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Trends in Water Quality at Bryce Canyon National Park, Water Years 2006–2021

Natural Resource Report NPS/NCPN/NRR—2022/2476



ON THE COVER

Springflow and irrigation water run through Water Canyon at Bryce Canyon National Park. NPS photo.

Trends in Water Quality at Bryce Canyon National Park, Water Years 2006–2021

Natural Resource Report NPS/NCPN/NRR—2022/2476

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Unit Abbreviations

Unit abbreviations used in this report.

Abbreviation	Meaning
kg/m^2	kilograms per square meter
mg/L	milligrams per liter
MPN/100 mL	most probable number per hundred milliliters
cfs	cubic feet per second
µS/cm	microSiemens per centimeter
NTU	nephelometric turbidity units
d	dissolved
µg/L	micrograms per liter

Executive Summary

The National Park Service collects water-quality samples on a rotating basis at three fixed water-quality stations in Bryce Canyon National Park (NP): Sheep Creek, Yellow Creek, and Mossy Cave Spring. Data collection began at Sheep Creek and Yellow Creek in November 2005 and at Mossy Cave in July 2008. Data on in-situ parameters, fecal-coliform samples, major ions, and nutrients are collected monthly, while trace elements are sampled quarterly. This report analyzes data from the beginning of the period of record for each station through water year 2021 to test for trends over time. Concentrations are also compared to relevant water-quality standards for the State of Utah.

Overall, water quality at the park's monitoring stations continues to be excellent, and park managers have been successful in their goal of maintaining these systems in unimpaired condition. High-quality conditions may qualify all three sites as Category 1 waters, the highest level of anti-degradation protection provided by the State of Utah. Infrequent but continued *Escherichia coli* exceedances coinciding with trespass livestock at Sheep and Yellow creeks support the need for regular fence maintenance along the park boundary.

Minimum and maximum air temperatures at the park have increased, while precipitation remains highly variable. Increasing air temperatures have led to increasing water temperatures in Sheep and Yellow creeks. Sheep Creek also had a decrease in flow across several quantiles from 2006 to 2021, while higher flows decreased at Yellow Creek in the same period. Surface flows in these two creeks are likely to be increasingly affected by higher evapotranspiration due to warming air temperatures and possibly decreasing snowmelt runoff as the climate changes. The influx of ancient groundwater in both creek drainages helps sustain base flows at the sites.

Mossy Cave Spring, which is sampled close to the spring emergence point, showed less of a climate signal than Sheep and Yellow creeks. In our record, the spring shows a modest increase in discharge, including higher flows at higher air temperatures. An uptick in visitation to Water Canyon and the Mossy Cave Trail has so far not been reflected by changes in water quality.

There were additional statistical trends in water-quality parameters at all three sites. However, most of these trends were quite small and likely ecologically negligible. Some statistical trends may be the result of instrument changes and improvements in quality assurance and quality control over time in both the field sampling effort and the laboratory analyses.

Long-term monitoring of water-quality stations at Bryce Canyon NP suggests relatively stable aquatic systems that benefit from protection within the park. To maintain these unimpaired conditions into the future, park managers could consider:

- Regular fence checks and maintenance along active grazing allotments at the park boundary to protect riparian areas and aquatic systems from trespass livestock.
- Developing a springs-monitoring program to track changes in springflow at spring emergences to better understand bedrock-aquifer water supplies. These data would also help quantify springflow for use in water-rights hearings.
- Supporting hydrogeologic investigations to map the extent and flow paths of groundwater aquifers.
- Working with the State of Utah to develop groundwater-protection zones to protect groundwater aquifers from developments that would affect springs in the park.
- Prioritizing watershed management with proactive fire risk-reduction practices.
- Explicitly including watershed protection as a goal in plans for fire management and suppression.

- Using additional data and analyses to better understand the drivers of trends in water quality and their ecological significance. These could include higher-frequency data to better understand relationships between groundwater, precipitation, and surface flows at the sites. These could also include watershed metrics, such as vegetation cover and site shading, or integrated aquatic metrics, such as aquatic-invertebrate sampling.

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1 Introduction

The overall mission of the National Park Service (NPS) is to conserve the natural and cultural resources of the National Park System for the enjoyment of this and future generations. Surface waters at Bryce Canyon National Park (NP) sustain aquatic and riparian habitat, serve as a source of drinking water for wildlife and backcountry visitors, and are active erosional agents that continue to carve drainages through the park's famous geologic formations (Thornberry-Ehrlich 2005).

The Northern Colorado Plateau Network (NCPN) began collecting routine water-quality data in November 2005 as part of an initiative to provide long-term monitoring of natural resources to parks. Such data are critical to protecting surface waters, groundwater, and drinking-water sources within the park (NPS 2014). Previous evaluations of water-quality data have documented very few exceedances of water-quality standards at Bryce Canyon NP (Thoma et al. 2008, Van Grinsven et al. 2010, Hackbarth and Weissinger 2013, Hackbarth and Weissinger 2016, Hackbarth and Weissinger 2020).

Potential land uses that may affect water quality include agricultural practices, conversion of wildlands to residential properties, increased population, livestock grazing, increased visitor use, and hydrologic diversions and dams (Evenden et al. 2002). Wildfire can also affect water quality, and dual threats of climate warming and previous fire suppression have tended to increase the size and severity of wildfires that now occur (Westerling et al. 2006). Exceedances of water-quality standards can also occur during flood events that mobilize soil, feces, and other potential contaminants from steep and sparsely vegetated watersheds.

Water-quality data are important not only for pinpointing problem areas, but also for showing long-term changes in watersheds and streams. Analysis of water-quality trends can indicate whether conditions are improving or degrading in the park's streams and rivers, providing valuable information to park managers for use in management decisions. Long-term datasets can also document variability in the aquatic system.

The purpose of the NCPN water-quality program can be framed in a series of general questions that can be answered quantitatively via measurable objectives.

1. What are the ranges in water-quality parameters for selected streams of NCPN parks?
2. What are the current status and long-term trends in selected water-quality parameters at surface-water sites monitored in NCPN parks?
3. How do NCPN surface waters compare to State of Utah standards for designated beneficial uses?

1.1 Purpose and scope

The purpose of this report is to evaluate water-quality data collected at three long-term monitoring sites in Bryce Canyon NP from water years (WY) 2006 to 2021 for statistically significant temporal trends, and to compare those concentrations to designated beneficial uses and water-quality standards for the State of Utah.

Water-quality stations were evaluated for as many as 34 constituents each. Constituents included core parameters such as flow, water temperature, dissolved oxygen, pH, specific conductance, and turbidity, as well as laboratory analyses, including fecal-indicator bacteria (*Escherichia coli*), major ions, nutrients, and trace elements (Table 1-1). All data are publicly available in the Environmental Protection Agency's Water Quality Exchange (WQX).

1.2 Study area

Bryce Canyon National Park is a long, roughly rectangular area located on the eastern rim of the Paunsaugunt Plateau in south-central Utah. The park is approximately 145 km^2 in size, and elevation ranges from approximately 2,300 to 2,760 meters. Annual precipitation averages 395 millimeters, with an average annual snowfall of 222 centimeters at park headquarters (wrcc.dri.edu, accessed 9/12/22). The park is located on the divide between the Paria River, a

Table 1-1. Water-quality parameters evaluated by the NCPN water-quality monitoring program.

Sample type	Parameters
Core parameters	flow, water temperature, dissolved oxygen, specific conductance, pH, turbidity, *Escherichia coli*
Major ions	alkalinity, calcium, chloride, magnesium, potassium, sodium, sulfate, total dissolved solids
Nutrients	ammonia, nitrite+nitrate, dissolved nitrogen, dissolved phosphorus, total phosphorus
Trace elements	aluminum, arsenic, barium, boron, cadmium, chromium, copper, iron, lead, manganese, mercury, nickel, silver, zinc

Colorado River tributary, and the East Fork Sevier River, which drains into the Great Basin to the north (Thornberry-Ehrlich 2005). The area is mostly rural, with low population density (Baril et al. 2018), and much of the park is bounded by national forest land. More than two million people visit the park each year (irma.nps.gov/STATS, accessed 9/12/22).

The Paunsaugunt Plateau is an upthrust fault block that forms the highest step of the Grand Staircase along the north side of the Colorado River. The plateau feeds surface runoff into the headwaters of the East Fork Sevier River, which flows northeast. Abundant snowmelt recharges quaternary valley-fill aquifers that supply the park water system and neighboring municipalities (Wallace et al. 2021). Vegetation on the plateau ranges from ponderosa-pine forests at the park's northern end to dense mixed-conifer forests in the south.

The fault that forms the east scarp of the Paunsaugunt Plateau exposes the Pink Cliffs of the Claron Formation, a Tertiary-age limestone, sandstone, mudstone, and conglomerate. This relatively soft rock has formed more than a dozen deeply eroded amphitheaters along the rim. Rapid erosion has also exposed Cretaceous-age sandstones and mudstones that make up the Grey Cliffs, predominately the Kaiparowits/Wahweap Formations and the Straight Cliffs Formation. Below the rim, ponderosa pine, Utah juniper, and pinyon pine dominate the overstory vegetation.

Bedrock aquifers flow primarily to the east and north, as indicated by the many springs emerging on the park's eastern slopes (Doremus and Kreamer 2000)—although some springs emerge on the western and southern ends, as well. Of 33 springs identified during a springs inventory in 1996, twenty had measurable flow (Ott 1996). Additional inventory work in 2022 identified more than 70 springs in the park (NPS unpublished data). Analyses of groundwater chemistry and hydrogeology suggest that spring water at Bryce Canyon emits via multiple subsurface flow systems. Valley-fill aquifers recharge rapidly following precipitation, while springs in the Claron Formation have modern groundwater with a likely travel time of several decades (Wallace et al. 2021). Much longer subsurface travel times, perhaps thousands of years, characterize springs emerging from Cretaceous aquifers, as evidenced by higher iron and sulfate concentrations (Doremus and Kreamer 2000).

Network and park staff selected three locations for long-term water-quality monitoring: Sheep Creek, Yellow Creek, and Mossy Cave Spring (Figure 1-1). Sheep and Yellow creeks drain into the Paria River, while Mossy Cave Spring drains into the East Fork Sevier River.

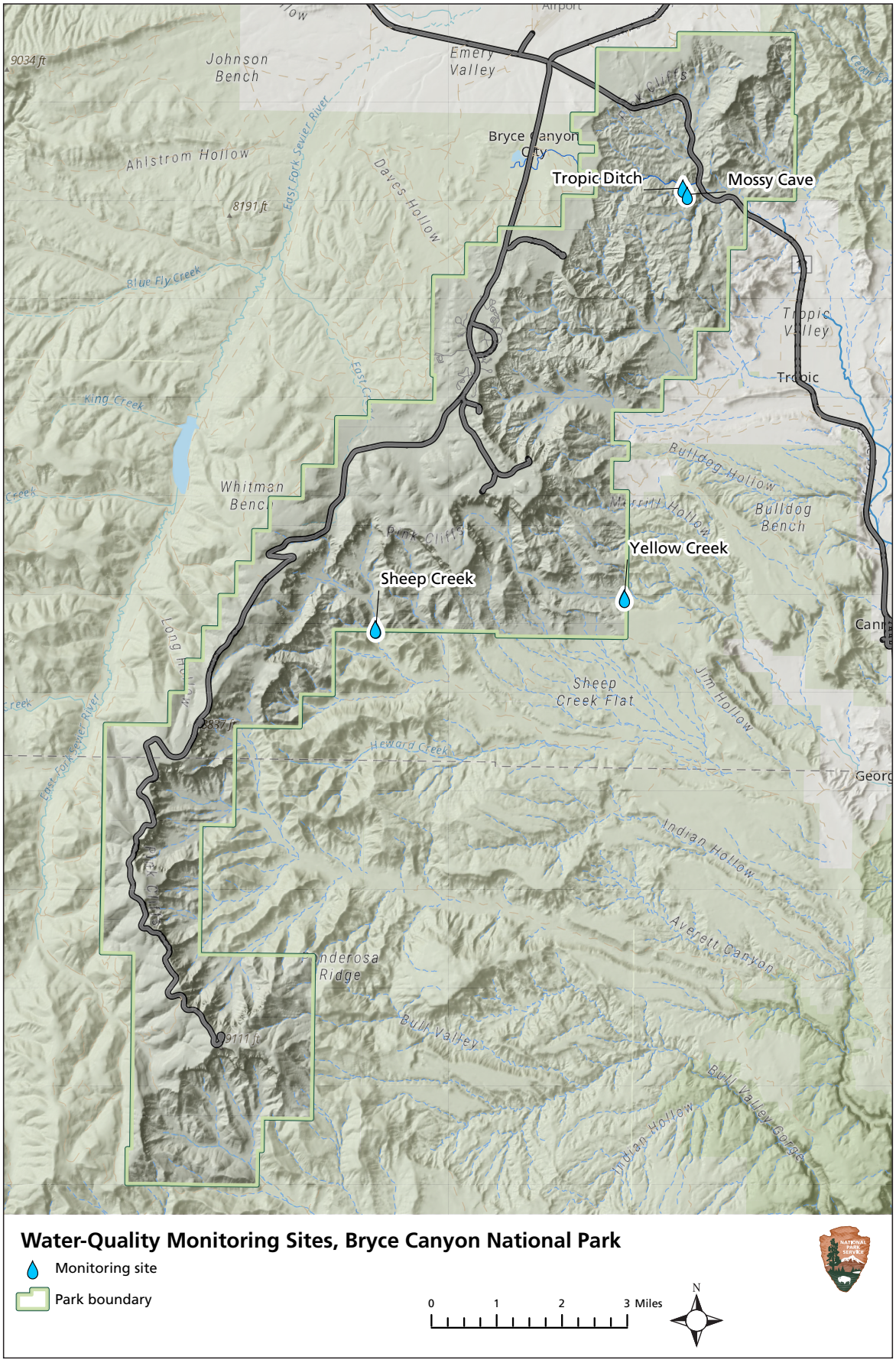


Figure 1-1. Long-term water-quality monitoring stations at Bryce Canyon National Park.

1.2.1 Sheep and Yellow creeks

The sampling locations in Sheep and Yellow creeks are in perennial reaches of intermittent streams in their respective drainages near the downstream boundary of the park (Figures 1-2 to 1-5). Water at the sampling locations is likely a variable mix of older groundwater and recent precipitation. The downstream locations were chosen due to concerns about frequent trespass cattle entering the drainages at this boundary. Both creeks have backcountry campsites upstream from the monitoring locations, and park visitors use the creeks as backcountry water sources.



Figure 1-2. Representative photo of the sampling location at Sheep Creek in August 2018.



Figure 1-3. Representative photo of the sampling location at Yellow Creek in August 2018.

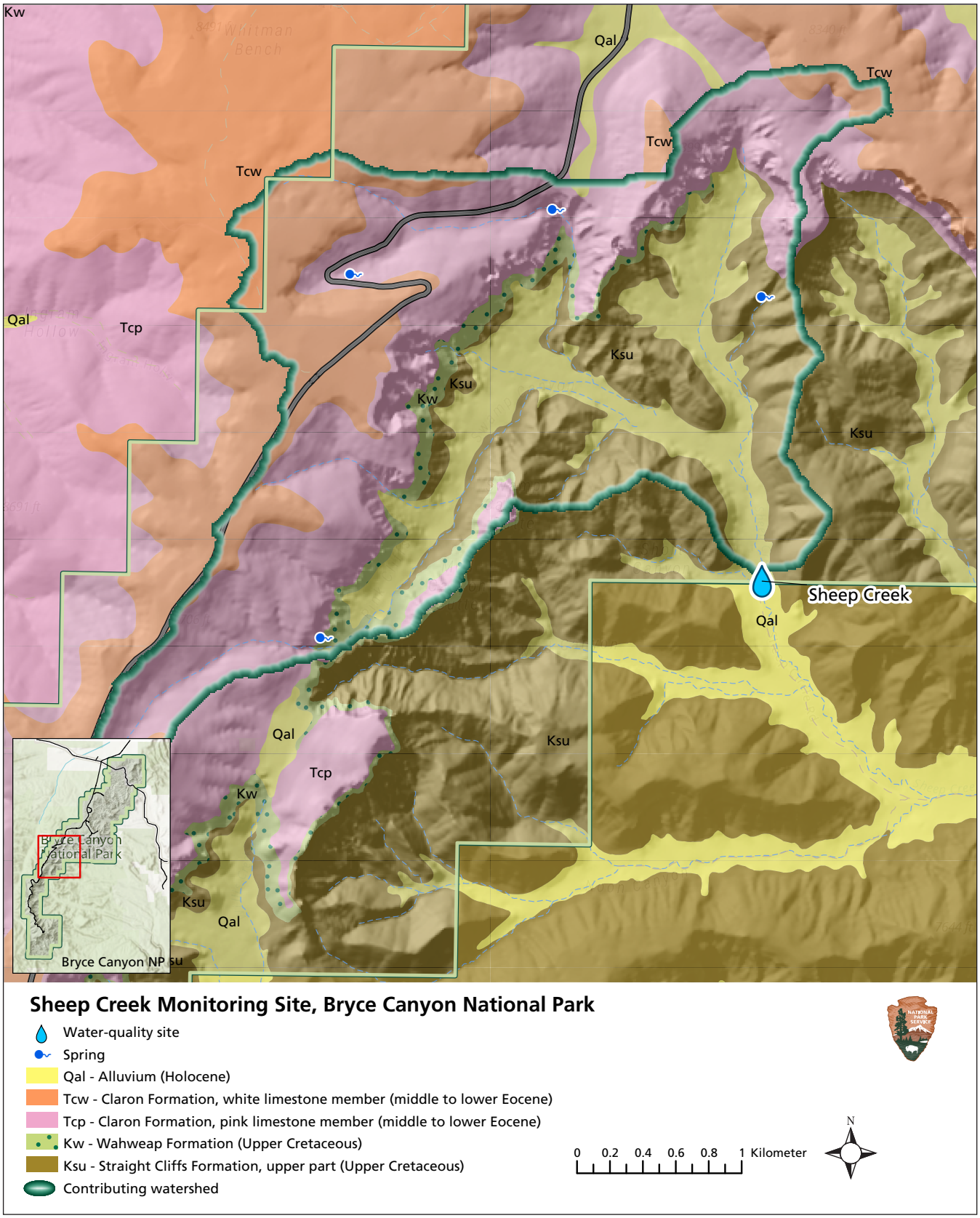


Figure 1-4. Location of the Sheep Creek water-quality monitoring station and geologic outcroppings in its contributing watershed. Watershed boundaries were estimated from digital elevation models using the AGWA toolset in ArcGIS.

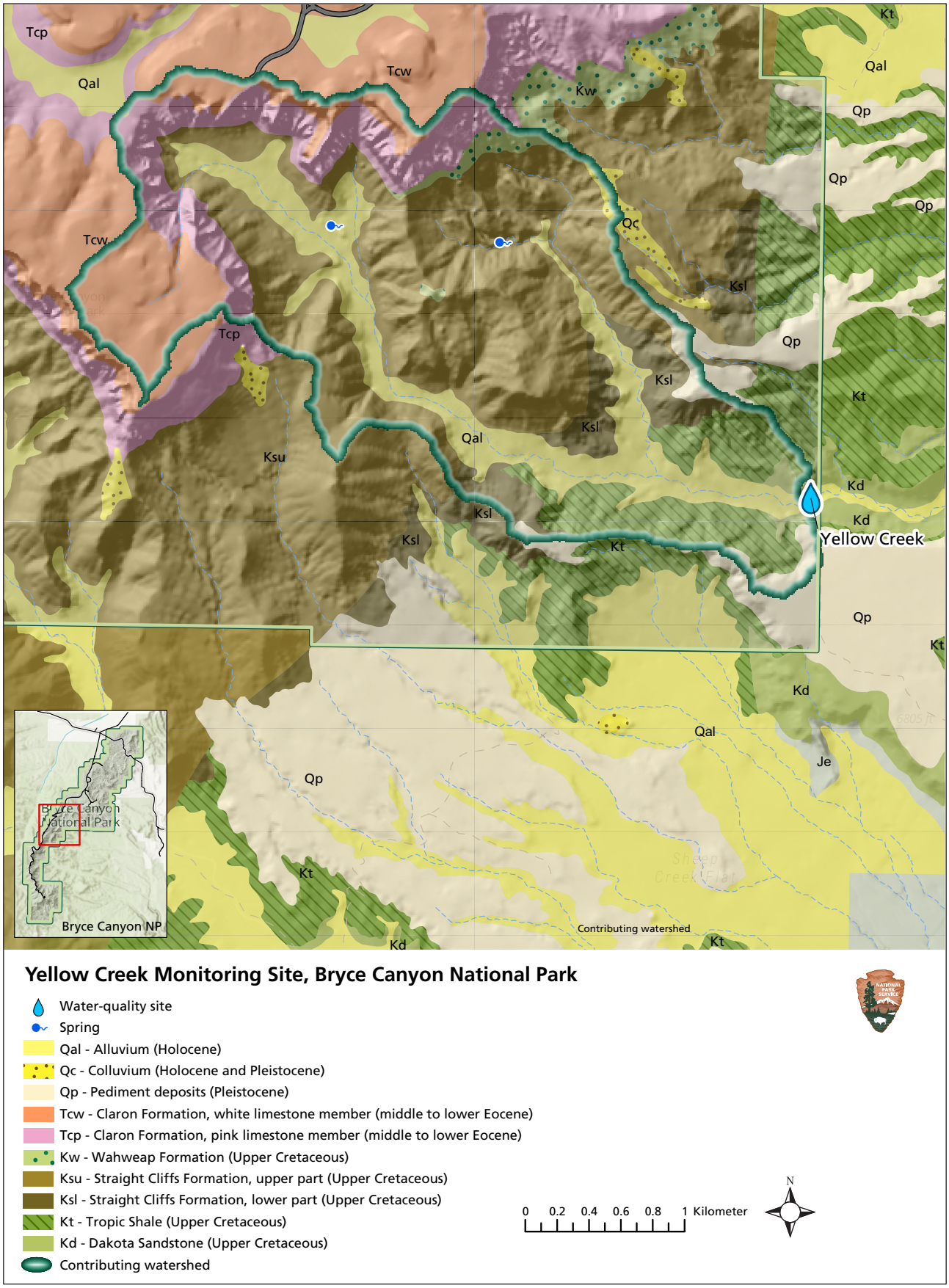


Figure 1-5. Location of the Yellow Creek water-quality monitoring station and geologic outcroppings in its contributing watershed. Watershed boundaries were estimated from digital elevation models using the AGWA toolset in ArcGIS.

