



Water Quality Monitoring for Bright Angel, Garden, Pipe, and Hermit Creeks in Grand Canyon National Park

2011–2013 Summary Report

Natural Resource Data Series NPS/SCPN/NRDS—2016/1220



ON THE COVER

Bright Angel Creek in Grand Canyon National Park, 2013
Photography by SCPN

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May 2016

U.S. Department of the Interior

National Park Service

Natural Resource Stewardship and Science

Fort Collins, Colorado

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

All manuscripts in the series receive the appropriate level of peer review to ensure that the information is scientifically credible, technically accurate, appropriately written for the intended audience, and designed and published in a professional manner. Data in this report were collected and analyzed using methods based on established, peer-reviewed protocols and were analyzed and interpreted within the guidelines of the protocols.

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Funding for the SCPN water resources field crew was provided to Northern Arizona University by the National Park Service through Colorado Plateau CESU Agreement H1200090005 (Task NAU-404, Task NAU-414). Funding for analysis of water samples for selected water quality constituents was provided by the National Park Service to USGS National Water Quality Laboratory through Colorado Plateau CESU Agreement F2121090111.

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Please cite this publication as:

Dyer, M., S. A. Monroe, and S. E. Stumpf. 2016. Water quality monitoring for Bright Angel, Garden, Pipe, and Hermit Creeks in Grand Canyon National Park: 2011–2013 Summary report. Natural Resource Data Series NPS/SCPN/NRDS—2016/1220. National Park Service, Fort Collins, Colorado.

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1 Introduction

The National Park Service Inventory and Monitoring Program was designed to determine the current status and monitor long-term trends in the condition of park natural resources, providing park managers with a scientific foundation for making decisions and working with other agencies and the public to protect park ecosystems. Hydrologic vital signs are the fundamental components that define overall riparian and aquatic ecosystem integrity. The Southern Colorado Plateau Network (SCPN) has identified 7 vital signs pertaining to riparian and spring ecosystems: 1) aquatic macroinvertebrates, 2) stream water quality, 3) stream flow and depth to groundwater, 4) spring water quality, 5) fluvial geomorphology, 6) riparian vegetation, composition, and structure, and 7) spring ecosystems. These vital signs are closely related and are all included in the Vital Signs Monitoring Plan for the Southern Colorado Plateau Network (Thomas et al. 2006). The context and ecological significance of these vital signs are further explained in Scott et al. (2005). In this report we focus on stream water quality.

Specific objectives for monitoring stream water quality in SCPN parks are

- Determine status and trends for selected core water quality parameters (water temperature, pH, specific conductance, dissolved oxygen, turbidity and discharge) at selected sites in priority streams within SCPN parks.
- Determine status and trends of selected water quality constituents, including bacteria, nutrients, major elements, and trace metals at selected sites in priority streams within SCPN parks.
- Compare water quality data against state standards for chronic exceedances. Multiple exceedances in a year typically indicate non-compliance.

1.1 Selecting potential water quality monitoring sites

We targeted SCPN streams and springs with potential for water quality monitoring by reviewing (1) water quality data inventory and analysis reports prepared by the Water Resources Division (WRD) of the National Park Service (NPS); (2) a USGS summary and review of available water quality data from streams in SCPN parks (Brown 2008); (3) data collected during a Level 1 water quality inventory of streams in SCPN parks (Macy and Monroe 2006); and (4) results of water quality monitoring planning meetings with park staff.

SCPN water bodies were selected for water quality monitoring based on the following criteria:

- 303(d) listed waters¹ — where previous sampling indicates one or more parameters regularly approach or exceed established water quality standards or recommended levels
- waters with demonstrated threat levels—where an analysis of existing data indicate that measured conditions regularly approach or exceed standards or recommended levels, but where the frequency of exceedances or the quality of the database do not support a 303(d) listing
- pristine waters—where there is no direct impact of human activities (provides baseline data)
- ecological significance—presence of unique species or species of concern
- waters of management concern—where past sampling may not indicate constituent values of concern, but where anthropogenic activities indicate that contamination is a significant threat
- historic data—waters identified as important, for which substantial historic water quality data are available
- data gaps—waters identified as important, but where little or no water quality information exists

Whenever possible, SCPN water quality monitoring sites are located where a history of water quality data collection exists, and co-located with SCPN aquatic macroinvertebrate monitoring sites.

¹ Under section 303(d) of the Clean Water Act, states, territories, and authorized tribes are required to develop lists of impaired waters— waters that are too polluted or otherwise degraded to meet the water quality standards set by states, territories, or authorized tribes (EPA 2011).

1.2 Water quality monitoring at Grand Canyon National Park

Garden Creek is a perennial stream originating from numerous springs surrounding Indian Gardens, a popular campground, day-hiking, and mule-riding destination located below the South Rim in Grand Canyon NP (GRCA). The campground and mule corral are located adjacent to the springs and Garden Creek. Just below Indian Gardens is a discharge pipe from the Trans-Canyon Pipeline, which transports water from Roaring Springs below the North Rim to a pumping station at Indian Gardens. From Indian Gardens, the water is pumped to the South Rim. When pumping is not occurring, the water is released into Garden Creek. Bright Angel Trail, the most popular trail into Grand Canyon, follows Garden Creek along most of its extent. The lower portion of the creek crosses the trail multiple times before converging with Pipe Creek, which flows into the Colorado River. In addition to as many as 800 hikers per day, up to 10 mule trips per day can occur along the Bright Angel Trail.

Bright Angel Creek is a perennial stream flowing from Roaring Springs near the North Rim of GRCA and runs parallel to the North Kaibab Trail before draining into the Colorado River. Just before the Colorado River, the creek passes along Phantom Ranch and the Bright Angel Campground, both extremely popular overnight destinations located at the bottom of Grand Canyon. Phantom Ranch is also the final destination for overnight mule rides into the canyon.

Hermit Creek is a perennial stream flowing from the Grand Canyon's South Rim into the Colorado River at Hermit Rapids. The Hermit Fault acts as one of the main pathways for the flow of groundwater from the South Rim. Consequently, this creek is one of the larger streams in this section of the Grand Canyon. The creek flows along the Hermit Campground and Hermit Trail before joining the Colorado River.

In 2013 SCPN implemented long-term water quality monitoring on Garden and Bright Angel Creeks in GRCA. Water samples are collected on a quarterly basis at the following sites (Figure 1, Table 1):

- *Garden Creek below Tonto Trail* (GRCAGAR01), identified in this report as GAR01, is located 1 km downstream from Indian Gardens. GAR01 is co-located with a SCPN aquatic macroinvertebrate monitoring site.
- *Bright Angel Creek near Colorado River* (GRCABRI02), identified in this report as BRI02, is located below Phantom Ranch and the Bright Angel Campground and is 0.2 km upstream from the Colorado River.

In addition to the long-term water quality monitoring sites listed above, core parameter measurements are collected at two aquatic macroinvertebrate monitoring sites. These sites are visited once per year:

- *Hermit Creek below Tonto Trail*. (GRCAHER01), identified in this report as HER01, is located just downstream of the Hermit Creek Campground and the Tonto Trail crossing.
- *Bright Angel Creek below First Footbridge* (GRCABRI01), identified in this report as BRI01 is located approximately 4.5 km upstream from Phantom Ranch, and downstream from the first large steel footbridge on the North Kaibab Trail.

In 2011 and 2013, SCPN also collected samples for bacteria at additional sites along Garden and Pipe Creeks during three 48-hour periods. Initially this was in response to concern about the potential effects that mule riding was having on *E. coli* levels in the creek. A review of the 2011 data indicated that the daily fluctuations of flow into Garden Creek were having more of an impact on *E. coli* levels. These flow fluctuations are caused by releases from the Trans-Canyon Pipeline. During this study, the water was pumped to the South Rim at night and released into Garden Creek during the day. During the 2013 bacteria sampling trip, sites and timing were adjusted to equally sample the two flow situations.

In 2011, bacteria samples were collected at the following sites listed in upstream to downstream order (Figure 2). The site visits occurred at eight hour intervals during two 48-hour periods: March 4–6 and May 25–27.

- *Garden Creek Upstream of Tonto Trail Crossing* (GRCAGAR02), identified in this report as GAR02, is located upstream of the portion of the Tonto Trail that heads west from Indian Gardens. The sample site is located just upstream from the mule corral.



Figure 1. Water quality and aquatic macroinvertebrate monitoring sites on Garden, Bright Angel and Hermit Creeks in Grand Canyon NP.

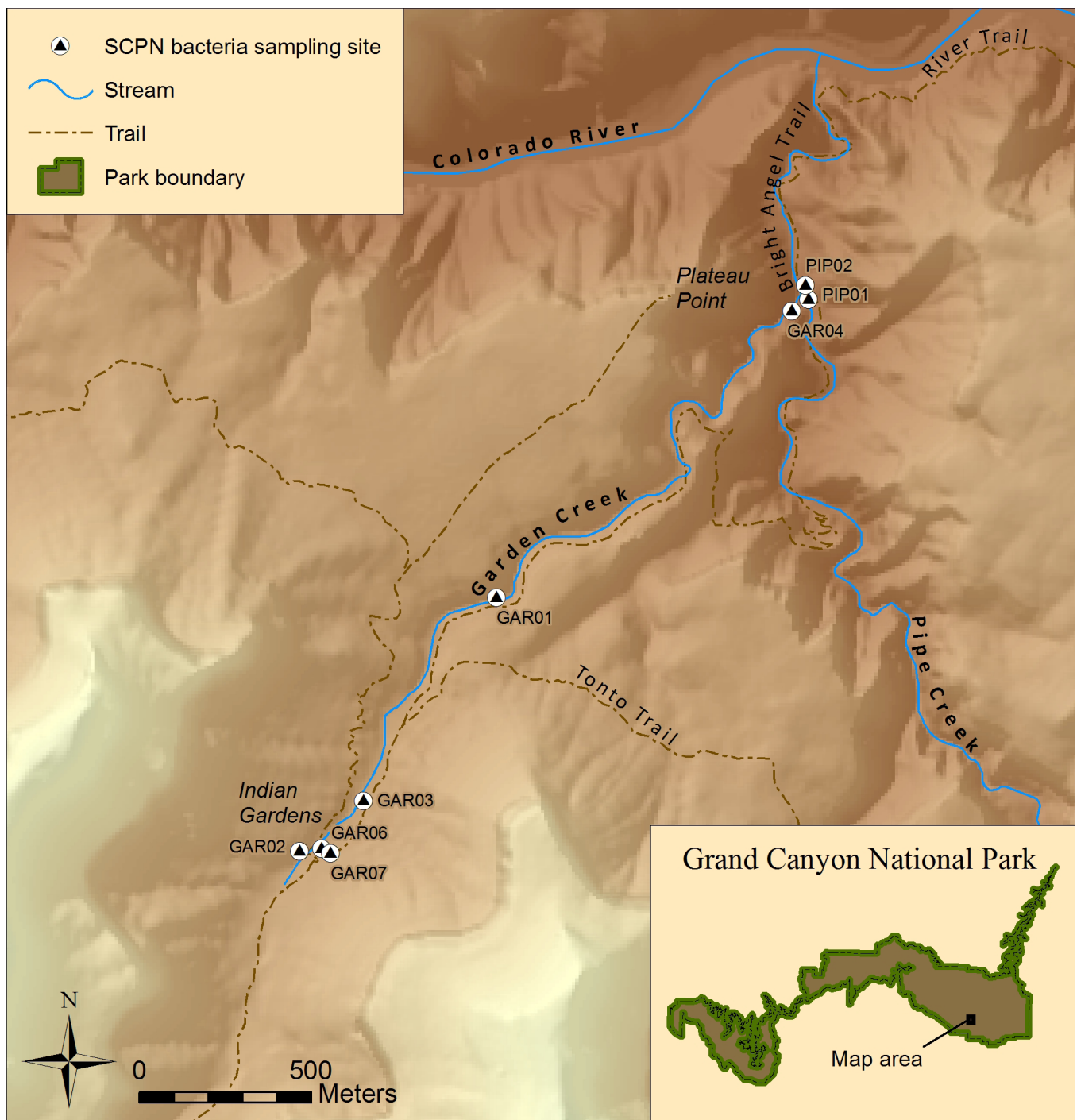


Figure 2. Bacteria sampling sites on Garden and Pipe Creeks at Grand Canyon NP, 2011 and 2013.

Table 1. Summary of data collected during Grand Canyon NP site visits and numbers of samples taken, 2011–2013. NMETM represents nutrients, major elements, and trace metals. CECs are contaminants of emerging concern, monitored by SCPN in conjunction with the US Environmental Protection Agency.

Site	Core parameter			Long-term temperature			Bacteria			NMETM	CEC samples	
	2011	2012	2013	2011	2012	2013	2011	2012	2013	2013	2012	2013
GAR01	13	2	7	Partial	Complete	Complete	12	X	7	3	2	3
BRI01	1	1	1	X	X	X	X	X	X	X	1	X
BRI02	X	X	4	X	X	X	X	X	4	4	X	3
GAR02	12	X	X	X	X	X	12	X	X	X	1	X
GAR03	12	X	X	X	X	X	10	X	X	X	X	X
GAR04	12	X	X	X	X	X	12	X	X	X	X	X
GAR06	X	X	4	X	X	X	X	X	5	X	X	X
GAR07	X	X	3	X	X	X	X	X	3	X	X	X
PIP01	12	X	X	X	X	X	12	X	X	X	X	X
PIP02	12	X	X	X	X	X	12	X	X	X	X	X
HER01	1	1	1	X	X	X	X	X	X	X	X	X

- *Garden Creek Downstream of Pump House Outlet Confluence (GRCAGAR03)*, identified in this report as GAR03, is located approximately 8 meters downstream from where the discharge from the Trans-Canyon Pipe joins Garden Creek.
- *Garden Creek below Tonto Trail (GRCAGAR01)*.
- *Garden Creek above confluence with Pipe Creek (GRCAGAR04)*, identified in this report as GAR04, is located below the waterfall just upstream of the junction with Pipe Creek.
- *Pipe Creek above confluence with Garden Creek (GRCAPIP01)*, identified in this report as PIP01, is located 15 meters upstream from the confluence with Garden Creek.
- *Pipe Creek below confluence with Garden Creek (GRCAPIP02)*, identified in this report as PIP02, is located downstream of the confluence with Garden Creek.

