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Escherichia coli Concentrations in Fremont River Tributaries at Capitol Reef National Park, 2008–2017

Natural Resource Report NPS/NCPN/NRR—2018/1698



ON THE COVER

Sulphur Creek, Capitol Reef National Park, May 13, 2017. NPS photo.

Escherichia coli Concentrations in Fremont River Tributaries at Capitol Reef National Park, 2008–2017

Natural Resource Report NPS/NCPN/NRR—2018/1698

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Executive Summary

This report summarizes *Escherichia coli* (*E. coli*) concentrations in water samples collected in tributaries of the Fremont River at Capitol Reef National Park between July 2008 and September 2017. *E. coli* is a fecal indicator bacteria found in waste from humans, livestock, and wildlife. High concentrations of *E. coli* bacteria can indicate a public health hazard. The Utah Division of Water Quality (UDWQ) has developed acceptable concentrations as part of the state's water-quality standards.

In 2014, a segment of the Fremont River, including the portion flowing through Capitol Reef National Park, was listed as impaired for *E. coli*, water temperature, and total dissolved solids. UDWQ prioritized developing a plan to reduce *E. coli* concentrations in the Fremont River. As part of this plan, water samples have been collected at numerous locations along the impaired segment of the Fremont River to test for *E. coli* concentrations. Along with efforts by UDWQ, the National Park Service Northern Colorado Plateau Network has monitored three tributaries to the Fremont River within Capitol Reef National Park since July 2008. This sampling is part of a long-term monitoring program that includes *E. coli* as part of a suite of water-quality parameters that have been reported elsewhere (e.g., Hackbarth and Weissinger 2016; Hackbarth and Weissinger 2013). Samples are collected monthly on a rotating schedule at two locations in Sulphur Creek and one location each in Pleasant Creek and Oak Creek. At all four water-quality sites within the park, *E. coli* concentrations have exceeded both chronic and acute state water-quality standards for recreational use.

Relationships between *E. coli*, streamflow, and turbidity were examined to determine if there were patterns that contributed to *E. coli* exceedances. At all three streams, high *E. coli* concentrations were found even during conditions of low flow and low turbidity, suggesting that *E. coli* contamination is not just due to flood events. Most exceedances occurred during the state-defined recreation season of May 1–October 31. This timeframe encompasses over 75% of the park's annual visitation and also corresponds to cattle trailing through Oak and Pleasant creeks and dispersed livestock grazing on public lands upstream of the park in all three watersheds. Paired samples taken upstream and downstream of a popular hiking area and the park developed area on Sulphur Creek showed similar patterns in *E. coli* concentrations, suggesting that in Sulphur Creek, most *E. coli* contamination enters upstream of the park, rather than coming from park visitation or infrastructure. Upstream and downstream comparisons are not available for Oak Creek and Pleasant Creek, which have less park infrastructure and visitation than Sulphur Creek. Results from this effort can help inform park managers of potential problems with *E. coli* contamination within the park and assist the State of Utah in determining potential sources of *E. coli* contamination in the Fremont River.

Acknowledgements

David Thoma designed and implemented the Northern Colorado Plateau Network (NCPN)'s water-quality monitoring program. David Thoma, Clay Bliss, Kelly Lawrence, Matt Van Grinsven, and Kelon Crawford collected water-quality data and samples. Thanks to Helen Thomas and Dean Tucker for providing database management, and to Aneth Wight for managing spatial data for the project. Additional thanks to Terry Fisk and Sandy Borthwick at Capitol Reef National Park, Amy Dickey at the Utah Division of Water Quality, and Dusty Perkins (NCPN) for reviewing this document.

1 Introduction

The Fremont River is a perennial stream originating on the Fish Lake Plateau of central Utah. From its high-elevation headwaters, the Fremont River runs south through Rabbit Valley, an agricultural area with a residential population of about 3,000, before entering Capitol Reef National Park. The Fremont River flows through the park and continues eastward to its confluence with the Dirty Devil River near Hanksville, Utah.

The Fremont River has a history of water-quality impairments. Its upper reaches were listed as impaired by the State of Utah in 2000 because of low dissolved-oxygen concentrations and high phosphorus concentrations (UDWQ 2002). A watershed management plan led to voluntary modifications in agricultural practices in this area, including relocating animal-feeding operations away from the river, reducing flood irrigation of pastures, and adding riparian fencing (EPA 2016). Improvements in water quality led to the removal of this segment of the Fremont River from the state's list of impaired waters in 2016, but additional impairments persist downstream of the headwaters and within Capitol Reef National Park.

In 2014, the segment of the Fremont River from the town of Bicknell, Utah, downstream through Capitol Reef National Park was listed as impaired for the fecal-indicator bacteria, *Escherichia coli* (*E. coli*), water temperature, and total dissolved solids (UDWQ 2016a). *E. coli* are bacteria that are present in fecal matter of humans, livestock, and wildlife. Because some forms of *E. coli* can be harmful to human health, they are used in water-quality monitoring as an indicator of a broader public health risk due to fecal contamination. The State of Utah has prioritized developing a plan to reduce *E. coli* concentrations in the Fremont River because the river is classified as a source of drinking water and has the potential for high recreational use within a national park (UDWQ 2016b).

As part of this plan, the State of Utah has organized *E. coli* sample collections along the Fremont River upstream and within Capitol Reef National Park (A. Dickey, UDWQ, pers. comm.). Three perennial tributaries to the Fremont River also pass through the park: Sulphur Creek, Pleasant Creek, and Oak Creek. Since July 2008, the National Park Service Northern Colorado Plateau Network (NCPN) has collected *E. coli* samples at four locations on these three creeks as part of a long-term water-quality monitoring effort (Thoma et al. 2017). From 2012 to 2015, *E. coli* concentrations exceeded state water-quality standards for chronic contamination in all three creeks (Hackbarth and Weissinger 2016).

The purpose of this report is to explore seasonal and flow-related patterns in *E. coli* contamination on tributaries to the Fremont River within Capitol Reef National Park. Results from this effort can help inform park managers of potential problems with *E. coli* contamination within the park and assist the State of Utah in determining potential sources of *E. coli* contamination in the Fremont River.

2 Methods

2.1 Study sites

The Northern Colorado Plateau Network monitors water quality at four sites within the Fremont River watershed. These sites are located on Sulphur Creek, Pleasant Creek, and Oak Creek (Table 2-1, Figure 2-1).

2.1.1 Sulphur Creek

Sulphur Creek originates at Thousand Lake Mountain in Fishlake National Forest and passes north of the town of Torrey before entering Capitol Reef National Park. Land uses in the forest include livestock grazing, logging, and recreation. Sulphur Creek flows about 6.5 miles through the park before reaching the Fremont River. The study site for Upper Sulphur Creek (Figure 2-2) is located about one mile downstream from the park's western boundary. The site for Lower Sulphur Creek (Figure 2-3) is located about five miles downstream from the upper site and just upstream of Sulphur Creek's confluence with the Fremont River. The section between the upstream and downstream sites is a popular hiking route through Sulphur Creek Canyon and sees heavy use by park visitors during the summer. Lower Sulphur Creek is downstream of park offices and housing, a leach field, and irrigated orchards. Deer are abundant throughout the developed area of the park. The upstream and downstream sites are regularly sampled on the same day to determine how park activities and infrastructure affect water quality.

2.1.2 Pleasant Creek

The headwaters of Pleasant Creek begin on Boulder Mountain. Boulder Mountain and the surrounding area are managed by the U.S. Forest Service. There are numerous grazing allotments on Boulder Mountain. Cattle trailing is permitted through Pleasant Creek for one day in October, when about 250 head pass through the park. The creek passes by U.S. Forest Service campgrounds and backcountry four-wheel drive roads as it makes its way to the park. Pleasant Creek flows about 2.5 miles from the west boundary of the park before reaching South Draw Road. The study site (Figure 2-4) is located just upstream of the road crossing and next to a small parking area and vault toilet. Pleasant Creek flows for another 4.5 miles before it leaves the park and passes through the small town of Notom, eventually entering the Fremont River about 10 miles past the east boundary of the park. Pleasant Creek is accessible within the park via a graded, two-wheel drive dirt road. There is no established trail at Pleasant Creek, and hiking involves numerous stream crossings. Visitation is much lower than in the high-use area around Sulphur Creek. Four outfitters have commercial use permits for horseback tours in Pleasant Creek.