Springs further up each canyon emerge in alluvial valley bottoms from the Straight Cliffs Formation (Ott 1996), and contribute to the groundwater component at the sites. High sulfate concentrations stem from interactions with the marine sediments in several layers of this formation (Doremus and Kreamer 2000). Radiocarbon samples from bedrock wells in similar geologic strata west of the park indicate a subsurface flow of at least 4,000–5,000 years (Wallace et al. 2021). Snowmelt and runoff from the watersheds of Sheep and Yellow creeks (9.6 km^2 and 8.2 km^2 respectively) contribute to surface flows at the sites and recharge the alluvial valley aquifers.

1.2.2 Mossy Cave Spring and Tropic Ditch

Mossy Cave Spring emerges from a shallow alcove in the pink limestone member of the Claron Formation, along a contact of bedrock and alluvium (Ott 1996). Rivulets flow about 10 meters down a vegetated alluvial slope and coalesce into a spring channel, where flow and water-quality measurements are taken (Figures 1-6 to 1-8). The water sampled is primarily spring-derived, with little influence from snowmelt. Tritium samples collected in 1999 indicated a subsurface flow of more than 50 years for groundwater emerging at Mossy Cave Spring (Doremus and Kreamer 2000). Additional sampling in 2019 suggested modern recharge since or just prior to 1952 (Wallace et al. 2021). Mossy Cave is located near the terminus of a short hiking trail that receives heavy visitation. Park staff have noticed an increase in visitors recreating in the water in Water Canyon, the drainage downslope of Mossy Cave that is augmented by flow from the spring, additional springs, and an irrigation canal.

Several additional springs emerge in the vicinity of Mossy Cave in Water Canyon. This area is also affected by the presence of a trans-basin irrigation canal, Tropic Ditch. The ditch was built in 1890–1892 to divert water from the East Fork Sevier River to the Paria River Valley for field irrigatation during the growing season, roughly April 1–October 15. The Tropic Ditch runs approximately 15 kilometers and is piped until it daylights in an unlined channel in Water Canyon, upgradient of Mossy Cave Spring. Seepage from the last 3–5 kilometers likely infiltrates into Water Canyon and could contribute to some portion of discharge from springs (Doremus and Kreamer 2000). However, water-chemistry analyses suggest the water is mostly distinct between the two (Doremus and Kreamer 2000, Wallace et al. 2021).



Figure 1-6. Representative photo of the outflow from Mossy Cave Spring, showing the outflow channel with weir in place and Water Canyon in the foreground, May 2019.



Figure 1-7. Representative photo of the outflow from Mossy Cave Spring, showing the outflow channel into Water Canyon with Tropic Ditch irrigation water flowing right to left through Water Canyon in the foreground, August 2016.

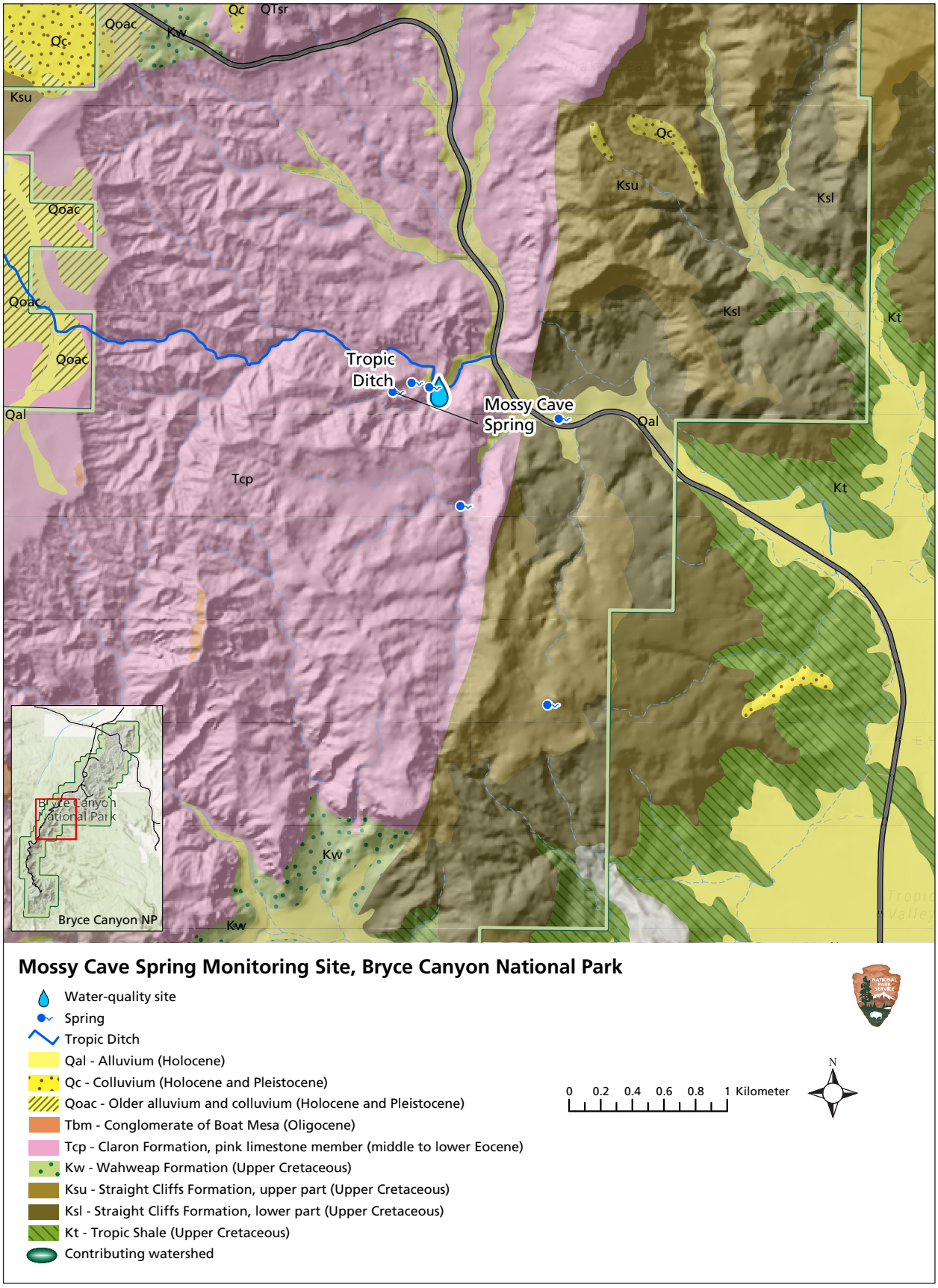


Figure 1-8. Location of the Mossy Cave water-quality monitoring location and the Claron Formation outcrop. An irrigation canal, Tropic Ditch, flows just upgradient from the spring and discharges through Water Canyon. Mossy Cave is a spring with only minimal surface inputs from the watershed.

2 Methods

2.1 Field data collection

Sampling began at Sheep and Yellow creeks in November 2005, and at Mossy Cave Spring in July 2008. Yellow Creek and Mossy Cave Spring are sampled on alternating two-year cycles, while Sheep Creek is sampled every year. From November 2005 to September 2011, core parameters, major ions, and nutrient samples were collected monthly, while trace-element samples were collected quarterly. From October 2011 to September 2021, monthly samples were collected for 10 months of the year, with only one sample collected during the winter months of December–February. Trace elements continued to be sampled quarterly. This change in sampling schedule was made because of the difficulty in accessing most sites during the winter, and was based on the observation that flow and water-quality conditions were typically consistent through the winter and could be adequately documented with fewer samples (Thoma et al. 2017).

Field-data collection methods follow standards outlined in the Northern Colorado Plateau Network's water-quality monitoring protocol (Thoma et al. 2017). During each sampling event, manual streamflow measurements were made using a flow meter, 8" portable flume, or portable v-notch weir, depending on site conditions. Water temperature, pH, specific conductance, and dissolved oxygen were measured in the field using a calibrated multiparameter water-quality sonde. Turbidity was measured in the field using a calibrated Hach 2100P turbidimeter. Fecal-indicator bacteria samples were collected, held on ice, and processed within eight hours using the IDEXX Colilert 2000 method (IDEXX undated).

Water samples were collected as surface grab samples from the center of the channel in a well-mixed portion of the stream. Each sample was processed into four aliquots according to requirements for preserving water chemistry until laboratory analysis: an unfiltered aliquot for major anions (unpreserved), an unfiltered and acidified (sulfuric acid) aliquot for total nutrients, a 0.45-µm filtered and acidified aliquot (sulfuric acid) for dissolved nutrients, and a 0.45-µm filtered and acidified aliquot (nitric acid) for major cations and trace metals. Samples were kept on ice and shipped to the Utah Public Health Laboratory within five days of sample collection.

2.2 Analytical methods and quality assurance

Water-quality samples were analyzed for major ions, nutrients, and trace elements at the EPA-certified Utah State Public Health Laboratory using EPA-approved methods. A list of analytical methods is presented in Appendix A. Replicate samples were collected monthly from the project's onset, while field blanks were added in October 2013. Quality assurance methods are detailed in Weissinger (2016). Data were reviewed visually for anomalous results, and by identifying outliers and calculating a charge balance for the sample. Anomalous results were reviewed for errors based on field datasheets, visit comments, and lab sheets. Charge balance could be calculated for 291 of 307 sample visits. Seven of these had a charge balance of >15%; lab results from these visits were excluded from the analysis.

2.2.1 Bias

Laboratory proficiency-testing data indicated a positive bias for total dissolved solids (TDS) from 2011 to 2016 and a negative bias from 2017 to 2021. Chloride had increasing positive bias from 2015 to 2020 that stabilized between 2% and 6% in 2021. These analytical biases, although within the acceptable range for lab certification, could underlie reported trends over time for these parameters. In 2013, the laboratory changed analytical methods for dissolved selenium, and the method change corresponded to a drop in reported concentrations below reporting limits for independent sites across the NCPN. Selenium is not included in this report because the data are not comparable before and after this analytical method change.

Field blanks were submitted beginning in October 2013, including 59 blanks for major ions and nutrients and 34 blanks for trace elements. Field-blank detections were gener-

ally less than the long-term reporting limits and detected concentrations in our source water samples. The exceptions were dissolved and total phosphorus. In April 2011, the Utah state lab began reporting phosphorus at the minimum detection levels (MDL) rather than at the long-term reporting limits. More than 50% of field blanks had detections higher than the MDL of 0.003 mg/L from 2013 to 2021. Most of the field-blank phosphorus detections ranged from 0.003 to 0.01 mg/L. In our source-water samples for Bryce Canyon NP, 94% of detected values were <0.01 mg/L. Most of our data overlapped the range with frequent blank detections for total and dissolved phosphorus. For a more detailed investigation of phosphorus, see Appendix B.

2.2.2 Variability

Variability was calculated as a Relative Percent Difference (RPD) between replicate and environmental samples using the formula:

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

Where:

- S_1 = concentration in the environmental sample
- S_2 = concentration in the replicate sample

Major constituents were evaluated for an RPD of <15%. Trace elements and nutrients are often detected at very low concentrations, increasing uncertainty about precision and accuracy (Hem 1985). For this reason, trace elements and nutrients were evaluated for an RPD of <30% (Thoma et al. 2017). Measurements also were considered to be acceptable if replicate pairs both fell below the reporting limit (values censored), or if one measurement was below the reporting limit and the other was within three times the reporting limit. Programmatically, 97.3% of major ions, 98.9% of trace elements, and 92.1% of nutrients met data-quality goals during the period of record.

2.3 Trend analysis

Data were evaluated for monotonic trends using a seasonal Kendall test adjusted for the possibility of serial correlation. Data summary and analysis were completed using the freeware R v.4.1.0 (R Core Team 2021). Seasonal Kendall tests and Sen-slope estimates were calculated using the EnvStats package for R (Millard 2013). Practices followed those outlined in the standard USGS approach to the seasonal Kendall analysis, as described in Schertz and others (1991).

The seasonal Kendall is a non-parametric, rank-based test, meaning it scores concentrations as higher or lower than a seasonal median value but does not evaluate the magnitude of departure from the median. For this reason, the seasonal Kendall test is robust for evaluating water-quality datasets, which often contain extreme concentrations and censored values.

The seasonal Kendall test accounts for expected seasonal variation in water-quality parameters by comparing concentrations within user-defined seasons (e.g., monthly, quarterly, semi-annual) and then aggregating the results for each season into an overall test for trend at a site (Helsel et al. 2002). For example, if the season is set to "monthly," then samples collected during May are always compared to other samples from May, while August samples are always compared to August samples. The trends for each defined season are then combined to determine whether there is an overall trend for that constituent. Seasons with opposite trends are cancelled out in this analysis, and would result in an overall evaluation of no trend. A consistent trend across seasons would result in an overall upward or downward trend.

For NCPN samples, monthly or quarterly seasons were used, depending on the sampling interval for each parameter. Data were summarized and evaluated to determine the number of samples available for each parameter and site combination (e.g., dissolved oxygen at Yellow Creek). Site and parameter combinations with fewer than five years or 20 observations were excluded from analysis due to the limited ability to detect trends in

very short or small datasets (Schertz et al. 1991). Trend analyses were evaluated at $p \leq 0.05$ for statistical significance: that is, at a level that indicates it is very likely a trend exists in the data.

2.3.1 Detection limits and data censoring

Some water-quality parameters, especially nutrients and trace elements, typically have very low concentrations that are close to the detection limits of common analytical methods. Water samples without detectable levels of an analyte are reported as below the reporting limit (e.g., <0.003 mg/L for total phosphorus) and are referred to as censored data because a cut-off, rather than a true value, is known. As analytical methods or laboratory practices change, the reporting limits can also change, so it is common for multiple reporting limits to apply to a single water-quality parameter over time. Unless otherwise noted below, datasets were censored to the highest reporting limit for analysis.

Site and parameter combinations with <50% of the dataset composed of non-detects (censored data) were analyzed for trends in ambient concentrations using the seasonal Kendall test. For site and parameter combinations with <5% censored concentrations, a non-parametric slope of the magnitude of the trend, called a Sen slope, was calculated to represent the median annual change in a parameter. We calculated an estimate of the total change over the period of record as (annual rate of change × number of years in record), and the magnitude of the change as (total change divided by the median concentration × 100). For datasets with >5% censored data, the Sen slope is biased toward being a low estimate of the rate of change, and no slope estimates or rates of change are presented (Schertz et al. 1991). Site and parameter combinations with >50% censored data are summarized in this report but were excluded from trend analysis due to the limited ability to detect trends in highly censored datasets.

For most parameters, changes in reporting limits did not change the analysis approach described above, with two notable exceptions. For chloride, the reporting limit changed from 10 mg/L to 3.5 mg/L in November 2011. Prior to this change, there were no chloride detections at any of the park monitoring sites. We removed the earlier data from the analysis and analyzed chloride concentrations from November 2011 on to enable censoring to the lower reporting limit of 3.5 mg/L.

Dissolved and total phosphorus dropped from a reporting limit of 0.02 mg/L to 0.003 mg/L in November 2011. For these parameters, detections above reporting limits occurred throughout the record, and removing part of the dataset or censoring to the highest reporting limit would have removed much of the available information. Phosphorus data were instead analyzed with censored regression models for multiple reporting limits using the NADA package in R (Lee 2017). Maximum Likelihood Estimation was used to estimate trends and summary statistics (Helsel 2012).

2.3.2 Relationships to flow

Many water-quality parameters change in concentration with changes in stream flow. Flow-related variability may be large in comparison to changes in water quality in response to other drivers, such as land-use changes or other human activities. Adjusting concentrations for flow can reduce variability in the dataset and make it easier to detect trends that stem from causes other than changes in streamflow. However, NCPN's sampling design avoids sampling during flash-flood events, and few higher-flow events are captured in our dataset. Targeted sampling of higher-flow events would be necessary to build these relationships in the future. Because we could not adequately model the relationship of concentration to flow, we do not present flow-adjusted concentrations in this report, instead focusing our analysis on ambient concentrations. One visit to Yellow Creek occurred during a high-flow event, resulting in outlying values for many parameters. We analyzed data for trends with and without this flood event; trend-analysis results did not differ. We present data for Yellow Creek without the high-flow event so that patterns are easier to see without these outliers.

2.4 Water-quality standards comparison

When applicable, concentrations were compared to basic and site-specific water-quality standards published by the State of Utah in R317-2 (effective date 12/3/2020; accessed at adminrules.utah.gov on 8/29/22). These standards include beneficial uses, such as drinking water, recreation, aquatic life, and agricultural uses, as assigned to each site. For a complete list of beneficial uses and associated water-quality standards used in this report, see Appendix C.

For a single parameter, numeric criteria for water-quality standards address potential effects of both chronic exposure over an extended period of time (months) and acute exposure over a short period of time (hours or days). Acute standards indicate poor water quality if even a single sample does not meet the standard. Chronic standards must be exceeded in 10% or more of samples to indicate poor water quality. Water-quality standards are much lower for chronic exposure than for acute exposure.

Criteria for chronic exposure are not directly comparable to the results obtained from a one-time monthly grab sample. From a compliance standpoint, the acute instantaneous criteria afford the only direct comparison for such concentrations. However, from a resource-conservation standpoint, instantaneous grab-sample concentrations, when compared against more-stringent chronic criteria, can provide a means of early warning and an indication of a problem that may require attention. We compare data to both acute and chronic standards in this report. Exceedances in this report, therefore, are meant to inform managers of potential problems rather than to report violations of standards. Reporting water-quality standards violations is the purview of the State of Utah in its 303(d) reports to Congress.

3 Results

3.1 Overview of trend analysis and water quality standards comparisons

An overview of statistical trend results and water-quality standards comparisons at Sheep Creek, Yellow Creek, and Mossy Cave Spring is presented in Table 3-1 (see the Table of Contents for a list of unit abbreviations used in this chapter and the appendices). All water-quality parameters met state water-quality standards, although Sheep and Yellow creeks had instantaneous *E. coli* counts higher than the state secondary recreational chronic standard on 6% and 8% of visits, respectively. There were few common trends in water-quality parameters; the only exception was an increase in pH across all three sites. Water temperature also increased at Sheep and Yellow creeks. Sheep Creek had decreases in flow, specific conductance, magnesium, and sodium. Yellow Creek had no trend in flow, but decreases in specific conductance and most major ions. Mossy Cave Spring had increases in flow and most major ions. Total phosphorus decreased at Sheep Creek and Mossy Cave Spring, but most nutrient and trace-element datasets were highly censored and not analyzed for trends.

3.2 Climate context

Climate summaries use DAYMET gridded climate data collected outside the visitor center at park headquarters (Thornton et al. 2018). Since 1980, Bryce Canyon NP has seen a gradual increase in both maximum and minimum air temperatures (Figure 3-1). Precipitation remains highly variable, although a LOESS smooth suggests a downward trend over the past 15 years (Figure 3-1). During the period of record for this report, annual average maximum and minimum temperatures were usually well above the 30-year climate normal (Figure 3-2). Total annual precipitation and peak snow water equivalent (SWE) varied from well below to well above average, although the years of highest snowpack did not necessarily correspond to the years with the highest total precipitation (Figure 3-2). SWE is an estimate of the total water that could instantaneously melt from a snowpack and is used to predict potential runoff and groundwater recharge.

3.2.1 Climate relationships with water temperature and flow

Air temperatures are measured concurrently with water temperatures during each site visit. At all three monitoring locations, water temperatures were strongly correlated with air temperatures (Figure 3-3). This suggests that sampling locations are far enough downstream from spring emergences for the water to be affected by interactions with the air and vegetation. Mossy Cave Spring had much lower water temperatures than air temperatures, as well as a smaller range in water temperature, due to the sampling location's close proximity to the spring emergence point.

The relationship of flow with air temperature is also notable in the humpback shapes of LOESS smooths at Sheep and Yellow creeks (Figure 3-4). At lower air temperatures, flow increases as snow melts, and surface flow is dominated by snowmelt and runoff. Later in the season, base flows are supported by groundwater, and the relationship transitions to one dominated by evapotranspiration at higher air temperatures, with steep decreases in flow. Interestingly, flow at Mossy Cave Spring continues to increase as air temperatures increase, suggesting that evapotranspiration is not a dominant driver of surface flow at this site.

Relationships between flow and precipitation are much less straightforward, due to the presence of groundwater with various time lags from recent precipitation. Annual modeled DAYMET precipitation and annual peak SWE have little correlation to observed annual average flows at each site, with high uncertainty due to the short period of record. At the monthly time step, quantile regressions at percentiles 10, 25, 50, 75, and 90 suggest that higher flows are decreasing at Yellow Creek, flows across all quantiles are decreasing at Sheep Creek, and flows across all quantiles are increasing at Mossy Cave Spring (Figure 3-5). Decreases

Table 3-1. Trends in water-quality parameters at three long-term monitoring stations at Bryce Canyon National Park, 2006–2021.

