemically with residence time in an aquifer. Farther upgradient waters tend to be rich in bicarbonate, grading to sulfate and then to chlorides downgradient. This evolution is known as the Chebotarev sequence (Chebotarev 1955). Not knowing the flow path lengths of the individual packets of water sampled for these analyses, we hypothesize that it might be correlated with elevation. If this is true, we would expect bicarbonate results to decrease with elevation from sampled springs while sulfate and chloride increase. To make this calculation, we ignored all QA samples and selected only samples collected from caves and springs. Samples were averaged over time at stations where multiple samples were collected.

Bicarbonate appeared to decrease with elevation in the cave samples (r^2= 0.25, n = 5, n.s.) but was not significantly correlated either in the samples of caves or in samples of springs (r^2= 0.07, p= 0.12) (Figure 19a). Both sulfate and chloride were weakly, but not significantly, correlated with elevation in the cave samples: (sulfate r^2= 0.25, n = 5, n.s.) and (chloride r^2= 0.25, n = 5, n.s.) (Figures 19b and 19c). Finally, although both sulfate and chloride appeared to generally increase with decreasing elevation (presumed flow path length) in the sampled springs, the correlation was significant for chloride (r^2= 0.47, $p < 0.0001$) but not for sulfate (r^2= 0.01, p = 0.57). In summary, there appeared to be little support for a Chebotarev type model of anion evolution along an elevational



Figures 19a.-c. Bicarbonate, sulfate, and chloride evolution along an elevational gradient.

gradient for either the cave or spring samples. Chloride in sampled springs was the only element of the Chebotarev sequence that increased significantly with decreasing elevation.

EPA Water Quality Criteria

Three metals, iron (Fe), manganese (Mg), and copper (Cu), were the only characters to exceed EPA criteria for drinking or fresh water aquatic life in the samples collected (Tables 12a-d). All other analyzed characters were within the EPA standards for fresh water aquatic life or drinking water.

Tables 12 a-d. Characters above EPA standards for drinking water or fresh water aquatic life from surveyed lakes (a), springs (b), caves (c), and streams (d). Limits for iron (Fe) are based on criteria for fresh water aquatic life, and limits for manganese (Mn) are based on criteria for drinking water (* EPA standard for fresh water aquatic life, ** EPA standard for drinking water).

a.

Characteristic	Sample Site	Sample Date	EPA Standard Value (mg/l)	Recorded Lab Value (mg/l)
Iron (Fe)*				
	Teresa Lake	9/13/2007	0.3	0.4

b.

Characteristic	Sample Site	Sample Date(s)	EPA Standard Value (mg/l)	Recorded Lab Value (mg/l)
Iron (Fe)*				
	Marmot Spring	6/14/2007	0.3	0.88
	Marmot Spring	6/14/2007	0.3	0.93
	Baker057	10/9/2007	0.3	0.75
	Baker059	10/9/2007	0.3	0.33
	Baker094	10/9/2007	0.3	0.52
	Baker130	10/2/2007	0.3	3.82
	Baker130	10/2/2007	0.3	1.53
	Baker137	10/2/2007	0.3	0.62
	Baker137	10/2/2007	0.3	0.58
	Burnt Mill Spring	6/14/2007	0.3	0.35
	Burnt Mill Spring	9/11/2007	0.3	0.54
	Can Young009	6/6/2007	0.3	0.44
	Can Young009	6/6/2007	0.3	0.43
	Can Young017	6/6/2007	0.3	1.16
	Lincoln001	9/4/2007	0.3	1.2
	Mill003	6/12/2007	0.3	0.84
	Mill003	6/12/2007	0.3	0.82
	Mill003	9/5/2007	0.3	0.58
	Outlet Spring (Snake)	12/4/2006	0.3	0.34
	Outlet Spring (Snake)	3/6/2007	0.3	0.35
	Outlet Spring (Snake)	3/6/2007	0.3	0.49
	Outlet Spring (Snake)	9/20/2007	0.3	0.47
	Decathon001	10/25/2007	0.3	0.77
	Decathon Spring	10/25/2007	0.3	0.54
	Lehman004	12/5/2006	0.3	0.51
	Lehman004	12/5/2006	0.3	0.50

Characteristic	Sample Site	Sample Date(s)	EPA Standard Value (mg/l)	Recorded Lab Value (mg/l)
	ehman004	6/5/2007	0.3	0.31
	Lehman004	9/5/2007	0.3	0.85
	Lehman006	10/1/2007	0.3	1.41
	Lehman013	10/1/2007	0.3	0.46
	Lehman013	10/1/2007	0.3	0.46
	Lehman052	12/11/2006	0.3	0.42
	Lehman052	6/5/2007	0.3	0.51
	Lehman052	10/2/2007	0.3	0.83
	Strawberry002	12/4/2006	0.3	1.6
	Strawberry002	12/4/2006	0.3	2.6
	Strawberry007	10/2/2007	0.3	0.48
Manganese (Mn)**				
	Baker130	10/2/2007	0.05	0.212
	Decathon Spring	10/25/2007	0.05	0.066
	Lehman006	10/1/2007	0.05	0.064
	Strawberry002	12/4/2007	0.05	0.48
	Strawberry002	12/4/2007	0.05	0.35

c.

Characteristic	Sample Site	Sample Date	EPA Standard Value (mg/l)	Recorded Lab Value (mg/l)
Copper (Cu)*				
	Lehman Caves	9/6/2007	0.013	0.027
Iron (Fe)*				
	Lehman Caves	9/6/2007	0.3	0.78
	Model Cave	3/13/2007	0.3	0.59
	Model Cave	9/24/2007	0.3	0.98
	Squirrel Springs Cave	9/24/2007	0.3	0.74
	Wheeler's Deep Cave	9/20/2007	0.3	1.48

d.

