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Hydrologic Study of Lower LaVerkin Creek and Smith Creek Wild and Scenic Rivers, Utah

Technical Note 461

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Acronyms and Abbreviations

afy	acre-feet per year
BLM	Bureau of Land Management
ft^3/day or cfd	cubic feet per day
cfs	cubic feet per second
DOI	Department of the Interior
EPA	Environmental Protection Agency
GMWL	Global Meteoric Water Line
gpm	gallons per minute
HUC	hydrologic unit code
NPS	National Park Service
PRISM	Parameter-elevation Regressions on Independent Slopes Model
USGS	U.S. Geological Survey

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Abstract

In 2022 and 2023, the Bureau of Land Management (BLM) and National Park Service performed a hydrologic study of LaVerkin Creek and Smith Creek Wild and Scenic Rivers in southwestern Utah. The BLM is responsible for protecting the free-flowing conditions, water quality, and outstandingly remarkable values of BLM-administered wild and scenic river segments. This technical note provides a summary of the study, which is intended to inform BLM decision-making processes pertaining to the protection and enhancement of river-related values, including supporting the administration of water rights and implementation of the Clean Water Act. Field and other analyses in the study include streamflow measurements; water quality, geochemical, and stable isotopic analyses; and estimates of water level responses and streamflow depletion by groundwater pumping wells. These analyses demonstrate that the subject rivers may be vulnerable to streamflow depletions if surface water is diverted or impounded or if groundwater is withdrawn nearby. Such depletions could degrade the outstandingly remarkable values of LaVerkin and Smith Creeks or have an adverse effect on the free-flowing condition of the designated river segments.

1. Introduction and Background Materials

1.1 Bureau of Land Management Mission

The Bureau of Land Management (BLM) is a federal agency within the U.S. Department of the Interior (DOI). The mission of the BLM is to sustain the health, diversity, and productivity of public lands for the use and enjoyment of present and future generations. In accordance with the Federal Land Policy and Management Act, the BLM manages public lands for a variety of uses, including, but not limited to, energy development, livestock grazing, recreation, and timber harvesting, while conserving natural, cultural, and historic resources. Accordingly, the BLM manages public lands under the principles of multiple use and sustained yield (43 U.S.C. 1702) and encourages the management of water as a renewable resource (DOI 1972).

In 2009, Congress established the BLM National Landscape Conservation System (commonly referred to as National Conservation Lands) to conserve, protect, and restore nationally significant landscapes that have outstanding cultural, ecological, and scientific values for the benefit of current and future generations (16 U.S.C. 7202). This system includes more than 37 million acres of national monuments, national conservation areas, wilderness areas, and other areas, as well as components of the National Wild and Scenic Rivers System.

1.2 Wild and Scenic Rivers Act

In 1968, Congress passed the Wild and Scenic Rivers Act creating the National Wild and Scenic Rivers System to preserve certain rivers with outstanding natural, cultural, and recreational values in a free-flowing condition for the enjoyment of present and future generations. The act is notable for safeguarding the special character of these rivers, while also recognizing the potential for their appropriate use and development. The act encourages river management that crosses political boundaries and promotes public participation in developing goals for river protection. Less than 0.5% of rivers in the United States and about 0.2% of rivers in Utah are protected under the National Wild and Scenic Rivers System. The act directs river management to protect and enhance the values identified in the legislation.

1.3 Project Background

In 2009, Congress designated LaVerkin[1] and Smith Creeks in southwest Utah as wild river segments as part of the Omnibus Public Land Management Act of 2009 (16 U.S.C. 1274). LaVerkin and Smith Creeks are tributaries of the Virgin River (Figures 1 and 2).

The designated portions of these rivers are administered by the BLM and National Park Service (NPS) and identified in Public Law 111-11 as:

- **LaVerkin Creek:** The 16.1-mile segment beginning in T. 38 S., R. 11 W., sec. 21, on Bureau of Land Management land, southwest through Zion National Park, and ending at the south end of T. 40 S., R. 12 W., sec. 7, and adjacent land ½-mile wide, as a wild river.

- **Smith Creek:** The 1.3-mile segment from the head of Smith Creek to the junction with LaVerkin Creek and adjacent land ½-mile wide, as a wild river.

Congress designated these river segments as wild because they support outstandingly remarkable values as described in the Wild and Scenic Rivers Act. Utah has approximately 81,899 miles of rivers, of which 232.3 miles are designated as wild and scenic rivers—approximately 0.2% of the state's river miles.

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[1] The word LaVerkin is spelled as one word in this technical note to be consistent with the spelling of LaVerkin Creek in Public Law 111-11, Omnibus Public Land Management Act of 2009.

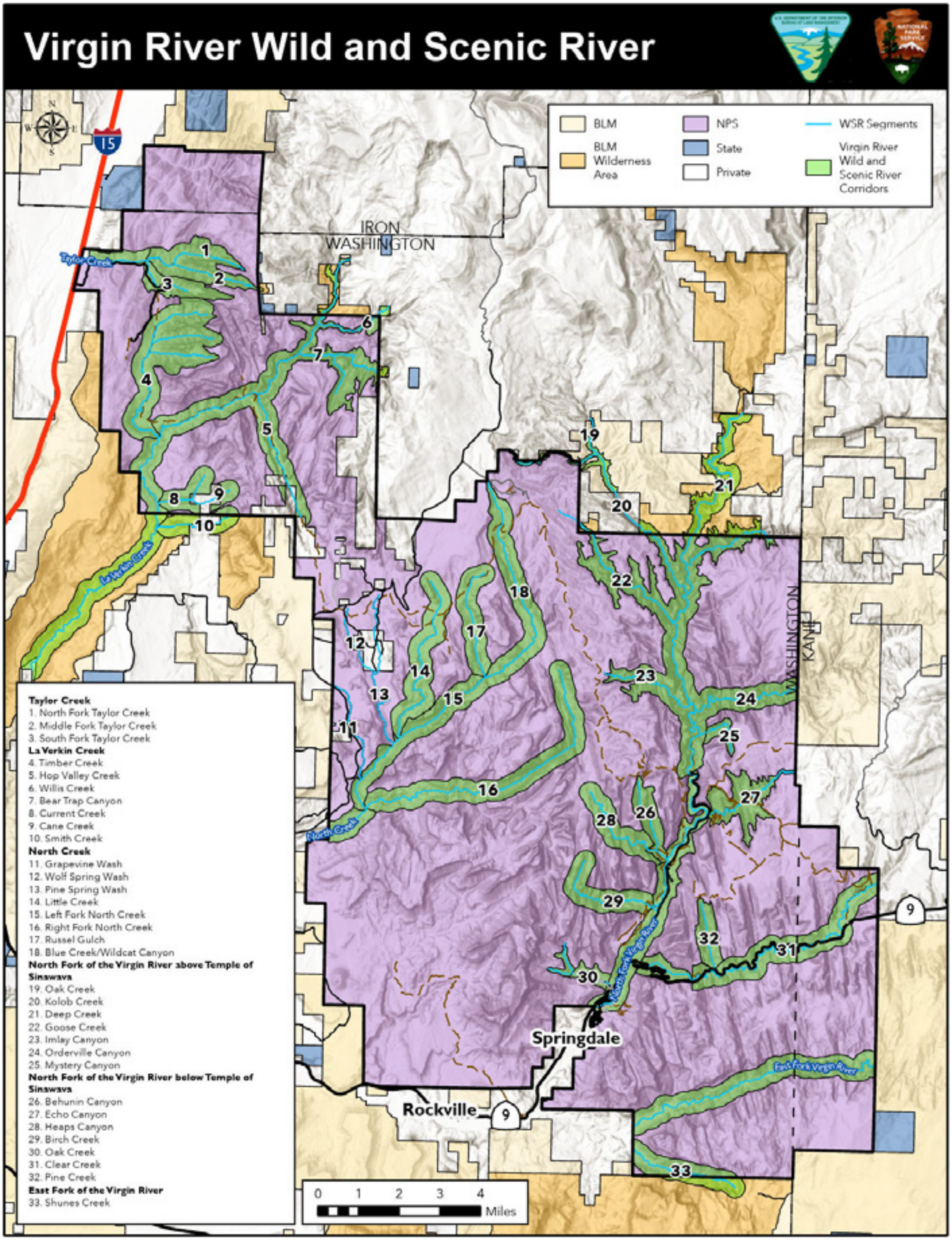


Figure 1. Designated wild and scenic river segments and corridors of the Virgin Wild and Scenic River. LaVerkin Creek is labeled by name, and Smith Creek is segment number 10.

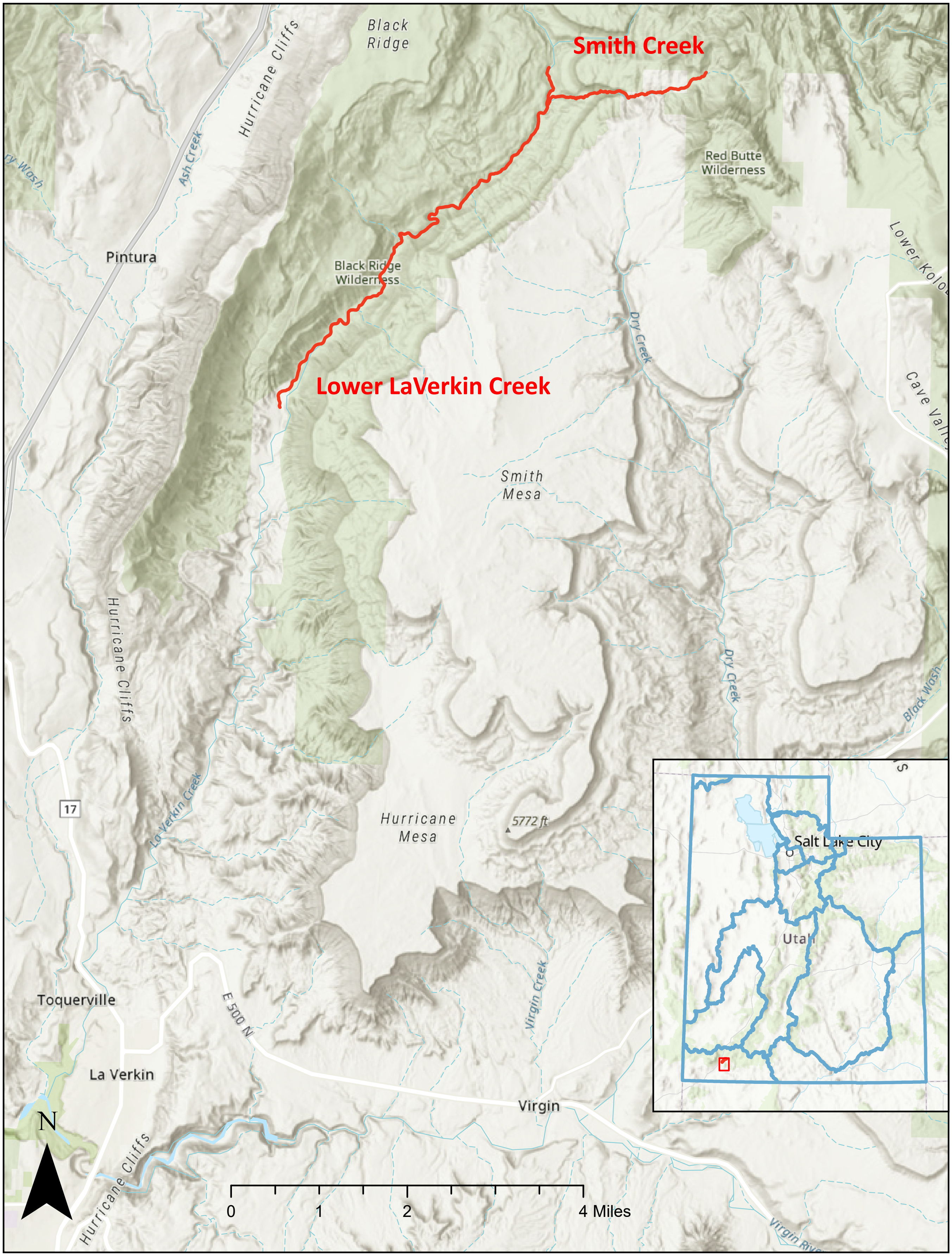


Figure 2. Map showing the locations within Utah of lower LaVerkin and Smith Creeks.

1.4 Purpose and Goal

The purpose of this technical note is to present and summarize the hydrologic study conducted on LaVerkin Creek and Smith Creek Wild and Scenic Rivers by the BLM and NPS. The BLM's goal is to inform strategies for preserving the free-flowing condition, water quality, and outstandingly remarkable values of these river segments in accordance with the Omnibus Public Land Management Act of 2009 and Wild and Scenic Rivers Act of 1968.

This study investigates the section of LaVerkin Creek downstream from the NPS boundary of Zion National Park, referred to in this tech note as lower LaVerkin Creek, and the entire length of Smith Creek. The BLM anticipates the information contained in this tech note will inform management of federal reserved water rights associated with the designated section of LaVerkin Creek below the NPS boundary and Smith Creek.

The remainder of this first chapter contains information about the river segments and their outstandingly remarkable values, physiographic province, geology, soils, hydrologic setting, ecoregions, and historical climate. Subsequent chapters summarize the fieldwork and other analyses as follows:

- Chapter 2: Streamflow Measurements
- Chapter 3: Water Quality Analyses
- Chapter 4: Stable Isotope Analysis
- Chapter 5: Theis Drawdown Analysis
- Chapter 6: Glover Streamflow Depletion Analysis

The rationale for this order is to, first, present what was learned about the rivers from the study, in terms of the streamflow measurements, water quality analyses, and isotopic analysis (chapters 2 through 4). Then chapters 5 and 6 present estimates of drawdown and streamflow depletion analysis based on field-collected data.

Appendix A provides precipitation data for 2022 and 2023 from the Cedar City – Zion National Park, Kolob Canyons Weather Station (ID 1262327). Appendix B provides Piper and Stiff diagrams. Appendix C contains photos of LaVerkin and Smith Creeks taken in October 2022. Appendix D provides information about the State of Utah water law and administration of water rights in Area 81 (Virgin River). Appendix E provides coordinates of the water quality sample locations.

1.5 Wild and Scenic Rivers

Nationwide, the BLM manages 81 designated wild and scenic rivers totaling nearly 2,700 miles. In Utah, the BLM manages or co-manages with the NPS 12 rivers totaling 82.0 miles.

In addition to protecting and enhancing free-flowing conditions, water quality, and outstandingly remarkable values, the designation of wild and scenic rivers helps protect biodiversity and increase resilience to the impacts of climate change.

- The BLM works cooperatively with the U.S. Environmental Protection Agency (EPA) and state water quality agencies to establish baseline conditions, identify water quality-related issues, and develop strategies to improve or protect water quality for designated wild and scenic rivers.

- Flows must be sufficient to sustain the outstandingly remarkable values of the river. Flows may be intermittent but should be predictable and derived from naturally occurring circumstances.

- Outstandingly remarkable values may be on the river or adjacent land area and may include scenic, recreational, geologic, fish and wildlife, historic, cultural, or other similar values.

The BLM, NPS, U.S. Fish and Wildlife Service, and U.S. Forest Service are the four federal agencies charged with managing the National Wild and Scenic Rivers System. The BLM and these federal partners actively collaborate through the Interagency Wild and Scenic Rivers Coordinating Council to administer wild and scenic rivers in a consistent and coordinated manner across the system.

The subjects of this study, lower LaVerkin Creek and Smith Creek, are tributaries to the Virgin River, which is tributary to the Colorado River. Table 1 lists the mileage of wild, scenic, and recreational segments of the Virgin River by administering agency.

Table 1. Mileage classifications of all segments of the Virgin River and certain tributaries (NPS and BLM 2013).

River	Administering Agency	Wild (mi)	Scenic (mi)	Recreational (mi)	Total Miles
Virgin River (all segments)	National Park Service	123.6	11.3	12.6	**147.5**
	Bureau of Land Management	21.8			**21.8**
	Virgin River Total	**145.4**	**11.3**	**12.6**	**169.3**
LaVerkin Creek	National Park Service	8.6			**8.6**
	Bureau of Land Management	7.6			**7.6**
	LaVerkin Creek Total	**16.2**			**16.2**
Smith Creek	Bureau of Land Management	**1.3**			**1.3**

1.6 Outstandingly Remarkable Values

According to the "Virgin River Comprehensive Management Plan/Environmental Assessment," LaVerkin Creek has three outstandingly remarkable values (geologic, recreational, and wildlife), and Smith Creek has one (geologic). Descriptions of these values follow (NPS and BLM 2013):

LaVerkin Creek

Geologic: Uniquely situated along the western margin of the Colorado Plateau, the recent history of tectonic activity and erosional downcutting has resulted in a labyrinth of deep sandstone canyons, volcanic phenomena, and widespread exposures of brilliantly colored sedimentary deposits. Unique geologic features include Navajo sandstone exposures, a remnant of the world's largest sand dune desert, river-carved canyons forming the world's tallest sandstone cliffs, narrow slot canyons, hanging waterfalls, springs, and seeps. This dynamic geologic system creates a diverse landscape of channels, canyons, and springs that support a variety of species and ecological communities, including hanging gardens and desert fish. The geology offers world-class opportunities for canyoneering, rock climbing, hiking, and wilderness experiences.

Recreational: Exceptional recreational opportunities provide visitors from around the world a chance to develop personal and lasting connections with the river within some of the most unique water-carved desert canyons in the region. The dramatic setting, dominated by scenic grandeur, contributes to a spectrum of river-related experiences, from the self-reliant adventure of canyoneering or hiking and backpacking through narrow river and creek channels, to enjoying photography and other artistic pursuits, to viewing scenery or camping along the river.

Wildlife: Similar to Goose Creek and Bear Trap Canyons, the habitat value of the LaVerkin Creek Wilderness is greatly enhanced by its proximity to Zion National Park and the thousands of acres of remote, private wildlands surrounding it. Dense vegetation of pines, juniper, and scrub oak; canyon wall-created shade; access to water; and other factors create habitat suitable for many plants and animals. Wildlife is an outstandingly remarkable value in the Virgin River and its tributaries due to the habitat for and populations of desert bighorn sheep, Mexican spotted owls, and endemic Zion snails. The federally threatened Mexican spotted owl breeds in many of the designated river corridors at the highest density in the state and region. Related to the river corridors are seven species of amphibians (four toads, two frogs, and one salamander) and many of the 80 mammalian species and 299 bird species in the park's certified species lists.

Smith Creek

Geologic: Uniquely situated along the western margin of the Colorado Plateau, the recent history of tectonic activity and erosional downcutting has resulted in a labyrinth of deep sandstone canyons, volcanic phenomena, and widespread exposures of brilliantly colored sedimentary deposits. Unique geologic features include Navajo sandstone exposures, a remnant of the world's largest sand dune desert, river-carved canyons forming the world's tallest sandstone cliffs, narrow slot canyons, hanging waterfalls, springs, and seeps. This dynamic geologic system creates a diverse landscape of channels, canyons, and springs that support a variety of species and ecological communities, including hanging gardens and desert fish. The geology offers world-class opportunities for canyoneering, rock climbing, hiking, and wilderness experiences.

1.7 Colorado Plateau Physiographic Province

According to the Fenneman and Johnson (1946) classification, LaVerkin and Smith Creeks are within the Intermontane Plateaus Division, Colorado Plateaus Province, and High Plateaus of Utah Section (FenCode 21a). The area is characterized by high block plateaus, some of which are lava capped. The south side of the area contains terraced plateaus. The rivers are located on the western side of the Colorado Plateau Physiographic Province in the vicinity of Zion National Park (Figure 3).

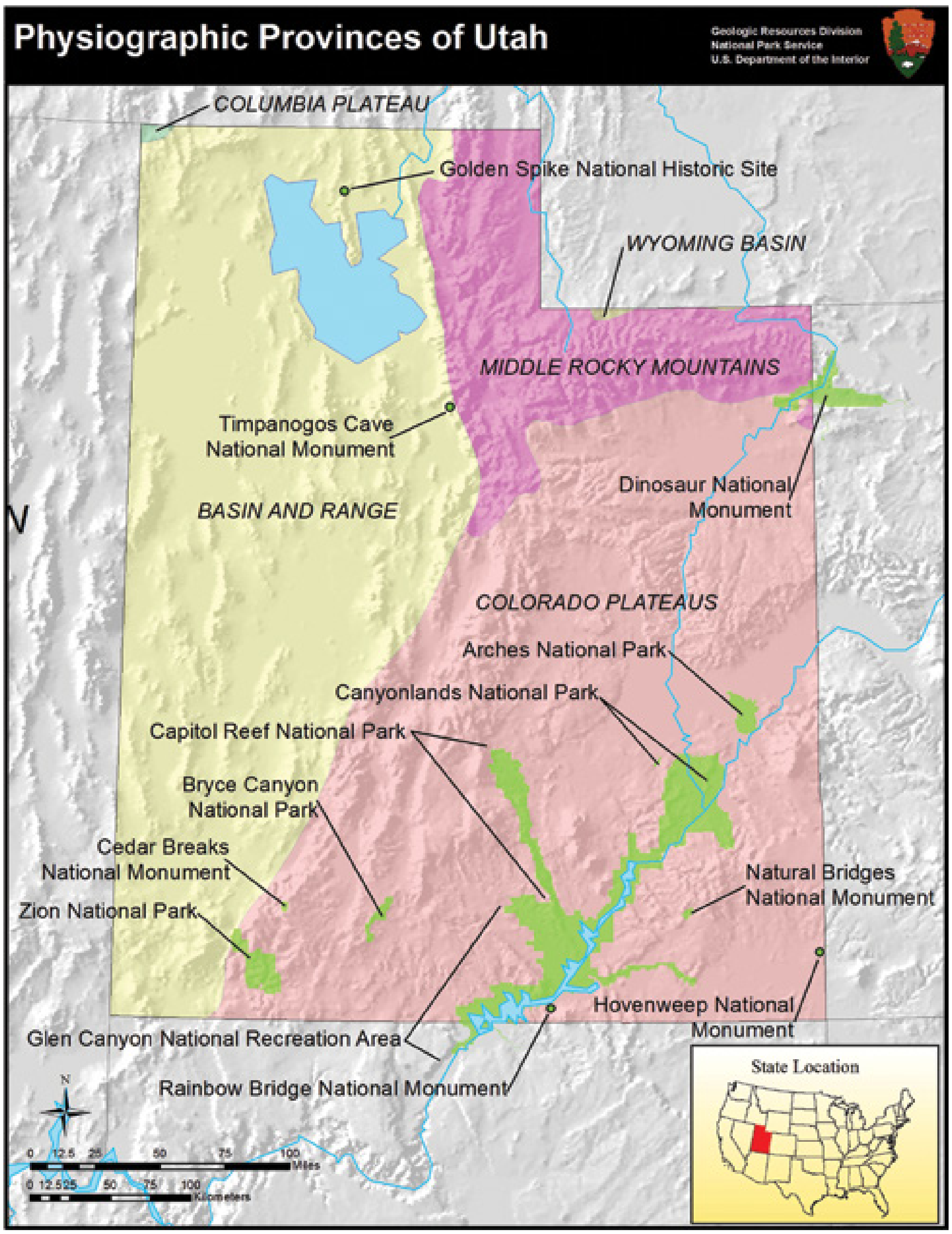


Figure 3. Physiographic provinces of Utah. LaVerkin Creek and Smith Creek are on the west side of Zion National Park in southwestern Utah.

1.8 Geology

LaVerkin Creek and Smith Creek are situated on the western boundary of the Colorado Plateau, an uplifted geologic feature covering parts of northern Arizona, western Colorado, northwestern New Mexico, and southern Utah. The sedimentary rock layers of the Colorado Plateau include the Grand Staircase sequence, a series of units that form colorful cliff faces between Grand Canyon National Park and Bryce Canyon National Park.

The local geology of the LaVerkin Creek and Smith Creek watersheds is characterized primarily by Triassic and Jurassic age sedimentary rock layers. Geologic layers include:

- Navajo Sandstone, a cliff-forming quartz sandstone.
- Kayenta Formation, consisting of slope-forming siltstones, sandstones, and shale.
- Dinosaur Canyon Sandstone Member of the Moenave Formation, a sandstone.
- Petrified Forest Member of the Chinle Formation, a shale with sandstone and limestone beds.
- Shinarump Member of the Chinle Formation, a sandstone and pebbly conglomerate.
- Upper Red Member of the Moenkopi Formation, a siltstone and shale.
- Shnabkaib Member of the Moenkopi Formation, a siltstone and shale with interbedded gypsum.
- Middle Red Member of the Moenkopi Formation, a siltstone and shale.
- Virgin Limestone Member of the Moenkopi Formation, a limestone with interbedded mudstone.

Smith Creek flows emanate from the Jurassic age Navajo Sandstone and continue across the Kayenta Formation and the Dinosaur Canyon Sandstone Member of the Moenave Formation. The confluence of Smith Creek and LaVerkin Creek is near the vicinity of the contact between the Petrified Forest Member and the Shinarump Member of the Triassic age Chinle Formation. Downstream of the boundary between Zion National Park and BLM-managed lands but upstream of the confluence with Smith Creek, LaVerkin Creek flows over the Petrified Forest Member of the Chinle Formation. Below the confluence with Smith Creek, LaVerkin Creek flows over the Shinarump Member of the Chinle Formation and the Upper Red, Shnabkaib, Middle Red, and Virgin Limestone Members of the Moenkopi Formation.

A geologic map of the study area (Figures 4 and 5) and the stratigraphic column (Figure 6) at and near Zion National Park (Biek et al. 2010) are provided for reference. Table 2 summarizes the lithology and aquifer characteristics of the geologic units.