In 2013, samples for bacteria were collected at the following sites, listed in upstream to downstream order (Table 1, Figure2). The sample visits took place twice per day during a 48-hour period from July 8–9.

- *Garden Creek Below Hitching Post (GRCAGAR06)*, identified in this report as GAR06, is located downstream from the westbound Tonto Trail below the hitching post.
- *North Rim Pipe Discharge to Garden Creek near Pumphouse (GRCAGAR07)*, is identified in this report as GAR07. Samples were collected directly from the pipe.
- *Garden Creek below Tonto Trail (GRCAGAR01)*

2 Methods

A brief description of water quality data collection and processing procedures followed by SCPN staff at GRCA during 2011–2013 is presented here. Detailed descriptions of these procedures are available in Water Quality Monitoring Protocol for Streams and Springs in the Southern Colorado Plateau Network (Monroe et al. in preparation).

2.1 Water quality core parameters

NPS core water quality parameters include water temperature, pH, specific conductance, dissolved oxygen, turbidity, and discharge. During each site visit, SCPN water resources field crew noted the hydrologic conditions and collected water quality core parameter data using the following methods:

- As soon as possible after arrival at the site a multiparameter sonde (Hydrolab-MS5; Hach Inc.) was calibrated and deployed in a well-mixed part of the stream channel, logging temperature, pH, specific conductance, and dissolved oxygen data at 5-second intervals. The sonde was left stationary in the stream for the duration of the site visit.
- Turbidity samples were kept on ice for no longer than 24 hours, and analyzed with a HACH 2100P Portable Turbidimeter (Hach Inc.).
- Discharge was measured using a Marsh-McBirney Flo-mate (Hach, Inc.), a Hach FH950, Baski Flume, or a Flowtracker ADV.

2.2 Water quality samples

In 2013 SCPN began collecting water quality samples at GRCA to analyze for bacteria, nutrients, major elements and trace metals at each quarterly site visit. Samples for contaminants of emerging concern and bacteria have been collected at GRCA since 2011.

Bacteria samples were collected by dipping a sample bottle into the center of flow. SCPN staff analyzed the sample for total coliforms and *E. coli* using the Quanti-Tray® 2000 system (IDEXX Inc.). We collected samples to be tested for other analytes in a similar manner. Sample water was filtered and/or acid-treated (as required), kept on ice, and shipped to the contract laboratory. In 2013 SCPN continued an Interagency Agreement with the USGS National Water Quality Laboratory (NWQL) in Denver, Colorado for analysis of water samples for selected water quality constituents (Table 2). This is the same laboratory used to analyze samples collected at other SCPN parks. Information documenting NWQL methods is included in SOP #8 of the SCPN water quality monitoring protocol (Monroe et al. in preparation).

From 2011–2013, SCPN collected samples at GRCA for a suite of contaminants of emerging concern (CECs), which include pharmaceuticals, personal care products, waste water indicators, and pesticides (Appendix C). The procedures described in NPS 2013 were followed, and the samples were analyzed by the EPA Region 8 laboratory. The purpose was to develop a baseline dataset documenting the occurrence of these contaminants within SCPN parks. Samples for these contaminants were collected at four sites in GRCA: GAR01, GAR02, BRI01, and

Table 2. USGS National Water Quality Laboratory and U.S. Environmental Protection Agency Laboratory sample analytes.

Analytical group	Analytes
Nutrients	ammonia, nitrite, nitrite + nitrate, orthophosphate
Major elements	calcium, chloride, fluoride, magnesium, potassium, silica, sodium, sulfate, acid neutralizing capacity (ANC; as CaCO ₃), total dissolved solids
Trace metals	aluminum, antimony, arsenic, barium, beryllium, boron, cadmium, chromium, cobalt, copper, iron, lead, manganese, mercury, molybdenum, nickel, selenium, silver, uranium, vanadium, zinc
Contaminants of emerging concern	pharmaceuticals, personal care products, waste water indicators, pesticides (Appendix C).

2.3 Data handling and analysis

All SCPN water quality data are entered in NPSTORET, v.1.83, a Microsoft Access database created by the Water Resources Division of the National Park Service. All multiparameter sonde electronic data, discharge, and temperature logger files are stored on the SCPN server. In this report, we include the median values of a subset of seven consecutive multiparameter sonde measurements, with the exception of the data presented in Table 4. Similarly, only the median values for each set of turbidity samples are presented.

All results from the NWQL and EPA are presented as they were reported from the lab. In cases where analytes were not detected, we present the applicable laboratory reporting level, which is the lowest concentration that can be reliably measured by a given analytical method. For the NWQL data, results which are below the laboratory reporting level but above the method detection level are flagged to indicate that the analyte was detected, but the concentration was not high enough to report.

Where applicable, we compared our results against the Arizona water quality standards applicable to the monitoring sites in GRCA (ADEQ 2009). We noted any exceedances of the applicable standards.

2.4 Understanding water quality data and standards

The NPS Natural Resource Challenge (NRC) provides funding for water quality monitoring in NPS park units. This funding is intended to advance NPS's long-term goals to protect pristine water quality and improve impaired water quality in parks by supporting Clean Water Act protections and provisions for designated unimpaired and impaired waters. Preliminary analysis of data available through the water quality data synthesis (Brown 2008), a Level 1 water quality inventory (Macy and Monroe 2006), and SCPN monitoring indicate that water quality conditions at many SCPN parks exceed established USEPA, State or Tribal standards.

The SCPN water quality monitoring program collects samples quarterly to document the range of hydrologic conditions that occur in network parks. Thus, rare and short-term events may not be captured. These grab samples represent conditions at the point and time of sampling; they do not represent the condition of the entire water body, spatially or temporally.

The Arizona DEQ has developed water quality standards and criteria to meet requirements of the Federal Clean Water Act. This report includes water quality standards and criteria applicable to waters in Arizona that are not on tribal land (ADEQ 2009). A water quality standard refers to a specific parameter and its associated designated beneficial use, in conjunction with a criterion, which is the numeric component against which a result is compared. For example, the standard for chronic mercury (parameter) for warm water aquatic and wildlife (use designation) is 0.01 µg/L (numeric criterion).

All of SCPN's sample results are for the dissolved concentration, meaning the samples are filtered through a 0.45µm filter to remove the particulate component of the sample before it is shipped for analysis of the dissolved fraction. Most Arizona aquatic life criteria for metals are based on the dissolved fraction. This method more accurately addresses the form of metals that is most toxic to aquatic life while excluding less toxic forms. However, not all Arizona water quality criteria are based on dissolved samples. Many are based on the total sample concentration, which includes the portion of the analyte bound to particulates. Because our samples exclude the particulate component, our data are not necessarily comparable to criteria based on the total sample. Therefore, only the criteria for dissolved parameters are listed in the Results section of this report. However, we note when dissolved concentrations exceed the criteria for total concentrations.

In this report results for each parameter are evaluated against applicable water quality standards as defined for each stream by the Arizona DEQ. There are three designated uses that apply to the SCPN water quality sites: aquatic and wildlife (warm water), full-body contact, and fish consumption. Each designated use may have differ-

ent criteria for one parameter. Also, aquatic and wildlife criteria are often dependent upon water hardness, which varies at each site visit. In these cases, the criteria are expressed as a range encompassing the lowest and highest values for the year.

For *E. coli*, we compared our results against the criteria for full body contact. SCPN bacteria data are expressed as a most probable number (MPN) per 100 mL. MPN is a statistical estimate of the number of bacteria per unit volume of a sample, determined by using a lookup table provided by the manufacturer (IDEXX Inc.). The Arizona water quality criteria are expressed either as the number of colony forming units per 100 mL (cfu/100 mL) or as a MPN.

2.4.1 Chronic and acute standards

Numeric criteria for aquatic life water quality standards address potential effects of both chronic exposure to a parameter over an extended period of time (months) and acute exposure over a short period of time (hours or days). Acute standards apply to any single sample and are not to be exceeded at any time. Criteria are much lower for chronic exposure than for acute exposure and are not directly comparable to the results obtained from a single sample because chronic standards are based on the geometric mean of four samples collected at least 24 hours apart (ADEQ 2009). From a compliance standpoint, the acute instantaneous criteria afford the only direct comparison for such data because they apply to a single sample. However, from a resource conservation standpoint, instantaneous grab-sample data, when compared against more stringent chronic criteria, can provide a means of early warning and an indication of a problem that may require more attention. Therefore, we have identified when results are outside the chronic criteria in the results section of this report.

2.4.2 Regulatory authority

The National Park Service does not have regulatory authority over waters in the U.S., or even the authority to make assessments for designated use. This report compares water quality data to designated use criteria without stating whether a designated use was attained. Those designations are reported by the states or tribes in their triennial 305(b) reports to Congress. However, the NPS cooperates with states and tribes in collecting data used in the protection of water bodies under state jurisdiction.

3 Results

This section summarizes data collected by SCPN from Bright Angel, Garden, Pipe, and Hermit Creeks in 2011–2013. All data collected from these creeks, including dates and sample times, are in Appendix B.

3.1 Bright Angel Creek

Each October, SCPN staff visits BRI01 on Bright Angel Creek to conduct aquatic macroinvertebrate monitoring. During these visits, water quality core parameter measurements are collected and, in 2012, one set of samples for contaminants of emerging concern was collected. In 2013, SCPN established BRI02, located near the Colorado River, as a long-term water quality monitoring site. Core parameter measurements and samples for bacteria, nutrients, major ions, and trace metals are to be collected on a quarterly basis. In 2013 these visits took place on January 8, April 25, July 9, and October 22 and SCPN crew measured water quality core parameters and collected samples for bacteria and the analytes in Table 2.

3.1.1 Water quality core parameter data

Core parameter data measured during aquatic macroinvertebrate site visits at BRI01 from 2010–2013 are summarized in Table 3, along with the Arizona water quality criteria. All measurements took place in October. For BRI01, the 2013 results did not differ significantly from measurements collected during previous years. The water quality criteria only apply to pH and dissolved oxygen. For pH, measurements should be between 6.5 and 9.0. None of the measurements at BRI01 and BRI02 were outside this range. Dissolved oxygen levels should be above 6.0 mg/L. All of the dissolved oxygen measurements were above this level at BRI01 and BRI02.

Figure 3 shows discharge recorded at 15 minute intervals during 2013 at the USGS streamflow gaging station located near BRI02, Bright Angel Creek near Grand Canyon, AZ (#09403000, USGS 2014). The station recorded increased flows from mid-March until mid-May due to snowmelt from the North Rim. The largest pulses occurred during the July–September monsoon season, and the maximum streamflow recorded in 2013 was 352 cfs on July 20. The discharge measured during the four quarterly SCPN site visits ranged from 13.1–25.8 cfs.

Table 3. Summary of water quality core parameter data from BRI01 and BRI02 in Grand Canyon NP, 2010–2013, and Arizona water quality criteria. A “nc” indicates that no criteria exist for a specific parameter. “nd” indicates that no data were collected.

Core parameters	Site	2010–2012			2013			Arizona state aquatic life criteria
		# of samples	Median	Range	# of samples	Median	Range	
Water temperature (°C)	BRI01	3	13.8	13.3–15.0	1	11.3	-	nc
	BRI02	nd	nd	nd	3	11.4	10.9–21.4	
pH	BRI01	3	8.8	8.6–8.8	1	8.7	-	>6.5 to <9.0
	BRI02	nd	nd	nd	3	8.5	8.4–8.7	
Specific conductance (µS/cm)	BRI01	3	343	332–352	1	351	-	nc
	BRI02	nd	nd	nd	3	341	278–356	
Dissolved oxygen (mg/L)	BRI01	3	9.4	8.6–9.4	1	10.3	-	>6.0
	BRI02	nd	nd	nd	3	9.1	7.9–10.4	
Turbidity (NTU)	BRI01	3	1.7	0.6–2.7	1	1.1	-	nc
	BRI02	nd	nd	nd	4	2.5	1.0–3.8	
Discharge (cfs)	BRI01	3	21.3	19.9–21.6	1	24.0	-	nc
	BRI02	nd	nd	nd	4	21.7	13.1–25.8	

The USGS station also records air and water temperatures at 15 minute intervals at Bright Angel Creek. The daily maximum, average, and minimum temperatures for 2013 are presented in Figure 4. The average air temperature was 16.3°C in 2013. The lowest temperature was -1.8°C on January 16, and the highest temperature was 45.2°C on June 27.

Water temperatures ranged from a high of 28.5°C on July 3 to a low of 1.1°C on January 15. The average water temperature was 13.7°C. There are no water quality criteria for temperature at Bright Angel Creek.

