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Status and Trends of Water Quality at Zion National Park

Water Years 2006–2016 (rev. June 2018)

Natural Resource Report NPS/NCPN/NRR—2018/1670



ON THE COVER

The Subway, Left Fork of North Creek, Zion National Park. NPS/L. Gommermann

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Contents

Figures v
Tables vii
Glossary ix
Acronyms and Abbreviations xi
Executive Summary xiii
Acknowledgements xvii

1 Introduction 1
1.1 Purpose and scope 1
1.2 Study area 2

2 Methods 7
2.1 Field data collection 7
2.2 Sample analytical methods and quality assurance 7
2.3 Trend analysis 8
2.4 Water-quality standards comparison 10

3 Results and Discussion 11
3.1 La Verkin Creek at Lee Pass Trail 11
3.2 North Creek 19
3.3 North Fork Virgin River at the Wilderness Study Area boundary 29
3.4 Supporting sites 36

4 Conclusions 37

5 Literature Cited 39

Appendices 41
Appendix A. Implications of Censoring Data at the Highest Reporting Limit for Parameters with More than One Reporting Limit and 5–50% Censored Data 41
Appendix B. Timeseries for Sites and Parameters with <50% censored data 45
Appendix C. State of Utah Water-Quality Beneficial Uses and Standards 47

Figures

Main Report

Figure 1-1. Overview of Zion National Park and water-quality stations....3

Figure 1-2. Departures in air temperature (degrees Fahrenheit) and precipitation amount (%), WY2006–2016 compared to the 30-year average (1981–2010) at the Zion NP weather station (429717)....5

Figure 1-3. Flow percentiles for the North Fork Virgin River near Springdale (USGS gage 09405500), based on 27 years of data....6

Figure 1-4. Daily mean discharge in cubic feet per second (cfs) for WY2006–2016 at the North Fork Virgin River near Springdale, Utah (USGS gage 09405500). 6

Figure 3-1. Watershed and water-sampling location on La Verkin Creek showing land ownership and Navajo Sandstone outcrops 12

Figure 3-2. The water-quality sampling location at La Verkin Creek during spring runoff in May 2006.....13

Figure 3-3. Flow recorded during monthly sample visits at La Verkin Creek. 13

Figure 3-4. Statistically significant decrease in specific conductance over time at La Verkin Creek 14

Figure 3-5. Statistically significant decrease in turbidity over time at La Verkin Creek....15

Figure 3-6. Statistically significant decline in sulfate over time at La Verkin Creek....16

Figure 3-7. Sulfate concentrations as related to flow in La Verkin Creek. 16

Figure 3-8. Watershed and water-sampling location on North Creek showing land ownership and Navajo Sandstone outcrops....20

Figure 3-9. The water-quality sampling location at North Creek....21

Figure 3-10. Flow recorded during monthly sample visits at North Creek. 21

Figure 3-11. pH over time at North Creek. Values in red exceeded the Utah water-quality standard of 9.0. 22

Figure 3-12. Decrease in the 0.9 quantile in alkalinity at North Creek over time.....26

Figure 3-13. Decrease in the 0.9 quantile in nitrogen at North Creek over time. Nitrogen was introduced to the analytical suite in July 2008, so data for the first two years after the fire were not available. 26

Figure 3-14. Decrease in the 0.9 quantile for specific conductance at North Creek over time. 27

Figure 3-15. Increase in the 0.9 quantile for water temperature at North Creek over time. 27

Figure 3-16. Increase in the 0.1 quantile for pH at North Creek over time. 28

Figure 3-17. Watershed and water-quality sampling location on the upper North Fork Virgin River showing land ownership and Navajo Sandstone outcrops 30

Figure 3-18. The water-quality sampling location at North Fork Virgin River near the Wilderness Study Area boundary....31

Figure 3-19. Flow recorded during monthly sample visits at North Fork Virgin River at the Wilderness Study Area boundary. 31

Figure 3-20. Exceedances of the chronic and acute primary recreation standard for *E. coli* in the North Fork Virgin River at the Wilderness Study Area boundary. 33

Figure 3-21. Exceedances of the state cold-water aquatic life standard of 20°C in the North Fork Virgin River at the Wilderness Study Area boundary 33

Figure 3-22. All fecal indicator bacteria data collected during the recreation season (May through September) for collection sites on the North Fork Virgin River downstream of pastures and upstream of the Narrows, including NCPN, park, and state samples, 2009–2017 34

Appendices

Figure A-1. Reported concentrations for dissolved phosphorus in field blanks for water years 2013–2016 43

Figure A-2. Reported concentrations for total phosphorus in field blanks for water years 2013–2016 44

Tables

Executive Summary

Trends in core parameters across streams monitored for water quality in Zion National Park, 2006–2016. xiv

Trends in major ions across streams monitored for water quality in Zion National Park, 2006–2016. xiv

Trends in nutrients across streams monitored for water quality in Zion National Park, 2006–2016. xv

Trends in trace elements across streams monitored for water quality in Zion National Park, 2006–2016. xv

Main Report

Table 1-1. Water-quality parameters evaluated by the NCPN water-quality monitoring program. .. 2

Table 1-2. Long-term NCPN water-quality monitoring stations in Zion NP. 2

Table 1-3. Water-quality stations in or near Zion NP sampled by the UDWQ or USGS. 4

Table 1-4. Average climate data from the Zion NP COOP weather station (429717), 1904–2016. 4

Table 3-1. Summary statistics for core parameters at La Verkin Creek at Lee Pass Trail, including concentrations at the 10th, 50th, and 90th percentiles; seasonal Kendall trend results; and the number of samples that were censored. 14

Table 3-2. Summary statistics for major ions at La Verkin Creek, including concentrations at the 10th, 50th, and 90th percentiles; seasonal Kendall trend results; and the number of samples that were censored. 15

Table 3-3. Summary statistics for nutrients at La Verkin Creek, including concentrations at the 10th, 50th, and 90th percentiles and the percent of the number of samples that were censored. 17

Table 3-4. Summary statistics for trace elements at La Verkin Creek, including concentrations at the 10th, 50th, and 90th percentiles; seasonal Kendall trend results; and the percent of the number of samples that were censored. 18

Table 3-5. Summary statistics for core parameters at North Creek at the planned gage in the park, including concentrations at the 10th, 50th, and 90th percentiles; seasonal Kendall trend results; and the number of samples that were censored. 22

Table 3-6. Summary statistics for major ions at North Creek, including concentrations at the 10th, 50th, and 90th percentiles; seasonal Kendall trend results; and the number of samples that were censored. 23

Table 3-7. Summary statistics for nutrients at North Creek, including concentrations at the 10th, 50th, and 90th percentiles; seasonal Kendall trend results; and the number of samples that were censored. 23

Table 3-8. Summary statistics for trace elements at North Creek, including concentrations at the 10th, 50th, and 90th percentiles; seasonal Kendall trend results; and the number of samples that were censored. 24

Table 3-9. Quantile regression results at the 0.9 and 0.1 quantiles for uncensored parameters at North Creek. 25

Table 3-10. Summary statistics for core parameters at North Fork Virgin River at WSA boundary, including concentrations at the 10th, 50th, and 90th percentiles; seasonal Kendall trend results; and the number of samples that were censored. 32

Table 3-11. Summary statistics for major ions at North Fork Virgin River at WSA boundary, including concentrations at the 10th, 50th, and 90th percentiles; seasonal Kendall trend results; and the number of samples that were censored. 34

Table 3-12. Summary statistics for nutrients at North Fork Virgin River at WSA boundary, including concentrations at the 10th, 50th, and 90th percentiles and the number of samples that were censored. 35

Table 3-13. Summary statistics for trace elements at North Fork Virgin River at WSA boundary, including concentrations at the 10th, 50th, and 90th percentiles and the number of samples that were censored. 35

Table 3-14. Summary statistics for selected parameters at North Fork Virgin River near Springdale, UT, inside the park boundary, including concentrations at the 10th, 50th, and 90th percentiles; seasonal Kendall trend results; and the number of samples that were censored. 36

Table 3-15. Summary statistics for selected parameters at Virgin River at Virgin, UT, downstream of Zion National Park, including concentrations at the 10th, 50th, and 90th percentiles; seasonal Kendall trend results; and the number of samples that were censored. 36

Appendices

Table A-1. Comparison of the amount of data censored before and after censoring to the highest reporting limit for datasets with 5–50% censored data. 42

Table B-1. State designated beneficial uses associated with water bodies in and near Zion National Park. 45

Table B-2. Water-quality standards associated with designated beneficial uses for the State of Utah. 46

Glossary

Censored data—Data for which a cut-off, rather than a true value, are known, such as for samples with concentrations below an analytical reporting limit (e.g., <0.02 mg/L).

Monotonic trend—A trend that always goes in one direction (e.g., always increasing or always decreasing).

Non-parametric—Mathematical procedures for statistical hypothesis testing which, unlike parametric statistics, make no assumptions about the probability distributions of the variables being assessed.

p-value—Statistical probability that the observed data would occur if there were no trend over time. Setting this value to a low number, such as $p = 0.05$, reduces the chance of falsely reporting a trend that does not exist.

Quantile regression—Quantile regression models the relationship between X and the conditional quantiles of Y, such as the median or the 0.9 quantile. In comparison, ordinary least squares regression models the mean (average) response, rather than the selected quantile response.

Relative Percent Difference (RPD)—A method for comparing two samples taken from the same water at the same time. A low RPD indicates low variability between samples and corresponding confidence in sample handling, analytical calibrations, and other processes that can introduce variability in samples. A high RPD indicates unexpected variability.

Seasonal Kendall test—A non-parametric test that analyzes seasonal data for monotonic trends.

Sen slope—Also known as a Theil–Sen slope, this is a non-parametric alternative to the parametric ordinary least squares regression line.

Serial correlation—The relationship between a given variable and itself over time, such that one measurement of the variable is highly related to the adjacent measurement.

Acronyms and Abbreviations

(d)	dissolved
µg/L	nanograms per liter
µS/cm	microSiemens per centimeter
cfs	cubic feet per second
EPA	U.S. Environmental Protection Agency
mg/L	milligrams per liter
NCPN	Northern Colorado Plateau Network
NOAA	National Oceanic and Atmospheric Administration
NP	national park
NPS	National Park Service
PQL	practical quantitation limit
UDWQ	Utah Department of Water Quality
USGS	U.S. Geological Survey
WQX	U.S. Environmental Protection Agency's Water Quality Exchange
WSA	Wilderness Study Area
WY	water year

Executive Summary

The National Park Service collects water-quality samples approximately monthly at three fixed water-quality stations in Zion National Park: La Verkin Creek, North Creek, and the North Fork Virgin River. Data collection began at La Verkin Creek and North Creek in November 2005, and at the North Fork Virgin River in July 2008. This report analyzes data from the beginning of the period of record for each station through water year 2016 to test for trends over time. Concentrations are also compared to relevant water-quality standards for the State of Utah.

Key findings include:

- Continued exceedances of state water-quality standards for fecal indicator bacteria in the North Fork Virgin River indicate a need for improved management upstream of the park to protect public health and safety and the need for continued monitoring as management actions are implemented.
- Water quality in North Creek appears to be stabilizing after a wildfire burned much of the watershed in 2006.
- Changes in water quality at La Verkin Creek are likely to be natural in origin and are not of a magnitude that warrants management concern at this time.

We used a seasonal Kendall test to test for trends in median concentrations over time. Few trends were detected in any water-quality parameters at any of the stations evaluated for Zion National Park, indicating that seasonal median concentrations have remained relatively stable over time. Only specific conductance, sulfate, and turbidity at La Verkin Creek showed statistically significant declines in seasonal median concentrations. The cause of these declines is not known, but likely is natural because this watershed has few developments and no changes in land uses or management practices. North Creek and the North Fork Virgin River had no statistically significant trends in seasonal median concentrations.

A portion of the North Creek watershed burned in 2006, followed by a catastrophic flood in 2007. While seasonal median concentrations did not show statistically significant trends after the fire, high and low concentrations in the dataset appeared to change over time. To evaluate changes in high and low concentrations, we used quantile regression to test for trends at the 0.1 and 0.9 quantiles, corresponding to the lowest 10% and highest 90% of data values. Alkalinity, nitrogen, and specific conductance decreased in the 0.9 quantile for post-fire concentrations at North Creek, and pH increased in the 0.1 quantile over time. Trends in the low and high concentrations of water-quality parameters suggest that post-fire variability is stabilizing in North Creek. Nitrogen species may have fallen below a critical threshold for eutrophication. This observation is supported by a reduction in observed algal blooms at the site since 2006. Although not statistically significant, there have also been fewer exceedances of the pH water-quality standard in North Creek in recent years.

Comparisons to water-quality standards reiterated previously recognized management issues, including pH at North Creek and fecal-indicator bacteria (*E. coli*) and water temperature at the North Fork Virgin River just upstream from the park boundary. The State of Utah has included the North Fork Virgin River on a list of impaired waters, known as a 303(d) list, for these parameters. The Utah Division of Water Quality is undertaking a Total Maximum Daily Load analysis for the North Fork that will include a plan to bring surface-water quality into compliance. Given its location in a warm desert environment, the state is investigating whether the North Fork Virgin River in Zion National Park should be reclassified from a cold-water aquatic system to a warm-water aquatic system. Extensive sampling and analysis indicate that the greatest amount of *E. coli* loading is from pastures adjacent to the river that

are flood-irrigated and grazed. Other possible sources include human waste. A vault toilet has been installed at the Narrows trailhead, and an outhouse previously located over an irrigation ditch has been removed. Continued exceedances of *E. coli* in the North Fork Virgin River support the need for management action to improve public health and safety in this stream.

The following tables summarize trends across the three sampling sites.

- Arrows indicate results of seasonal Kendall trend analysis
  - ↔ = no trend;
  - ↓ = decreasing trend;
  - (cens.) = 5–50% dataset censored;
  - cens. = >50% of dataset censored (no trend analysis)
- Box color indicates status compared to water-quality standards or recommended concentrations for State of Utah
  - blank = no water-quality standard
  - green = 0–5% exceedances
  - yellow = 6–9% exceedances
  - red = 10% or more exceedances

Trends in core parameters across streams monitored for water quality in Zion National Park, 2006–2016.

Parameter	La Verkin Creek		North Creek		North Fork Virgin River	
	Trend	Exceedances	Trend	Exceedances	Trend	Exceedances
Dissolved oxygen (mg/L)	↔	0–5%	↔	0–5%	↔	0–5%
Dissolved oxygen saturation (%)	↔	–	↔	–	↔	–
Escherichia coli (MPN/100 mL)	↔ (cens.)	0–5%	↔ (cens.)	≥10%	↔ (cens.)	≥10%
Flow (cfs)	↔	–	↔	–	↔	–
pH	↔	≥10%	↔	0–5%	↔	0–5%
Specific conductance (µS/cm)	↓	–	↔	–	↔	–
Turbidity (NTU)	↓ (cens.)	–	↔	–	↔	–
Water temperature (°C)	↔	0–5%	↔	≥10%	↔	≥10%

Trends in major ions across streams monitored for water quality in Zion National Park, 2006–2016.

Parameter (mg/L)	La Verkin Creek		North Creek		North Fork Virgin River	
	Trend	Exceedances	Trend	Exceedances	Trend	Exceedances
Alkalinity	↔	–	↔	–	↔	–
Calcium (dissolved)	↔	–	↔	–	↔	–
Chloride	cens.	–	cens.	–	cens.	–
Magnesium (dissolved)	↔	–	↔	–	↔	–
Potassium (dissolved)	↔	–	↔	–	↔	–
Sodium (dissolved)	↔	–	↔	–	↔	–
Sulfate (mg/L)	↓	–	↔	–	↔	–
Total dissolved solids (mg/L)	↔	0–5%	↔	0–5%	↔	0–5%

Trends in nutrients across streams monitored for water quality in Zion National Park, 2006–2016.

Parameter (mg/L)	La Verkin Creek		North Creek		North Fork Virgin River	
	Trend	Exceedances	Trend	Exceedances	Trend	Exceedances
Ammonia as N	cens.	0–5%	cens.	0–5%	cens.	0–5%
Nitrite + Nitrate as N	cens.	-	↔	–	cens.	–
Nitrogen (dissolved)	cens.	-	↔	–	cens.	–
Phosphorus as P (dissolved)	cens.	-	cens.	–	cens.	–
Total Phosphorus as P	cens.	≥10%	cens.	0–5%	cens.	6–9%

Trends in trace elements across streams monitored for water quality in Zion National Park, 2006–2016.

Parameter (µg/L)	La Verkin Creek		North Creek		North Fork Virgin River	
	Trend	Exceedances	Trend	Exceedances	Trend	Exceedances
Aluminum (dissolved)	cens.	0–5%	cens.	0–5%	cens.	0–5%
Arsenic (dissolved)	cens.	0–5%	↔	0–5%	cens.	0–5%
Barium (dissolved)	↔	–	↔	0–5%	cens.	0–5%
Boron (dissolved)	↔	0–5%	↔	0–5%	cens.	0–5%
Cadmium (dissolved)	cens.	0–5%	cens.	0–5%	cens.	0–5%
Chromium (dissolved)	cens.	0–5%	cens.	0–5%	cens.	0–5%
Copper (dissolved)	cens.	0–5%	cens.	0–5%	cens.	0–5%
Iron (dissolved)	cens.	0–5%	cens.	0–5%	cens.	0–5%
Lead (dissolved)	cens.	0–5%	cens.	0–5%	cens.	0–5%
Manganese (dissolved)	↔	–	↔	–	cens.	–
Mercury (dissolved)	cens.	0–5%	cens.	0–5%	cens.	0–5%
Nickel (dissolved)	cens.	0–5%	cens.	0–5%	cens.	0–5%
Selenium (dissolved)	cens.	0–5%	↔	0–5%	cens.	0–5%
Silver (dissolved)	cens.	0–5%	cens.	0–5%	cens.	0–5%
Zinc (dissolved)	cens.	0–5%	cens.	0–5%	cens.	0–5%

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1 Introduction

The 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. Maintaining unimpaired streams and rivers is a high priority for park managers at Zion National Park (NP). These aquatic systems sustain native fish and other biota uniquely adapted to the rigors of inhabiting desert canyons. They also provide spectacular scenery and recreational opportunities for park visitors.

The "flows of the North Fork of the Rio Virgin" were cited as "an extraordinary example of canyon erosion . . . of the greatest scientific interest" in the 1909 proclamation that established Zion National Monument [36 Stat. 2498]. By virtue of this establishment and subsequent acts and proclamations, Zion NP secured federal reserved water rights to meet park purposes that include the natural flows of streams and springs, scenic beauty, recreation, and administrative uses.

These rights were formally recognized in 1996, in the Zion NP Water Rights Settlement Agreement. The agreement prevents new major impoundments and diversions upstream from the park and limits the amount of well development within a buffer area around portions of the park, protecting instream flows and groundwater (USDI 1996). As a result of the relatively minor degree of water development upstream from the park and this formal recognition of reserved water rights, the quantity of flow in park streams and springs can be described as minimally affected by human activity. In 2009, the U.S. Congress recognized the outstanding values of Zion's surface water systems, and all rivers and streams within the park were designated as Wild and Scenic Rivers.