Category	Parameter (unit)	Sheep Creek		Yellow Creek		Mossy Cave Spring	
		Trend[1]	Standard exceedances[2]	Trend[1]	Standard exceedances[2]	Trend[1]	Standard exceedances[2]
Core	Dissolved oxygen (mg/L)	none	0–4%	none	0–4%	↑	0–4%
Core	*Escherichia coli* (MPN/100 mL)	none	5–9%	none	5–9%	C	0–4%
Core	Flow (cfs)	↓	NS	none	NS	↑	NS
Core	pH	↑	0–4%	↑	0–4%	↑	0–4%
Core	Specific conductance (µS/cm)	↓	NS	↓	NS	none	NS
Core	Turbidity (NTU)	↓	NS	↓	NS	none	NS
Core	Water temperature (°C)	↑	0–4%	↑	0–4%	none	0–4%
Major ions	Alkalinity as $CaCO_3$ (mg/L)	none	NS	↓	NS	↓	NS
Major ions	Calcium (d) (mg/L)	none	NS	none	NS	↑	NS
Major ions	Chloride (mg/L)	↑	NS	none	NS	↑	NS
Major ions	Magnesium (d) (mg/L)	↓	NS	↓	NS	none	NS
Major ions	Potassium (d) (mg/L)	↑	NS	↓	NS	↑	NS
Major ions	Sodium (d) (mg/L)	↓	NS	↓	NS	↑	NS
Major ions	Sulfate as SO_4 (mg/L)	none	NS	↓	NS	C	NS
Major ions	Total dissolved solids (mg/L)	none	0–4%	↓	0–4%	none	0–4%
Nutrients	Ammonia as N (mg/L)	C	0–4%	C	0–4%	C	0–4%
Nutrients	Nitrite + Nitrate as N (d) (mg/L)	C	NS	C	NS	none	NS
Nutrients	Phosphorus as P (d) (mg/L)	none	NS	C	NS	C	NS
Nutrients	Phosphorus as P (mg/L)	↓	0–4%	C	0–4%	↓	0–4%
Nutrients	Total Nitrogen (d) (mg/L)	C	NS	C	NS	none	NS
Trace elements	Aluminum (d) (µg/L)	C	0–4%	C	0–4%	C	0–4%
Trace elements	Arsenic (d) (µg/L)	C	0–4%	C	0–4%	none	0–4%
Trace elements	Barium (d) (µg/L)	C	NS	C	NS	none	NS
Trace elements	Boron (d) (µg/L)	none	0–4%	none	0–4%	none	0–4%
Trace elements	Cadmium (d) (µg/L)	C	0–4%	C	0–4%	C	0–4%
Trace elements	Chromium (d) (µg/L)	C	0–4%	C	0–4%	C	0–4%
Trace elements	Copper (d) (µg/L)	C	0–4%	C	0–4%	C	0–4%
Trace elements	Iron (d) (µg/L)	C	0–4%	C	0–4%	C	0–4%
Trace elements	Lead (d) (µg/L)	C	0–4%	C	0–4%	C	0–4%

Table 3-1, cont. Trends in water-quality parameters at three long-term monitoring stations at Bryce Canyon National Park, 2006–2021.

Category	Parameter (unit)	Sheep Creek		Yellow Creek		Mossy Cave Spring	
		Trend[1]	Standard exceedances[2]	Trend[1]	Standard exceedances[2]	Trend[1]	Standard exceedances[2]
Trace elements	Manganese (d) (µg/L)	C	NS	C	NS	C	NS
Trace elements	Mercury (d) (µg/L)	C	0–4%	C	0–4%	C	0–4%
Trace elements	Nickel (d) (µg/L)	C	0–4%	C	0–4%	C	0–4%
Trace elements	Silver (d) (µg/L)	C	0–4%	C	0–4%	C	0–4%
Trace elements	Zinc (d) (µg/L)	C	0–4%	C	0–4%	C	0–4%

[1]C = >50% censored data (no analysis); ↑ = increasing trend (p <= 0.05); none = no trend (p >0.05); ↓ = decreasing trend (p <=0.05).
[2]NS = no standard. Colors also correspond to water-quality standards comparisons. NS is clear, 0–4% is green, 5–9% is yellow. A complete listing of applicable state water-quality standards is provided in Appendix C.

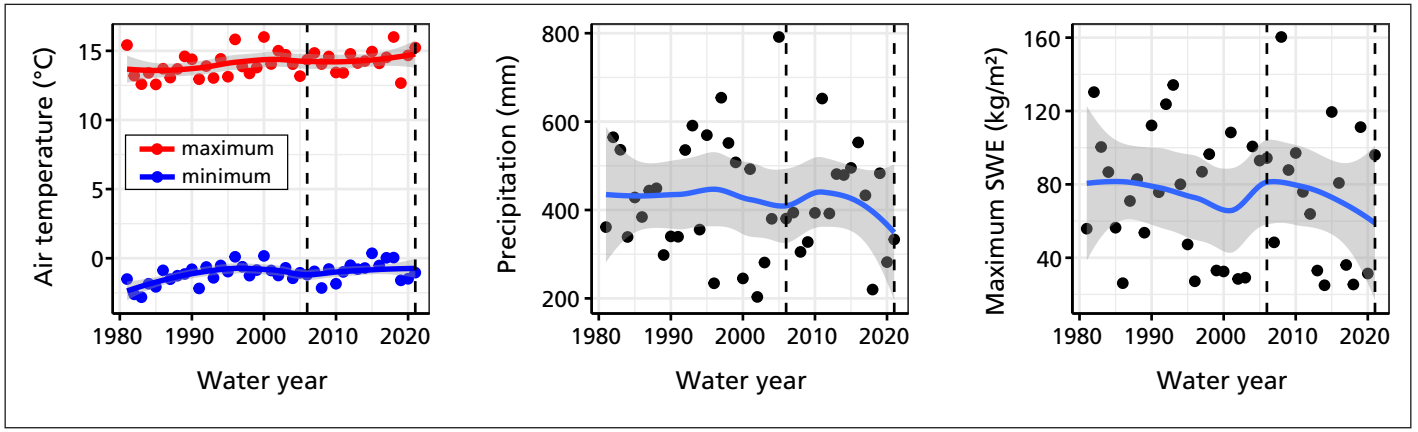


Figure 3-1. Annual average maximum and minimum air temperature, cumulative precipitation, and maximum snow water equivalent with a LOESS smooth using DAYMET data for the headquarters visitor center, Bryce Canyon National Park, water years 1981–2021. The period of interest for this report is shown with dashed lines at water years 2006 and 2021.

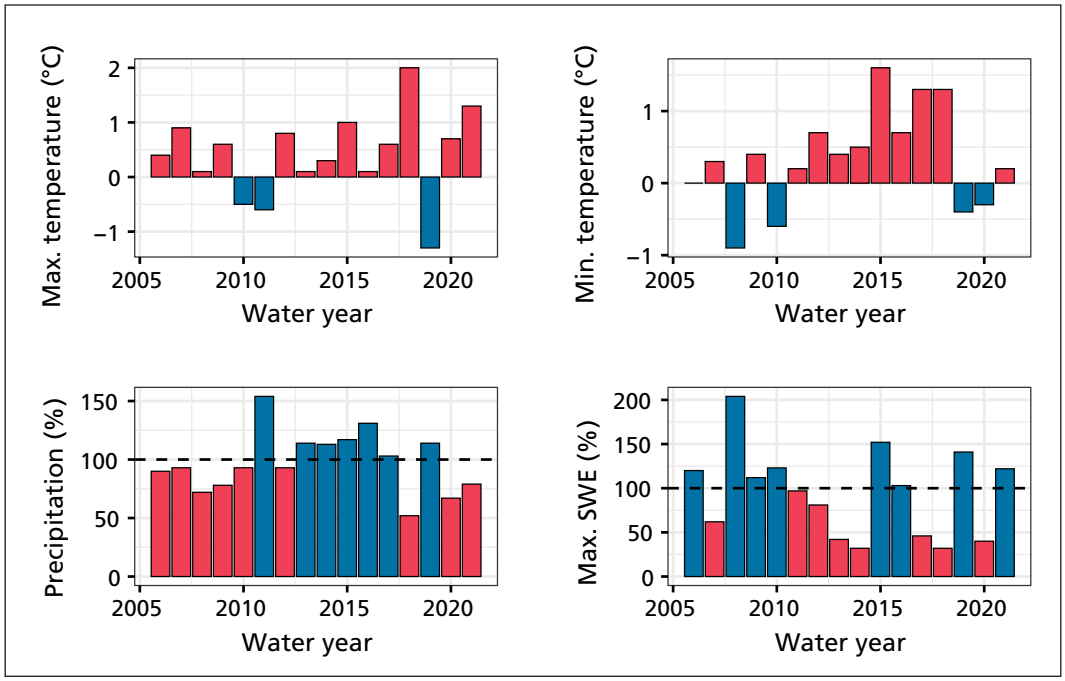


Figure 3-2. DAYMET data showing annual departures from 30-year averages for maximum and minimum air temperature, cumulative precipitation, and annual maximum snow water equivalent for the headquarters visitor center, Bryce Canyon National Park, water years 2006–2021.

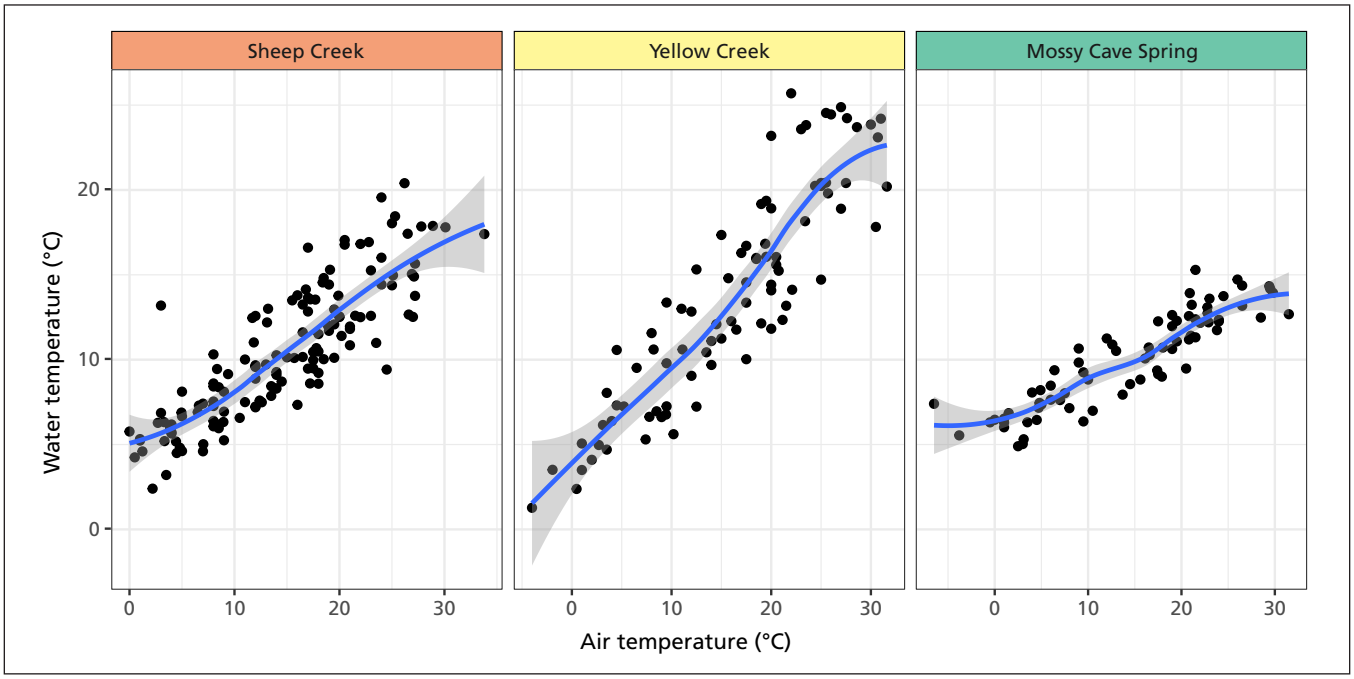


Figure 3-3. Water temperature is related to air temperature (LOESS smooth) at all three monitoring locations in Bryce Canyon National Park.

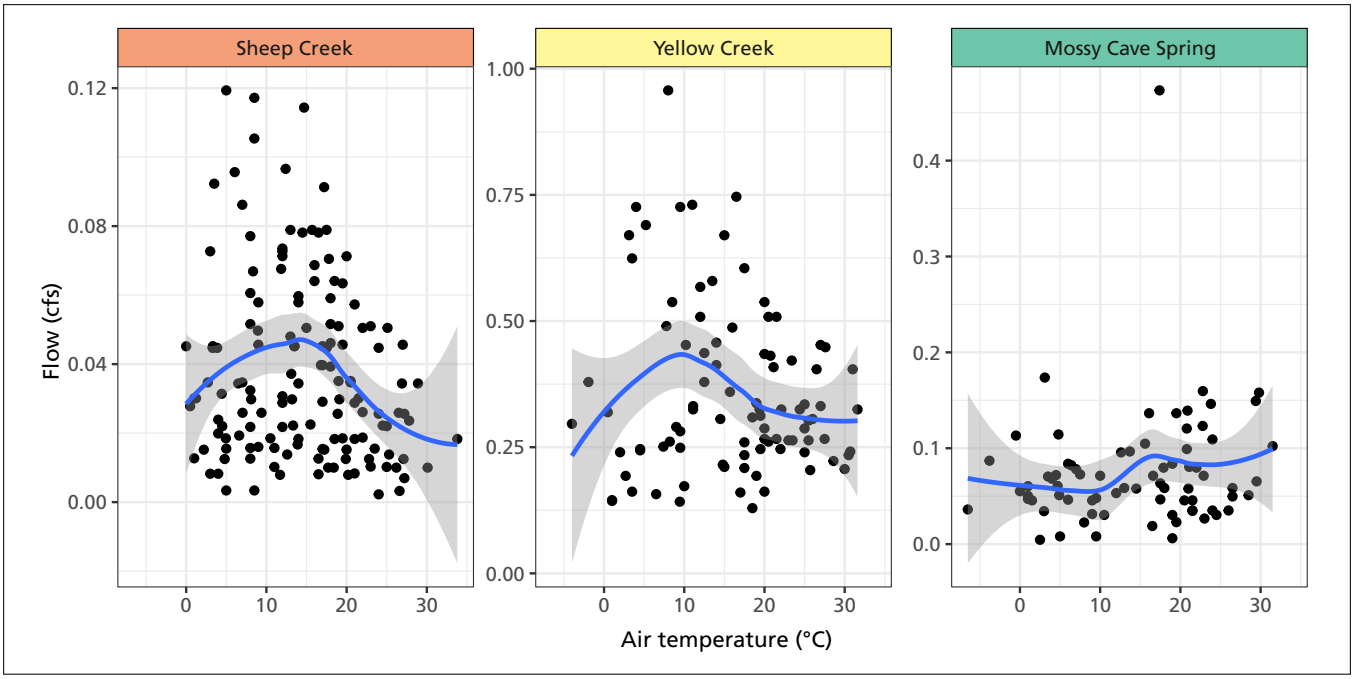


Figure 3-4. Relationships of flow to air temperature, with LOESS smooths.

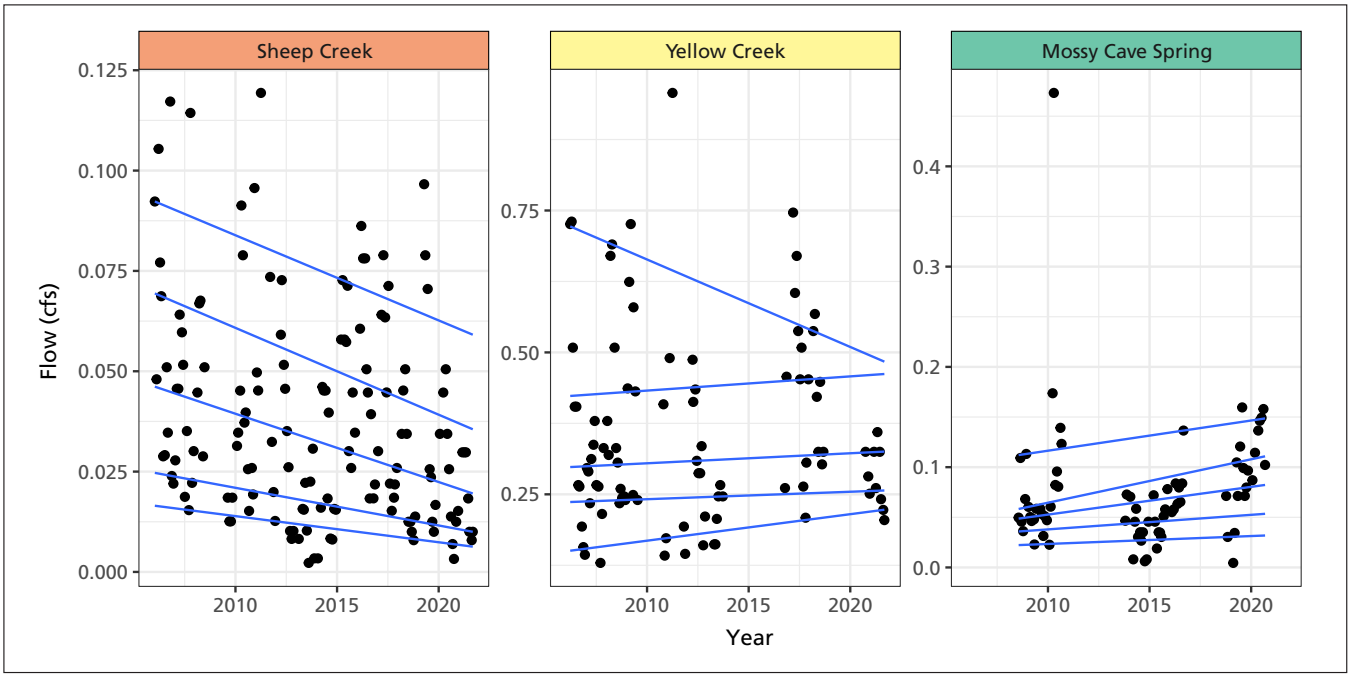


Figure 3-5. Quantile regression trends in flow at percentiles 10, 25, 50, 75, and 90 (blue lines, from bottom to top) at monitoring locations in Bryce Canyon National Park.

in higher flows at Sheep and Yellow creeks likely relate to fluctuations in snowmelt and runoff, while base flows are more groundwater-dependent. Increasing flows at Mossy Cave Spring are surprising, and may be due to fluctuations in recharge decades ago or to local seepage from the irrigation flows of Tropic Ditch. Higher-frequency data over a longer time period are needed to better understand the relationships between groundwater, precipitation, and surface flows at these sites.

3.3 Sheep Creek

Flow decreased by an estimated 0.016 cfs over the 16-year record at Sheep Creek (Figure 3-6, Table 3-2). Sheep Creek had increasing trends in pH (estimated total change of 0.30), water temperature (2.6 °C), chloride (1.1 mg/L), and potassium (0.3 mg/L). There were decreasing trends in specific conductance (−37 µS/cm), turbidity (−2.0 NTU), magnesium (−5.2 mg/L), sodium (−0.4 mg/L), and total phosphorus (−0.0025 mg/L). The magnitude of change was greater than 10% of the median value for flow, turbidity, water temperature, chloride, potassium, and total phosphorus. The chronic secondary recreation standard for fecal coliforms was not met on 6% of sample visits, with one exceedance of the acute water-quality standard (Figure 3-7). Summary statistics and timeseries graphs are presented below for core parameters (Table 3-3, Figure 3-8), major ions (Table 3-4, Figure 3-9), nutrients (Table 3-5, Figure 3-10), and trace elements (Table 3-6, Figure 3-11).

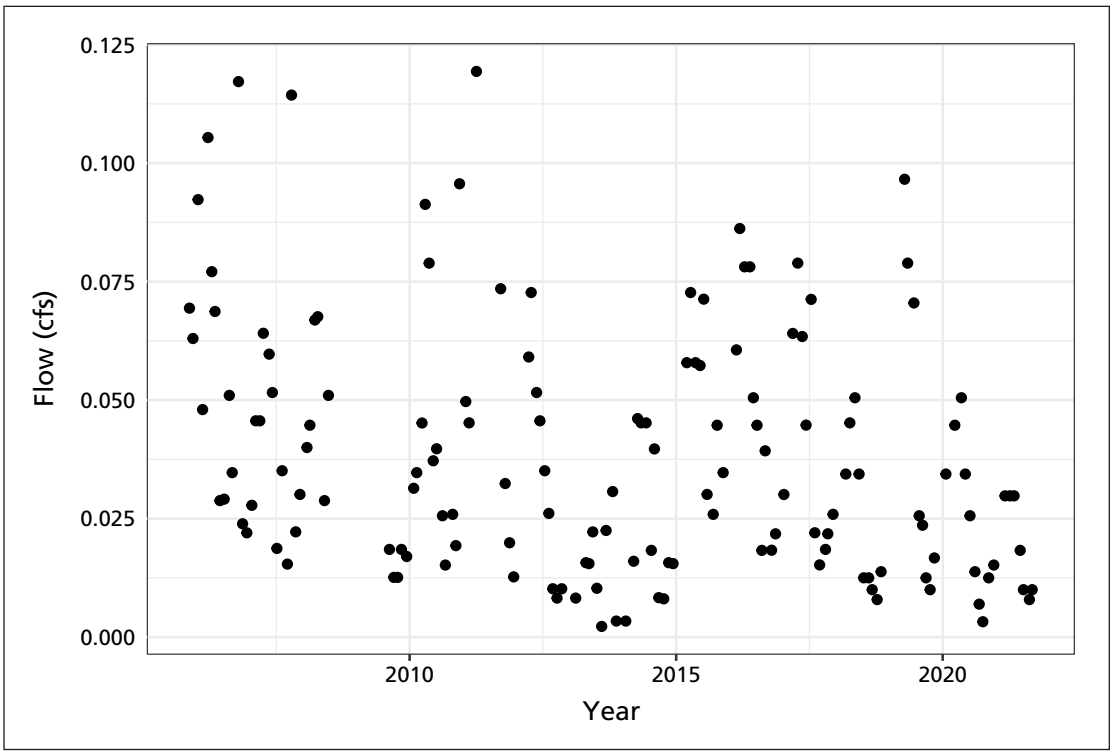


Figure 3-6. Surface flow over time at Sheep Creek, WY2006–2021. There was a statistically significant decrease in flow, equivalent to about 0.016 cfs at the 50th percentile.