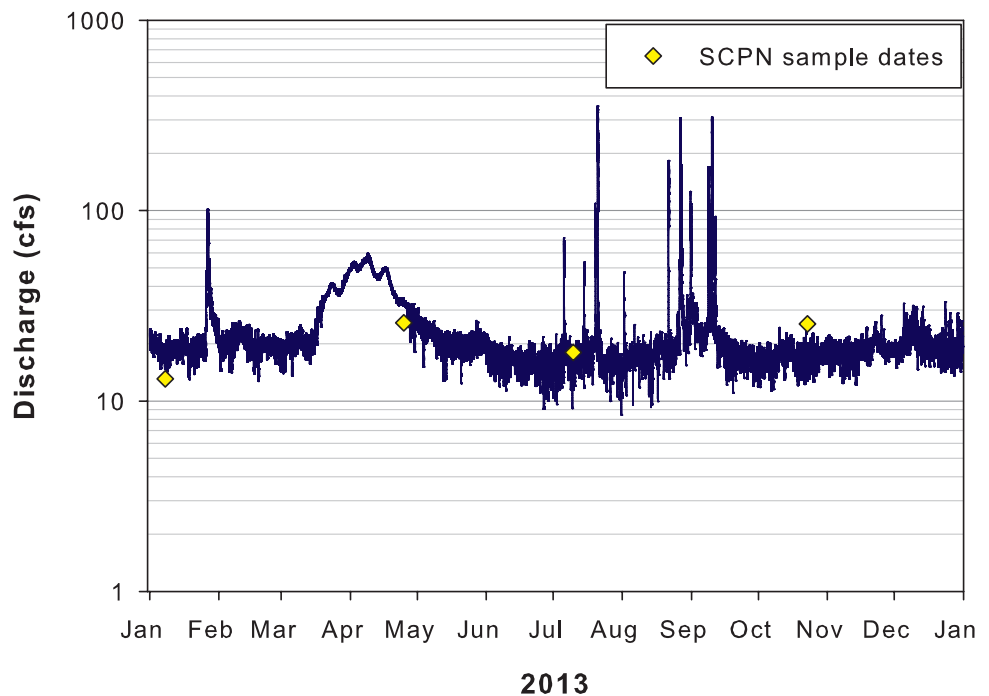


Figure 3. Discharge recorded at 15 minute intervals at Bright Angel Creek in 2013 from USGS streamflow gaging station #09403000 located near BRI02 in Grand Canyon NP. Discharge measured during SCPN site visits are in yellow.

3.1.2 Precipitation

Daily precipitation measurements for 2013 from the NOAA/NCDC monitoring station at Phantom Ranch are presented in Figure 5 (NOAA/NCDC 2015), along with the dates of SCPN water quality site visits. Precipitation occurred primarily during the summer months, when events were frequent. With the exception of one larger precipitation event in January, winter, spring, and fall were dry. A total of 269 mm of precipitation was recorded in 2013. None of the water quality site visits occurred during a precipitation event.

3.1.3 Total coliforms and *E. coli*

SCPN began collecting samples for total coliforms and *E. coli* in 2013, as part of its quarterly water quality monitoring. Results are presented in Figure 6 and listed in Appendix B. Bright Angel Creek is protected for full body contact (ADEQ 2009), meaning there is a high likelihood of complete submergence in the water leading to ingestion. The water quality criteria for *E. coli* are a four-sample geometric mean of 126 MPN/100 mL or a single-sample maximum of 235 MPN/100 mL. *E. coli* results at BRI02 were very low and well below the water quality criteria. Results ranged from <1–14 MPN/100 mL.

Total coliforms, which include *E. coli* and many other types of bacteria, are also included in the analyses. They are indicators of the presence of all coliform groups of bacteria, both vegetative and fecal in origin. Total coliforms are used in drinking water testing because their presence indicates contamination of a water supply by an outside source. There are no water quality standards for total coliforms. Results from BRI02 ranged from 550 to >2400 MPN/100 mL.

3.1.4 Water quality laboratory data

Nutrients, major element, and trace metal results from BRI02 are presented in Tables 4–6, along with the Arizona water quality standards applicable to this reach of Bright Angel Creek (ADEQ 2009).

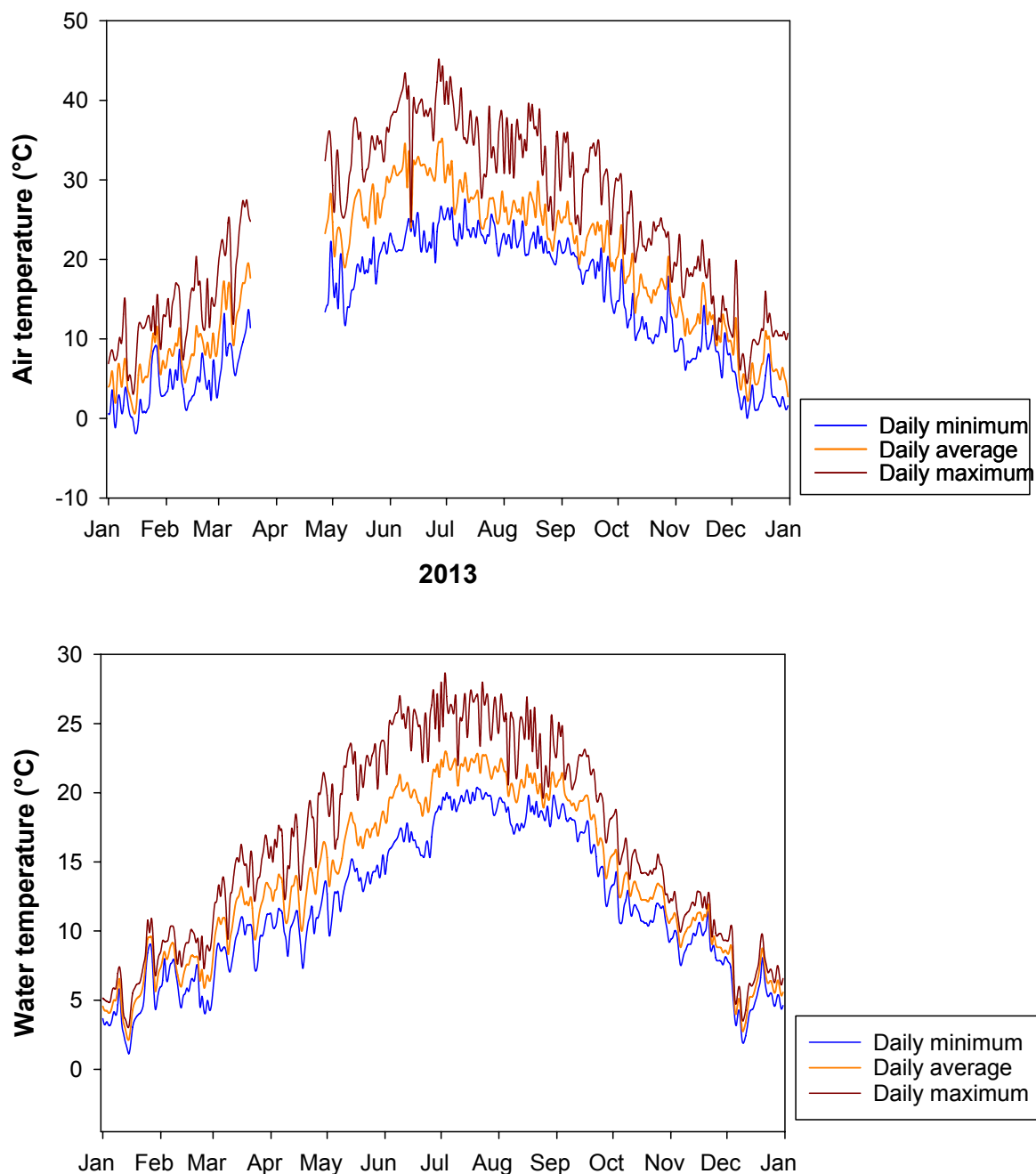


Figure 4. Daily minimum, maximum, and mean air (top) and water (bottom) temperatures recorded in 2013 from Bright Angel Creek in Grand Canyon NP by USGS Station #09403000.

Nutrient data are presented in Table 4. Ammonia, nitrite+nitrate, and nitrite were each only detected once above the laboratory reporting levels. For ammonia, the water quality standard is based on the total concentration, which is not directly comparable to results from filtered samples. The highest concentration for ammonia was very low, however, at 0.0433 mg/L. Nitrite+nitrate was detected once, at 0.205 mg/L, which is well below the 3,733 mg/L water quality criterion for nitrate. Nitrite was detected at 0.00121 mg/L, well below the water quality criterion of 233 mg/L. Orthophosphate was present in all samples in low concentrations ranging from 0.00437–0.0159 mg/L. There are no water quality criteria for orthophosphate.

Major element data are presented in Table 5. Total dissolved solids ranged from 160–219 mg/L, the highest result

was from January and the lowest result was from July. Silica concentrations were low and consistent in the four samples, ranging from 3.30–5.92 mg/L. Acid neutralizing capacity also did not vary significantly between samples, ranging from 170–192 mg/L. Major ions for BRI02 and GAR01 are plotted in Figure 7, also showing that ion concentrations did not change significantly between site visits. Anions almost entirely consisted of bicarbonate/carbonate. Cations were mainly split between calcium and magnesium, with very little sodium or potassium.

Trace metal results for BRI02, as well as the most stringent criteria which apply to dissolved parameters, are shown in Table 6. These results were evaluated against the Arizona water quality standards that apply to this reach of Bright Angel Creek (ADEQ 2009): aquatic and wildlife (warm water), full-body contact, and fish consumption. None of the trace metals results exceeded the most stringent water quality criteria. Of the 21 metals, seven were not detected in any of the four samples: beryllium, cadmium, copper, mercury, nickel, silver, and zinc. The remaining metals were present in most samples but in low concentrations.

3.1.5 Contaminants of emerging concern

On October 11, 2012, one set of samples was collected at BRI01 to be analyzed for contaminants of emerging concern, which fall in the following categories: pesticides, pharmaceuticals, personal care products, and waste indicators (complete analyte list is in Appendix C). Of the over 250 analytes, none were found in the BRI01

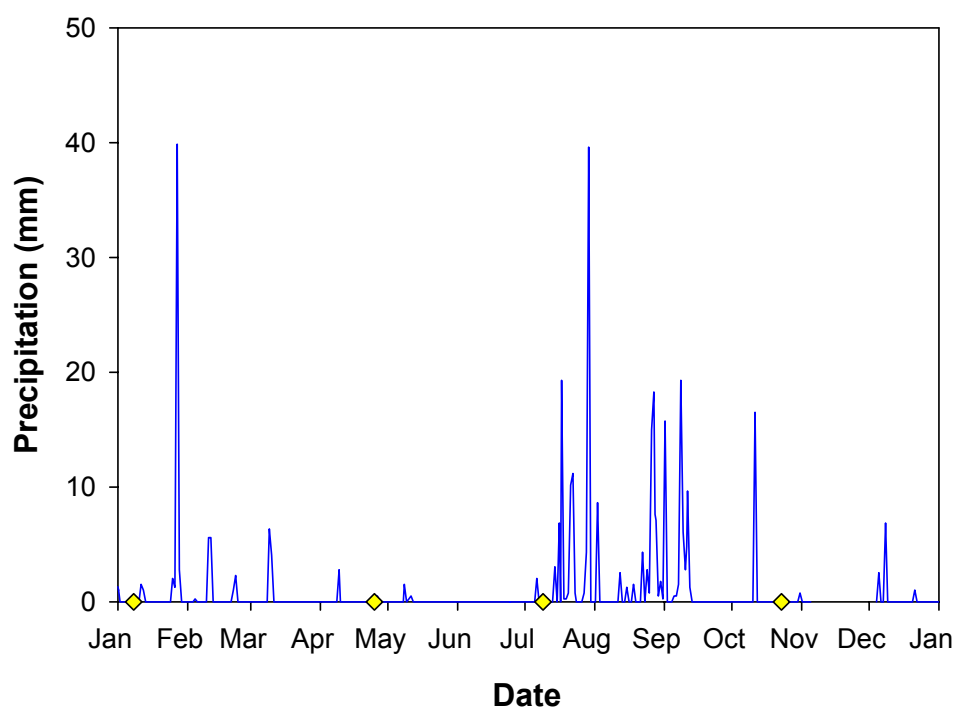


Figure 5. Total daily precipitation from the NOAA/NCDC monitoring station (#026471) at Phantom Ranch in Grand Canyon NP, 2013. Yellow diamonds represent SCPN water quality site visits.

Table 4. Nutrient data from BRI02 on Bright Angel Creek at Grand Canyon NP, 2013. A “nc” indicates that no criteria have been developed for a particular nutrient; a “ndc” indicates that no dissolved criteria has been developed. Results that were lower than the National Water Quality Laboratory reporting levels are noted as “<[reporting level]”.