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 for parks. Previous evaluations of water-quality data have documented few exceedances of water-quality standards for the State of Utah (Thoma et al. 2008; Van Grinsven et al. 2010; Sharrow 2012b; Hackbarth and Weissinger 2013; Hackbarth and Weissinger 2016), although some chronic problems have been noted. Potential land uses that may affect water quality include agricultural practices, conversion of wildlands to residential properties, increased population, livestock grazing, increased visitor use, hydrologic diversions and dams, and historical mining (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 streams and rivers of Zion NP, 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 monitoring program can be framed in a series of general questions that can be quantitatively answered via measurable objectives.

- What are the ranges in water-quality parameters for selected streams of NCPN parks?
- What are the current status and long-term trends in selected water-quality parameters at surface-water sites monitored in NCPN parks?
- 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 long-term monitoring sites in Zion NP from water years (WY) 2006–2016 for statistically significant temporal trends, and to compare those concentrations to designated beneficial uses and

water-quality standards for the State of Utah. The 11-year period of record analyzed in this study is recognized as a relatively short period for trend analysis, as interannual variability in streams can have an influence on water-quality trends that is larger than the influence of pollutant loading. It is, however, useful as a status check of the program and as a means of highlighting the most significant problem areas for park managers.

Three stations were evaluated for as many as 33 constituents. Constituents included core parameters, major ions, nutrients, and trace elements (Table 1-1). All data are publicly available in the Environmental Protection Agency's Water Quality Exchange (WQX).

As per NCPN's water-quality monitoring protocol (Thoma et al. 2017), stations relevant to Zion NP sampled by the Utah Division of Water Quality (UDWQ) and the U.S. Geological Survey (USGS) were also included in this report if recent data were publicly available in WQX or in the public USGS database, the National Water Information System. Relevance is defined as sites in or near Zion with data within five years of the end of the period of interest.

1.2 Study area

1.2.1 Description

Zion NP protects 60,192 hectares (148,733 acres) within southwestern Utah (Figure 1-1). Elevations range from 1,128 meters (3,700 feet) in the park's southwestern corner to 2,660 meters (8,726 feet) on Horse Ranch Mountain in the northeast. Climatic zones range from desert to subalpine, as influenced by elevation and topography. The topography is characterized by high plateaus dissected by deep, narrow canyons carved by perennial and intermittent streams. Within the deep canyons of Zion NP, the main drainages include the east and north forks of the Virgin River. Other important perennial tributaries include North, La Verkin, Deep, Kolob, and Pine creeks. The majority of the stream flow that supports perennial streams within the park comes from groundwater seepage at the contact between the Navajo Sandstone (aquifer unit) and the underlying, less permeable, Kayenta Formation (confining unit). The headwaters for the systems often lie upstream of the park boundary.

1.2.2 Water-quality monitoring

In November 2005, the Northern Colorado Plateau Network, as part of a National Park Service initiative to develop long-term monitoring of natural resources in national park units, established water-quality monitoring locations within the park on La Verkin Creek and North Creek (Figure 1-1, Table 1-2). A station was also established on the North Fork Virgin River upstream from the park

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, total dissolved nitrogen, total dissolved phosphorus, total phosphorus
Trace elements	aluminum, arsenic, barium, cadmium, chromium, copper, iron, lead, manganese, mercury, selenium, silver, zinc

Table 1-2. Long-term NCPN water-quality monitoring stations in Zion NP.

Station name	WQX ID	Latitude	Longitude
La Verkin Creek at Lee Pass Trail	4950800	37.4072027	-113.1757943
North Creek at planned gage in park	4950920	37.2610949	-113.1063463
North Fork Virgin River at Wilderness Study Area boundary	4951265	37.370127	-112.882809

Datum is NAD83. Data for WY2006–2016 are publicly available in the Water Quality Exchange (WQX) database.

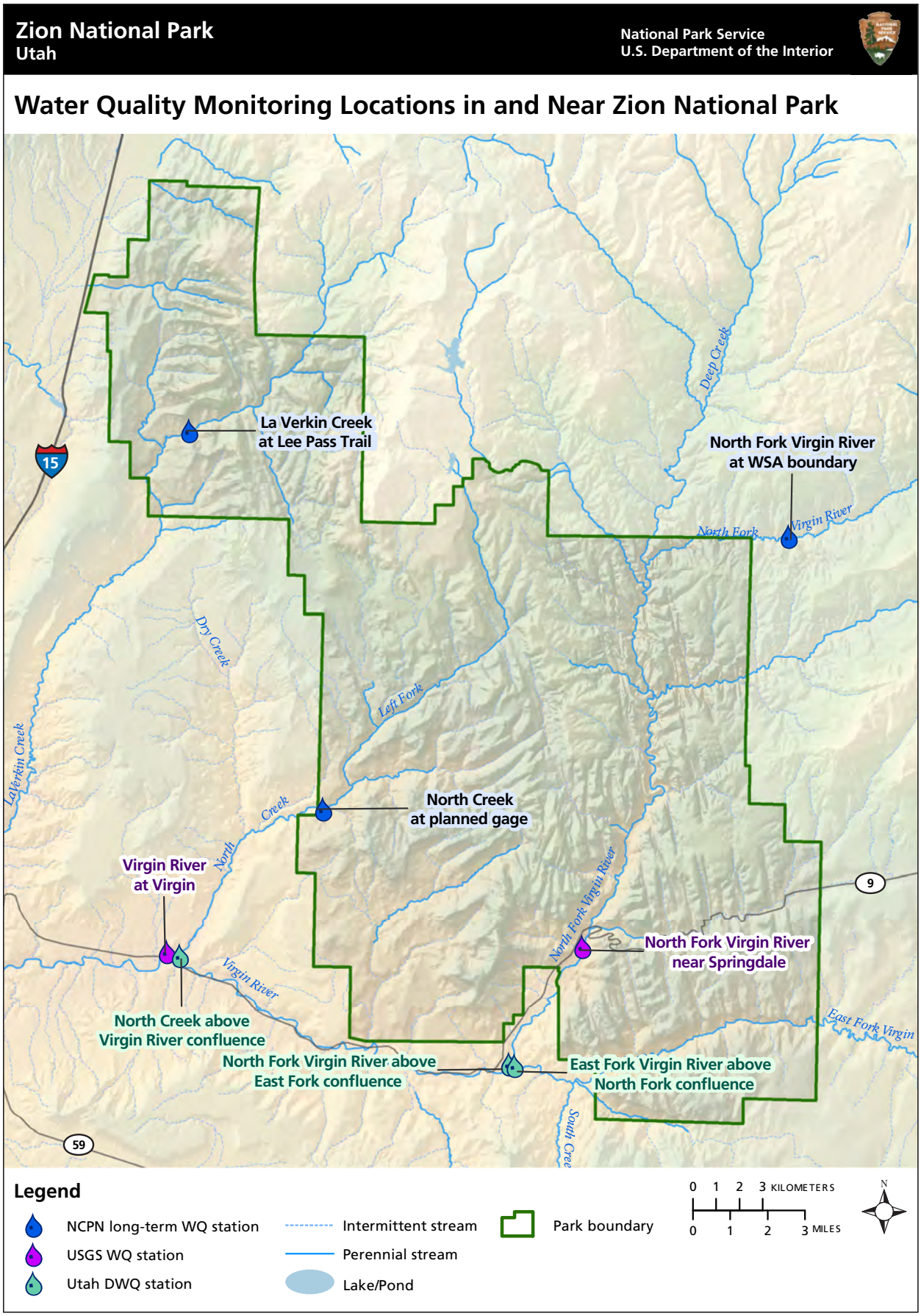


Figure 1-1. Overview of Zion National Park and the water-quality stations included in this report.

boundary, but due to the potential for watershed development between that station and the park boundary, the station was moved to a downstream location in July 2008. Many other, smaller streams exist in the park, as evidenced by the Wild and Scenic Rivers designation of 38 named streams. Some of the more prominent among these were also considered for monitoring. Deep and Kolob creeks were not selected for monitoring due to their remote locations and difficult access. Pine Creek was not selected due to its intermittent flow.

Five additional stations sampled by UDWQ and USGS (Table 1-3) were investigated for potentially relevant data (Thoma et al. 2017). Of those, only two stations sampled by the USGS had been sampled within five years of the end of the period of interest. USGS data were summarized and analyzed without any additional quality assurance.

1.2.3 Climate

The climate at Zion NP varies greatly based on elevation and topography. Conditions in the park's main canyon (North Fork Virgin River) are generally warm and dry (Table 1-4). For the water years analyzed in this report, maximum and minimum air temperatures were generally warmer than the 30-year average (1981–2010), while precipitation was generally lower than average (Figure 1-2). Water years 2010, 2011, and 2016 were wetter than average years.

There are two distinct wet seasons at Zion NP: a winter season from December through April, when frontal storms produce rain and snow events, and a moist summer monsoon in July through September that produces daily cycles of thunderstorms that are sometimes intense. Sixty percent of annual precipitation falls during the winter season. Winter snowpack at higher elevations produces snowmelt-driven springtime floods that are quite variable year-to-year, and contributes to groundwater recharge that sustains base flow through the rest of the year. In summer, monsoonal rainstorms are associated with flash floods and occasional debris flows.

For streams with smaller watersheds (< ~260 km^2/100 mi^2), the largest floods are produced by brief monsoonal storms that, while intense, are usually localized. These floods typically have an abrupt onset and short du-

Table 1-3. Water-quality stations in or near Zion NP sampled by the UDWQ or USGS.

Station ID	Station name	Sampled by	Database	Most recent data	Included?
4950890	North Creek above confluence with Virgin River	UDWQ	WQX	6/26/2007	No
4950950	North Fork Virgin River above confluence with East Fork Virgin River	UDWQ	WQX	1/12/2009	No
4951400	East Fork Virgin River above confluence with North Fork Virgin River	UDWQ	WQX	1/12/2009	No
09405500	North Fork Virgin River near Springdale, UT	USGS	NWIS	9/6/2016	Yes
09406000	Virgin River at Virgin, UT	USGS	NWIS	8/15/2016	Yes

Table 1-4. Average climate data from the Zion NP COOP weather station (429717), 1904–2016.

Location	Elevation	Average annual maximum air temperature	Average annual minimum air temperature	Average annual precipitation
Zion NP Visitor's Center	1,231 m (4,039 ft)	23.9°C (75.1 °F)	8.3°C (46.9 °F)	38.3 cm (15.06 in)

Data accessed from the Western Regional Climate Center, 5/10/2017; https://wrcc.dri.edu/.

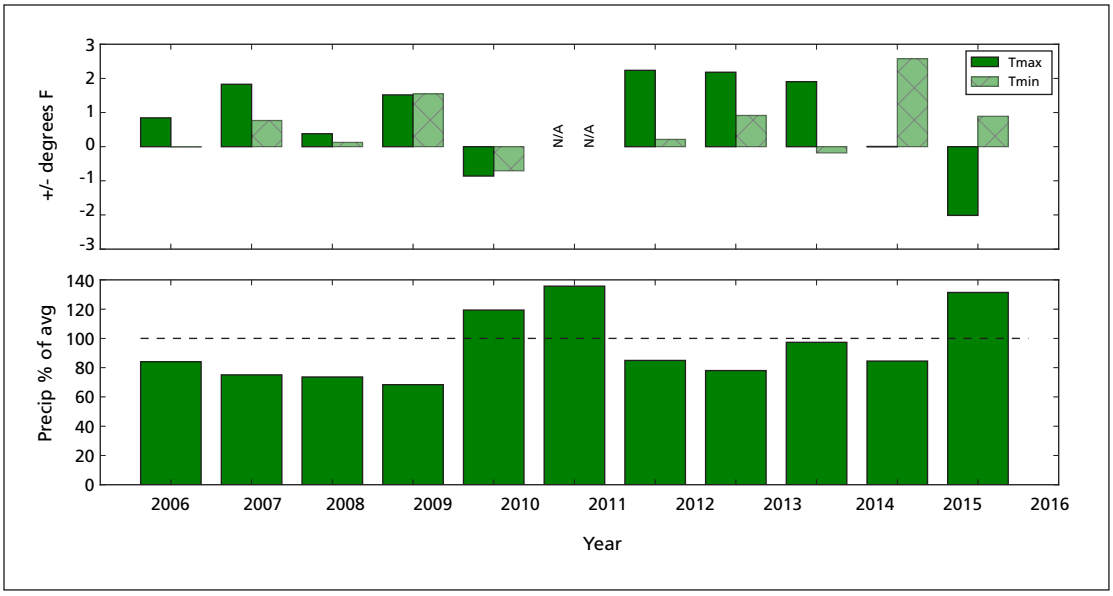


Figure 1-2. Departures in air temperature (degrees Fahrenheit) and precipitation amount (%), WY2006–2016 compared to the 30-year average (1981–2010) at the Zion NP weather station (429717). Figure accessed 4/28/2017 at www.climateanalyzer.org.

ration, and are heavily laden with sediment. Floods on larger watersheds (>780 km^2/300 mi^2) are most often produced by multi-day winter rain and snow events that are regional in scale. These floods typically build over one to several days and may sustain flood flows for several days following the peak. Spring snowmelt runoff in years with a significant snowpack also produces high flow events in some watersheds. Snowmelt events produce relatively small discharge peaks but are several weeks in duration.

The North Fork Virgin River is an example of a stream with a larger watershed within the park. Spring runoff generally occurs from April through May (Figure 1-3), and flood peaks are visible throughout the monsoon and winter storm-front seasons. USGS gaging station 09405500 is located on this stream, near Springdale.

Climate variability can affect water-quality trend analysis because concentrations of dissolved and total constituents often vary with discharge. The relative proportion of instream flows based on groundwater versus surface-water inputs can also affect parameter concentrations. In years with a high snowpack, higher and longer runoff periods can elevate base flows, likely corresponding to lower concentrations of dissolved constituents. In contrast, during drought periods, when streams are predominantly fed by groundwater, higher concentrations of dissolved constituents are likely. Instream flows on the North Fork Virgin River have both high variation within each year (Figure 1-3) and high year-to-year variation (Figure 1-4). Other streams at Zion NP are likely to have a similar pattern.

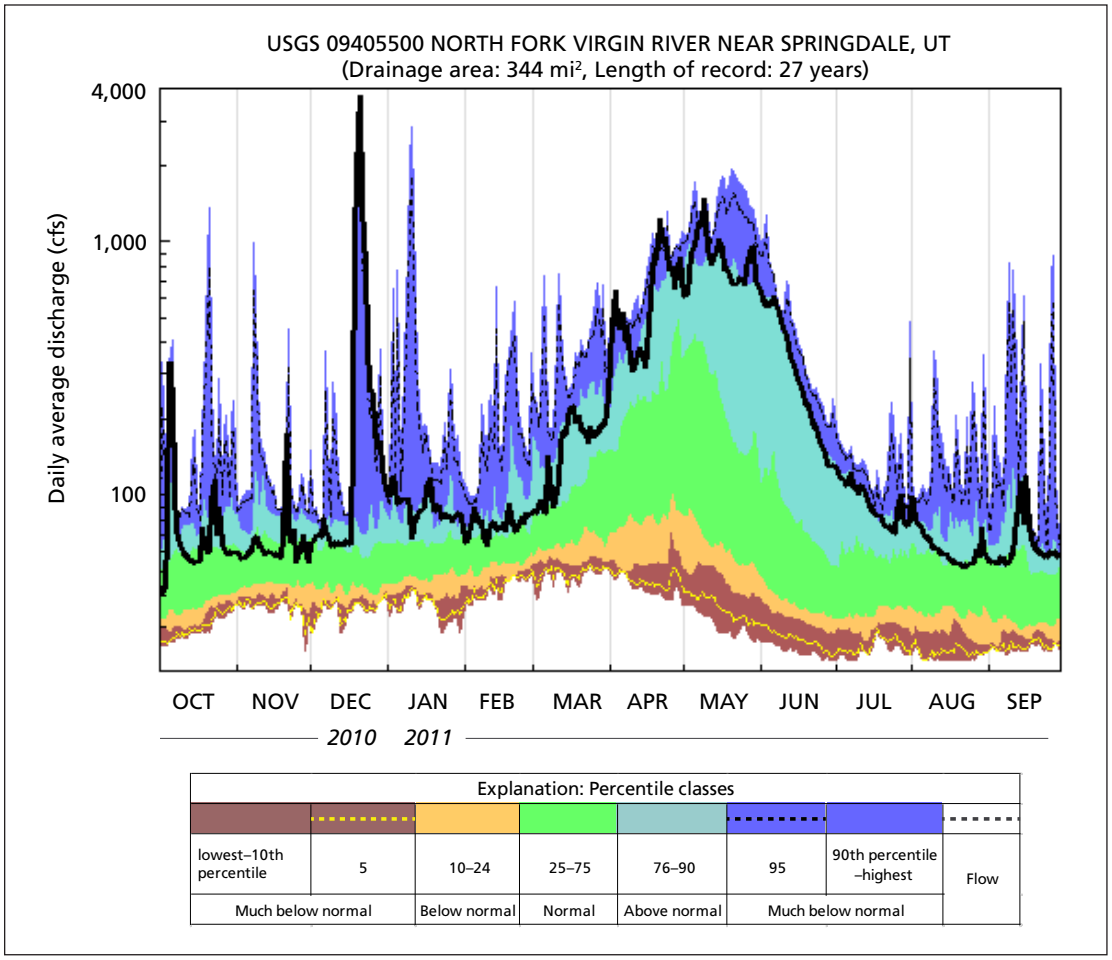


Figure 1-3. Flow percentiles for the North Fork Virgin River near Springdale (USGS gage 09405500), based on 27 years of data. The black line corresponds to the water year 2011 hydrograph. Graph accessed on the USGS WaterWatch website on 6/9/2017; https://waterwatch.usgs.gov/.

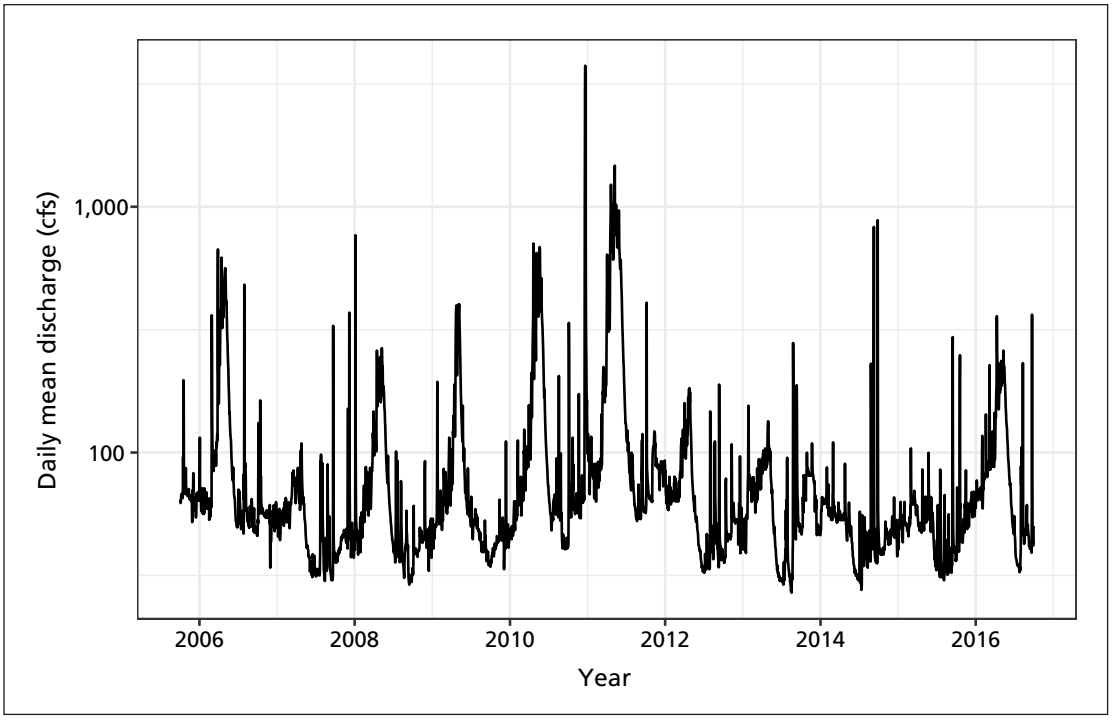


Figure 1-4. Daily mean discharge in cubic feet per second (cfs) for WY2006–2016 at the North Fork Virgin River near Springdale, Utah (USGS gage 09405500).