Characteristic	Sample Site	Sample Date	EPA Standard Value (mg/l)	Recorded Lab Value (mg/l)
Iron (Fe)*				
	Baker Creek Lower	9/11/2007	0.3	0.34
	Baker Creek Upper	10/10/2007	0.3	1.09
	Lehman Creek Lower	6/5/2007	0.3	1.01
	Mill Creek Lower	6/18/2007	0.3	1.54
	Mill Creek Lower	10/23/2007	0.3	0.81
	Mill Creek Upper	6/7/2007	0.3	1.06
	Mill Creek Upper	10/3/2007	0.3	0.58
	Strawberry Creek Lower	9/17/2007	0.3	1.12
	Strawberry Creek Upper	12/4/2006	0.3	0.95
	Timber Creek	10/2/2007	0.3	0.4
Manganese (Mn)**				
	Mill Creek Lower	6/18/2007	0.05	0.088
	Strawberry Creek Lower	9/17/2007	0.05	0.106
	Strawberry Creek Upper	12/4/2006	0.05	0.084

Macroinvertebrates

Six lakes, seven springs, one cave, and fifteen stream locations were sampled from July 30 to September 26, 2007. A total of 157 taxa were found, with the orders Diptera, Ephemeroptera, and Coleoptera most prevalent (Table 13). Chironomids of the subfamily Orthocladiinae made up 30 percent of the overall samples collected and were found in all samples except four. The top ten most abundant taxa accounted for 63.8 percent of the taxa collected. Sixty-seven taxa had a relative abundance of less than 0.1 percent.

Table 13. Ten most abundant macroinvertebrate taxa found in Great Basin National Park, 2007.

Order	Family	Subfamily	Genus	Total	Relative abundance (percent)
Diptera	Chironomidae	Orthocladiinae		8770.98	30.0
Ephemeroptera	Baetidae		*Baetis*	1441.28	4.9
Diptera	Chironomidae	Chironominae		1438.42	4.9
Coleoptera	Elmidae		*Heterlimnius*	1355.87	4.6
Trichoptera	Rhyacophilidae		*Rhyacophila*	1218.63	4.2
Plecoptera	Nemouridae		*Zapada*	1196.60	4.1
Trichoptera	Lepidostomatidae		*Lepidostoma*	929.68	3.2
Ephemeroptera	Heptageniidae		*Cinygmula*	872.92	3.0
Ephemeroptera	Heptageniidae		*Epeorus*	738.13	2.5
Plecoptera	Perlidae		*Hesperoperla*	703.49	2.4

Increased complexity of the aquatic system resulted in higher abundance and richness. The cave sampled only had one family present, while lakes on average had six, springs ten, and streams 19 (Table 14). Sites were grouped into elevational categories of lower (1,900-2,200 m/6,244-7,200 ft), middle (2,200-2,500 m/7,200-8,200 ft), and upper (>2,500 m/>8,200 ft). Elevational changes had no noticeable effects on abundance or richness (Table 15).

Table 14. Comparison of common macroinvertebrate indices among types of water bodies for Great Basin National Park, 2007.

Name	# sites	Abundance	EPTA	EPTT	RICH	Families	H'
Cave	1	20	3	1	3	1	0.975
Lakes	6	287	7	1	10	6	1.424
Springs	7	843	114	5	13	10	1.488
Stream	15	744	415	16	28	19	2.406

EPTA= EPT abundance; EPTT= EPT taxa (richness); RICH=richness; H'=Shannon Diversity Index.

Table 15. Comparison of common macroinvertebrate indices by elevation for Great Basin National Park samples, 2007.

Elevation	Abundance	EPTA	EPTT	RICH	Families	H'
Lower	525	321	12	21	16	1.867
Middle	525	321	12	21	16	1.867
Upper	523	288	14	25	18	2.113

EPTA= EPT abundance; EPTT= EPT taxa (richness); RICH=richness; H'=Shannon Diversity Index.

Just one cave was sampled because only one of the four baseline sites had running water. The cave had an overall abundance of 20, EPT abundance of 3, EPT richness of 1, Overall Richness of 3, 1 Family, and Shannon Diversity index score of 0.975. Only three taxa were present: Annelida (Citellata-oligochaeta), Plecoptera (Chloroperlidae-Swetsa), and Platyhelinthes (Turbellaria).

Of the lakes, highest taxa abundance was in Johnson and Brown lakes, followed by Stella Lake (Table 16). While Johnson Lake also had the highest EPT abundance, Stella Lake had no EPT taxa, and Teresa Lake had 17. Family richness was highest in Brown Lake with eight families, followed by Stella and Johnson lakes. The observed differences in richness parameters may not have been significantly different among lakes, given the sampling variability typical observed among benthic invertebrate samples

Table 16. Common macroinvertebrate indices for lakes in Great Basin National Park, 2007.

Lake name	Sampdate	Abundance	EPTA	EPTT	RICH	Families	H'
Baker	9/12/2007	126	1	1	8	5	0.976
Brown	9/6/2007	166	1	1	13	8	1.750
Dead	9/24/2007	144	0	0	10	6	0.971
Johnson	7/30/2007	916	23	2	13	7	1.611
Stella	9/6/2007	257	0	0	10	7	1.839
Teresa	9/6/2007	113	17	2	7	5	1.398
Average		287	7	1	10	6	1.424

EPTA= EPT abundance; EPTT= EPT taxa (richness); RICH=richness; H'=Shannon Diversity Index.