Table 3-2. Trend analysis for Sheep Creek datasets with <50% censored data, median concentration, total ambient change over the period of record, and percent change compared to the median concentration (magnitude of change).

Parameter	Analysis type[1]	Period of record (years)	Test stat[2]	p-value	Trend	Median concentration	Ambient change	Percent change
Dissolved oxygen (mg/L)	SK	16	0.048	0.676	none	7.8	–	–
Escherichia coli (MPN/100 mL)	cenSK	16	0.026	0.786	none	2.0	–	–
Flow (cfs)	SK	16	–0.241	<0.001	↓	0.031	–0.016	–52
pH	SK	16	0.302	0.001	↑	7.69	0.30	4
Specific conductance (µS/cm)	SK	16	–0.164	0.003	↓	1284	–37	–3
Turbidity (NTU)	SK	16	–0.453	<0.001	↓	0.98	–2.0	–201
Water temperature (°C)	SK	16	0.181	0.008	↑	10.0	2.6	26
Alkalinity as $CaCO_3$ (mg/L)	SK	16	–0.06	0.795	none	369	–	–
Calcium (d) (mg/L)	SK	16	0.082	0.494	none	146	–	–
Chloride (mg/L)	SK	10	0.233	0.007	↑	6.25	1.1	18
Magnesium (d) (mg/L)	SK	16	–0.182	0.038	↓	102	–5.2	–5
Potassium (d) (mg/L)	SK	16	0.297	0.004	↑	2.8	0.3	10
Sodium (d) (mg/L)	SK	16	–0.18	0.032	↓	4.7	–0.4	–9
Sulfate as SO_4 (mg/L)	SK	16	–0.071	0.314	none	393	–	–
Total dissolved solids (mg/L)	SK	16	–0.019	0.951	none	936	–	–
Phosphorus as P (d) (mg/L)	cenreg	13	0	0.97	none	0.0033	–	–
Phosphorus as P (mg/L)	cenreg	16	7.67	0.005	↓	0.0045	–0.0025	–56
Boron (d) (µg/L)	cenSK	16	–0.239	0.118	none	30	–	–

[1]SK = seasonal Kendall, cenSK = censored seasonal Kendall, cenreg = censored regression using Maximum Likelihood Estimation.
[2]The test statistic is Kendall's tau for SK and cenSK and the chi-squared value with one degree of freedom for cenreg.

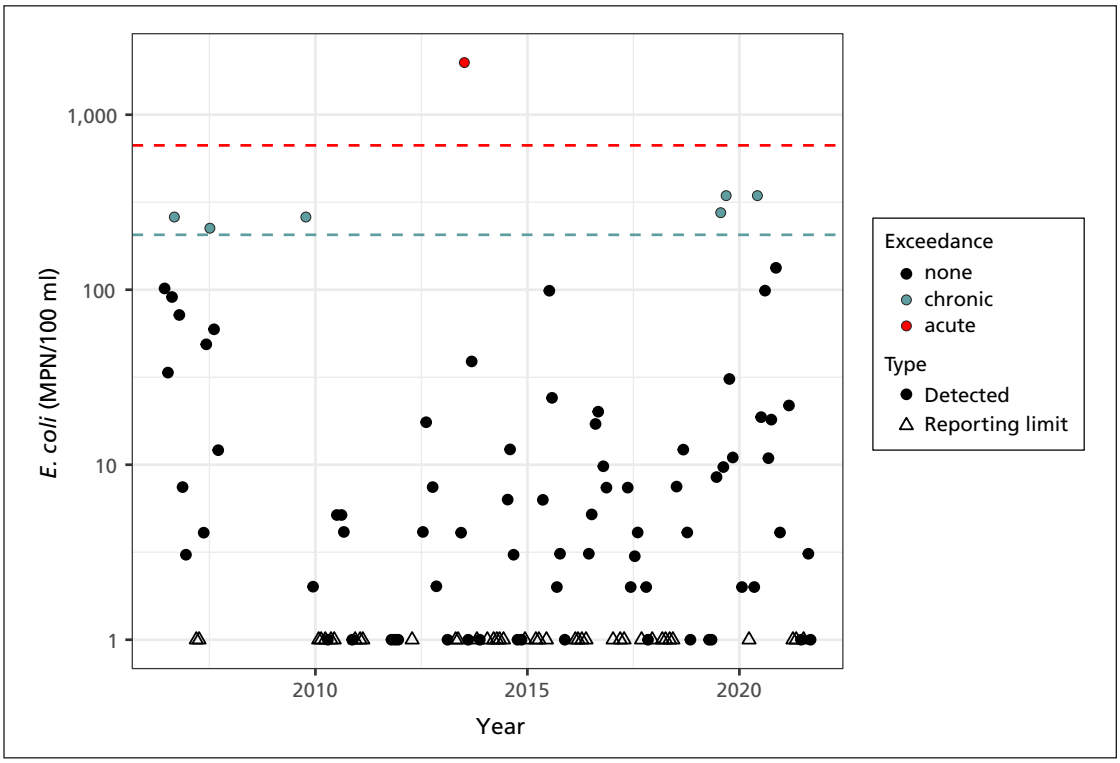


Figure 3-7. Exceedances of the state *E. coli* chronic standard for secondary recreation occurred on 6% of sample visits at Sheep Creek.

Table 3-3. Summary statistics for core parameters at Sheep Creek, including sample period; total number of samples (N); number of censored samples; percentiles 10, 50, and 90 of the dataset; and the percent of samples that did not meet state water-quality standards.

Parameter	Start	End	Sample yrs	N	Censored n	Percentile			Exceedance %
						10	50	90	
Dissolved oxygen (mg/L)	11/15/2005	9/5/2021	16	137	0	6.7	7.8	8.7	0
Escherichia coli (MPN/100 mL)	6/12/2006	9/5/2021	14	120	40	<1	2.0	73.6	6
Flow (cfs)	11/15/2005	9/5/2021	16	149	2	<0.029	0.031	0.074	–
pH	11/15/2005	9/5/2021	16	148	0	7.45	7.69	7.94	0
Specific conductance (µS/cm)	11/15/2005	9/5/2021	16	142	0	1,221	1,284	1,330	–
Turbidity (NTU)	12/9/2005	9/5/2021	16	138	0	0.25	0.98	5.0	–
Water temperature (°C)	11/15/2005	9/5/2021	16	143	0	5.2	10.0	15.9	0

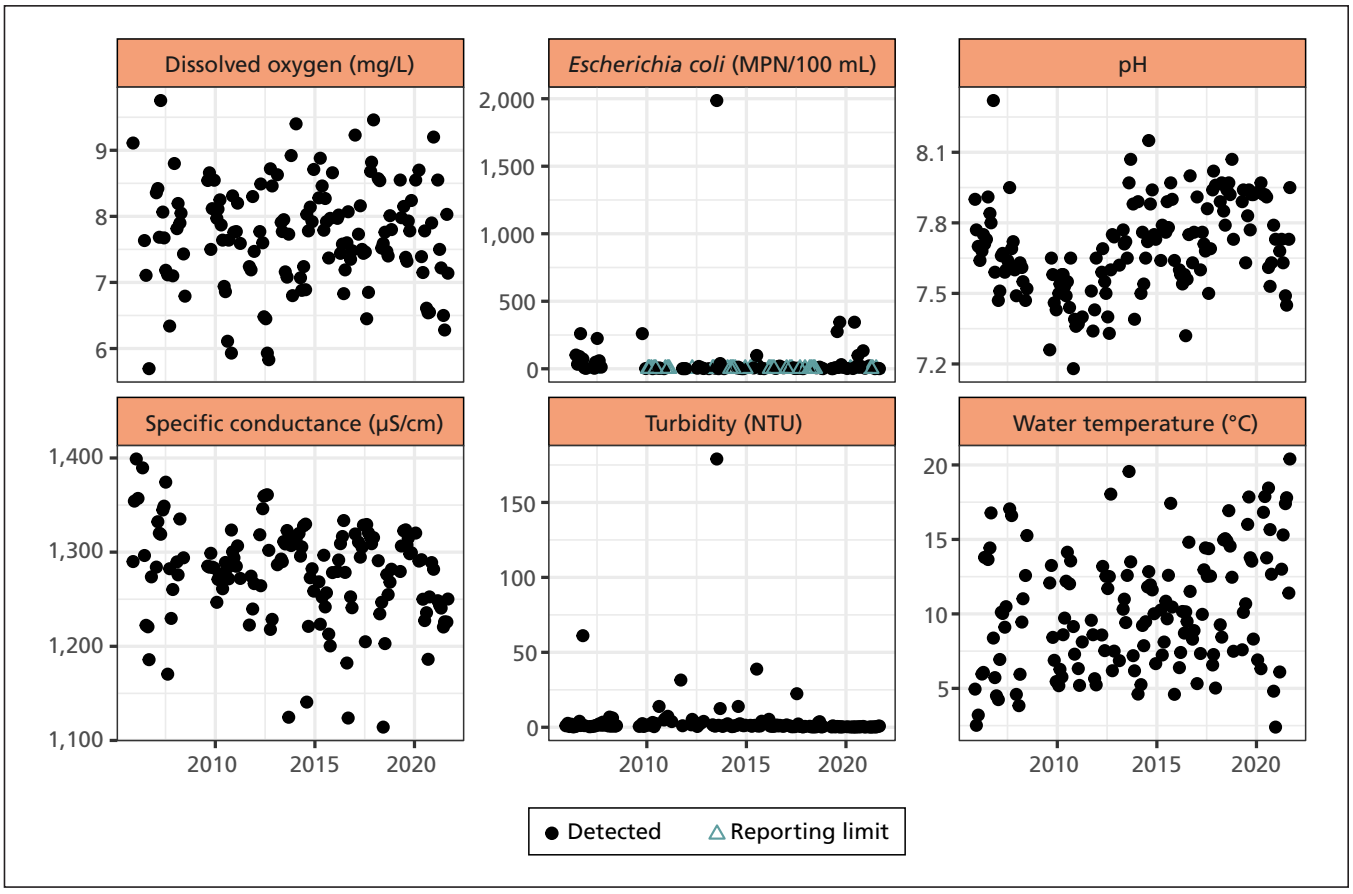


Figure 3-8. Core parameters over time at Sheep Creek, WY2006–2021. There were statistically significant increases in pH and water temperature, decreases in specific conductance and turbidity, and no trend in dissolved oxygen or *E. coli*.

Table 3-4. Summary statistics for major ions at Sheep Creek, including sample period; total number of samples (N); number of censored samples; percentiles 10, 50, and 90 of the dataset; and the percent of samples that did not meet state water-quality standards.

Parameter	Start	End	Sample yrs	N	Censored n	Percentile			Exceedance %
						10	50	90	
Alkalinity as $CaCO_3$ (mg/L)	11/15/2005	9/5/2021	16	134	0	327	369	399	–
Calcium (d) (mg/L)	11/15/2005	9/5/2021	16	132	0	133	146	162	–
Chloride (mg/L)	11/17/2011	9/5/2021	10	83	0	5.06	6.25	7.18	–
Magnesium (d) (mg/L)	11/15/2005	9/5/2021	16	132	0	93.5	102	113	–
Potassium (d) (mg/L)	11/15/2005	9/5/2021	16	132	1	2.5	2.8	3.2	–
Sodium (d) (mg/L)	11/15/2005	9/5/2021	16	132	0	4.3	4.7	5.9	–
Sulfate as SO_4 (mg/L)	11/15/2005	9/5/2021	16	133	0	337	393	447	–
Total dissolved solids (mg/L)	12/9/2005	9/5/2021	16	132	0	886	936	1020	1

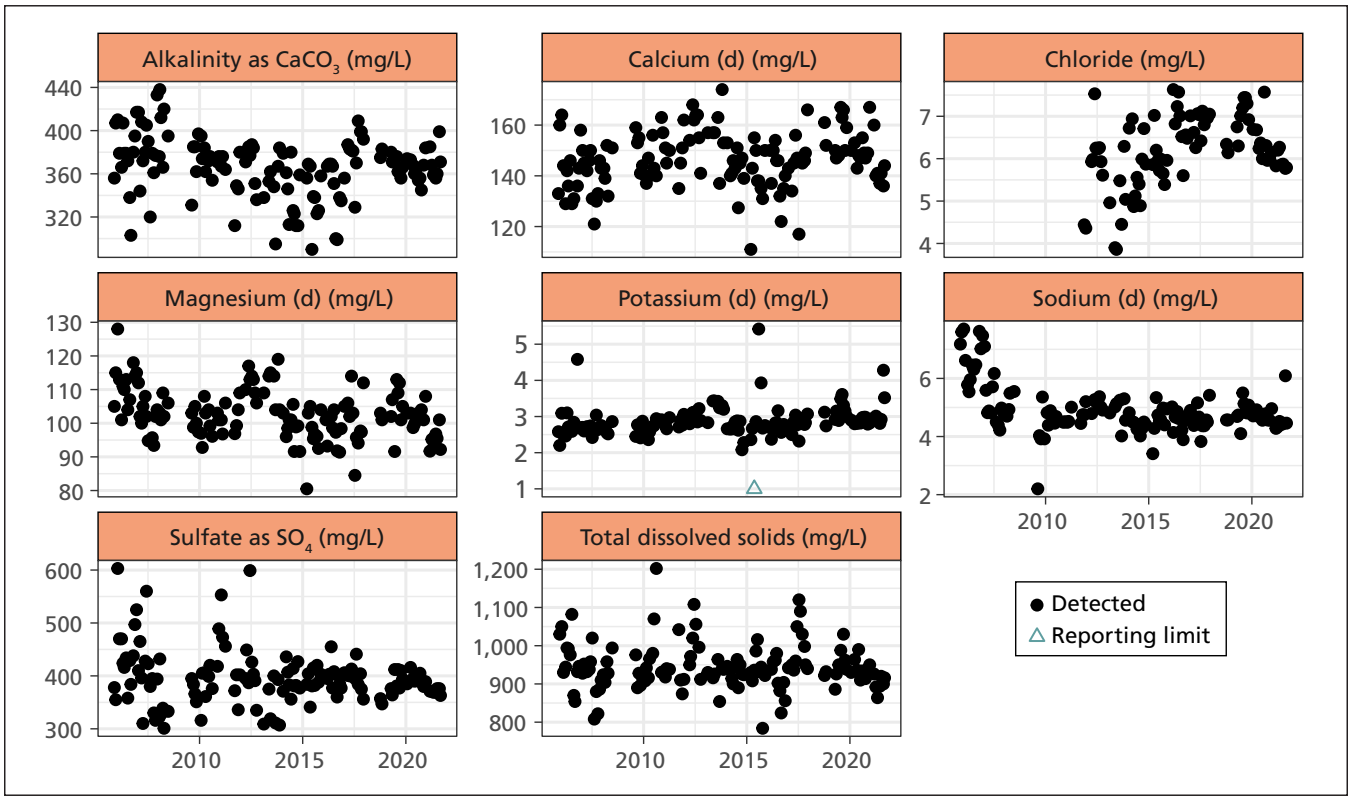


Figure 3-9. Major ions over time at Sheep Creek, WY2006–2021. There were statistically significant increases in chloride and potassium; decreases in magnesium and sodium; and no trend in alkalinity, calcium, sulfate, or total dissolved solids.

Table 3-5. Summary statistics for nutrients at Sheep Creek, including sample period; total number of samples (N); number of censored samples; percentiles 10, 50, and 90 of the dataset; and the percent of samples that did not meet state water-quality standards.

Parameter	Start	End	Sample yrs	N	Censored n	Percentile			Exceedance %
						10	50	90	
Ammonia as N (mg/L)	8/16/2009	9/5/2021	13	102	102	<0.05	<0.05	<0.05	0
Nitrite + Nitrate as N (d) (mg/L)	8/16/2009	9/5/2021	13	103	99	<0.1	<0.1	<0.1	–
Phosphorus as P (d) (mg/L)	8/16/2009	9/5/2021	13	95	44	<0.003	0.0033	0.006	–
Phosphorus as P (mg/L)	11/15/2005	9/5/2021	16	127	60	<0.003	0.0045	0.012	1
Total Nitrogen (d) (mg/L)	8/16/2009	9/5/2021	13	103	97	<0.2	<0.2	<0.2	–

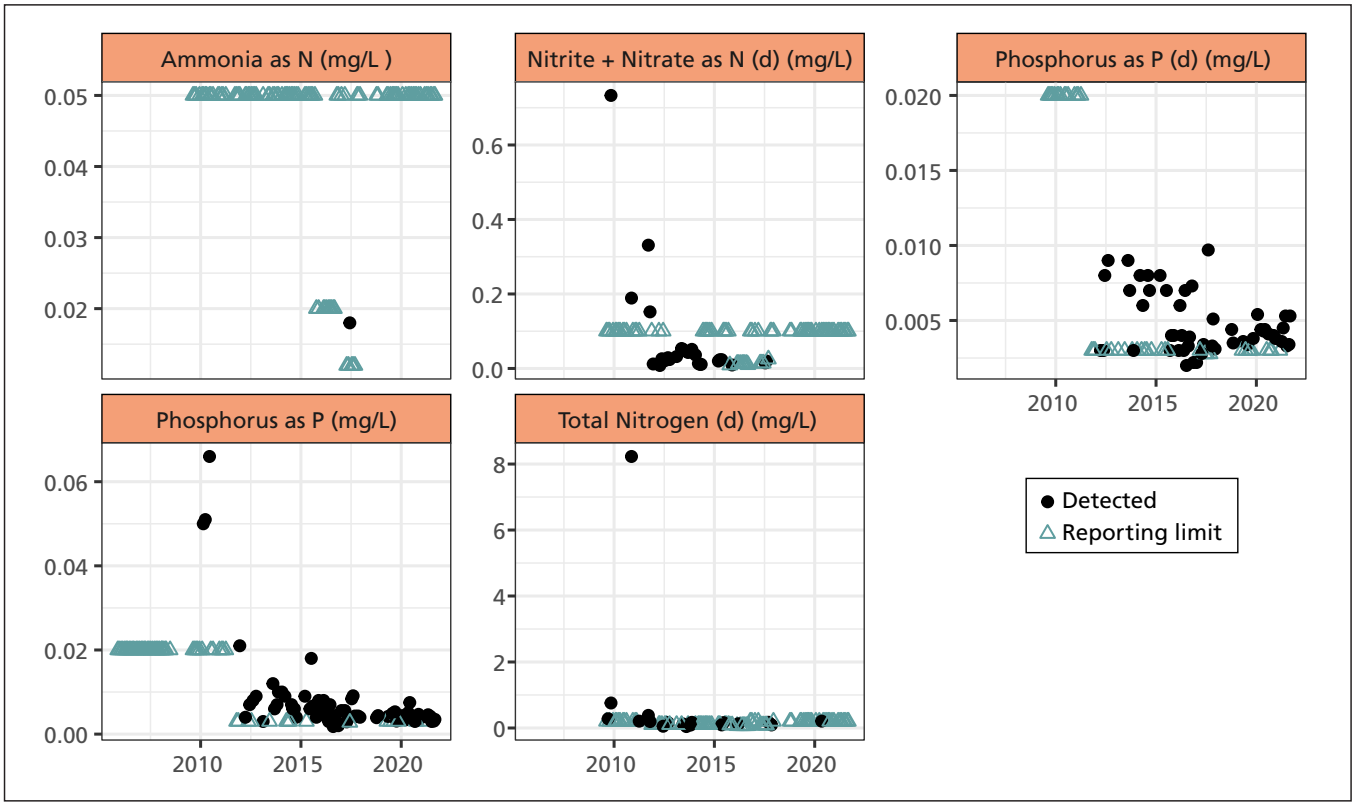


Figure 3-10. Nutrients over time at Sheep Creek, WY2006–2021. There was a statistically significant decrease in total phosphorus and no trend in dissolved phosphorus. All other nutrients had >50% censored data.

Table 3-6. Summary statistics for trace elements at Sheep Creek, including sample period; total number of samples (N); number of censored samples; percentiles 10, 50, and 90 of the dataset; and the percent of samples that did not meet state water-quality standards.