Nutrient mg/L	Sample collection date and time				Most stringent criterion	# of exceedances	Beneficial use
	1/8/13 11:00	4/25/13 7:30	7/10/13 23:55	10/23/13 9:15			
Ammonia as N	0.0433	<0.0100	<0.0100	<0.0100	ndc	ndc	ndc
Nitrite + nitrate as N	<0.040	0.205	<0.040	<0.040	3733 (NO ₃ as N)	0	FBC ^a
Nitrite as N	0.00121	<0.00100	<0.00100	<0.00100	233	0	FBC
Orthophosphate as P	0.0159	0.0141	0.00437	0.00840	nc	nc	nc

^a FBC = full body contact

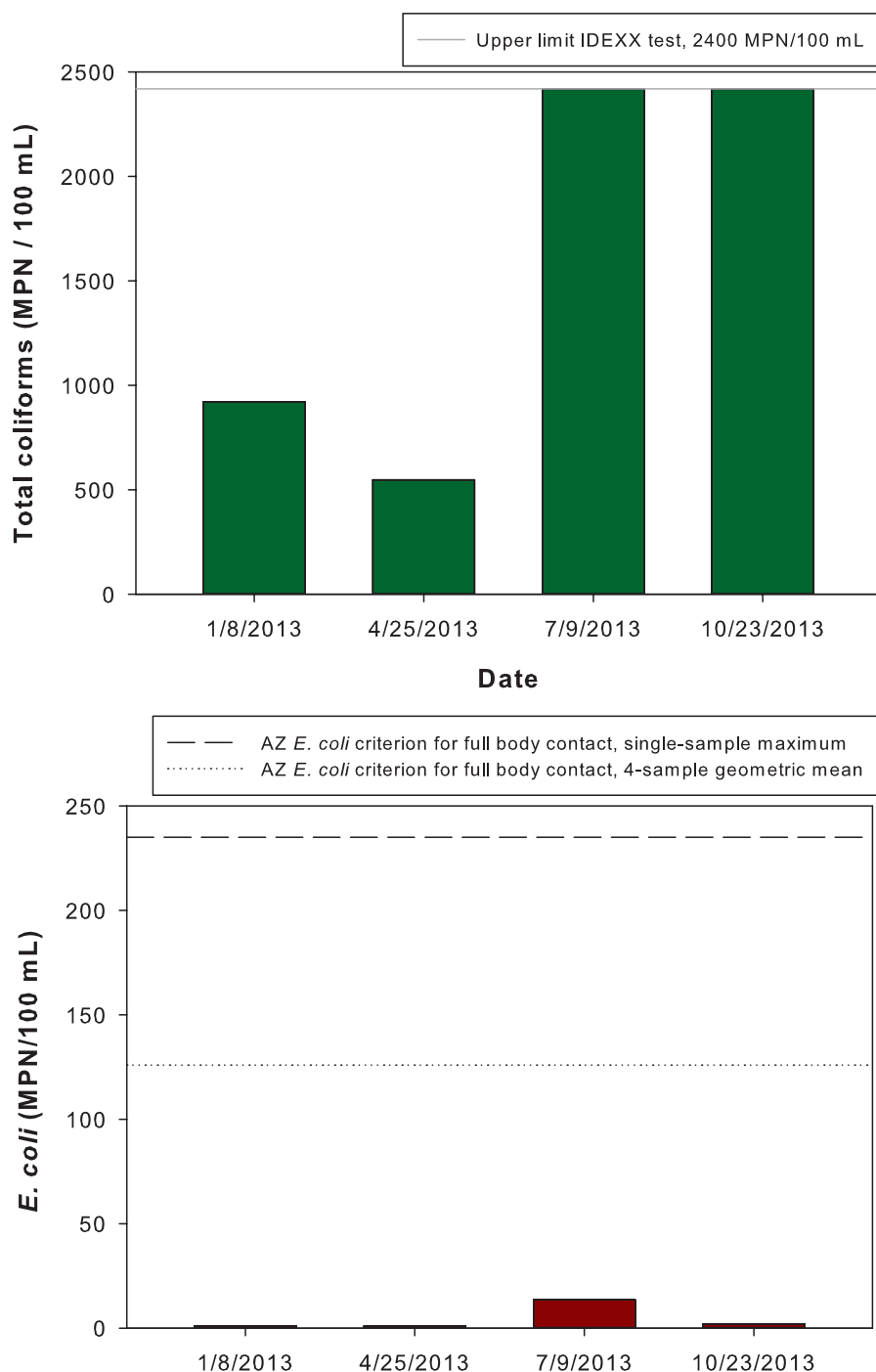


Figure 6. Total coliforms (top) and *E. coli* (bottom) results for samples collected at BRI02 in Grand Canyon NP in 2013.

the Arizona warm water aquatic life criteria for pH and dissolved oxygen. No exceedances were observed.

Median core parameter measurements for the Garden Creek bacteria monitoring sites are summarized in Table 9. The data are split between sites that are not affected by the input of North Rim water, either because they are upstream of the discharge pipe (GAR02 and GAR06) or because they are from a different creek entering down-

samples.

In 2013, three samples for contaminants of emerging concern were collected in April, July, and October at BRI02. There were two detections. The April sample contained 95.3 ng/L of tri(dichloroisopropyl) phosphate, a widely-used flame retardant in polyurethane foam (Table 7). There were no CEC detections in the July sample, and the October sample contained 24.9 ng/L of caffeine.

3.2 Garden and Pipe Creeks

The following sections summarize data collected at Garden and Pipe Creeks from 2011–2013. Data presented include bacteria and core parameter results from sampling trips in March 2011, May 2011, and July 2013. In 2013, SCPN established GAR01 as a long-term water quality monitoring site. Core parameter measurements, bacteria results, and the results for nutrients, major elements, trace metals, and contaminants of emerging concern are presented below.

3.2.1 Water quality core parameter data

Table 8 summarizes water quality core parameter data collected during site visits at GAR01 from 2011–2013. This table includes data measured during the quarterly water quality monitoring in 2013 as well as data collected during the bacteria sampling trips in 2011 and 2012. Also included are

Table 5. Dissolved major element results from BRI02 on Bright Angel Creek in Grand Canyon NP, 2013. Acid neutralizing capacity was determined from an unfiltered sample. No Arizona state criteria have been developed for these analytes.

Major element (mg/L)	Sample collection date and time			
	1/8/13 11:00	4/25/13 7:30	7/10/13 23:55	10/23/13 9:15
Calcium	41.3	37.7	37.7	42.0
Chloride	3.77	2.80	3.16	3.96
Fluoride	0.067	0.061	0.060	0.058
Magnesium	21.0	18.4	20.8	21.1
Potassium	0.932	0.738	1.00	0.907
Silica	5.92	4.46	3.30	5.16
Sodium	3.70	2.85	3.09	3.79
Sulfate	6.00	4.61	4.47	5.77
Acid neutralizing capacity, as CaCO ₃ (unfiltered)	192	170	187	185
Total dissolved solids	219	192	160	164

Table 6. Dissolved trace metal results from samples collected at BRI02 on Bright Angel Creek in Grand Canyon NP, 2013, and number of times samples were outside the applicable water quality criteria. A “nc” indicates that no criterion has been developed for a particular trace metal. A “ndc” indicates that there is no dissolved criterion for the trace metal. Results that were lower than the NWQL reporting levels are noted as “<[reporting level]”.

Trace metal (µg/L)	Sample collection date and time				Most stringent criterion	# of exceedances	Beneficial use ^a
	1/8/13 11:00	4/25/13 7:30	7/10/13 23:55	10/23/13 9:15			
Aluminum	6.31	16.6	2.34	<2.20	nc	nc	nc
Antimony	0.0387	0.0425	0.0564	<0.0270	30, chronic	0	A&Ww
Arsenic	0.902	0.910	0.879	0.855	150, chronic	0	A&Ww
Barium	137	115	140	140	ndc	ndc	ndc
Beryllium	<0.040	<0.040	<0.040	<0.040	ndc	ndc	ndc
Boron	19.6	14.4	19.4	17.1	ndc	ndc	ndc
Cadmium	<0.060	<0.060	<0.060	<0.060	0.81–0.88, chronic	0	A&Ww
Chromium	1.02	0.796	<0.600 ^b	0.690	Cr (III), 114–126; Cr (VI), 11, chronic	0	A&Ww
Cobalt	0.344	0.152	0.246	0.203	nc	nc	nc
Copper	<0.800	<0.800	<0.800	<0.800	14.1–15.6, chronic	0	A&Ww
Iron	25.3	10.7	4.75	9.68	1000, chronic	0	A&Ww
Lead	<0.080 ^b	<0.080	0.254	<0.080	4.46–5.08, chronic	0	A&Ww
Manganese	3.10	1.50	2.01	2.67	ndc	ndc	ndc
Mercury	<0.005	<0.005	<0.005	<0.005	0.01, chronic	0	A&Ww
Molybdenum	0.176	0.138	0.167	0.164	nc	nc	nc
Nickel	<0.400 ^b	<0.400 ^b	<0.400 ^b	<0.400 ^b	81.5–90.3, chronic	0	A&Ww
Selenium	0.371	0.279	0.199	0.284	2 (total), chronic	0	A&Ww
Silver	<0.040	<0.040	<0.040	<0.040	8.01–9.88, acute	0	A&Ww
Uranium	0.634	0.454	0.489	0.540	ndc	ndc	ndc

Table 6. (*continued*) Dissolved trace metal results from samples collected at BRI02 on Bright Angel Creek in Grand Canyon NP, 2013, and number of times samples were outside the applicable water quality criteria. A “nc” indicates that no criterion has been developed for a particular trace metal. A “ndc” indicates that there is no dissolved criterion for the trace metal. Results that were lower than the NWQL reporting levels are noted as “<[reporting level]”.

Trace metal (µg/L)	Sample collection date and time				Most stringent criterion	# of exceedances	Beneficial use ^a
	1/8/13 11:00	4/25/13 7:30	7/10/13 23:55	10/23/13 9:15			
Vanadium	0.759	0.735	0.750	0.625	nc	nc	nc
Zinc	<4.00	<4.00	<4.00	<4.00	184–204, chronic	0	A&Ww

^a A&Ww = Aquatic and Wildlife (warm water) beneficial use designation

^b Results were below the Laboratory Reporting Level, but above the Minimum Detection Level.

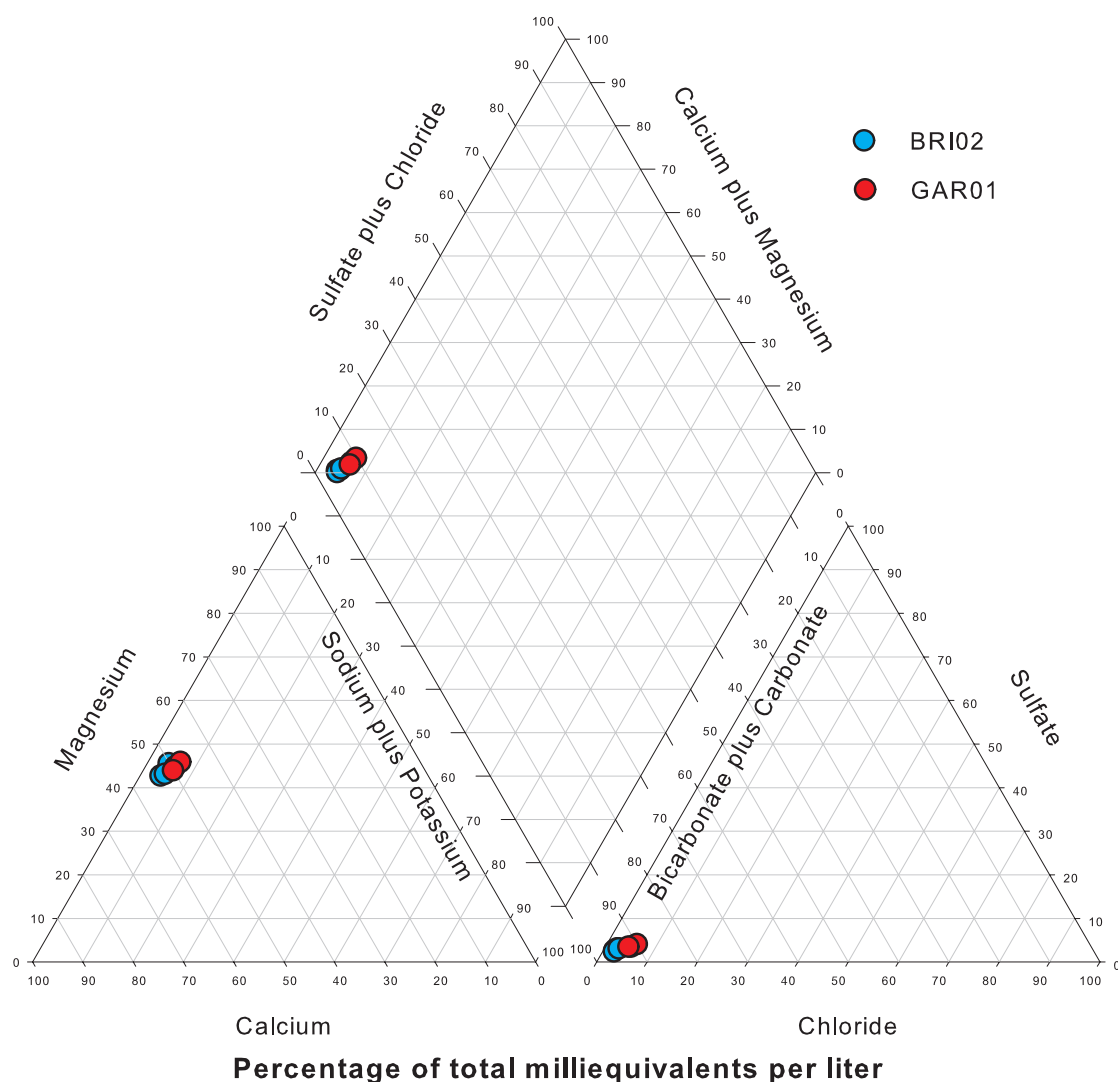


Figure 7. Major ion composition at BRI02 and GAR01 in Grand Canyon NP, 2013.

Table 7. Contaminants of emerging concern (CEC) detections for BRI02 on Bright Angel Creek in Grand Canyon NP, 2013. In 2012, no CECs were detected above the reporting limit in one sample collected at BRI01. In 2013, no CECs were detected above the reporting limit in the sample collected on July 10. There are no Arizona state water quality standards for these analytes. See Appendix C for a complete list of analytes.

CEC	Reporting limit (ng/L)	Use	Sampling date	
			4/25/2013	10/23/2013
Pesticides - no detections				
Pharmaceuticals and Personal Care Products (PPCPs)				
Caffeine	10	Stimulant drug		24.9
Waste Indicators				
Tri(dichloroisopropyl) phosphate	50	Flame retardant	95.3	

Table 8. Summary of water quality core parameter data from GAR01 in Grand Canyon NP, 2011–2013, and Arizona water quality criteria. A “nc” indicates that no criterion exists for a specific parameter.