For springs, Rowland, Pipeline Outlet, and Lehman004 had the highest overall macroinvertebrate abundances, all greater than 200 (Table 17). EPT abundance in multiple habitat samples was nearly ten times higher in Rowland and Outhouse springs than in the other springs. Outhouse and Pipeline Outlet springs had the highest richness, each with 14 families, most likely due to the underlying carbonate rocks. Springs in the Lehman watershed had the fewest number of families, from six to nine.

Streams had both qualitative and quantitative surveys done. The quantitative surveys in the riffles generally had greater abundance and richness than in the qualitative surveys. EPT abundance and richness were high in all the streams (Table 18). Overall and EPT taxa abundance was especially high in Upper Baker and Ridge creeks, but the sites with the highest richness were Lower Baker, Lower Lehman, Shingle, and Upper Strawberry creeks.

Table 17. Common macroinvertebrate indices for selected springs in Great Basin National Park, 2007.

Spring name	Sampdate	Habitat	Area	Abun-dance	EPTA	EPTT	RICH	Families	H'
Lehman 25	9/19/2007	Multiple	1.000	98	11	4	8	6	0.659
Lehman 004	8/30/2007	Multiple	1.000	233	3	3	10	8	0.721
Rowland	8/30/2007	Multiple	1.000	272	179	5	10	10	1.553
Burnt Mill	9/11/2007	Multiple	1.000	100	19	5	16	12	1.874
Outhouse	8/21/2007	Multiple	1.000	191	146	8	17	14	1.991
Pipeline Outlet	8/21/2007	Multiple	1.000	254	27	6	20	14	2.391
Average				843	114	5	13	10	1.488

EPTA= EPT abundance; EPTT= EPT taxa (richness); RICH=richness; H'=Shannon Diversity Index.

Table 18. Common macroinvertebrate indices for selected stream sites in Great Basin National Park, 2007.

Creek name	Sampdate	Habitat	Area	Abun-dance	EPTA	EPTT	RICH	Families	H'
Baker - Upper	9/19/2007	Riffle	0.744	3353	2719	16	23	16	2.500
Baker - Upper	9/19/2007	Multiple	1.000	263	180	14	22	17	2.410
Baker - Lower	9/11/2007	Riffle	0.744	767	511	27	47	26	2.971
Baker - Lower	9/11/2007	Multiple	1.000	134	52	12	24	16	2.252
Lehman-Upper	9/19/2007	Riffle	0.744	742	507	16	25	17	2.547
Lehman-Upper	9/19/2007	Multiple	1.000	306	242	10	18	13	1.897
Lehman-Lower	8/30/2007	Riffle	0.744	1536	605	27	43	24	2.372
Lehman-Lower	8/30/2007	Multiple	1.000	180	146	12	22	15	2.465
Mill	8/23/2007	Riffle	0.744	495	441	24	35	23	2.820
Mill	8/23/2007	Multiple	1.000	229	204	14	24	22	2.633
Mill at Pk Bdy	8/30/2007	Riffle	0.744	509	151	18	35	23	2.613
Mill at Pk Bdy	8/23/2007	Multiple	1.000	91	46	12	27	20	2.772
Pine	9/26/2007	Riffle	0.744	368	171	17	27	20	2.118
Pine	9/26/2007	Multiple	1.000	178	138	15	21	18	2.331
Ridge	9/26/2007	Riffle	0.744	3941	2086	22	37	28	2.580
Ridge	9/26/2007	Multiple	1.000	293	252	16	26	20	2.483
Shingle	9/26/2007	Riffle	0.744	1441	820	23	38	26	2.921
Shingle	9/26/2007	Multiple	1.000	154	121	18	27	19	2.725
S. Fk. Baker	9/13/2007	Riffle	0.744	595	267	12	25	19	1.862
S. Fk. Baker	9/13/2007	Multiple	1.000	87	24	7	16	10	2.274
SF Big Wash	8/22/2007	Riffle	0.744	2367	699	12	23	14	2.054
SF Big Wash	8/22/2007	Multiple	1.000	172	116	8	18	13	1.980
Snake-Upper	8/21/2007	Riffle	0.744	1559	549	20	34	23	2.120
Snake-Upper	8/21/2007	Multiple	1.000	184	136	14	28	20	2.772
Strawberry-Up	8/27/2007	Riffle	0.744	583	290	18	38	26	2.662
Strawberry-Up	8/27/2007	Multiple	1.000	145	76	15	27	21	2.818
StrawberryLow	8/27/2007	Riffle	0.744	466	149	18	30	23	2.542
StrawberryLow	8/27/2007	Multiple	1.000	155	58	14	26	18	2.469
Williams	9/27/2007	Multiple	1.000	286	273	9	15	13	0.814
Average				744	415	16	28	19	2.406

EPTA= EPT abundance; EPTT= EPT taxa (richness); RICH=richness; H'=Shannon Diversity Index.

Discussion

Basic Water Quality Parameters

Seasonal fluctuations from spring run-off and rain events have an effect on discharge that influences other water quality parameters, including water temperature, dissolved oxygen, turbidity, total dissolved solids, and specific conductance. Because data were collected for less than one year, annual changes in water chemistry and discharge are not captured here. The warmer water temperatures recorded in Lehman Cave and Squirrel Springs Cave indicate the effect of cave pools influenced by warmer ambient air temperatures. Greater variation in water temperatures in Model Cave and Wheeler's Deep also indicates the influence of surface water and snowmelt on these cave systems. Stream discharge and water temperatures are also greatly affected by seasonality.

Turbidity is the estimation of suspended particles in water, suggesting that turbidity values should increase as water flows downstream, accumulating more sediment and particles as stream length increases. Therefore, we would expect higher turbidity for a lower elevation stream site and lower turbidity for higher elevations. This was illustrated by our data at four of the streams surveyed with an upper and lower elevation survey site. However, Snake and Strawberry Creeks turbidity was higher in the higher elevation sites (Figure 10). Stream gradient also plays a role in turbidity values for streams. The streams within the park all have a high gradient, resulting in higher turbidity values.