2 Methods

2.1 Field data collection

Sampling began at La Verkin Creek and North Creek in November 2005, and at the North Fork Virgin River in July 2008. 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 2016, 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 documented adequately with fewer samples (Thoma et al. 2017). Gaps in data collection occurred in May–August 2011 due to staff turnover and occasionally due to weather, safety, or access issues.

Field-data collection methods followed 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 an Aquacalc and mini-meter or a Sontek Flowtracker acoustic Doppler velocity meter. Water temperature, pH, specific conductance, and dissolved oxygen were measured in the field using a calibrated In-Situ TROLL 9000 or 9500 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: 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 collection.

2.2 Sample analytical methods and quality assurance

Water-quality samples were analyzed for major ions, nutrients, and trace elements at the U.S. Environmental Protection Agency (EPA)-certified Utah State Public Health Laboratory using EPA-approved methods. 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 for anomalous results in three ways: visually, by identifying outliers, and by calculating a charge balance for the sample. Anomalous results were reviewed for errors based on field datasheets, visit comments, and lab sheets. If no errors were found, the data were retained in the dataset.

2.2.1 Bias

Laboratory proficiency-testing data indicated a low bias for sulfate and a high bias for total dissolved solids from 2011 to 2013 (Weissinger 2016). Beginning in October 2013, field blanks were submitted to better track possible contamination in the samples, including 21 blanks for major ions and nutrients and 9 blanks for trace elements. All results were below reporting limits, with the exception of several cases discussed below.

Chloride was a contaminant in the blank water until March 2016, when we switched to a different blank water source. Detected concentrations in blank samples were similar to detected concentrations in environmental water samples, raising possible concerns about whether reported environmental water sample concentrations were accurate. We addressed this concern by comparing major ion concentrations using a charge-balance analysis (Weissinger 2016) to see if reported concentrations of chloride in environmental water samples balanced out with reported concentrations of other major cations and anions. Because the charge-balance analyses indicated that reported concentrations of

chloride were reasonable for environmental water samples, we used the environmental water concentrations in this report.

In April 2011, the Utah lab began reporting nutrients at minimum detection levels rather than at previously used reporting limits. Field blanks repeatedly had detections for dissolved and total phosphorus, nitrate plus nitrite, and nitrogen near the detection limits. Because all of the blank detections for nutrients fell below the previously used reporting limits, we retained the use of the higher reporting limits for nutrients for this report. For further discussion of phosphorus blanks and implications of this decision on trend analysis, see Appendix A.

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 less than 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 less than 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, defined as Sample A + Sample B. For all samples, 97.5% of major ions, 99.3% of trace elements, and 99.2% of nutrients met data-quality goals.

2.3 Trend analysis

Data were evaluated for monotonic trends using a seasonal Kendall test adjusted for the possibility of serial correlation (see Glossary for definitions of statistical terms). Data summary and analysis was completed using the freeware R v.3.3.3 (R Core Team 2017). 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 that 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 and Hirsch 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-collected samples, monthly or quarterly seasons were used, depending on the sampling interval for each parameter. For USGS-collected samples, the median value for all samples collected in a month was used, and sites were analyzed using months as seasons.

Data were summarized and evaluated to determine the number of samples available for each parameter and site combination (e.g., dissolved oxygen at North Creek). Site and parameter combinations with fewer than 5 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=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 Limits of detection and censoring of data

Some water-quality parameters, especially nutrients and trace elements, typically have very low concentrations that are close to the detection limitations 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. For example, the reporting limit for total phosphorus decreased from 0.02 mg/L in 2006 to 0.003 mg/L after 2012. For datasets with multiple censoring levels in this study, we decided to re-censor data to the highest reporting limit over the period of record. In this example, all concentrations during the period of record that were non-detects or were detected concentrations below the 0.02 mg/L reporting limit were set to the reporting limit and evaluated as ties during the seasonal Kendall analysis. For additional discussion of data censoring and its implications for trend analysis in our dataset, see Appendix A.

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 (see Appendix B, at https://irma.nps.gov/DataStore/Reference/Profile/2252076). For site and parameter combinations with <5% censored concentrations, a non-parametric slope of the magnitude of the trend, called a Sen slope, represents the median annual change in a parameter. We calculated a median annual rate of change: (Sen slope/median value) ∗100, as well as an estimate of the total change over the period of record: annual rate of change ∗ number of years in record. For datasets with >5% censored data, the Sen slope is biased towards being a low estimate of the rate of change, and no slope estimates or rates of change are presented, as recommended by Schertz and others (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.

2.3.2 Relationships to flow

Many water-quality parameters change in concentration with changes in stream flow. Flow-related variability may be large compared to changes in response to other drivers, such as land use 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.

2.3.3 Strengths and limitations of our approach

The seasonal Kendall test is best suited to detecting fairly consistent changes over time. It is a standard approach to testing for water-quality trends because it can handle datasets that violate the assumptions of many other statistical tests. However, there are some significant limitations to this approach. Short-term changes in water-quality parameters may not be captured in a test for long-term trends. A focus on seasonal median concentrations may ignore trends in low or high concentrations in the dataset, as noted in Section 3.2.5.

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. 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 (months) and acute exposure over a short period (hours or days). Permitted levels 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 more attention. Exceedances in this report, therefore, are meant to inform managers of potential problems rather than to reflect regulatory definitions. Regulatory comparisons are made by the State of Utah in their 303(d) reports to Congress.

This report notes exceedances of the chronic standard 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.

3 Results and Discussion

3.1 La Verkin Creek at Lee Pass Trail

La Verkin Creek cuts deep canyons through the north-central portion of the park in a northeast-to-southwest direction (Figures 3-1 and 3-2; see also Figure 1-1). The creek drains an area of 257.2 km^2 (99.3 mi^2). Of that, 150.5 km^2 (58.1 mi^2) lie within the park and 59.6 km^2 (23 mi^2) are upstream from the park. A large majority of the lands upstream from the park are privately owned. Because most of the land is steeply sloped and road access is difficult, land uses include just a few private residences and livestock grazing.

Perennial flow of La Verkin Creek is derived almost entirely from groundwater discharge from the base of the Navajo Sandstone, a regional aquifer with generally good water quality. There are several small stockponds and small spring diversions in the upper part of the watershed 5–10 kilometers (3–6 mi) upstream of where the channel cuts through the Navajo Sandstone, but there are no appreciable diversions or impoundments downstream nearer the park. Surface discharge in this reach is protected by federal reserved and appropriative water rights held by the NPS and recognized in the Zion National Park Water Rights Settlement Agreement and a Wild and Scenic Rivers designation. La Verkin Creek is permitted for backcountry use. Backpackers use the creek as a primary water source, including as part of the popular trans-Zion route, which links trails to other areas of the park.

The Hop Valley tributary enters La Verkin Creek approximately 3.2 kilometers (2 mi) upstream of the water-quality sampling location. Hop Valley is a patchwork of park-owned property and private inholdings. Cattle grazing on private lands have access to the riparian corridor in Hop Valley and frequently trespass on park lands. The perennial flow in the Hop Valley tributary in the area of cattle use becomes subsurface for about 1.5 kilometers (1 mi) before joining La Verkin Creek. The lower end of Hop Valley is blocked by a very large Holocene landslide deposit. Surface flow connects over the landslide deposit to La Verkin Creek only during large runoff events. Subsurface flow may connect to a spring discharging along La Verkin Creek.

3.1.1 Core parameters

Flow conditions during sampling events had no trend over time (Figure 3-3), although variability during sample visits was higher earlier in the period of record. Higher flow events earlier in the record corresponded with spring runoff. A reduced snowpack in 2012 and 2013 may have resulted in lower spring peak flows during the latter part of the record.

Specific conductance and turbidity had statistically significant downward trends at La Verkin Creek (Table 3-1). The median annual decline in specific conductance was 0.6% (-4.3 µS/cm per year), for a total decline of almost 7% over the period of record (Figure 3-4). Turbidity data had too many censored values to estimate a trend slope (Figure 3-5). State standards exist for dissolved oxygen, *E. coli*, pH, and water temperature. No exceedances of these parameters were found for La Verkin Creek.

3.1.2 Major ions

Sulfate had a statistically significant downward trend at a median annual rate of -1.5% (-2.5 mg/L per year), resulting in a 17% decrease in sulfate concentrations over the period of record (Table 3-2; Figure 3-6). A laboratory low bias for sulfate was noted for 2011–2013 (Weissinger 2016), but laboratory data did not show a similar bias during 2014–2015, when lower-than-normal sulfate concentrations continued to be reported. Decreases in an anion, such as sulfate, should be matched by decreases in cations (Hem 1985). A decrease in sodium did not quite meet our criteria for statistical significance ($p = 0.06$), but other major cations, such as calcium and magnesium, were stable over time. Variability in flow did not show a compelling relationship with sulfate concentrations (Figure 3-7). State standards exist for total dissolved solids. No exceedances were found for this parameter on La Verkin Creek.

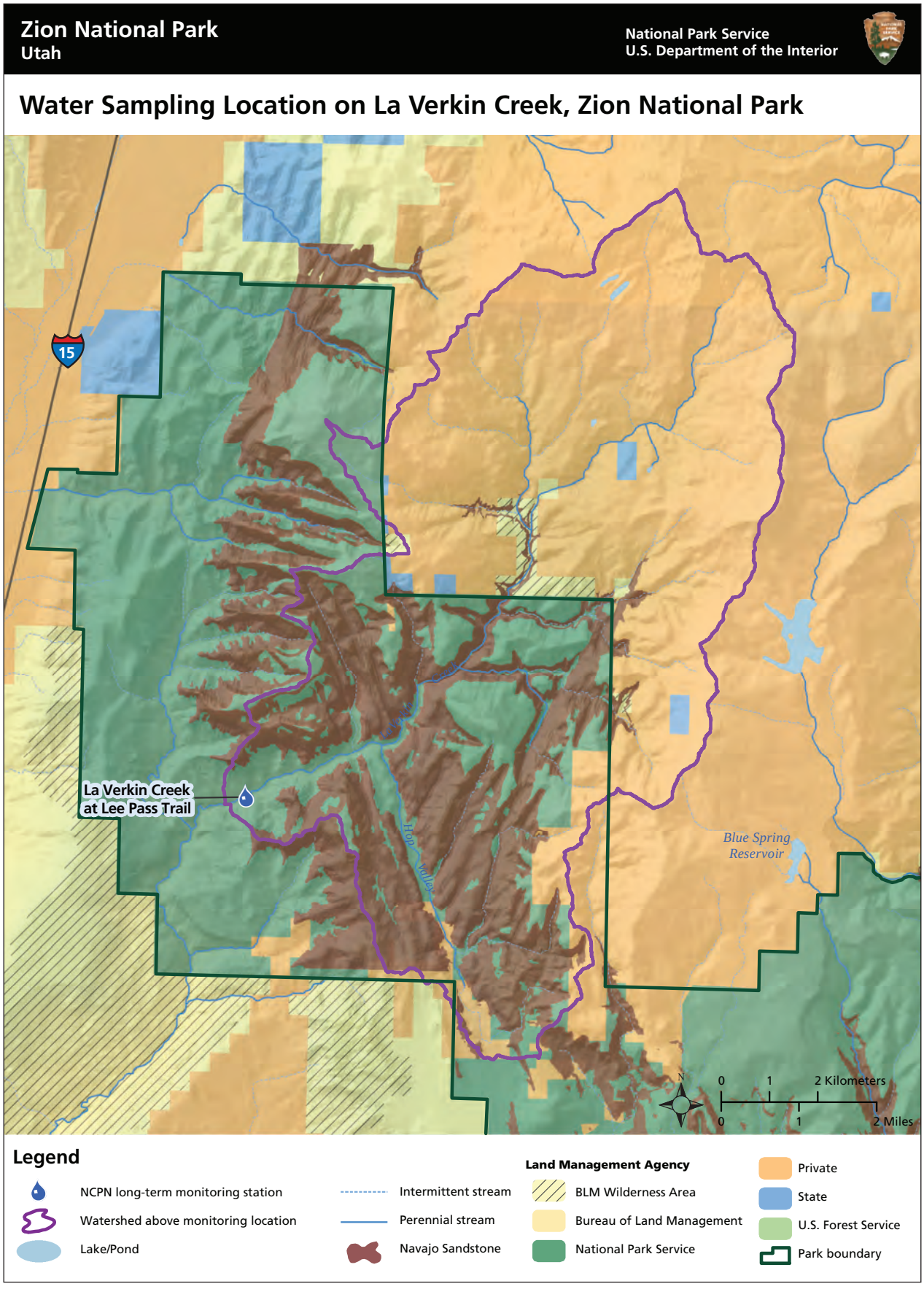


Figure 3-1. Watershed and water-sampling location on La Verkin Creek showing land ownership and Navajo Sandstone outcrops. Flow is from the northeast to the southwest.



Figure 3-2. The water-quality sampling location at La Verkin Creek during spring runoff in May 2006.

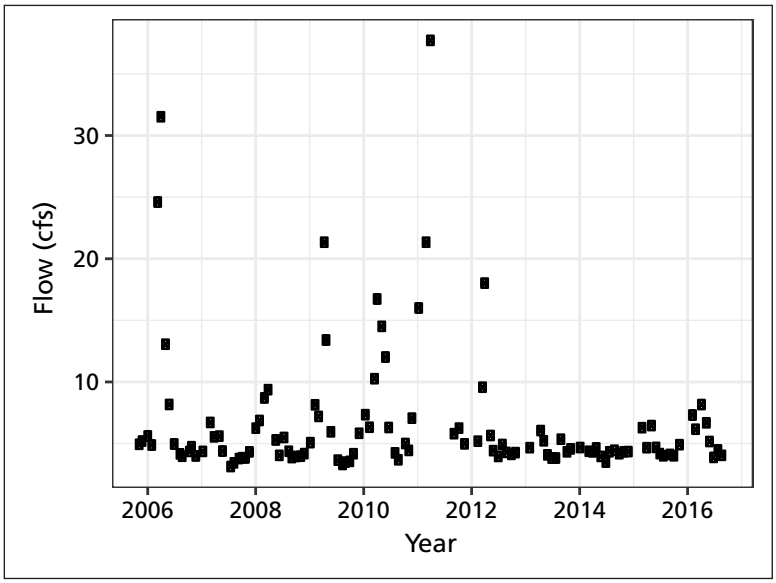


Figure 3-3. Flow recorded during monthly sample visits at La Verkin Creek.

Table 3-1. Summary statistics for core parameters at La Verkin Creek at Lee Pass Trail, including concentrations at the 10th, 50th, and 90th percentiles; seasonal Kendall trend results; and the number of samples that were censored.

Parameter	Test	Sampling dates		Samples		Concentration percentile			p-value	Trend direction
		Start	End	Total #	Total censored	10th	Median	90th		
Dissolved oxygen (mg/L)	U	1/15/2006	9/3/2016	98	0	7.66	9.06	10.82	0.899	none
Dissolved oxygen saturation (%)	U	1/15/2006	9/3/2016	98	0	100.7	104.2	108.4	0.109	none
Escherichia coli (MPN/100 mL)	C	6/9/2006	9/3/2016	82	19	<1	2.02	21.82	0.211	none
Flow (cfs)	U	11/18/2005	9/3/2016	114	0	3.7	4.7	10.1	0.952	none
pH	U	11/18/2005	9/3/2016	114	0	8.36	8.49	8.62	0.122	none
Specific conductance (µS/cm)	U	11/18/2005	9/3/2016	103	0	648.1	682.1	734.0	0.013	**down**
Turbidity (NTU)	C	12/8/2005	9/3/2016	99	5	1.3	9.1	317.2	0.025	**down**
Water temperature (°C)	U	11/18/2005	9/3/2016	109	0	6.01	12.01	22.18	0.543	none

U=uncensored; C=censored

Statistically significant changes are bolded.

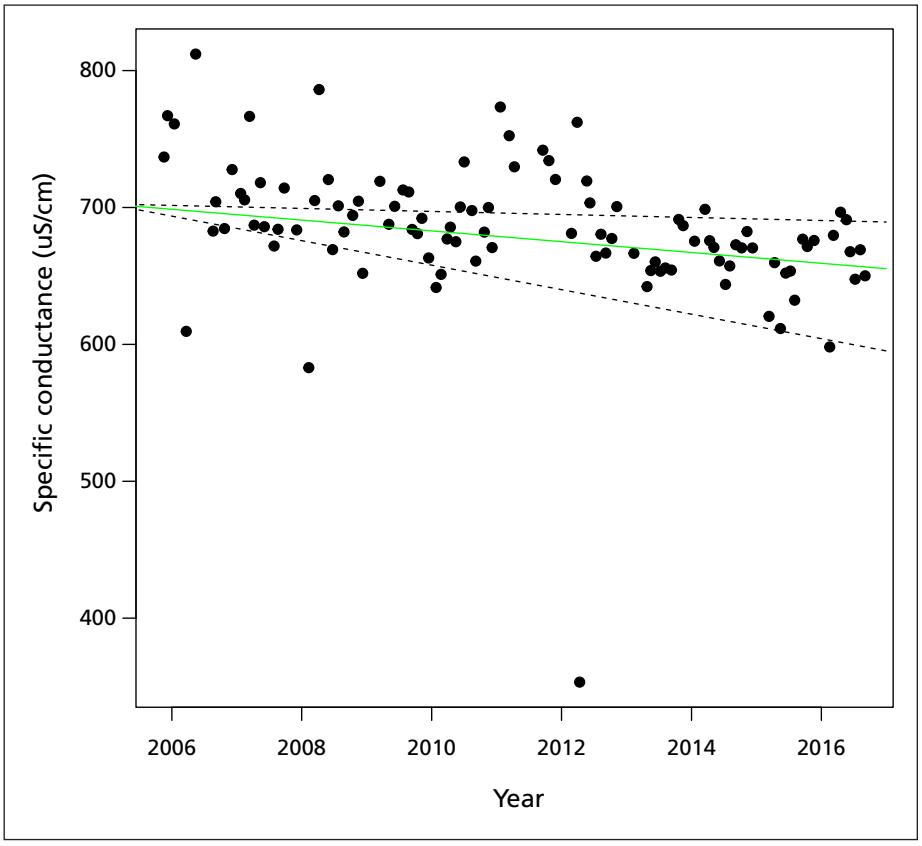


Figure 3-4. Statistically significant decrease in specific conductance over time at La Verkin Creek. The estimated trend of -4.3 µS/cm per year is presented by a Sen slope (green line) with the 95% confidence interval of the slope estimate (dashed lines).