Parameter	Sampling year						AZ state aquatic life (warm water) criteria
	2011, n=13		2012, n=2		2013, n=7		
	Median	Range	Median	Range	Median	Range	
Water temperature (°C)	14.9	10.5–16.6	15.8	15.7–15.8	17.9 ^b	15.2–19.0	nc
pH	8.5	8.4–8.7	8.3	8.2–8.3	8.3 ^b	7.9–8.6	>6.5 to <9.0
Specific conductance (µS/cm)	395	267–441	380	304–456	375 ^b	360–475	nc
Dissolved oxygen (mg/L)	8.5	8.2–9.6	8.3	7.7–8.9	7.7 ^b	7.6–8.6	>6.0
Turbidity (NTU)	1.2	0.60–8.3	13.9 ^a	13.9 ^a	1.6	0.35–6.3	nc
Discharge (cfs)	1.5	0.7–2.8	1.5	1.1–1.8	1.8	0.5–3.2	nc

^a based on one measurement

^b based on six measurements

stream from the pipe (PIP01). The data from these sites are further split between times that the North Rim water was discharged into Garden Creek and times when the water was being pumped to the South Rim.

Several core parameters in Garden Creek were affected by the input of North Rim water upstream—discharge, turbidity, and specific conductance. The input of North Rim water doubled the discharge of Garden Creek from a median of 1.0 cfs to 2.1 cfs. In addition, an increase in turbidity was observed. Turbidity was very low in all of the Garden Creek samples, but the added input of North Rim water roughly tripled the median measurements of these sites from 0.9 to 2.6 NTU. At the sites GAR02, GAR06, and PIP01, the median discharge was 0.2 cfs and the median turbidity was 0.4 NTU; these medians were the same during times that the pipe was discharging and during times that the water was pumped to the South Rim.

Specific conductance is the third parameter that was affected by the input of North Rim water. Due to this water input, the median specific conductance dropped from 424 µS/cm to 344 µS/cm. At the sites that do not receive the North Rim water, the median specific conductance was 496 µS/cm during times the pipe was discharging and 494 µS/cm during times the water was pumped to the South Rim.

Table 9. Median core parameter measurements for all Garden Creek bacteria monitoring sites in Grand Canyon NP. Sites GAR02, GAR06, and PIP01 do not receive water from the North Rim Pipe, while sites GAR03, GAR01, GAR04, and PIP02 do receive North Rim water when the pipe is discharging. Data for all sites are separated by whether the pipe was discharging during sample collection.

Parameter	Sites	During discharge of North Rim water		Without discharge of North Rim water		AZ state aquatic life (warm water) criteria
		# of samples	Median	# of samples	Median	
Water temperature (°C)	GAR02, GAR06, PIP01	12	16.0	16	17.0	nc
	GAR03, GAR01, GAR04, PIP02	26	15.2	31	14.0	
pH	GAR02, GAR06, PIP01	12	8.1	16	8.2	>6.5 to <9.0
	GAR03, GAR01, GAR04, PIP02	26	8.5	31	8.6	
Specific conductance (µS/cm)	GAR02, GAR06, PIP01	12	496	16	494	nc
	GAR03, GAR01, GAR04, PIP02	26	344	31	426	
Dissolved oxygen (mg/L)	GAR02, GAR06, PIP01	12	7.5	16	7.7	>6.0
	GAR03, GAR01, GAR04, PIP02	26	8.9	30	9.0	
Turbidity (NTU)	GAR02, GAR06, PIP01	13	0.5	16	0.4	nc
	GAR03, GAR01, GAR04, PIP02	27	2.6	30	0.9	
Discharge (cfs)	GAR02, GAR06, PIP01	10	0.2	15	0.2	nc
	GAR03, GAR01, GAR04, PIP02	24	2.1	30	1.0	

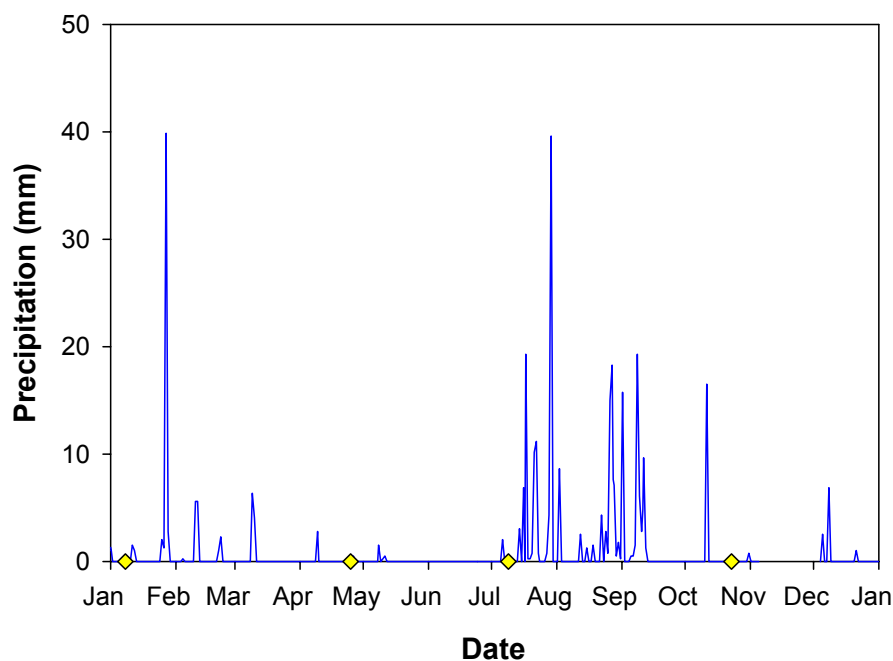


Figure 8. Total daily precipitation from the NADP/NTN AZ03 monitoring station at Hopi Point in Grand Canyon NP, 2013. Yellow diamonds represent SCPN water quality site visits.

3.2.2 Precipitation

Daily precipitation data from 2013 from the NADP/NTN AZ03 weather monitoring station at Hopi Point is presented in Figure 8, along with data from water quality monitoring site visits. Precipitation totaled 341 mm in 2013, though most of the data from November are missing. With the exception of a large event in January, the majority of the precipitation was concentrated during the monsoonal months of July, August, and September; while winter, spring, and fall were dry. None of the water quality visits to Garden Creek occurred during a precipitation event.

3.2.3 Total coliforms and *E. coli*

The results from three *E. coli* sample trips in March 2011, May 2011,

Table 10. Summary of *E. coli* data collected at GAR02, GAR03, GAR01, GAR04, PIP01, and PIP02 in Grand Canyon NP, March 4–6, 2011. Results are separated by whether discharge of North Rim water was occurring. Sites are arranged from upstream to downstream.

Site	During discharge of North Rim water			Without discharge of North Rim water		
	Number of samples	Geometric mean (MPN/100 mL)	Range (MPN/100 mL)	Number of samples	Geometric mean (MPN/100 mL)	Range (MPN/100 mL)
GAR02	n=3	no detections	no detections	n=3	no detections	no detections
GAR03	n=1	no detections	no detections	n=3	no detections	no detections
GAR01	n=3	no detections	no detections	n=3	1	<1–2
GAR04	n=3	no detections	no detections	n=3	1	<1–1
PIP01	n=3	1	<1–4	n=3	1	<1–1
PIP02	n=3	1	<1–1	n=3	no detections	no detections

Table 11. Summary of *E. coli* data collected at GAR02, GAR03, GAR01, GAR04, PIP01, and PIP02 in Grand Canyon NP, May 25–27, 2011. Results are separated by whether Garden Creek was receiving North Rim water or not. Sites are arranged in upstream to downstream order.

Site	During discharge of North Rim water			Without discharge of North Rim water		
	Number of samples	Geometric mean (MPN/100 mL)	Range (MPN/100 mL)	Number of samples	Geometric mean (MPN/100 mL)	Range (MPN/100 mL)
GAR02	n=2	no detections	no detections	n=4	2	<1–12
GAR03	n=2	61	52–72	n=4	1	<1–1
GAR01	n=2	125	120–130	n=4	10	4–21
GAR04	n=2	74	71–78	n=4	14	4–27
PIP01	n=2	1	<1–1	n=4	1	<1–4
PIP02	n=2	66	56–78	n=4	27	6–88

Table 12. Summary of *E. coli* data collected at GAR06, the North Rim Pipe, and GAR01 in Grand Canyon NP, July 8–10, 2013. Results are separated by whether Garden Creek was receiving North Rim water or not. Sites are arranged from upstream to downstream.

	During discharge of North Rim water			Without discharge of North Rim water		
	Number of samples	Geometric mean (MPN/100 mL)	Range (MPN/100 mL)	Number of samples	Geometric mean (MPN/100 mL)	Range (MPN/100 mL)
GAR06	n=2	6	6–7	n=2	4	2–10
North Rim Pipe	n=2	no detections	no detections	–	–	–
GAR01	n=2	20	20–20	n=2	5	4–6

and July 2013 are summarized in Tables 10–12. The sites are arranged in downstream to upstream order, and the data are separated by whether discharge from the North Rim Pipe was occurring. The sites GAR02 and GAR06 on Garden Creek are upstream from the pumphouse and do not receive the additional discharge. The site PIP01 is on Pipe Creek upstream of the confluence with Garden Creek and also does not receive the North Rim water; however the data for these sites are separated for comparison.

During the March 2011 sample event, samples were collected approximately every eight hours during a period of

two days at the six sites in Table 10. The sites GAR02 and PIP01 do not receive the North Rim discharge; GAR02 is located upstream from the pumphouse and PIP01 is located on Pipe Creek just upstream from the confluence with Garden Creek. During this sample event, nearly all results were non-detects (Table 10).

Like the March 2011 sample event, the May 2011 sample event took place during a two day period with samples collected every eight hours. However, during this sample event, the geometric means of every site affected by the North Rim water were higher while the discharge was occurring than when it was not occurring (Table 11). The geometric means for GAR02 and PIP01, which do not receive the additional discharge, were not significantly different. Despite the increase in *E. coli* concentrations during the discharges of North Rim water, none of the samples exceeded the Arizona water quality criteria for *E. coli* during this time period. Those criteria are 235 MPN/100 mL for a single sample or 126 MPN/100 mL for the geometric mean of four samples in a 24-hour period. The highest *E. coli* result occurred at GAR01 and was 130 MPN/100 mL; this result occurred with the input of North Rim water. However, this was not an exceedance of the water quality criteria because the geometric mean of all the samples occurring within that 24-hour period did not exceed 126 MPN/100 mL.

A third bacteria sampling trip occurred in July 2013; this time with fewer sites and reduced number of samples. A new site, GAR06, was added. This site is located upstream from the pumphouse and just downstream from the mule hitching post at Indian Garden. The North Rim Pipe was sampled when it was releasing water, and GAR01 the sampled site downstream from the pipe. Samples were collected every twelve hours over two days, resulting in two samples while the pipe was discharging and two samples while it was not discharging. Results are summarized in Table 12. *E. coli* was not detected in water coming directly from the pipe. However, *E. coli* results were slightly higher at GAR01 while it was receiving water from the North Rim Pipe, though concentrations were well below the Arizona water quality criteria (ADEQ 2009).

Bacteria results from samples taken at all SCPN sites in Garden Creek from 2011–2013 are summarized in Figure 9; the complete dataset is in Appendix B. Included in the dataset are samples collected at GAR01 and the North Rim Pipe during the quarterly site visits in 2014 as well as during the three sample trips in March 2011, May 2011, and July 2013. As in Tables 10–12, the results have been separated into two categories: samples collected while the North Rim water was discharging into Garden Creek, and samples collected while the water was not discharging.

3.2.4 Water quality laboratory data

Results from three sets of samples sent to the NWQL for nutrients, trace metals, and major elements are presented in Tables 13–15. The lowest water quality criteria for dissolved nutrients and trace metals are also presented for the three beneficial uses applicable to this portion of Garden Creek: aquatic and wildlife (warm water), full-body contact, and fish consumption.

Nutrient levels were low and did not change significantly between samples (Table 13). Only the nitrogen species had water quality criteria and levels were well below these criteria. Ammonia and nitrite were present at concentrations near the reporting levels in the January samples but were not detected above 0.0100 mg/L (ammonia) and 0.00100 mg/L (nitrite) in the April and October samples. Nitrite + nitrate was detected in all samples, ranging from 0.078–0.137 mg/L. Orthophosphate ranged from 0.0129–0.0179 mg/L.

Major element results are presented in Table 14; concentrations for each of these analytes did not change significantly between samples. Silica concentrations ranged from 7.50–7.99 mg/L. Acid neutralizing capacity ranged from 199–207 mg/L, and total dissolved solids ranged from 200–217 mg/L. Major ions are plotted in Figure 10, along with results from Garden Creek. The ion composition between the two streams were similar in all samples; cations mainly consisted of calcium and magnesium with very little sodium and potassium. Anions almost entirely consisted of bicarbonate plus carbonate. There are no water quality criteria for these analytes.