2.1.3 Oak Creek

Oak Creek begins on Boulder Mountain, near the headwaters of Pleasant Creek, and flows east through the Waterpocket Fold. Cattle trailing is permitted through Oak Creek in the spring and fall, with about 1,100 head passing through the park for approximately one week in spring and one week in fall. Trespass cattle have been frequently noted along Oak Creek within the park. The site for water-quality monitoring (Figure 2-5) is located about four miles downstream from the western park boundary and just upstream from Oak Creek Dam, an impoundment that diverts water into irrigation ditches

Table 2-1. Northern Colorado Plateau Network water-quality monitoring sites and location information in Capitol Reef National Park.

Site name	Site ID	Site description	Latitude	Longitude	Date established
Lower Sulphur Creek	4954770	Sulphur Ck ab cnfl / Fremont R in Picnic Area	38.2874	-111.2487	7/22/2008
Upper Sulphur Creek	4954775	Sulphur Ck bl road to Goosenecks Overlook	38.3034	-111.3060	7/22/2008
Pleasant Creek	4954780	Pleasant Ck S of Sleeping Rainbow Ranch	38.1801	-111.1808	7/22/2008
Oak Creek	4954795	Oak Creek ab Sandy Ranch Dam	38.0844	-111.1397	10/27/2010

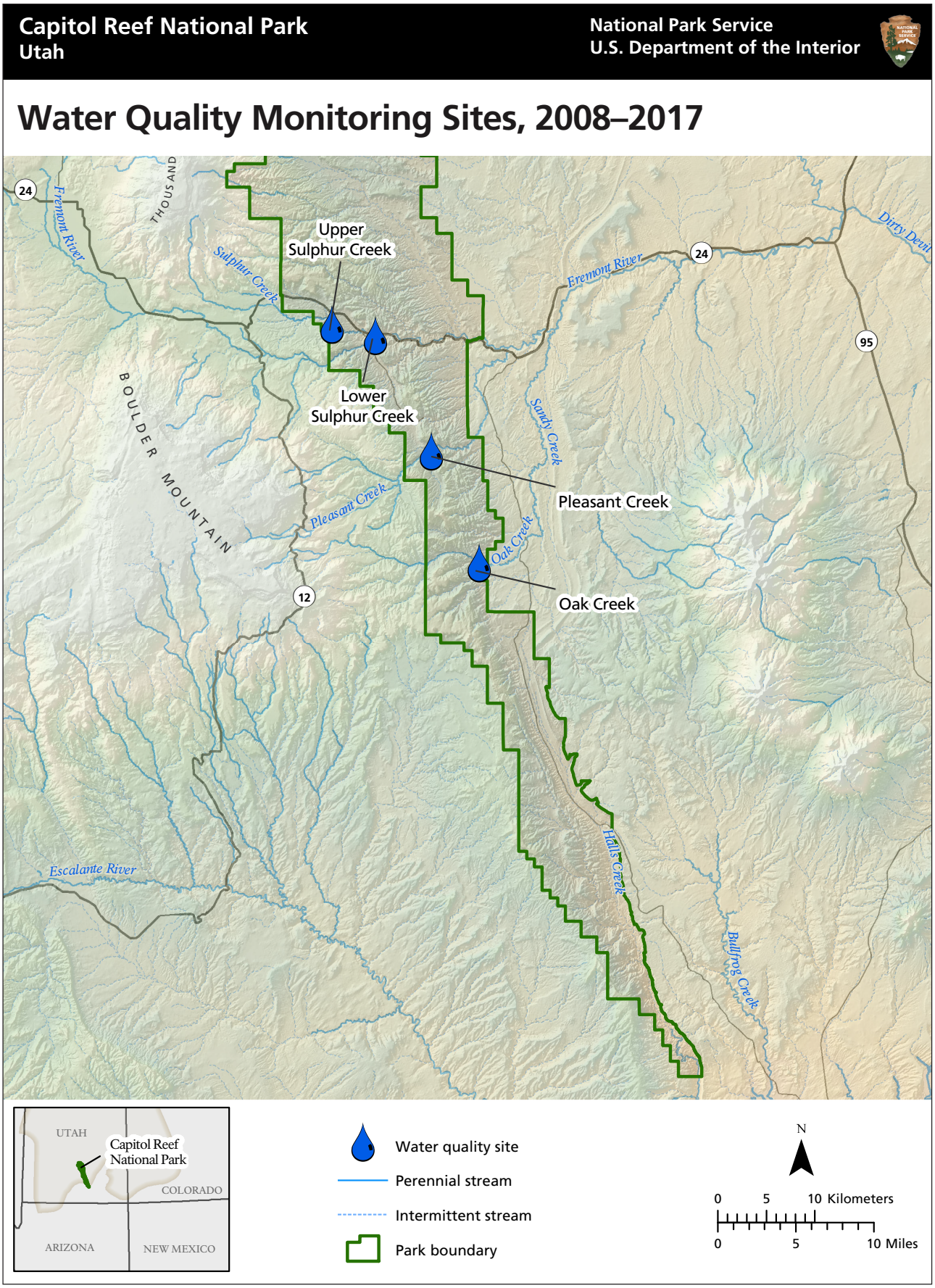


Figure 2-1. Northern Colorado Plateau Network water-quality monitoring sites in Capitol Reef National Park.



Figure 2-2. Upper Sulphur Creek water-quality site on April 18, 2017, looking upstream.



Figure 2-3. Lower Sulphur Creek water-quality site on March 18, 2017, looking upstream.



Figure 2-4. Pleasant Creek water-quality site on May 12, 2017, looking downstream.



Figure 2-5. Oak Creek water-quality site on June 13, 2017, looking upstream.

for a nearby cattle ranch. During the summer months, the majority of the water at the dam is diverted to irrigate pastures on these private lands. The rest of the year, the water passes through a gate at the dam and continues its natural course through Oak Creek Canyon before joining Sandy Creek and eventually flowing into the Fremont River. Oak Creek is accessible via a rough four-wheel-drive road upstream on U.S. Forest Service land or via private land or land managed by the Bureau of Land Management on the downstream end. Visitation is negligible. One outfitter has a commercial-use permit for horseback tours in Oak Creek.

2.2 Sample collection methods

Water-quality sites in Capitol Reef National Park are sampled on a rotating schedule: monthly for two years and then not sampled for the following two years. During the period discussed in this report, there were occasions when a site was monitored for longer than two years and times when a site was not visited for an extended period of time. Samples were collected monthly during the entirety of the year until October 2011. After October 2011, samples were collected monthly for 10 months of the year, with only one of three months visited during the winter period of December–February.

Field sampling and laboratory analysis for enumeration of fecal bacteria in stream water is based on the IDEXX Colilert Quanti-Tray 2000 method (IDEXX undated). Field collection of bacterial samples, turbidity, and streamflow is performed by trained NCPN staff. Streamflow is measured using a current meter and wading rod when flows are greater than one cubic foot per second (cfs). When flows are low, an eight-inch Baski cutthroat flume is used to measure streamflow. Water samples are measured for turbidity using a HACH 2100P portable turbidimeter. Field and laboratory procedures are documented in detail in the NCPN water-quality monitoring protocol (Thoma et al. 2017). Sample collection, processing, and analysis for *E. coli* bacteria are summarized as follows.

2.2.1 Sample collection

Bacterial samples are collected in sealed and sterilized 100-mL bottles. Samples are collected just below the surface, mid-channel, in a well-mixed portion of the stream. Samples are immediately placed on ice in an insulated container at <10°C and processed within eight hours of collection.

2.2.2 Sample processing

Samples are processed using the IDEXX Colilert Quanti-Tray 2000 method. One packet of pre-measured Colilert media is added to 100 mL of sample. The sample/media mixture is poured into a Quanti-Tray 2000 and sealed using the IDEXX heat sealer. The sample trays are incubated for 24–28 hours at the designated temperature. For portable incubators, the acceptable temperature range is 34–36.5°C.

2.2.3 Laboratory analysis

After incubation, the number of positive wells on the sample tray is counted. For enumerating total coliform bacteria, a well is counted as positive if bacteria growth turns the media yellow under ambient light. For enumerating *E. coli*, a well is counted as positive if it is both yellow and fluoresces under ultraviolet light. The amount of bacteria is determined using the IDEXX Most Probable Number (MPN) table.