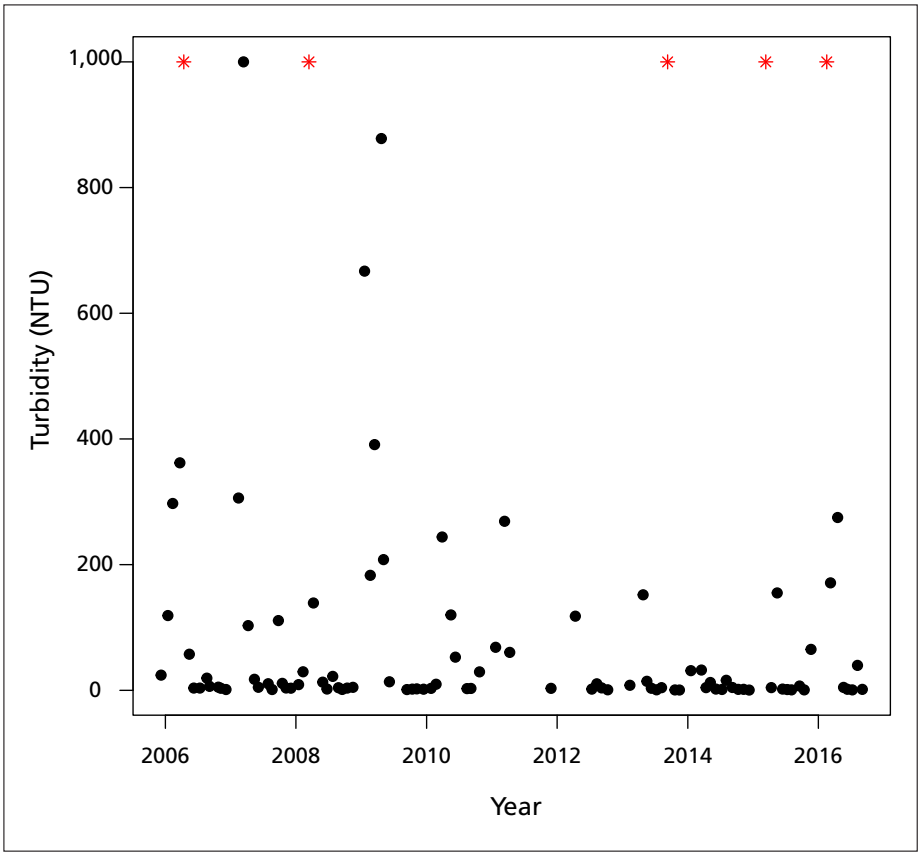


Figure 3-5. Statistically significant decrease in turbidity over time at La Verkin Creek. More than 5% of the data were censored at the reporting limit of 1,000 NTU, represented by red stars. No estimate of the slope is presented.

Table 3-2. Summary statistics for major ions at La Verkin Creek, including concentrations at the 10th, 50th, and 90th percentiles; seasonal Kendall trend results; and the number of samples that were censored.

		Sampling dates		Samples		Concentration percentile				
Parameter (mg/L)	Test	Start	End	Total #	Total censored	10th	Median	90th	p-value	Trend
Alkalinity	U	11/18/2005	9/3/2016	113	0	147	166	190	0.332	none
Calcium (d)	U	11/18/2005	9/3/2016	112	0	80.1	93.3	104	0.696	none
Chloride	>50% C	11/18/2005	9/3/2016	113	109	<10	<10	<10	–	–
Magnesium (d)	U	11/18/2005	9/3/2016	112	0	26.81	30.95	33.99	0.139	none
Potassium (d)	U	11/18/2005	9/3/2016	112	0	2.44	2.79	3.21	0.117	none
Sodium (d)	U	11/18/2005	9/3/2016	112	0	8.97	10.85	13.09	0.056	none
Sulfate	U	11/18/2005	9/3/2016	111	0	160	183	216	0.012	**down**
Total dissolved solids	U	11/18/2005	9/3/2016	113	0	414	446	503	0.216	none

U=uncensored; C=censored

Statistically significant changes are bolded.

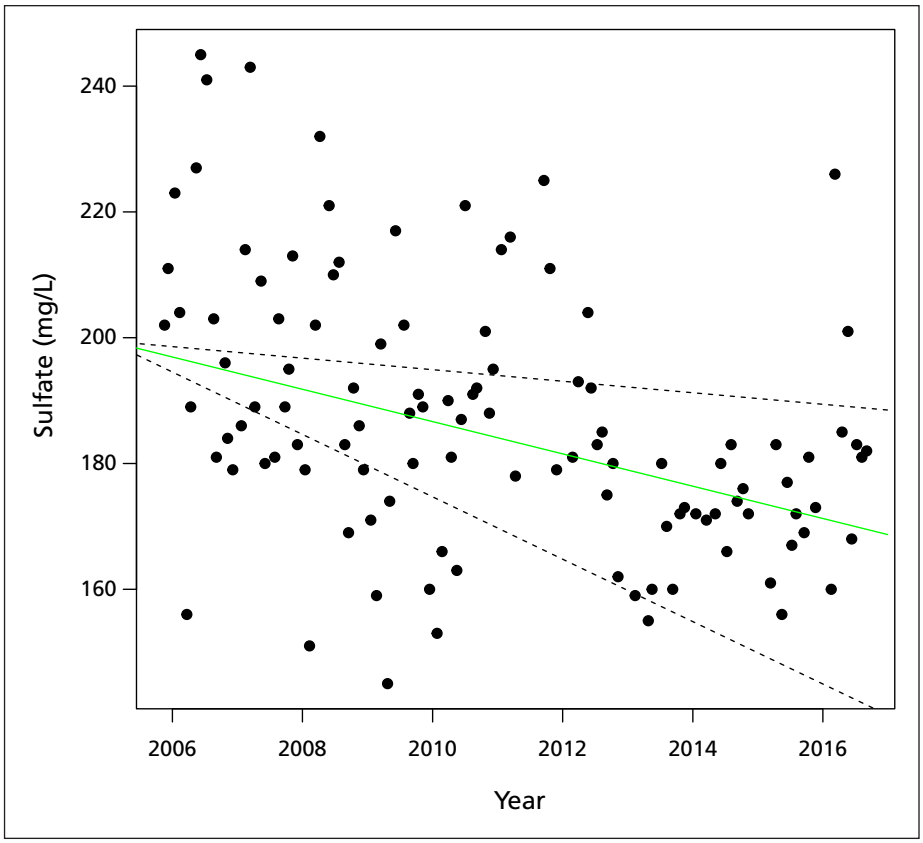


Figure 3-6. Statistically significant decline in sulfate over time at La Verkin Creek. The estimated trend of -2.8 mg/L per year is presented by a Sen slope (green line) with the 95% confidence interval of the slope estimate (dashed lines).

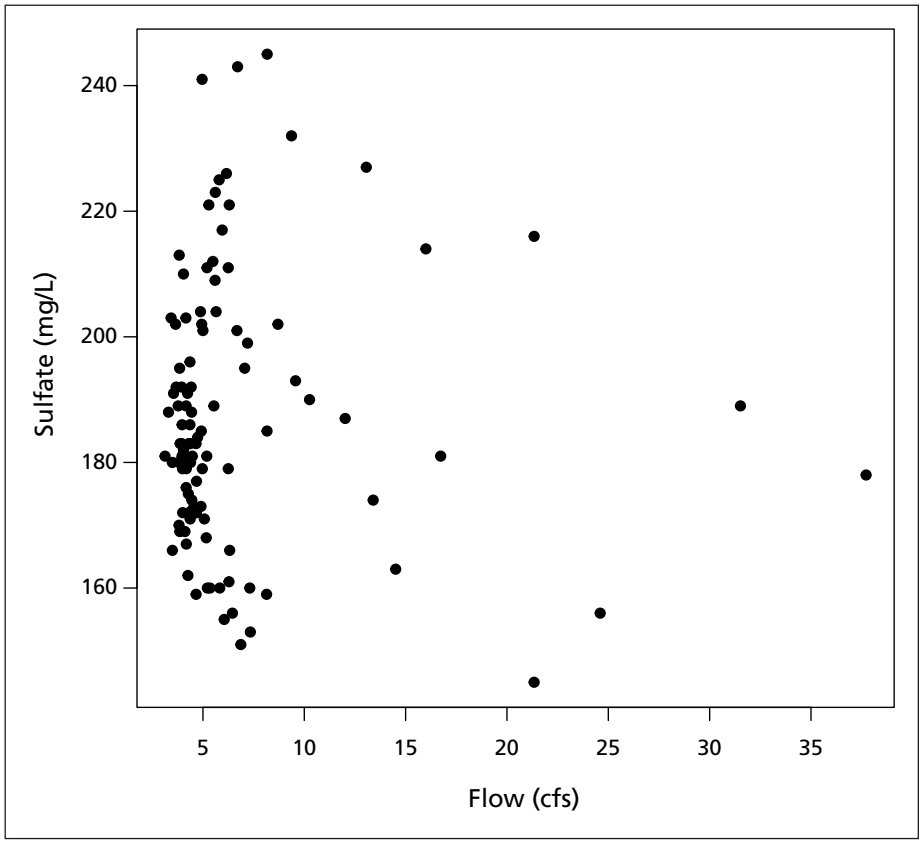


Figure 3-7. Sulfate concentrations as related to flow in La Verkin Creek.

3.1.3 Nutrients

Most nutrient concentrations on La Verkin Creek fell below analytical reporting levels (Table 3-3) and were not evaluated for trends over time. Samples exceeded the warm-water aquatic life pollution indicator of 0.05 mg/L for total phosphorus in 25% of samples (28 of 110). Phosphorus exceedances were evaluated to determine whether additional indicators of impairment, such as low dissolved oxygen or high pH, were present, indicating potential nutrient enrichment. Associated indicators of nutrient enrichment have not been observed in La Verkin Creek. The presence of phosphorus in the stream is likely due to bedrock weathering. State water-quality standards exist for ammonia. There were no exceedances found for this parameter on La Verkin Creek.

3.1.4 Trace elements

All trace elements except barium, boron, and manganese had >50% censored concentrations (Table 3-4) and were not evaluated for temporal trends. There were no statistically significant trends in barium, boron, or manganese. All trace elements except for barium and manganese have an associated State of Utah water-quality standard. No exceedances were noted.

Table 3-3. Summary statistics for nutrients at La Verkin Creek, including concentrations at the 10th, 50th, and 90th percentiles and the percent of the number of samples that were censored.

		Sampling dates		Samples		Concentration percentile		
Parameter (mg/L)	Test	Start	End	Total #	Total censored	10th	Median	90th
Ammonia as N	>50% C	7/25/2008	9/3/2016	82	82	<0.05	<0.05	<0.05
Nitrite + Nitrate as N	>50% C	11/18/2005	9/3/2016	112	93	<0.1	<0.1	0.1327
Nitrogen (d)	>50% C	9/16/2008	9/3/2016	80	68	<0.2	<0.2	0.2432
Phosphorus as P (d)	>50% C	7/25/2008	9/3/2016	78	71	<0.02	<0.02	<0.02
Total Phosphorus as P	>50% C	11/18/2005	9/3/2016	110	56	<0.02	<0.02	0.1781

C=censored

Table 3-4. Summary statistics for trace elements at La Verkin Creek, including concentrations at the 10th, 50th, and 90th percentiles; seasonal Kendall trend results; and the percent of the number of samples that were censored.

		Sampling dates		Samples		Concentration percentile				
Parameter (µg/L)	Test	Start	End	Total #	Total censored	10th	Median	90th	p-value	Trend
Aluminum (d)	>50% C	1/15/2006	7/9/2016	38	37	<30	<30	<30	–	–
Arsenic (d)	>50% C	1/15/2006	7/9/2016	39	20	<1	<1	1.136	–	–
Barium (d)	C	1/15/2006	7/9/2016	39	3	107	179	199	0.203	none
Boron (d)	U	1/15/2006	9/3/2016	41	1	37.8	52.6	69.8	0.417	none
Cadmium (d)	>50% C	1/15/2006	7/9/2016	39	39	<1	<1	<1	–	–
Chromium (d)	>50% C	1/15/2006	7/9/2016	39	39	<5	<5	<5	–	–
Copper (d)	>50% C	1/15/2006	7/9/2016	39	39	<12	<12	<12	–	–
Iron (d)	>50% C	1/15/2006	9/3/2016	41	36	<20	<20	20	–	–
Lead (d)	>50% C	1/15/2006	4/18/2016	38	38	<3	<3	<3	–	–
Manganese (d)	C	1/15/2006	4/18/2016	38	13	<5	6.9	14.4	0.65	none
Mercury (d)	>50% C	1/15/2006	7/9/2016	39	39	<0.2	<0.2	<0.2	–	–
Nickel (d)	>50% C	1/15/2006	4/18/2016	38	38	<10	<10	<10	–	–
Selenium (d)	>50% C	1/15/2006	4/18/2016	38	33	<1	<1	1.02	–	–
Silver (d)	>50% C	1/15/2006	7/9/2016	39	39	<2	<2	<2	–	–
Zinc (d)	>50% C	1/15/2006	4/18/2016	38	38	<30	<30	<30	–	–

U=uncensored; C=censored

3.2 North Creek

North Creek drains the western slopes of Horse Pasture Plateau, carving several deep, narrow canyons into the Navajo Sandstone, which is about 550 meters (1,800 ft) thick at this location (Figure 3-8). Once below the Navajo Sandstone, the creek cuts into the underlying Kayenta, Moenave, and Chinle formations, which are more easily eroded, resulting in a widening of the canyons (Figure 3-9). There are also remnants of at least two lava flows that poured down the ancestral North Creek within the last million years. The drainage is very steep, dropping 36 meters per kilometer (190 ft/mile) in the perennial reaches, and has demonstrated the energy to transport large boulders during flood events.

The North Creek watershed lies almost entirely within Zion NP. There are no significant diversions or impoundments within the park. In 1957, Blue Spring Reservoir was established on the headwaters of North Creek, one mile upstream of the park. The reservoir has a capacity of 275 acre-feet (approximately 339,000 cubic meters), or roughly 3% of the annual discharge of North Creek. The left fork of North Creek is a popular canyoneering route requiring prolonged wading and swimming in the stream.

In July 2006, a high-intensity wildfire burned 20% of the North Creek watershed. A monsoonal rainstorm the following summer triggered a flood and debris flow with a peak discharge of 13,500 cubic feet per second (cfs), or roughly 2.5 times larger than an estimated 100-year flood event for a watershed of this size and elevation (Sharrow 2013). Radar precipitation estimates from NOAA indicated two to four inches of precipitation fell on the burned portions of the watershed. The flood removed riparian vegetation, destabilized the channel, and decimated native fish from the stream (Sharrow 2013). Algal blooms were observed for several years following the flood, while some native fish were observed by 2011 (Van Grinsven et al. 2010; Hackbarth and Weissinger 2013).

3.2.1 Core parameters

Flow conditions during sampling events had no trend over time (Figure 3-10), although variability was higher earlier in the period of record. Higher flow events earlier in the record corresponded with spring runoff. Reduced snowpack in 2012 and 2013 may have resulted in lower spring peak flows during the latter part of the record.

There were no statistically significant trends in core parameters in North Creek (Table 3-5). State water-quality standards exist for dissolved oxygen, *E. coli*, pH, and water temperature. There were no exceedances of water-quality standards for dissolved oxygen. The secondary recreation criterion for *E. coli* was exceeded once (1 of 82 samples). North Creek exceeded the warm-water aquatic life standard of pH 9.0 in 21% of samples (24 of 116). The number of pH readings above 9.0 appears to have declined in the last two years (2015–2016; Figure 3-11). The warm-water aquatic life standard for water temperature was exceeded in 3% of samples (3 of 111).

3.2.2 Major ions

There were no significant trends in major ions at North Creek (Table 3-6). A site-specific state standard of 2,035 mg/L exists for total dissolved solids. There were no exceedances noted for this parameter on North Creek.

3.2.3 Nutrients

Ammonia and phosphorus concentrations in most samples fell below analytical detection limits (Table 3-7) and were not evaluated for trends over time. There were no statistically significant trends in nitrite plus nitrate or dissolved nitrogen. Total phosphorus exceeded the state water-quality pollution indicator of 0.05 mg/L in 5% of samples (6 of 111). A state water-quality standard for ammonia exists; no exceedances were observed.

3.2.4 Trace elements

Trace elements except arsenic, barium, boron, manganese, and selenium had >50% censored concentrations (Table 3-8) and were not evaluated for trends over time. There were no statistically significant trends in arsenic, barium, boron, manganese, or selenium. All trace elements except for manganese have an associated state water-quality standard. No exceedances were observed in the available sample data.

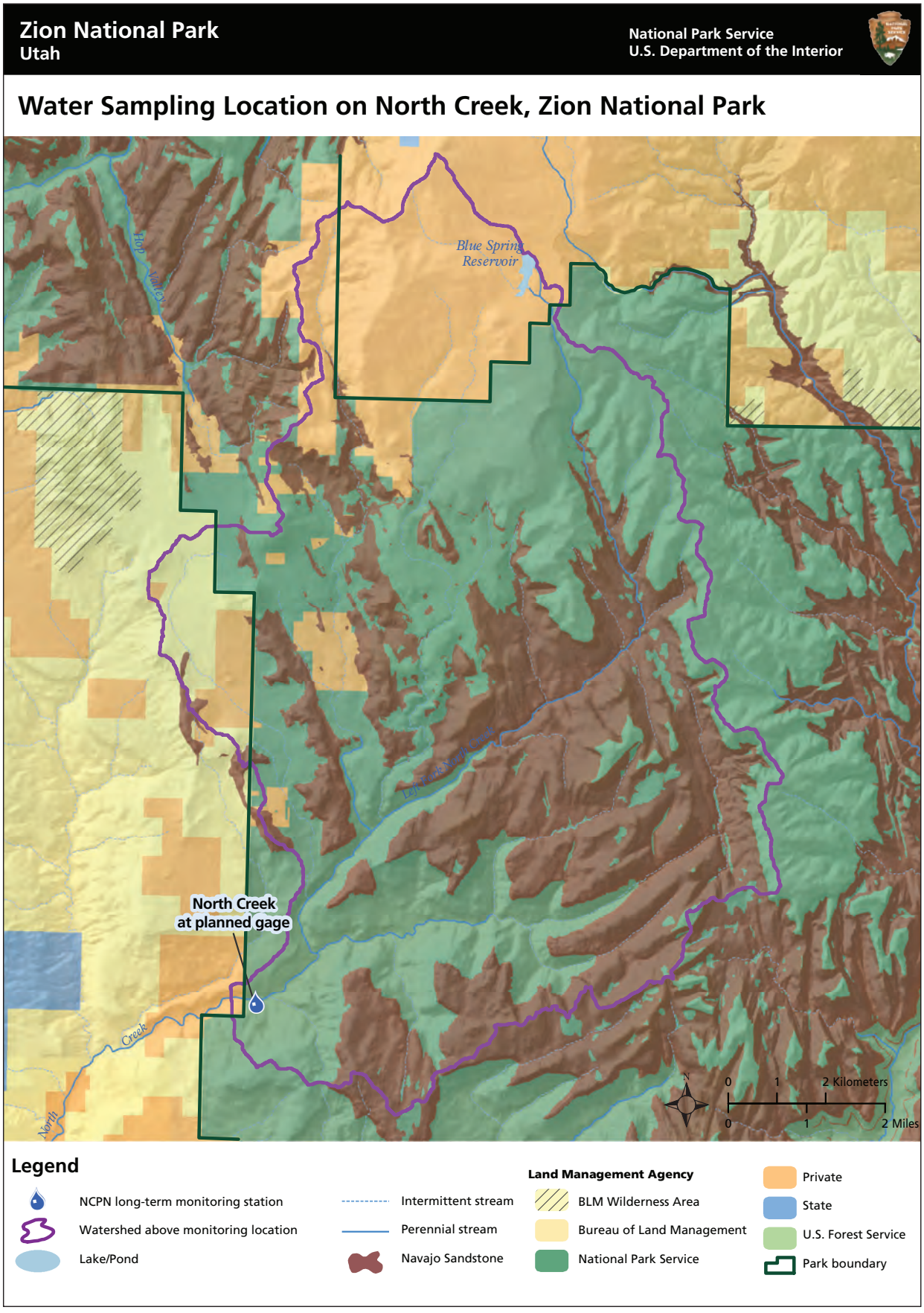


Figure 3-8. Watershed and water-sampling location on North Creek showing land ownership and Navajo Sandstone outcrops. Flow is from north to south.