Trace metal results are presented in Table 15. Concentrations did not vary significantly between samples, and none of the trace metals were present at levels which exceed the water quality criteria. Eight analytes were not de-

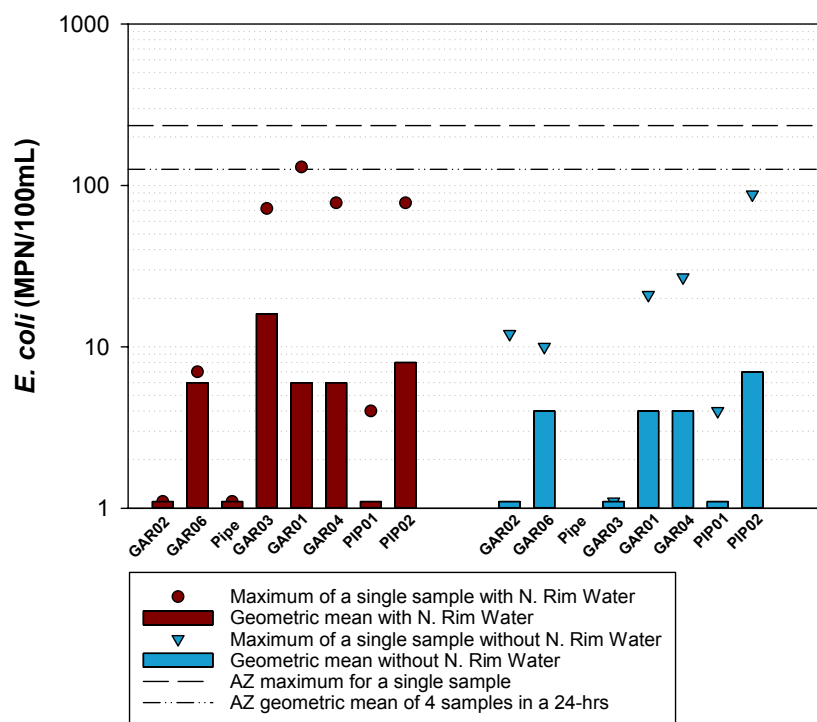


Figure 9. Summary of *E. coli* results from samples taken at Garden and Pipe Creeks in Grand Canyon NP, 2011–2013, with Arizona water quality criteria (AZDEQ 2009).

tected above the laboratory reporting levels: beryllium, cadmium, copper, lead, mercury, nickel, silver, and zinc.

3.2.5 Contaminants of emerging concern

Table 16 summarizes detections for contaminants of emerging concern at GAR01 and GAR02 in 2012–2013. The complete list of analytes is in Appendix C. GAR02 was only sampled once for pesticides, pharmaceuticals, and personal care products on 6/5/12, and there were no detections. Five samples were collected at GAR01 in 2012–2013 and two contaminants were detected: the pain reliever ibuprofen and acetophenone, a chemical used in fragrances and resins.

Table 13. Dissolved nutrient data from GAR01 at Grand Canyon NP, 2013. A “nc” indicates that no criteria have been developed for a particular nutrient. Results that were lower than the National Water Quality Laboratory reporting levels are noted as “<[reporting level]”.

Nutrient mg/L	Sampling date and time			Most stringent criterion	# of exceedances	Beneficial use ^a
	1/8/13 14:05	4/25/13 11:15	10/23/13 13:15			
Ammonia as N	0.0444	<0.0100	<0.0100	2.7–3.2, chronic	0	A&Ww
Nitrite + nitrate as N	0.137	0.0780	0.128	3733 (NO ₃ only)	0	FBC
Nitrite as N	0.00123	<0.00100	<0.00100	233	0	FBC
Orthophosphate as P	0.0145	0.0129	0.0179	nc	nc	nc

^a Beneficial use abbreviations: A&Ww = Aquatic and Wildlife (warm water); FBC=full body contact

Table 14. Dissolved major element results from GAR01 on Garden Creek in Grand Canyon NP, 2013. Acid neutralizing capacity was determined from an unfiltered sample. There are no Arizona state criteria for these analytes.

Major element (mg/L)	Sampling date and time		
	1/8/13 14:05	4/25/13 11:15	10/23/13 13:15
Calcium	42.3	44.0	42.9
Chloride	6.00	7.79	5.33
Fluoride	0.096	0.107	0.088
Magnesium	23.2	25.5	22.7
Potassium	1.10	1.05	1.08
Silica	7.50	7.99	7.54
Sodium	3.98	4.84	3.99
Sulfate	7.94	9.69	7.99
Acid neutralizing capacity, as CaCO ₃ (unfiltered)	199	207	203
Total dissolved solids	217	222	200

Table 15. Dissolved trace metal results from GAR01 on Garden Creek in Grand Canyon NP, 2013, and number of times samples were outside the applicable water quality criteria. A “nc” indicates that no criterion has been developed for a particular trace metal. A “ndc” indicates that there is no dissolved criterion for the trace metal. Results that were lower than the NWQL reporting levels are noted as “<[reporting level]”.

Trace metal (µg/L)	Sampling date and time			Most stringent criterion	# of exceedances	Beneficial use ^a
	1/8/13 11:00	4/25/13 7:30	10/23/13 9:15			
Aluminum	12.1	27.6	9.53	nc	nc	nc
Antimony	0.0336	0.0398	<0.0270	30, chronic	0	A&Ww
Arsenic	1.44	1.47	1.42	150, chronic	0	A&Ww
Barium	215	234	197	ndc	ndc	ndc
Beryllium	<0.040	<0.040	<0.040	ndc	ndc	ndc
Boron	18.0	21.9	15.3	ndc	ndc	ndc
Cadmium	<0.060	<0.060	<0.060	0.91 - 0.95, chronic	0	A&Ww
Chromium	0.903	<0.600	0.930	Cr (III), 131–139; Cr (VI), 11, chronic	0	A&Ww
Cobalt	0.181	0.157	<0.100 ^b	nc	nc	nc
Copper	<0.800	<0.800	<0.80	16.3–17.2, chronic	0	A&Ww
Iron	26.9	28.1	9.85	1000, chronic	0	A&Ww
Lead	<0.080 ^b	<0.080 ^b	<0.080 ^b	5.33–17.3, chronic	0	A&Ww
Manganese	3.89	3.44	2.39	ndc	ndc	ndc
Mercury	<0.005	<0.005	<0.005	0.01, chronic	0	A&Ww
Molybdenum	0.346	0.420	0.333	nc	nc	nc
Nickel	<0.400 ^b	<0.400 ^b	<0.400 ^b	93.9–99.4, chronic	0	A&Ww
Selenium	1.39	1.65	1.18	ndc	ndc	ndc
Silver	<0.040	<0.040	<0.040	10.7–12.0, acute	0	A&Ww
Uranium	0.989	1.06	0.784	ndc	ndc	ndc
Vanadium	0.944	0.831	0.919	nc	nc	nc

Table 15. (continued) Dissolved trace metal results from GAR01 on Garden Creek in Grand Canyon NP, 2013, and number of times samples were outside the applicable water quality criteria. A “nc” indicates that no criterion has been developed for a particular trace metal. A “ndc” indicates that there is no dissolved criterion for the trace metal. Results that were lower than the NWQL reporting levels are noted as “<[reporting level]”.

Trace metal (µg/L)	Sampling date and time			Most stringent criterion	# of exceedances	Beneficial use ^a
	1/8/13 11:00	4/25/13 7:30	10/23/13 9:15			
Zinc	<4.00	<4.00	<4.00	202–212, chronic	0	A&Ww

^a Beneficial use abbreviations: A&Ww = Aquatic and Wildlife (warm water)

^b Results were below the Laboratory Reporting Limit but above the Method Detection Limit.

Table 16. Contaminants of emerging concern detections for GAR01 on Garden Creek in Grand Canyon NP, 2012–2013. No CECs were detected above the reporting limit in samples collected on 6/5/2012, 10/12/2012, 4/25/2013, and 7/10/2013. There are no Arizona state water quality standards for these analytes. See Appendix C for a complete list of CECs.

			Sampling date
CEC	Reporting limit (ng/L)	Use	10/23/2013
Pesticides - no detections			
Pharmaceuticals and Personal Care Products (PPCPs)			
Ibuprofen	10	pain reliever	27.3
Waste Indicators - no detections			

3.3 Hermit Creek

Hermit Creek is visited annually for aquatic macroinvertebrate monitoring. Core parameter data are measured at HER01; the results for 2009–2013 are displayed below in Table 17. None of the measurements exceeded the Arizona water quality criteria.

Table 17. Summary of water quality core parameter data from HER01 in Grand Canyon NP, 2009–2013, and Arizona water quality criteria (warm water criteria). A “nc” indicates that no criterion exists for a specific parameter.

Parameter	Sampling year					AZ state aquatic life
	2009	2010	2011	2012	2013	
Water temperature (°C)	17.5	15.6	13.2	16.7	15.7	nc
pH	8.5	8.7	8.6	8.4	8.8	>6.5 to <9.0
Specific conductance (µS/cm)	429	575	435	442	461	nc
Dissolved oxygen (mg/L)	11.1	nd	9.5	8.7	9.6	<6.0
Turbidity (NTU)	0.35	0.32	nd	5.7	2.2	nc
Discharge (cfs)	nd	nd	0.8	0.6	0.7	nc

4 Quality assurance/Quality control

We followed the Quality Assurance/Quality Control procedures described in Monroe et al. (in preparation) and in National Park Service (2013). To ensure accuracy of the instruments, we calibrated and performed maintenance on the multiparameter sondes in an indoor laboratory four times per year. We checked the current meters according to manufacturer recommendations to determine that they were in working order, and calibrated the turbidimeter quarterly in the lab. The turbidimeter was also checked for drift in the field prior to each measurement.

From 2011–2013, ten blank bacteria samples were processed at GRCA using sterile water. During the same time period, eleven duplicate bacteria samples were collected at several of the GRCA sample sites by filling sample bottles in succession and comparing tray results after the incubation period.

To verify the cleanliness of both the sampling equipment and the sample filtration process for nutrients, major elements, and trace metals, NWQL analyzed two sample sets of certified inorganic blank water in 2013. The results were compared against the 2014 reporting levels. To verify the cleanliness of the sample collection process for Contaminants of Emerging Concern, one bank sample was collected at BRI01 to be analyzed for pesticides, pharmaceuticals, personal care products, and waste indicators.

5 Summary

This report summarizes water quality monitoring activities at Garden, Pipe, Bright Angel, and Hermit Creeks in 2011–2013 in GRCA, and compares the results to the Arizona water quality standards (ADEQ 2009).

NPS core parameter measurements for water temperature, pH, specific conductance, dissolved oxygen, turbidity and discharge were recorded at all site visits. Measurements for pH and dissolved oxygen were within the Arizona state water quality criteria.

In 2011 and 2013, numerous *E. coli* samples were collected along Garden and Pipe Creeks during three two-day sampling efforts to characterize bacteria levels along these streams. No exceedances of Arizona water quality criteria were observed; however, a pattern of increased *E. coli* levels was observed as a result of increased flow levels caused by inputs from the Transcanyon Pipeline. In 2013, *E. coli* samples were collected at BRI02 on Bright Angel Creek as part of SCPN's quarterly water quality monitoring in that stream. No exceedances of Arizona water quality criteria were observed.

Nutrient and trace metal concentrations were below the Arizona water quality criteria at BRI02 and GAR01. A total of ten samples for contaminants of emerging concern were collected at GAR01 and GAR02 on Garden Creek and BRI01 and BRI02 on Bright Angel Creek. Three contaminants were detected: ibuprofen, caffeine, and the flame retardant tri(dichloroisopropyl) phosphate.

The data in this report should be viewed as a snapshot of water quality conditions existing at the time that the data was collected. Data in this report has been validated, but as we continue to explore and use it, we may find issues that cause us to make changes to this data. When sufficient data are available, SCPN plans to produce an interpretive report which will include trend analysis of water quality data for Bright Angel and Garden Creeks in Grand Canyon National Park.

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Appendices

Appendix A: Southern Colorado Plateau Network Water Quality Monitoring Sites in Grand Canyon National Park

Table A1. Southern Colorado Plateau Network (SCPN) water quality monitoring sites for Grand Canyon NP, 2011–2013.

Site code	Common name	Report name	Northing (m) ^a	Easting (m) ^a	Elevation (m) ^a
GRCABRI01 ^b	Bright Angel Creek below first footbridge	BRI01	3998996	403192	945
GRCABRI02	Bright Angel Creek near Colorado River	BRI02	3995562	401526	752
GRCAGAR01 ^b	Garden Creek below Tonto Trail	GAR01	3993992	399029	1085
GRCAGAR02	Garden Creek upstream of Tonto Trail Crossing	GAR02	3993255	398456	1153
GRCAGAR03	Garden Creek downstream of pump house outlet confluence	GAR03	3993402	398642	1129
GRCAGAR04	Garden Creek above confluence with Pipe Creek	GAR04	3994826	399889	807
GRCAGAR06	Garden Creek below Hitching Post	GAR06	3993262	398520	1144
GRCAGAR07	North Rim Pipe discharge to Garden Creek near Pumphouse	GAR07	3993249	398546	1147
GRCAHER01	Hermit Creek below crest stage gage	HER01	3993801	390832	867
GRCAPIP01	Pipe Creek above confluence with Garden Creek	PIP01	3994860	399938	794
GRCAPIP02	Pipe Creek below confluence with Garden Creek	PIP02	3994901	399929	798

^a Horizontal coordinates are reported in Universal Transverse Mercator (UTM) Projection, Zone 1, North American Datum of 1983 (NAD 83). Vertical coordinates are referenced to the North American Vertical Datum of 1988 (NAVD 88).

^b SCPN long-term water quality monitoring sites.

Appendix B: Water quality monitoring results for Bright Angel, Garden, and Pipe Creeks in Grand Canyon National Park, 2011–2013

Table B1. Water quality core parameter data from BRI02 at Bright Angel Creek in Grand Canyon NP, 2013. "nd" indicates that data for the parameter was not collected on that day.

Parameter	Sampling date and time			
	1/8/2013 11:00	4/25/2013 8:10	7/9/2013 23:55	10/23/2013 9:15
Water temperature (°C)	nd	10.9	21.4	11.4
pH	nd	8.4	8.5	8.7
Specific conductance (µS/cm)	nd	278	341	356
Dissolved oxygen (mg/L)	nd	9.1	7.9	10.4
Dissolved oxygen (% saturation)	nd	90	98	103
Turbidity (NTU)	3.8	3.6	1.5	1.0
Discharge cfs	13.1	25.8	18.0	25.4

Table B2. Total coliforms and *E. coli* in samples collected at BRI02 on Bright Angel Creek in Grand Canyon NP, 2013.