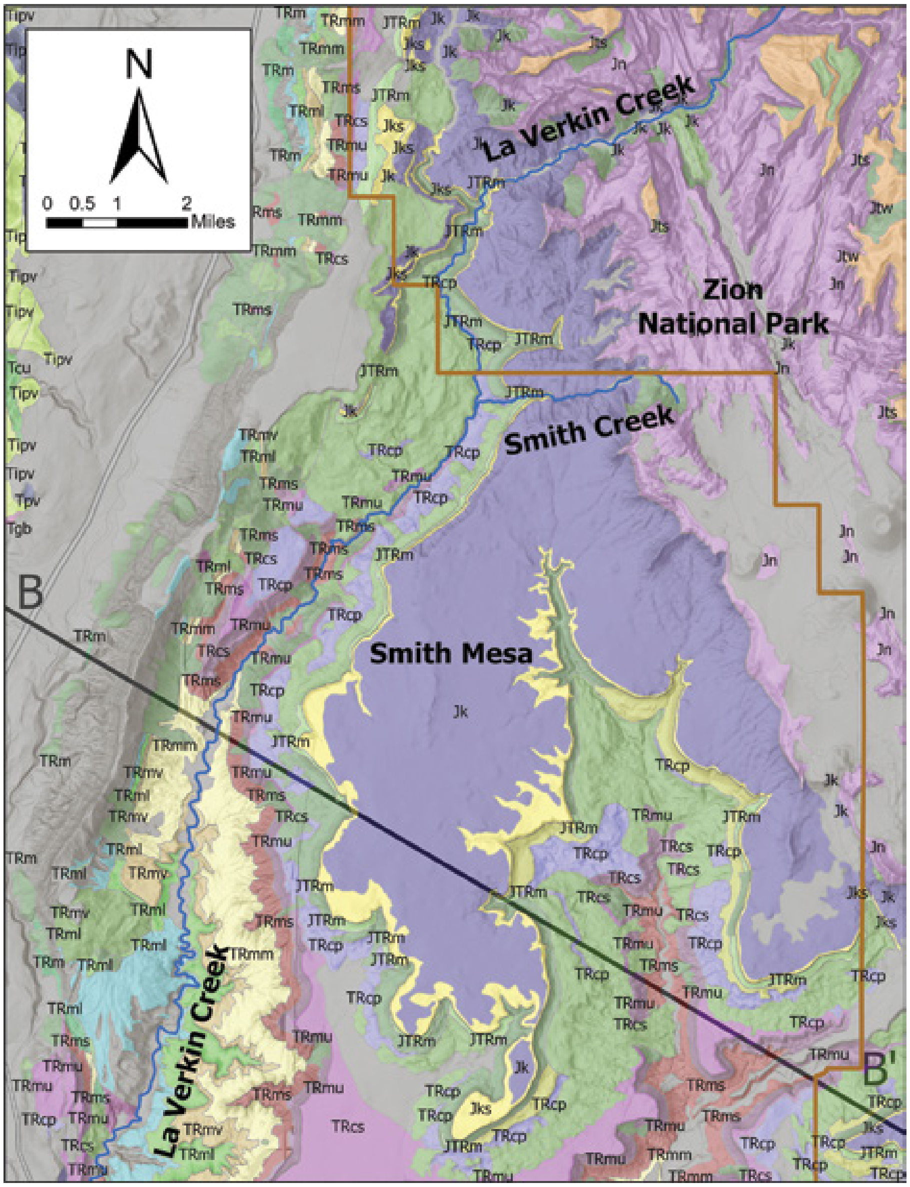


Figure 4. Geologic formations in the study area based upon the work of Biek et al. (2010). The B to B′ cross section is shown in Figure 5. Geologic unit symbols are defined in Figure 6 and Table 2.

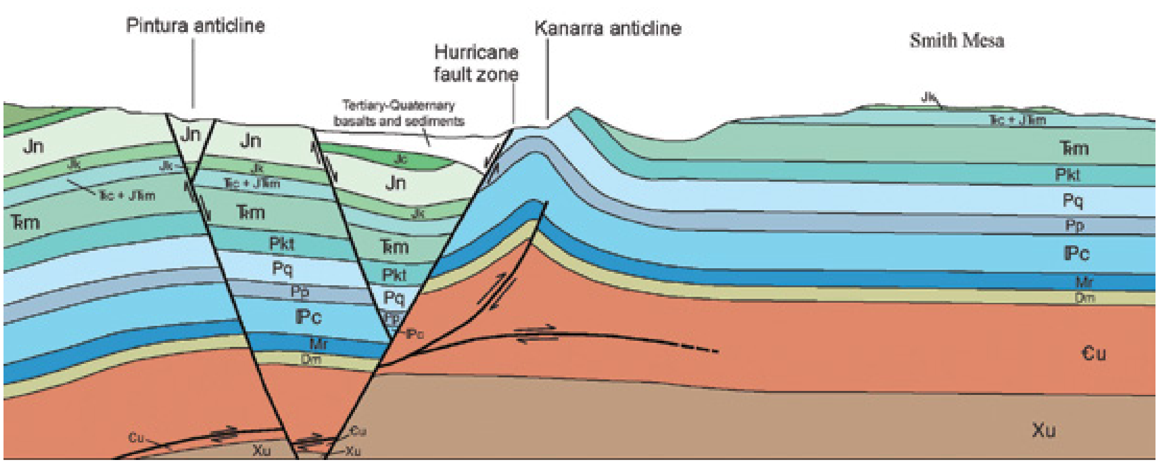


Figure 5. A portion of cross section B-B′ from Biek et al. (2010), from northwest to southeast across the study area. The LaVerkin Creek basin lies in the saddle between the Kanarra anticline and Smith Mesa. The Kayenta Formation is shown to be considerably higher and not in contact with the streambed.

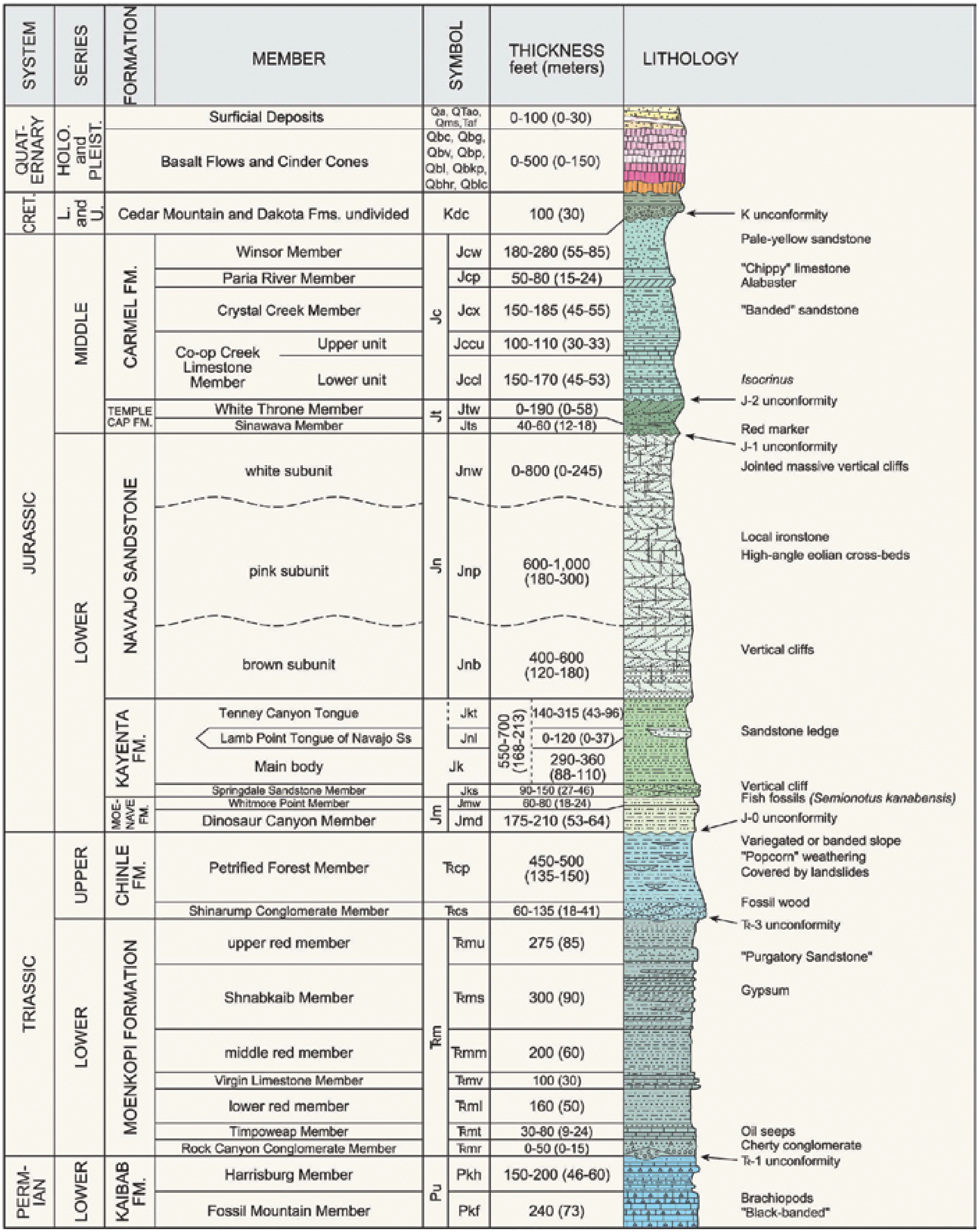


Figure 6. Stratigraphic section of Zion National Park and surrounding area (in Lund et al. 2010 and modified from Biek et al. 2003).

Table 2. Geologic units of the study area, including lithology and aquifer characteristics (Graham 2006).

Map ID	Geologic Unit	Lithology	Aquifer Characteristics
Jn	Navajo Sandstone	Moderately well-cemented, well-rounded, frosted, fine-to-medium grained quartz sandstone; weathers to bold, rounded cliffs; large-scale crossbeds; locally exceeds 610 m (2,000 ft); three informal subunits based on color, in ascending order, brown, pink, and white. White subunit: forms highest cliffs in Zion National Park (Great White Throne); highly jointed massive vertical cliffs; top is locally stained red by runoff from the mudstone and siltstone of the overlying Sinawava Member of the Temple Cap Fm.; 0–244 m (0–800 ft) thick. Pink subunit: uniformly stained by iron oxides (hematite); porous and friable; high-angle eolian cross-beds; sheets, concretions, and nodules of ironstone (1–20 percent iron oxide) litter some outcrops; 183–305 m (600–1,000 ft) thick. Brown subunit: vertical cliff-former; cemented by iron oxide; hanging valleys form at top; 122–183 m (400–600 ft) thick.	Primary aquifer; moderate to very large yields; fresh water quality.
Jk	Kayenta Fm. Main Body	Red and mauve siltstones, shale, and sandstones; slope-former; commonly covered by talus; Lamb Point Tongue (0–37 m, 0–120 ft thick) of Navajo Sandstone forms a ledge about one-third of the way down from the base of the Navajo in Zion and Parunuweap Canyons; lower two-thirds is the main body of the Kayenta and is 88–110 m (290–360 ft) thick, upper one-third is the Tenney Canyon Tongue and is 43–96 m (140–315 ft) thick; entire formation is 168–213 m (550–700 ft) thick.	Springs and seeps; small to moderate yields; fresh to saline water quality.
Jks	Kayenta Fm. Springdale Sandstone Mbr.	Thin, discontinuous lenses of intraformational conglomerate, with mudstone and siltstone rip-up clasts; forms the first significant cliff below the Navajo Sandstone; 27–46 m (90–150 ft) thick.	Limited aquifer potential; small to moderate yields; fresh to saline water quality.
Jmw	Moenave Fm. Whitmore Point Mbr.	Sandstone, siltstone, and reddish-purple to greenish-gray mudstone and claystone and thin dolomitic limestone beds; limestones are bioturbated and contain small, moderate reddish-brown chert nodules and blebs, algal structures, and fossil fish scales and bones of *Semionotus kanabensis*; slope-former; 18–24 m (60–80 ft) thick.	Limited aquifer potential; small yields; poor water quality.
Jmd	Moenave Fm. Dinosaur Canyon Sandstone Mbr.	Reddish-brown, thin-bedded, very fine-to-fine grained sandstone and silty sandstone; ripple marks and low-angle cross-bedding; slope-former; 53–64 m (175–210 ft) thick.	Limited aquifer potential; small yields; poor water quality.
TRcp	Chinle Fm. Petrified Forest Mbr.	Variegated gray, purple, and white shale with several layers of light-colored sandstone and limestone; abundant bentonite produces badlands topography of bare clay hills with "popcorn" weathering; paleosols are common; 137–152 m (450–500 ft) thick.	Not an aquifer; fresh to saline water quality.
TRcs	Chinle Fm. Shinarump Mbr.	Sandstone, pebbly sandstone, pebbly conglomerate; forms prominent east-dipping cuesta in Kolob Canyons area; 18–41 m (60–135 ft) thick.	Limited aquifer potential; small to moderate yields; fresh to saline water quality.
TRmu	Moenkopi Fm. Upper Red Mbr.	Reddish-brown siltstone and shale; ripple marks; mudcracks, thin laminated bedding; regressive member; 84 m (275 ft) thick.	Limited aquifer potential; small yields; poor water quality.
TRms	Moenkopi Fm. Shnabkaib Mbr.	Siltstone and shale interbedded with abundant gypsum; thickens westward; transgressive member; 91 m (300 ft) thick.	Limited aquifer potential; small yields; poor water quality.
TRmm	Moenkopi Fm. Middle Red Mbr.	Reddish-brown siltstone and shale; ripple marks; mudcracks, thin laminated bedding; regressive member; 61 m (200 ft) thick.	Limited aquifer potential; small yields; poor water quality.
TRmv	Moenkopi Fm. Virgin Limestone Mbr.	Fossiliferous limestone with interbedded mudstone; thickens westward; transgressive member; 30 m (100 ft) thick.	Limited aquifer potential; small to moderate yields; poor water quality.

1.9 Soils

LaVerkin Creek and Smith Creek flow over or adjacent to four soil types according to a Utah soils geographic information system (GIS) layer derived from the Natural Resources Conservation Service Soil Survey Geographic Database (Figure 7). The formations over which the creeks flow are described in Table 3 and include badlands, rock outcrops, Schmutz loam, and stony colluvial lands (Mortensen et al. 1977). Badlands incorporate shale, sandstone, and gypsum rock layers with areas of shallow soils in channels. Rock outcrop areas are characterized by sedimentary and volcanic layers comprised of sandstone, limestone, conglomerate, and basalt. Schmutz series soils contain gypsum and are well-drained. Stony colluvial lands are comprised of rocky areas at the bottoms of hills with shale bedrock just below the land surface.

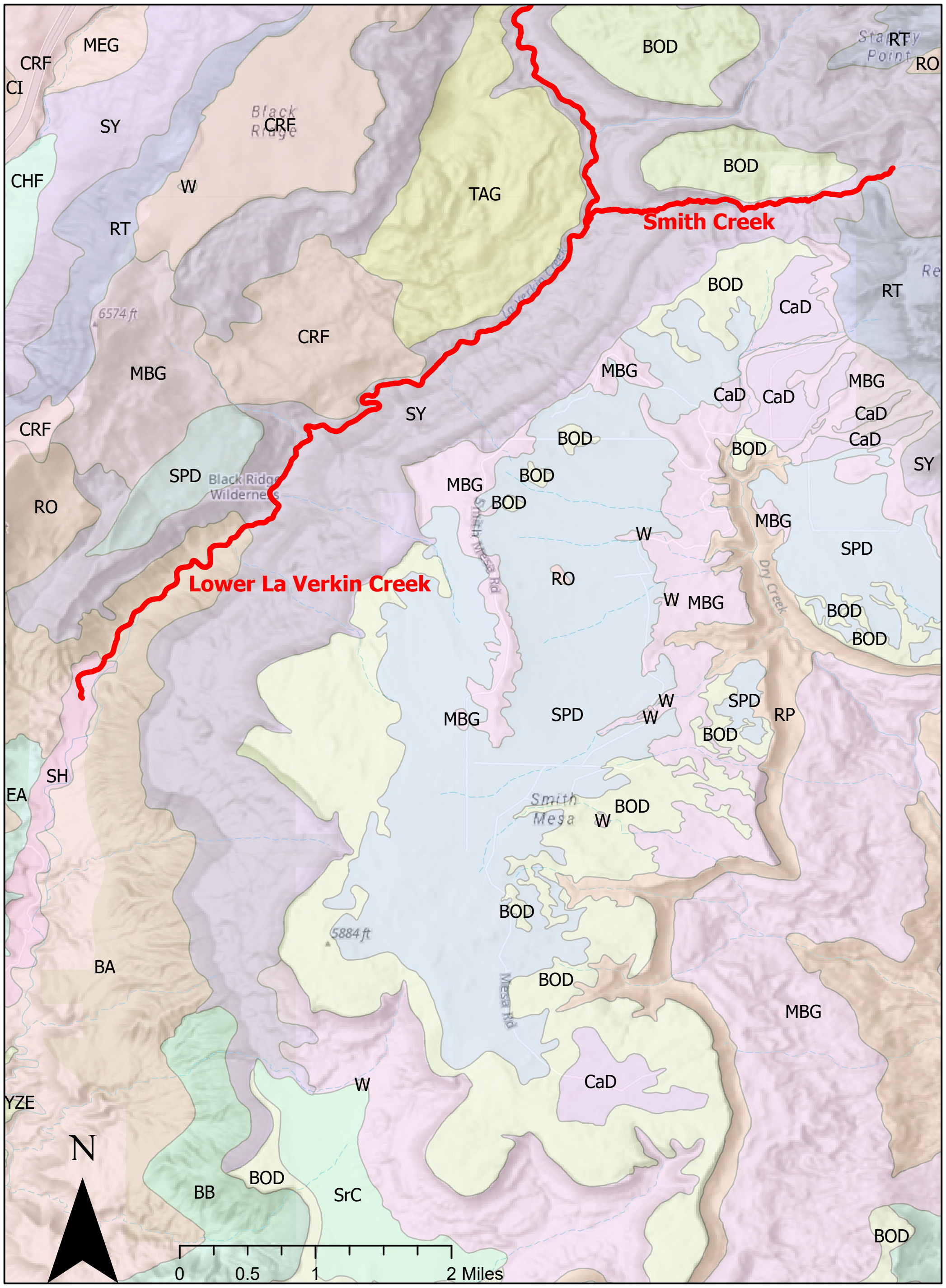


Figure 7. Soil survey map of the study area.

Table 3. Descriptions of the soils over which LaVerkin and Smith Creeks flow (Mortensen et al. 1977).

Soil Name	Soil Symbol	Soil Description
Badland	BA	Badland (BA) consists of nearly barren, multicolored beds of actively eroding shale, shale interbedded with sandstone, and shale interbedded with layers of gypsum. The landscape is rolling and severely dissected, and channels of intermittent streams form a branching pattern. Included with this land type in mapping are small areas of shallow soils in drainageways. Runoff is very rapid. The sediment potential is high during intense thunderstorms in summer. Badland supports only a sparse stand of vegetation.
Rock Outcrop	RT	Rock outcrop (RT) consists of exposures of bare bedrock, mostly sandstone, limestone, conglomerate, or basalt. This mapping unit is extensive throughout the survey area. Slopes are variable, ranging from sloping to very steep or nearly vertical. Rock outcrop generally has no vegetation, but in some places stunted pinyon or ponderosa pine grow in crevices or pockets of soil material.
Schmutz Loam	SH	The Schmutz series (SH) consists of well-drained soils that are high in content of gypsum. These soils are in alluvial valleys and on alluvial fans. They formed in mixed alluvium weathered from sandstone, gypsiferous siltstone, and shale. Slopes range from 1 to 5 percent. Elevation is 3,600 to 4,800 feet. The native vegetation is desert shrubs, grasses, and cactus. Average annual precipitation is 10 to 13 inches, average annual air temperature is 52° to 56° F, and the frost-free period is 165 to 170 days. Schmutz soils are commonly associated with Redbank, Naplene, and Shalet soils. In a representative profile the surface layer is brown loam about 4 inches thick. The underlying material is reddish-brown and light reddish-brown loam to a depth of 60 inches. Permeability is moderate. Available water capacity is 8 to 10 inches to a depth of 5 feet. The water supplying capacity is 6 to 8 inches. Roots penetrate to a depth of 5 feet or more. Schmutz soils are used mainly for range. Schmutz loam (SH): This soil is on alluvial fans and in valleys. Slopes are 1 to 5 percent. Runoff is medium, and the hazard of erosion is moderate. Included with this soil in mapping are small areas of Naplene silt loam, 2 to 6 percent slopes, and Shalet clay loam, 2 to 20 percent slopes. Also included are areas of Badland, which make up about 5 percent of the mapped area, and Gullied land, which make up about 3 percent. This Schmutz soil is used for range. The native vegetation is big sagebrush, rabbitbrush, galleta, Indian ricegrass, and cholla cactus.
Stony Colluvial Land	SY	Stony colluvial land (SY) consists of unconsolidated colluvial land covered with stones and rock fragments that accumulate on slopes and at the base of slopes, mainly by gravity. Shale bedrock is at a variable depth, but generally at a depth of less than 12 inches. There are a few small areas of shallow soils. Slopes are 30 to 70 percent. Erosion is moderate, and sediment production is low to medium, depending on the vegetative cover. Most areas have a cover of grasses, shrubs, and forbs. Pinyon pine and juniper are at the higher elevations.

1.10 Hydrologic Setting

The U.S. Geological Survey (USGS) delineates watersheds using a nationwide hierarchical system based on surface hydrological features. The system organizes the country into regions, subregions, basins, subbasins, watersheds, and subwatersheds. Each level of the system is assigned a hydrologic unit code (HUC). The study area is in Lower LaVerkin Creek Subwatershed drainage area (HUC12: 150100080302) within the Upper Virgin Subbasin (HUC8: 15010008) (Figure 8). Table 4 provides HUC2 through HUC12 names and numbers. LaVerkin Creek and Smith Creek are located within the Utah Division of Water Rights water basin 81 – Virgin River. Information about the Utah Division of Water Rights and Area 81 is included in Appendix D.

Table 4. Hydrologic unit codes of the study area.

HUCs	Classification	HUC Number	HUC Name
2-Digit	Region	15	Lower Colorado
4-Digit	Subregion	1501	Lower Colorado – Lake Mead
6-Digit	Basin	150100	Lower Colorado – Lake Mead
8-Digit	Subbasin	15010008	Upper Virgin
10-Digit	Watershed	1501000803	LaVerkin Creek
12-Digit	Subwatershed	150100080302	Lower LaVerkin Creek

USGS (1982) describes the region and subregion as follows:

Description of Region 15, Lower Colorado: The drainage within the United States of: (A) the Colorado River Basin below the Lee Ferry Compact Point which is 1 mile below the mouth of the Paria River; (B) streams that originate within the United States and ultimately discharge into the Gulf of California; and (C) the Animas Valley, Willcox Playa, and other smaller closed basins. Includes parts of Arizona, California, Nevada, New Mexico, and Utah.

Description of Subregion 1501, Lower Colorado – Lake Mead: The Colorado River Basin from the Lee Ferry Compact Point to Hoover Dam, but excluding the Little Colorado River Basin. Arizona, Nevada, and Utah.

1.11 Utah Ecoregions

According to the "Ecoregions of Utah" map (Figure 9) (Woods et al. 2001), LaVerkin and Smith Creeks are in the following ecoregions:

- North American Deserts (10) Level I Ecoregion
- Cold Deserts (10.1) Level II Ecoregion
- Colorado Plateaus (20) Level III Ecoregion
- Escarpments (20e) Level IV Ecoregion

Woods et al. (2001) describe the ecoregions as follows:

Colorado Plateaus Level III Ecoregion: An uplifted, eroded, and deeply dissected tableland. Its benches, mesas, buttes, salt valleys, cliffs, and canyons are formed in and underlain by thick layers of sedimentary rock. Juniper-pinyon woodland dominates higher elevations. Saltbush-greasewood and blackbrush communities are common at lower elevations. Summer moisture from thunderstorms supports warm season grasses. Many endemic plants occur. Several national parks are located in this ecoregion and attract many visitors to view their arches, spires, and canyons.

Escarpments Level IV Ecoregion (Figure 10): Characterized by extensive, deeply-dissected, cliff-bench complexes that ascend dramatically from Ecoregions 20b (Shale Deserts) or 20c (Semiarid Benchlands and Canyonlands) to the forested mountain rim. Local relief can be as great as 3,000 feet. This ecoregion includes major scarp slopes of the Tavaputs Plateau, the Book Cliffs, and the Grand Staircase. Natural vegetation ranges from Douglas-fir forest on steep, north-facing slopes at higher elevations to desert and semidesert grassland or shrubland on lower, drier sites. Pinyon-juniper woodland often dominates escarpments and benches that are covered by shallow soils. This rugged, remote, and varied landscape provides habitat for wildlife.

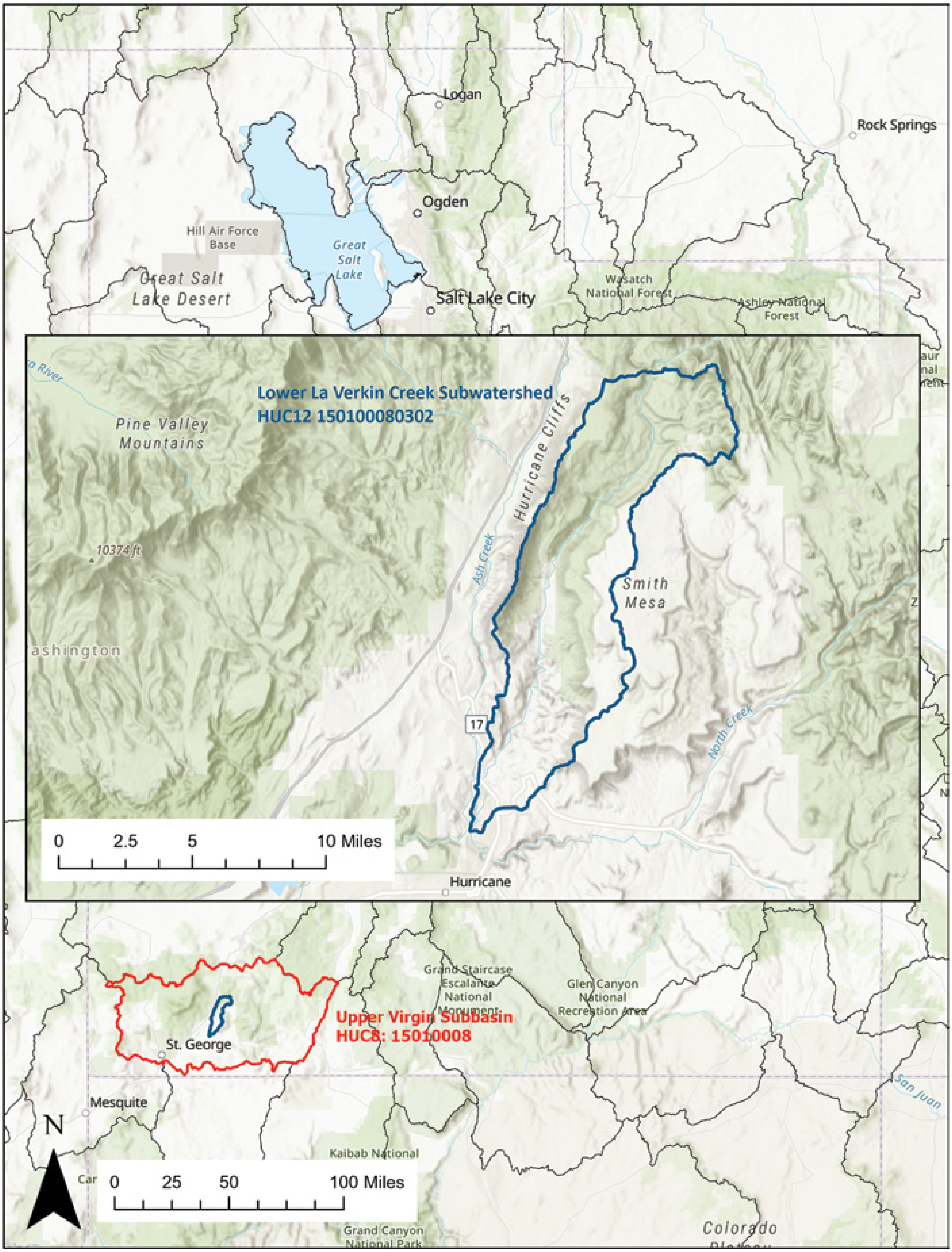


Figure 8. Upper Virgin Subbasin HUC8 and Lower LaVerkin Creek Subwatershed HUC12 boundaries.