Figure 3-9. The water-quality sampling location at North Creek. Photo taken June 2013.

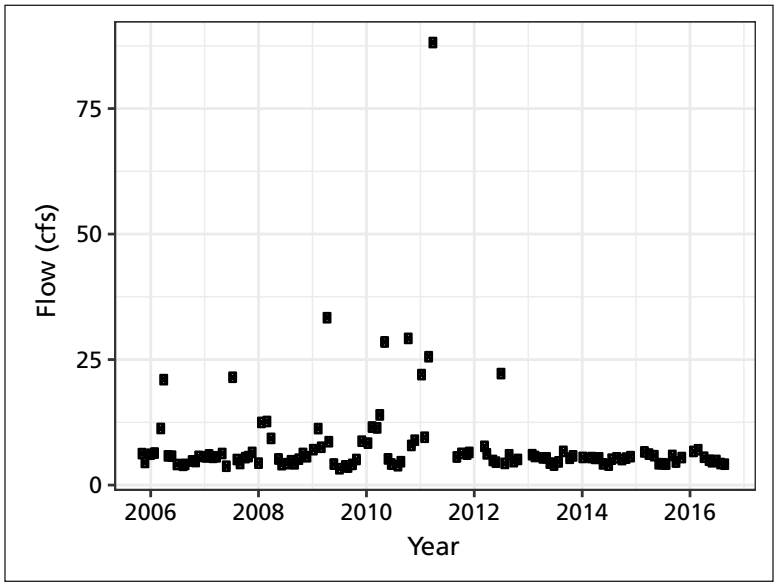


Figure 3-10. Flow recorded during monthly sample visits at North Creek.

Table 3-5. Summary statistics for core parameters at North Creek at the planned gage in the park, including concentrations at the 10th, 50th, and 90th percentiles; seasonal Kendall trend results; and the number of samples that were censored.

Parameter	Test	Sampling dates		Samples		Concentration percentile			p-value	Trend
		Start	End	Total #	Total censored	10th	Median	90th		
Dissolved oxygen (mg/L)	U	11/17/2005	9/6/2016	101	0	7.38	8.68	10.79	0.086	none
Dissolved oxygen saturation (%)	U	1/14/2006	9/6/2016	100	0	101.8	105.4	110.6	0.32	none
Escherichia coli (MPN/100 mL)	C	6/8/2006	9/6/2016	82	28	<1	2	14.51	0.695	none
Flow (cfs)	U	11/17/2005	9/6/2016	117	0	4.11	5.50	11.92	0.737	none
pH	U	11/17/2005	9/6/2016	116	0	8.40	8.72	9.09	0.776	none
Specific conductance (µS/cm)	U	11/17/2005	9/6/2016	108	0	284.89	366.07	398.33	0.809	none
Turbidity (NTU)	U	12/7/2005	9/6/2016	101	0	0.95	2.43	22.5	0.36	none
Water temperature (°C)	U	11/17/2005	9/6/2016	111	0	6.73	16.71	25.71	0.077	none

U=uncensored; C=censored

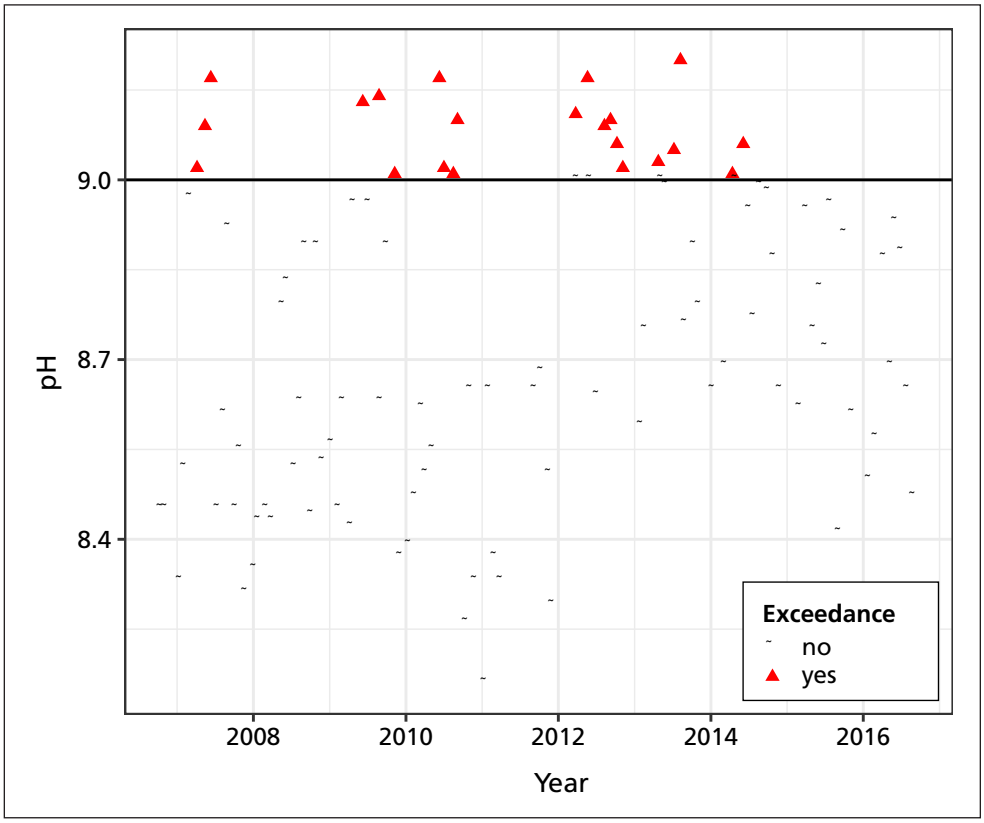


Figure 3-11. pH over time at North Creek. Values in red exceeded the Utah water-quality standard of 9.0.

Table 3-6. Summary statistics for major ions at North Creek, including concentrations at the 10th, 50th, and 90th percentiles; seasonal Kendall trend results; and the number of samples that were censored.

		Sampling dates		Samples		Concentration percentile				
Parameter (mg/L)	Test	Start	End	Total #	Total censored	10th	Median	90th	p-value	Trend
Alkalinity	U	11/17/2005	9/6/2016	116	0	107	141	160	0.413	none
Calcium (d)	U	11/17/2005	9/6/2016	115	0	25.54	34.3	38.72	0.108	none
Chloride	>50% C	11/17/2005	9/6/2016	115	114	<10	<10	<10	–	–
Magnesium (d)	U	11/17/2005	9/6/2016	115	0	12.12	16.70	18.52	0.855	none
Potassium (d)	U	11/17/2005	9/6/2016	115	0	2.15	3.02	3.40	0.897	none
Sodium (d)	U	11/17/2005	9/6/2016	115	0	13.54	17.60	21.30	0.908	none
Sulfate	U	11/17/2005	9/6/2016	115	5	26.2	35.1	48.7	0.812	none
Total dissolved solids	U	11/17/2005	9/6/2016	116	0	162	210	234	0.603	none

U=uncensored; C=censored

Table 3-7. Summary statistics for nutrients at North Creek, including concentrations at the 10th, 50th, and 90th percentiles; seasonal Kendall trend results; and the number of samples that were censored.

		Sampling dates		Samples		Concentration percentile				
Parameter (mg/L)	Test	Start	End	Total #	Total censored	10th	Median	90th	p-value	Trend
Ammonia as N	>50% C	7/26/2008	9/6/2016	84	82	<0.05	<0.05	<0.05	–	–
Nitrite + Nitrate as N	U	11/17/2005	9/6/2016	115	2	0.3300	0.5970	0.7412	0.21	none
Nitrogen (d)	U	8/23/2008	9/6/2016	83	1	0.4438	0.6550	0.8472	1	none
Phosphorus as P (d)	>50% C	7/26/2008	9/6/2016	79	73	<0.02	<0.02	<0.02	–	–
Total Phosphorus as P	>50% C	11/17/2005	9/6/2016	111	94	<0.02	<0.02	0.045	–	–

U=uncensored; C=censored

Table 3-8. Summary statistics for trace elements at North Creek, including concentrations at the 10th, 50th, and 90th percentiles; seasonal Kendall trend results; and the number of samples that were censored.

		Sampling dates		Samples		Concentration percentile				
Parameter (µg/L)	Test	Start	End	Total #	Total censored	10th	Median	90th	p-value	Trend
Aluminum (d)	>50% C	1/14/2006	7/11/2016	36	33	<30	<30	<30	–	–
Arsenic (d)	C	1/14/2006	7/11/2016	37	2	1.89	2.77	3.94	0.778	none
Barium (d)	U	1/14/2006	7/11/2016	37	1	123	209	237	0.781	none
Boron (d)	U	1/14/2006	9/6/2016	39	1	46.2	68.3	82.2	0.958	none
Cadmium (d)	>50% C	1/14/2006	7/11/2016	37	37	<1	<1	<1	–	–
Chromium (d)	>50% C	1/14/2006	7/11/2016	37	37	<5	<5	<5	–	–
Copper (d)	>50% C	1/14/2006	7/11/2016	37	37	<12	<12	<12	–	–
Iron (d)	>50% C	1/14/2006	9/6/2016	39	30	<20	<20	40.62	–	–
Lead (d)	>50% C	1/14/2006	4/19/2016	36	36	<3	<3	<3	–	–
Manganese (d)	C	1/14/2006	4/19/2016	36	8	<5	6.2	20.5	0.219	none
Mercury (d)	>50% C	1/14/2006	7/11/2016	37	37	<0.2	<0.2	<0.2	–	–
Nickel (d)	>50% C	1/14/2006	4/19/2016	36	36	<10	<10	<10	–	–
Selenium (d)	C	1/14/2006	4/19/2016	35	13	<1	1.2	1.74	0.071	none
Silver (d)	>50% C	1/14/2006	7/11/2016	37	37	<2	<2	<2	–	–
Zinc (d)	>50% C	1/14/2006	4/19/2016	36	36	<30	<30	<30	–	–

U=uncensored; C=censored

3.2.5 North Creek response to wildfire

Despite a lack of statistically significant trends in water-quality parameters using the seasonal Kendall test, there has been a visual improvement in water quality since the Kolob Fire, with a reduction in algal blooms. There were insufficient samples taken before the fire to compare pre- and post-fire data. However, when inspecting graphs of parameters over time, the magnitude of departures from the median often seems greater just after the fire than later in the dataset. Because the seasonal Kendall test only ranks parameters as above or below the median, it is insensitive to the magnitude of those departures. We hypothesized that the magnitude of departures from the median were decreasing over time, such that high concentrations were decreasing and low concentrations were increasing.

To investigate the change in high and low concentrations over time, we performed quantile regression on datasets with <5% censored data at the 0.9 quantile for all parameters and at the 0.1 quantile for dissolved oxygen, dissolved oxygen saturation, and pH (Table 3-9). These quantiles were selected to correspond to the State of Utah's percentiles for determining exceedances of water-quality standards and as useful proxies for high and low water-quality concentrations in the stream. The analysis was performed using the quantreg package in R (Koenker 2017).

Quantile regression is a form of linear regression that estimates the conditional quantile (e.g., the median or the 90th percentile) rather than the mean of the dataset (Koenker and Bassett 1978). It is especially useful when variability in the dataset changes over time, as in many ecological datasets (Cade and Noon 2003). We converted each sample date to a decimal number of years since fire, then analyzed a model of the form y = concentration ~ years since fire. Standard errors and p-values were estimated by bootstrapping with 10,000 iterations (Rogers 1992). Bootstrapping uses the distribution of the dataset to generate the likelihood of a trend occurring, rather than an assumed distribution. As such, we used a likelihood of 0.9 (p = 0.1) to indicate a likely trend in the quantile regression.

Table 3-9. Quantile regression results at the 0.9 and 0.1 quantiles for uncensored parameters at North Creek.

Parameter	0.9 quantile		0.1 quantile	
	p-value	Trend	p-value	Trend
Alkalinity (mg/L)	**<0.001**	**down**	–	–
Barium (d) (µg/L)	0.17	none	–	–
Boron (d) (µg/L)	0.12	none	–	–
Calcium (d) (mg/L)	0.69	none	–	–
Dissolved oxygen (mg/L)	0.20	none	0.34	none
Dissolved oxygen saturation (%)	0.34	none	0.12	none
Flow (cfs)	0.18	none	–	–
Magnesium (d) (mg/L)	0.91	none	–	–
Nitrite + Nitrate as N (mg/L)	0.15	none	–	–
Nitrogen (d) (mg/L)	**0.06**	**down**	–	–
pH	**0.16**	**none**	**0.05**	**up**
Potassium (d) (mg/L)	0.68	none	–	–
Sodium (d) (mg/L)	0.31	none	–	–
Specific conductance (µS/cm)	**0.03**	**down**	–	–
Sulfate (mg/L)	0.60	none	–	–
Water temperature (°C)	**0.04**	**up**	–	–
Total dissolved solids (mg/L)	0.65	none	–	–
Turbidity (NTU)	0.21	none	–	–

Trends with a 90% or greater likelihood are bolded. At the 0.1 quantile, only parameters with associated water quality standards at that quantile were analyzed for trend.

Decreases in the 0.9 quantile, equivalent to the 90th percentile, were noted for alkalinity (slope = -2.84; Figure 3-12), nitrogen (slope = -0.022; Figure 3-13), and specific conductance (slope = -3.186; Figure 3-14). These are all consistent with the hypothesis that the highest concentrations in the dataset are decreasing as time goes on. The decrease in nitrogen may have corresponded to a drop below a critical threshold for eutrophication in the stream, although nitrate plus nitrite did not show a corresponding statistically significant decline at the 0.9 quantile.

Water temperature increased at the 0.9 quantile (slope = 0.403; Figure 3-15), which is not typical for post-fire recovery. In forested systems, water temperatures tend to decrease over time after a fire as vegetation canopy cover regrows and shades the stream. However, North Creek is in a semi-arid region that is prone to flash flooding, and there has been little regrowth of shade trees since the Kolob Fire. A closed canopy is not expected even under optimal conditions. Water temperatures are closely tied to air temperatures, which have warmed in recent years (Monahan and Fisichelli 2014). It is likely that the increase in water temperature noted at North Creek is linked to climate rather than a response to wildfire.

At the 0.1 quantile, equivalent to the 10th percentile, pH increased over time (slope = 0.019; Figure 3-16). This corroborates the hypothesis that low values are increasing over time, but there was no corresponding statistically significant decrease in pH at the 0.9 quantile.

Most parameters did not show statistically significant trends at high concentrations corresponding to the 0.9 quantile (see Table 3-9). It is surprising that more parameters do not show a trend following such a large disturbance as the fire and flood events of 2006 and 2007. The most disturbed conditions may occur during high-flow events, which are not captured in our samples.

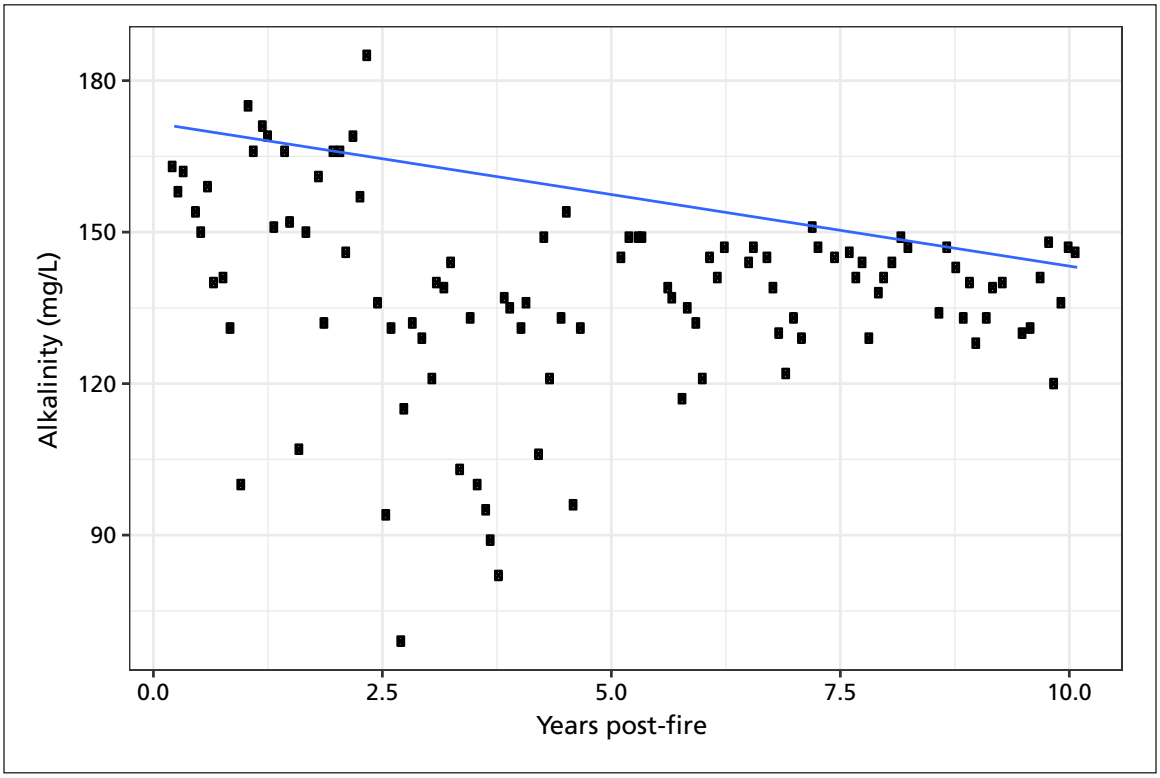


Figure 3-12. Decrease in the 0.9 quantile in alkalinity at North Creek over time.