Parameter	Start	End	Sample yrs	N	Censored n	Percentile			Exceedance %
						10	50	90	
Aluminum (d) (µg/L)	1/13/2006	7/7/2021	15	47	46	<30	<30	<30	0
Arsenic (d) (µg/L)	1/13/2006	7/7/2021	15	46	46	<1	<1	<1	0
Barium (d) (µg/L)	1/13/2006	7/7/2021	15	46	46	<100	<100	<100	–
Boron (d) (µg/L)	1/13/2006	7/7/2021	15	51	24	<30	30	38	0
Cadmium (d) (µg/L)	1/13/2006	7/7/2021	15	47	47	<1	<1	<1	0
Chromium (d) (µg/L)	1/13/2006	7/7/2021	15	47	39	<5	<5	6.55	0
Copper (d) (µg/L)	1/13/2006	7/7/2021	15	47	47	<12	<12	<12	0
Iron (d) (µg/L)	1/13/2006	7/7/2021	15	51	49	<30	<30	<30	0
Lead (d) (µg/L)	1/13/2006	7/7/2021	15	46	46	<3	<3	<3	0
Manganese (d) (µg/L)	1/13/2006	7/7/2021	15	45	34	<5	<5	9.4	–
Mercury (d) (µg/L)	1/13/2006	7/7/2021	15	47	47	<0.2	<0.2	<0.2	0
Nickel (d) (µg/L)	1/13/2006	7/7/2021	15	46	46	<10	<10	<10	0
Silver (d) (µg/L)	1/13/2006	7/7/2021	15	47	47	<2	<2	<2	0
Zinc (d) (µg/L)	1/13/2006	7/7/2021	15	46	46	<30	<30	<30	0

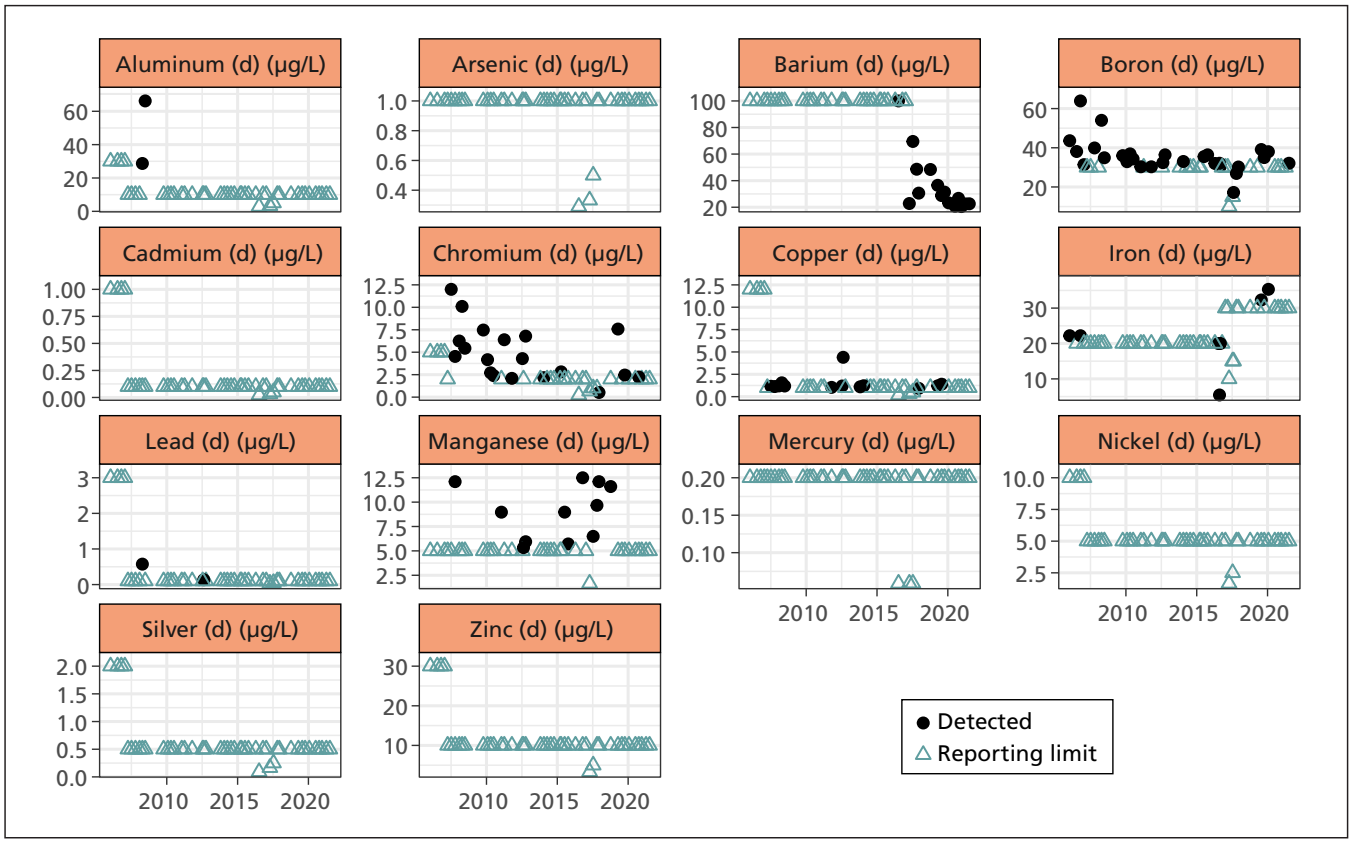


Figure 3-11. Trace elements over time at Sheep Creek, WY2006–2021. There was no trend in boron. All other trace elements had >50% censored data.

3.4 Yellow Creek

There was no trend in flow over the 16-year record at Yellow Creek (Figure 3-12, Table 3-7). Yellow Creek had increasing trends in pH (estimated total change of 0.08) and water temperature (2.4°C). There were decreasing trends in specific conductance (−70 µS/cm), turbidity (−1.6 NTU), alkalinity (−19 mg/L), magnesium (−9.1 mg/L), potassium (−0.3 mg/L), sodium (−6.8 mg/L), sulfate (−39 mg/L) and total dissolved solids (−61 mg/L). The magnitude of change was greater than 10% of the median value for turbidity, water temperature, magnesium, potassium, sodium, sulfate, and total dissolved solids. The chronic secondary recreation standard for fecal coliforms was not met on 8% of sample visits, with three exceedances of the acute water-quality standard (Figure 3-13). Summary statistics and timeseries graphs are presented below for core parameters (Table 3-8, Figure 3-14), major ions (Table 3-9, Figure 3-15), nutrients (Table 3-10, Figure 3-16), and trace elements (Table 3-11, Figure 3-17).

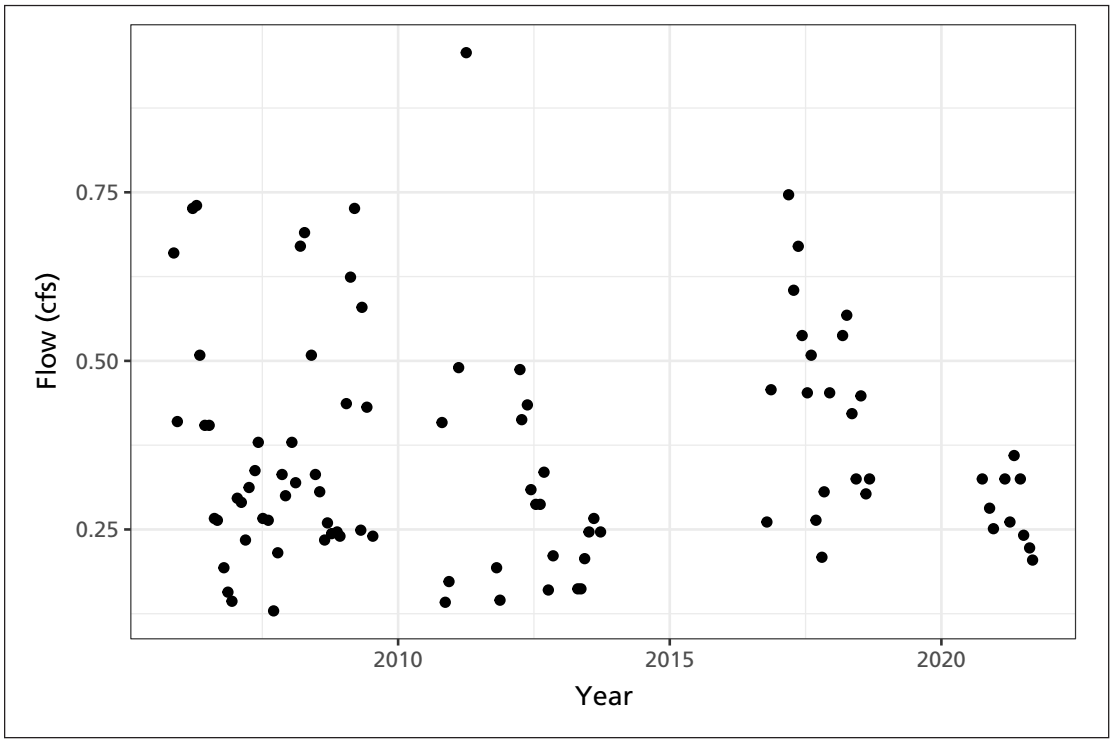


Figure 3-12. Surface flow over time at Yellow Creek, WY2006–2021. There was no trend in flow.

Table 3-7. Trend analysis for Yellow Creek datasets with <50% censored data, median concentration, total ambient change over the period of record, and percent change compared to the median concentration (magnitude of change).

Parameter	Analysis type[1]	Period of record (years)	Test stat[2]	p-value	Trend	Median concentration	Ambient change	Percent change
Dissolved oxygen (mg/L)	SK	16	–0.103	0.135	none	8.0	–	–
Escherichia coli (MPN/100 mL)	cenSK	16	–0.178	0.072	none	3.1	–	–
Flow (cfs)	SK	16	0.027	0.558	none	0.311	–	–
pH	SK	16	0.127	0.052	↑	8.20	0.08	1
Specific conductance (µS/cm)	SK	16	–0.513	<0.001	↓	828	–70	–9
Turbidity (NTU)	SK	16	–0.271	0.004	↓	2.0	–1.6	–77
Water temperature (°C)	SK	16	0.23	0.008	↑	13.1	2.4	18
Alkalinity as $CaCO_3$ (mg/L)	SK	16	–0.222	0.001	↓	282	–19	–7
Calcium (d) (mg/L)	SK	16	–0.053	0.828	none	79.1	–	–
Chloride (mg/L)	SK	10	–0.053	1	none	5.55	–	–
Magnesium (d) (mg/L)	SK	16	–0.411	0.004	↓	65.9	–9.1	–14
Potassium (d) (mg/L)	SK	16	–0.111	0.003	↓	2.8	–0.3	–10
Sodium (d) (mg/L)	SK	16	–0.538	<0.001	↓	12.8	–6.8	–53
Sulfate as SO_4 (mg/L)	SK	16	–0.534	<0.001	↓	179	–39	–22
Total dissolved solids (mg/L)	SK	16	–0.362	0.013	↓	525	–61	–12
Boron (d) (µg/L)	cenSK	16	–0.429	0.405	none	42	–	–

[1]SK = seasonal Kendall, cenSK = censored seasonal Kendall, cenreg = censored regression using Maximum Likelihood Estimation.
[2]The test statistic is Kendall's tau for SK and cenSK and the chi-squared value with one degree of freedom for cenreg.

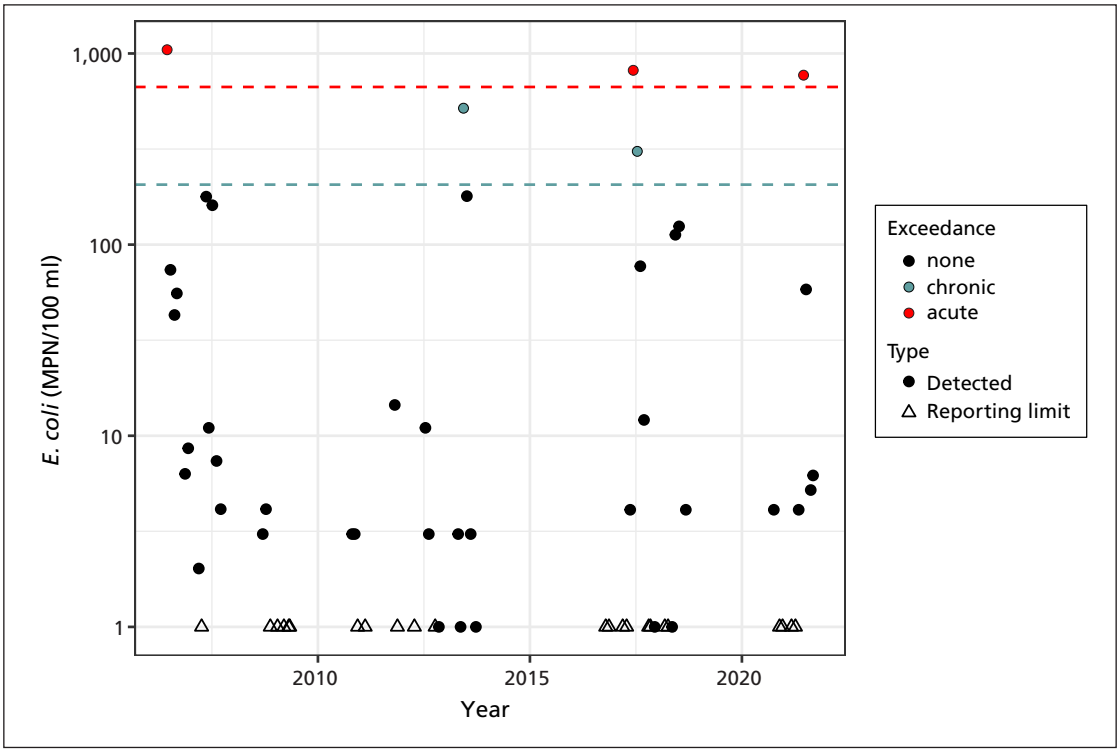


Figure 3-13. Exceedances of the state *E. coli* chronic standard for secondary recreation occurred on 8% of sample visits at Yellow Creek.

Table 3-8. Summary statistics for core parameters at Yellow Creek, including sample period; total number of samples (N); number of censored samples; percentiles 10, 50, and 90 of the dataset; and the percent of samples that did not meet state water-quality standards.

Parameter	Start	End	Sample yrs	N	Censored n	Percentile			Exceedance %
						10	50	90	
Dissolved oxygen (mg/L)	11/15/2005	9/5/2021	10	82	0	6.7	8.0	9.8	0
Escherichia coli (MPN/100 mL)	6/12/2006	9/5/2021	10	65	23	<1	3.1	171.2	8
Flow (cfs)	11/15/2005	9/5/2021	10	94	0	0.193	0.311	0.618	–
pH	11/15/2005	9/5/2021	10	95	0	8.04	8.20	8.35	0
Specific conductance (µS/cm)	11/15/2005	9/5/2021	10	88	0	779	828	896	–
Turbidity (NTU)	12/9/2005	9/5/2021	10	83	0	0.47	2.0	42	–
Water temperature (°C)	11/15/2005	9/5/2021	10	90	0	4.9	13.1	23.6	0

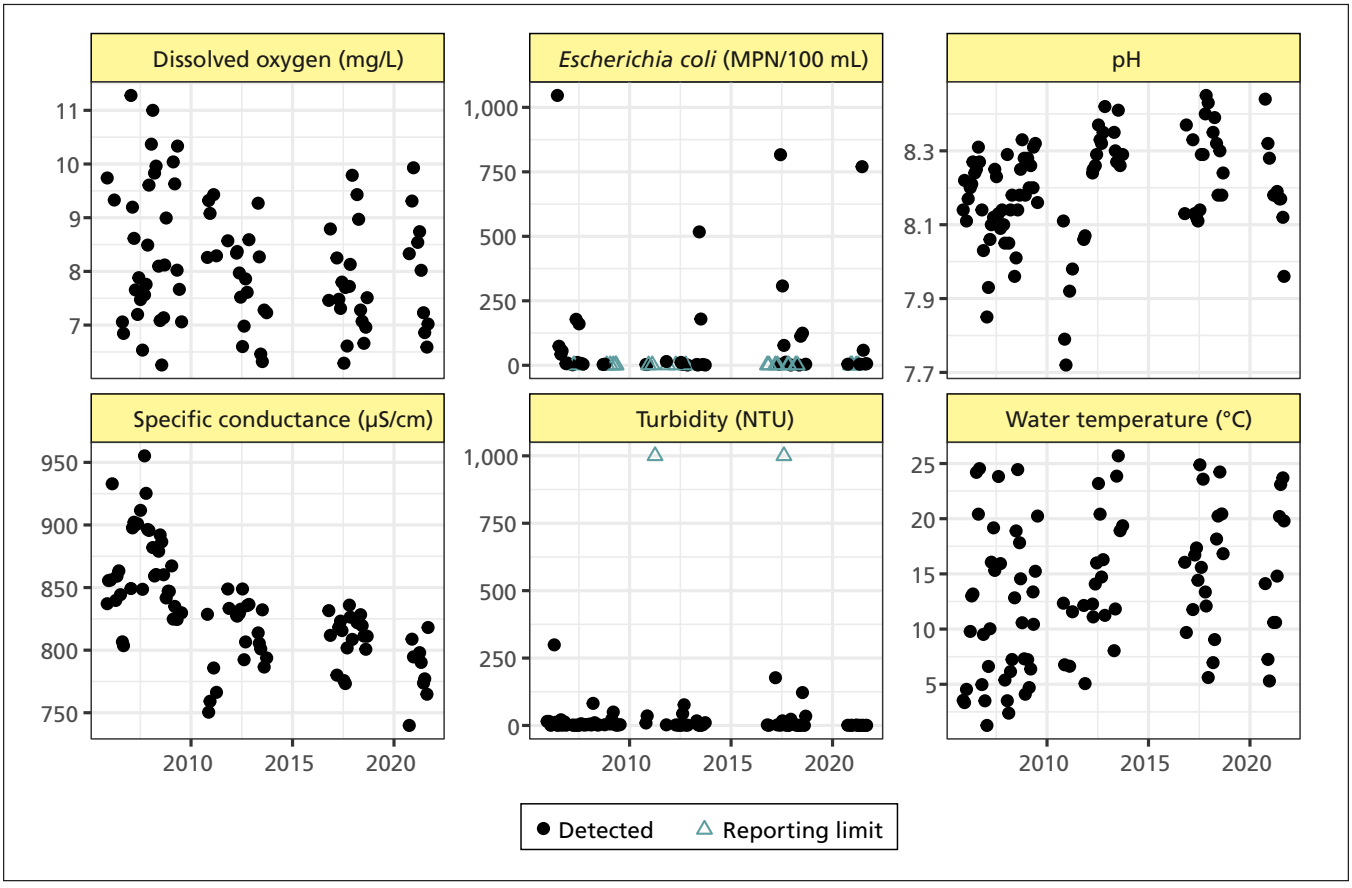


Figure 3-14. Core parameters over time at Yellow Creek, WY2006–2021. There were statistically significant increases in pH and water temperature, decreases in specific conductance and turbidity, and no trend in dissolved oxygen or *E. coli*.

Table 3-9. Summary statistics for major ions at Yellow Creek, including sample period; total number of samples (N); number of censored samples; percentiles 10, 50, and 90 of the dataset; and the percent of samples that did not meet state water-quality standards.

Parameter	Start	End	Sample yrs	N	Censored n	Percentile			Exceedance %
						10	50	90	
Alkalinity as $CaCO_3$ (mg/L)	11/15/2005	9/5/2021	10	89	0	257	282	308	–
Calcium (d) (mg/L)	11/15/2005	9/5/2021	10	87	0	70.5	79.1	85.3	–
Chloride (mg/L)	11/17/2011	9/5/2021	5	38	0	4.37	5.55	6.14	–
Magnesium (d) (mg/L)	11/15/2005	9/5/2021	10	87	0	57.7	65.9	70.2	–
Potassium (d) (mg/L)	11/15/2005	9/5/2021	10	87	0	2.4	2.8	3.2	–
Sodium (d) (mg/L)	11/15/2005	9/5/2021	10	87	0	9.1	12.8	16.7	–
Sulfate as SO_4 (mg/L)	11/15/2005	9/5/2021	10	88	0	159	179	214	–
Total dissolved solids (mg/L)	12/9/2005	9/5/2021	10	88	0	480	525	572	0

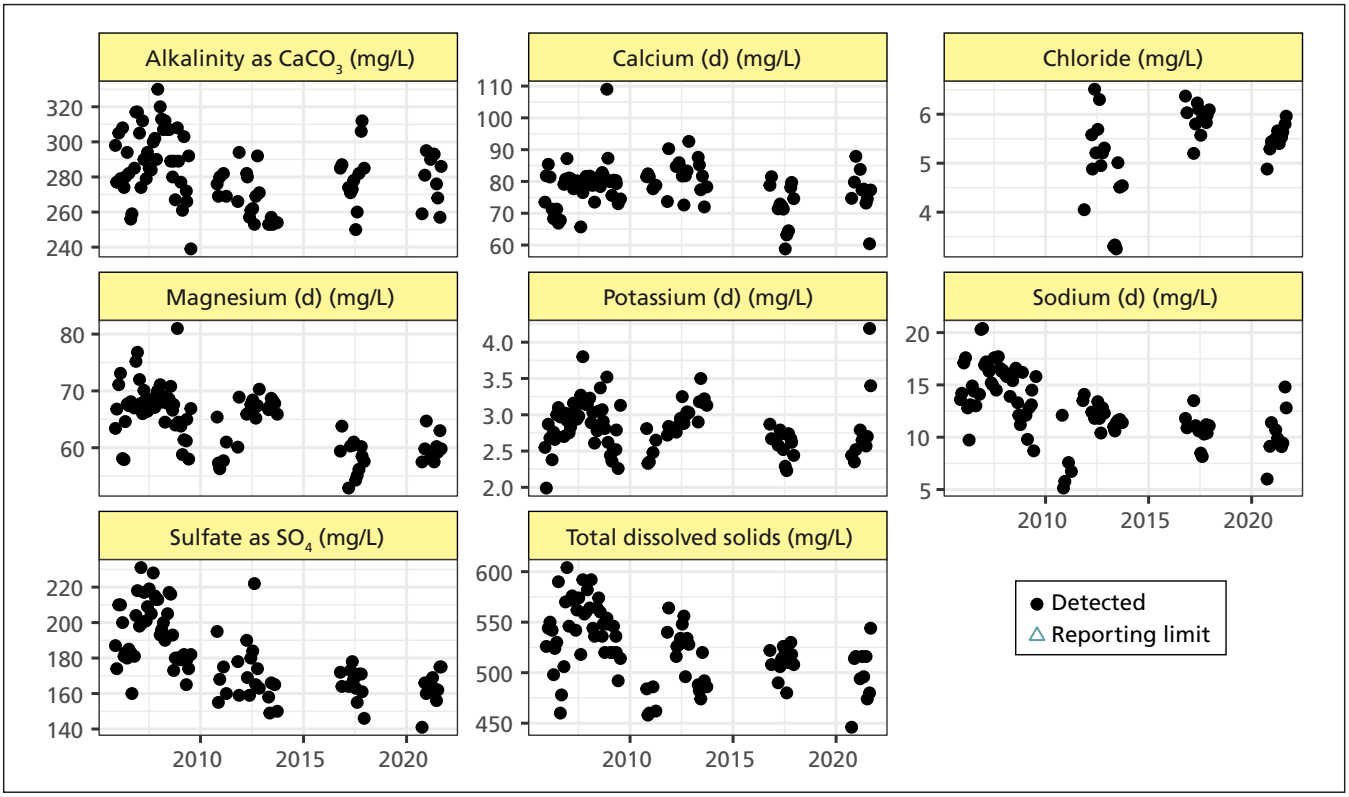


Figure 3-15. Major ions over time at Yellow Creek, WY2006–2021. There were statistically significant decreases in all major ions except for calcium and chloride, which had no trend.