Laboratory Water Chemistry

Accuracy of laboratory analyses on these samples is in question based on the calculated charge balance of the results provided by the laboratories. Either ions exist which were not accounted for or the results are in error. Sample 169 from Lehman 52 and sample 53 from Lehman 004 are missing cations while sample 74 from Baker Lake and sample 75 from Baker 200 are missing anions. Quality Assurance samples indicate that maximum percent error ranges from 2.5 for pH to 97 for Fe. Generally the average percent error ranges less than 10; only Fe and TDS are higher. A few samples (e.g., Baker 130 and Baker Creek Lower) dominate the error.

Total dissolved solids increases as elevation decreases and precipitation falling on the land runs off and begins dissolving minerals. This relationship is stronger at higher elevations, becoming weaker and more scattered at lower elevations. Lehman Cave, Can Young 20, Squirrel Spring, and Decathon Spring stand out in map view (Figure 13).

Waters in Great Basin National Park are naturally in equilibrium with limestone (calcite) and are dominated by dissolved calcium with bicarbonate alkalinity. Some proportion of magnesium likely comes from Mg-rich calcite or dolomite.

Waters at higher pH appear to be supersaturated with respect to silica, but this is likely due to disassociation of H_4SiO_4. Sample 103 from Stella Lake and samples 65 and 148 from Dead Lake are significantly undersaturated with respect to silica ($<10^{-5}$ molal).

Alkalinity in Great Basin water samples is exclusively from bicarbonate. The aquifer system is likely well-buffered. A pH - bicarbonate plot shows slightly acidic to slightly alkaline system buffered by bicarbonate and carbonic acid.

If total nitrogen and nitrate plus nitrite were considered most indicative of anthropogenic impact, then the water sources in Lehman Caves are most impacted by human factors. Squirrel Springs has the greatest concentrations of sulfate and chloride, and springs with noticeable human impact include Squirrel Springs and Can Young 20. Note that high total nitrogen could also result from heavy animal inputs, such as from bat droppings.

Anions are predominately bicarbonate along the flow path with decreasing elevation. Chloride gradually increases with lower elevation, whereas sulfate is more random. Samples collected from caves appear to be generally from the same statistical population as samples collected from springs. Even though caves are restricted to elevations between 2080 and 2280 m, the range of bicarbonate, sulfate, and chloride is similar to sampled springs. This flow system is in the upper reaches of the Chebotarev sequence.

EPA Water Quality Criteria

In 2000, the NPS Water Resources Division compiled water quality data in and adjacent to Great Basin National Park using the EPA's STORET database for data retrieval and synthesis (WRD 2000). Data was analyzed from a total of 428 sampling locations. This analysis for waters inside and adjacent to the park found barium and lead levels above the EPA criteria for drinking water, and levels of pH, copper, and zinc exceeded their respective criteria levels for fresh water aquatic life in several samples.

A total of 293 stations included in the 2000 synthesis fall within the park's boundaries. Thirty-two of these stations were either re-sampled or are in close proximity to the stations sampled for the 2007 baseline water quality survey. The majority of these stations were stream or lake sources; only six spring survey stations coincided. Seven sites exceeded the EPA criteria for levels of zinc for fresh water aquatic life, and two sites exceeded acceptable limits for copper for fresh water aquatic life. Only one site, Johnson Lake, had pH values above the EPA standard for fresh water aquatic life. Comparatively, there were no sites sampled in 2006 and 2007 with limits above the EPA criteria for pH or zinc, and only one station, Lehman Cave, had values exceeding the EPA standard for copper.

Macroinvertebrates

Macroinvertebrates are often used to infer water quality because they are sensitive to changing physical, chemical, and biological conditions over multiple spatial and temporal scales and exhibit taxon-specific responses to spatial and temporal variation in water quality parameters that are informative when comparing macroinvertebrate assemblages (Barbour et al. 1999; Karr and Chu 1999). Macroinvertebrate samples are also useful in detecting the presence of non-native species.

Macroinvertebrate abundance and richness is typical of Great Basin mountain aquatic systems. Richness was highest in the most complex ecosystems, streams, and lowest in the least complex ecosystem, caves, as is typical throughout North America (Thorp and Covich 2001). This pattern is thought to result from relatively high variation in flow, temperature, and food conditions in stream–compared to cave systems with lower food inputs and relatively homogenous and constant physiochemical environments. Abundance was similar in both spring and stream systems.

The numbers of taxa in the different functional groups (shredders, scrapers, collectors, and predators) tell a lot about variation in stream ecosystems. Vinson (2008) gives a breakdown of these functional groups for each sampling location. For instance, Williams Creek, Pine Creek, Upper Baker Creek, and the South Fork of Baker Creek have lots of scrapers, suggesting adequate sunlight penetration and photosynthesis drives stream productivity at these sites. By contrast, collectors dominate Lehman Creek (and the two Lehman springs), Outhouse Spring, Outlet Spring, Lower Baker Creek, and Rowland Spring, suggesting greater detritivory at these locations. Shredders are well-represented at Upper Lehman Creek, Mill Creek, Upper Snake Creek, and Upper Strawberry Creek, indicating that leaf litter and other course particulate organic matter may contribute the most to ecosystem productivity in the higher elevations of these streams, as predicted by the River Continuum Concept (Vannote et al. 1980).

Ideally, the results would be compared to a biological index for streams in Nevada; however, such an index does not currently exist.