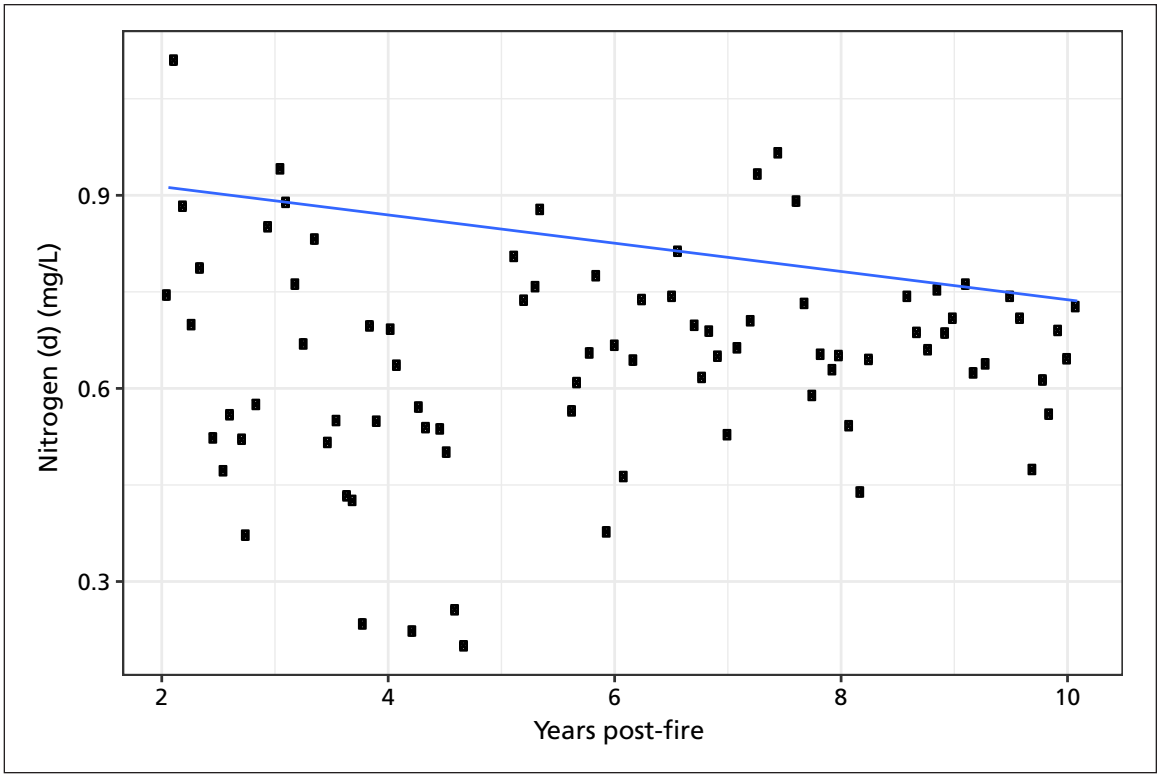


Figure 3-13. Decrease in the 0.9 quantile in nitrogen at North Creek over time. Nitrogen was introduced to the analytical suite in July 2008, so data for the first two years after the fire were not available.

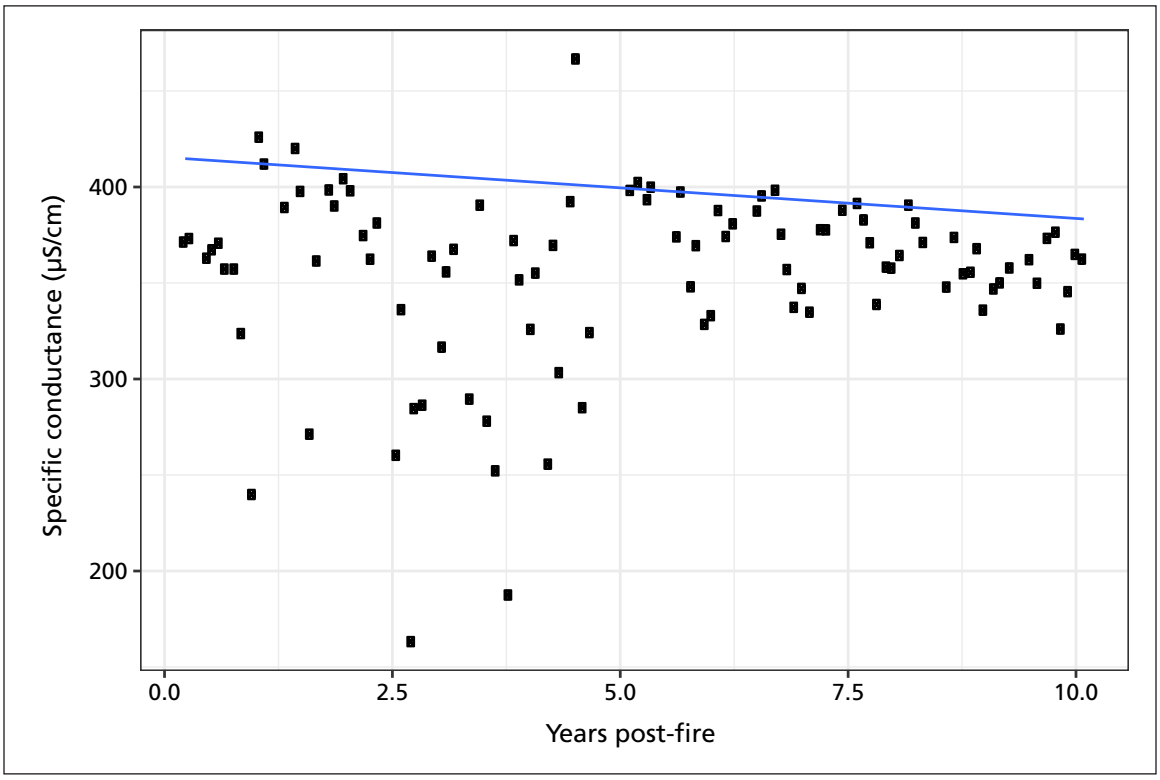


Figure 3-14. Decrease in the 0.9 quantile for specific conductance at North Creek over time.

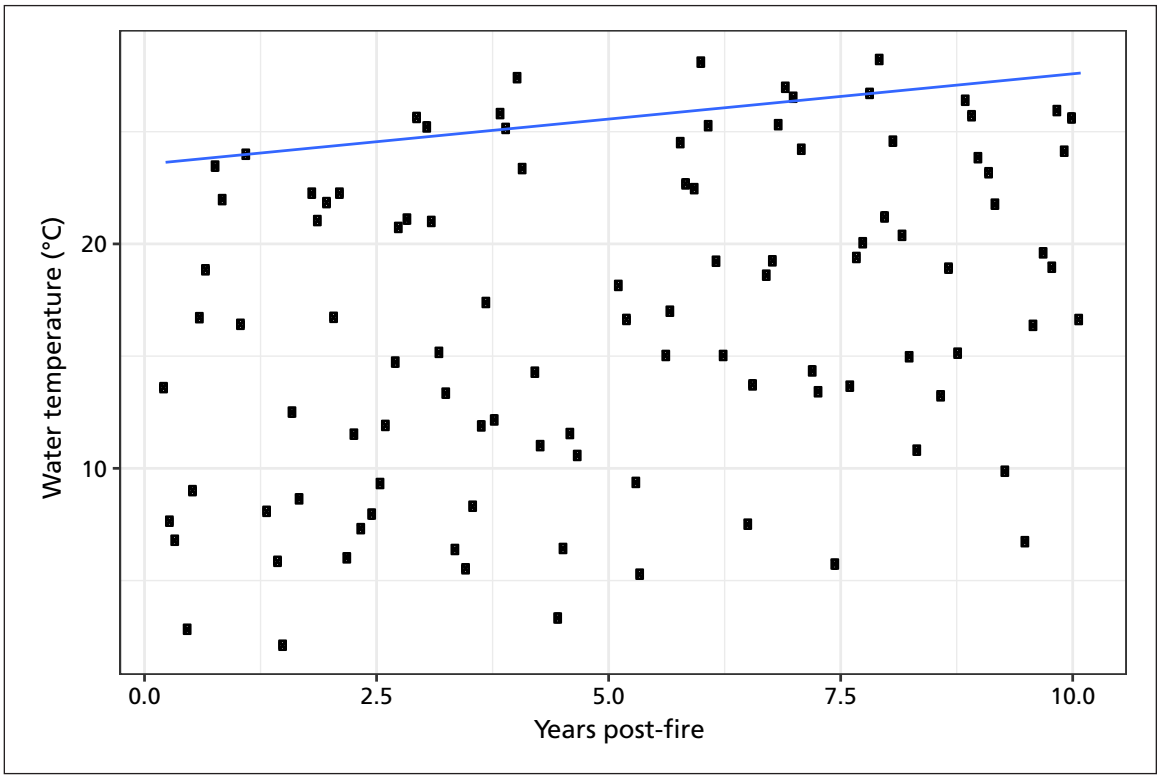


Figure 3-15. Increase in the 0.9 quantile for water temperature at North Creek over time.

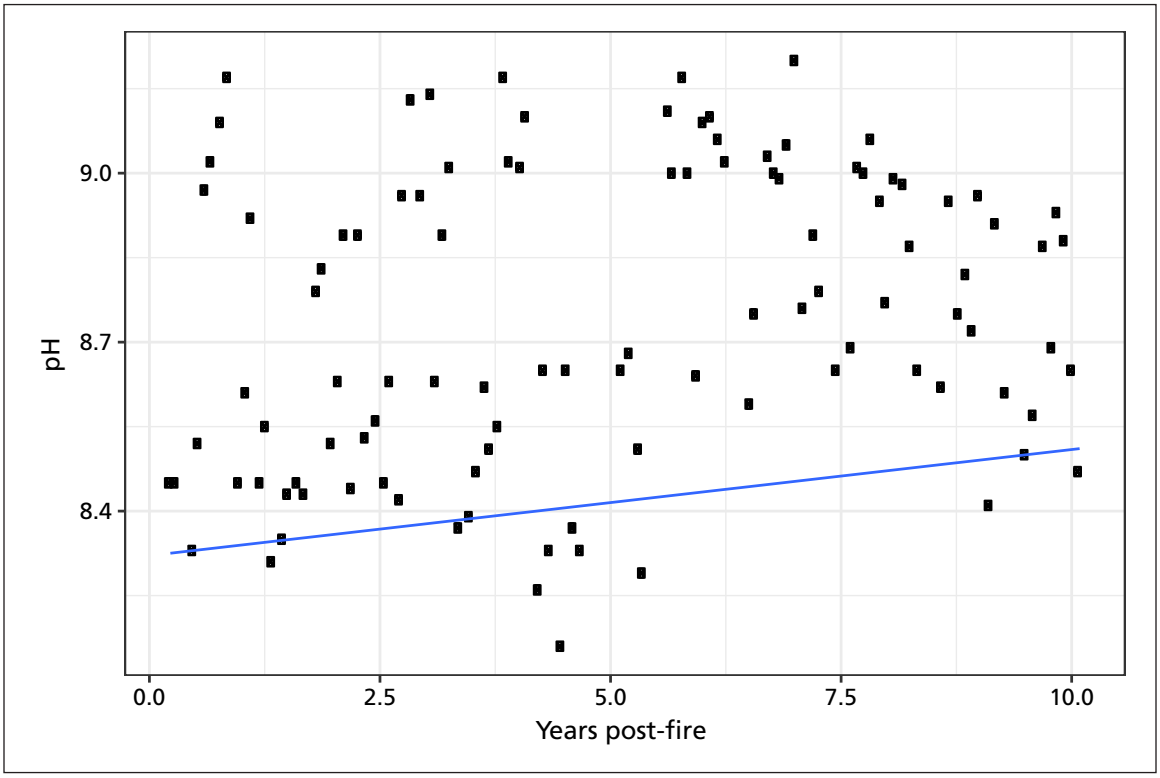


Figure 3-16. Increase in the 0.1 quantile for pH at North Creek over time.

3.3 North Fork Virgin River at the Wilderness Study Area boundary

The North Fork Virgin River is a major tributary to the Virgin River. Its headwaters lie at 3,050 meters (10,000 ft) in elevation along the edge of the Markagunt Plateau, and include subsurface drainage from Navajo Lake, a natural lake with engineered controls on water delivery. Waters from Navajo Lake and other portions of the plateau contribute to natural spring discharges from the Claron Formation limestone and underlying strata that support perennial streams in at least eight tributaries of the Virgin River.

The North Fork is one of the larger tributaries. It flows through a mix of private (83%), Bureau of Land Management (12%), U.S. Forest Service (3%), and state lands (2%) for 13 miles before reaching the sample site just upstream from the park (Figure 3-17; see also Figure 1-1). Streamflow upstream of the park is a small portion (~22%) of the flow measured downstream in Zion Canyon, which is augmented by several tributaries and the substantial discharge of numerous springs discharging from the Navajo Sandstone. Consumptive use of water upstream from the park amounts to about 6% of the average annual discharge. Most of this occurs as summer diversions for irrigation, livestock water, and private residences. In exceptionally dry years, the upper portion of the North Fork Virgin River above the park boundary can be completely dewatered.

The sampling location on the North Fork Virgin River is located upstream from the park, at a Wilderness Study Area (WSA) boundary, to monitor water conditions flowing into the park (Figure 3-18). This area is the trailhead for one of the most popular wading backpacking trips in the park, the Zion Narrows. Just upstream of the WSA site, the river runs through a patchwork of federal, state, and private land. Flood irrigation of cattle pastures adjacent to the stream has led to an impaired listing for fecal indicator bacteria by the State of Utah (Van Grinsven et al. 2010; Hackbarth and Weissinger 2013; Hackbarth and Weissinger 2016). Intensive monitoring by the park, NCPN, and UDWQ has demonstrated that the source of the problem is excessive runoff of irrigation water from these pastures, which carries cattle feces into the stream (Sharrow 2012a). Combined data from the NCPN and park found that when the pastures were irrigated and cattle were present, the *E. coli* standard was exceeded in 82% of 44 samples (Sharrow 2012a).

The segment of the river from the WSA through Zion NP is listed as an impaired water by the State of Utah, and is the highest-priority non-point pollution impairment in the state (UDWQ 2016). The park, state, and other parties are working together on suitable management actions to improve stream-water quality. Zion NP worked with the Bureau of Land Management and State of Utah to install a pit toilet for hikers beginning their trip into the Narrows. A monitoring weir has been installed on the irrigation channel to ensure that water usage remains compliant with the established water right. In addition, different grazing and temporary fencing alternatives are being attempted to reduce pasture runoff into the stream. Finding a solution, however, is made difficult by the remote location (irrigators must drive over an hour to reach the site and it may be unreachable for days during wet weather), lack of electric power (making automated irrigation controls difficult), and the relatively small number of livestock, which makes for a very high cost per animal.

The state is also studying stream-water temperatures to determine whether the segment is more accurately classified as a warm-water stream, given its warm desert setting within this segment. NPS has a primary concern for native fish in this reach, which have a higher thermal tolerance than the exotic salmonids for which the current cold-water fishery designation is based, and would support this reclassification if the data warrant it.

3.3.1 Core parameters

Flow conditions during sampling events had no trend over time (Figure 3-19). Flows increased through 2012, probably because the dike that impounds water at Navajo Lake was breached. Flows may have been reduced in 2013, as the dike was repaired and the lake refilled. Lower snowpacks in 2012 and 2013 may also have contributed to reduced flows.

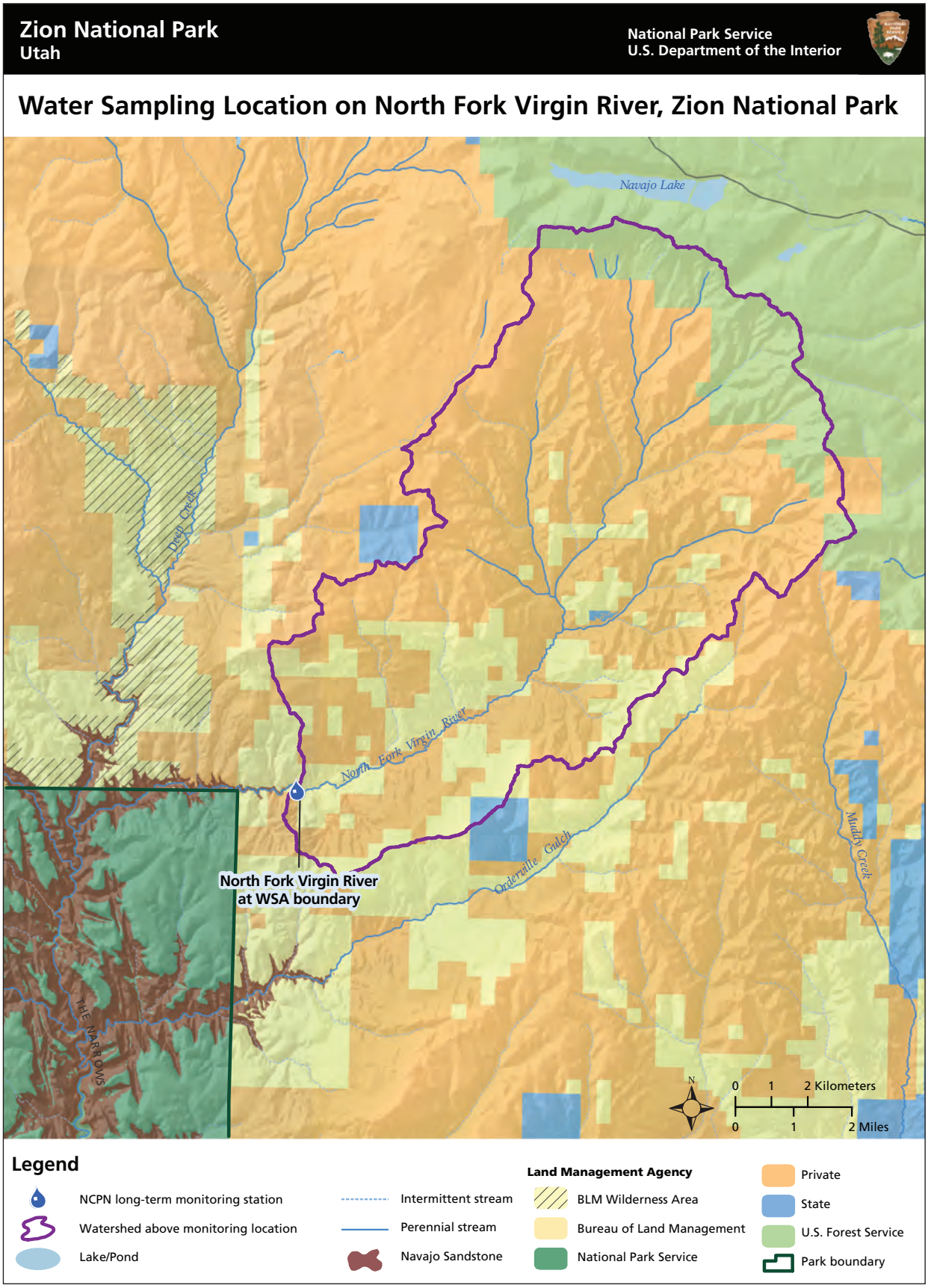


Figure 3-17. Watershed and water-quality sampling location on the upper North Fork Virgin River showing land ownership and Navajo Sandstone outcrops. Flow is from the northeast to the southwest, with the Narrows beginning near the southwestern corner of the map.