2.3 Quality assurance and quality control

The NCPN monitoring protocol outlines several steps to ensure the quality of *E. coli* samples. Results from a sample are rejected if one or more of the following occurs:

- Holding time of sample exceeded eight hours before processing.
- Sample was held at a temperature higher than 10°C.
- Sample was incubated outside of the acceptable temperature range.
- Sample tray was not read within 24–28 hours after incubation.

- Sample bottle, Quanti-tray, or Colilert media was expired.

In the first few years of sampling, samples were rejected most often because the temperature in the portable incubator was out of range. The temperature in the incubator would become too hot when operating in a vehicle in the summer months. This issue was resolved by purchasing a newer model of a portable incubator and placing the incubator in temperature-controlled buildings while at sites for extended periods of time.

Because *E. coli* bacteria are present in humans, it is important to document that no sample contamination is occurring. Field blanks using clean, deionized water were processed identically to environmental samples to check for contamination bias. Of 51 field blanks taken between October 2012 and September 2017, all 51 samples met the quality goal of having no detections of *E. coli*.

Variability in sample handling and natural variability in a stream can be assessed through the use of replicate samples, which are collected in an identical manner and processed simultaneously with the environmental (field) samples. Variability can be 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

Out of 70 replicate samples, 10 replicates did not meet quality goals of +/- 60% RPD (Thoma et al. 2017). However, these 10 samples were all less than 11 MPN/100 mL, and the high RPD was due to differences between low numbers. For example, the RPD between 1 MPN/100 mL and 2 MPN/100 mL is 67%, even though the actual difference between results is small. The interquartile range for the difference between replicates and source samples was 0 MPN/100 mL at the 25th percentile and 9.26 MPN/100 mL at the 75th percentile, indicating fairly good agreement across the results.

2.4 Data summary and analysis methods

The State of Utah water-quality standards for *E. coli* are associated with beneficial-use designations for recreational use and drinking-water supply. Water-quality standards define acceptable concentrations for both acute (short-term over hours or days) and chronic (longer-term over months) exposures. Any acute exceedance is considered of public health concern with potentially immediate effects, while chronic exceedances are indicative of ongoing exposure. For regulatory purposes, waters are also classified by whether recreation is likely to include full-body contact activities, such as swimming, or lesser-contact activities, such as wading and fishing, with different concentrations deemed acceptable for different types of recreation. The State of Utah evaluates the recreational-use water-quality standards within a state-defined recreation season of May 1–October 31. Park visitation also occurs outside the May–October timeframe. Data are presented both within the state-defined recreation season and using all available data.

Waters protected for frequent primary-contact recreation, such as swimming, are classified as 2A by the State of Utah. The numeric standards applied to Class 2A waters for *E. coli* are 126 MPN/100 mL for chronic exposure and 409 MPN/100 mL for acute exposure. Class 2B waters are protected for infrequent primary-contact or secondary-contact recreation, such as wading and fishing. The numeric standards for class 2B waters for *E. coli* are 206 MPN/100 mL for chronic exposure and 668 MPN/100 mL for acute exposure. Class 1C waters are protected for drinking-water supply; numeric standards for *E. coli* are the same as class 2B waters. Capitol Reef water-quality sites and their designated beneficial uses are listed in Table 2-2.

For regulatory purposes, the acute standard for *E. coli* is the maximum concentration in one sample in a 30-day period. The chronic

Table 2-2. Beneficial-use designations and associated *E. coli* standard for water-quality sites at Capitol Reef National Park.

Use code	Beneficial-use description	Sites with associated beneficial-use	*E. coli* chronic standard (MPN/100 mL)	*E. coli* acute standard (MPN/100 mL)
1C	Drinking-water supply	Lower Sulphur, Upper Sulphur, Pleasant, and Oak creeks	206	668
2A	Primary-contact recreation	Lower Sulphur, Upper Sulphur, and Oak creeks	126	409
2B	Secondary-contact recreation	Pleasant Creek	206	668

standard is calculated as the geometric mean of samples in a 30-day period. The 30-day geometric mean should be based on no fewer than five samples. Permitted levels are much lower for chronic exposure than for acute exposure. Calculations for averages of *E. coli* concentrations in this report were made using geometric means. This is common practice with bacteria data, to prevent rare samples with high values from skewing the results. The geometric mean, unlike the arithmetic mean, is not influenced by outliers that might bias the data. In a sample where *E. coli* was not detected, the result was reported as <1 MPN/100 mL, and a value of 1 MPN/100 mL was used to calculate the geometric mean.

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 chronic criteria, can provide a means of early warning and an indication of a problem that may require more attention. For these reasons, *E. coli* concentrations were compared against both the acute and the more stringent chronic standards.

Monthly 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. Samples were routinely collected several times per year in order to build a database that represents the range of conditions that occur, with a focus on base flow conditions. Thus, rare and short-term events were often not captured.

For this report, *E. coli* exceedances of the chronic standard were analyzed if they occurred for more than 10% of results. This approach minimizes reporting of short-duration changes in water chemistry that may result from natural variability associated with runoff events, which may not be of management concern, or of artifacts introduced by sample handling and analysis. It also follows the assessment guidelines used by the Utah Division of Water Quality to prepare their list of impaired water bodies.

3 Results

3.1 *E. coli* concentrations

Sample results and exceedances of water-quality standards related to recreational use are summarized in Table 3-1 and Appendix A. At each of the four sites, *E. coli* concentrations exceeded the chronic standard for their associated recreational beneficial use for more than 10% of site visits, with a range of 17% (Pleasant and Oak creeks) to 35% (Lower Sulphur Creek). At Lower Sulphur Creek, *E. coli* concentrations also exceeded the acute daily standard for *E. coli* for more than 10% of total results.

E. coli concentrations at each site are displayed in Figures 3-1 through 3-4. Data points are marked as either recreation season (May 1–October 31) or non-recreation season. During the recreation season, people are more likely to be recreating in rivers, streams, lakes, and reservoirs. A log scale was used for displaying *E. coli* results in order to accommodate a wide range of values and show the distribution of both very low and very high values. The majority of *E. coli* exceedances at each site occurred during the summer months, which coincide with the state-defined recreation season.

3.2 *E. coli* and streamflow

At each site, *E. coli* concentrations were compared against flow and turbidity to determine if runoff from rainfall events was a factor in *E. coli* exceedances. During high-discharge events, runoff from the watershed contributes large amounts of sediment and organic material to streams. Fecal matter and its microbial components, such as *E. coli*, are carried into nearby streams during these events. *E. coli* readily binds to benthic and suspended sediment in surface waters, and is able to survive for prolonged periods when attached to sediments (Sampson et al. 2006). Except for a few events, high *E. coli* concentrations were not directly correlated to higher flows (Figures 3-5 through 3-8).

3.3 *E. coli* in Sulphur Creek

To evaluate the potential contribution of park developed areas and management practices on *E. coli* concentrations in Sulphur Creek, a subset of samples was taken from Upper Sulphur Creek and Lower Sulphur Creek on the same day for comparison (Figure 3-9). Of the 41 paired samples, 17 were within ±10 MPN/100 mL, indicating relative agreement between samples. Twelve paired samples were higher at Upper Sulphur Creek (range in difference -156.3 MPN/100 mL to -11.4 MPN/100 mL), and 12 paired samples were higher at Lower Sulphur Creek (range in difference 11.1 MPN/100 mL to 433 MPN/100 mL). The median difference between the two sampling sites was 0 MPN/100 mL.

E. coli concentrations at both the upstream and downstream sites met the primary contact recreational water-quality standards for 24 out of the 41 paired samples. Eight paired samples exceeded the chronic standard for *E. coli,* with two of those paired samples also exceeding the acute standard. On five sampling visits, *E. coli* exceedances occurred at Lower Sulphur Creek with no comparable exceedances at Upper Sulphur Creek on the same day (see Appendix A). Likewise, there were four sampling visits in which *E. coli* exceedances occurred at Upper Sulphur Creek with no comparable exceedances at the

Table 3-1. Results summary for bacterial water quality in Capitol Reef National Park, July 2008–September 2017.