Conclusions and Recommendations

Despite questions in the accuracy of laboratory results, waters within Great Basin National Park fall into acceptable chemical and biological limits for pristine natural water sources. This conclusion was supported by the results of the macroinvertebrate surveys. We obtained predictable and often obvious results based on the current knowledge of the park's geology and the relationship between water source types. This data now provides a baseline for future sampling to determine how potential threats, if realized, will affect the park's water resources in the future.

The 2007 efforts were the most intensive sampling effort covering the entire park to date. Sampling should be repeated at least every five years to look for trends.

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Appendix A. Data Quality Assurance / Quality Control Checks

Electrical Neutrality

An aqueous solution cannot be electrically charged so cations must be balanced by anions in the solution. A charge balance between cations and anions is used here as a check on the laboratory analyses. An example calculation of charge balance is given for sample 1, neglecting ionic strength.

Sample calculation for charge balance in sample 1 tested by Lab 1
(Sierra Environmental Testing).

Species	Result (mg/l)	Detection Limit	Method	Mol. Wt.	Val-ence	moles/l	cations epl	anions epl
Bicarbonate	245	2	SM 2320	61.02	-1	4.015E-03		4.015E-03
Carbonate	10	2	SM 2320	60.01	-2	1.666E-04		3.333E-04
As (Arsenic)	0	0.002	EPA 200.8	74.92	3	0.000E+00	0.000E+00	
Ba (Barium)	0.094	0.002	EPA 200.8	137.33	2	6.845E-07	1.369E-06	
B (Boron)	0.06	0.05	EPA 200.7	10.81	3	5.550E-06	1.665E-05	
Ca (Calcium)	77	0.5	EPA 200.7	40.08	2	1.921E-03	3.843E-03	
Chlorides	23	0.5	EPA 300.0	35.45	-1	6.487E-04		6.487E-04
Cu (Copper)	0.002	0.002	EPA 200.8	63.55	2	3.147E-08	6.295E-08	
Fluoride	0.1	0.1	EPA 300.0	19.00	-1	5.264E-06		5.264E-06
Fe (Iron)	0.15	0.05	EPA 200.7	55.85	3	2.686E-06	8.058E-06	
Lead - ICP-MS	0.003	0.002	EPA 200.8	207.20	2	1.448E-08	2.896E-08	
Mg (Magnesium)	20	0.5	EPA 200.7	24.31	2	8.229E-04	1.646E-03	
Mn (Manganese)	0.008	0.002	EPA 200.8	54.94	2	1.456E-07	2.912E-07	
Nitrate-N	0.35	0.05	EPA 300.0	62.00	-1	5.645E-06		5.645E-06
K (Potassium)	1.7	0.5	EPA 200.7	39.10	1	4.348E-05	4.348E-05	
Si (Silica)	18	0.4	EPA 200.7	28.09	0	6.409E-04	0.000E+00	
Na (Sodium)	21	0.5	EPA 200.7	22.99	1	9.134E-04	9.134E-04	
Sulfate	30	0.2	EPA 300.0	96.06	-2	3.123E-04		6.246E-04
Zn (Zinc)	0.029	0.01	EPA 200.8	65.41	2	4.434E-07	8.867E-07	

In sample 1 the equivalents per liter (epl) of cations sum to 6.473E-03 and the anions sum to 5.633E-03 for a charge imbalance of 6.9%. Typically we would like to see a charge imbalance of less than 5%. Appendix C shows all 186 samples sorted by increasing charge imbalance. Keep in mind that this is charge imbalance in the laboratory results, not in nature, where there can be no charge imbalance in an aqueous solution. We use a negative percent to show an excess of negative charge.

The charge imbalance values given in Appendix C indicate quality control issues during laboratory analysis and raise some specific questions. For example, where are the cations in samples 169 from Lehman 52 and 53 from Lehman 004? There are no anions whatsoever in samples 74 and 75 from Baker Lake and Baker 200. Only 6 samples meet the 5% charge imbalance criterion and only 36 are within 10%. Are the laboratory results simply wrong or are there important chemical species not tested for? These uncertainties propagate through the following analyses.

Appendix A. Data Quality Assurance / Quality Control Checks (continued)

QA Samples

There were 26 replicate samples collected for the purposes of quality assurance. Here we look at the difference between a sample and corresponding QA sample for the species given. Percent error is defined as

$$percent\ error = \frac{\left|C_{Sample} - C_{QA}\right|}{\max\left(C_{Sample}, C_{QA}\right)} \times 100$$

where C is the concentration of a species. Mean, median, standard deviation, and maximum percent error are also given, along with largest difference between a sample and its QA sample in mg/l.

Percent error represented by QA samples with locations of maximum percent error and largest chemical difference between sample and QA in mg/l.

Species	Mean	Std. Dev.	Maximum percent error location		Max. difference mg/l location	
HCO3	2.73	2.98	13.33	BakerCreekLower	20	SquirrelSprings
Ba	4.18	9.76	50.00	Baker130	0.076	Baker130
B	8.52	15.4	62.07	Baker130	0.03	Lehman004
Ca	4.92	12.1	62.22	Baker130	14	Baker130
Fe	20.2	25.8	97.25	BakerUpper	2.29	Baker130
Mg	5.19	14.3	68.33	Baker130	4.1	Baker130
pH	0.57	0.54	2.54	BakerCreekLower	0.17	BakerCreekLower
Si	3.90	6.52	23.91	Baker130	3.3	Baker130
Na	6.86	13.6	65.67	Baker130	4.4	Baker130
TDS	15.5	20.0	72.97	SouthForkBakerCreek	44	Lehm013

Based on the QA samples, we can say that pH is fairly accurate, within 3%, while Fe may have an error of almost 100%. The error is dominated by the QA samples from Baker 130, and Baker Creek Lower.