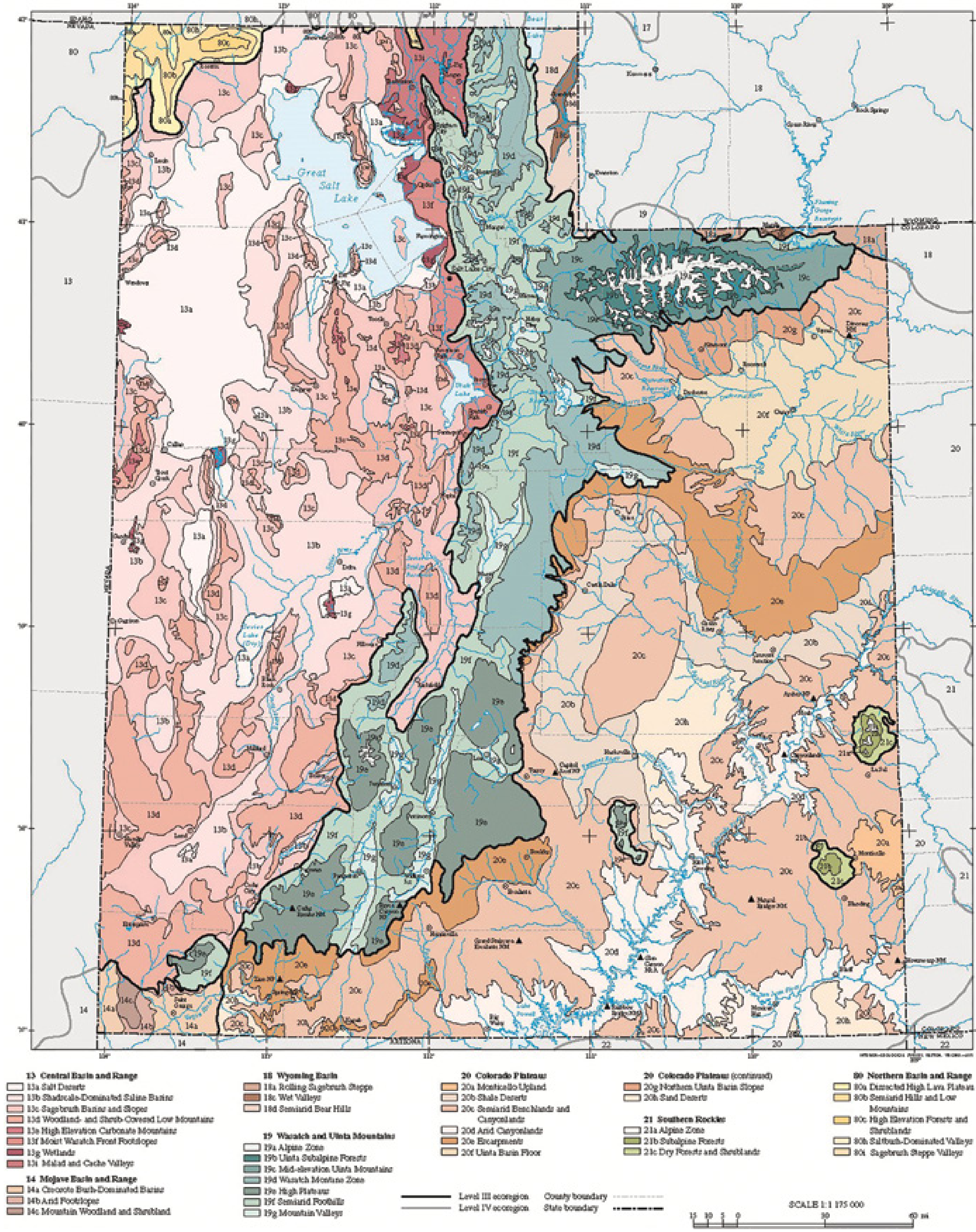


Figure 9. Map of the ecoregions of Utah (Woods et al. 2001).

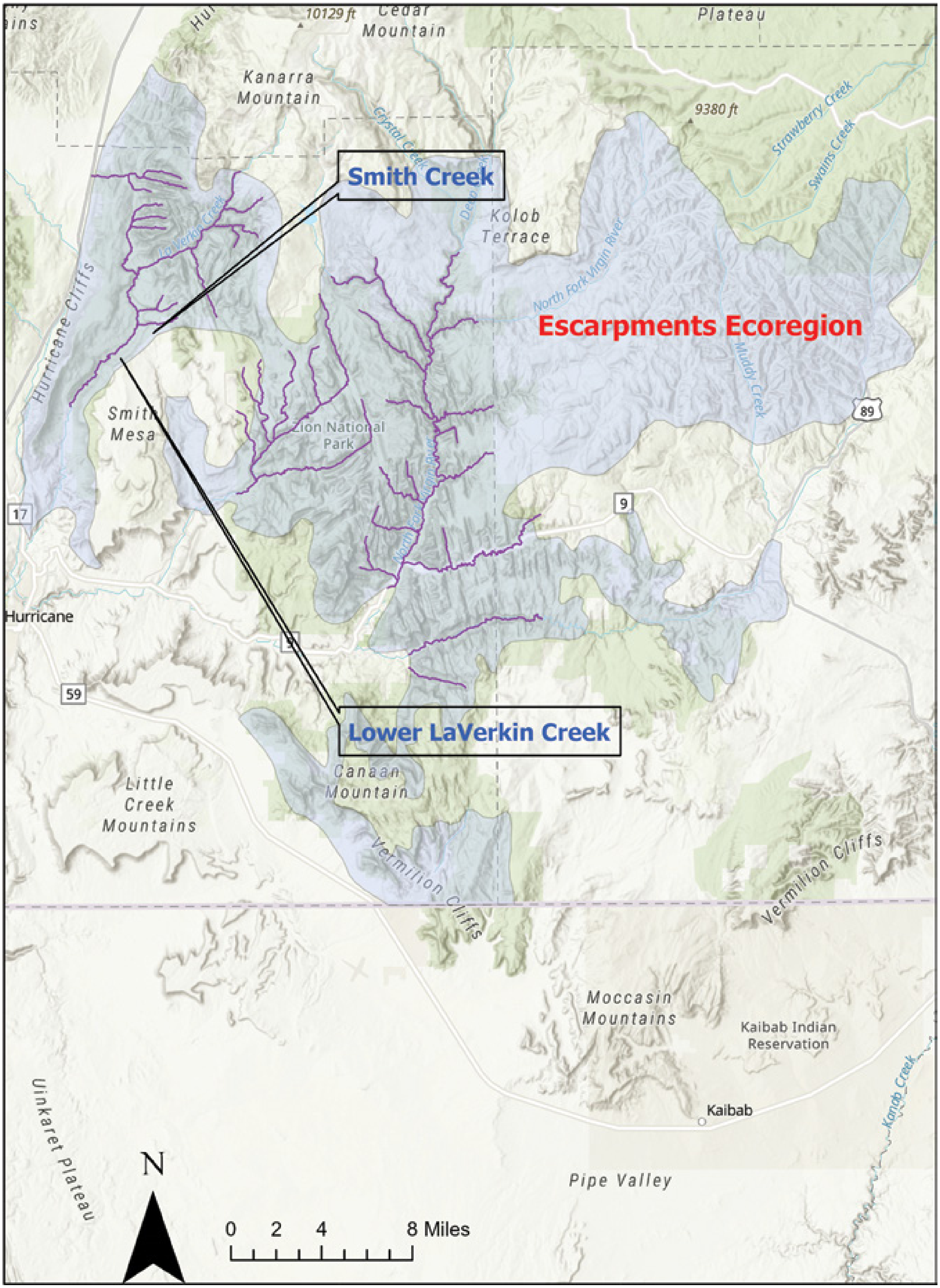


Figure 10. Map of the Escarpments ecoregion (Woods et al. 2001) and the locations of LaVerkin Creek and Smith Creek within the ecoregion.

1.12 Estimated Historical Climate Data

Figure 11 shows estimated historical monthly average temperature and precipitation data for the 30-year period from 1991 to 2020 for an arbitrary point (latitude 37.3673°, longitude -113.1892°) at an elevation of 4,715 feet above mean sea level near the confluence of LaVerkin and Smith Creeks (PRISM Climate Group 2023). Minimum, mean, and maximum temperatures are provided. Although no direct read station exists at this location, PRISM (Parameter-elevation Regressions on Independent Slopes Model) data were extrapolated from nearby actual stations. Table 5 provides the estimated historical monthly average temperature and precipitation data. The spatial resolution is 800 meters (m), and the data are monthly normals. Normals are baseline datasets containing average monthly and annual conditions during the most recent 30 years (PRISM Climate Group 2023).

Measured precipitation data from the Cedar City – Zion National Park, Kolob Canyons Weather Station (ID 1262327) are provided in chapter 3 and Appendix A.

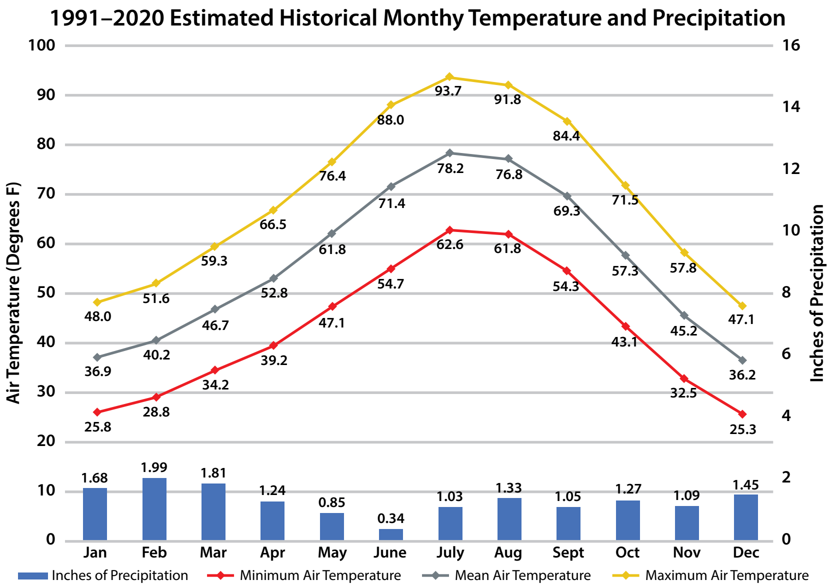


Figure 11. Graphical representation of the estimated historical monthly average temperature and precipitation data near the confluence of LaVerkin and Smith Creeks from 1991 to 2020 (PRISM Climate Group 2023).

Table 5. Estimated historical monthly average temperature and precipitation data near the confluence of LaVerkin and Smith Creeks from 1991 to 2020 (PRISM Climate Group 2023).

Month	Precipitation (inches)	Minimum Temperature (°F)	Mean Temperature (°F)	Maximum Temperature (°F)
January	1.68	25.8	36.9	48.0
February	1.99	28.8	40.2	51.6
March	1.81	34.2	46.7	59.3
April	1.24	39.2	52.8	66.5
May	0.85	47.1	61.8	76.4
June	0.34	54.7	71.4	88.0
July	1.03	62.6	78.2	93.7
August	1.33	61.8	76.8	91.8
September	1.05	54.3	69.3	84.4
October	1.27	43.1	57.3	71.5
November	1.09	32.5	45.2	57.8
December	1.45	25.3	36.2	47.1
Annual	**Total 15.13**	**Average 42.5**	**Average 56.1**	**Average 69.7**

2. Streamflow Measurements

2.1 Introduction

BLM and NPS field personnel measured streamflow at multiple locations in both rivers. The purposes of these measurements included quantifying flow conditions, identifying gaining and losing reaches, and evaluating changes in flow across different geological formations. Measurements were made in October 2022 and October 2023. Because monsoons may occur July through September and snow accumulation and runoff may occur between November and June, streamflow measurements were done in October when base flow conditions were anticipated. Field personnel endeavored to obtain the flow measurements at the end of a minimum 7-day period with no precipitation.

In October 2022, BLM and NPS field personnel measured streamflow at 13 locations in Smith Creek and 7 locations in LaVerkin Creek. Because time constraints prevented streamflow measurements at several planned locations in 2022, additional streamflow measurements were made at 18 locations in October 2023—12 in Smith Creek and 6 in LaVerkin Creek. In 2023, some measurements were made in new locations and others were made at or near locations measured in 2022. Not all locations measured in 2022 were remeasured in 2023. Flow measurement locations are depicted in Figure 12, and coordinates are provided in Appendix E.

2.2 Methods

In general, flow measurements were made in accordance with the sampling plan (BLM 2022). Several flow measurement techniques were used depending on the flow volume at the measurement location. Some flow measurements were made using a modified USGS Parshall flume. This flume is portable with a 3-inch throat and a 7.75-inch-wide mouth. Flow depth was converted to discharge in gallons per minute (gpm) using a table per standard operating procedure (Turnipseed and Sauer 2010).

A portable weir plate was used when depth and velocities were low and site conditions were unsuitable for the portable Parshall flume. The portable weir plate directed all flow through a V-shaped notch, and water height (measured from the bottom of the notch) was read off a scale scored into the weir plate's surface. The water height measurement was used to compute the volumetric discharge using a standard equation (Buchanan and Somers 1969). After flows stabilized over the portable weir plate, height readings were recorded at 30-second intervals for about 3 minutes. At low discharges, field personnel accounted for effects of surface tension in weir plate readings (Springer et al. 2006).

Flow measurements for lower LaVerkin Creek were taken using the velocity-area method as described by Nolan and Shields (2000). Suitable measurement sites were selected where channel dimensions were favorable and minimal backwater and other obstructions were observed. A topographic survey was conducted at each measurement site to document the wetted width, floodplain, and flood-prone areas. Measurements were collected with a top-setting wading rod and a Marsh-McBirney Flo-Mate Model 2000 portable flowmeter.

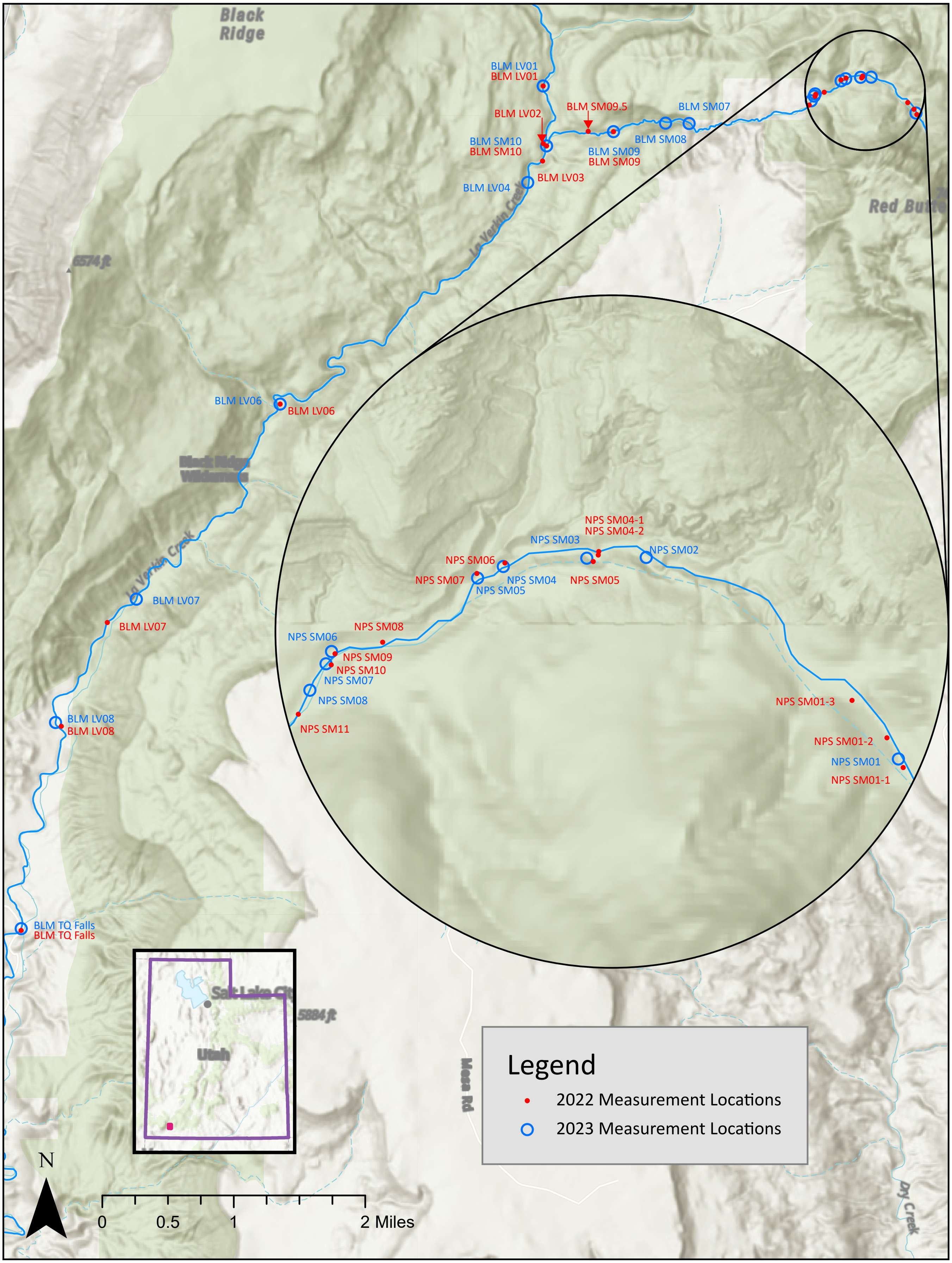


Figure 12. Streamflow measurement and water quality sample locations of LaVerkin and Smith Creeks.

2.3 Results

Tables 6 and 7 summarize flow measurement locations and methods, the geologic formation at each sampling location, and discharge measurements for 2022 and 2023, respectively. For Smith Creek, the approximate distance downstream from the beginning of the creek is provided for each measurement location. For LaVerkin Creek, the approximate distance downstream from the first sample location (BLM LV01) is given for each measurement location. Discharge results and inferred geologic contacts are shown graphically in Figure 13 for both 2022 and 2023.

In 2022, Smith Creek discharge was low or zero near the headwaters. Flow increased in the vicinity of the contact between Navajo Sandstone and the Kayenta Formation. Thereafter, discharge declined in the downstream direction. Similar to 2022, Smith Creek discharge in 2023 was low near the headwaters but increased in the vicinity of the contact between Navajo Sandstone and the Kayenta Formation. Discharge remained unchanged in the Kayenta Formation and the Springdale Member of the Kayenta Formation. Flow increased in each of the downstream formations, the Whitmore Point and Dinosaur Canyon Members of the Moenave Formation and Petrified Forest Member of the Chinle Formation.

In 2022, LaVerkin Creek discharge remained relatively constant between the upstream location and the downstream measurement locations. A temporary increase in flow was measured just upstream of the confluence with Smith Creek at a location upstream of the contact between the Petrified Forest Member and the Shinarump Member of the Chinle Formation. A temporary decrease in discharge was measured in the vicinity of the contact between Shnabkaib and Middle Red Members of the Moenkopi Formation. In 2023, LaVerkin Creek discharge was higher at all measurement locations than in 2022, probably in response to more precipitation. As shown in Figure 13, discharge increased between the Petrified Forest and Shinarump Members of the Chinle Formation. Flow at the measurement location in the Upper Red Member of the Moenkopi Formation decreased compared to the upstream measurement location and was comparable to the flow in the Petrified Forest Member of the Chinle Formation. Flow increased in each of the subsequent measurement locations including in the Shnabkaib, Middle Red, and Virgin Limestone Members of the Moenkopi Formation.

2.4 Influence of Precipitation on Streamflow Measurements

Because precipitation in the watersheds could increase the streamflow, precipitation information is given for water years 2021 (partial), 2022, and 2023 (Figure 14). Precipitation data are from the Utah Climate Center (2024). Daily precipitation data for 2022 from the Cedar City – Zion National Park, Kolob Canyons Weather Station (ID 1262327) are provided in Appendix A (Figure A1 and Table A1). Daily precipitation data for 2023 from that station are provided in Figure A2 and Table A2. The weather station is located at 37.4572° north latitude, -113.2248° west longitude at an elevation of 5,096 feet above mean sea level. The weather station is located about 7 miles to the north-northwest of the confluence of LaVerkin and Smith Creeks.

The total precipitation in calendar year 2022 up until the flow measurements were made was 7.94 inches. There were no significant precipitation events in the week prior to 2022 fieldwork. The precipitation in the 30 days prior to the flow measurements was 0.26 inches. In the 60 days before the flow measurements, 3.13 inches of precipitation was measured. In the 90 days prior to the flow measurements, 4.84 inches of precipitation was measured. In calendar year 2022, a total of 13.81 inches of precipitation fell.

The total precipitation in calendar year 2023 up until the flow measurements were made was 24.58 inches. Precipitation events totaling 0.21 inches occurred on October 1 and 2, 2023. Flows appeared slightly elevated compared to scour line, about 2 to 3 inches higher than normal base flow. The precipitation in the 30 days prior to the flow measurements was 0.73 inches. In the 60 days before the flow measurements, 4.83 inches of precipitation was measured. In the 90 days prior to the flow measurements, 5.17 inches of precipitation was measured. In calendar year 2023, a total of 26.03 inches of precipitation fell.

Table 8 shows the total annual precipitation for the Cedar City – Zion National Park, Kolob Canyons

Weather Station (ID 1262327) for calendar years 2016 through 2023. Total annual precipitation values range from nearly 11 inches in 2020 to more than 30 inches in 2019. The average is about 20 inches for the 8-year period for which data are available at this station. The purpose of this information is to show how precipitation in calendar years 2022 and 2023 compared to other available years. The goal is to better understand whether measured flow rates represent short-term high rates of groundwater discharge that might be associated with a year with high precipitation. Whereas the annual precipitation in 2022 was on the lower end of the range, the annual precipitation in 2023 was on the higher end of the range.

Table 6. 2022 streamflow measurements, geologic units, and notes for Smith and LaVerkin Creeks.

Measurement Date	Site ID	Approximate Distance Downstream* (river meters)	Measured Discharge (cubic feet per second)	Measured Discharge (gallons per minute)	Flow Measurement Method	Geologic Formation Symbol	Geologic Formation Name	Notes
Smith Creek								
10/19/2022	NPS SM01-1	265	< 0.0001	< 0.0001	Weir Plate	Jn	Navajo Sandstone	
10/19/2022	NPS SM01-2	322	< 0.0001	0.404	Weir Plate			
10/19/2022	NPS SM01-3	412	0	0	Weir Plate			
10/19/2022	NPS SM04-1	951	< 0.0001	< 0.0001	Weir Plate			
10/19/2022	NPS SM04-2	955	0	0	Weir Plate			
10/19/2022	NPS SM05	983	< 0.0001	0.220	Weir Plate			Perennial flow starts
10/19/2022	NPS SM06	1,139	0.145	65.2	USGS Modified Parshall 3-inch Flume	Jk	Kayenta Fm.	
10/19/2022	NPS SM08	1,403	0.0862	38.7	USGS Modified Parshall 3-inch Flume			
10/19/2022	NPS SM09	1,490	0.170	76.3	USGS Modified Parshall 3-inch Flume			
10/19/2022	NPS SM11	1,613	0.0655	29.4	USGS Modified Parshall 3-inch Flume			
Not collected	BLM SM06							Not measured due to time constraints
Not collected	BLM SM07							
Not collected	BLM SM08							
10/19/2022	BLM SM09	3,792	0.0483	21.7	USGS Modified Parshall 7.75-inch Flume	Jmd/just below Jmw	Moenave Fm. Dinosaur Canyon Sandstone Mbr.	
10/19/2022	BLM SM09.5	4,069	0.0426	19.1	USGS Modified Parshall 7.75-inch Flume	TRcp	Chinle Fm. Petrified Forest Mbr.	
10/19/2022	BLM SM10	4,569	0.036	16.3	USGS Modified Parshall 7.75-inch Flume	TRcp/TRcs contact	Chinle Fm. Petrified Forest Mbr./ Shinarump Mbr.	Alluvium/ TRcp-TRcs

Table 6 continued. 2022 streamflow measurements, geologic units, and notes for Smith and LaVerkin Creeks.

Measurement Date	Site ID	Approximate Distance Downstream* (river meters)	Measured Discharge (cubic feet per second)	Measured Discharge (gallons per minute)	Flow Measurement Method	Geologic Formation Symbol	Geologic Formation Name	Notes
LaVerkin Creek								
10/19/2022	BLM LV01	0	3.36	1,510	Velocity-Area	TRcp	Chinle Fm. Petrified Forest Mbr.	At Zion NP/BLM boundary
10/19/2022	BLM LV02	625	4.24	1,900	Velocity-Area	TRcp lower	Chinle Fm. Petrified Forest Mbr.	Slight flow increase likely due to confluence with Smith Creek to the east
10/19/2022	BLM LV03	793	3.59	1,610	Velocity-Area	Bottom TRcp/ Upper TRcs contact	Chinle Fm. Petrified Forest Mbr./ Shinarump Mbr.	
Not collected	BLM LV04							Not measured due to time constraints
10/18/2022	BLM LV06	5,142	3.45	1,550	Velocity-Area	TRmu	Moenkopi Fm. Upper Red Mbr.	
10/18/2022	BLM LV07	8,244	3.40	1,530	Velocity-Area	TRms middle	Moenkopi Fm. Shnabkaib Mbr.	
10/18/2022	BLM LV08	9,490	3.12	1,400	Velocity-Area	TRms/ TRmm contact	Moenkopi Fm. Shnabkaib Mbr./ Middle Red Mbr.	
10/18/2022	BLM TQ Falls (Toquerville Falls)	12,036	3.54	1,590	Velocity-Area	TRmv	Moenkopi Fm. Virgin Limestone Mbr.	Falls located below private land along LaVerkin Creek

* For Smith Creek, this is the approximate distance downstream from the beginning of the creek. For LaVerkin Creek, this is the approximate distance downstream from the first sample location.