Site name	# samples	*E. coli* minimum (MPN/100 mL)	*E. coli* maximum (MPN/100 mL)	*E. coli* geometric mean (MPN/100 mL)	Number and % exceeding chronic standard	Number and % exceeding acute standard
Lower Sulphur Creek	52	<1	1,413.6	35.6	18 (35%)	7 (13%)
Upper Sulphur Creek	53	<1	517.2	32.6	14 (26%)	4 (8%)
Pleasant Creek	42	<1	866.4	9.1	7 (17%)	1 (2%)
Oak Creek	35	<1	648.8	14.0	6 (17%)	2 (6%)

See Table 2-2 for beneficial-use designations and associated *E. coli* standards.

downstream site. Paired sampling at Sulphur Creek indicated that *E. coli* concentrations from Lower Sulphur Creek did not tend to be higher than concentrations from Upper Sulphur Creek (see Figure 3-9).

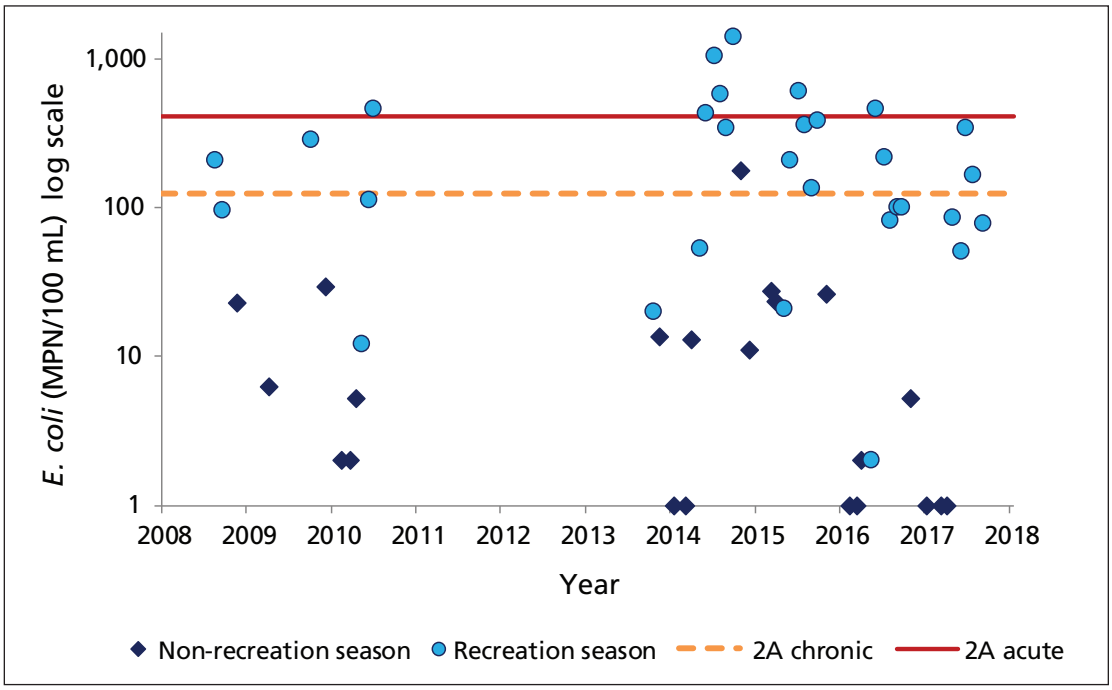


Figure 3-1. *E. coli* concentrations during monthly sampling visits at Lower Sulphur Creek site.

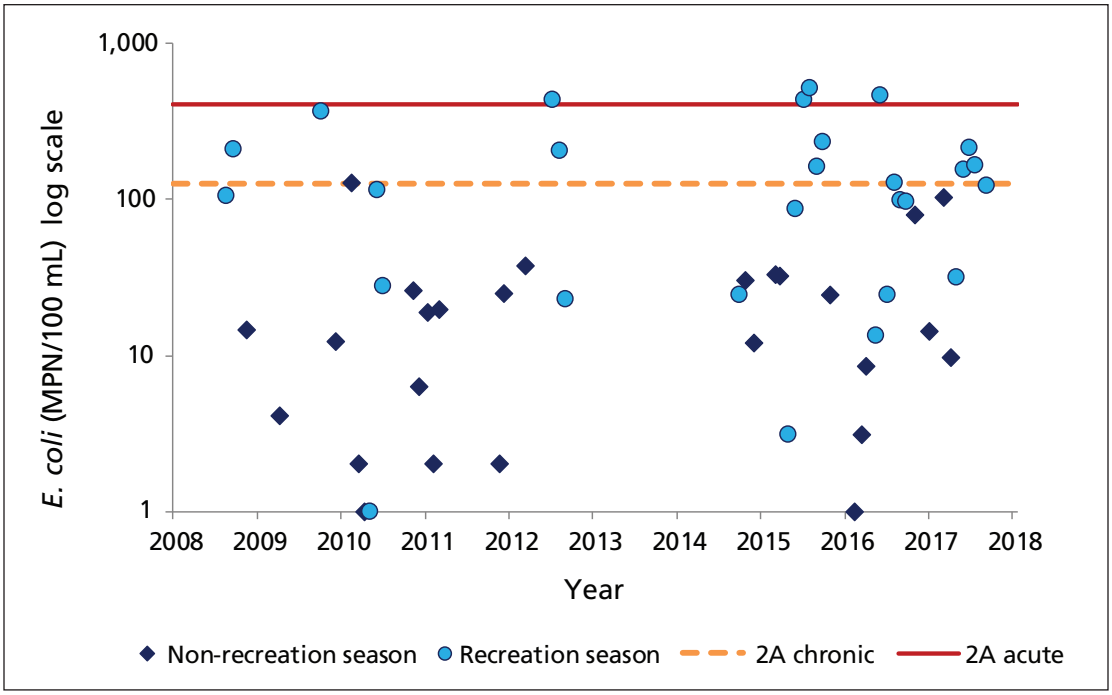


Figure 3-2. *E. coli* concentrations during monthly sampling visits at Upper Sulphur Creek site.

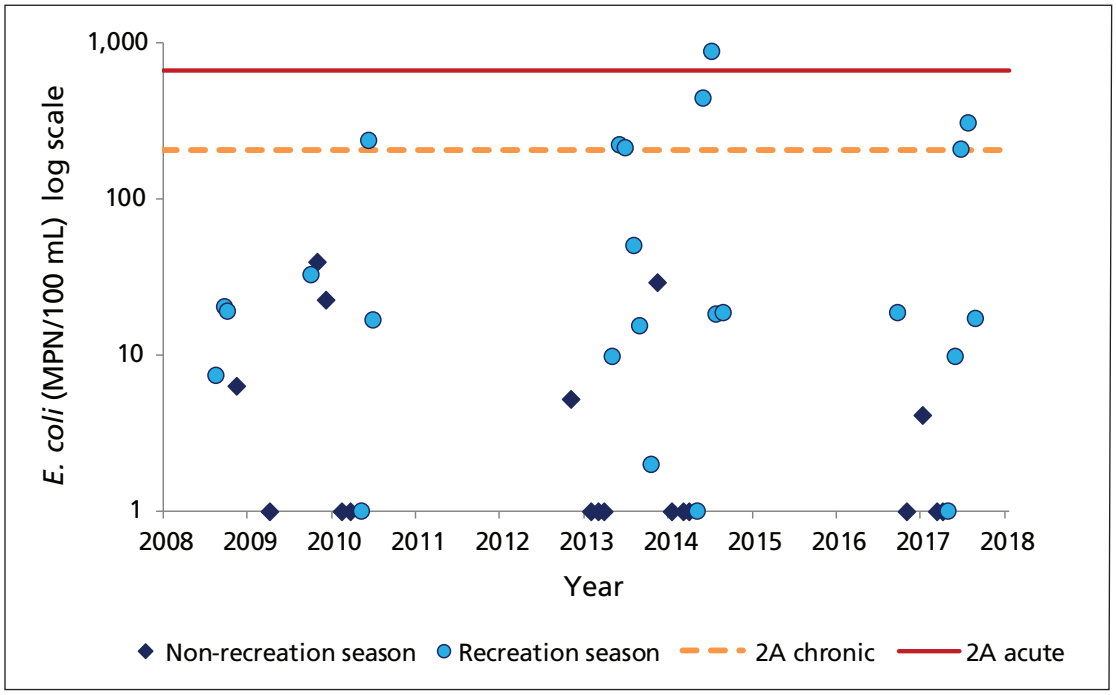


Figure 3-3. *E. coli* concentrations during monthly sampling visits at Pleasant Creek site.