Table 3-10. Summary statistics for nutrients at Yellow Creek, including sample period; total number of samples (N); number of censored samples; percentiles 10, 50, and 90 of the dataset; and the percent of samples that did not meet state water-quality standards.

Parameter	Start	End	Sample yrs	N	Censored n	Percentile			Exceedance %
						10	50	90	
Ammonia as N (mg/L)	7/23/2008	9/5/2021	8	57	57	<0.05	<0.05	<0.05	0
Nitrite + Nitrate as N (d) (mg/L)	7/23/2008	9/5/2021	8	57	56	<0.1	<0.1	<0.1	–
Phosphorus as P (d) (mg/L)	7/23/2008	9/5/2021	8	57	40	<0.003	<0.003	0.006	–
Phosphorus as P (mg/L)	11/15/2005	9/5/2021	10	89	58	<0.003	<0.003	0.020	3
Total Nitrogen (d) (mg/L)	7/23/2008	9/5/2021	8	57	56	<0.2	<0.2	<0.2	–

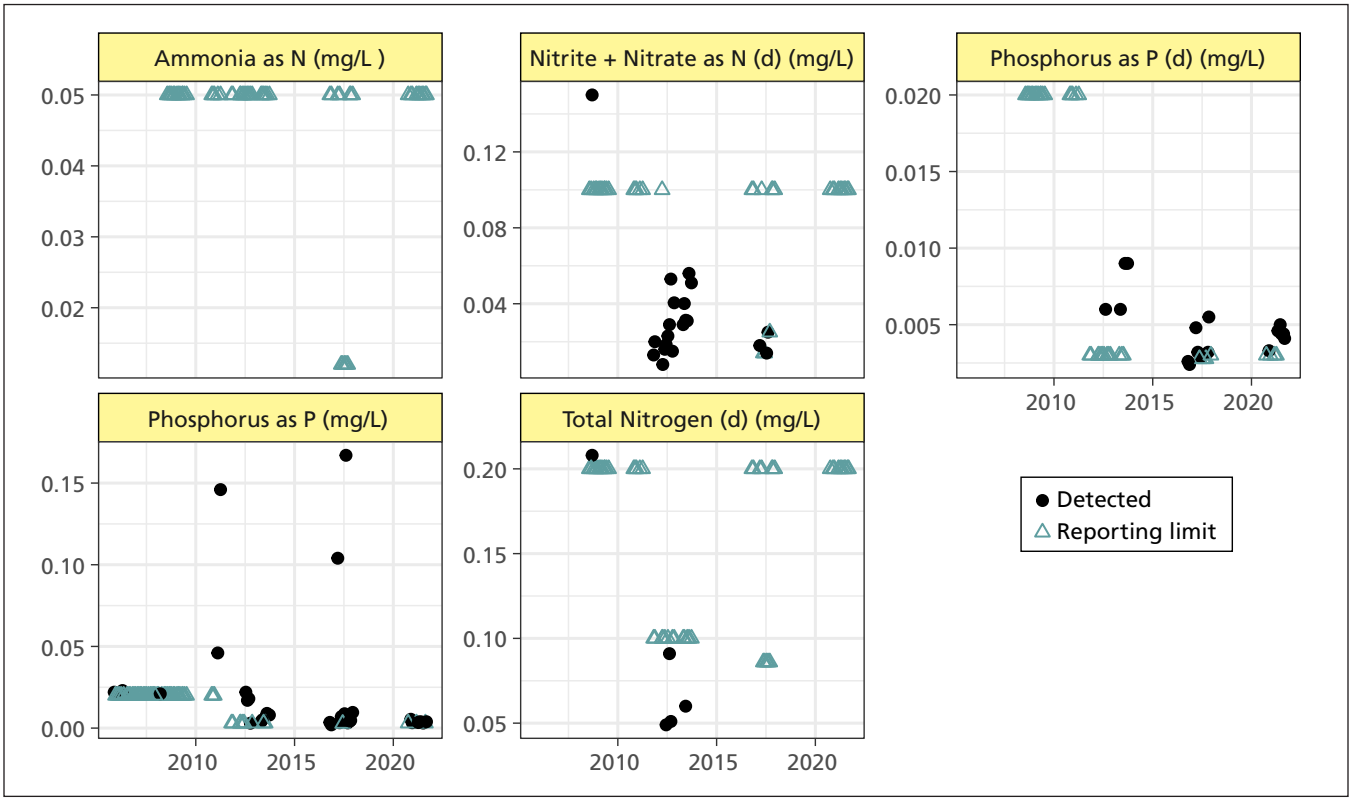


Figure 3-16. Nutrients over time at Yellow Creek, WY2006–2021. All nutrients had >50% censored data.

Table 3-11. Summary statistics for trace elements at Yellow Creek, including sample period; total number of samples (N); number of censored samples; percentiles 10, 50, and 90 of the dataset; and the percent of samples that did not meet state water-quality standards.

Parameter	Start	End	Sample yrs	N	Censored n	Percentile			Exceedance %
						10	50	90	
Aluminum (d) (µg/L)	1/13/2006	7/7/2021	10	30	30	**<30**	<30	<30	0
Arsenic (d) (µg/L)	1/13/2006	7/7/2021	10	30	29	<1	<1	<1	0
Barium (d) (µg/L)	1/13/2006	7/7/2021	10	30	30	<100	<100	<100	–
Boron (d) (µg/L)	1/13/2006	7/7/2021	10	35	4	31	42	55	0
Cadmium (d) (µg/L)	1/13/2006	7/7/2021	10	31	31	<1	<1	<1	0
Chromium (d) (µg/L)	1/13/2006	7/7/2021	10	31	27	<5	<5	5.16	0
Copper (d) (µg/L)	1/13/2006	7/7/2021	10	31	31	<12	<12	<12	0
Iron (d) (µg/L)	1/13/2006	7/7/2021	10	36	36	<30	<30	<30	0
Lead (d) (µg/L)	1/13/2006	7/7/2021	10	31	31	<3	<3	<3	0
Manganese (d) (µg/L)	1/13/2006	7/7/2021	10	31	26	<5	<5	6.0	–
Mercury (d) (µg/L)	1/13/2006	7/7/2021	10	31	31	<0.2	<0.2	<0.2	0
Nickel (d) (µg/L)	1/13/2006	7/7/2021	10	31	31	<10	<10	<10	0
Silver (d) (µg/L)	1/13/2006	7/7/2021	10	31	31	<2	<2	<2	0
Zinc (d) (µg/L)	1/13/2006	7/7/2021	10	31	31	<30	<30	<30	0

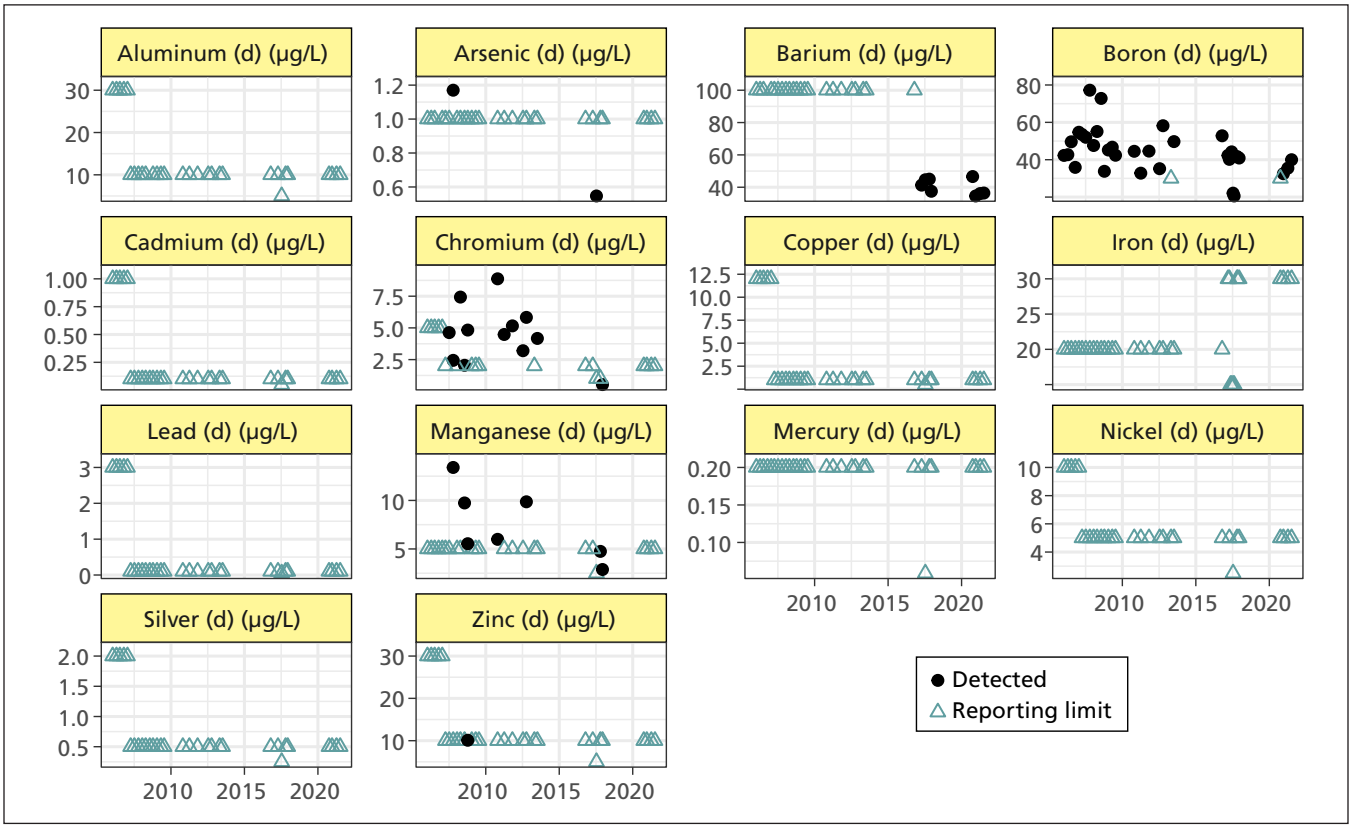


Figure 3-17. Trace elements over time at Yellow Creek, WY2006–2021. Boron had no trend. All other trace elements had >50% censored data.

3.5 Mossy Cave Spring

There was an estimated increase in flow of 0.052 cfs over the 13-year record at Mossy Cave Spring (Figure 3-18, Table 3-12). The spring had increasing trends in dissolved oxygen (estimated total change of 0.2 mg/L), pH (0.47), calcium (3.1 mg/L), chloride (1.7 mg/L), potassium (0.1 mg/L), and sodium (0.6 mg/L). There were decreasing trends in alkalinity (–12 mg/L) and total phosphorus (–0.004 mg/L). The magnitude of change was greater than 10% of the median value for flow, chloride, sodium, and total phosphorus. Summary statistics and timeseries graphs are presented below core parameters (Table 3-13, Figure 3-19), major ions (Table 3-14, Figure 3-20), nutrients (Table 3-15, Figure 3-21), and trace elements (Table 3-16, Figure 3-22).

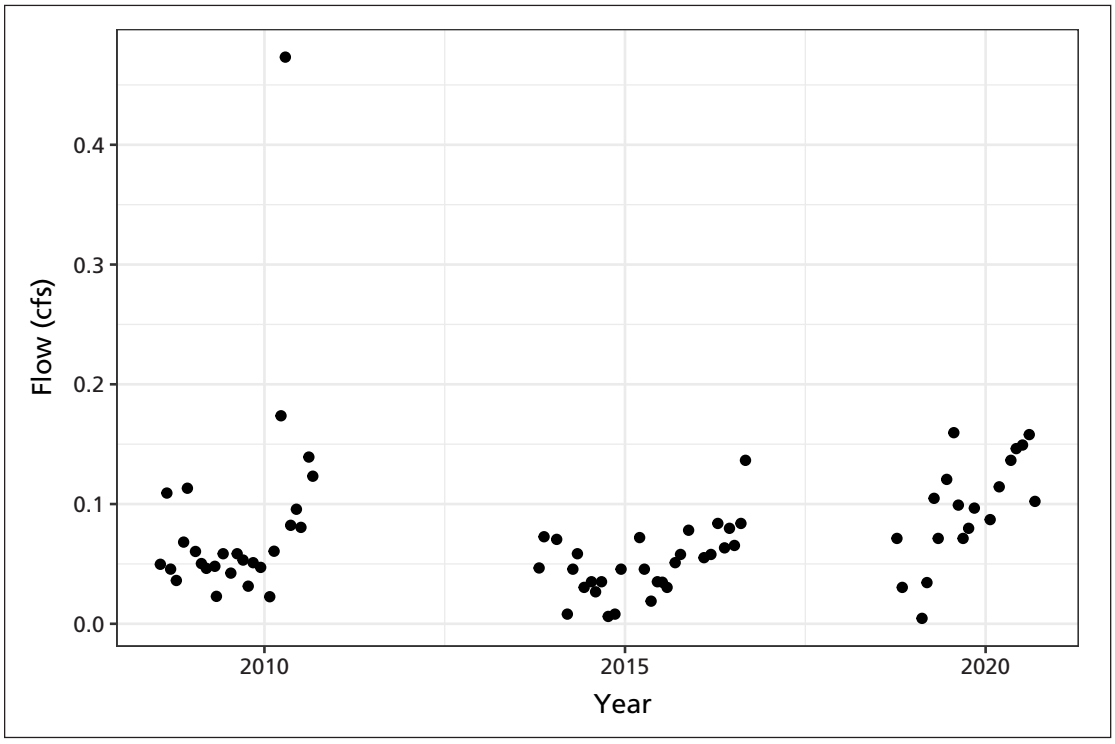


Figure 3-18. Surface flow at Mossy Cave Spring, July 2008–September 30, 2021. Flow had an increasing trend, estimated at 0.052 cfs at the 50th percentile.

Table 3-12. Trend analysis for Mossy Cave Spring datasets with <50% censored data, median concentration, total ambient change over the period of record, and percent change compared to the median concentration (magnitude of change).

Parameter	Analysis type[1]	Period of record (years)	Test stat[2]	p-value	Trend	Median concentration	Ambient change	Percent change
Dissolved oxygen (mg/L)	SK	13	0.199	0.003	↑	8.6	0.2	2
Flow (cfs)	SK	13	0.25	0.001	↑	0.059	0.052	87
pH	SK	13	0.645	<0.001	↑	8.19	0.47	6
Specific conductance (µS/cm)	SK	13	0.068	0.897	none	458	–	–
Turbidity (NTU)	SK	13	–0.342	0.069	none	2.9	–	–
Water temperature (deg C)	SK	13	–0.009	0.922	none	10.4	–	–
Alkalinity as $CaCO_3$ (mg/L)	SK	13	–0.337	<0.001	↓	233	–12	–5
Calcium (d) (mg/L)	SK	13	0.266	0.005	↑	41.7	3.1	7
Chloride (mg/L)	SK	7	0.667	<0.001	↑	6.58	1.7	25
Magnesium (d) (mg/L)	SK	13	0.036	0.67	none	34.2	–	–
Potassium (d) (mg/L)	SK	13	0.132	0.032	↑	1.8	0.1	3
Sodium (d) (mg/L)	SK	13	0.266	0.001	↑	4.3	0.6	13
Total dissolved solids (mg/L)	SK	13	0.163	0.103	none	233	–	–
Nitrite + Nitrate as N (d) (mg/L)	SK	13	–0.122	0.107	none	0.40	–	–
Phosphorus as P (mg/L)	cenreg	13	12.28	<0.001	↓	0.0045	–0.004	–89
Total Nitrogen (d) (mg/L)	SK	13	0.119	0.082	none	0.44	–	–
Arsenic (d) (µg/L)	SK	13	0.251	0.666	none	4.7	–	–
Barium (d) (µg/L)	SK	13	–0.067	0.95	none	438	–	–
Boron (d) (µg/L)	cenSK	13	0.279	0.609	none	34	–	–

[1]SK = seasonal Kendall, cenSK = censored seasonal Kendall, cenreg = censored regression using Maximum Likelihood Estimation.
[2]The test statistic is Kendall's tau for SK and cenSK and the chi-squared value with one degree of freedom for cenreg.

Table 3-13. Summary statistics for core parameters at Mossy Cave Spring, including sample period; total number of samples (N); number of censored samples; percentiles 10, 50, and 90 of the dataset; and the percent of samples that did not meet state water-quality standards.

Parameter	Start	End	Sample yrs	N	Censored n	Percentile			Exceedance %
						10	50	90	
Dissolved oxygen (mg/L)	7/23/2008	9/7/2020	8	74	0	8.0	8.6	9.5	0
Escherichia coli (MPN/100 mL)	8/25/2008	9/7/2020	8	66	48	<1	<1	5.7	0
Flow (cfs)	7/23/2008	9/7/2020	8	76	0	0.029	0.059	0.137	–
pH	7/23/2008	9/7/2020	8	76	0	7.91	8.19	8.42	0
Specific conductance (µS/cm)	7/23/2008	9/7/2020	8	74	0	443	458	472	–
Turbidity (NTU)	8/25/2008	9/7/2020	8	71	0	1.5	2.9	7.6	–
Water temperature (°C)	7/23/2008	9/7/2020	8	76	0	6.3	10.4	13.7	0

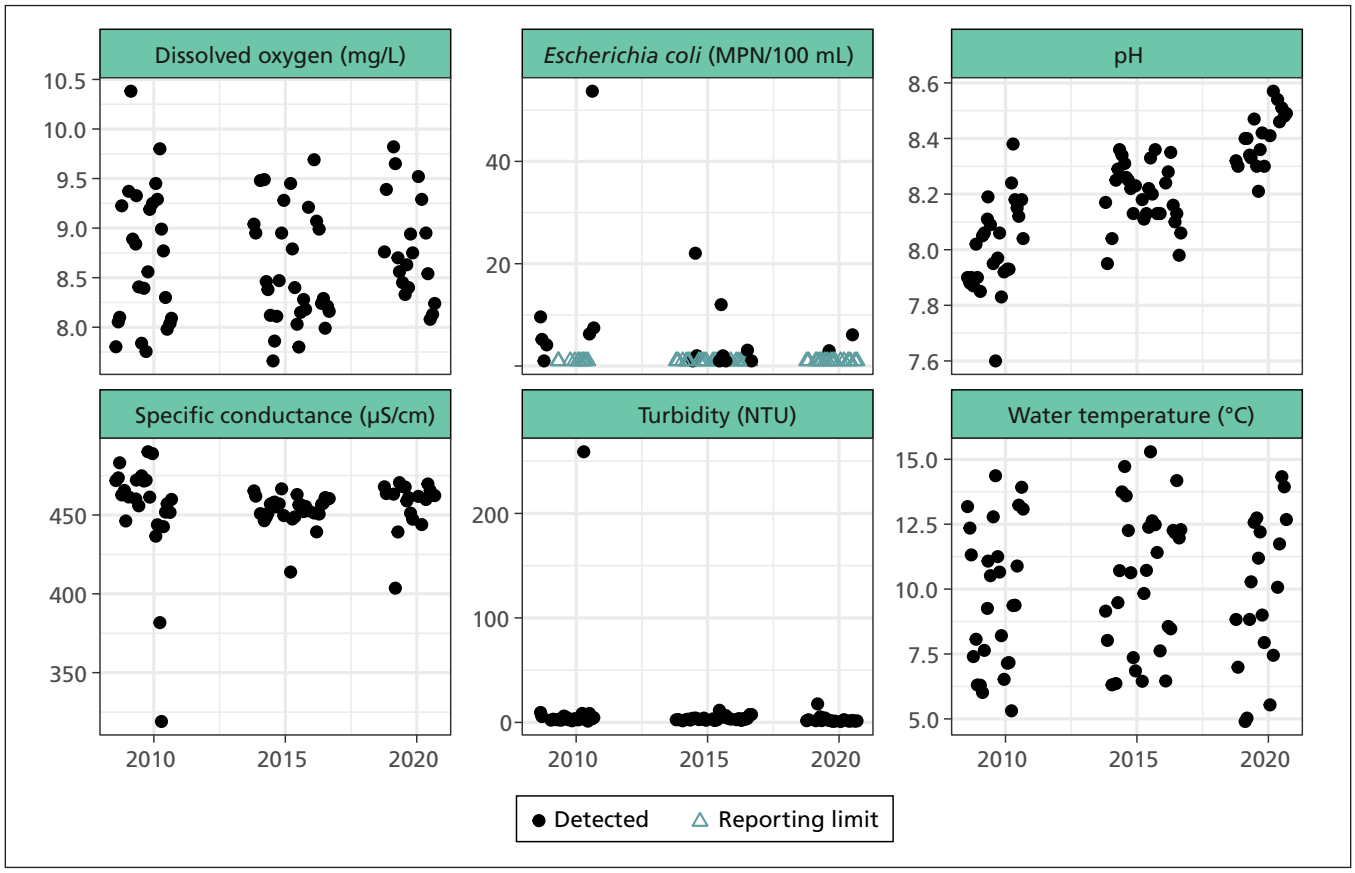


Figure 3-19. Core parameters over time at Mossy Cave Spring, July 2008–September 2021. There were statistically significant increases in dissolved oxygen and pH and no trend in specific conductance, turbidity, or water temperature. *E. coli* had >50% censored data.