Figure 3-18. The water-quality sampling location at North Fork Virgin River near the Wilderness Study Area boundary. Photo taken July 2008.

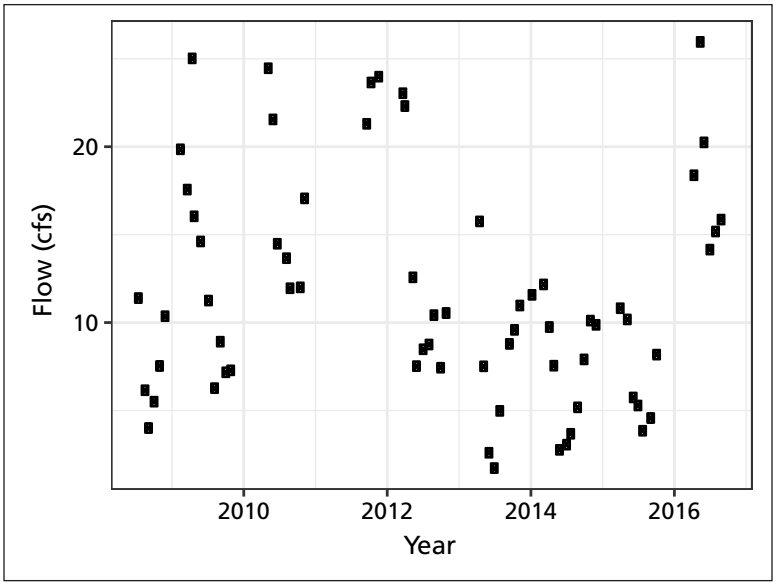


Figure 3-19. Flow recorded during monthly sample visits at North Fork Virgin River at the Wilderness Study Area boundary.

There were no statistically significant trends in core parameters (Table 3-10). State standards exist for dissolved oxygen, *E. coli*, pH, and water temperature. The state water-quality standard for dissolved oxygen was exceeded once (1 of 64 samples). The site exceeded the chronic primary recreation standard for *E. coli* (126 MPN/100 mL) for 27% of samples (15 of 55; Figure 3-20) and the cold-water aquatic life standard for water temperature (20°C) for 25% of samples (17 of 67; Figure 3-21). There were no exceedances of state water-quality standards for pH.

Though a long-term trend was not identified in *E. coli*, a clear seasonal pattern is present each year (Sharrow 2012a). *E. coli* levels are typically very low during the fall and early spring (and presumably winter), when cattle are not present and irrigation is not occurring. The levels are much higher during the summer irrigation season, often exceeding the chronic exposure standard when cattle are present and irrigation is occurring, and often falling below the standard when irrigation ceases—even if cattle remain on the pastures and have unrestricted access to the stream (Figure 3-22).

3.3.2 Major ions

There were no significant trends in major ion concentrations (Table 3-11). A state water-quality standard for total dissolved solids exists; no exceedances were noted.

3.3.3 Nutrients

Nutrient concentrations mostly fell below analytical reporting limits (Table 3-12) and were not evaluated for trend over time. Total phosphorus exceeded the state pollution indicator of 0.05 mg/L on 6% of sample visits (4 of 65). Phosphorus exceedances are evaluated to determine whether additional indicators of impairment, such as low dissolved oxygen or high pH, are present, indicating potential nutrient enrichment. Associated indicators of nutrient enrichment have not been observed, and the presence of phosphorus in the stream is likely due to natural sources. A state water-quality standard for ammonia exists; no exceedances were noted.

3.3.4 Trace elements

Trace element concentrations mostly fell below analytical reporting limits (Table 3-13) and were not evaluated for trends over time. All trace elements except for manganese have an associated state water-quality standard; there were no exceedances noted.

Table 3-10. Summary statistics for core parameters at North Fork Virgin River at WSA boundary, including concentrations at the 10th, 50th, and 90th percentiles; seasonal Kendall trend results; and the number of samples that were censored.

		Sampling dates		Samples		Concentration percentile				
Parameter	Test	Start	End	Total #	Total censored	10th	Median	90th	p-value	Trend
Dissolved oxygen (mg/L)	U	7/24/2008	9/5/2016	64	0	7.18	8.39	10.49	0.084	none
Dissolved oxygen saturation (%)	U	7/24/2008	9/5/2016	64	0	100.5	102.5	104.9	0.118	none
Escherichia coli (MPN/100 mL)	C	8/27/2008	9/5/2016	55	6	<1	37.9	387.32	0.09	none
Flow (cfs)	U	7/24/2008	9/5/2016	67	0	4.16	10.42	21.85	1	none
pH	U	7/24/2008	9/5/2016	67	0	8.34	8.49	8.60	0.903	none
Specific conductance (µS/cm)	U	7/24/2008	9/5/2016	64	0	387.83	465.99	545.08	0.887	none
Turbidity (NTU)	U	7/24/2008	9/5/2016	58	0	3.20	8.14	51.96	0.418	none
Water temperature (°C)	U	7/24/2008	9/5/2016	67	0	4.84	14.71	23.27	0.282	none

U=uncensored; C=censored

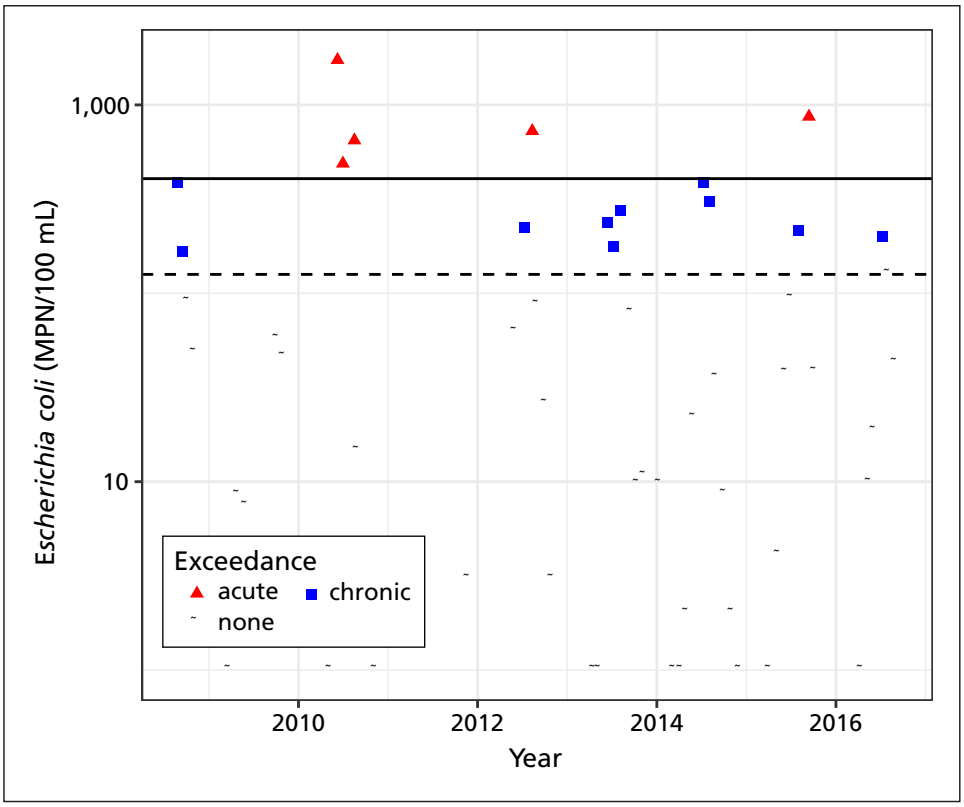


Figure 3-20. Exceedances of the chronic and acute primary recreation standard for *E. coli* in the North Fork Virgin River at the Wilderness Study Area boundary. Only NCPN bacteria data are included in this graph. Additional data have been collected by the park and the State of Utah as reported in Sharrow (2012a) and (2012b).

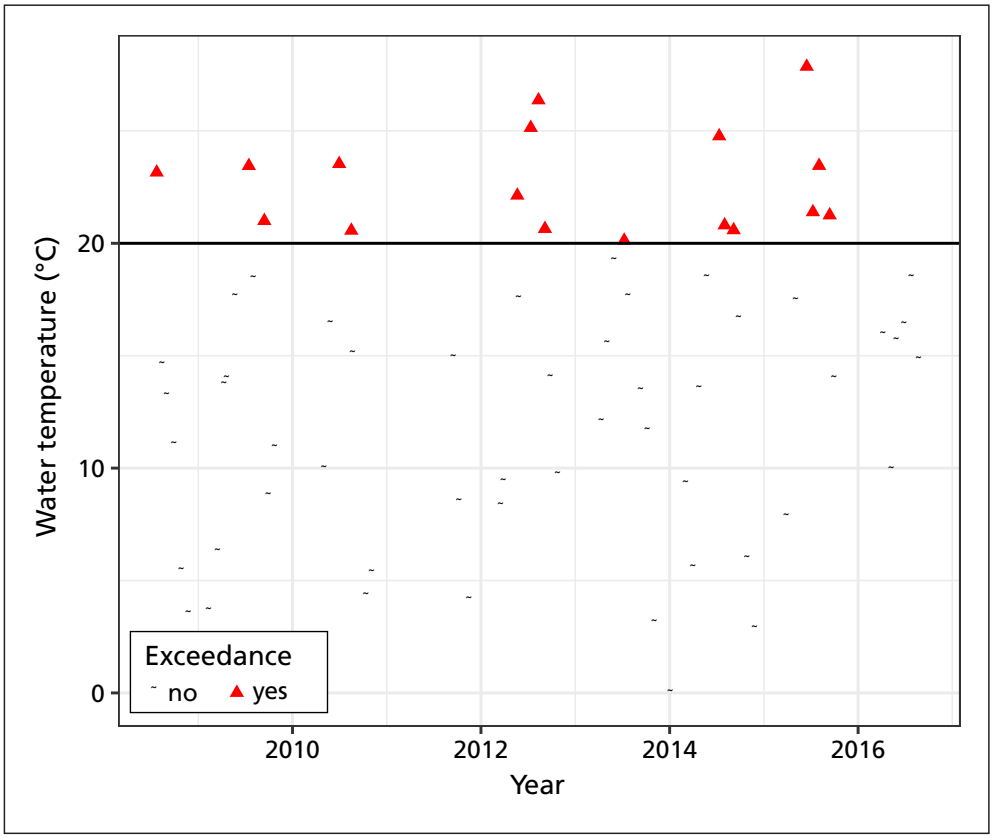


Figure 3-21. Exceedances of the state cold-water aquatic life standard of 20°C in the North Fork Virgin River at the Wilderness Study Area boundary. The state is evaluating whether the stream is more appropriately classified as a warm-water stream.

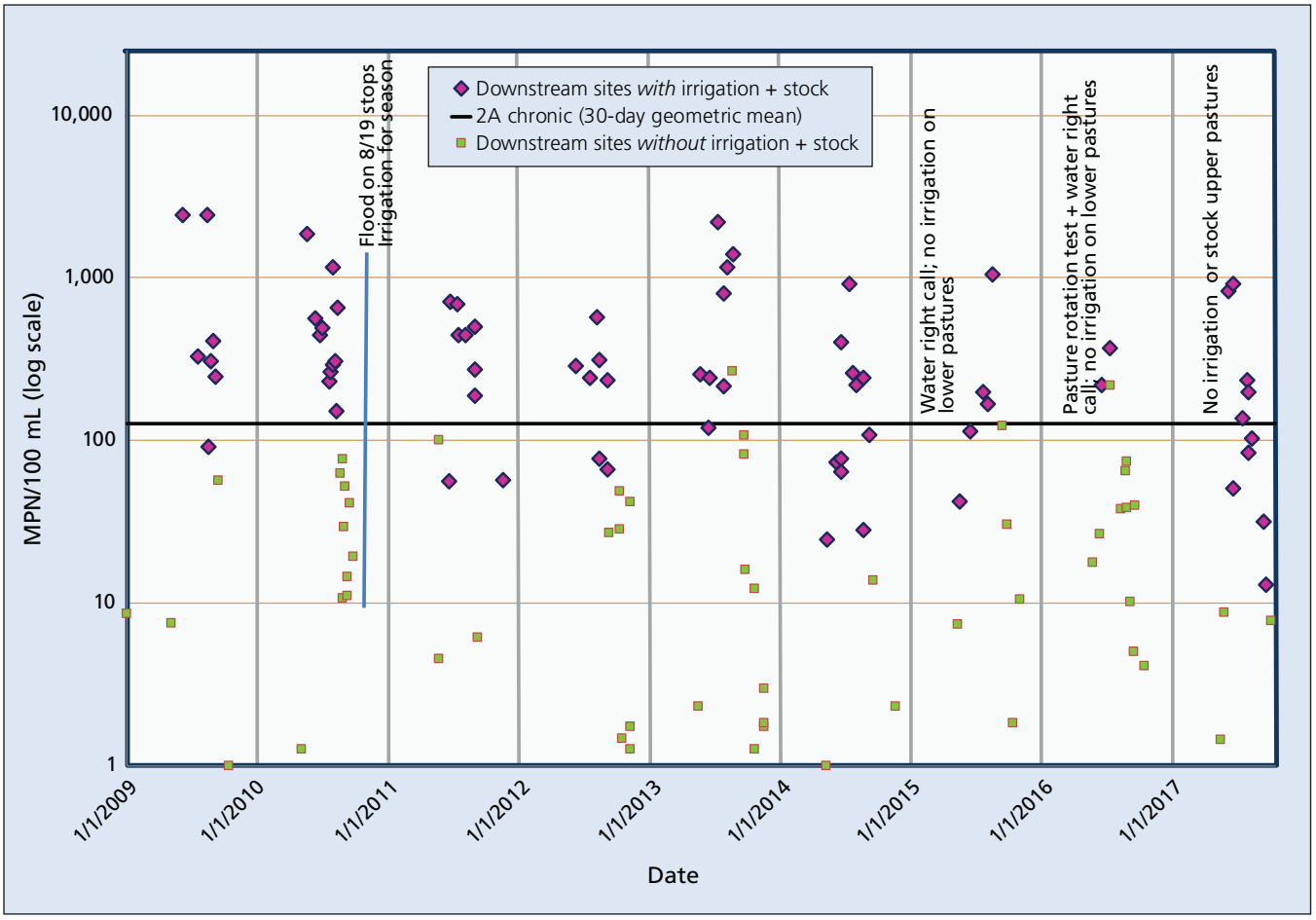


Figure 3-22. All fecal indicator bacteria data collected during the recreation season (May through September) for collection sites on the North Fork Virgin River downstream of pastures and upstream of the Narrows, including NCPN, park, and state samples. Note that exceedances of the 2A chronic standard are common when irrigation and livestock are both present on pastures, but uncommon when one or both are absent.

Table 3-11. Summary statistics for major ions at North Fork Virgin River at WSA boundary, including concentrations at the 10th, 50th, and 90th percentiles; seasonal Kendall trend results; and the number of samples that were censored.

		Sampling dates		Samples		Concentration percentile				
Parameter (mg/L)	Test	Start	End	Total #	Total censored	10th	Median	90th	p-value	Trend
Alkalinity	U	7/24/2008	9/5/2016	66	0	181	195	214	0.753	none
Calcium (d)	U	7/24/2008	9/5/2016	65	0	50.24	58.50	64.90	1	none
Chloride	>50% C	7/24/2008	9/5/2016	66	66	<10	<10	<10	–	–
Magnesium (d)	U	7/24/2008	9/5/2016	65	0	20.04	24.70	28.66	0.843	none
Potassium (d)	C	7/24/2008	9/5/2016	65	11	<1	1.27	1.89	0.482	none
Sodium (d)	U	7/24/2008	9/5/2016	65	0	4.74	8.31	10.90	0.887	none
Sulfate	U	7/24/2008	9/5/2016	66	3	25.4	39.9	64.9	0.371	none
Total dissolved solids	U	7/24/2008	9/5/2016	66	0	218	257	305	0.578	none

U=uncensored; C=censored

Table 3-12. Summary statistics for nutrients at North Fork Virgin River at WSA boundary, including concentrations at the 10th, 50th, and 90th percentiles and the number of samples that were censored.

		Sampling dates		Samples		Concentration percentile		
Parameter (mg/L)	Test	Start	End	Total #	Total censored	10th	Median	90th
Ammonia as N	>50% C	7/24/2008	9/5/2016	66	66	<0.05	<0.05	<0.05
Nitrite + Nitrate as N	>50% C	7/24/2008	9/5/2016	65	60	<0.1	<0.1	<0.1
Nitrogen (d)	>50% C	7/24/2008	9/5/2016	65	61	<0.2	<0.2	<0.2
Phosphorus as P (d)	>50% C	7/24/2008	9/5/2016	65	64	<0.02	<0.02	<0.02
Total Phosphorus as P	>50% C	7/24/2008	9/5/2016	65	45	<0.02	<0.02	0.0456

U=uncensored; C=censored

Table 3-13. Summary statistics for trace elements at North Fork Virgin River at WSA boundary, including concentrations at the 10th, 50th, and 90th percentiles and the number of samples that were censored.

		Sampling dates		Samples		Concentration percentile		
Parameter (µg/L)	Test	Start	End	Total #	Total censored	10th	Median	90th
Aluminum (d)	>50% C	10/12/2008	7/10/2016	21	21	<10	<10	<10
Arsenic (d)	>50% C	7/24/2008	7/10/2016	22	21	<1	<1	<1
Barium (d)	>50% C	7/24/2008	7/10/2016	22	17	<100	<100	104
Boron (d)	>50% C	7/24/2008	9/5/2016	24	22	<30	<30	<30
Cadmium (d)	>50% C	7/24/2008	7/10/2016	22	22	<0.1	<0.1	<0.1
Chromium (d)	>50% C	7/24/2008	7/10/2016	22	22	<2	<2	2.469
Copper (d)	>50% C	7/24/2008	7/10/2016	22	22	<1	<1	<1
Iron (d)	>50% C	7/24/2008	9/5/2016	24	21	<20	<20	<20
Lead (d)	>50% C	7/24/2008	4/20/2016	21	21	<0.1	<0.1	<0.1
Manganese (d)	>50% C	7/24/2008	4/20/2016	21	17	<5	<5	5.1
Mercury (d)	>50% C	7/24/2008	7/10/2016	22	22	<0.2	<0.2	<0.2
Nickel (d)	>50% C	7/24/2008	4/20/2016	21	21	<5	<5	<5
Selenium (d)	>50% C	7/24/2008	4/20/2016	21	21	<1	<1	<1
Silver (d)	>50% C	7/24/2008	7/10/2016	22	22	<0.5	<0.5	<0.5
Zinc (d)	>50% C	7/24/2008	4/20/2016	21	21	<10	<10	<10

C=censored

3.4 Supporting sites

Two sites sampled by the USGS had enough data to evaluate for this report: North Fork Virgin River near Springdale (09405500), located at a gaging station inside the park, and Virgin River near Virgin (09406000), downstream of the park. Only a few parameters had sufficient data for analysis, including specific conductance and water temperature at both stations, and dissolved oxygen and turbidity at the Virgin River station. There were no trends in any of the parameters (Tables 3-14 and 3-15). State water-quality standards exist for dissolved oxygen and water temperature. Dissolved oxygen and water temperature did not exceed the state warm-water aquatic-life criteria at the Virgin River site. Exceedances of the cold-water aquatic-life criterion for the North Fork Virgin River station occurred for fewer than 10% of samples (3 of 38; 6%). Given that water temperature exceedances are more frequent upstream, groundwater inputs within the park and shading from the tall canyon walls may be stabilizing water temperature at this site.