Appendix B: Water Quality Parameters

Arsenic

A metal found in the earth's crust, arsenic typically enters surface waters through natural weathering processes. Arsenic can be toxic to aquatic organisms. At lower concentrations it often inhibits plant growth while at higher concentrations it can cause death. An organism's sensitivity to arsenic can vary amongst the species. However, smaller organisms such as aquatic invertebrates tend to be more sensitive than larger animals such as fish. Because arsenic has a lower bioaccumulation factor, it tends to not affect predators who feed on contaminated prey.

Boron

Boron is a trace element that occurs naturally in the environment and is released through natural weathering processes. It is essential for plant growth as well as the growth of some algae, fungi, and bacteria species. Usually boron is not a problem for aquatic organisms as its concentrations have to reach upwards to 18000 mg/L to produce toxic effects, and in rivers the maximum levels of boron present usually only reach 5 mg/L.

Barium

Barium is a yellow white metal that usually enters streams in the form of its salts which are soluble in water. These salts are toxic to aquatic organisms when their concentrations exceed 50 mg/L. However, in rivers and streams, barium often is precipitated out of the water column through its contact with sulfates and carbonates before it can have an adverse effects on aquatic life. Barium is often tested in drinking water, for it can cause problems in the central nervous system as well as the gastrointestinal tract in humans.

Bicarbonate

Carbonates and bicarbonates play an important role in determining pH in stream water. They contribute to a stream's total alkalinity and help to buffer water against changes in pH. Because fluctuations in pH can have adverse effects on aquatic life, bicarbonates can be critical in maintaining pH levels through their buffering capabilities, especially when present in high concentrations.

Calcium

Calcium originates from the weathering of sedimentary carbonate rocks such as limestone and gypsum which dissolve into both calcium and magnesium ions. Its concentration combined with the amount of magnesium in a stream determines the hardness of the water.

Chlorides

The chloride concentration of a stream can have large impacts on aquatic life. When chlorides enter streams along with sodium, the level of salt in the stream increases, making the water more brackish. Because many aquatic organisms are sensitive to salt levels in stream water, high concentrations of chlorides can have deleterious consequences. Concentrations that exceed 400 mg/L can be toxic to aquatic life. In arid regions such as Great Basin, chloride levels are especially significant, because often there is not enough precipitation to dilute high salt concentrations.

Appendix B: Water Quality Parameters (continued)

Color

Along with its negative affects on the aesthetic quality of a stream, color can also negatively impact aquatic life. Color is usually caused by complex organic compounds that originate from decomposing plants. When enough of these compounds are present, they can block sunlight and thus inhibit the photosynthetic processes in aquatic plants. If this happens, it can reduce the vertical zones in which plants can grow.

Copper

Copper is a trace element that is found naturally in the earth's crust and surface waters. At low levels, copper is a micronutrient that is vital to the health of both plants and animals. However, at higher levels it can be toxic to aquatic organisms. Both fishes and invertebrates are equally affected by the toxicity of copper. However, it does not appear to bioaccumulate enough to have any adverse affects on predator species.

Iron

Like copper, iron is also a trace element that is required for both plants and animals. Its abundance in the earth's crust makes it a common presence in rocks and soils. Its importance to organism health makes it a limiting factor for certain plant and animal species. In streams, the criterion for iron is 1.0 mg/L.

Fluoride

Fluoride can be extremely toxic to aquatic life and is known to accumulate in the tissues of animals. Several factors influence the toxicity level of fluoride. One is temperature, for as the metabolic processes of animals increase with increasing temperature, so does the absorption of fluoride ions into the tissues. Another factor is size. For fishes, the larger the fish the more tolerant they seem to be to fluoride toxicity. Certain species such as trout and salmon have been known to be more susceptible. The criterion for fluoride levels in streams is .2 mg/L for aquatic life.

Potassium

Potassium is an essential element for both plants and animals. It usually enters streams through the leaching of soils and organic residues. In rivers, it is one of the least abundant and least variable of the cations.

Magnesium

Magnesium helps to determine the hardness of stream water along with the combined presence of calcium. It usually enters the stream through natural weathering processes, especially on Mg-silicate materials and dolomite.

Manganese

Manganese is usually present in streams in the form of salts and minerals. It is an important nutrient for aquatic life. Insufficient quantities can lead to chlorosis in plants. Manganese does not affect aquatic life unless it is present in extremely high concentrations (exceeding 1000 mg/L). However, it can bioaccumulate in mollusks and thus its criterion in streams is 100 mg/L.

Appendix B: Water Quality Parameters (continued)

Sodium

Sodium enters streams through the weathering of rocks containing sodium chloride. However, another important source can be irrigation, especially in dry areas such as Great Basin National Park which receives little precipitation. Irrigated water that evaporates leaves salt residue on the soil which can then enter surface waters via runoff. When sodium chloride is present in high concentrations, it can cause death to aquatic life.

Sulfate

Sulfate enters stream systems through the weathering of sedimentary rocks, pollution from fertilizers and wastes, and through atmospheric deposition in the form of sulphuric acid rain. Sulfate concentrations above 0.5 mg/L are necessary for algal growth in streams and tend to be harmless to plants and animals when present at normal concentrations. When sulfates are present in high concentrations they can alter the pH levels in streams through their ability to form strong acids. In addition, the presence of sulfate salts can have serious consequences on aquatic life. Sulfides are highly toxic to fishes and humans and are unfortunately also very soluble in stream water.