Table 3-14. Summary statistics for major ions at Mossy Cave Spring, including sample period; total number of samples (N); number of censored samples; percentiles 10, 50, and 90 of the dataset; and the percent of samples that did not meet state water-quality standards.

Parameter	Start	End	Sample yrs	N	Censored n	Percentile			Exceedance %
						10	50	90	
Alkalinity as $CaCO_3$ (mg/L)	7/23/2008	9/7/2020	8	72	0	225	233	246	–
Calcium (d) (mg/L)	7/23/2008	9/7/2020	8	74	0	39.1	41.7	44.6	–
Chloride (mg/L)	10/23/2013	9/7/2020	5	48	0	5.26	6.58	7.18	–
Magnesium (d) (mg/L)	7/23/2008	9/7/2020	8	74	0	32.0	34.2	36.6	–
Potassium (d) (mg/L)	7/23/2008	9/7/2020	8	74	1	1.5	1.8	1.9	–
Sodium (d) (mg/L)	7/23/2008	9/7/2020	8	74	0	3.7	4.3	4.7	–
Sulfate as SO_4 (mg/L)	7/23/2008	9/7/2020	8	71	68	<20	<20	<20	–
Total dissolved solids (mg/L)	7/23/2008	9/7/2020	8	74	0	213	233	247	0

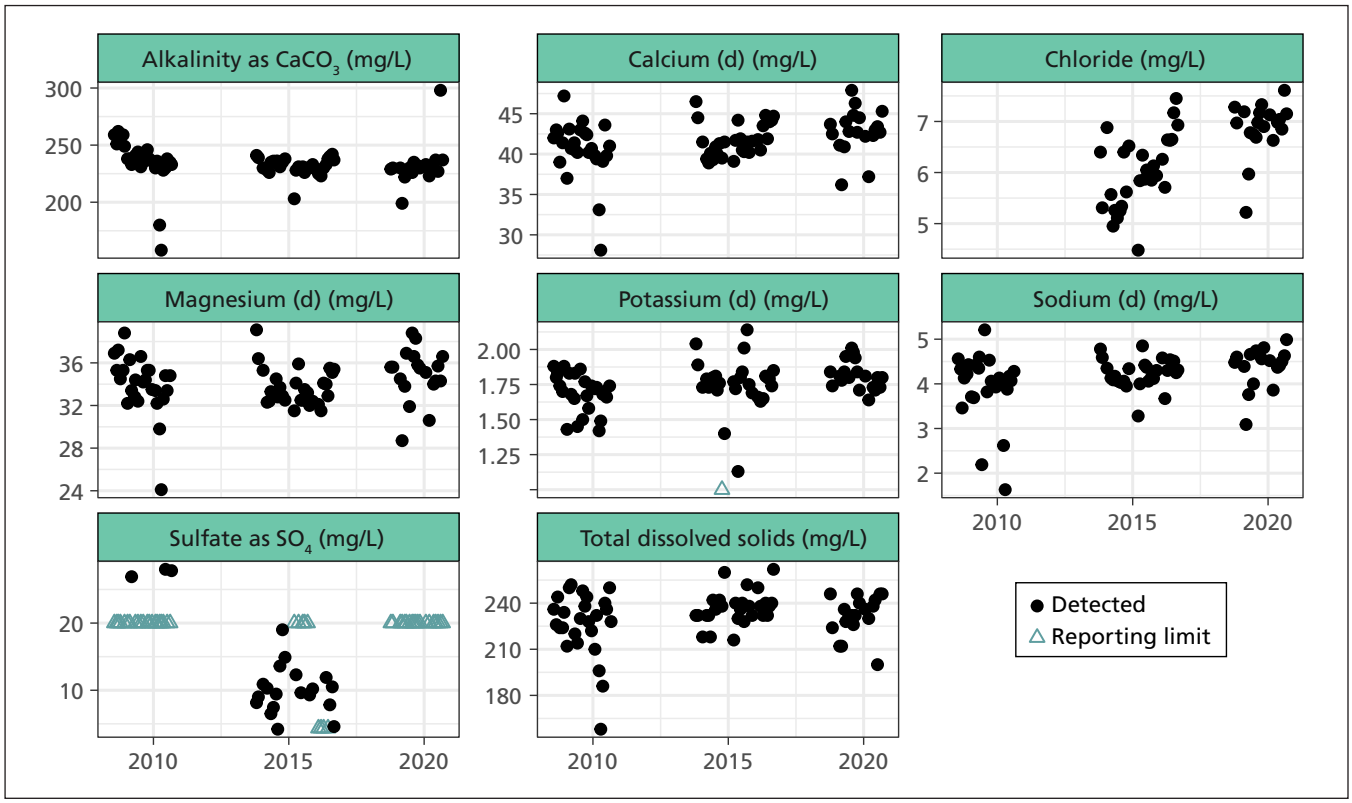


Figure 3-20. Major ions over time at Mossy Cave Spring, July 2008–September 2021. There were statistically significant increases in calcium, chloride, potassium, and sodium, a decreasing trend in alkalinity, and no trend in magnesium or total dissolved solids. Sulfate had >50% censored data.

Table 3-15. Summary statistics for nutrients at Mossy Cave Spring, including sample period; total number of samples (N); number of censored samples; percentiles 10, 50, and 90 of the dataset; and the percent of samples that did not meet state water-quality standards.

Parameter	Start	End	Sample yrs	N	Censored n	Percentile			Exceedance %
						10	50	90	
Ammonia as N (mg/L)	7/23/2008	9/7/2020	8	74	74	<0.05	<0.05	<0.05	0
Nitrite + Nitrate as N (d) (mg/L)	7/23/2008	9/7/2020	8	74	0	0.36	0.40	0.48	–
Phosphorus as P (d) (mg/L)	8/25/2008	9/7/2020	8	72	46	<0.003	<0.003	0.009	–
Phosphorus as P (mg/L)	8/25/2008	9/7/2020	8	72	32	<0.003	0.0045	0.013	2
Total Nitrogen (d) (mg/L)	7/23/2008	9/7/2020	8	74	0	0.35	0.44	0.57	–

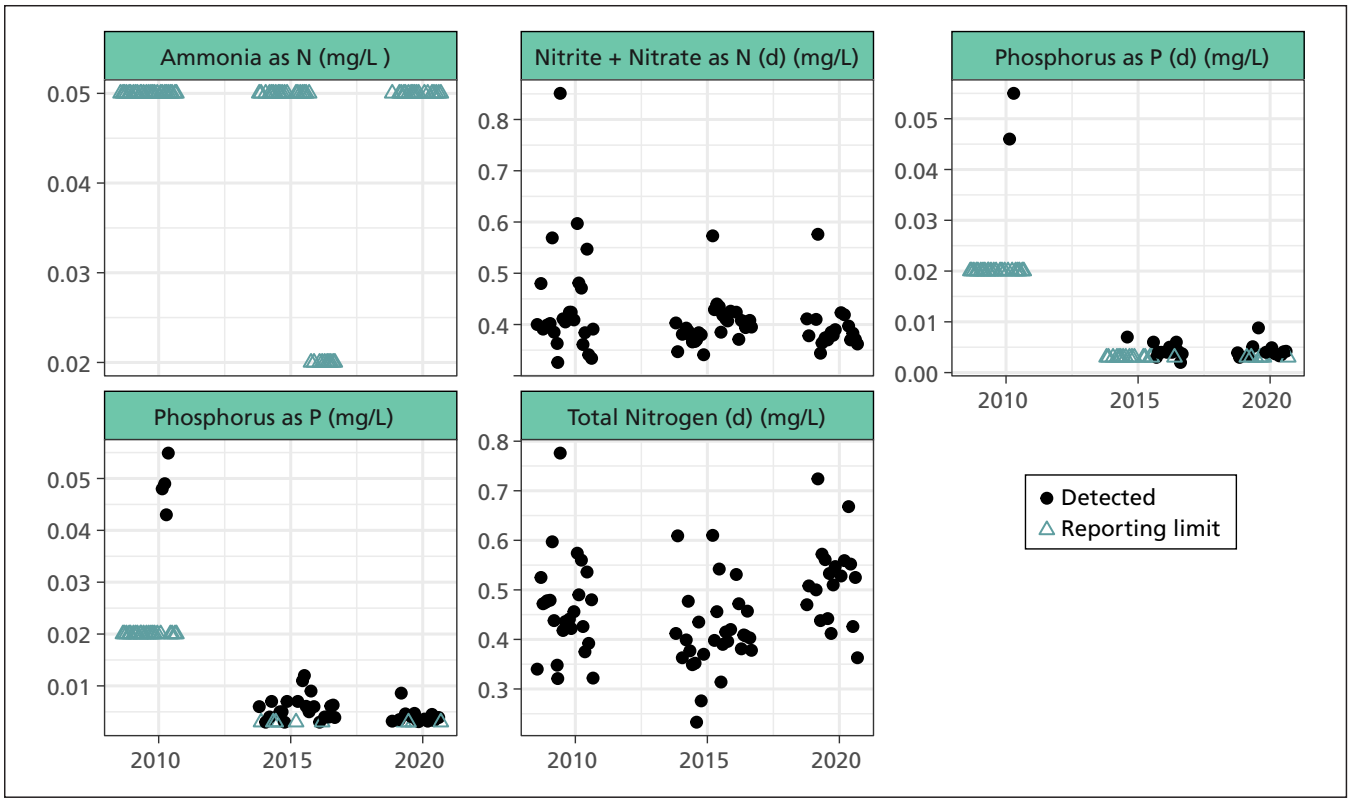


Figure 3-21. Nutrients over time at Mossy Cave Spring, July 2008–September 2021. There was a statistically significant decrease in total phosphorus and no trend in nitrate plus nitrite or total dissolved nitrogen. Ammonia and dissolved phosphorus had >50% censored data.

Table 3-16. Summary statistics for trace elements at Mossy Cave Spring, including sample period; total number of samples (N); number of censored samples; percentiles 10, 50, and 90 of the dataset; and the percent of samples that did not meet state water-quality standards.

Parameter	Start	End	Sample yrs	N	Censored n	Percentile			Exceedance %
						10	50	90	
Aluminum (d) (µg/L)	7/23/2008	7/6/2020	8	26	24	<10	<10	<10	0
Arsenic (d) (µg/L)	7/23/2008	7/6/2020	8	26	0	4.4	4.7	5.1	0
Barium (d) (µg/L)	7/23/2008	7/6/2020	8	26	0	376	438	469	–
Boron (d) (µg/L)	7/23/2008	7/6/2020	8	28	8	<30	34	38	0
Cadmium (d) (µg/L)	7/23/2008	7/6/2020	8	26	26	<0.1	<0.1	<0.1	0
Chromium (d) (µg/L)	7/23/2008	7/6/2020	8	26	21	<2	<2	3.68	0
Copper (d) (µg/L)	7/23/2008	7/6/2020	8	26	26	<1	<1	<1	0
Iron (d) (µg/L)	7/23/2008	7/6/2020	8	28	28	<30	<30	<30	0
Lead (d) (µg/L)	7/23/2008	7/6/2020	8	25	23	<0.1	<0.1	<0.1	0
Manganese (d) (µg/L)	7/23/2008	7/6/2020	8	25	25	<5	<5	<5	–
Mercury (d) (µg/L)	7/23/2008	7/6/2020	8	26	26	<0.2	<0.2	<0.2	0
Nickel (d) (µg/L)	7/23/2008	7/6/2020	8	25	25	<5	<5	<5	0
Silver (d) (µg/L)	7/23/2008	7/6/2020	8	26	26	<0.5	<0.5	<0.5	0
Zinc (d) (µg/L)	7/23/2008	7/6/2020	8	25	25	<10	<10	<10	0

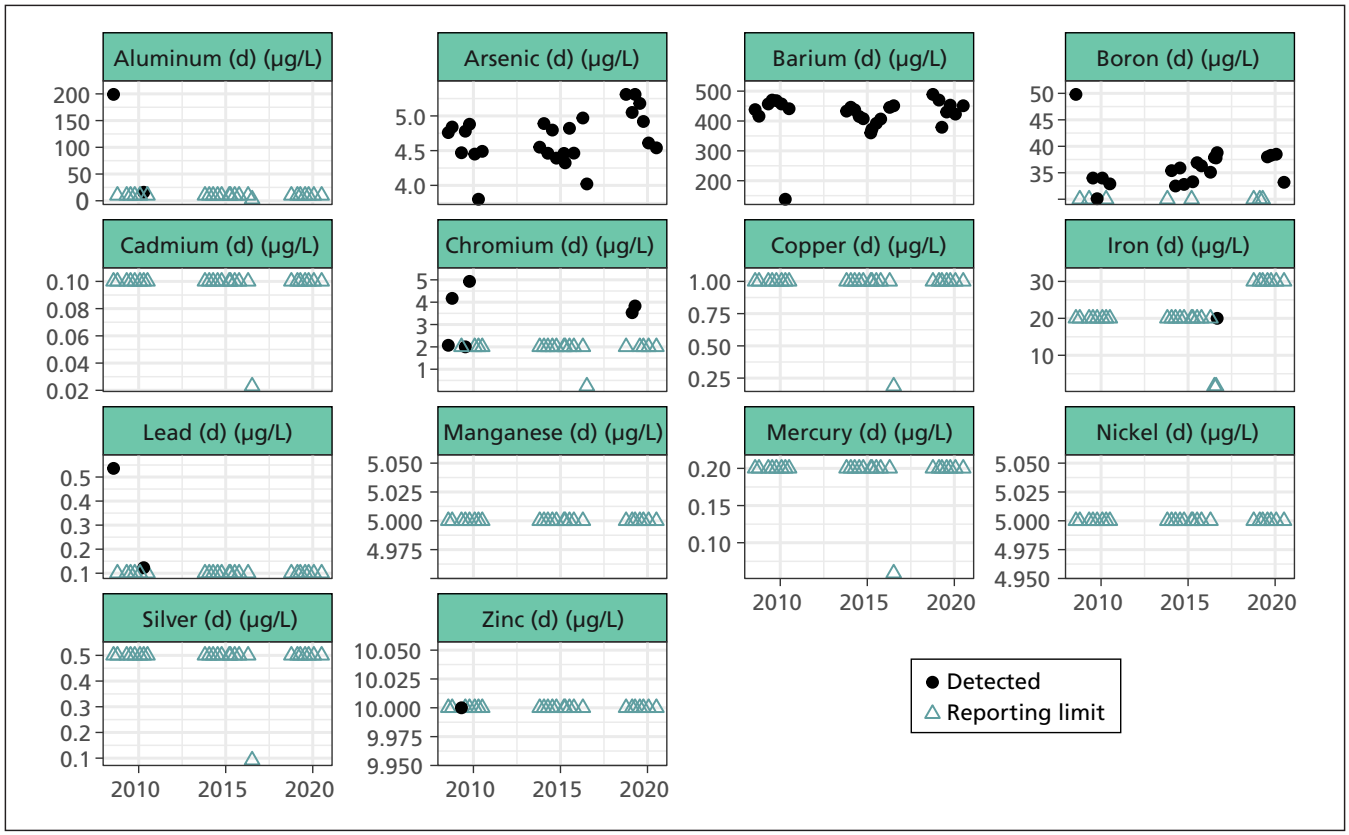


Figure 3-22. Trace elements over time at Mossy Cave Spring, July 2008–September 2021. There was no trend in arsenic, barium, or boron. All other trace elements had >50% censored data.

3.5.1 Comparison to Tropic Ditch

Because Tropic Ditch runs just upgradient of Mossy Cave Spring and has seepage into Water Canyon, NCPN has taken concurrent samples of core parameters in Tropic Ditch (Table 3-17). There appears to be little instantaneous influence of Tropic Ditch on Mossy Cave Spring (Figure 3-23). However, any seepage from the irrigation canal would have an unknown time lag prior to being discharged through the spring. It is possible that higher flows in Tropic Ditch during the growing season contribute to the surprising increases in flow seen at Mossy Cave Spring at higher air temperatures.

Table 3-17. Summary statistics for core parameters at Tropic Ditch, including sample period; total number of samples (N); number of censored samples; and percentiles 10, 50, and 90 of the dataset.

Parameter	Start	End	Sample yrs	N	Censored n	Percentile		
						10	50	90
Dissolved oxygen (mg/L)	7/23/2008	9/7/2020	8	74	0	7.6	8.6	9.9
Escherichia coli (MPN/100 mL)	8/25/2008	9/7/2020	8	66	29	<1	1.5	50.1
Flow (cfs)	7/23/2008	9/7/2020	8	76	2	0.075	12.6	20.3
pH	7/23/2008	9/7/2020	8	76	0	8.32	8.60	8.78
Specific conductance (µS/cm)	7/23/2008	9/7/2020	8	70	0	333	413	472
Turbidity (NTU)	7/23/2008	9/7/2020	5	23	0	4.1	22	158
Water temperature (°C)	7/23/2008	9/7/2020	8	76	0	5.3	11.4	17.6

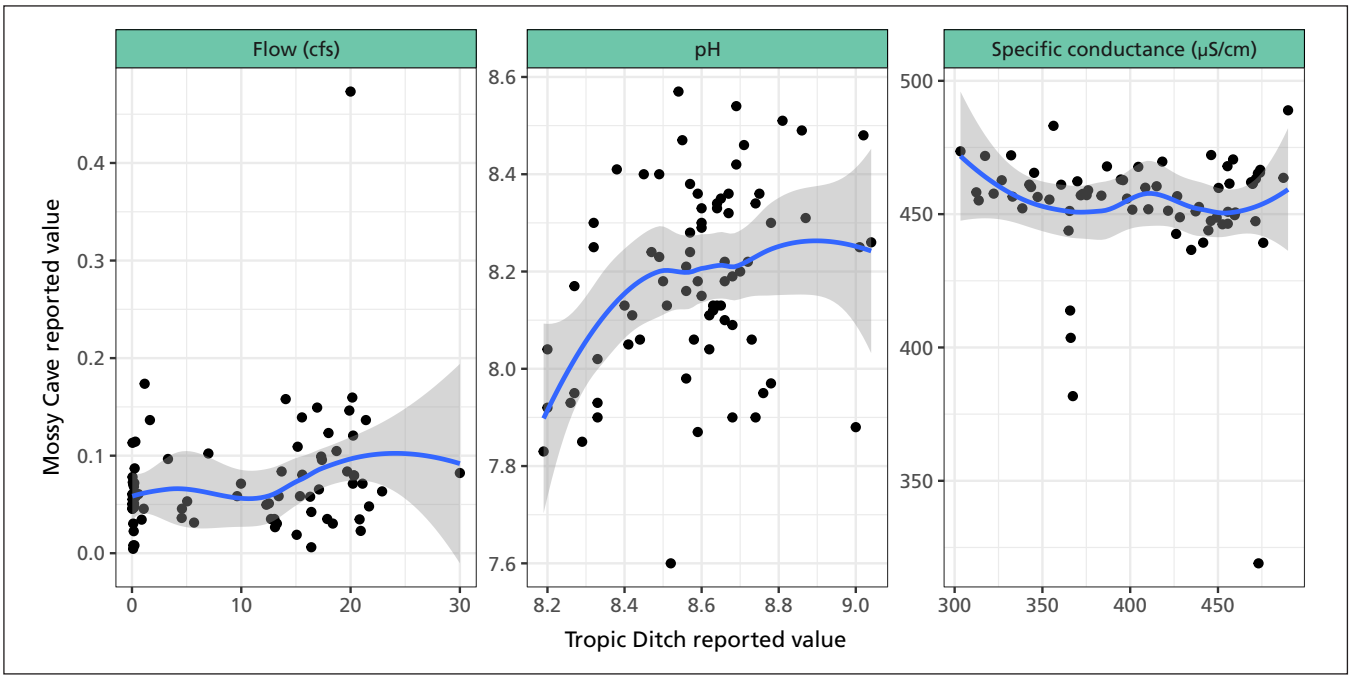


Figure 3-23. Relationships of concurrent measurements at Mossy Cave Spring and Tropic Ditch with a LOESS smooth.

4 Conclusions

4.1 Current status and trends

The water quality at monitoring stations in Bryce Canyon NP continues to be excellent, and park managers have been successful in their goal of maintaining these systems in unimpaired condition. Tributaries to the East Fork Sevier River originating on the Paunsaugunt Plateau have previously been recognized for their excellent water quality and high ecological significance through designation as Category 1 waters by the State of Utah. This status confers the highest degree of anti-degradation protection under the auspices of the Clean Water Act. Based on our dataset, Sheep Creek, Yellow Creek, and Mossy Cave Spring may also qualify for Category 1 status. The primary management concern noted in our dataset was infrequent but continued *E. coli* exceedances at Sheep and Yellow creeks. These exceedances have coincided with flood damage to park fencing and the subsequent presence of trespass livestock in the riparian corridors, as has been noted in previous reports (e.g., Hackbarth and Weissinger 2020, Hackbarth and Weissinger 2016). It is important that fences are maintained along active grazing allotments at the park boundary.

All told, 29 of 109 (27%) site-parameter combinations had statistically significant trends over time. The causes of these trends are mostly unknown, and for most parameters there is no quantified ecological threshold of concern other than state water-quality standards. Most of the trends, with the exception of a few discussed below, do not appear concerning at this time. For many parameters with statistical trends, either the total change or the magnitude of change when compared to the median value—sometimes both—was quite low. For example, high-magnitude decreasing trends in turbidity were noted for sites with median values of 0.98 and 2 NTU—values that are comparable to drinking-water sources and represent very small changes in the ambient turbidity. Such trends are likely to have little ecological significance in streams.

In other cases, statistical trends may be related to artifacts, such as analytical and instrument changes. For example, trends in dissolved phosphorus occurred near the method detection limit, where exact quantification is unreliable (see Appendix B). Many major ions also show a pattern of higher variability earlier in the record, where less information on data quality is available. Increases in chloride at Sheep Creek and Mossy Cave Spring, and a decrease in TDS at Yellow Creek, may be related to laboratory bias noted in proficiency-testing data. Both NCPN and the Utah state laboratory have added quality-assurance and quality-control measures over the years (Weissinger 2016), but analytical uncertainty will persist when testing for very low concentrations in high-quality waters.