Table 7. 2023 streamflow measurements, geologic units, and notes for Smith and LaVerkin Creeks.

Measurement Date	Site ID	Approximate Distance Downstream* (river meters)	Measured Discharge (cfs)	Measured Discharge (gpm)	Flow Measurement Method	Geologic Formation Symbol	Geologic Formation Name	Notes
Smith Creek								
10/4/2023	NPS SM01	265	0.00355	1.59	Weir	Jn	Navajo Sandstone	Near 2022 SM01-1
Not collected	NPS SM01-2							
Not collected	NPS SM01-3							
10/4/2023	NPS SM02	951	0.00159	0.714	Weir	Jn		Near 2022 SM04-1
Not collected	NPS SM04-2							
10/4/2023	NPS SM03	983	0.00651	2.92	Weir	Jn		Near 2022 SM05
10/4/2023	NPS SM04	1,139	0.0949	42.59	Weir	Jk	Kayenta Fm.	Near 2022 SM06
10/4/2023	NPS SM05	Tributary	0.00052	0.233	Weir	Jn/Jk	Navajo Sandstone/ Kayenta Fm.	Near 2022 SM07
10/4/2023	NPS SM06	1,490	0.116	51.9	Weir	Jk	Kayenta Fm.	Near 2022 SM09
10/4/2023	NPS SM07	Tributary	0.00099	0.444	Weir	Jk	Kayenta Fm.	Near 2022 SM10-2
10/4/2023	NPS SM08	1,613	0.0999	44.8	USGS Modified Parshall 3-inch Flume	Jk	Kayenta Fm.	Near 2022 SM11
Not collected	BLM SM06							At BLM/ private boundary. Large waterfall present. Other talus and other Quaternary hillslope deposits present
10/4/2023	BLM SM07	3,365	0.0971	43.6	USGS Modified Parshall 7.75-inch Flume	Jks	Kayenta Fm. Springdale Mbr.	
10/4/2023	BLM SM08	3,565	0.127	57.0	USGS Modified Parshall 7.75-inch Flume	Jmw (?)	Moenave Fm. Whitmore Point Mbr. (?)	
10/4/2023	BLM SM09	3,792	0.197	88.6	USGS Modified Parshall 7.75-inch Flume	Jmd/just below Jmw	Moenave Fm. Dinosaur Canyon Sandstone Mbr.	
Not collected	BLM SM09.5					TRcp		Not measured
10/4/2023	BLM SM10	4,569	0.228	102.4	USGS Modified Parshall 7.75-inch Flume	TRcp/TRcs contact	Chinle Fm. Petrified Forest Mbr./ Shinarump Mbr.	Alluvium/ TRcp-TRcs

Table 7 continued. 2023 streamflow measurements, geologic units, and notes for Smith and LaVerkin Creeks.

Measurement Date	Site ID	Approximate Distance Downstream* (river meters)	Measured Discharge (cfs)	Measured Discharge (gpm)	Flow Measurement Method	Geologic Formation Symbol	Geologic Formation Name	Notes
LaVerkin Creek								
10/4/2023	BLM LV01	0	3.87	1,740	Velocity-Area	TRcp	Chinle Fm. Petrified Forest Mbr.	At Zion NP/BLM boundary
Not collected	BLM LV02							Not measured
Not collected	BLM LV03							Not measured
10/4/2023	BLM LV04	1,100	5.68	2,550	Velocity-Area	TRcp or TRcs (?)	Chinle Fm. Petrified Forest Mbr. or Shinarump Mbr. (?)	
10/3/2023	BLM LV06	5,142	4.11	1,840	Velocity-Area	TRmu	Moenkopi Fm. Upper Red Mbr.	
10/3/2023	BLM LV07	8,244	4.64	2,080	Velocity-Area	TRms middle	Moenkopi Fm. Shnabkaib Mbr.	
10/3/2023	BLM LV08	9,490	5.35	2,400	Velocity-Area	TRms/ TRmm contact	Moenkopi Fm. Shnabkaib Mbr./Middle Red Mbr.	
10/3/2023	BLM TQ Falls (Toquerville Falls)	12,036	5.48	2,460	Velocity-Area	TRmv	Moenkopi Fm. Virgin Limestone Mbr.	Falls located below private land along LaVerkin Creek

* For Smith Creek, this is the approximate distance downstream from the beginning of the creek. For LaVerkin Creek, this is the approximate distance downstream from the first sample location.

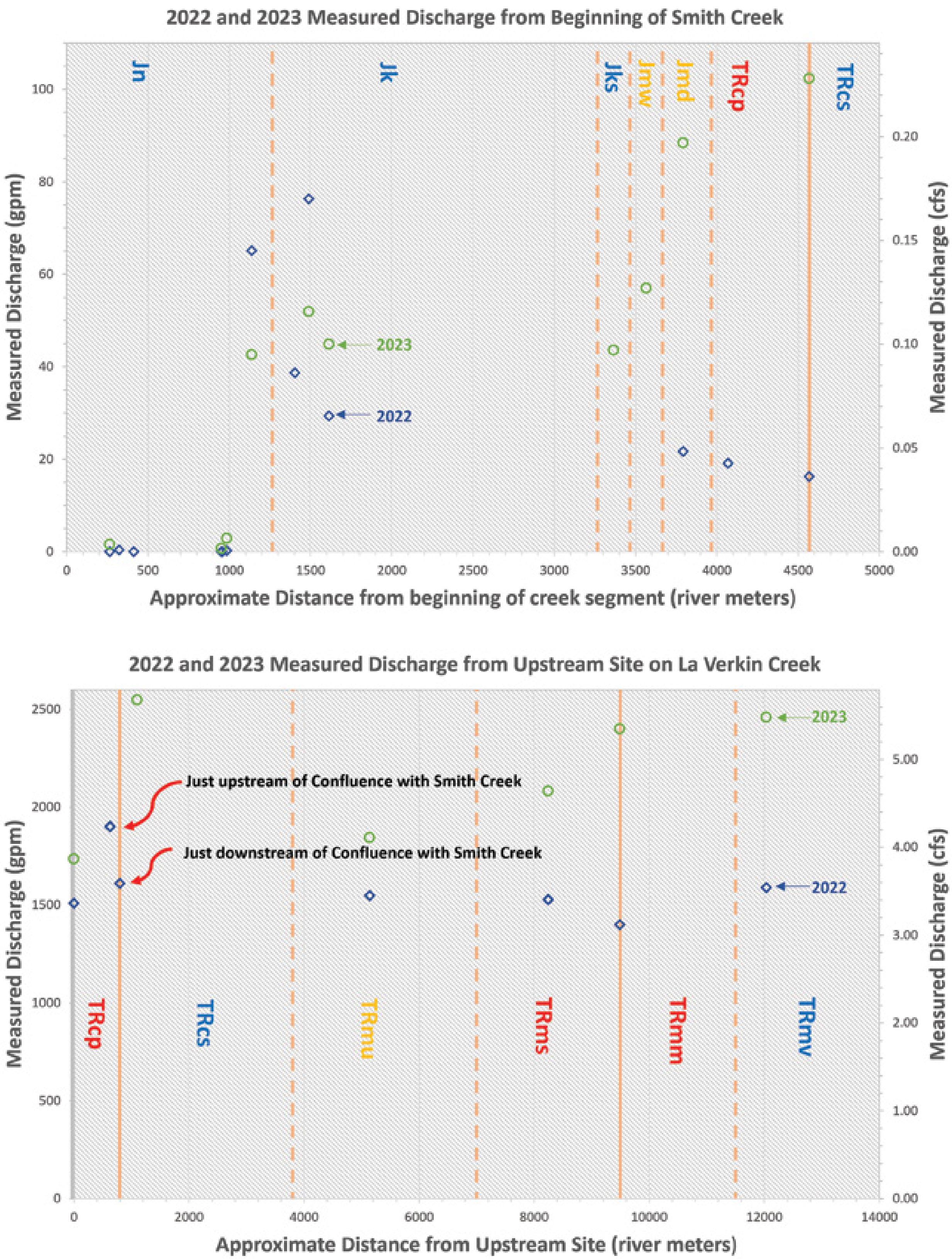


Figure 13. (Top) 2022 and 2023 measured discharge on Smith Creek with geologic formations. (Bottom) 2022 and 2023 measured discharge on LaVerkin Creek with geologic formations. Blue diamonds represent 2022 data. Green circles represent 2023 data. Geologic unit boundary locations are inferred. Color coding of geologic formations corresponds to the water-bearing properties shown in Table 14 (chapter 6). Blue font indicates the formation is an aquifer; yellow represents a marginal aquifer; and red is a confining unit.

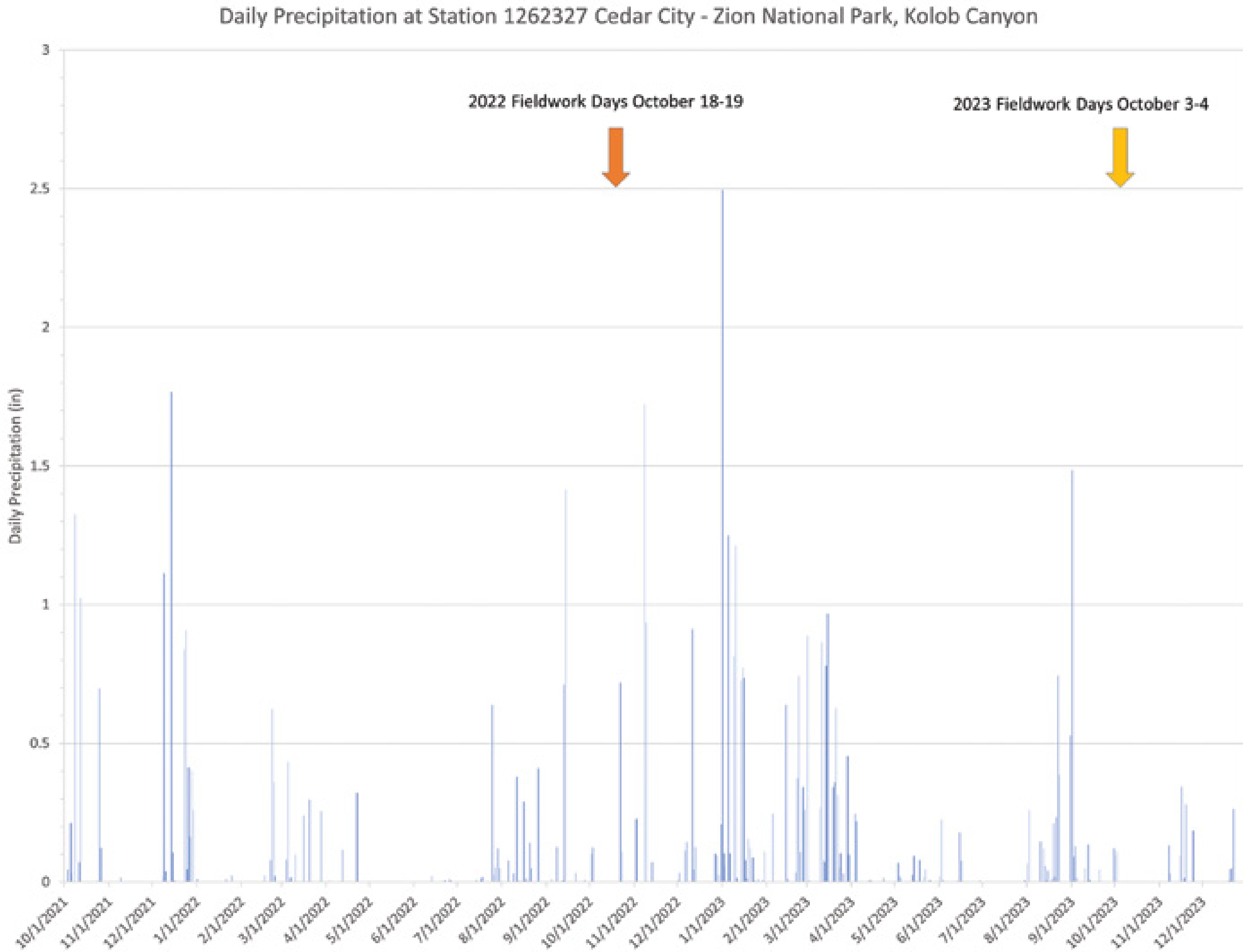


Figure 14. Daily precipitation at Cedar City – Zion National Park, Kolob Canyons Weather Station (ID 1262327) for water years 2021 (partial), 2022, and 2023. Fieldwork days in 2022 and 2023 are indicated.

Table 8. Annual precipitation at Cedar City – Zion National Park, Kolob Canyons Weather Station (ID 1262327) between 2016 and 2023.

Calendar Year	Total Precipitation (inches)
2016	21.97
2017	14.78
2018	16.98
2019	30.51
2020	10.86
2021	22.44
2022	13.81
2023	26.03
Minimum	10.86
Mean	19.67
Maximum	30.51

3. Water Quality Analyses

3.1 Introduction

The purpose of the water quality analyses was to evaluate baseline water quality, potential groundwater contributions to surface water, and possible changes in water chemistry along flow paths. In October 2022, surface water in lower LaVerkin Creek and Smith Creek was measured for field water quality parameters, and samples were collected for laboratory analysis of selected parameters. In October 2023, additional field water quality parameters were measured, but no new laboratory analyses were completed. Sample locations are shown in Figure 12. A list of water quality sample location coordinates is provided in Appendix E.

3.2 Methods

Sampling and quality assurance/quality control was completed as specified in the sampling plan (BLM 2022). Water quality was measured at BLM field sites with a YSI Pro Plus hand-held water quality meter in 2022 and with a YSI Pro 1030 hand-held water quality meter in 2023. The NPS used a HANNA multiparameter sonde (HI98194) in both 2022 and 2023. Hand-held water quality meters were calibrated daily prior to measurements. Results are provided in Table 9.

Water samples were also collected in 2022 for laboratory analysis (Table 10). Chemtech-Ford Laboratories in Sandy, Utah, performed the laboratory analyses. The laboratory analytical method used is provided in Table 10. Piper (1944) and Stiff (1951) diagrams are provided in Appendix B (Figures B1 through B10). The Piper and Stiff diagrams were generated using an Excel-based analysis developed by Halford Hydrology (Halford 2023). The total dissolved solids value given in the Piper and Stiff diagrams is not the same value measured by the lab. The Piper and Stiff diagrams use the sum of anions and cations as the total dissolved solids value, whereas in the laboratory method an aqueous sample is measured, the water is evaporated completely in an oven, and the dry residue is weighed.

3.3 Results

As shown in the Piper diagrams in Appendix B, upper Smith Creek waters are calcium bicarbonate waters. This designation is typical of shallow, fresh groundwater. Lower LaVerkin Creek and lower Smith Creek waters are calcium sulfate waters, suggesting water from a gypsum-bearing geologic formation contributed to the surface water. Based on geologic information, lower LaVerkin Creek and lower Smith Creek may be picking up sulfate from the Shnabkaib Member of the Moenkopi Formation. There also appears to be a restricting aquitard-type member at the top of the Petrified Forest Member of the Chinle Formation where springs and seeps were present about halfway up Smith Mesa. This clay unit likely influences the water chemistry and may be associated with the hillslope/gravity-driven springs and seep areas that are expressed in the lower Smith Creek water chemistry. Total dissolved solids and conductivity generally increase in the downstream direction.

Table 9. 2022 and 2023 field water quality results for LaVerkin and Smith Creeks.

Date Collected	Site ID	Dissolved Oxygen (%)	Conductivity (µs/cm)	Specific Conductivity (µs/cm)	pH	Water Temperature (°C)	Total Dissolved Solids (ppm)
2022							
10/19/2022	BLM LV01	76.9	523	713	7.58	11.0	-
10/19/2022	BLM LV02	72.1	550	713	7.57	13.0	-
10/19/2022	BLM LV03	74.7	585	722	7.92	15.1	-
10/18/2022	BLM LV06	85.9	593	732	7.92	15.1	-
10/18/2022	BLM LV07	81.6	639	763	7.81	16.5	-
10/18/2022	BLM LV08	75.7	676	784	7.41	17.8	-
10/18/2022	BLM TQ Falls	86.6	678	848	7.20	14.4	-
10/19/2022	BLM SM09	65.0	1,737	2,299	7.25	12.2	-
10/19/2022	BLM SM09.5	70.5	1,880	2,522	6.50	11.7	-
10/19/2022	BLM SM10	72.0	2,040	2,688	7.38	12.4	-
10/19/2022	NPS SM01	-	414	-	-	16.7	208
10/19/2022	NPS SM04	-	571	-	-	12.5	286
10/19/2022	NPS SM05	-	481	-	-	11.2	240
10/19/2022	NPS SM06	-	408	-	-	10.3	204
10/19/2022	NPS SM07	-	765	-	-	9.4	382
10/19/2022	NPS SM08	-	504	-	-	8.9	252
10/19/2022	NPS SM09	-	511	-	-	9.3	256
10/19/2022	NPS SM10	-	413	-	-	11.3	216
10/19/2022	NPS SM11	-	527	-	-	10.3	263
2023							
10/4/2023	BLM LV01	-	-	713	8.28	16.3	-
10/4/2023	BLM LV04	-	-	769	8.41	16.3	-
10/3/2023	BLM LV06	-	-	794	8.13	15.3	-
10/3/2023	BLM LV07	-	-	334	8.13	16.0	-
10/3/2023	BLM LV08	-	-	841	7.80	13.4	-
10/4/2023	NPS SM01	-	84	-	-	12.2	42
10/4/2023	NPS SM02	-	545	-	-	10.9	273
10/4/2023	NPS SM03	-	331	-	-	11.1	167
10/4/2023	NPS SM04	-	266	-	-	12.3	130
10/4/2023	NPS SM05	-	505	-	-	11.6	247
10/4/2023	NPS SM06	-	481	-	-	10.5	240
10/4/2023	NPS SM07	-	709	-	-	11.8	354
10/4/2023	NPS SM08	-	533	-	-	11.4	268

In 2022, field parameters were measured by the BLM using a YSI Pro Plus hand-held water quality meter. The meter was calibrated daily on October 18 and 19, prior to sampling per the sampling plan. In 2023, the BLM used a YSI Pro 1030 hand-held water quality meter. In 2023, the NPS used a calibrated HANNA Instruments Portable Multiparameter Meter (HI98194).

A dash ("-") indicates the parameter was not measured.

Table 10. 2022 laboratory water quality results for LaVerkin and Smith Creeks.

Parameter/ Location	BLM LV02	BLM LV03	BLM LV06	BLM LV07	BLM LV08	NPS SM01*	NPS SM05	BLM SM09	BLM SM9.5	BLM SM10	Minimum Reporting Limit	Method
Inorganic												
Alkalinity – Bicarbonate (as $CaCO_3$)	172	170	158	145	143	221	245	219	231	230	1.0	SM 2320 B
Alkalinity – Carbonate (as $CaCO_3$)	-	-	-	-	-	-	-	-	-	-	1.0	SM 2320 B
Alkalinity – Hydroxide (as $CaCO_3$)	-	-	-	-	-	-	-	-	-	-	1.0	SM 2320 B
Alkalinity – Total (as $CaCO_3$)	172	170	158	145	143	221	245	219	231	230	1.0	SM 2320 B
Chloride	7.75†	8.88†	9.30†	9.93†	10.1†	3.88†	6.70†	93.0†	110‡	130‡	1.00†, 5.00‡	EPA 300.0
Fluoride	0.149	ND	0.150	ND	0.153	-	-	-	-	-	0.100	EPA 300.0
Nitrate + Nitrite, Total, as N	-	-	-	-	-	-	-	1.29	0.796	0.435	0.100	EPA 353.2
Sulfate	205‡	219‡	230‡	259† E***	275‡	1.20†	10.9†	980**	1060**	1120**	1.00†, 5.00‡, 100**	EPA 300.0
Total Dissolved Solids	420	488	472	512	528	228	280	1840	1540	2130	20	SM 2540 C
Metals												
Arsenic, Total	0.0010	0.0011	0.0010	0.0010	0.0009	0.0028	0.0024	0.0021	0.0021	0.0018	0.0005	EPA 200.8
Calcium, Total	94.3	91.9	95.2	98.5	96.1	53.0	62.6	294	314	307	0.2	EPA 200.7
Iron, Total	0.03	0.04	0.08	0.08	0.03	0.68	1.54	0.03	0.08	0.02	0.02	EPA 200.7
Magnesium, Total	31.9	31.4	34.5	35.8	33.8	21.2	24.4	85.0	95.8	98.6	0.2	EPA 200.7
Manganese, Total	0.0108	0.0100	0.0123	0.0096	0.0071	0.329	0.373	0.0275	0.0574	0.0449	0.0005	EPA 200.8
Phosphorus, Total as P	-	-	-	0.01	-	0.03	0.06	-	0.01	-	0.01	EPA 200.7
Potassium, Total	2.9	2.9	3.1	3.2	3.0	2.0	2.0	7.6	8.4	8.6	0.5	EPA 200.7
Silica, (as SiO_2) Total	8.1	7.8	8.6	8.5	7.5	14.2	16.0	14.9	16.5	14.4	0.1	EPA 200.7
Sodium, Total	15.3	16.3	18.8	20.2	18.8	3.8	7.8	149	196	208	0.5	EPA 200.7
Strontium, Total	1.72	1.69	1.82	1.94	1.87	0.08	0.18	4.94	5.31	5.25	0.005	EPA 200.7
Uranium, Total	0.0018	0.0019	0.0020	0.0018	0.0020	-	-	0.0250	0.0261	0.0237	0.0005	EPA 200.8

All units are in milligrams per liter (mg/L). A dash ("-") indicates no data. Samples were analyzed by Chemtech-Ford Laboratories, Sandy, Utah.
* Sample collected at NPS SM01-2 in Figure 12.
† The sample had a minimum reporting limit of 1.00 mg/L.
‡ The sample had a minimum reporting limit of 5.00 mg/L.
** The sample had a minimum reporting limit of 100 mg/L.
*** E = The concentration indicated for this analyte is an estimated value above the calibration range of the instrument. This value is considered an estimate (CLP E-flag).

3.4 Water Quality Standards

According to the "Final 2022 Integrated Report on Water Quality," the most recent water quality report by the Utah Department of Environmental Quality, LaVerkin Creek is not meeting benthic macroinvertebrates criteria, and a total maximum daily load (TMDL) is needed (Table 11).

Table 11. Assessment information for LaVerkin Creek from the "Final 2022 Integrated Report on Water Quality."

Assessment Unit Information	
Watershed Management Unit	Lower Colorado River
Assessment Unit (AU) ID	UT15010008-010_00
AU Name	LaVerkin Creek
Water Size/Unit	48.0 miles
AU Category	5
Category Description	Not Supporting
Associated Parameter Information	
Water Quality Parameter	Benthic Macroinvertebrates Bioassessments
Parameter Status	Not meeting criteria
303(d) Status	TMDL Needed
Use(s)	Aquatic Wildlife (Warm Water)
Cycle First Listed	2016
303(d) Priority	Low

4. Stable Isotope Analysis

4.1 Introduction

Stable isotope data can be used to determine water sources and flow paths. BLM and NPS personnel collected 13 stable isotope (hydrogen and oxygen) samples on October 18 and 19, 2022. Five samples were collected from LaVerkin Creek, and eight samples were collected from Smith Creek. Sample locations are listed in Table 12 and are shown in Figure 12.

4.2 Methods

Sampling and quality assurance/quality control was completed as specified in the sampling plan (BLM 2022). Samples were collected in 5 mL bottles with no headspace and analyzed by the Stable Isotope Ratio Facility for Environmental Research (SIRFER) Lab at the University of Utah.

4.3 Results

Steven Rice, NPS hydrologist, interpreted the isotope results. Figure 15 is a stable isotopic signature reference. The stable isotope results are shown in Figure 16 and Table 12. Results of three samples collected by the NPS in September 2022 in Hop Valley are included.

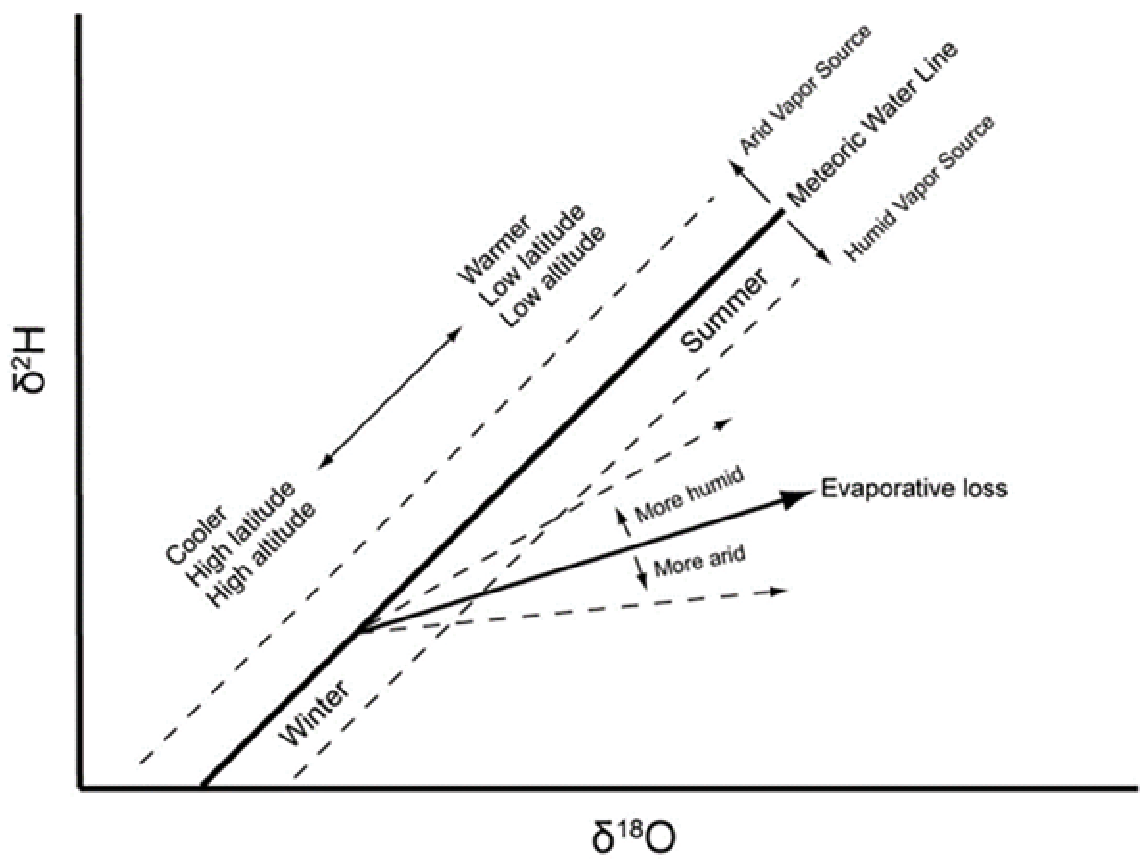


Figure 15. Generalized stable isotopic signature reference (modified from Clark and Fritz 1997).