Total Dissolved Solids

Total dissolved solids (TDS) are classified as particles that are able to pass through a filter that is only 2 microns in size. Examples include calcium, phosphorus, iron, sulfur, nitrates, and chlorides. TDS levels can have significant effects on aquatic life if they are present at extremely high or extremely low concentrations. This is because TDS can affect how water is balanced and moved in the cells of stream organisms. For example, if an organism is placed in water that has comparatively higher levels of TDS than what is found in its cells, then water will tend to move out of the cell and into the outside water, causing the cell to shrink. In waters with low levels of TDS, the opposite occurs resulting in the expansion of cells. This in turn can affect the organism's maintenance of its proper cell density and can thus cause it to either float up or sink down in the water column into zones where it may not be properly adapted to survive.

Turbidity

Turbidity measures the clarity of a water body by estimating the amount of suspended particles within a water sample. The clarity of any water body can be affected by the presence of phytoplankton, algae, benthic sediments, rain, wind, run-off, and shoreline erosion. These sediments increase turbidity which can affect the fecundity of fish and macroinvertebrates, benthic habitats, limit light penetration affecting photosynthesis and food production and consumption, and affect the availability of oxygen. Heavy metals such as mercury and lead, toxic contaminants, and microorganisms like protozoa can accumulate on the particulates in the water column affecting water quality

Zinc

Zinc is a trace element that is found in the metabolism of most organisms and can enter streams through runoff from roads and industrial waste sites. Zinc tends only to be toxic to aquatic life in its dissolved state where it can bind to other biological materials. Macroinvertebrates are affected more acutely than other stream organisms, such as fishes and plant life. The standard for zinc in streams is 50 ug/L.

Appendix C: Laboratory Results Sorted by Charge Imbalance

Sample number	Watershed	Sampling Station	Percent charge imbalance	TDS mg/l
169	LEHM	Lehman52	-57.38	51
53	LEHM	Lehman004	-52.12	113
165	STRA	Straw007	-34.55	112
11	LEHM	LehmanCreekLower	0.52	48
12	LEHM	LehmanCave	3.32	280
16	BAKE	TimberCreek	4.20	89
27	BAKE	ModelCave	4.31	69
10	STRA	StrawberryLower	4.41	110
4	SNAK	SnakeCreekLower	4.65	120
26	BAKE	WheelersDeep	5.08	82
41	BAKE	BakerCreekLower	5.11	38
6	LEHM	RowlandSpring	5.35	88
13	LEHM	LehmanCave	6.07	280
7	STRA	StrawberryCreekUpper	6.26	70
25	SNAK	SouthForkSnakeCreek	6.40	56
24	SNAK	SnakeCreekUpper	6.57	54
47	SHIN	ShingleCreek	6.69	52
1	SNAK	SquirrelSprings	6.94	340
42	BAKE	WheelersDeep	7.18	81
43	BAKE	ModelCave	7.22	74
20	LEHM	Lehman52	7.32	58
14	BAKE	Baker53	7.35	72
5	SFBW	SFBWLower	7.35	240
44	SNAK	SnakeCreekUpper	7.68	68
8	STRA	Strawberry002	7.88	250
23	SHIN	ShingleCreek	8.06	48
2	SNAK	OutletSpring	8.09	180
3	SNAK	OuthouseSpring	8.13	170
37	SNAK	OuthouseSpring	8.37	160
28	STRA	StrawberryLower	8.45	100
9	STRA	Strawberry002	8.53	260
38	SNAK	SnakeCreekLower	8.55	140
46	STRA	StrawberryCreekUpper	8.56	72
18	LEHM	Lehman004	8.57	120
19	BAKE	PoleCanyonCreek	8.59	170
29	LEHM	Lehman004	9.20	140
45	BAKE	PoleCanyonCreek	9.79	170
17	LEHM	Lehman004	9.88	120
30	LEHM	LehmanCreekLower	9.91	46
39	BAKE	Baker53	10.28	81
65	SNAK	DeadLake	10.33	14
36	SNAK	OuthouseSpring	10.38	160
160	SFBW	SFBWLower	10.98	260
31	LEHM	LehmanCave	11.49	280
15	BAKE	SouthForkBakerCreek	11.62	32

Sample number	Watershed	Sampling Station	Percent charge imbalance	TDS mg/l
84	BAKE	TimberCreek	11.89	94
127	BAKE	BakerLake	12.07	0
128	BAKE	BakerLake	12.07	0
69	LEHM	TeresaLake	12.10	15
163	LEHM	Lehm067	12.22	108
34	SNAK	OutletSpring	12.26	180
148	SNAK	DeadLake	12.29	23
66	SNAK	OuthouseSpring	12.35	142
62	SNAK	OutletSpring	12.47	162
147	SNAK	SquirrelSprings	12.48	274
22	BAKE	BakerCreekLower	12.52	38
104	LEHM	TeresaLake	12.53	0
21	BAKE	BakerCreekLower	12.58	38
63	SNAK	SquirrelSprings	12.66	344
124	BAKE	BakerCreekLower	12.73	30
60	SNAK	SnakeCreekLower	12.82	87
130	BAKE	SouthForkBakerCreek	12.84	43
162	LEHM	Lehm013	12.88	70
161	LEHM	Lehm013	12.89	26
136	SNAK	SnakeCreekUpper	12.89	42
187	DECA	DecathonSpring	12.93	341
85	BAKE	PoleCanyonCreek	12.95	174
50	LEHM	LehmanCave	12.95	272
35	SNAK	OutletSpring	13.09	180
40	BAKE	BakerCreekLower	13.19	41
111	BAKE	BakerLake	13.58	0
105	BAKE	BakerLake	13.68	15
103	LEHM	StellaLake	13.79	5
122	CANY	CanYoung17	13.86	167
61	SNAK	SnakeCreekLower	14.03	85
87	STRA	StrawberryLower	14.18	95
106	BAKE	BakerLake	14.37	16
144	SNAK	OutletSpring	14.39	168
143	BAKE	WheelersDeep	14.45	136
80	BUMI	BurntMill	14.52	128
145	SNAK	OuthouseSpring	14.73	161
186	DECA	Decathon1	14.85	237
109	LEHM	StellaLake	14.87	40
33	SNAK	SquirrelSprings	15.10	340
55	CANY	CanYoung17	15.13	172
64	SNAK	SouthForkSnakeCreek	15.20	54
32	LEHM	RowlandSpring	15.45	92
97	SFBW	SFBWLower	15.48	222
137	SNAK	SnakeCreekUpper	15.57	44
68	LEHM	TeresaLake	15.60	10
92	LINC	Lincoln1	15.74	204
96	SFBW	SFBWLower	15.77	228