Parameter	Sampling date and time			
	1/8/2013 11:00	4/25/2013 8:10	7/9/2013 23:55	10/23/2013 9:15
Total coliforms, MPN/100mL	920	550	>2400 ^a	>2400 ^a
<i>E. coli</i> , MPN/100mL	<1	<1	14	2

^a Exceeded the maximum detection level of the IDEXX system, which is 2400 MPN/100 mL

Table B3. Water quality core parameter data from GAR01 at Garden Creek in Grand Canyon NP, 2011–2013. Whether the creek was experiencing discharge from the North Rim at the time the sample was collected is also noted.

		Sampling date and time							
		3/4/2011 15:45	3/5/2011 0:18	3/5/2011 9:45	3/5/2011 17:25	3/6/2011 1:40	3/6/2011 9:46	4/20/2011 12:00	5/25/2011 18:50
Parameter \	North Rim discharge	yes	no	no	no	yes	yes	yes	yes
Water temperature (°C)		12.4	10.5	10.5	12.1	10.7	11.6	15.2	15.6
pH		8.5	8.5	8.6	8.4	8.5	8.7	8.6	8.4
Specific conductance (µS/cm)		348	396	395	403	352	350	267	324
Dissolved oxygen (mg/L)		9.3	9.4	9.6	9.1	9.4	9.5	8.5	8.4
Dissolved oxygen (% saturation)		99.4	96.3	98.7	96.9	96.8	99.9	96.5	96.8
Turbidity (NTU)		0.90	1.2	0.70	0.85	2.0	1.3	8.3	2.9
Discharge (cfs)		2.8	1.5	1.2	1.2	2.5	2.4	2.1	2.2

		5/26/2011 2:40	5/26/2011 10:40	5/26/2011 15:08	5/27/2011 1:25	5/27/2011 10:06	4/25/2012 12:00	10/12/2012 11:00	1/8/2013 14:05
Parameter \	North Rim discharge	no	no	yes	no	no	yes	no	yes
Water temperature (°C)		14.9	16.6	16.5	15.2	16.3	15.7	15.8	
pH		8.5	8.7	8.5	8.6	8.7	8.3	8.2	
Specific conductance (µS/cm)		437	441	321	436	440	304	456	
Dissolved oxygen (mg/L)		8.3	8.3	8.4	8.2	8.4	8.9	7.7	
Dissolved oxygen (% saturation)		94.1	98.2	98.7	94.3	98.0	102	94.2	
Turbidity (NTU)		0.80	0.80	2.6	2.6	0.60	13.9	-	6.3
Discharge (cfs)		1.2	0.7	1.9	0.8	0.7	1.8	1.1	2.0

		4/25/2013 11:15	7/8/2013 20:20	7/9/2013 7:30	7/9/2013 19:05	7/10/2013 3:20	10/23/2013 13:15
Parameter \	North Rim discharge	yes	yes	no	yes	no	yes
Water temperature (°C)		15.3	18.5	17.8	19.0	17.9	15.2
pH		8.6	7.9	8.3	8.3	8.2	8.5
Specific conductance (µS/cm)		360	371	475	366	468	378
Dissolved oxygen (mg/L)		8.4	7.7	7.6	7.7	7.7	8.6
Dissolved oxygen (% saturation)		95.9	94.4	91.5	93.8	93.0	97.4
Turbidity (NTU)		1.6	2.1	0.85	1.5	0.35	1.9
Discharge (cfs)		2.1	1.7	0.5	1.8	0.5	3.2

Table B4. Water quality core parameter data from GAR02 at Garden Creek in Grand Canyon NP, 2011.

Parameter	Sampling date and time					
	3/4/2011 18:50	3/4/2011 23:00	3/5/2011 7:55	3/5/2011 18:02	3/6/2011 2:35	3/6/2011 10:30
Water temperature (°C)	13.9	13.4	12.9	14.1	13.0	14.1
pH	8.1	8.1	8.2	8.0	8.2	8.3
Specific conductance (µS/cm)	458	457	457	467	469	470
Dissolved oxygen (mg/L)	7.6	7.7	7.9	7.5	7.7	8.0
Dissolved oxygen (% saturation)	84.4	84.4	85.1	84.0	83.7	88.9
Turbidity (NTU)	0.80	0.65	0.80	0.75	0.80	0.85
Discharge (cfs)	0.16	0.16	0.16	-	0.14	0.14

Parameter	Sampling date and time					
	5/25/2011 15:35	5/25/2011 23:49	5/26/2011 7:25	5/26/2011 18:05	5/27/2011 2:00	5/27/2011 7:23
Water temperature (°C)	17.9	17.0	17.3	17.9	17.4	17.2
pH	7.8	8.2	8.1	8.1	8.2	8.3
Specific conductance (µS/cm)	460	471	461	459	464	463
Dissolved oxygen (mg/L)	6.5	6.9	6.7	6.6	6.8	6.8
Dissolved oxygen (% saturation)	78.9	82.7	80.3	80.3	81.0	81.5
Turbidity (NTU)	0.15	0.20	0.15	0.30	0.20	0.30
Discharge (cfs)	0.19	0.24	0.24	-	0.22	0.22

Table B5. Water quality core parameter data from GAR03 at Garden Creek in Grand Canyon NP, 2011. Whether the creek was experiencing discharge from the North Rim at the time the sample was collected is also noted.

		Sampling date and time					
		3/4/2011 18:10	3/5/2011 1:02	3/5/2011 8:30	3/5/2011 16:15	3/6/2011 0:30	3/6/2011 8:20
Parameter \	North Rim discharge	yes	no	no	no	yes	yes
Water temperature (°C)		12.1	11.6	11.3	13.0	11.6	11.6
pH		8.4	8.4	8.5	8.3	8.5	8.5
Specific conductance (µS/cm)		333	380	380	384	335	334
Dissolved oxygen (mg/L)		9.0	8.9	9.0	8.7	9.1	9.1
Dissolved oxygen (% saturation)		96.1	93.5	94.0	94.6	95.4	96.2
Turbidity (NTU)		0.90	0.75	0.65	0.50	1.4	1.1
Discharge (cfs)		2.5	1.3	1.3	1.1	3.0	2.2

		5/25/2011 17:25	5/26/2011 00:25	5/26/2011 8:50	5/26/2011 17:13	5/26/2011 23:54	5/27/2011 8:30
Parameter \	North Rim discharge	yes	no	no	yes	no	no
Water temperature (°C)		15.7	15.8	16.1	15.8	15.7	16.0
pH		8.2	8.0	8.5	8.0	8.4	8.6
Specific conductance (µS/cm)		297	426	430	299	424	432
Dissolved oxygen (mg/L)		8.3	7.8	7.7	8.4	-	7.7
Dissolved oxygen (% saturation)		96.2	91.4	89.8	97.9	-	89.9
Turbidity (NTU)		2.6	0.80	0.80	2.4	0.80	0.65
Discharge (cfs)		2.0	0.5	0.6	2.1	-	0.6

Table B6. Water quality core parameter data from GAR04 at Garden Creek in Grand Canyon NP, 2011.

Parameter \ North Rim discharge	Sampling date and time					
	3/4/2011 18:05	3/5/2011 1:42	3/5/2011 8:31	3/5/2011 16:55	3/6/2011 0:48	3/6/2011 7:59
	yes	no	no	no	yes	yes
Water temperature (°C)	10.0	7.4	6.7	10.1	8.3	8.3
pH	8.6	8.5	8.6	8.8	8.8	8.9
Specific conductance (µS/cm)	358	397	395	379	339	336
Dissolved oxygen (mg/L)	10.4	10.5	10.8	9.8	10.7	10.7
Dissolved oxygen (% saturation)	100.2	98.9	99.3	99.1	100.0	99.9
Turbidity (NTU)	3.1	1.0	1.0	0.85	3.4	2.9
Discharge (cfs)	2.7	1.2	1.2	1.2	-	-

Parameter \ North Rim discharge	5/25/2011 18:00	5/25/2011 0:40	5/26/2011 8:21	5/26/2011 17:24	5/27/2011 0:40	5/27/2011 8:32
	yes	no	no	yes	no	no
Water temperature (°C)	16.0	13.7	14.5	16.0	14.1	14.7
pH	8.7	8.8	8.9	8.6	8.6	8.7
Specific conductance (µS/cm)	329	369	418	335	363	429
Dissolved oxygen (mg/L)	8.9	9.3	9.3	8.8	9.1	9.1
Dissolved oxygen (% saturation)	99.6	99.1	100.7	98.6	98.4	99.6
Turbidity (NTU)	2.9	2.0	1.0	4.8	1.5	0.90
Discharge (cfs)	1.9	0.8	0.7	1.9	0.8	0.8

Table B7. Water quality core parameter data from from GAR06 at Garden Creek in Grand Canyon NP, 2013.

Parameter	Sampling date and time				
	4/25/2013 11:40	7/8/2013 21:05	7/9/2013 8:20	7/9/2013 19:52	7/10/2013 4:00
Water temperature (°C)	-	19.9	19.8	20.0	19.4
pH	-	7.8	8.0	7.9	7.9
Specific conductance (µS/cm)	-	497	493	495	494
Dissolved oxygen (mg/L)	-	5.8	6.3	5.6	6.0
Dissolved oxygen (% saturation)	-	73.1	78.8	70.5	74.2
Turbidity (NTU)	0.20	0.70	0.50	0.45	0.60
Discharge (cfs)	-	0.2	0.2	0.3	0.2

Table B8. Water quality core parameter data from GAR07 (the Trans Canyon Pipeline) at Garden Creek in Grand Canyon NP, 2013.

Parameter	Sampling date and time		
	4/25/2013 11:30	7/8/2013 20:35	7/9/2013 19:40
Water temperature (°C)	-	18.2	20.5
pH	-	8.2	8.1
Specific conductance (µS/cm)	-	308	296
Dissolved oxygen (mg/L)	-	8.1	7.6
Dissolved oxygen (% saturation)	-	97.8	96.0
Turbidity (NTU)	5.7	0.60	0.30
Discharge (cfs)	-	-	-

Table B9. Water quality core parameter data from PIP01 at Pipe Creek in Grand Canyon NP, 2011.

Parameter	Sampling date and time					
	3/4/2011 17:34	3/5/2011 1:24	3/5/2011 8:04	3/5/2011 16:23	3/6/2011 0:00	3/6/2011 7:40
Water temperature (°C)	12.4	8.7	7.6	13.2	9.3	8.4
pH	8.3	8.2	8.3	8.5	8.6	8.6
Specific conductance (µS/cm)	1498	1364	1482	1411	1405	1400
Dissolved oxygen (mg/L)	9.4	9.9	10.2	8.9	10.1	10.4
Dissolved oxygen (% saturation)	96.8	95.7	96.6	96.3	96.6	97.8
Turbidity (NTU)	0.60	0.90	0.55	0.35	3.4	0.30
Discharge (cfs)	0.2	0.1	0.2	0.1	0.2	

Parameter	Sampling date and time					
	5/25/2011 17:16	5/26/2011 0:09	5/26/2011 8:02	5/26/2011 16:50	5/27/2011 0:15	5/27/2011 8:05
Water temperature (°C)	20.5	17.6	17.0	19.8	17.8	16.9
pH	8.1	8.3	8.4	8.0	8.2	8.2
Specific conductance (µS/cm)	1326	1323	1304	1370	1350	1315
Dissolved oxygen (mg/L)	7.2	7.8	8.3	7.3	7.6	8.0
Dissolved oxygen (% saturation)	89.2	90.9	95.6	89.1	89.7	92.1
Turbidity (NTU)	0.25	0.40	0.40	0.35	0.40	0.45
Discharge (cfs)	0.0	0.0	0.0	0.0	0.0	0.0

Table B10. Water quality core parameter data from PIP02 at Pipe Creek in Grand Canyon NP, 2011.

Parameter \ North Rim discharge	Sampling date and time					
	3/4/2011 16:39	3/5/2011 1:10	3/5/2011 7:39	3/5/2011 15:39	3/5/2011 0:37	3/6/2011 7:33
	yes	no	no	no	yes	yes
Water temperature (°C)	10.8	7.7	6.6	10.7	8.4	8.1
pH	8.5	8.4	8.6	8.7	8.8	8.9
Specific conductance (µS/cm)	545	579	531	505	414	405
Dissolved oxygen (mg/L)	10.1	10.3	10.7	9.7	10.6	10.7
Dissolved oxygen (% saturation)	99.3	97.8	98.5	99.0	99.2	99.4
Turbidity (NTU)	2.7	1.1	1.1	1.2	3.2	2.0
Discharge (cfs)	2.7	1.2	1.4	1.4	2.2	-

Parameter \ North Rim discharge	5/25/2011 16:32	5/25/2011 23:30	5/26/2011 7:30	5/26/2011 14:40	5/26/2011 23:27	5/27/2011 7:23
	yes	no	no	yes	no	no
Water temperature (°C)	16.6	14.0	13.9	16.4	14.6	13.8
pH	8.6	8.7	8.8	8.6	8.6	8.6
Specific conductance (µS/cm)	348	390	488	352	368	501
Dissolved oxygen (mg/L)	8.7	9.1	9.2	8.6	8.8	9.0
Dissolved oxygen (% saturation)	98.9	97.7	98.2	97.7	96.6	97.0
Turbidity (NTU)	2.7	2.2	1.1	5.1	4.9	1.1
Discharge (cfs)	2.0	1.0	0.7	1.8	1.1	0.8

Table B11. Total coliforms and *E. coli* in samples collected in Garden and Pipe Creeks in Grand Canyon NP, 2011 and 2013. Sites are listed in upstream to downstream order. Samples that exceeded the maximum detection level of the IDEXX system, which is 2400 MPN/100 mL, are indicated by ">2400". GAR02, GAR06 and PIP01 do not receive water from North Rim discharge,