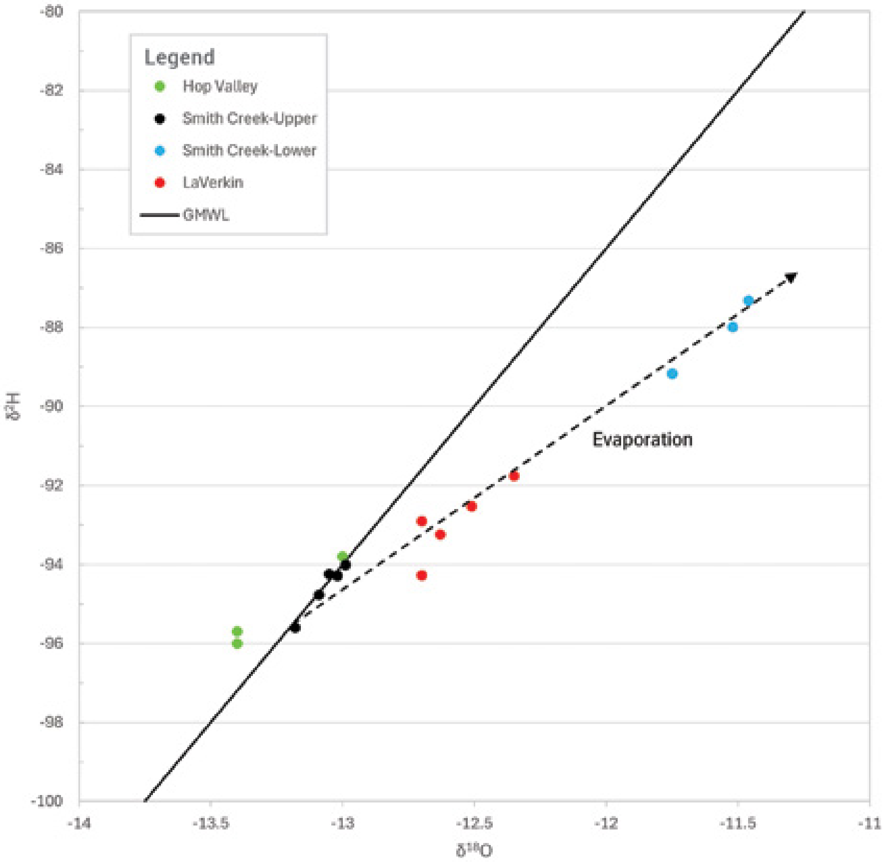


Figure 16. Stable isotope analysis results from LaVerkin and Smith Creeks.

Table 12. Stable isotope analysis results from LaVerkin and Smith Creeks.

Date Collected	Site ID	Elevation (meters AMSL)	δ Oxygen 18	δ Deuterium (Hydrogen 2)
10/19/2022	BLM LV02	1,397	-12.70	-94.27
10/19/2022	BLM LV03	1,393	-12.63	-93.24
10/18/2022	BLM LV06	1,270	-12.51	-92.52
10/18/2022	BLM LV07	1,206	-12.70	-92.90
10/18/2022	BLM LV08	1,183	-12.35	-91.75
10/19/2022	NPS SM01* (Upper)	1,758	-12.99	-94.01
10/19/2022	NPS SM05 (Upper)	1,721	-13.05	-94.24
10/19/2022	NPS SM07 (Upper)	1,715	-13.18	-95.60
10/19/2022	NPS SM010 (Upper)	1,688	-13.02	-94.28
10/19/2022	NPS SM011 (Upper)	1,681	-13.09	-94.77
10/19/2022	BLM SM9 (Lower)	1,479	-11.75	-89.17
10/19/2022	BLM SM09.5 (Lower)	1,443	-11.52	-87.99
10/19/2022	BLM SM10 (Lower)	1,398	-11.46	-87.32
9/1/2022	Hop Valley 01	1,762	-13.4	-96.0
9/1/2022	Hop Valley 02	1,771	-13.4	-95.7
9/1/2022	Hop Valley 03	1,764	-13.0	-93.8

* Sample collected at NPS SM01-2 in Figure 12.

4.4 Discussion

The samples collected in the upper portion of Smith Creek and Hop Valley (largely if not entirely Navajo Sandstone groundwater) are depleted and plot along the Global Meteoric Water Line (GMWL), indicating they were probably recharged mainly by winter precipitation and did not experience much, if any, evaporation prior to recharge. The samples from the lower part of Smith Creek and LaVerkin Creek are more enriched (less negative) and plot along a trend line off the GMWL, indicating they have been partially evaporated.

The intersection of the evaporative trend line and the GMWL coincides with the upper Smith Creek samples. This suggests it is likely all the water originated from a similar source initially (Navajo Sandstone) and that there has been little to no other source of groundwater input to alter the stable isotope signatures of the lower reaches of Smith Creek and LaVerkin Creek (though groundwater chemistry indicates further circulation of this groundwater through and contact with other geologic units – see chapter 3).

The indication that lower reaches of Smith Creek are even more evaporatively impacted than LaVerkin Creek may be a result of the difference in discharge, with LaVerkin Creek having a much higher flow and therefore a smaller proportional amount of evaporation.

5. Theis Drawdown Analysis

5.1 Introduction to Streamflow Depletion Analysis

Evaluation of potential risks from streamflow depletions of LaVerkin Creek and Smith Creek requires an analysis of the most likely groundwater development scenarios on private lands adjacent to the two creeks. Smith Mesa, which is located immediately to the south of Smith Creek and immediately to the east of LaVerkin Creek, contains substantial acreage of private lands that is easily accessed by county roads. Given the pace of private land development adjacent to Zion National Park, this area could experience significant residential development that would likely rely upon groundwater, since there are no perennial streams on Smith Mesa.

To better understand the risks associated with new groundwater uses on Smith Mesa, the BLM and NPS estimated the risks from streamflow depletion by using two analytical techniques. This chapter presents a Theis drawdown analysis, which identifies the potential groundwater drawdown of the creeks from various pumping scenarios. The next chapter contains a streamflow depletion analysis using the Glover method, which quantifies cumulative depletions as both a volume (ft^3) and a flow rate (gallons per minute, gpm) from various well development scenarios.

5.2 Methods

An analytical solution by Theis (1935, 1940) was implemented to estimate drawdown (groundwater-level decline) resulting from potential future groundwater pumping near LaVerkin and Smith Creeks. Drawdown caused by pumping wells depends on several factors including the pumping rate (Q), aquifer transmissivity (T), aquifer storage coefficient (S), radial distance from the pumping well (r), and time since pumping started (t).

Primary assumptions include:

- The aquifer is flat, homogeneous, isotropic, and infinite in areal extent.
- The pumping well fully penetrates the aquifer.
- Flow is horizontally radial towards the well.

The Theis drawdown equation is:

$$ho - h = \frac{Q}{4\pi T} W(u) \qquad u = \frac{(r^2 S)}{4Tt}$$

Where:

ho – h or *s* is the drawdown in the aquifer (L)

ho is the initial water level in the aquifer (L)

h is the water level in the aquifer at a radial distance (r) at a time (t) since pumping started (L)

Q is the constant pumping rate (L^3/T)

T is the aquifer transmissivity (L^2/T)

W(u) is the Theis well function

r is the radial distance from the pumping well to the observation point (L)

S is the aquifer storage coefficient (dimensionless)

t is the time since pumping started (T)

Table 13 summarizes the input parameters used in the water-level drawdown analysis. This drawdown analysis uses the same values for transmissivity (T) and storage coefficient (S) selected for the Glover streamflow depletion analysis presented in chapter 6. The T and S values are for the Kayenta Formation from USGS reports by Wilkowske et al. (1998) and Cordova et al. (1972) because the Kayenta Formation is the likely source for future wells that may be developed on Smith Mesa. To be consistent with the Glover analysis, values of the pumping rate and distance from the river of hypothetical wells were chosen based on reasonably foreseeable development scenarios on Smith Mesa for dispersed parcels of largely residential potable water needs. It is assumed that hydraulic properties in geologic units below the Kayenta Formation are similar to those in that formation.

Table 13. Summary of input parameters for the Theis drawdown analysis.

Input Parameter	Unit	Value(s)
Transmissivity (T)	ft^2/day	3,500
Storage coefficient (S)	dimensionless	0.006
Distance from river (r)	ft	2,640, 5,280, 10,560 *
Pumping rate (Q)	ft^3/day	206, 1,790 **

* Values equivalent to a well 0.5, 1, and 2 miles from the river.
** Values equivalent to 1.73 acre-feet per year (Utah Division of Water Resources domestic use) and 15 acre-feet per year.

5.3 Results

The drawdown results in Table 14 and Figure 17 are for a single pumping well. For situations with multiple pumping wells in an ideal aquifer, the drawdowns are additive. For example, column 5 in Table 14 shows drawdown of 0.0307 ft from one well pumping 206 cubic feet per day at a distance of 2,640 ft from the stream after 10 years. For 50 individual wells, the drawdown would be about 1.5 ft (0.0307 ft x 50 wells = 1.535 ft).

Table 14. Summary of results for six pumping scenarios involving a single pumping well. Drawdown (ft) was estimated using the Theis solution (Theis 1935, 1940).

Distance (ft)	Pumping Rate (ft^3/day)	Drawdown after 1 Year (ft)	Drawdown after 5 Years (ft)	Drawdown after 10 Years (ft)	Drawdown after 50 Years (ft)	Drawdown after 100 Years (ft)
2,640	206	0.0199	0.0274	0.0307	0.0382	0.0415
2,640	1,790	0.172	0.238	0.266	0.331	0.360
5,280	206	0.0135	0.0209	0.0242	0.0317	0.0350
5,280	1,790	0.117	0.182	0.210	0.275	0.303
10,560	206	0.00743	0.0145	0.0177	0.0252	0.0285
10,560	1,790	0.0645	0.126	0.154	0.219	0.247

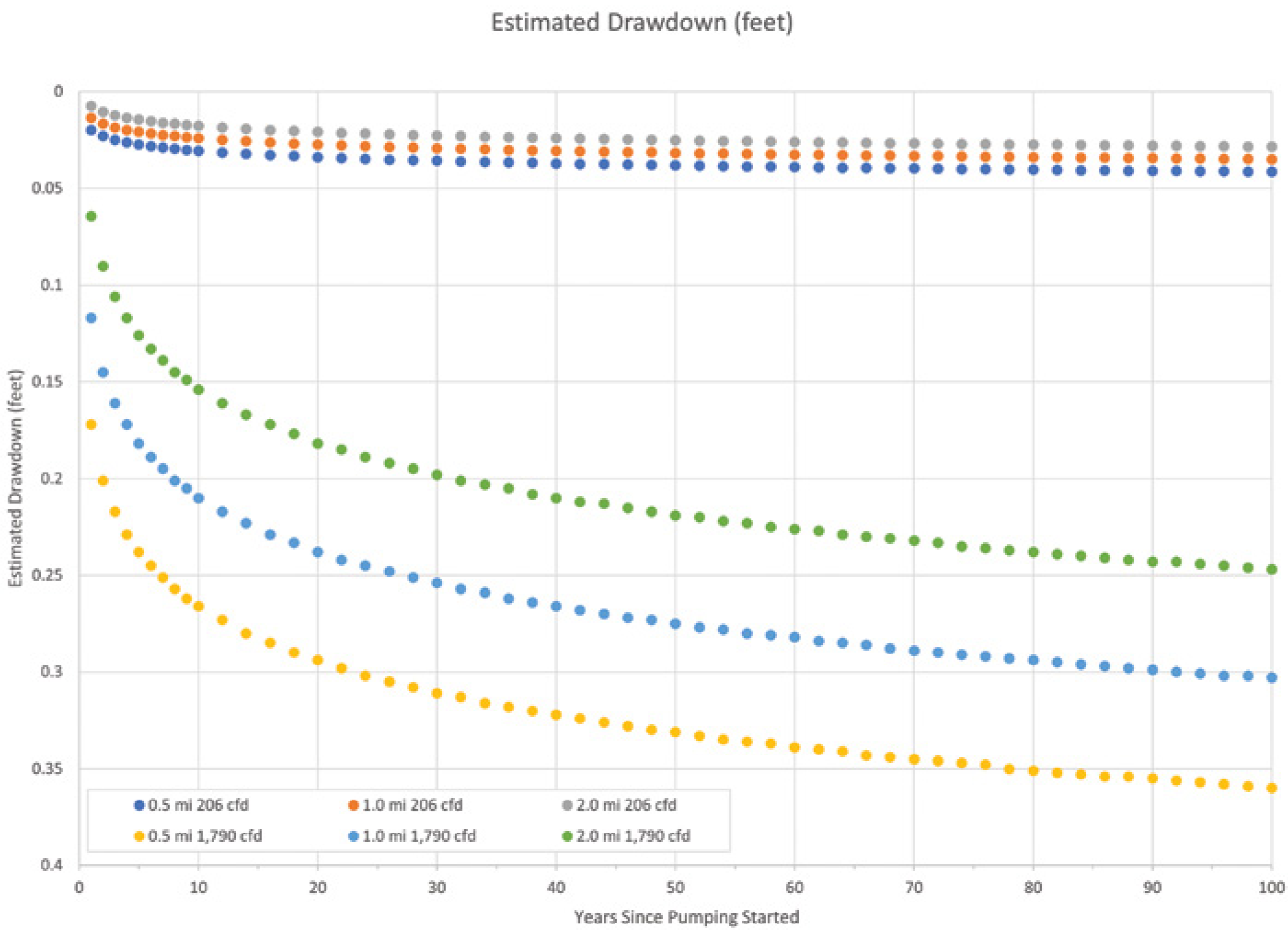


Figure 17. Estimated drawdown for six distance and pumping rate scenarios involving a single pumping well.

6. Glover Streamflow Depletion Analysis

6.1 Hydrogeologic Setting

While LaVerkin Creek has a substantial watershed upstream of the designated segment administered by the BLM, Smith Creek by contrast has a relatively short (approximately 2.5 miles) path from its headwaters in Zion National Park to its confluence with LaVerkin Creek (Figure 4). Perennial flow in both rivers is supported by groundwater discharge in gaining reaches or springflow input from the two major aquifers in the area—Navajo Sandstone (Jn) and Kayenta Formation (Jk).

Geologic mapping of the area by Biek et al. (2010) as described in chapter 1 of this tech note, indicates that sections of Smith and LaVerkin Creeks are also in contact with stratigraphically lower and potentially water-bearing strata including the Springdale Sandstone Member of the Kayenta Formation (Jks), the Shinarump Member of the Chinle Formation (TRcs), and the Virgin Limestone Member of the Moenkopi Formation (TRmv) (Table 15). Previous studies in the region have shown these units provide groundwater to wells (Wilkowske et al. 1998; Inkenbrandt et al. 2013), and the discharge measurements of this study suggest at least the Shinarump Member of the Chinle Formation can contribute discharge to the creeks when local precipitation is high.

The Kayenta Formation is in contact with Smith Creek near the boundary of Zion National Park. However, the remainder of Smith Creek approaching the confluence with LaVerkin Creek, and the entirety of LaVerkin Creek, are in contact with geologic units that underlie the Kayenta, including members of the Moenave, Chinle, and Moenkopi Formations; and no springs are known to discharge from the Kayenta to LaVerkin Creek (Biek et al. 2010) (Figure 5). As such, units of the Kayenta are unlikely to provide baseflow to LaVerkin Creek, except for what may be derived from upper Smith Creek or from the upstream, protected reaches within Zion National Park.

Table 15. Summary of bedrock geologic units within the study area including known or suspected water-bearing potential.

Unit Name	Map Symbol	Age	Lithology	Water-bearing properties[1]
Kayenta Fm.	Jk	Lower Jurassic	Sandstone, siltstone, mudstone	Aquifer
Kayenta Fm. Springdale Sandstone Mbr.	Jks	Lower Jurassic	Sandstone	Aquifer
Moenave Fm.	Jm	Jurassic-Triassic	Sandstone, siltstone, mudstone, limestone	Marginal aquifer
Chinle Fm. Petrified Forest Mbr.	TRcp	Upper Triassic	Claystone, mudstone, sandstone	Confining unit
Chinle Fm. Shinarump Mbr.	TRcs	Upper Triassic	Conglomerate, sandstone	Aquifer
Moenkopi Fm. Upper Red Mbr.	TRmu	Lower Triassic	Siltstone, sandstone, mudstone	Possibly connected to Shinarump
Moenkopi Fm. Shnabkaib Mbr.	TRms	Lower Triassic	Siltstone, mudstone, gypsum	Confining unit
Moenkopi Fm. Middle Red Mbr.	TRmm	Lower Triassic	Siltstone, sandstone, mudstone	Confining unit
Moenkopi Fm. Virgin Limestone Mbr.	TRmv	Lower Triassic	Limestone, mudstone	Aquifer (low production)
Moenkopi Fm. Lower Red Mbr.	TRml	Lower Triassic	Siltstone, sandstone, mudstone	Marginal aquifer

[1] Water-bearing properties from Inkenbrandt et al. (2013).

Given that the Kayenta Formation is dissected by LaVerkin Creek on the west side of Smith Mesa, and that the dip is generally away from the river (to the east), productive wells on Smith Mesa are likely to be located to the north and east of the mesa and are more likely to reduce spring flow and baseflow (if present) into Dry Creek, which dissects the center of Smith Mesa (Figure 5).

6.2 Use of the Glover Analytical Solution

The factors that control streamflow depletion by wells are similar to those that control the response of an aquifer to pumping (e.g., Theis 1940). These factors include the physical dimensions of the aquifer units and their hydraulic properties, the distance between the well and the river, and the pumping rate; the most important of which are distance and the values of aquifer transmissivity and storage coefficient (Barlow and Leake 2012). It is important to note that the pumping rate does not affect the timing of streamflow depletion, but the magnitude of depletion is proportional to the rate of withdrawal (Konikow and Bredehoeft 2020).

The Glover analytical solution (Glover and Balmer 1954) is a simplified method of estimating the timing and magnitude of streamflow depletion by groundwater withdrawal from a nearby well. As an analytical method, some simplifying assumptions must be made about both the river and the aquifer to allow for a simple analytical solution, including:

- The river fully penetrates the aquifer.
- Water moves freely between the river and aquifer (hydraulically connected).
- The aquifer is homogeneous, isotropic, and semi-infinite, and it has a constant saturated thickness.

The computation of streamflow depletion over time is made by:

$Q_s(t) = Q_w erfc(z)$

Where:

$Q_s(t)$ is the total rate of streamflow depletion with time (L^3/T)

Q_w is the pumping rate of the well (L^3/T)

erfc is a complementary error function (dimensionless)

z is a variable equal to $\sqrt{(d^2S)/(4Tt)}$, in which:

d is the shortest distance from the well to the river (L)

S is the aquifer storage coefficient (dimensionless)

T is the aquifer transmissivity (L^2/T)

t is the elapsed time (T)

To simplify the mathematical complexities of the analytical solutions, Jenkins (1968) used a semianalytical approach that introduced the concept of a stream depletion factor (sdf), which represents the time at which streamflow depletion is equal to 28 percent of the volume pumped from a well at a given location (Barlow and Leake 2012):

$sdf = d^2/D$

Where:

D is the hydraulic diffusivity; $D = T/S$ (L^2/T)

The Jenkins stream depletion factor provides an estimate of time until streamflow depletion occurs in response to pumping. In some instances, pumping can occur for significant amounts of time until the effects of pumping on streamflow are realized, and the effects of pumping can remain long after pumping has ceased.

6.3 Scenario Analysis

During hydrogeologic studies of the area, USGS researchers determined values of aquifer transmissivity and storage coefficient for the Kayenta Formation (Wilkowske et al. 1998; Cordova et al. 1972), but information on hydraulic properties of this unit are generally sparse. Values of the pumping rate and distance from the river of hypothetical wells were chosen based on reasonably foreseeable development scenarios on Smith Mesa for dispersed parcels of largely residential potable water needs. No hydraulic parameters for the Shinarump or Virgin Limestone Members were found for the area, but assuming they are relatively similar to the Kayenta Formation, it can be assumed that streamflow would respond similarly to pumping from these aquifers where they discharge groundwater to the river. Table 16 shows a summary of the Glover solution input parameters.

Table 16. Summary of input parameters for the Glover streamflow depletion analysis.

Input Parameter	Unit	Value(s)
Transmissivity (T)	ft^2/day	3,500
Storage coefficient (S)	dimensionless	0.006
Distance from river (r)	ft	2,640, 5,280, 10,560 *
Pumping rate (Q)	ft^3/day	206, 1,790 **

* Values equivalent to a well 0.5, 1, and 2 miles from the river.
** Values equivalent to 1.73 acre-feet per year (Utah Division of Water Resources domestic use) and 15 acre-feet per year.

While pumping from deeper aquifer units would have similar reductions in streamflow as from the Kayenta Formation, it should be noted that the feasibility of these units being developed for production is relatively low. LaVerkin Creek is disconnected from the Kayenta Formation for the full reach, but it does cut across lower units that may be water-bearing. However, these units would only be targeted for water development by the construction of relatively deep wells that may not be feasible given the costs of construction and potential production rates.

Using an average Smith Mesa elevation of 5,600 feet, wells drilled into the Kayenta Formation would likely extend to a depth of approximately 200–400 feet to the base of the Springdale Sandstone Member. The approximate depth of a well on Smith Mesa targeting a stratigraphically lower aquifer such as the Shinarump Member would approach 1,000 feet, a depth that may not be economically feasible for development of a small production well.

Scenarios run using the Glover solution utilized two pumping rates and three distances between a well and a river. The two pumping rates were 1.73 acre-feet per year (afy) (206 ft^3/day) and 15 afy (1,790 ft^3/day). The rate of 1.73 afy represents the rate from the Utah Division of Water Rights for domestic use, and the rate of 15 afy represents the value used in the Zion National Park Water Rights Settlement Agreement (1996). The three distances represent wells at 0.5, 1, and 2 miles from a river. Table 17 provides a summary of the Glover solution results.

6.4 Discussion

Results of the Glover analytical solution indicate that pumping wells completed in the Kayenta Formation (or another deeper aquifer with similar properties) near Smith Creek or LaVerkin Creek have the potential to capture streamflow within 200 days from the start of pumping if the rivers receive groundwater discharge from this aquifer (Figure 18). Groundwater withdrawals from Smith Mesa may impact streamflow of LaVerkin Creek and Smith Creek. Therefore, given the outstandingly remarkable values for which the rivers were designated, an acceptable rate of stream depletion should be determined to manage sustainable rates of streamflow.

Results of the Glover solution show greater impacts from wells closer to the river, both in time to streamflow capture and the percent of the pumping rate that comes from captured streamflow (Figure 18 and Table 17). These results are for a single well. For a scenario in which multiple parcels are developed, each with a domestic well in an ideal aquifer, effects are additive. For example, wells within 1–2 miles of the rivers might be pumped at 35 gpm or 15 afy, the same rates included in the Zion National Park Water Rights Settlement Agreement (1996) for potential developments north of the park. Conceivably, 10 such wells, each at 1 mile from the river on individual parcels, could deplete streamflow by approximately 40 gpm after 100 days of pumping.

Table 17. Summary of results for six streamflow depletion scenarios. Streamflow depletion was estimated using the Glover solution (Glover and Balmer 1954) and the Jenkins approach (Jenkins 1968). The table presents cumulative depletion as both a volume (ft^3) and a flow rate (gallons per minute, gpm) as two means of evaluating effects on streamflow. The depletion rate, however, is not linear over time and represents an average rate of loss over the first 100 days of pumping. Note that the pumping rate does not affect the timing of stream depletion, whereas distance does.

Distance (ft)	Pumping Rate (ft^3/day)	Stream Depletion Factor (days)	Stream Depletion, % of Pumping Rate, Day 100	Cumulative Depletion, Day 100 (ft^3)	Cumulative Depletion, Day 100 (gpm)
2,640	206	12	81	13,800	0.72
2,640	1,790	12	81	120,000	6.2
5,280	206	48	62	8,890	0.46
5,280	1,790	48	62	77,200	4.0
10,560	206	191	33	3,300	0.17
10,560	1,790	191	33	28,600	1.5

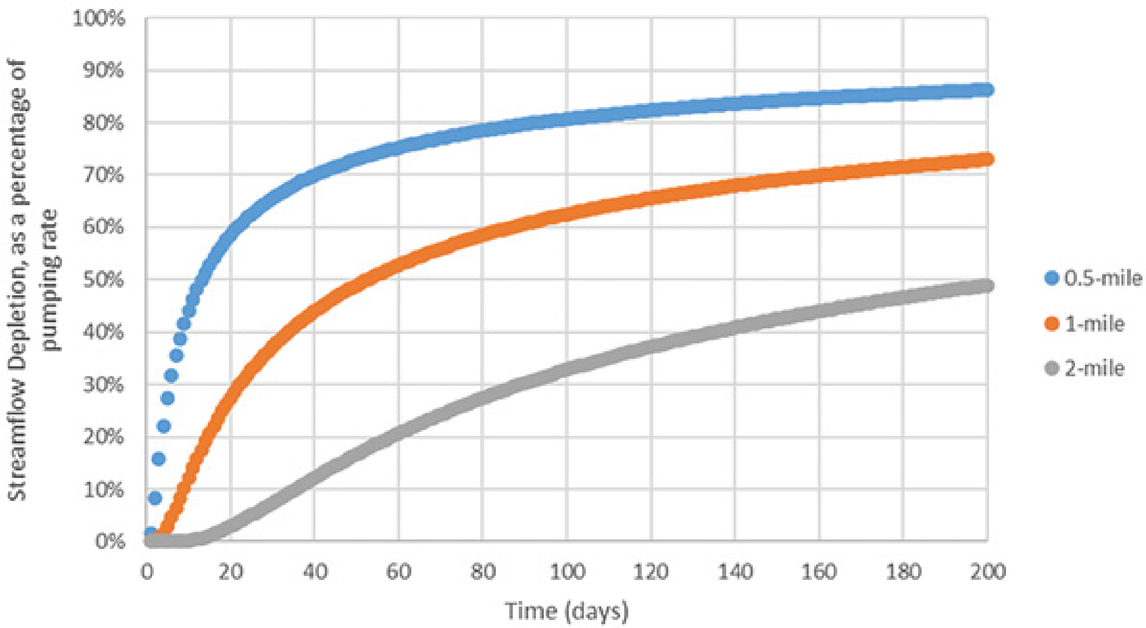


Figure 18. Estimated streamflow depletion for pumping wells at three distances from a connected river. Streamflow depletion was estimated using the Glover solution (Glover and Balmer 1954) and the Jenkins approach (Jenkins 1968).