The most concerning trends in water quality at Bryce Canyon NP appear to be related to climate change. Minimum and maximum air temperatures are increasing at the park, while precipitation remains highly variable. Increasing air temperatures have led to increasing water temperatures in Sheep and Yellow creeks. Sheep Creek also had a decrease in flow across several quantiles, while higher flows decreased at Yellow Creek in the same period. Surface flows in these two creeks are likely to decrease during base flow periods because of higher evapotranspiration due to warming air temperatures and possibly decreasing snowmelt runoff as the climate changes, as is projected for much of the southwestern United States (Seager et al. 2013).

Mossy Cave Spring, which is sampled close to the spring emergence point, had less of a climate signal than Sheep and Yellow creeks. In our record, the spring shows a modest increase in discharge, including higher flows at higher air temperatures. This pattern may reflect a wetter climate in the recent past, or it may also reflect seepage from irrigation flows routed through Tropic Ditch upgradient of the spring. Water-quality data do not suggest a strong, instantaneous link between the two water sources. An uptick in visitation to Water Canyon and the Mossy Cave Trail has so far not been reflected by changes in water quality at this site, which remains excellent.

4.2 Future concerns and needs

The most significant threats to future water quality at Bryce Canyon National Park are likely to be from the direct and indirect effects of climate change. Groundwater emergence plays an important role in maintaining base flows at all three monitoring stations. The increasing aridity associated with climate change tends to increase demand for groundwater pumping (Wu et al. 2020). Recent studies suggest that the plateau valley-fill aquifer on which the park and neighboring municipalities rely may be especially sensitive to climate change, because it is directly recharged by recent precipitation events (Wallace et al. 2021). The park has already seen an increase in water-development requests adjacent to the park over the past 10 years. If the valley-fill aquifer becomes less reliable, developers may increasingly explore other groundwater sources. The NPS is currently supporting investigations into the potential effects of developments along the park boundary on recharge to the Claron Formation aquifer that feeds Mossy Cave Spring (Wallace et al. 2021). However, the extent of the aquifer and flow paths within the aquifer are still relatively poorly understood. Even less is known about the extent and flow paths of the bedrock aquifers supporting springs in Sheep and Yellow creeks. Protecting these aquifers from increased groundwater withdrawals is imperative for maintaining surface flows at these sites in a hotter world.

Water quality is also affected by the condition of the watershed. While wildfire is a natural and integral disturbance in many forest ecosystems, high-severity fires are increasing in frequency in the western United States due to a hotter, drier climate and high fuel loads. These fires can have catastrophic and multi-year effects on water quality. Bryce Canyon NP has thus far escaped the increase in high-severity wildfire, but the conditions that increase its risk are present within the park. Protecting the park's creeks and springs from high-severity wildfire could include actions such as proactive fire-risk reduction practices and prioritizing watershed protection during wildfire response.

Long-term monitoring of water-quality stations at Bryce Canyon NP suggests relatively stable aquatic systems that benefit from protection within the park. To maintain these unimpaired conditions into the future, park managers could consider:

- Regular fence checks and maintenance along active grazing allotments at the park boundary to protect riparian areas and aquatic systems from trespass livestock.
- Developing a springs-monitoring program to track changes in springflow at spring emergences to better understand bedrock-aquifer water supplies. These data would also help quantify springflow for use in water-rights hearings.
- Supporting hydrogeologic investigations to map the extent and flow paths of groundwater aquifers.
- Working with the State of Utah to develop groundwater protection zones to protect groundwater aquifers from developments that would affect springs in the park.
- Prioritizing watershed management with proactive fire-risk reduction practices.
- Explicitly including watershed protection as a goal in plans for fire management and suppression.
- Using additional data and analyses to better understand the drivers of trends in water quality and their ecological significance. These could include higher-frequency data to better understand relationships between groundwater, precipitation, and surface flows at the sites. These could also include watershed metrics, such as vegetation cover and site shading, or integrated aquatic metrics, such as aquatic invertebrate sampling.

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Appendix A. Utah Public Health Laboratory Analytical Methods

Table A-1. Analytical methods and reporting limits for water-quality parameters analyzed at the Utah Public Health Laboratory.

Category	Parameter	Analytical method[1]	Start date	End date	Highest reporting limit[2]	Samples analyzed
Major ions	Alkalinity as $CaCO_3$ (mg/L)	SM 2320-B	9/30/2005	9/5/2021	NR	304
Major ions	Calcium (d) (mg/L)	EPA 200.7(W)	9/30/2005	9/5/2021	NR	255
Major ions	Calcium (d) (mg/L)	EPA 200.8(W)	10/15/2016	1/24/2020	NR	47
Major ions	Chloride (mg/L)	EPA 325.2	11/17/2011	9/5/2021	NR	172
Major ions	Magnesium (d) (mg/L)	EPA 200.7(W)	9/30/2005	9/5/2021	NR	255
Major ions	Magnesium (d) (mg/L)	EPA 200.8(W)	10/15/2016	1/24/2020	NR	47
Major ions	Potassium (d) (mg/L)	EPA 200.7(W)	9/30/2005	9/5/2021	1	255
Major ions	Potassium (d) (mg/L)	EPA 200.8(W)	10/15/2016	1/24/2020	NR	47
Major ions	Sodium (d) (mg/L)	EPA 200.7(W)	9/30/2005	9/5/2021	NR	255
Major ions	Sodium (d) (mg/L)	EPA 200.8(W)	10/15/2016	1/24/2020	NR	47
Major ions	Sulfate as SO_4 (mg/L)	EPA 375.2	9/30/2005	9/5/2021	20	301
Major ions	Total dissolved solids (mg/L)	EPA 160.1	7/8/2016	9/5/2021	NR	87
Major ions	Total dissolved solids (mg/L)	SM 2540-C	9/30/2005	6/13/2016	NR	216
Nutrients	Ammonia as N (mg/L)	EPA 350.1	7/23/2008	9/5/2021	0.05	240
Nutrients	Nitrite + Nitrate as N (d) (mg/L)	EPA 353.2	7/23/2008	9/5/2021	0.1	241
Nutrients	Phosphorus as P (d) (mg/L)	EPA 365.1	11/17/2011	9/5/2021	0.003	167
Nutrients	Phosphorus as P (mg/L)	EPA 365.1	11/17/2011	9/5/2021	0.003	166
Nutrients	Total Nitrogen (d) (mg/L)	SM 4500-N-C	7/23/2008	9/7/2020	0.2	221
Nutrients	Total Nitrogen (d) (mg/L)	ASTM D8083-16	10/2/2020	9/5/2021	0.2	20
Trace elements	Aluminum (d) (µg/L)	EPA 200.8(W)	9/30/2005	7/7/2021	30	107
Trace elements	Arsenic (d) (µg/L)	EPA 200.8(W)	9/30/2005	7/7/2021	1	106
Trace elements	Barium (d) (µg/L)	EPA 200.8(W)	9/30/2005	7/7/2021	100	106
Trace elements	Boron (d) (µg/L)	EPA 200.7(W)	9/30/2005	7/7/2021	30	90
Trace elements	Boron (d) (µg/L)	EPA 200.8(W)	10/15/2016	1/24/2020	30	28
Trace elements	Cadmium (d) (µg/L)	EPA 200.8(W)	9/30/2005	7/7/2021	1	108
Trace elements	Chromium (d) (µg/L)	EPA 200.8(W)	9/30/2005	7/7/2021	5	108
Trace elements	Copper (d) (µg/L)	EPA 200.8(W)	9/30/2005	7/7/2021	12	108
Trace elements	Iron (d) (µg/L)	EPA 200.7(W)	9/30/2005	7/7/2021	30	90
Trace elements	Iron (d) (µg/L)	EPA 200.8(W)	10/15/2016	1/24/2020	30	29
Trace elements	Lead (d) (µg/L)	EPA 200.8(W)	9/30/2005	7/7/2021	3	106
Trace elements	Manganese (d) (µg/L)	EPA 200.8(W)	9/30/2005	7/7/2021	5	105
Trace elements	Mercury (d) (µg/L)	EPA 245.1	9/30/2005	7/7/2021	0.2	108
Trace elements	Nickel (d) (µg/L)	EPA 200.8(W)	9/30/2005	7/7/2021	10	106
Trace elements	Silver (d) (µg/L)	EPA 200.8(W)	9/30/2005	7/7/2021	2	108
Trace elements	Zinc (d) (µg/L)	EPA 200.8(W)	9/30/2005	7/7/2021	30	106

[1]SM = Standard Methods for the Examination of Water and Wastewater, EPA = US Environmental Protection Agency methods, ASTM = American Society for Testing and Materials (ASTM International).
[2]NR = Not Reported (all results detected and quantified).

Appendix B. Analytical Considerations for Dissolved and Total Phosphorus

Changes in dissolved and total phosphorus reporting limits in our dataset correspond to a change in the way the Utah state laboratory reported results. Until 2011, the laboratory used a practical quantitation limit (PQL), which is defined as the lowest concentration that can be quantified with statistical rigor (US EPA 2006), in our case 0.02 mg/L. The PQL takes into account the sensitivity of the instrument and variability in sample handling between individual technicians, then applies a factor (2–10×) to determine the concentration that can be reliably reported for the laboratory. It is a conservative report of the results, however, because concentrations lower than the PQL can still be reliably detected. In 2011, the laboratory began reporting at the minimum level, the lowest concentration on the instrument-calibration curve when a signal can be detected (US EPA Method 1631 Revision E, 2002, Page 32, Office of Water). This dropped the reporting level in the dataset to a concentration of 0.003 mg/L. However, reported concentrations near the minimum level are estimated concentrations, rather than rigorously quantified detections.

One way to evaluate the robustness of estimated concentrations is to use field blanks to evaluate the possibility of bias or contamination. NCPN began submitting programmatic field blanks in October 2013. The goal for field blanks is to have all concentrations reported as less than the minimum level. Sixty field blanks were submitted for dissolved and total phosphorus during water years 2013–2021. Of these, 24 field blanks for dissolved phosphorus reported concentrations greater than the minimum level of 0.003 mg/L, with a maximum reported concentration of 0.047 mg/L (Figure B-1). Twenty-three field blanks for total phosphorus had reported concentrations greater than the minimum level of 0.003 mg/L, with a maximum reported concentration of 0.029 mg/L (Figure B-1).

It is apparent from our field-blank dataset that both dissolved and total phosphorus are frequently reported in concentrations above the lower laboratory reporting limit in our period of record (the minimum level of 0.003 mg/L). This issue is not isolated to NCPN field blanks. From 2016 to 2017, field-blank samples submitted to the same laboratory by the Utah Division of Water Quality also reported detections in more than half of dissolved-phosphorus samples and about one-third of total-phosphorus samples (personal communication, T. Hooker, UTDWQ 12/12/2017). The source of the contamination or bias is at this point unknown. However, reported concentrations appear to be mostly decreasing over time in the NCPN field blanks. Field-blank detections were observed regardless of the source of the blank water used, the person submitting the sample, or the field site where the blank was processed.

When comparing programmatic replicate samples, precision is more variable below a concentration of about 0.01 mg/L between reported source and replicate concentrations for dissolved and total phosphorus (Figure B-2).

NCPN's quality-control data suggest there is considerable analytical uncertainty in phosphorus results as the reported concentration approaches the minimum detection limit of 0.003 mg/L. However, censoring all of the data to the earlier 0.02-mg/L practical quantitation limit would result in almost all phosphorus data at Bryce Canyon National Park falling below the reporting limit. In discussion with park staff, we opted to analyze trends in reported values using the method detection limit of 0.003 mg/L, even though analytical uncertainty at very low reported concentrations may result in spurious trends.

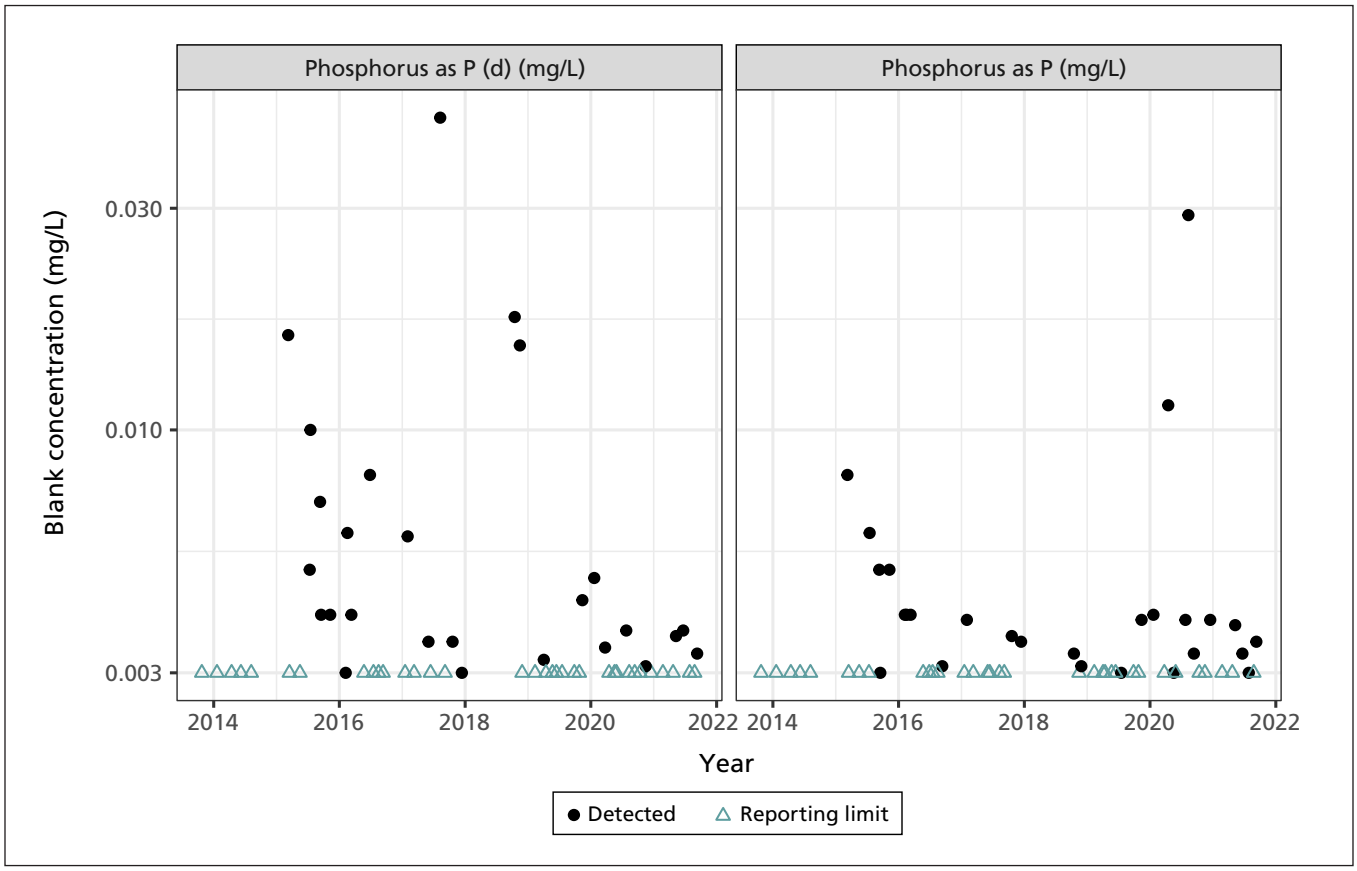


Figure B-1. Reported concentrations for total and dissolved phosphorus in field blanks for water years 2013–2021.

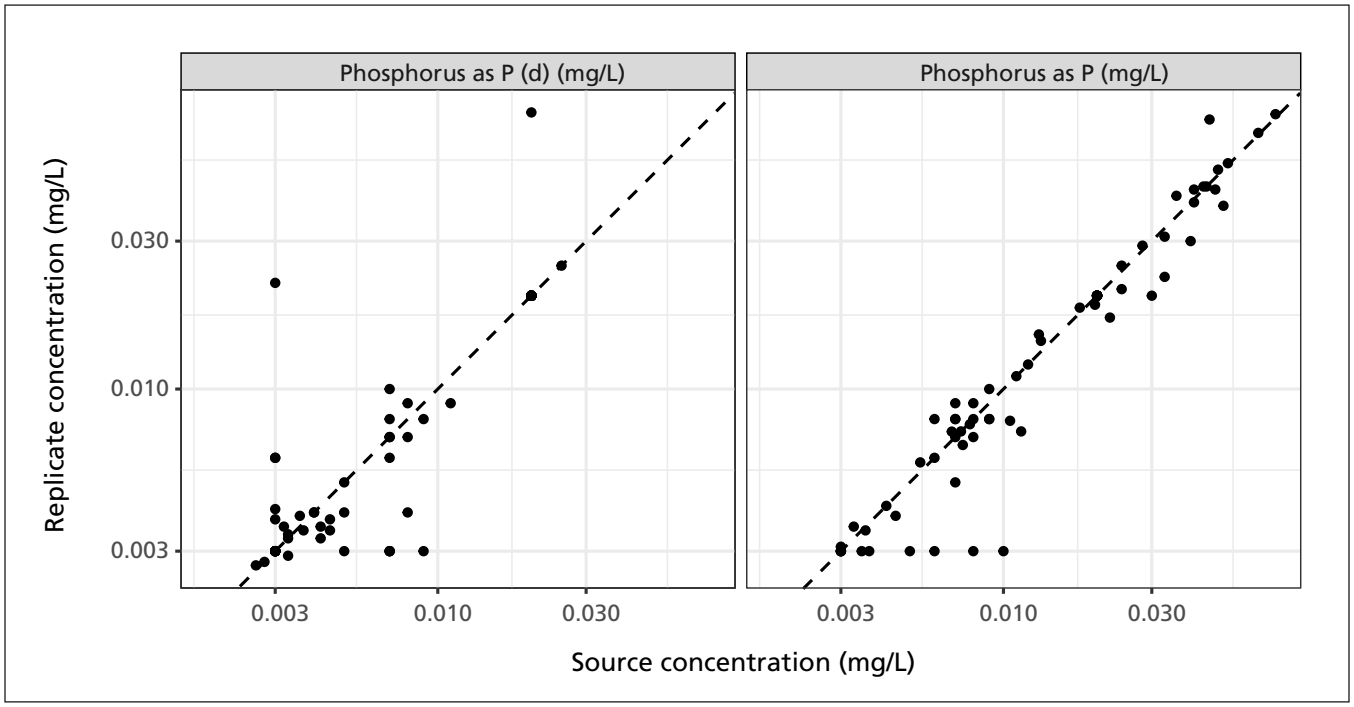


Figure B-2. Reported concentrations for dissolved and total phosphorus between source and replicate samples. The dashed line represents perfect agreement between the two reported concentrations.

Appendix C. State of Utah Water-Quality Beneficial Uses and Standards

State water-quality designated beneficial uses (Table C-1) and associated water-quality standards (Table C-2) for stations analyzed in Bryce Canyon National Park. Beneficial uses include drinking water supply (1C), recreational use (primary 2A, secondary 2B), aquatic life (cold water game fish 3A, warm water game fish 3B, non-game species 3C), and agricultural uses (4). Each designated beneficial use is associated with multiple water-quality standards. For most water-quality standards, a value higher than the standard value is considered an exceedance, or an indicator of poor water quality. If poor water quality is indicated by a value lower than the water-quality standard, the Type is indicated as "low" in the table. Acute standards indicate poor water quality if even a single sample does not meet the standard. Chronic standards must be exceeded in 10% or more of samples to indicate poor water quality.

Table C-1. State-designated beneficial uses associated with water bodies in Bryce Canyon National Park.

WQX ID	WQX station name	Latitude	Longitude	Utah beneficial uses
4951855	Sheep Ck bl Spring in Bryce Cyn NP	37.571	–112.201	2B, 3C, 4
4951857	Yellow Ck bl Spring in Bryce Cyn NP	37.574	–112.141	2B, 3C, 4
4951915	Mossy Cave Spring NW of Tropic	37.665	–112.115	2B, 3C, 4

Table C-2. Water-quality standards associated with designated beneficial uses for the State of Utah.

Parameter	Type	2B	3C	4
Dissolved oxygen (mg/L)	low	–	5	–
Escherichia coli (MPN/100 mL)	acute	668	–	–
Escherichia coli (MPN/100 mL)	chronic	206	–	–
pH	low	6.5	6.5	6.5
pH	–	9	9	9
Water temperature (°C)	–	–	27	–
Total dissolved solids (mg/L)	–	–	–	1200
Ammonia as N (mg/L)	–	–	pH Dep.	–
Total Phosphorus as P (mg/L)	–	0.05	0.05	–
Aluminum (d) (µg/L)	acute	–	750	–
Aluminum (d) (µg/L)	chronic	–	87	–
Arsenic (d) (µg/L)	acute	–	340	100
Arsenic (d) (µg/L)	chronic	–	150	–
Boron (d) (µg/L)	–	–	–	750
Cadmium (d) (µg/L)	–	–	HD	10
Chromium (d) (µg/L)	–	–	HD	100
Copper (d) (µg/L)	–	–	HD	200
Iron (d) (µg/L)	–	–	1,000	–
Lead (d) (µg/L)	–	–	HD	100
Mercury (d) (µg/L)	–	–	0.012	–
Nickel (d) (µg/L)	–	–	HD	–
Silver (d) (µg/L)	–	–	HD	–
Zinc (d) (µg/L)	–	–	HD	–

pH Dep. = Standard is dependent on concurrently measured pH value. HD = Standard is dependent on concurrently measured hardness concentration.

The Department of the Interior protects and manages the nation's natural resources and cultural heritage; provides scientific and other information about those resources; and honors its special responsibilities to American Indians, Alaska Natives, and affiliated Island Communities.

NPS 129/186522, November 2022

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