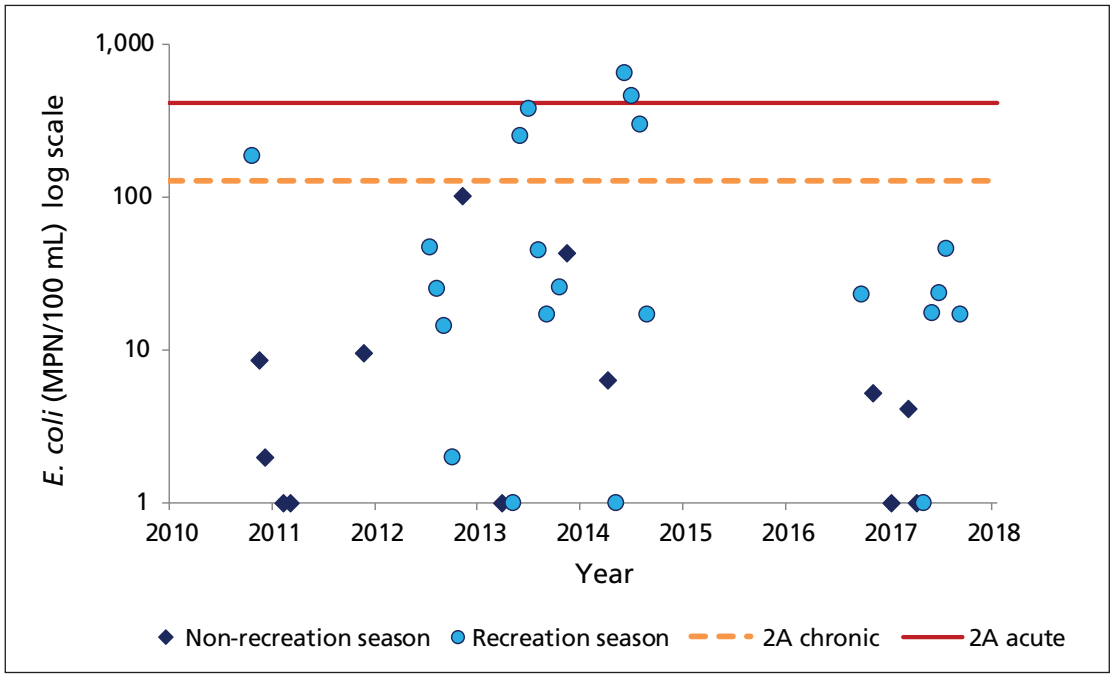


Figure 3-4. *E. coli* concentrations during monthly sampling visits at Oak Creek site.

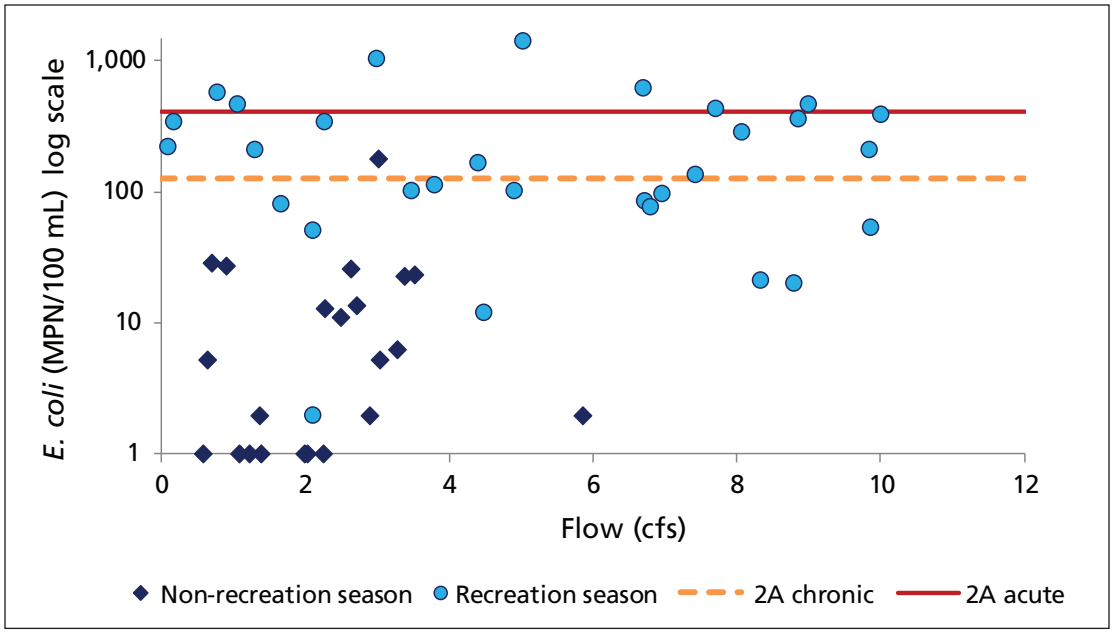


Figure 3-5. *E. coli* concentrations relative to flow in Lower Sulphur Creek.

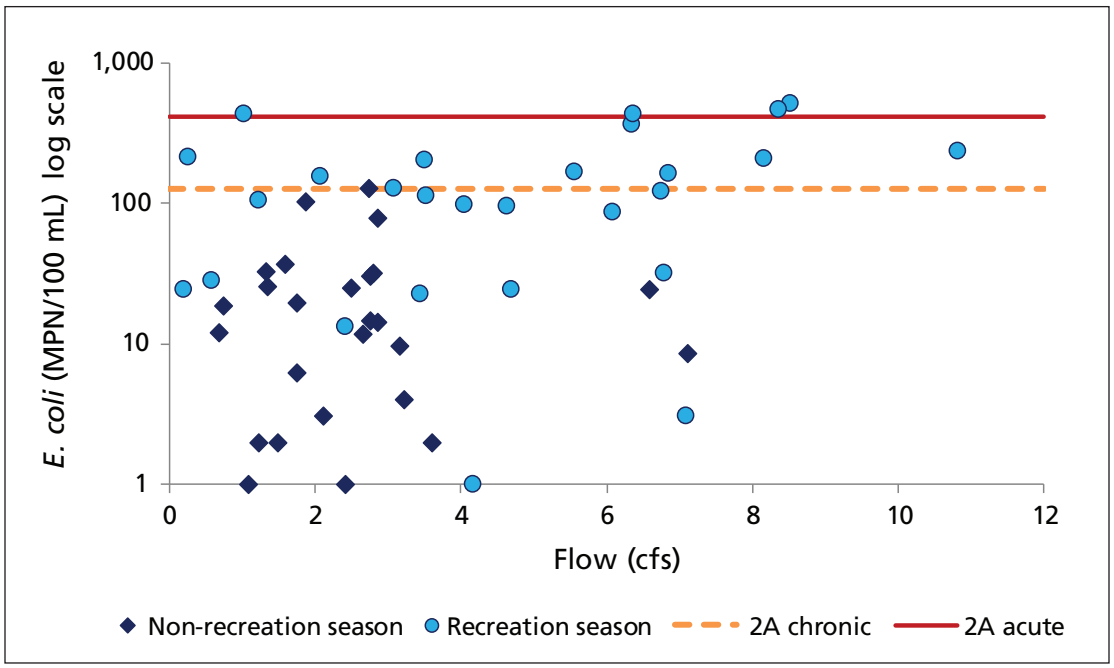


Figure 3-6. *E. coli* concentrations relative to flow in Upper Sulphur Creek.