While the input parameters for pumping rate and distance from the river were selected based on reasonable assumptions of future development on Smith Mesa, the values for transmissivity and storage coefficient were best estimates based on limited data from the area. Due to secondary permeability from fracturing and jointing and inherent heterogeneity in the lithology, there may be localized differences in these parameters. If transmissivity were higher than the value used in this analysis, the time for an equivalent fraction of the pumping rate coming from streamflow depletion would decrease proportionally and would increase if the actual transmissivity were lower than the value used here. Similarly, if the aquifer storage coefficient values were higher, the effects of pumping on streamflow would be more muted and take longer to reach the river, while effects on streamflow would be more pronounced and more quickly observed if the aquifer storage coefficient were lower.

While the Kayenta Formation was used for this analysis, this aquifer may only be in hydraulic connection with Smith Creek; the LaVerkin Creek channel has incised through the Kayenta Formation on the west side of Smith Mesa, and the aquifer lies well above any contact with the streambed and is not known to provide any measurable discharge to the channel. Any reductions in Smith Creek baseflow will be propagated to the entire section of LaVerkin Creek as this contribution is occurring at the upper reaches of the BLM-administered designated segment. By contrast, if pumping were to occur in one of the lower water-bearing units, the potential effects on LaVerkin Creek would be limited to a short section of the lower portion of the designated reach where these units are in connection with the river.

Much of the topography of Smith Mesa drains to Dry Creek which bisects the mesa and flows to the south, away from LaVerkin and Smith Creeks. Mapped springs on the mesa discharge to drainages following this same orientation. Some evidence exists of groundwater discharge occurring along the north end of Smith Mesa. The fieldwork portion of this study sought to determine whether the Kayenta Formation contributes baseflow to Smith Creek. In 2022, a dryer year in terms of precipitation, there did not appear to be much contribution to baseflow in Smith Creek from the Kayenta Formation. However, in 2023, a wetter year, field personnel observed several springs and seeps from the Kayenta Formation contributing flow into Smith Creek near BLM SM07 and BLM SM08 (Figure 12). The 2023 field observations suggest that the minor groundwater contributions to Smith Creek from the Kayenta Formation add to the water in the river derived from the overlying Navajo Sandstone. This suggests that pumping in the Kayenta Formation on Smith Mesa may be detrimental to flows in Smith Creek. If wells are completed on Smith Mesa in aquifers below the Kayenta Formation, these wells may reduce flows in LaVerkin Creek.

7. Discussion and Conclusions

The purpose of this tech note is to present field information and predictive analyses to help inform decision-making processes pertaining to the protection and enhancement of the free-flowing condition and outstandingly remarkable values for lower LaVerkin Creek and Smith Creek. This tech note includes flow conditions for both rivers in drier (2022) and wetter (2023) years and presents the results of geochemical and stable isotope analyses. It also presents the results of standard analytical models intended to help develop a common understanding of the factors that affect whether a pumping well could impact streamflow.

Upper Smith Creek is supported by flow from Navajo Sandstone. Lower Smith Creek is supported by flow from a combination of Navajo Sandstone and the Kayenta Formation. Northern portions of Smith Mesa possibly contribute to groundwater discharge to Smith Creek as evidenced by water chemistry (isotopic and other chemistry data presented) and spring/seep discharges along portions of lower Smith Creek.

Streamflow in the designated reach of Smith Creek is relatively low during baseflow conditions and is ecologically important within the watershed. Designated reaches of LaVerkin Creek do not significantly gain or lose streamflow throughout the study area. The flow contribution of Smith Creek into LaVerkin Creek is a small percentage of the total flow in LaVerkin Creek.

The BLM and NPS are responsible for managing and maintaining the outstandingly remarkable values of the designated wild and scenic river segments. This study provides evidence of the groundwater-surface water connection. Consequently, LaVerkin and Smith Creeks may be susceptible to flow reductions if groundwater underlying adjacent lands is developed or if surface waters tributary to the wild and scenic river segments are diverted or impounded.

Appendix A: Precipitation Data from the Cedar City – Zion National Park, Kolob Canyons Weather Station (ID 1262327)

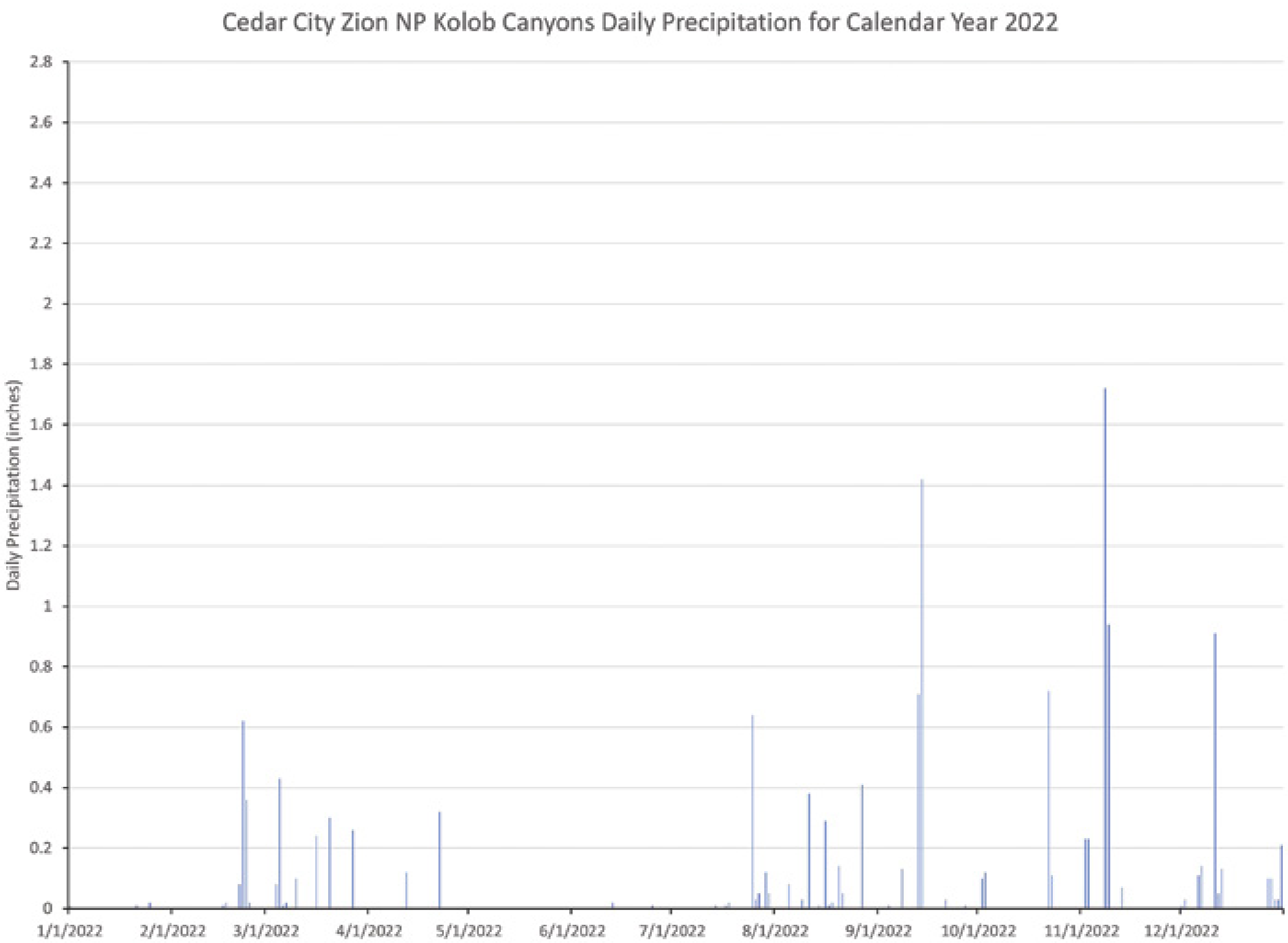


Figure A1. Daily precipitation at Cedar City – Zion National Park, Kolob Canyons Weather Station (ID 1262327) for calendar year 2022 (latitude 37.4572°, longitude -113.2248°; elevation 5,096 ft above mean sea level). Sampling occurred on October 18 and 19, 2022.

Table A1. Daily precipitation at Cedar City – Zion National Park, Kolob Canyons Weather Station (ID 1262327) for calendar year 2022.

Day	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	0.01	0	0	0	0	0	0	0	0	0	0	0.01
2	0	0	0	0	0	0	0	0	0	0.10	0.23	0.03
3	0	0	0	0	0	0	0	0	0	0.12	0.23	0
4	0	0	0.08	0	0	0	0	0	0.01	0	0	0
5	0	0	0.43	0	0	0	0	0.08	0	0	0	0
6	0	0	0.01	0	0	0	0	0	0	0	0	0.11
7	0	0	0.02	0	0	0	0	0	0	0	0	0.14
8	0	0	0	0	0	0	0	0	0.13	0	1.72	0
9	0	0	0	0	0	0	0	0.03	0	0	0.94	0
10	0	0	0.10	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0.38	0	0	0	0.91
12	0	0	0	0.12	0	0	0	0	0	0	0	0.05
13	0	0	0	0	0	0.02	0	0	0.71	0	0.07	0.13
14	0	0	0	0	0	0	0.01	0.01	1.42	0	0	0
15	0	0	0	0	0	0	0	0	0	0	0	0
16	0	0.01	0.24	0	0	0	0	0.29	0	0	0	0
17	0	0.02	0	0	0		0.01	0.01	0	0	0	0
18	0	0	0	0	0	0	0.02	0.02	0	0	0	0
19	0	0	0	0	0	0	0	0	0	0	0	0
20	0	0	0.30	0	0	0	0	0.14	0	0	0	0
21	0.01	0.08	0	0	0	0	0	0.05	0.03	0	0	0
22	0	0.62	0	0.32	0	0	0	0	0	0.72	0	0
23	0	0.36	0	0	0	0	0	0	0	0.11	0	0
24	0	0.02	0	0	0	0	0	0	0	0	0	0
25	0.02	0	0	0	0	0.01	0.64	0	0	0	0	0
26	0	0	0	0	0	0	0.03	0.41	0	0	0	0
27	0	0	0	0	0	0	0.05	0	0.01	0	0	0.10
28	0	0	0.26	0	0	0	0	0	0	0	0	0.10
29	0			0	0	0	0.12	0	0	0	0	0.03
30	0			0	0	0	0.05	0		0		0.03
31					0		0	0				0.21
TOTAL	**0.04**	**1.11**	**1.44**	**0.44**	**0.00**	**0.03**	**0.93**	**1.42**	**2.31**	**1.05**	**3.19**	**1.85**

All daily precipitation values are in inches.
Blank days indicate no data available.

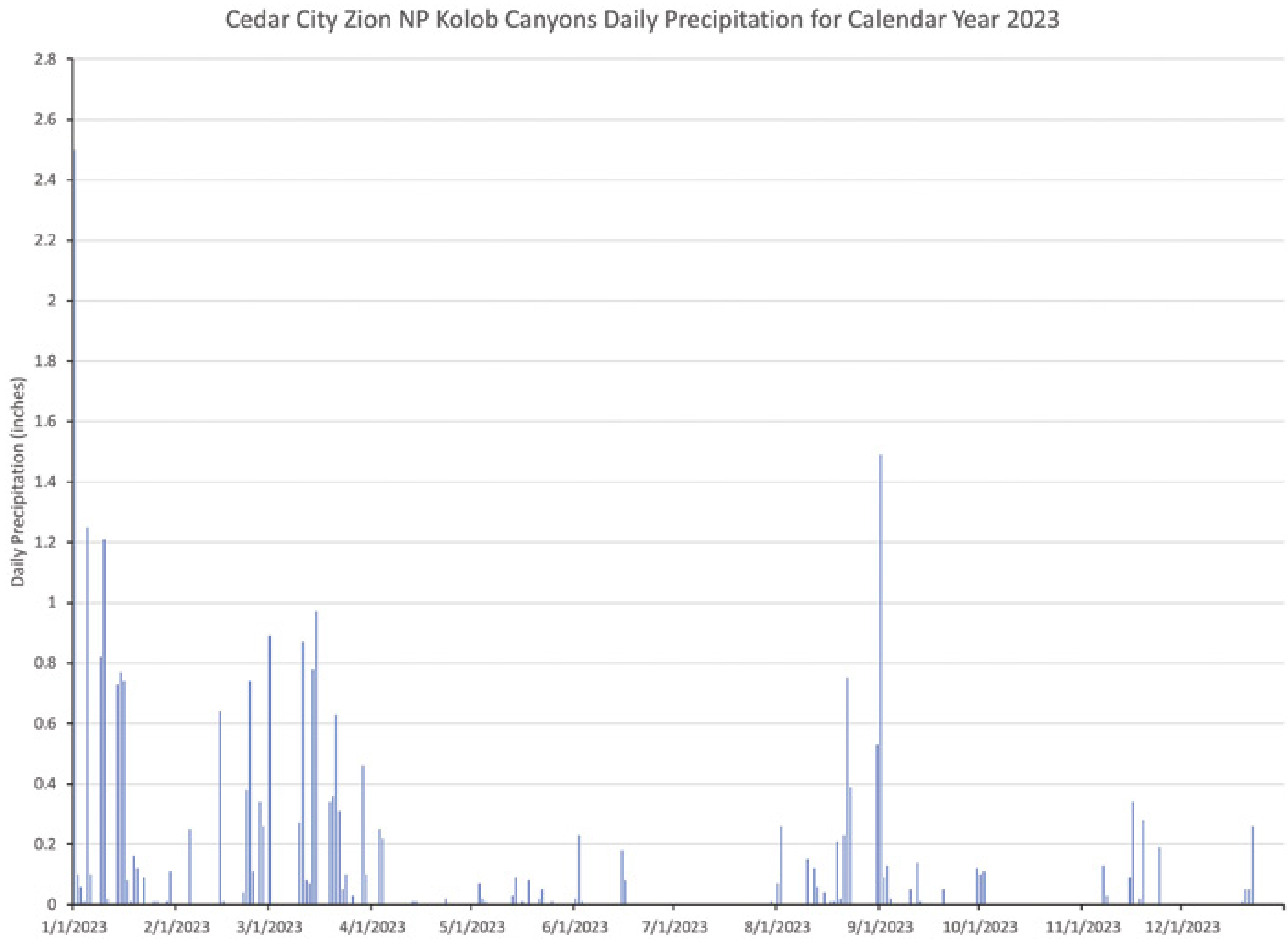


Figure A2. Daily precipitation at Cedar City – Zion National Park, Kolob Canyons Weather Station (ID 1262327) for calendar year 2023 (latitude 37.4572°, longitude -113.2248°; elevation 5,096 ft above mean sea level). Sampling occurred October 3 and 4, 2023.

Table A2. Daily precipitation at Cedar City – Zion National Park, Kolob Canyons Weather Station (ID 1262327) for calendar year 2023.

Day	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	2.50	0	0.89	0	0	0.02	0	0.07	1.49	0.10	0	0
2	0.10	0	0	0	0	0.23	0	0.26	0.09	0.11	0	0
3	0.06	0	0	0.25	0.07	0.01	0	0	0.13	0	0	0
4	0.01	0	0	0.22	0.02	0	0	0	0.02	0	0	0
5	1.25	0.25	0	0	0.01	0	0	0	0	0	0	0
6	0.10	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0.13	0
8	0	0	0	0	0	0	0	0	0	0	0.03	0
9	0.82	0	0	0	0	0	0	0	0	0	0	0
10	1.21	0	0.27	0	0	0	0	0.15	0.05	0	0	0
11	0.02	0	0.87	0	0	0	0	0	0	0	0	0
12	0	0	0.08	0	0	0	0	0.12	0.14	0	0	0
13	0	0	0.07	0.01	0.03	0	0	0.06	0.01	0	0	0
14	0.73	0.64	0.78	0.01	0.09	0	0	0	0	0	0	0
15	0.77	0.01	0.97	0	0	0.18	0	0.04	0	0	0.09	0
16	0.74	0	0	0	0.01	0.08	0	0	0	0	0.34	0
17	0.08	0	0	0	0	0	0	0.01	0	0	0	0
18	0.01	0	0	0	0.08	0		0.01	0	0	0.02	0
19	0.16	0	0.34	0	0	0		0.21	0	0	0.28	0.01
20	0.12	0	0.36	0	0	0		0.02	0.05	0	0	0.05
21	0	0.04	0.63	0	0.02	0		0.23	0	0	0	0.05
22	0.09	0.38	0.31	0	0.05	0		0.75	0	0	0	0.26
23	0	0.74	0.05	0.02	0	0		0.39	0	0	0	0
24	0	0.11	0.10	0	0	0	0	0	0	0	0.19	0
25	0.01	0	0	0	0.01	0	0	0	0	0	0	0
26	0.01	0.34	0.03	0	0	0	0	0	0	0	0	0
27	0	0.26	0	0	0	0	0	0	0	0	0	0
28	0		0	0	0	0	0	0	0	0	0	0
29	0.01		0.46	0	0	0	0	0	0	0	0	0
30	0.11		0.10		0		0.01	0	0.12	0	0	0
31			0		0			0.53		0		
TOTAL	**8.91**	**2.77**	**6.31**	**0.51**	**0.39**	**0.52**	**0.01**	**2.85**	**2.10**	**0.21**	**1.08**	**0.37**

All daily precipitation values are in inches.
Blank days indicate no data available.

Appendix B: Piper and Stiff Diagrams

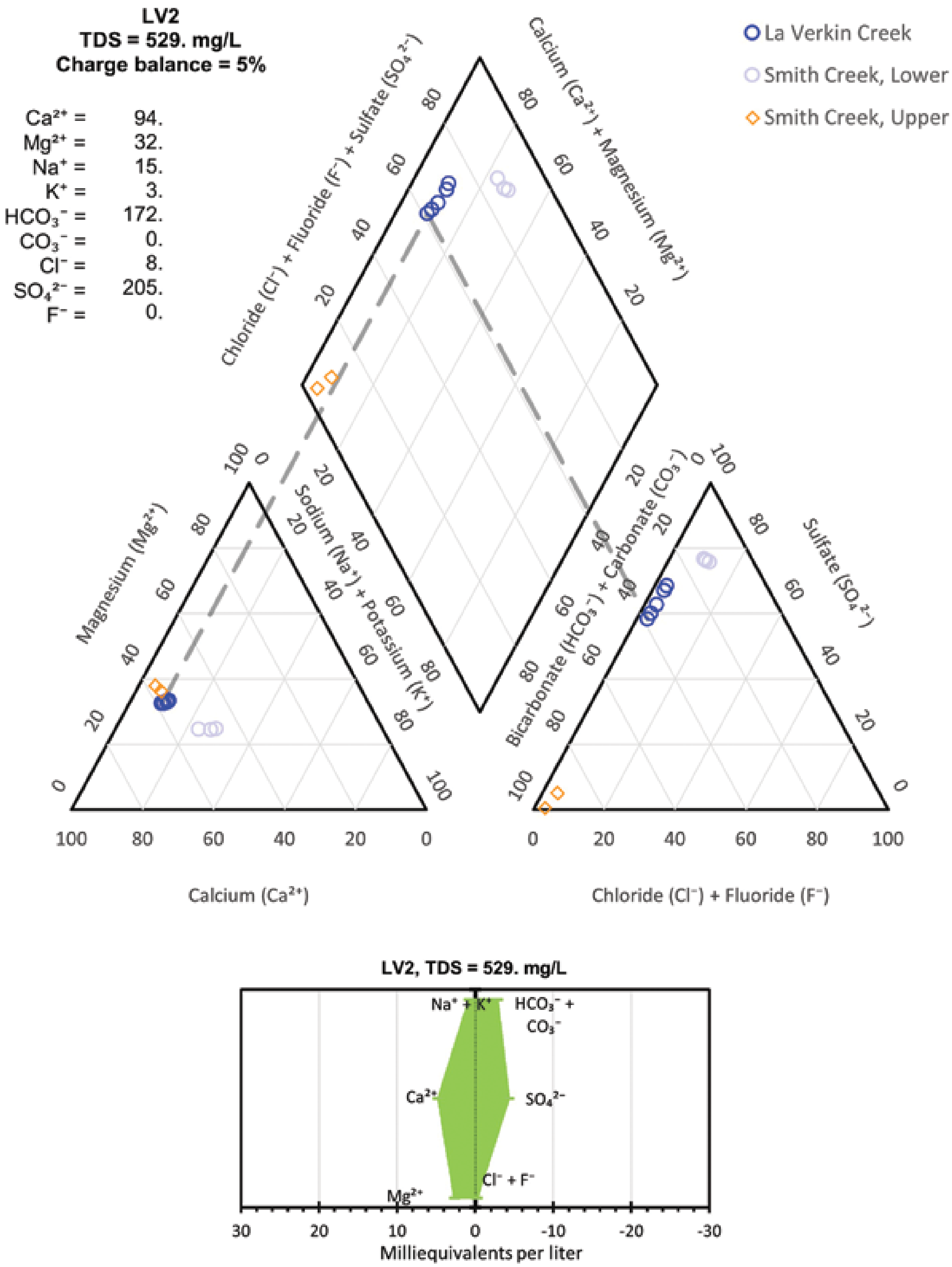


Figure B1. LaVerkin Creek 2 (LV2) Piper and Stiff diagrams.

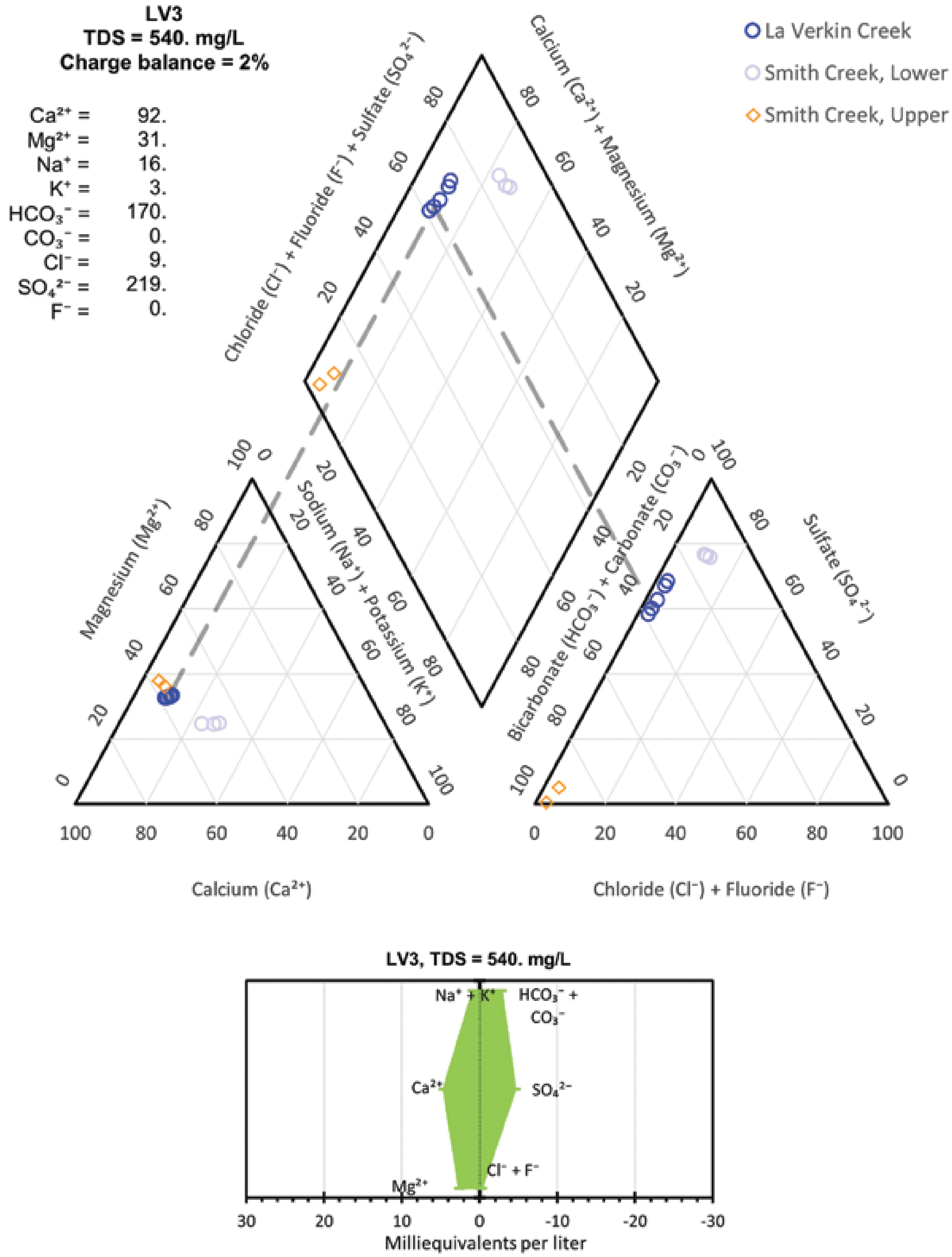


Figure B2. LaVerkin Creek 3 (LV3) Piper and Stiff diagrams.