Sample number	Watershed	Sampling Station	Percent charge imbalance	TDS mg/l
188	NFBW	NFBW6	15.83	201
146	SNAK	SquirrelSprings	15.89	273
166	BAKE	TimberCreek	16.16	108
126	BUMI	BurntMill	16.33	105
58	LEHM	StellaLake	16.68	7
141	LEHM	LehmanCreekUpper	16.82	18
181	CANY	CanYoung20	16.98	243
70	LEHM	LehmanCreekUpper	17.13	19
110	LEHM	StellaLake	17.33	37
123	CANY	CanYoung9	17.36	72
153	SHIN	ShingleCreek	17.38	36
149	BAKE	PoleCanyonCreek	17.52	164
91	WILM	WilliamsCreek	17.66	36
152	PIRI	RidgeCreek	17.71	13
120	LEHM	StellaLake	17.86	24
57	CANY	CanYoung9	17.90	76
125	BAKE	Baker53	18.20	74
49	BAKE	ModelCave	18.26	77
178	BAKE	Baker136	18.38	58
86	SNAK	SnakeCreekUpper	18.44	40
99	PIRI	PineCreek	18.49	36
95	SFBW	SFBWUpper	18.55	232
88	STRA	StrawberryCreekUpper	18.55	62
138	SNAK	SouthForkSnakeCreek	18.57	49
158	WILM	WilliamsCreek	18.61	45
155	PIRI	PIRI010	18.65	58
142	LEHM	Lehman25	18.85	15
100	PIRI	PineCreek	18.98	22
51	LEHM	Lehman52	19.03	72
78	BAKE	Baker53	19.22	61
131	STRA	Strawberry50	19.26	83
93	SHIN	ShingleCreek	19.29	58
121	LEHM	LehmanCave	19.40	286
139	LEHM	LehmanCreekUpper	19.54	28
48	BAKE	WheelersDeep	19.54	59
132	STRA	Strawberry50	19.70	94
52	LEHM	RowlandSpring	19.81	83
94	SHIN	ShingleCreek	19.84	59
159	WILM	WilliamsCreek	19.89	40
79	BAKE	Baker53	20.09	57
56	CANY	CanYoung9	20.20	77
135	SNAK	JohnsonLake	20.21	21
133	STRA	StrawberryCreekUpper	20.25	79
101	PIRI	RidgeCreek	20.51	21
67	LEHM	BrownLake	20.83	16
81	BAKE	SouthForkBakerCreek	21.06	10
113	LINC	Lincoln1	21.13	192

Sample number	Watershed	Sampling Station	Percent charge imbalance	TDS mg/l
140	LEHM	Lehman25	21.14	21
134	STRA	StrawberryLower	21.15	126
154	PIRI	PIRI008	21.17	22
180	BAKE	Baker59	21.24	51
173	SFBW	SFBW5	21.64	149
189	LEHM	CaveSprings	21.99	86
151	PIRI	PineCreek	22.24	21
164	LEHM	Lehm006	22.65	37
98	STRA	Strawberry50	22.97	56
170	BAKE	Baker137	23.01	25
171	BAKE	Baker137	23.12	34
112	SNAK	JohnsonLake	23.31	12
185	MILL	MillCreekLower	23.37	66
82	BAKE	SouthForkBakerCreek	23.42	37
108	LEHM	TeresaLake	23.49	9
90	WILM	Williams5	23.64	39
174	MILL	MillCreekUpper	23.64	48
114	LEHM	Lehman004	23.81	81
116	LEHM	RowlandSpring	24.49	97
71	LEHM	Lehman25	24.49	23
83	MILL	MillCreekLower	24.53	58
77	BAKE	BakerCreekLower	24.55	17
89	SNAK	JohnsonLake	25.48	16
184	LEHM	CaveSprings2	25.57	255
150	BAKE	ModelCave	25.60	56
179	BAKE	Baker57	25.71	76
129	BAKE	Baker200	25.80	0
115	LEHM	LehmanCreekLower	26.21	33
107	SNAK	JohnsonLake	26.37	22
118	LEHM	BrownLake	26.48	43
59	MILL	MillCreekUpper	26.48	36
72	MILL	MillCreek3	27.23	37
76	BAKE	BakerUpper	27.91	19
73	MILL	MillCreek3	28.59	46
177	BAKE	Baker94	28.99	46
157	WILM	WILM005	29.35	42
156	WILM	WILM004	29.36	36
119	LEHM	TeresaLake	30.45	18
117	MILL	MillCreek3	30.58	31
183	BAKE	BakerUpper	36.24	26
168	BAKE	Baker130	36.27	60
182	BAKE	BakerUpper	40.49	23
172	SFBW	SFBWUpper	70.71	235
167	BAKE	Baker130	71.15	59
54	LEHM	LehmanCreekLower	76.47	38
74	BAKE	BakerLake	100.00	24
75	BAKE	Baker200	100.00	10

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