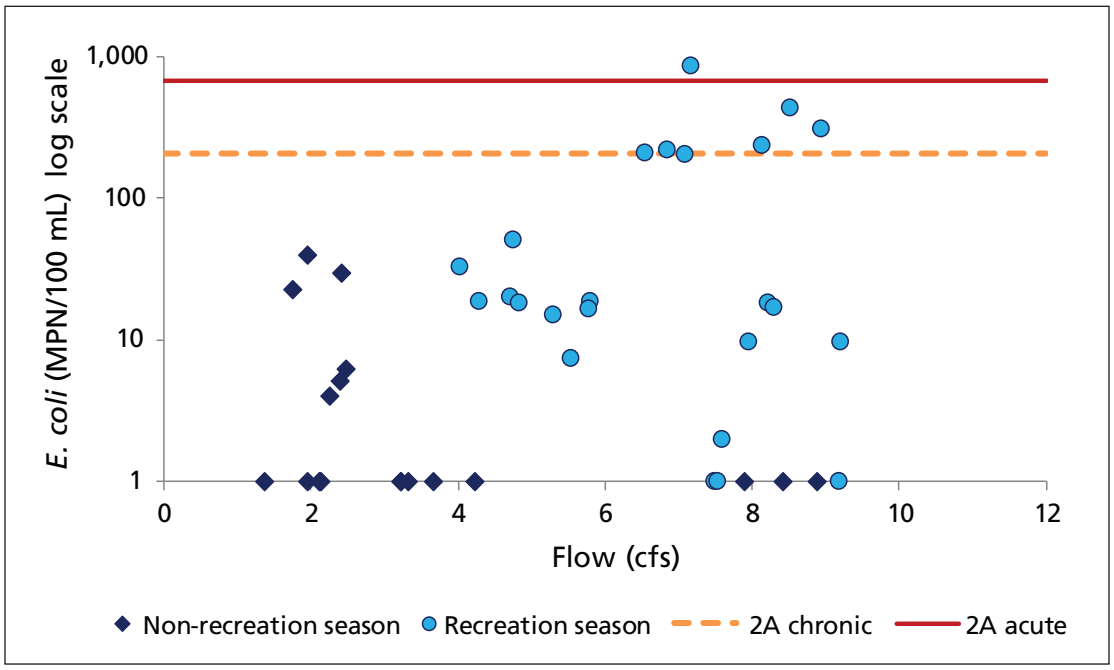


Figure 3-7. *E. coli* concentrations relative to flow in Pleasant Creek.

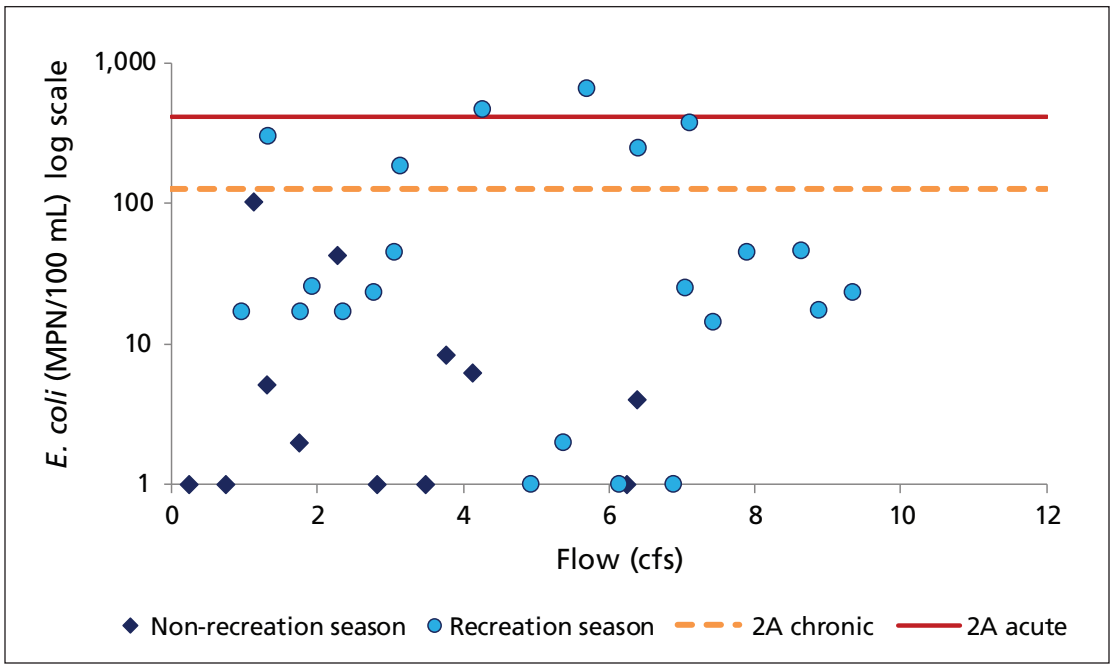


Figure 3-8. *E. coli* concentrations relative to flow in Oak Creek.

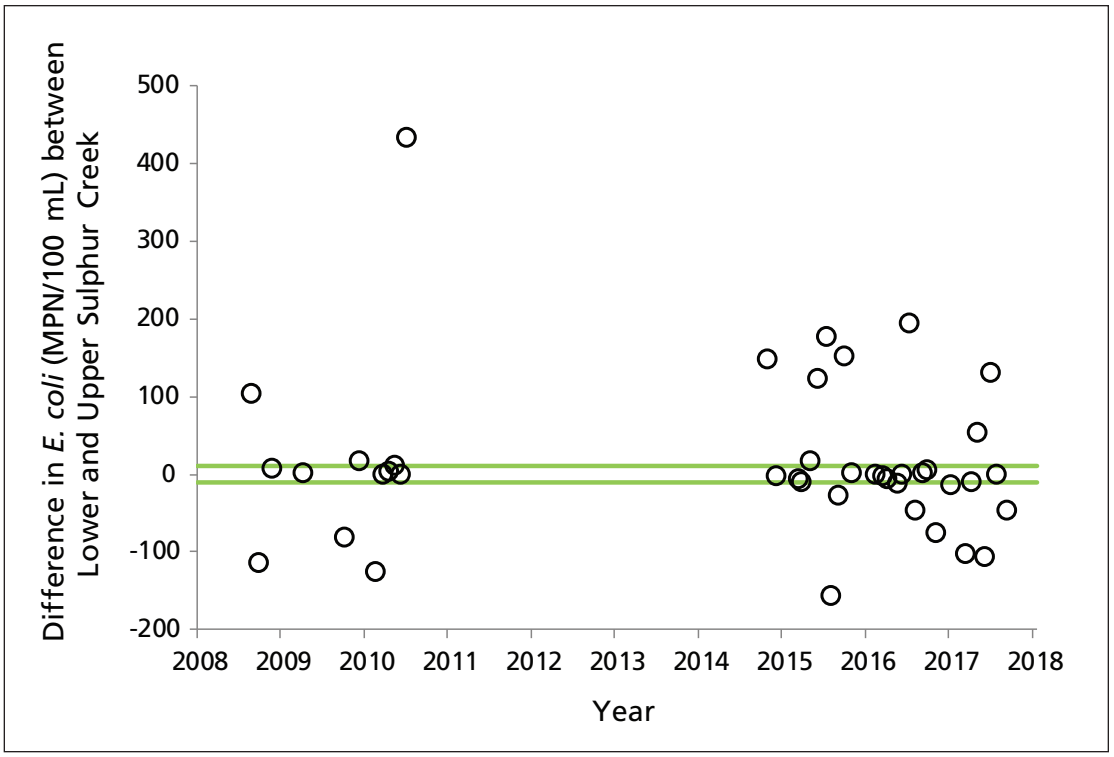


Figure 3-9. Comparison of *E. coli* concentrations upstream and downstream of park developed areas. Positive numbers indicate that concentrations were higher at Lower Sulphur Creek than at Upper Sulphur Creek, as would be expected if park visitation and infrastructure contribute to *E. coli* contamination. Values from -10 to +10 MPN/100 mL (green lines) indicate relative agreement between paired samples.

4 Discussion and Conclusions

4.1 Sulphur Creek

The majority of *E. coli* samples at Sulphur Creek were collected during base flow conditions, when there would be the least influence from rain events and overland flow. High *E. coli* concentrations in Sulphur Creek were most often observed during the summer months, when flows were low-to-base flow, and when the most park visitation occurs and livestock are present upstream of the park. There was no direct correlation between *E. coli* exceedances and turbid water or higher flows at either site on Sulphur Creek (see Figures 3-5, 3-6, Appendix A). During the 2014 recreation season, two *E. coli* concentrations at Lower Sulphur Creek exceeded the acute standard for drinking-water supply (668 MPN/100 mL). Samples were not collected at Upper Sulphur Creek when these exceedances were observed downstream. The exceedances at Lower Sulphur Creek occurred during base flow conditions in relatively clear water.

Heavy visitor use occurs between the upper and lower sampling sites. The sites also bracket park offices, employee housing, and irrigated orchards. When samples were collected from the upstream and downstream sites on the same day, *E. coli* concentrations did not significantly increase from Upper Sulphur Creek to Lower Sulphur Creek, as would be expected if recreational use and park developed areas contributed to contamination (Figure 3-9). Park developed areas and management practices do not seem to contribute substantially to *E. coli* concentrations in Sulphur Creek. In most instances when water-quality standard exceedances occurred, high *E. coli* concentrations were present near the western park boundary and persisted through the developed area. Cattle trailing occurs along the main highway through the park one day each year in late October, in which the cattle stop to fill up on water at Sulphur Creek, near the park visitor center. No pack-animal use or grazing occurs along Sulphur Creek within the park, but agricultural development and dispersed livestock grazing occurs upstream of the park boundary.