Table 3-14. Summary statistics for selected parameters at North Fork Virgin River near Springdale, UT, inside the park boundary, including concentrations at the 10th, 50th, and 90th percentiles; seasonal Kendall trend results; and the number of samples that were censored.

		Sampling dates		Samples		Concentration percentile				
Parameter	Test	Start	End	Total #	Total censored	10th	Median	90th	p-value	Trend
Specific conductance	U	6/18/2008	9/6/2016	48	0	394	692	848.5	0.247	none
Temperature, water	U	6/18/2008	9/6/2016	48	0	3.75	10.65	19.9	0.084	none

U=uncensored

Table 3-15. Summary statistics for selected parameters at Virgin River at Virgin, UT, downstream of Zion National Park, including concentrations at the 10th, 50th, and 90th percentiles; seasonal Kendall trend results; and the number of samples that were censored.

		Sampling dates		Samples		Concentration				
Parameter	Test	Start	End	Total #	Total censored	10th	Median	90th	p-value	Trend
Dissolved oxygen (DO)	U	6/3/2009	10/28/2015	66	0	7.5	9.1	11.4	0.181	none
Specific conductance	U	7/23/2008	8/15/2016	78	0	665	774.5	857	0.339	none
Temperature, water	U	7/23/2008	8/15/2016	78	0	6.88	16.3	22.73	0.677	none
Turbidity	U	6/3/2009	10/28/2015	67	0	14	63	898	0.18	none

U=uncensored

4 Conclusions

Our analyses indicate that, with the exceptions discussed below, water quality at the stations monitored in and near Zion NP is stable and of high quality. Few trends were noted in seasonal median concentrations, and most water-quality parameters met state water-quality standards.

Specific conductance, sulfate, and turbidity showed statistically significant decreases in seasonal median values at La Verkin Creek. The cause of these decreases is unknown, but as land use and management has not changed in the watershed over time, the process is likely natural.

There were no trends in seasonal median concentrations at North Creek, but low and high concentrations in some parameters have changed since a wildfire burned much of the watershed in 2006. High concentrations of alkalinity, nitrogen, and specific conductance have decreased at the 0.9 quantile, and low values of pH at the 0.1 quantile have increased. pH values above 9.0, exceeding the state water-quality standard for aquatic life, have occurred in more than 10% of samples throughout the post-fire period. However, there were no pH exceedances from July 2014 to September 2016, indicating a possible improvement in water-quality conditions. Trends in the low and high concentrations of water-quality parameters suggest that post-fire variability is stabilizing in North Creek. Nitrogen species may have fallen below a critical threshold for eutrophication, as evidenced by a reduction in observed algal blooms at the site since 2006.

The North Fork Virgin River had no trends in seasonal median concentrations over time. Water-quality standard comparisons reiterate previously recognized management issues, including fecal indicator bacteria (*E. coli)* and water temperature. The Utah Division of Water Quality is undertaking a Total Maximum Daily Load analysis for the North Fork that will include a plan to bring surface-water quality into compliance. Given its location in a warm desert environment, the state is investigating whether the North Fork Virgin River in Zion National Park should be reclassified from a cold-water aquatic system to a warm-water aquatic system. Extensive sampling to isolate the suspected source of *E. coli* in the river has led to improved facilities for hikers at the Narrows trailhead, but flood irrigation of grazed pastures adjacent to the channel continues to impair the river. Continued exceedances of *E. coli* in the North Fork Virgin River support the need for management action to improve public health and safety in this stream.

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Appendix A. Implications of Censoring Data at the Highest Reporting Limit for Parameters with More than One Reporting Limit and 5–50% Censored Data

Water-quality datasets can sometimes have multiple reporting limits for a single parameter over time because of changes in analytical detection limits, programmatic issues with contamination, or other factors. When testing for trends over time, the analyst must determine how to compare datasets that include concentrations such as <1, 2.5, <5, and 7.5. It is apparent that the 7.5 concentration is greater than the other values, but how does one compare 2.5 and <5, or <1 and <5?

For datasets with less than 5% censored data, comparisons of analyses with and without substitutions for the censored data have indicated that direct substitution of the reporting limit does not skew the dataset in a way that would affect trend results (Schertz et al. 1991). Practically speaking, in our dataset, if a dataset has less than 5% censored data, it tends to have no censored data at all. Of the 45 parameter and station combinations analyzed using the uncensored seasonal Kendall test in this report, only seven included any censored data.

When more than 5% of the data are censored, substitution can create false patterns. For a thorough examination of how substitution can affect data analysis, see Helsel (2012). It is imperative, then, that the analyst select a statistical method that handles censored data appropriately. There are several choices, two of which we discuss here.

First, the data can be re-censored to the highest reporting limit and analyzed with a seasonal Kendall test. In the example above, following this re-censoring approach, the concentrations become <5, <5, <5, and 7.5. In this scenario, all censored data, and any detected concentrations below the highest reporting limit, are treated as ties. This approach loses some information in the dataset (for example, the detected concentration of 2.5), but maintains the benefits of a nonparametric approach, including freedom from an assumed underlying distribution.

The second approach uses a censored-regression technique that estimates censored data concentrations using a maximum likelihood approach based on a presumed distribution of the data, usually a lognormal distribution. The residuals from each censored regression must be evaluated to ensure that the distributional assumptions of the model are met.

For datasets with 5–50% censored data, we compared the percent censoring of the dataset before and after censoring to the highest reporting limit (Table A-1). Only dissolved and total phosphorus, and chloride at the North Fork Virgin River, had increases in the percent of censoring. For most of our parameters, using the highest reporting limit did not greatly decrease the amount of information in the dataset. For these data, using the seasonal Kendall test is straightforward and robust. Further investigation of phosphorus was indicated.

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 (USEPA 2006); in this 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 (2–10x) 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 (USEPA 2002). 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

Table A-1. Comparison of the amount of data censored before and after censoring to the highest reporting limit for datasets with 5–50% censored data.

Station	Parameter	Total samples	Non-detects in original dataset	Non-detects after censoring at highest reporting limit	Highest reporting limit	Percent censored in original dataset	Percent censored after re-censoring to highest reporting limit
North Creek	Arsenic (d) (µg/L)	37	2	2	1	5.4	5.4
La Verkin Creek	Barium (d) (µg/L)	39	3	3	100	7.7	7.7
NFV at WSA bndry	Chloride (mg/L)	66	23	66	10	34.8	100.0
La Verkin Creek	Escherichia coli (MPN/100 mL)	82	19	19	1	23.2	23.2
NFV at WSA bndry	Escherichia coli (MPN/100 mL)	55	6	6	1	10.9	10.9
North Creek	Escherichia coli (MPN/100 mL)	82	28	28	1	34.1	34.1
La Verkin Creek	Manganese (d) (µg/L)	38	13	13	5	34.2	34.2
North Creek	Manganese (d) (µg/L)	36	8	8	5	22.2	22.2
La Verkin Creek	Phosphorus as P (d) (mg/L)	78	26	71	0.02	33.3	91.0
North Creek	Phosphorus as P (d) (mg/L)	79	33	73	0.02	41.8	92.4
NFV at WSA bndry	Potassium (d) (mg/L)	65	10	11	1	15.4	16.9
North Creek	Selenium (d) (µg/L)	35	13	13	1	37.1	37.1
La Verkin Creek	Total Phosphorus as P (mg/L)	110	28	56	0.02	25.5	50.9
NFV at WSA bndry	Total Phosphorus as P (mg/L)	65	15	45	0.02	23.1	69.2
North Creek	Total Phosphorus as P (mg/L)	111	51	94	0.02	45.9	84.7
La Verkin Creek	Turbidity (NTU)	99	5	5	>1500	5.1	5.1

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 field blanks in October 2013. The goal for field blanks is to have all concentrations reported as less than the minimum level. Twenty-one field blanks were submitted during water years 2013–2016. Of these, 13 field blanks for dissolved phosphorus reported concentrations greater than the minimum level of 0.003 mg/L, with a maximum reported concentration of 0.016 mg/L (Figure A-1). Eleven field blanks for total phosphorus had reported concentrations greater than the minimum level of 0.003 mg/L, with a maximum reported concentration of 0.008 mg/L (Figure A-2).

It is apparent from our field-blank dataset that both dissolved and total phosphorus were 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 was not isolated to NCPN field blanks. For 2016–2017, field-blank samples submitted to the same laboratory by the Utah Division of Water Quality also reported detections in over half of dissolved phosphorus samples and about one-third of total phosphorus samples (personal communication, T. Hooker, UDWQ, 12/12/2017). The source of the contamination or bias is at this point unknown, although reported concentrations appear to be decreasing over time in the NCPN field blanks.

Because of the limited record of field blanks, it is not currently possible to determine an accurately quantified reporting level for dissolved and total phosphorus that is lower than the PQL of 0.02 mg/L. In the future, as more field blanks are submitted, a more nu-

anced approach to reported phosphorus concentrations should be feasible.

Using the higher reporting limit of 0.02 mg/L results in the loss of a considerable amount of information from the dataset, although some of that information is uncertain, as noted above. To test whether we might be missing trends over time by censoring to the highest reporting limit, we ran a censored regression on the original datasets with estimated concentrations and multiple reporting limits using the NADA package in R (Lee 2017). The censored regression model was of the form y = (Concentration, Censoring) ~ time, where Concentration is the reported concentration for detected data or the reporting limit for censored data, Censoring is a TRUE/ FALSE vector, and time is the number of days from the beginning of the period of record. There were no statistically significant trends in dissolved or total phosphorus at any of the three water quality stations. Because of the uncertainty associated with concentrations lower than the PQL of 0.02 mg/L, we present the seasonal Kendall trend test results in the report rather than the censored regression results.

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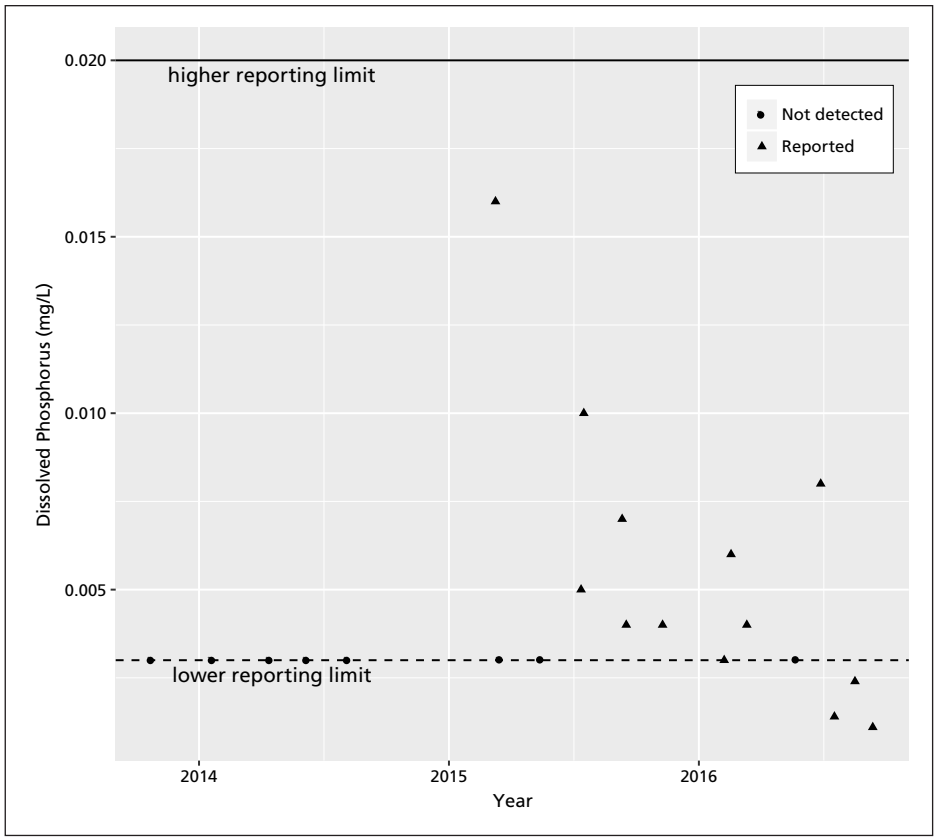


Figure A-1. Reported concentrations for dissolved phosphorus in field blanks for water years 2013–2016. Reported concentrations are shown with triangles, while censored data are shown with circles.

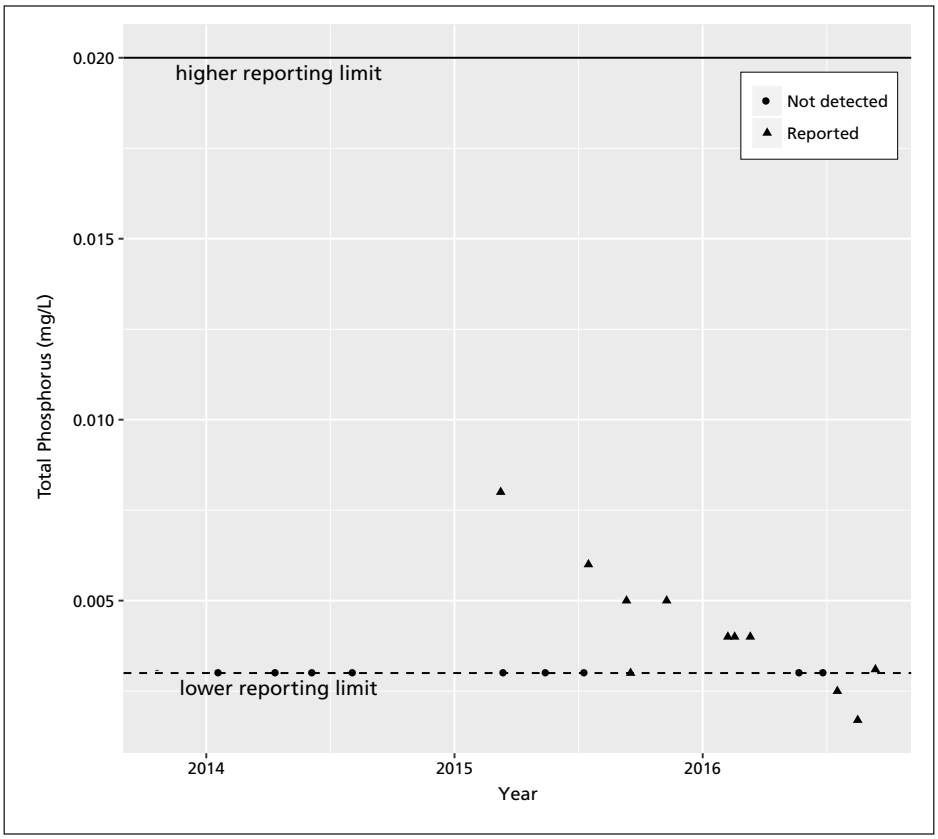


Figure A-2. Reported concentrations for total phosphorus in field blanks for water years 2013–2016. Reported concentrations are shown with triangles, while censored data are shown with circles.

Appendix B. Timeseries for Sites and Parameters with <50% censored data

Appendix B can be found at https://irma.nps.gov/DataStore/Reference/Profile/2252076.

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

The State of Utah has designated beneficial uses and associated water-quality standards for stations analyzed in and near Zion 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). Site-specific standards may also exist (Table C-1). Where a site-specific standard exists, the site-specific standard supercedes the beneficial use standard, as for total dissolved solids at North Creek (NoCrk), with a site-specific standard of 2,035 mg/L. Each designated beneficial use is associated with multiple water-quality standards (Table C-2).

Table C-1. State designated beneficial uses associated with water bodies in and near Zion National Park.

Station #	Site name	Latitude	Longitude	Beneficial use
4950800	La Verkin Ck at Lee Pass Trail	37.407	-113.176	2B, 3B, 4
4950920	North Ck at planned gage in park	37.261	-113.106	1C, 2B, 3C, 4, NoCrk
4951265	North Fork Virgin R at WSA bndry	37.371	-112.882	1C, 2A, 3A, 4
09405500	North Fork Virgin R nr Springdale, UT	37.210	-112.979	1C, 2A, 3A, 4
09406000	Virgin R at Virgin, UT	37.204	-113.181	1C, 2B, 3C, 4

1C=drinking-water supply, 2A=recreational use (primary contact), 2B=recreational use (secondary contact), 3A=aquatic life (cold-water game fish), 3B=aquatic life (warm-water game fish), 3C=non-game species, 4=agricultural uses

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

Parameter	Type	1C	2A	2B	3A	3B	3C	4
Dissolved oxygen (mg/L)	low	–	–	–	6.5	5.5	5	–
Escherichia coli (MPN/100 mL)	acute	668	409	668	–	–	–	–
Escherichia coli (MPN/100 mL)	chronic	206	126	206	–	–	–	–
pH	low	6.5	6.5	6.5	6.5	6.5	6.5	6.5
pH	–	9	9	9	9	9	9	9
Water temperature (°C)	–	–	–	–	20	27	27	–
Total dissolved solids (mg/L)	–	–	–	–	–	–	–	1200
Ammonia as N (mg/L)	–	–	–	–	pH Dep.	pH Dep.	pH Dep.	–
Total Phosphorus as P (mg/L)	–	–	0.05	0.05	0.05	0.05	0.05	–
Aluminum (d) (µg/L)	acute	–	–	–	750	750	750	–
Aluminum (d) (µg/L)	chronic	–	–	–	87	87	87	–
Arsenic (d) (µg/L)	acute	10	–	–	340	340	340	100
Arsenic (d) (µg/L)	chronic	–	–	–	150	150	150	–
Barium (d) (µg/L)	–	1000	–	–	–	–	–	–
Boron (d) (µg/L)	–	–	–	–	–	–	–	750
Cadmium (d) (µg/L)	–	10	–	–	HD	HD	HD	10
Chromium (d) (µg/L)	–	50	–	–	HD	HD	HD	100
Copper (d) (µg/L)	–		–	–	HD	HD	HD	200
Iron (d) (µg/L)	–		–	–	1000	1000	1000	–
Lead (d) (µg/L)	–	15	–	–	HD	HD	HD	100
Mercury (d) (µg/L)	–	2	–	–	0.012	0.012	0.012	–
Nickel (d) (µg/L)	–	–	–	–	HD	HD	HD	–
Selenium (d) (µg/L)	acute	50	–	–	18.4	18.4	18.4	50
Selenium (d) (µg/L)	chronic	–	–	–	4.6	4.6	4.6	–
Silver (d) (µg/L)	–	50	–	–	HD	HD	HD	–
Zinc (d) (µg/L)	–	–	–	–	HD	HD	HD	–

1C=drinking-water supply, 2A=recreational use (primary contact), 2B=recreational use (secondary contact), 3A=aquatic life (cold-water game fish), 3B=aquatic life (warm-water game fish), 3C=non-game species, 4=agricultural uses

pH Dep. = Standard is dependent on concurrently measured pH value. HD = Standard is dependent on concurrently measured hardness concentration. 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, while chronic standards must be exceeded in 10% or more of samples to indicate poor water-quality.

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.

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