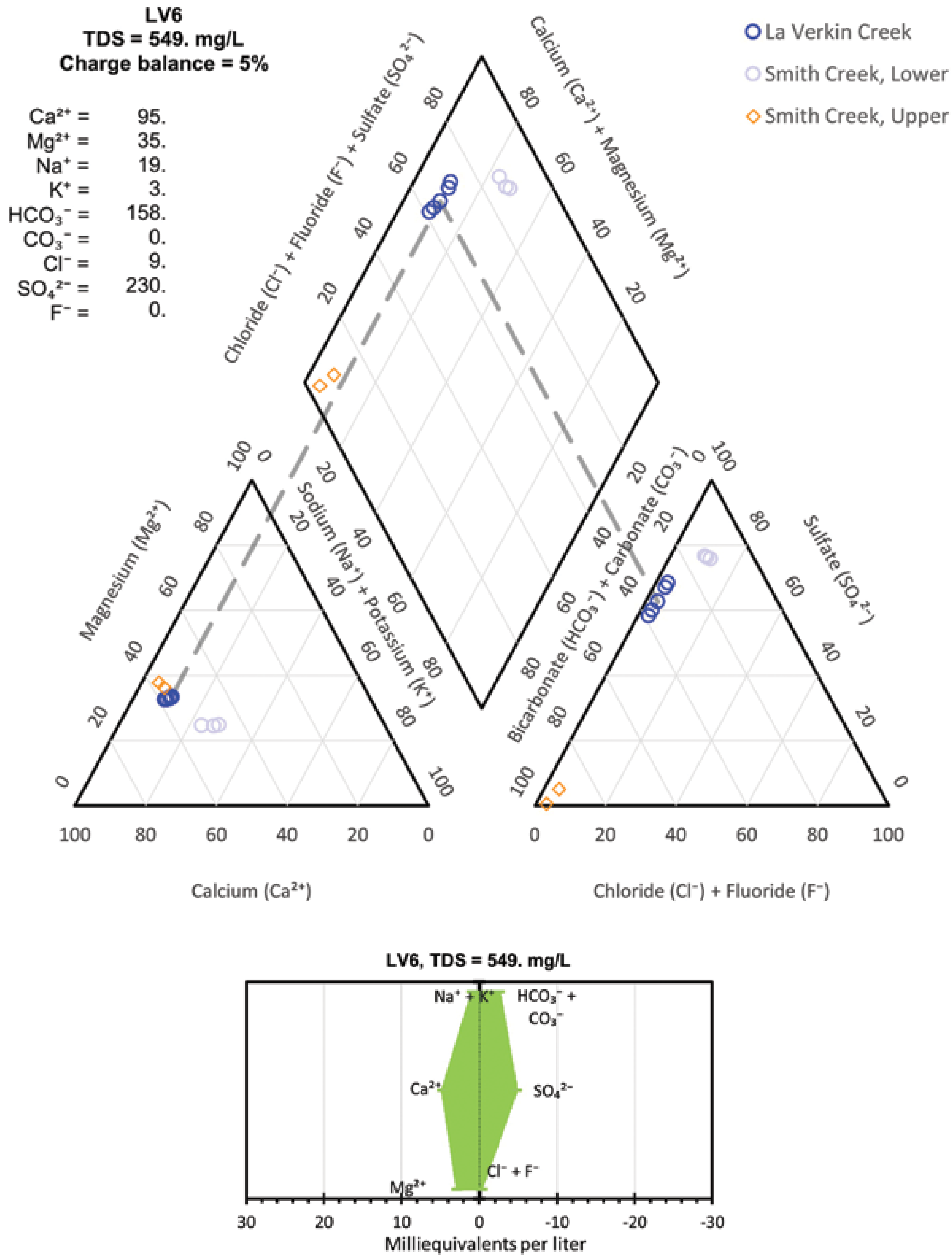
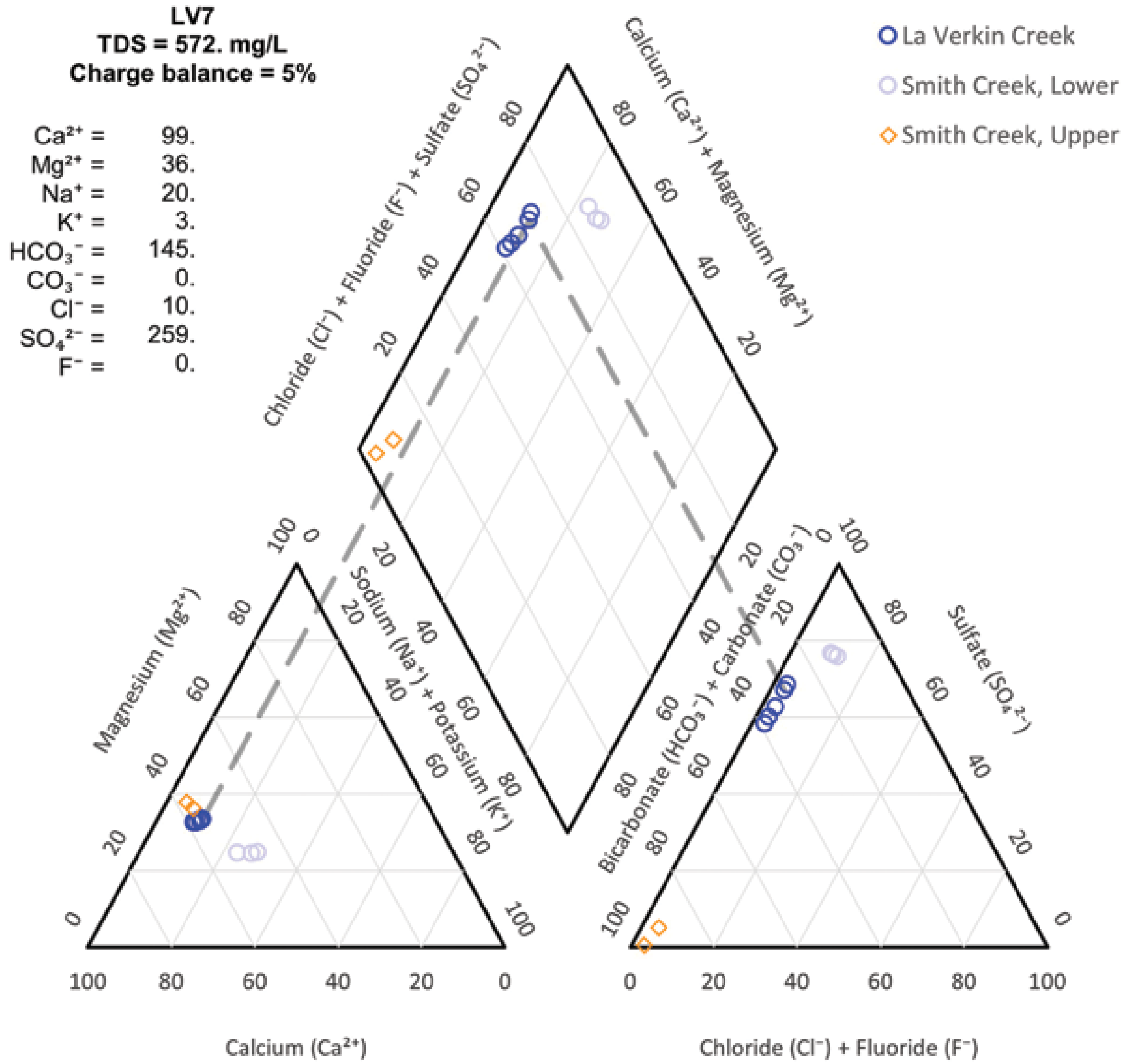


Figure B3. LaVerkin Creek 6 (LV6) Piper and Stiff diagrams.



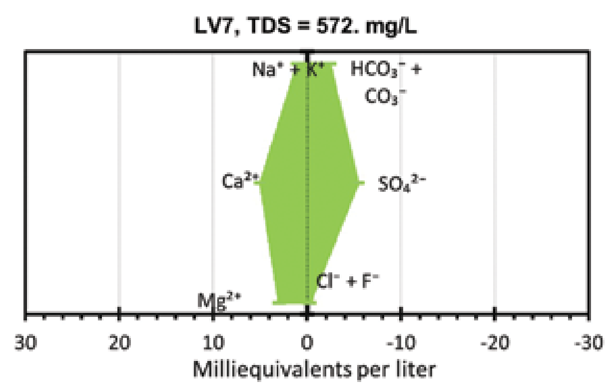


Figure B4. LaVerkin Creek 7 (LV7) Piper and Stiff diagrams.

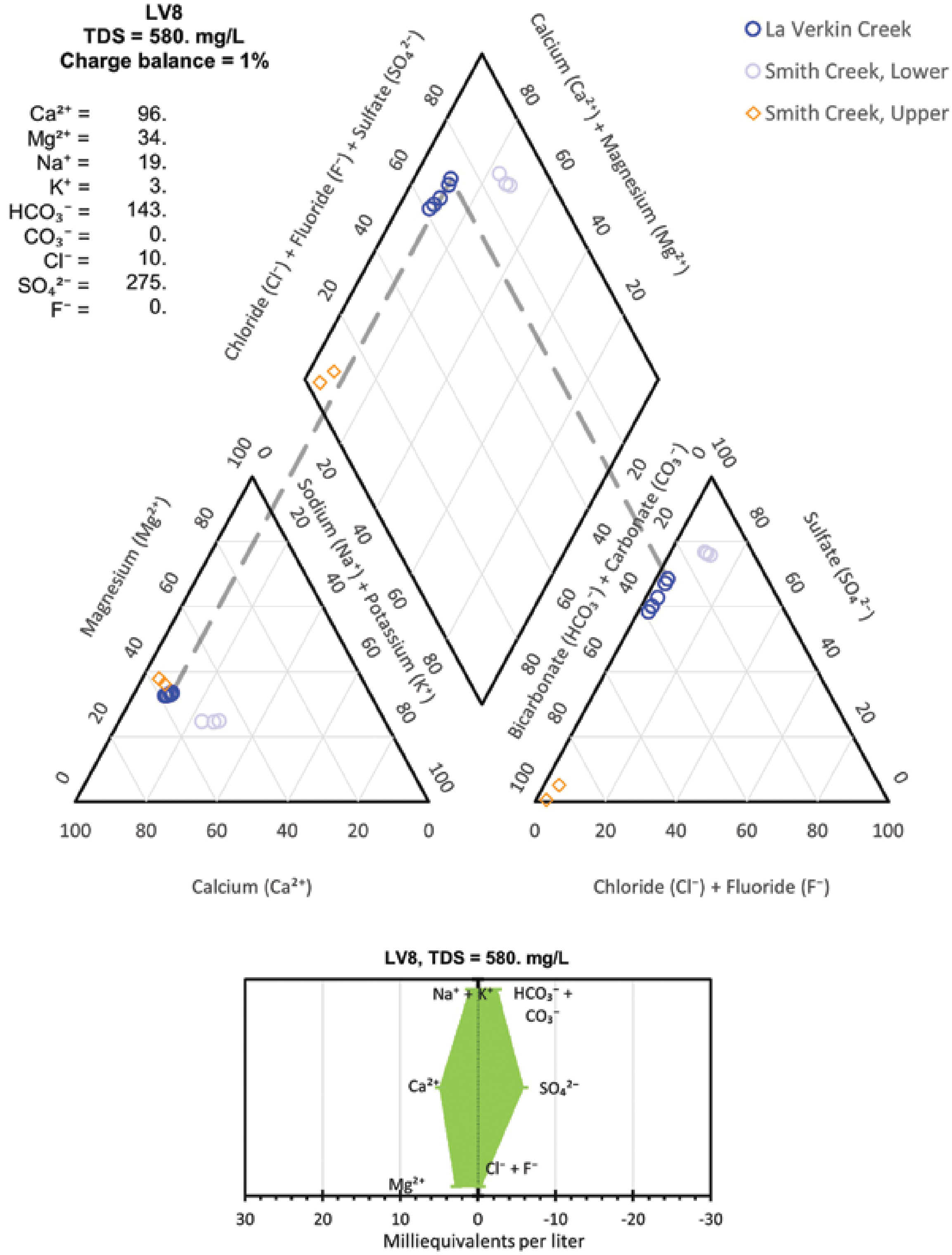
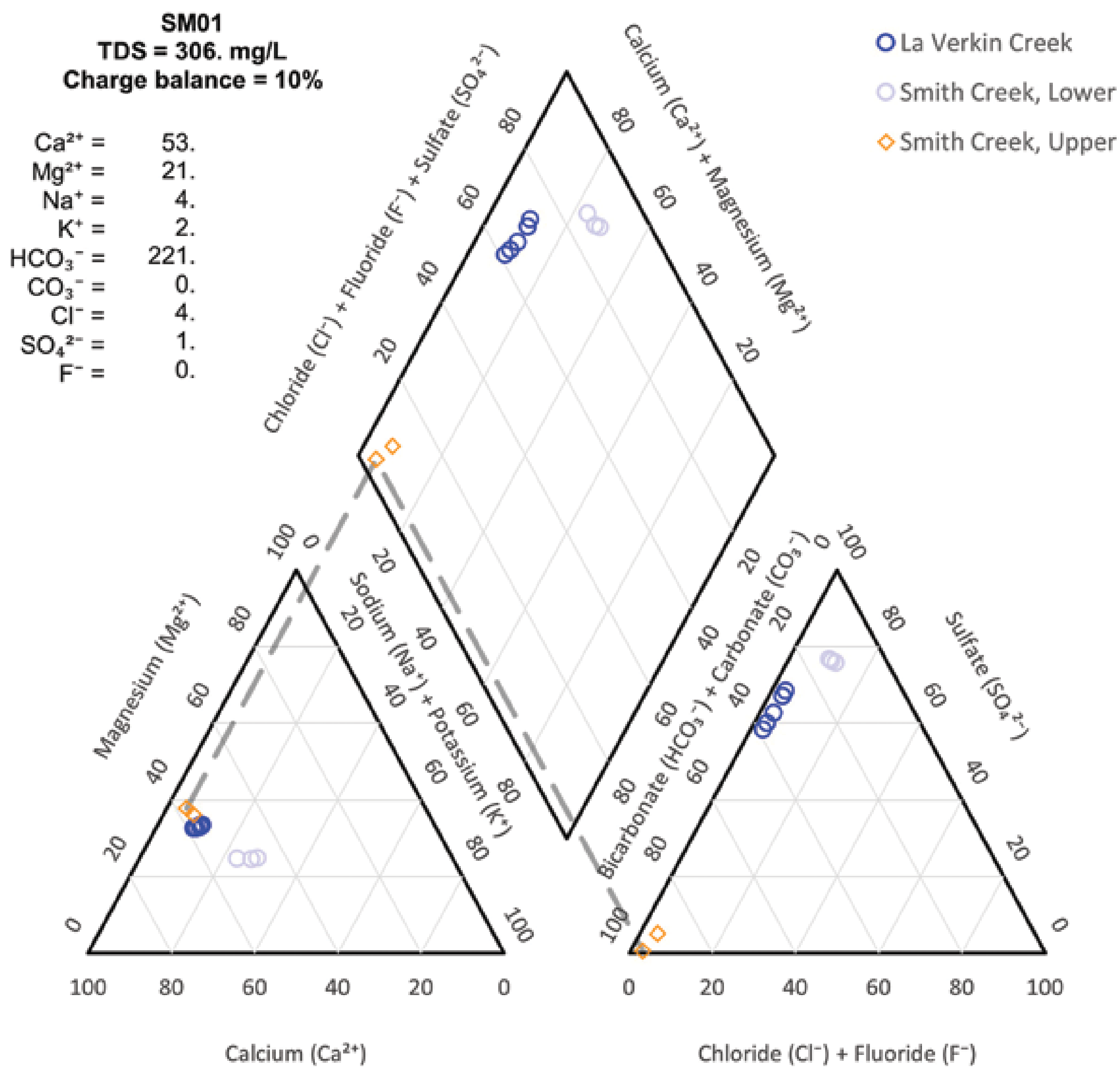


Figure B5. LaVerkin Creek 8 (LV8) Piper and Stiff diagrams.



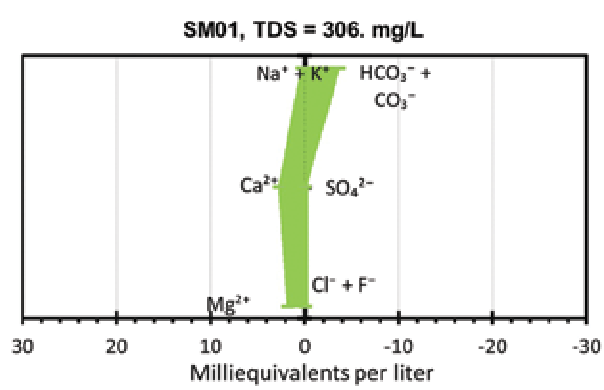


Figure B6. Smith Creek 01 (SM01) Piper and Stiff diagrams.

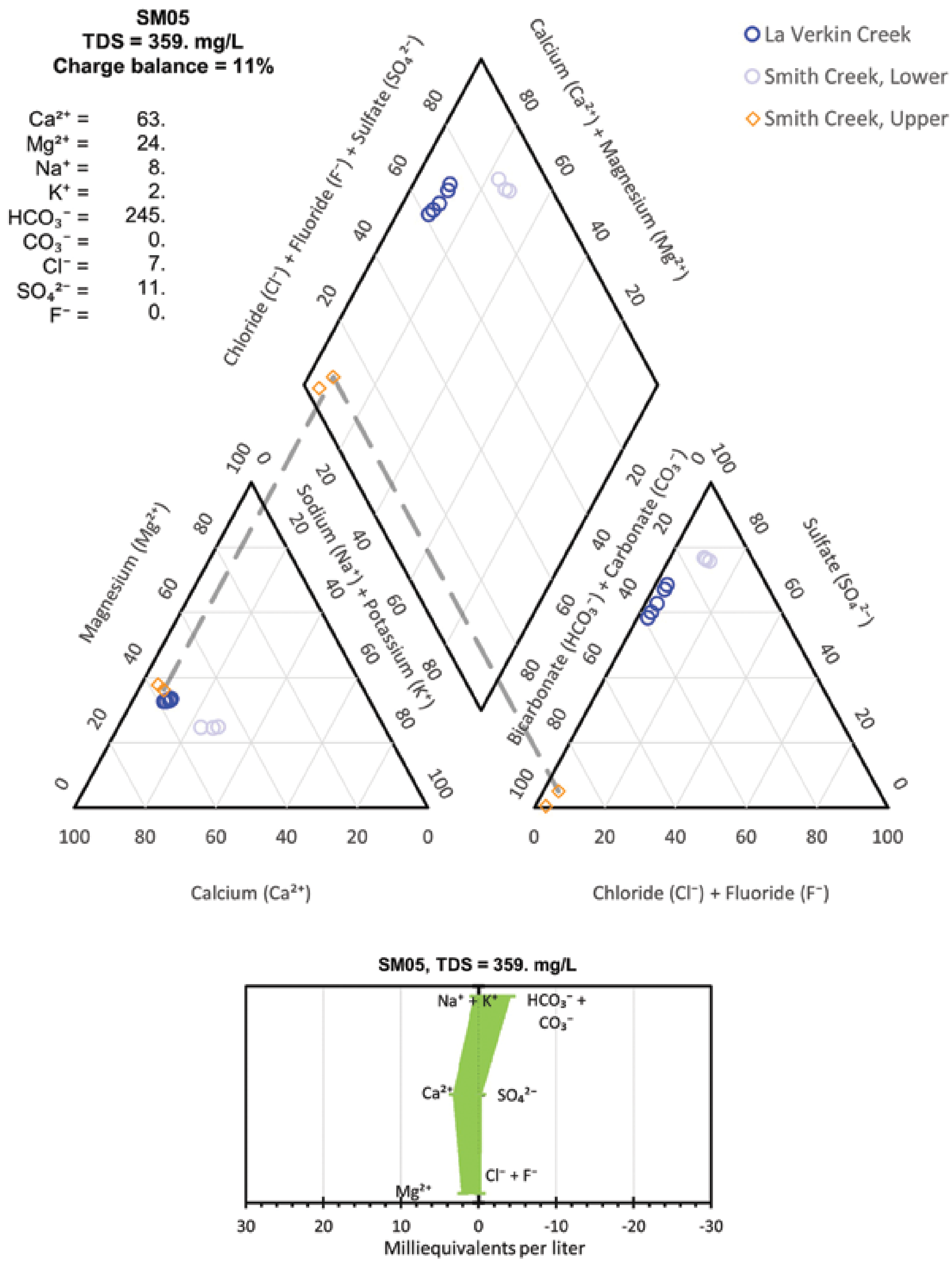


Figure B7. Smith Creek 05 (SM05) Piper and Stiff diagrams.

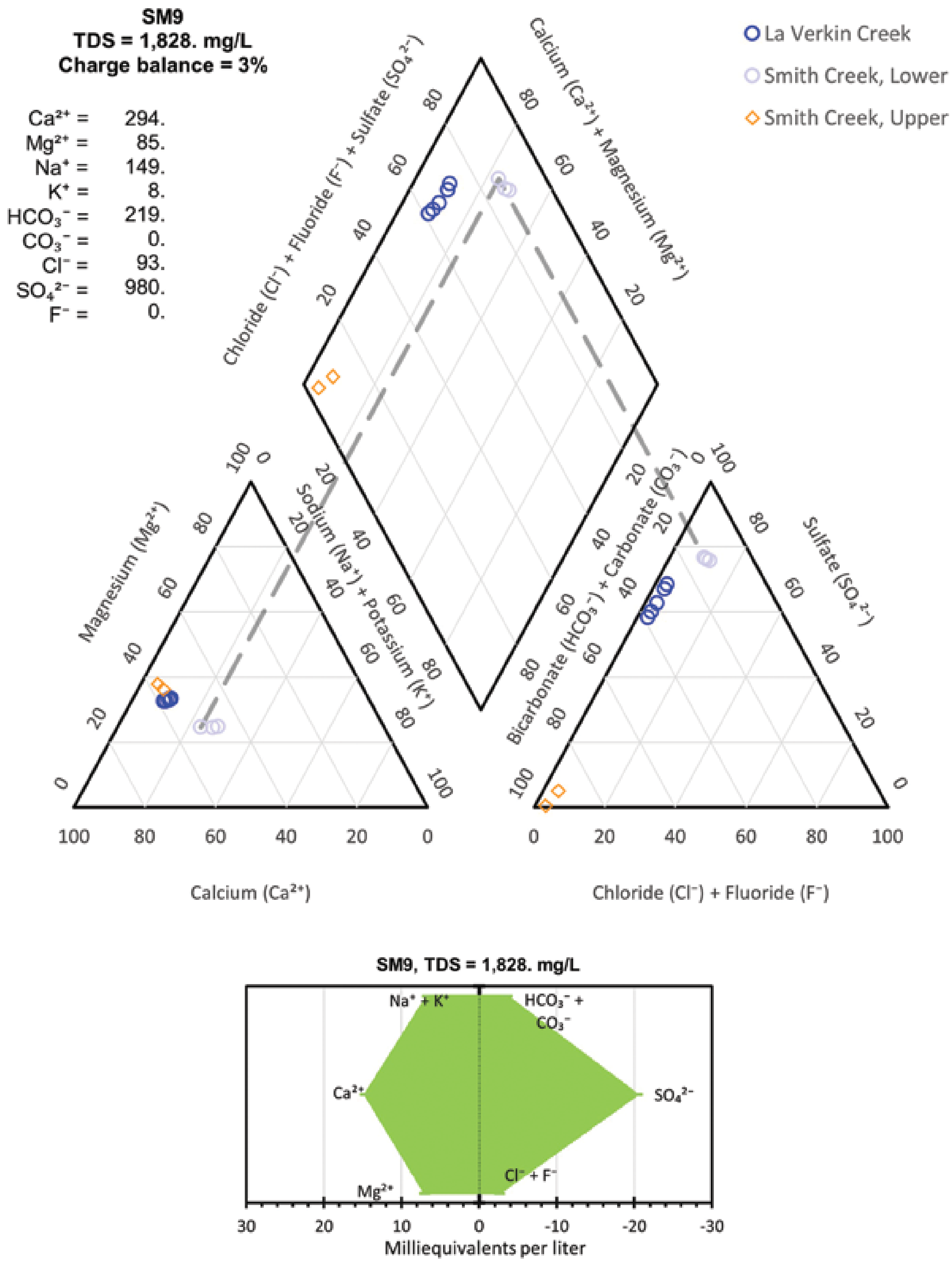


Figure B8. Smith Creek 9 (SM9) Piper and Stiff diagrams.