4.2 Pleasant Creek

Elevated *E. coli* concentrations at Pleasant Creek were observed during the summer months of June, July, and August, when park visitation is high and livestock grazing occurs on Boulder Mountain, upstream of the park. There was only one occurrence when the *E. coli* concentration exceeded the acute secondary-contact recreation standard of 668 MPN/100 mL. This event occurred in July 2014, and was characterized by base flow and high turbidity. High turbidity is associated with more suspended sediment and could be a source of high bacterial counts, because *E. coli* readily binds to silts and sediments. On the seven occasions when *E. coli* exceeded the chronic 2B standard (see Table 3-1), the exceedances were not directly correlated to high flows or turbid water (see Figure 3-7). Cattle trailing occurs along Pleasant Creek once per year, in October, but no exceedances were noted in October. Within the park, foot-traffic recreational use at Pleasant Creek is much lower than at Sulphur Creek. Pleasant Creek is listed as a suggested backpacking destination on the park's website, but the limited recreational use that occurs is generally downstream of the water-quality sampling site, in the more scenic, canyon-bound section of the stream. Pack-animal use is also permitted along Pleasant Creek. Dispersed livestock grazing and recreation occurs on public lands upstream of the park.

4.3 Oak Creek

As with the other sites, *E. coli* exceedances at Oak Creek occurred during the summer months (see Appendix A). High *E. coli* concentrations were not associated with elevated flow or turbidity (see Figure 3-8). *E. coli* concentrations exceeded the acute primary-contact recreation standard of 409 MPN/100 mL on two occasions (see Table 3-1). These exceedances occurred in consecutive months in summer 2014, when there were base flows and slightly turbid water. The majority of the higher *E. coli* concentrations coincided with the months directly following cattle trailing and when grazing occurs on U.S. Forest Ser-

vice land upstream of the park. Cattle have also been frequently observed along Oak Creek, within the park boundary, outside the permitted time periods for cattle trailing. Recreational use within the park around Oak Creek is minimal due to its limited accessibility. Roads to Oak Creek require four-wheel drive or access through private land—making visitation negligible, and humans less likely to be a significant source of *E. coli* contamination. Dispersed livestock grazing and recreation occurs on public lands upstream of the park.

4.4 Potential contributors to *E. coli* contamination

Most *E. coli* exceedances occurred during the state-defined recreation season, in the summer months of June–August. Applicable chronic water-quality standards were exceeded at all four water-quality sites on more than 10% of visits. Only Lower Sulphur Creek exceeded the acute water-quality standard on more than 10% of visits.

Flow and turbidity were generally low when exceedances occurred, indicating that the exceedances captured in our monitoring data were not caused by flood events. This suggests that a recurring source for *E. coli* contamination exists either upstream of the park or within park boundaries. Low-flow conditions have been associated with higher fecal coliform concentrations (Roche et al. 2013). These conditions are common during the summer in the small, semi-arid streams discussed in this report.

E. coli is found in the waste of humans, livestock, and wildlife. Potential sources of contamination in surface waters can be both natural and related to human activities. Bacterial-source tracking is expensive, and reliable methods to distinguish between livestock and wildlife sources are still in development (EPA 2002; SWCSMH 2017). The National Park Service has not pursued bacterial-source tracking for streams in Capitol Reef National Park.

The state-defined recreation season of May 1–October 31 coincides with the period of highest visitation within Capitol Reef National Park each year. From 2009 to 2017, approximately 74–82% of the park's annual visitation occurred during those months (NPS 2018). Developed campgrounds on U.S. Forest Service land upstream of the park tend to be open from May to September, depending on snow cover. This time period also coincides with cattle moving from winter range, at lower elevations downstream of the park, to summer range, upstream of the park. Cattle trailing in Oak and Pleasant creeks, and trespass cattle in Oak Creek, are also potential sources of *E. coli* contamination.

In a study of public lands in California, a comparison of watersheds with pack-animal use, foot-traffic recreation, wildlife use, and livestock use found that wildlife use and foot-traffic recreation were not associated with *E. coli* contamination, while pack-animal and livestock use were associated with *E. coli* contamination (Derlet and Carlson 2006). Similarly, *E. coli* concentrations were lower in streams associated with recreational use than in streams associated with livestock grazing (Roche et al. 2013). A study in Yosemite National Park found increases in *E. coli* concentrations in streams downstream of backpacker use sites and pack-stock stream crossings, although increases tended to be small (Forrester et al. 2017).

Research at Yosemite National Park has shown increases in *E. coli* concentrations downstream from pack-stock stream crossings that see 1,600–4,500 crossings per year, with a median increase of 32 colony-forming units per 100 mL (Forrester et al. 2017). However, given the comparatively low numbers for pack-animal use at Capitol Reef National Park, its effects are likely to be lower than that observed at Yosemite National Park. Pack-animal use is allowed in Pleasant and Oak creeks but prohibited in Sulphur Creek. Day use with pack animals by park visitors is not tracked, but any overnight use requires a free backcountry permit. Four commercial outfitters are also permitted to conduct daytrip horseback tours in Pleasant Creek. In 2017, only three outfitters used their permits, serving a total of 264 customers during the year (unpublished data, Capitol Reef National Park). All three outfitters offer tours other than horseback riding, so the total pack-animal use for the year may have been less than

264. No commercial outfitter offered tours in Oak Creek in 2017, although one commercial outfitter is permitted for day use in Oak Creek.

Despite frequent hiker use of Sulphur Creek, we did not observe chronic increases in *E. coli* concentrations or more frequent water-quality standard exceedances downstream of the hiker-use area in paired upstream and downstream samples. Park orchards, employee housing, and an extensive developed area are also located between the upstream and downstream sites. On Sulphur Creek, it did not appear that foot-traffic recreation use or park infrastructure was reliably contributing to *E. coli* exceedances in the stream. Although upstream and downstream samples are not available for Pleasant and Oak creeks, both of these streams have much less visitation than Sulphur Creek, and the contribution of foot-traffic recreational use to *E. coli* contamination is expected to be less than in Sulphur Creek.

Wildlife use occurs throughout the park and in watersheds upstream of the park. Higher-than-average concentrations of deer occur in the park developed area, which includes orchards, pastures, and lawns. This area is bracketed by the Sulphur Creek sampling locations. In this area, heavy wildlife use does not appear to chronically contribute to *E. coli* exceedances. Deer concentrations are expected to be less along Pleasant and Oak creeks, which offer only natural vegetation.

In areas with livestock grazing, pasture management is an important predictor of *E. coli* contamination. While dispersed livestock grazing generally does not cause *E. coli* concentrations higher than applicable water-quality standards (Roche et al. 2013), there are certain livestock-grazing and agricultural practices that have been associated with high fecal-coliform concentrations. These include higher densities of cattle (Gary et al. 1983; Tiedemann et al. 1987), areas of concentrated effects, such as feeding operations (EPA 2016), and flood irrigation of grazed pastures (Weissinger and Sharrow 2018).

The Sulphur Creek water-quality sites are located downstream of agricultural areas near Torrey, Utah, and flood irrigation and confined-feeding operations were previously practiced in the Fremont River watershed nearby (EPA 2016). It is unknown whether these types of practices occur in the Sulphur Creek watershed, but they have been noted in other locations in the state (Weissinger and Sharrow 2018). The Oak Creek water-quality site is located close to a gate where cattle often bunch during cattle trailing activities, and frequent trespass grazing has also been noted. At least one exceedance of water-quality standards was noted in Oak Creek following cattle trailing in the stream. Exceedances have not been observed in Pleasant Creek following trailing, and the number of cattle that trail through Pleasant Creek is about one-quarter the number of cattle that trail through Oak Creek. Trespass grazing has not been noted near the water-quality site at Pleasant Creek.

4.5 Conclusions

The majority of *E. coli* exceedances in Fremont River tributaries in Capitol Reef National Park have been observed during the summer months, when activities upstream of the park—including livestock grazing, recreation, agriculture, and wildlife use—could be introducing fecal contamination into the streams. Other possible factors in degraded water quality could be due to cattle trailing and trespass cattle in and along Oak Creek. The Northern Colorado Plateau Network will continue to monitor for bacterial contamination in waters at Capitol Reef National Park.