Site	Sampling date	Sampling time	Total coliforms (MPN/100 mL)	<i>E. coli</i> (MPN/100 mL)	During discharge from North Rim?
GRCAGAR02	3/4/2011	18:50	180	<1	yes
	3/4/2011	23:00	180	<1	no
	3/5/2011	7:55	180	<1	no
	3/5/2011	18:02	300	<1	no
	3/6/2011	2:35	>2400	<1	yes
	3/6/2011	10:30	220	<1	yes
	5/25/2011	15:35	870	<1	yes
	5/25/2011	23:49	790	12	no
	5/26/2011	7:25	1200	<1	no
	5/26/2011	18:05	1000	<1	yes
	5/27/2011	2:00	610	1	no
	5/27/2011	7:23	920	<1	no
GRCAGAR06	4/25/2013	11:40	1700	<1	yes
	7/8/2013	21:05	>2400	6	yes
	7/9/2013	8:20	>2400	2	no
	7/9/2013	19:52	>2400	7	yes
	7/10/2013	4:00	>2400	10	no
GRCAGAR07 (North Rim pipe)	4/25/2013	11:30	<1	<1	-
	7/8/2013	20:35	22.8	<1	-
	7/9/2013	19:40	<1	<1	-
GRCAGAR03	3/4/2011	18:10	300	<1	yes
	3/5/2011	1:02	770	<1	no
	3/5/2011	8:30	920	<1	no
	3/5/2011	16:15	1600	<1	no
	5/25/2011	17:25	>2400	72	yes
	5/26/2011	0:25	>2400	<1	no
	5/26/2011	8:50	2400	<1	no
	5/26/2011	17:13	>2400	52	yes
	5/26/2011	23:54	2400	<1	no
	5/27/2011	8:30	>2400	1	no
GRCAGAR01	3/4/2011	15:45	520	<1	yes
	3/5/2011	0:18	870	<1	no
	3/5/2011	9:45	1200	2	no
	3/5/2011	17:25	1600	<1	no
	3/6/2011	1:40	820	<1	yes
	3/6/2011	9:46	370	<1	yes
	5/25/2011	18:50	>2400	120	yes
	5/26/2011	2:40	2400	4	no
	5/26/2011	10:40	>2400	8	no

Table B11. (continued) Total coliforms and *E. coli* in samples collected in Garden and Pipe Creeks in Grand Canyon NP, 2011 and 2013. Sites are listed in upstream to downstream order. Samples that exceeded the maximum detection level of the IDEXX system, which is 2400 MPN/100 mL, are indicated by ">2400".

Site	Sampling date	Sampling time	Total coliforms (MPN/100 mL)	<i>E. coli</i> (MPN/100 mL)	During discharge from North Rim?
	5/26/2011	15:08	>2400	130	yes
	5/27/2011	1:25	>2400	21	no
	5/27/2011	10:06	>2400	17	no
	1/8/2013	14:05	2400	1	yes
	4/25/2013	11:15	1300	<1	yes
	7/8/2013	20:20	>2400	20	yes
	7/9/2013	7:30	>2400	4	no
	7/9/2013	19:05	>2400	20	yes
	7/10/2013	3:20	1700	6	no
	10/23/2013	13:15	480	<1	no
GRCAGAR04	3/4/2011	18:05	1200	<1	yes
	3/5/2011	1:42	610	<1	no
	3/5/2011	8:31	920	<1	no
	3/5/2011	16:55	1600	1	no
	3/6/2011	0:48	>2400	<1	yes
	3/6/2011	7:59	870	<1	yes
	5/25/2011	18:00	2400	78	yes
	5/26/2011	0:40	1600	24	no
	5/26/2011	8:21	2000	4	no
	5/26/2011	17:24	>2400	71	yes
	5/27/2011	0:40	>2400	27	no
	5/27/2011	8:32	1400	13	no
GRCAPIP01	3/4/2011	17:34	2000	4	yes
	3/5/2011	1:24	1200	1	no
	3/5/2011	8:04	1100	<1	no
	3/5/2011	16:23	1700	<1	no
	3/6/2011	0:00	1700	1	yes
	3/6/2011	7:40	1300	<1	yes
	5/25/2011	17:16	1000	<1	yes
	5/26/2011	0:09	1600	<1	no
	5/26/2011	8:02	2400	<1	no
	5/26/2011	16:50	1700	1	yes
	5/27/2011	0:15	2400	<1	no
	5/27/2011	8:05	1600	4	no
GRCAPIP02	3/4/2011	16:39	920	1	yes
	3/5/2011	1:10	490	<1	no
	3/5/2011	7:39	920	<1	no
	3/5/2011	15:39	1700	<1	no
	3/6/2011	0:37	2000	<1	yes
	3/6/2011	7:33	870	<1	yes

Table B11. (*continued*) Total coliforms and *E. coli* in samples collected in Garden and Pipe Creeks in Grand Canyon NP, 2011 and 2013. Sites are listed in upstream to downstream order. Samples that exceeded the maximum detection level of the IDEXX system, which is 2400 MPN/100 mL, are indicated by ">2400".

Site	Sampling date	Sampling time	Total coliforms (MPN/100 mL)	<i>E. coli</i> (MPN/100 mL)	During discharge from North Rim?
	5/25/2011	16:32	>2400	78	yes
	5/25/2011	23:30	1600	48	no
	5/26/2011	7:30	>2400	6	no
	5/26/2011	15:40	>2400	56	yes
	5/26/2011	23:27	>2400	88	no
	5/27/2011	7:23	1100	20	no

Appendix C: List of analytes and reporting limits for contaminants of emerging concern

Table C1. Target analytes and U.S. Environmental Protection Agency reporting limits for pesticides

Analyte	Reporting limit (ng/L)	Analyte	Reporting limit (ng/L)
2,4,5-T	10	EPTC	20
2,4,5-TP	10	Ethoprop	10
2,4-D	10	Fipronil	20
3-Hydroxycarbofuran	10	Fipronil sulfide	10
Acetochlor	20	Hexazinone	10
Acetochlor OA	20	Imazaquin	20
Alachlor	20	Imazethapyr	10
Alachlor OA	50	Imidacloprid	20
Aldicarb	10	Linuron	20
Aldicarb sulfone	20	Malathion	10
Aldicarb sulfoxide	10	MCPP	20
Atrazine	10	Metalaxyl	10
Atrazine de-ethyl	20	Methiocarb	10
Atrazine de-isopropyl	20	Methomyl	20
Atraton	50	Metolachlor	10
Azoxystrobin	20	Metolachlor ESA	20
Bentazon	10	Metribuzin	20
Bromacil	50	Monuron	10
Bromoxynil	10	Neburon	50
Butachlor ESA	10	Oryzalin	20
Carbaryl	10	Oxamyl	10
Carbofuran	10	Pentachlorophenol	50
Chlorimuron ethyl	20	Prometon	10
Cyanazine	10	Propachlor	10
3-Hydroxycarbofuran	10	Propachlor ESA	20
Dacthal monoacid	20	Propazine	50
Diazinon	10	Propiconazole	20
Dichloroprop	10	Propoxur	10
Dimethachlor	10	Simazine	20
Dimethenamid	10	Sulfometuron methyl	20
Dimethenamid ESA	20	Tebuconazole	50
Disulfoton sulfone	20	Tebuthiuron	10
Diuron	50	Terbuthylazine	10
Diuron Metabolite	50	Thiamethoxam	20

Table C2. Target analytes and U.S. Environmental Protection Agency reporting limits for pharmaceuticals and personal care products

Analyte	Reporting limit (ng/L)	Analyte	Reporting limit (ng/L)
Acebutolol	10.0	Fenbufen	10.0
Albuterol	10.0	Fentanyl	10.0
Alprazolam	10.0	Flunitrazepam	10.0
Amitriptyline	10.0	Furosemide	10.0
Amitriptyline, (+/-)-E-10-hydroxylated	10.0	Gabapentin	25.0
Amphetamine	10.0	Gemfibrozil	10.0
Atenolol	10.0	Glipizide	10.0
Atrazine	10.0	Glyburide	10.0
Benzoylecgonine	10.0	Hydrocodone	10.0
Benzphetamine	10.0	Hydromorphone	10.0
Bezafibrate	10.0	m-Hydroxybenzoylecgonine	10.0
Brombuterol	10.0	Ibuprofen	10.0
Butabarbital	25.0	Levorphanol	10.0
Butalbital	10.0	Loratadine	10.0
n-Butylparaben	25.0	Mefenamic acid 3-carboxy	10.0
Carbamazepine 10,11 epoxide	10.0	MDA	10.0
Caffeine	10.0	MDEA	10.0
Cannabidiol	25.0	MDMA	10.0
Cannabinol	25.0	Meperidine	10.0
Carbamazepine	10.0	Mephobarbital	25.0
Carisoprodol	10.0	Meprobamate	10.0
Chloramphenicol	10.0	Metformin	10.0
Chlordiazepoxide	10.0	Methamphetamine	10.0
Chlorpheniramine	10.0	Methaqualone	10.0
Cimetidine	10.0	Methylparaben	10.0
Clenbuterol	10.0	Methypylon	10.0
Clobazam	10.0	Metoprolol	10.0
Clonazepam	10.0	Monensin	10.0
Clonidine	10.0	Morphine	10.0
Cocaethylene	10.0	Naproxen	10.0
Cocaine	10.0	Nifedipine	10.0
Codeine	10.0	Nifedipine oxidized	10.0
DEET	10.0	Nitrazepam	10.0
Dextromethorphan	10.0	Norfentanyl	10.0
Diazepam	10.0	Norfluoxetine	10.0
Diclofenac	10.0	Norverapamil	10.0
aDiltiazem	10.0	Omeprazole	10.0
Diphenhydramine	10.0	Oxycodone	10.0
Ecognine Methyl Ester	10.0	Oxymorphone	10.0
Erythromycin	10.0	Paroxetine	10.0

Table C2. (*continued*) Target analytes and U.S. Environmental Protection Agency reporting limits for pharmaceuticals and personal care products

Analyte	Reporting limit (ng/L)	Analyte	Reporting limit (ng/L)
Famotidine	10.0	Pentazocine	10.0
Fenbendazole	10.0	Phencyclidine	10.0
Phendimetrazine	10.0	Talbutal	25.0
Phenmetrazine	10.0	Temazepam	10.0
Phenobarbital	10.0	Testosterone	10.0
Phentermine	10.0	(+/-)11-nor-9-carboxy-delta-THC	10.0
Phenylpropanolamine	10.0	THC	25.0
Phenytoin	10.0	Thebaine	10.0
Pindolol	10.0	Thiabendazole	10.0
Prazepam	10.0	Tramadol	10.0
Progesterone	10.0	Trazodone	10.0
Propranolol	10.0	Triamterene	10.0
Pseudoephedrine	10.0	Triazolam	10.0
Ranitidine	10.0	Triclocarban	10.0
Secobarbital	10.0	Triclosan	10.0
Sildenafil	10.0	Trimethoprim	10.0
Simvastatin	10.0	Tylosin	10.0
Sotalol	10.0	Venlafaxine	10.0
Sulfamethazine	10.0	Verapamil	10.0
Sulfamethoxazole	10.0	Warfarin	10.0
Sumatriptan	10.0		

Table C3. Target analytes and U.S. Environmental Protection Agency reporting limits for wastewater indicators

Analyte	Reporting limit (ng/L)	Analyte	Reporting limit (ng/L)
Acetophenone	50.0	Menthol	50.0
Benzophenone	50.0	3-Methyl Indole	50.0
Bisphenol A	50.0	Methyl Salicylate	50.0
Bromacil	50.0	2-Methylnaphthalene	50.0
Butylated Hydroxyanisole	50.0	1-Methylnaphthalene	50.0
Caffeine	50.0	2,6-Dimethylnaphthalene	50.0
Camphor	50.0	Metolachlor	50.0
Carbaryl	50.0	Musk ketone	50.0
Carbazole	50.0	Naphthalene	50.0
Celestolide	50.0	Nonylphenol	50.0
Chlorpyrifos	50.0	4-n-Octylphenol	50.0
p-Cresol	50.0	4-tert-Octylphenol	50.0
4-Cumylphenol	50.0	Pentachlorophenol	50.0
Dacthal	50.0	Phantolide	50.0
Diazinon	50.0	Phenanthrene	50.0
1,4-Dichlorobenzene	50.0	Phenol	50.0
Dichlorvos	50.0	Prometon	50.0
Equilenin	50.0	Pyrene	50.0
17beta-Estradiol	50.0	Tonalide	50.0
Estrone	50.0	Tributyl Phosphate	50.0
Ethinylestradiol	50.0	Triclosan	50.0
Fluoranthene	50.0	Tri(dichloroisopropyl) Phosphate	50.0
Galaxolide	50.0	Triethyl Citrate	50.0
Indole	50.0	Tri(2-butoxyethyl) Phosphate	50.0
Isoborneol	50.0	Tri(2-chloroethyl) Phosphate	50.0
Isophorone	50.0	Triphenyl phosphate	50.0
Isoquinoline	50.0		

Appendix D: Abbreviations, chemical formulas, and symbols used in this report

Term	Definition
ANC	acid neutralizing capacity of solutes plus particulates in an unfiltered water sample
CaCO ₃	chemical formula for calcium carbonate
cfs	cubic feet per second
cfu/100 ml	colony forming units, for bacteria sampling, a measure of the number of viable bacteria per 100 mL
LRL	laboratory reporting level
MDL	method detection level
µg/L	micrograms per liter
µS/cm	microsiemens per centimeter at 25°C, a measure of specific conductance
mg/L	milligrams per liter
Milliequivalents per liter	an expression of the concentration of substances that is chemically equivalent in terms atomic weight and electrical charge
MPN/100 mL	most probable number, for sampling bacteria, a statistical estimation of the number of coliform that would give the results shown by the laboratory examination
N	chemical symbol for the element nitrogen
ng/L	nanograms per liter
NTU	nephelometric turbidity unit, a measure of turbidity
P	chemical symbol for the element phosphorous

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