5 Literature Cited

Derlet, R. W., and J. R. Carlson. 2006. Coliform bacteria in Sierra Nevada wilderness lakes and streams: What is the impact of backpackers, pack animals, and cattle? Wilderness and Environmental Medicine 17:15–20. https://www.highsierrahikers.org/Derlet-and-Carlson-2006.pdf.

Environmental Protection Agency (EPA). 2002. Wastewater technology fact sheet: Bacterial source tracking. EPA Office of Water EPA 832-F-02-010. https://www3.epa.gov/npdes/pubs/bacsortk.pdf.

——. 2016. Nonpoint source success story: The watershed approach results in reduced phosphorus in the Fremont River. U.S. EPA 841-F-16-001CC. EPA Office of Water, Washington, D.C. https://www.epa.gov/sites/production/files/2016-10/documents/ut_fremontriver_508.pdf.

Forrester, H., D. Clow, J. Roche, A. Heyvaert, and W. Battaglin. 2017. Effects of backpacker use, pack stock trail use, and pack stock grazing on water-quality indicators, including nutrients, *E. coli*, hormones, and pharmaceuticals, in Yosemite National Park, USA. Environmental Management 60:526–543.

Gary, H. L., S. R. Johnson, and S. L. Ponce. 1983. Cattle grazing impact on surface water quality in a Colorado Front Range stream. Journal of Soil and Water Conservation 38:124–128. https://www.fs.fed.us/rm/pubs_exp_forests/manitou/rmrs_1983_gary_h001.pdf.

Hackbarth, C., and R. Weissinger. 2013. Water quality in the Northern Colorado Plateau Network, water years 2010–2012. Natural Resource Technical Report NPS/NCPN/NRTR—2013/831. National Park Service, Fort Collins, Colorado.

——. 2016. Water quality in the Northern Colorado Plateau Network: Water years 2013–2015. Natural Resource Report NPS/NCPN/NRR—2016/1332. National Park Service, Fort Collins, Colorado.

IDEXX. Undated. Colilert test kit procedure. IDEXX, Westbrook, Maine. https://123.idexx.com/resource-library/water/colilert-procedure-en.pdf.

National Park Service (NPS). 2018. Visitor use statistics database. https://irma.nps.gov/Stats accessed 5/29/2018.

Roche, L. M., L. Kromschroeder, E. R. Atwill, R. A. Dahlgren, and K. W. Tate. 2013. Water quality conditions associated with cattle grazing and recreation on national forest lands. PLoS ONE 8(6):e68127. http://journals.plos.org/plosone/article?id=10.1371/journal.pone.0068127.

Sampson, R. W., S. A. Swiatnicki, V. L. Osinga, J. L. Supita, C. M. McDermott, and G. T. Kleinheinz. 2006. Effects of temperature and sand on *E. coli* survival in a northern lake water microcosm. Journal of Water and Health 4(3):389–393.

Soil and Water Conservation Society of Metro Halifax (SWCSMH). 2017. Bacterial/microbial source tracking: A review. http://lakes.chebucto.org/H-2/bst.html.

Tiedemann, A. R., D. A. Higgins, T. M. Quigley, H. R. Sanderson, and D. B. Marx. 1987. Responses of fecal-coliform in streamwater to four grazing strategies. Journal of Range Management 40:322–329.

Thoma, D., H. Thomas, D. Sharrow, K. Wynn, J. Brown, and M. Beer. 2017. Water quality vital signs monitoring protocol for park units in the Northern Colorado Plateau Network: Version 1.03. Natural Resource Report NPS/NCPN/NRR—2017/1499. National Park Service, Fort Collins, Colorado.

Utah Division of Water Quality (UDWQ). 2002. Fremont River watershed water quality management plan. State of Utah, Department of Environmental Quality, Salt Lake City, Utah. https://deq.utah.gov/ProgramsServices/programs/water/watersheds/docs/2006/09Sep/FREMONT_WQMP.pdf.

——. 2016a. Utah's final 2016 integrated report. State of Utah, Department of Environmental Quality, Salt Lake City,

Utah. https://documents.deq.utah.gov/water-quality/monitoring-reporting/integrated-report/DWQ-2017-004941.pdf.

——. 2016b. Prioritizing Utah's 303(d) list. State of Utah, Department of Environmental Quality, Salt Lake City, Utah. https://deq.utah.gov/Programs-Services/programs/water/watersheds/docs/2016/303d-list-for%20tmdl-development.pdf.

Weissinger, R., and D. Sharrow. 2018. Status and trends of water quality at Zion National Park: Water years 2006–2016. Natural Resource Report NPS/NCPN/NRR—2018/1628. National Park Service, Fort Collins, Colorado.

Appendix A. Dates of *E. coli* Exceedances, Shown with Flow and Turbidity Measurements in Fremont River Tributaries at Capitol Reef National Park, 2008–2017

Site	Date	*E. coli* (MPN/100mL)	Flow (cfs)	Turbidity (NTU)
Lower Sulphur Creek	08/22/08	209.8	1.31	7.27
Lower Sulphur Creek	10/09/09	285.1	8.08	114
Lower Sulphur Creek	07/06/10	461.1	0.33	1.88
Lower Sulphur Creek	06/11/14	435.2	7.72	268
Lower Sulphur Creek	07/16/14	1046.2	3.01	54
Lower Sulphur Creek	08/08/14	579.4	0.79	7.44
Lower Sulphur Creek	09/03/14	344.8	2.29	2.97
Lower Sulphur Creek	10/08/14	1413.6	5.03	13.2
Lower Sulphur Creek	11/05/14	178.2	3.02	3.18
Lower Sulphur Creek	06/08/15	209.8	9.85	271
Lower Sulphur Creek	07/17/15	613.1	6.72	494
Lower Sulphur Creek	08/10/15	360.9	8.87	368
Lower Sulphur Creek	09/11/15	135.4	7.44	74.2
Lower Sulphur Creek	10/08/15	387.3	10.01	203
Lower Sulphur Creek	06/14/16	461.1	9.01	308
Lower Sulphur Creek	07/17/16	218.7	0.10	1.82
Lower Sulphur Creek	07/07/17	344.8	0.18	0.61
Lower Sulphur Creek	08/04/17	167.0	4.40	15.5
Upper Sulphur Creek	09/23/08	209.8	8.16	61.6
Upper Sulphur Creek	10/09/09	365.4	6.35	78.5
Upper Sulphur Creek	02/18/10	127.4	2.75	168
Upper Sulphur Creek	07/17/12	435.2	1.04	35.4
Upper Sulphur Creek	08/14/12	206.4	3.51	93.7
Upper Sulphur Creek	07/17/15	435.2	6.38	276
Upper Sulphur Creek	08/10/15	517.2	8.54	155
Upper Sulphur Creek	09/11/15	162.4	6.86	65.6
Upper Sulphur Creek	10/08/15	235.9	10.83	136
Upper Sulphur Creek	06/14/16	461.1	8.36	125
Upper Sulphur Creek	08/14/16	128.1	3.08	77.8
Upper Sulphur Creek	06/14/17	156.5	2.09	1.9
Upper Sulphur Creek	07/07/17	214.3	0.27	0.28
Upper Sulphur Creek	08/04/17	167.4	5.56	27.9
Oak Creek	10/27/10	186.0	3.15	31.1
Oak Creek	06/07/13	248.9	6.40	29.4
Oak Creek	07/06/13	378.4	7.11	22.9
Oak Creek	06/10/14	648.8	5.69	34.2
Oak Creek	07/08/14	461.1	4.27	37.4
Oak Creek	08/07/14	298.7	1.33	8.52
Pleasant Creek	06/13/10	235.9	8.14	14.3
Pleasant Creek	06/08/13	218.7	6.86	8.52
Pleasant Creek	07/06/13	209.8	6.54	14.6
Pleasant Creek	06/11/14	435.2	8.52	13.4

Appendix A. Dates of E. coli Exceedances, Shown with Flow and Turbidity Measurements in Fremont River Tributaries at Capitol Reef National Park, 2008–2017, cont.

Site	Date	*E. coli* (MPN/100mL)	Flow (cfs)	Turbidity (NTU)
Pleasant Creek	07/16/14	866.4	7.18	114
Pleasant Creek	07/06/17	206.4	7.09	8.44
Pleasant Creek	08/04/17	307.6	8.95	17.6

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