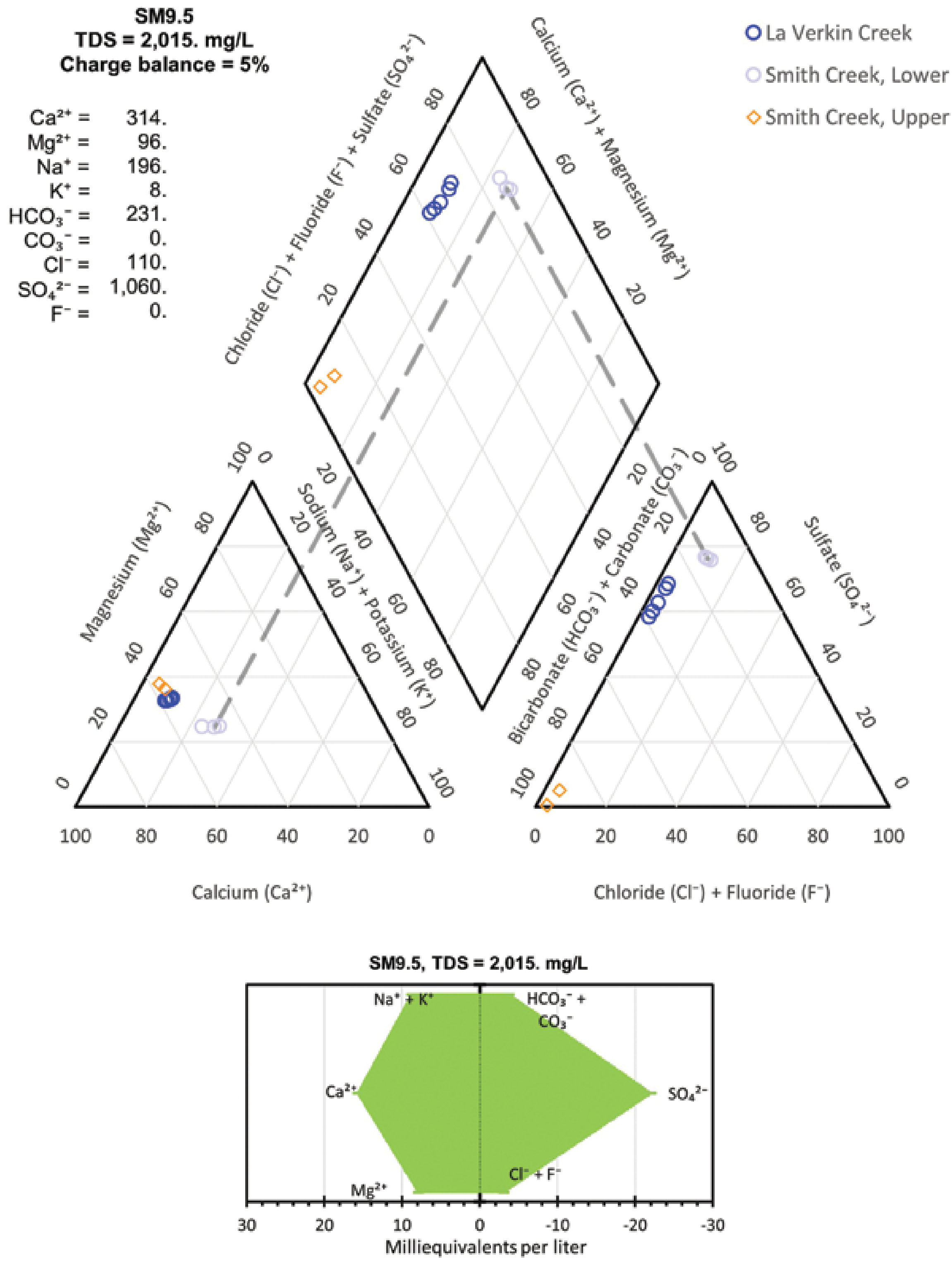
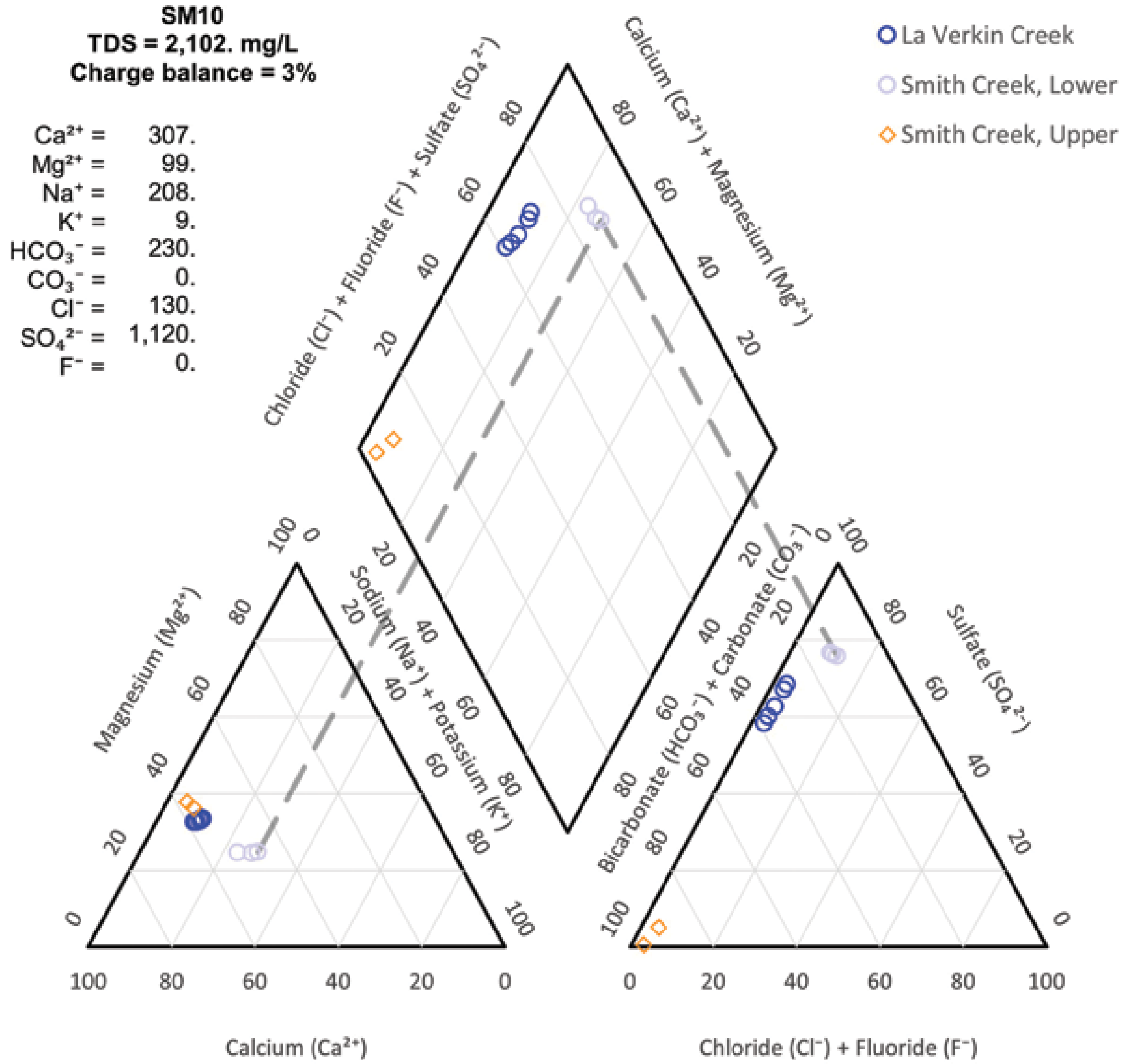


Figure B9. Smith Creek 9.5 (SM09.5) Piper and Stiff diagrams.



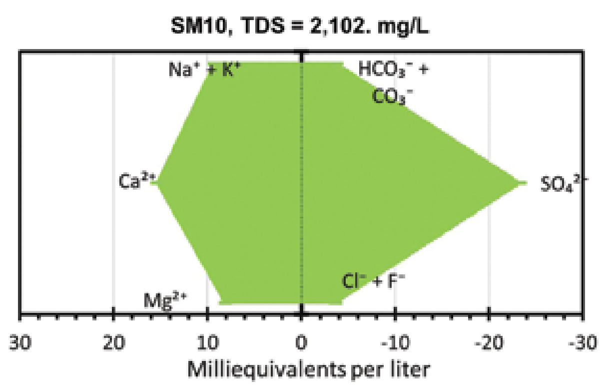


Figure B10. Smith Creek 10 (SM10) Piper and Stiff diagrams.

Appendix C: Photos of October 2022 Fieldwork

The BLM took these photographs on October 18, 19, and 20, 2022, during the LaVerkin Creek and Smith Creek hydrology fieldwork.

Photograph 1. Starting location near Ash Creek, taken at 9:41 a.m. on October 18, 2022.

Photograph 2. LaVerkin Creek at Toquerville Falls, taken at 12:07 p.m. on October 18, 2022.

Photograph 3. LaVerkin Creek at Toquerville Falls, taken at 12:07 p.m. on October 18, 2022.

Photograph 4. LaVerkin Creek at Toquerville Falls, taken at 12:08 p.m. on October 18, 2022.

Photograph 5. LaVerkin Creek measurement location BLM LV08, taken at 2:49 p.m. on October 18, 2022.

Photograph 6. LaVerkin Creek measurement location BLM LV08, taken at 2:49 p.m. on October 18, 2022.

Photograph 7. LaVerkin Creek measurement location BLM LV08, taken at 2:50 p.m. on October 18, 2022.

Photograph 8. Along LaVerkin Creek between BLM LV07 and BLM LV08, taken at 4:07 p.m. on October 18, 2022.

Photograph 9. LaVerkin Creek downstream of BLM LV07, taken at 4:16 p.m. on October 18, 2022.

Photograph 10. LaVerkin Creek downstream of BLM LV07, taken at 4:16 p.m. on October 18, 2022.

Photograph 11. LaVerkin Creek downstream of measurement location BLM LV06, taken at 4:43 p.m. on October 18, 2022.

Photograph 12. LaVerkin Creek downstream of measurement location BLM LV06, taken at 4:43 p.m. on October 18, 2022.

Photograph 13. LaVerkin Creek downstream of measurement location BLM LV06, taken at 4:54 p.m. on October 18, 2022.

Photograph 14. LaVerkin Creek measurement location BLM LV06, taken at 5:15 p.m. on October 18, 2022.

Photograph 15. LaVerkin Creek measurement location BLM LV06, taken at 5:15 p.m. on October 18, 2022.

Photograph 16. LaVerkin Creek measurement location BLM LV06, taken at 5:16 p.m. on October 18, 2022.

Photograph 17. LaVerkin Creek measurement location BLM LV07, taken at 6:29 p.m. on October 18, 2022.

Photograph 18. LaVerkin Creek measurement location BLM LV07, taken at 6:29 p.m. on October 18, 2022.

Photograph 19. LaVerkin Creek measurement location BLM LV07, taken at 6:29 p.m. on October 18, 2022.

Photograph 20. LaVerkin Creek upstream of BLM LV07, taken at 9:49 a.m. on October 19, 2022.

Photograph 21. LaVerkin Creek downstream of measurement location BLM LV06, taken at 9:59 a.m. on October 19, 2022.

Photograph 22. LaVerkin Creek upstream of measurement location BLM LV06, taken at 10:27 a.m. on October 19, 2022.

Photograph 23. LaVerkin Creek at measurement location BLM LV01, taken at 12:05 p.m. on October 19, 2022.

Photograph 24. LaVerkin Creek at measurement location BLM LV01, taken at 12:05 p.m. on October 19, 2022.

Photograph 25. LaVerkin Creek at measurement location BLM LV01, taken at 12:05 p.m. on October 19, 2022.

Photograph 26. LaVerkin Creek downstream of measurement location BLM LV01, taken at 12:45 p.m. on October 19, 2022.

Photograph 27. LaVerkin Creek at measurement location BLM LV02, taken at 1:21 p.m. on October 19, 2022.

Photograph 28. LaVerkin Creek at measurement location BLM LV02, taken at 1:22 p.m. on October 19, 2022.

Photograph 29. LaVerkin Creek at measurement location BLM LV02, taken at 1:22 p.m. on October 19, 2022.

Photograph 30. Near the confluence of LaVerkin and Smith Creeks, taken at 1:29 p.m. on October 19, 2022.

Photograph 31. Near the confluence of LaVerkin and Smith Creeks, taken at 1:30 p.m. on October 19, 2022.

Photograph 32. Near the confluence of LaVerkin and Smith Creeks, taken at 1:30 p.m. on October 19, 2022.

Photograph 33. Near the confluence of LaVerkin and Smith Creeks, taken at 1:31 p.m. on October 19, 2022.

Photograph 34. Smith Creek measurement location BLM SM10, taken at 1:45 p.m. on October 19, 2022.

Photograph 35. Smith Creek measurement location BLM SM10, taken at 1:46 p.m. on October 19, 2022.

Photograph 36. Smith Creek upstream of measurement location BLM SM10, taken at 2:04 p.m. on October 19, 2022.

Photograph 37. Smith Creek downstream of measurement location BLM SM09.5, taken at 2:12 p.m. on October 19, 2022.

Photograph 38. Smith Creek downstream of measurement location BLM SM09.5, taken at 2:17 p.m. on October 19, 2022.

Photograph 39. Smith Creek upstream of measurement location BLM SM09.5, taken at 2:30 p.m. on October 19, 2022.

Photograph 40. Smith Creek upstream of measurement location BLM SM09.5, taken at 2:30 p.m. on October 19, 2022.

Photograph 41. Smith Creek measurement location BLM SM09, taken at 2:57 p.m. on October 19, 2022.

Photograph 42. Smith Creek measurement location BLM SM09, taken at 2:57 p.m. on October 19, 2022.

Photograph 43. Smith Creek measurement location BLM SM09, taken at 3:03 p.m. on October 19, 2022.

Photograph 44. Smith Creek downstream of measurement location BLM SM09, taken at 3:10 p.m. on October 19, 2022.

Photograph 45. Smith Creek at measurement location BLM SM09.5, taken at 3:29 p.m. on October 19, 2022.

Photograph 46. Smith Creek at measurement location BLM SM09.5, taken at 3:29 p.m. on October 19, 2022.

Photograph 47. Smith Creek downstream of measurement location BLM SM09.5, taken at 3:42 p.m. on October 19, 2022.

Photograph 48. LaVerkin Creek measurement location BLM LV03, taken at 4:28 p.m. on October 19, 2022.

Photograph 49. LaVerkin Creek measurement location BLM LV03, taken at 4:28 p.m. on October 19, 2022.

Photograph 50. LaVerkin Creek measurement location BLM LV03, taken at 4:28 p.m. on October 19, 2022.

Photograph 51. LaVerkin Creek downstream of BLM LV03, taken at 5:54 p.m. on October 19, 2022.

Photograph 52. LaVerkin Creek upstream of BLM LV07, taken at 6:39 p.m. on October 19, 2022.

Photograph 53. Along LaVerkin Creek upstream of Toquerville Falls, taken at 8:30 a.m. on October 20, 2022.

Photograph 54. Ash Creek near starting location, taken at 10:55 a.m. on October 20, 2022.

Appendix D: Utah Division of Water Rights Information

The Utah Division of Water Rights is an agency of Utah State Government within the Department of Natural Resources that administers the appropriation and distribution of the state's water resources. The information in this appendix is included to provide context for the state's administration of any federal reserved water rights that are ultimately adjudicated for the designated wild and scenic river segments. Specifically, this information indicates that the BLM and NPS will claim federal reserved water rights for the designated segments, and that any adjudicated federal reserved water rights will be adjudicated and administered along with other water rights priorities in Area 81. The source for this information is Utah Division of Water Rights 2023.

Area 81 – Virgin River

LaVerkin Creek and Smith Creek are in Water Rights Area 81 – Virgin River (Figure D1).

Area 81 Description

Covering most of Washington County and the western part of Kane County, this area reaches from T37S to T43S, and is bordered on the west by Nevada and on the south by Arizona. It includes the main stem of the Virgin River from below Zion National Park, through the Hurricane Cliffs to St. George and south to Arizona. Also, in this area are several major tributaries: 1) the East Fork of the Virgin River traversing Long Valley and the White Cliffs area, 2) the North Fork of the Virgin River from Kolob Terrace through Zion Canyon, 3) North Creek out of Kolob Terrace, 4) Ash Creek from the New Harmony area, 5) Quail Creek from the Pine Valley Mountains, and 6) the Santa Clara River entering above St. George. Several reservoirs store winter flows to supplement summer needs. These include Quail Creek, Gunlock, Kolob, Ash Creek, and Baker. A new reservoir is currently under construction at Sand Hollow near Hurricane. The area is bounded on the east by the 9,630 foot Paunsagunt Plateau and on the north by the 7,514 foot Cougar Mountains, the 10,238 foot Pine Valley Mountain, and the 10,027 foot Markagunt Plateau. The lowest point is where Beaver Dam Wash crosses the border into Arizona at 2,199 feet, giving the area a total relief of about 8,040 feet.

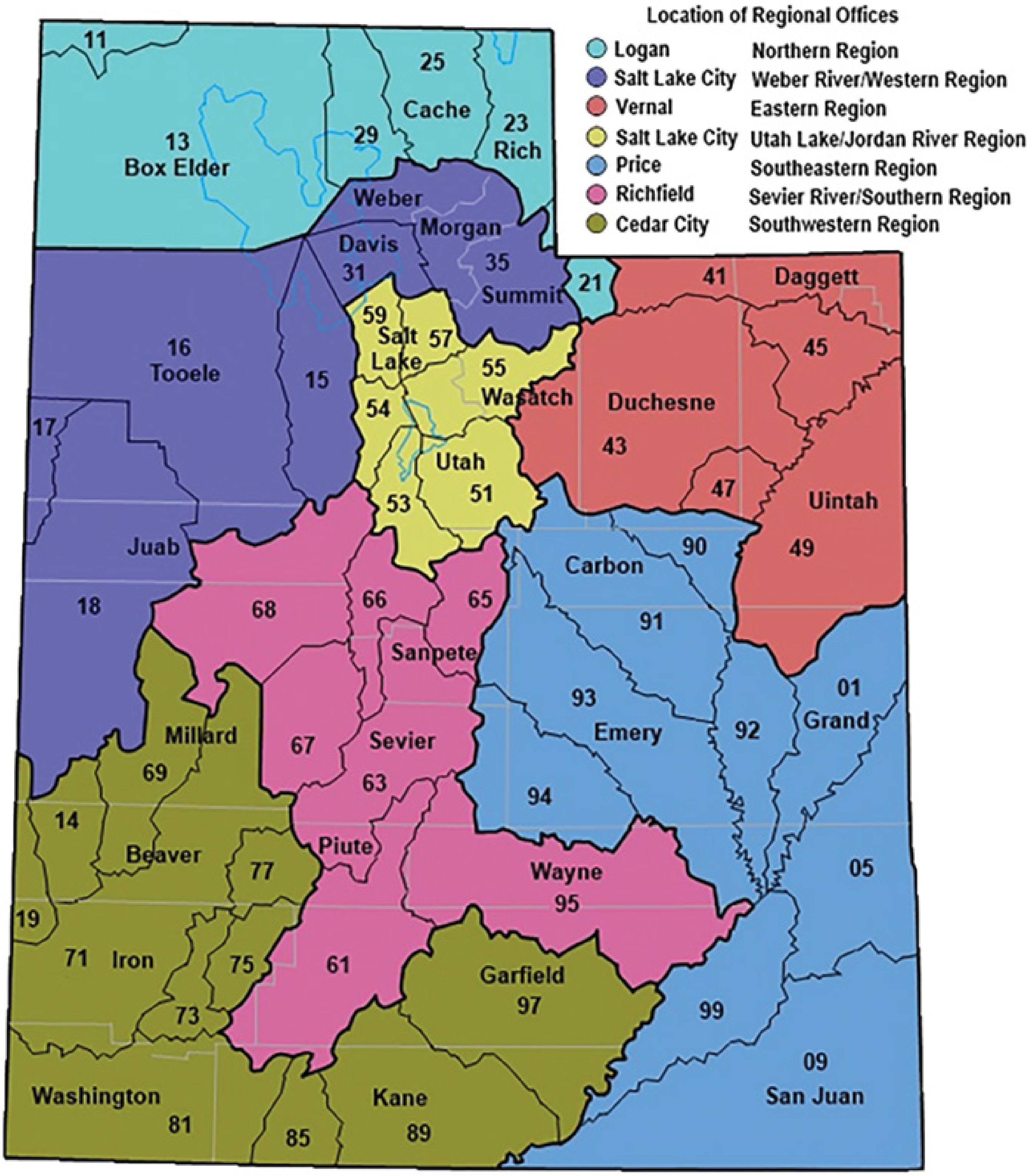


Figure D1. Map of Utah water right areas from the Utah Division of Water Rights.

Management

According to the Utah Division of Water Rights, water rights in the Virgin River and its tributaries have been allocated under several court decrees including the Santa Clara Decree in 1922 with a supplemental decree in 1928, the Quail Creek Decree in 1923, and the Virgin River Decree in 1926 with a supplemental and final decree in 1931.

Water rights in this area are currently being compiled into Proposed Determinations of Water Rights under the court ordered general adjudication of the Virgin River. The Beaver Dam Wash and Santa Clara River Proposed Determination (Book 1) was submitted to the court in 1988 while the North Fork and East Fork of the Virgin River Proposed Determination (Book 2) was submitted in 1992. No comprehensive pre-trial orders have been issued on either Book 1 or Book 2.

An Addendum to Book 1 was distributed in September 1999 in anticipation of a pre-trial order that will affirm all rights excepting those on which objections have been properly filed. In February of 2002, a "Partial Interlocutory Decree" was entered by the Fifth District Court affirming a number of water rights from Book 1. The rights affirmed are those related to a series of agreements designed to create a federal reserved water right for the Shivwits Band of Paiute Indians, whose reservation lands are located in the Santa Clara River drainage.

In June/July of 2000, a Proposed Determination (Book 6) covering the state originated and federal reserved rights within Zion National Park was distributed. In January of 2001, an "Interlocutory Decree" was entered by the Fifth District Court affirming the rights in Book 6. Part of this agreement limits the amount of available water that can be developed above the park. Scanned pages of the Zion National Park Settlement Agreement are available online. Table D1 shows water remaining for development and is updated regularly as change applications are approved and developed. A map showing the regions and subregions is available as a printable PDF.

Table D1. Water remaining for development in the East Fork and North Fork Virgin River Regions as of November 21, 2024.

East Fork Virgin River Region						
Subregion	**Total AF Permitted**	**Total AF Appropriated**	**Total AF Remaining**	**Surface AF Permitted**	**Surface AF Appropriated**	**Surface AF Remaining**
East Fork Virgin River	5,000	8.13	4,991.87	3,250	3.94	3,246.06
North Fork Virgin River Region						
Subregion	**Total AF Permitted**	**Total AF Appropriated**	**Total AF Remaining**	**Surface AF Permitted**	**Surface AF Appropriated**	**Surface AF Remaining**
Camp Creek	250	0.00	250.00	250	0.00	250.00
Clear Creek	250	192.22	57.78	250	175.77	74.23
Crystal Creek	1,000	1,429.99	0	1,000	1,429.99	0
Deep Creek	750	0.56	749.44	250	0.56	249.44
Echo Canyon	250	2.31	247.69	250	2.31	247.69
Goose Creek	250	0.00	250.00	250	0.00	250.00
Kolob Creek	2,000	26.61	1,973.39	2,000	26.23	1,973.77
LaVerkin Creek	750	59.07	690.93	250	59.06	190.94
Underground Rights 81-5074 – 0.01 af **Surface Rights** 81-179 – 18.63 af 81-179 – 18.63 af 81-179 – 18.63 af 81-4730 – 0.23 af 81-5034 – 0.32 af 81-5034 – 0.32 af 81-5077 – 0.44 af 81-5556 – 1.86 af						
North Creek	750	12.35	737.65	250	12.20	237.80
Orderville Canyon	750	0.38	749.62	250	0.38	249.62
Shunes Creek	250	0.00	250.00	250	0.00	250.00
Taylor Creek	250	0.00	250.00	250	0.00	250.00
Upper North Fork Virgin River	1,000	2.46	997.54	1,000	2.46	997.54
Totals	**6,000**	**1,725.94**	**4,274.06**	**2,500**	**1,708.96**	**791.04**

In 2009, H.R.146 became law designating as 'Wild and Scenic Rivers' approximately 165.5 miles of segments of the Virgin River and tributaries of the Virgin River across Federal land within and adjacent to Zion National Park. This designation provides protections which are described in U.S. Code TITLE 16 chapter 28 for these river segments as of the date of the designation. H.R. 146 specifically states that the stream segments within Zion National Park are governed by the 'Zion National Park Rights Settlement Agreement' dated December 4, 1996. The designation of Stream Segments as 'Wild and Scenic Rivers' outside of Zion National Park established a federal reserved water right for the purpose of the reservation with a priority date of 2009. This federal reserved right restricts future appropriation or water right changes that would reduce the flow of the river in these segments.

There are three state-administered surface water distribution systems in this area: The East Fork of the Virgin River, the Santa Clara River, and the Virgin River. These systems are under the jurisdiction of the East Fork of the Virgin River Commissioner, the Santa Clara River Commissioner, and the Virgin River Commissioner, respectively.

Because this area is tributary to the Colorado River, it is covered under the Colorado River Compact of 1922 and the Mexican Treaty of 1944. However, there are no interstate compacts which specifically apportion the waters of the Virgin River basin. There are three federal reserved water right agreements in force in this area. The Zion National Park Water Right Settlement Agreement deals with National Park Service water rights within the park and affects the administration of the North Fork and East Fork of the Virgin River drainages. The Shivwits Band of the Paiute Indian Tribe of Utah Water Rights Settlement Agreement quantifies the water rights of the Band on the Santa Clara River. The Water Rights Settlement Agreement for Leap, South Ash, Wet Sandy, Leeds and Quail Creeks deals with water right claims in the Dixie National Forest on the southeast flank of the Pine Valley Mountains.

Sources

Surface and Ground Water - The waters of this area are considered to be fully appropriated with a few exceptions. New diversions and uses must be accomplished by change applications based on valid existing water rights. Fixed-time projects involving surface waters must be accomplished by temporary change applications on valid existing water rights, which require annual renewal. Change applications proposing a change from surface to underground sources, or vice versa, will be critically reviewed to assure hydrologic connection, that there are no enlargements of the underlying right(s), and that there will be no impairment of other rights.

Appendix E: Water Quality Sample Location Coordinates

Table E1. 2022 and 2023 water quality sample locations (incomplete list).

Date Collected	Site ID	Site Name	Location Latitude UTM 12 S (meters)	Location Longitude UTM 12 S (meters)	Location Latitude (Decimal Degrees WGS)	Location Longitude (Decimal Degrees WGS)
2022						
10/19/2022	BLM LV01	LaVerkin Creek #1	306148	4138472	37.37274	-113.18929
10/19/2022	BLM LV02	LaVerkin Creek #2	306136	4137913	37.367706	-113.18928
10/19/2022	BLM LV03	LaVerkin Creek #3	306125	4137744	37.366181	-113.189359
10/18/2022	BLM LV06	LaVerkin Creek #6	303514	4135444	37.344916	-113.218214
10/18/2022	BLM LV07	LaVerkin Creek #7	301781	4133364	37.325813	-113.237209
10/18/2022	BLM LV08	LaVerkin Creek #8	301309	4132367	37.316732	-113.242266
10/18/2022	BLM TQ Falls	Toquerville Falls	300869	4130393	37.29886	-113.24669
10/19/2022	BLM SM09	Smith Creek #9	306822	4138013	37.36875	-113.181564
10/19/2022	BLM SM09.5	Smith Creek #9.5	306567	4138021	37.368769	-113.184444
10/19/2022	BLM SM10	Smith Creek #10	306167	4137889	37.367496	-113.188923
2023						
10/4/2023	BLM LV04	LaVerkin Creek #4	305976	4137539	37.364302	-113.190991
10/4/2023	NPS SM01	Smith Creek 1 (Near 2022 NPS SM01-1)	309772	4138126	37.3703772	-113.1483000
10/4/2023	NPS SM02	Smith Creek 2 (Near 2022 NPS SM04-1)	309343	4138484	37.3735138	-113.1532339
10/4/2023	NPS SM03	Smith Creek 3 (Near 2022 NPS SM05)	309240	4138485	37.3735017	-113.1543967
10/4/2023	NPS SM04	Smith Creek 4 (Near 2022 NPS SM06)	309095	4138474	37.3733727	-113.1560304
10/4/2023	NPS SM05	Smith Creek 5 (Near 2022 NPS SM07)	309050	4138455	37.3731923	-113.1565334
10/4/2023	NPS SM06	Smith Creek 6 (Near 2022 NPS SM09)	308794	4138334	37.3720497	-113.1593914
10/4/2023	NPS SM07	Smith Creek 7 (Near 2022 NPS SM10-2)	308784	4138313	37.3718585	-113.1594989
10/4/2023	NPS SM08	Smith Creek 8 (Near 2022 NPS SM11)	308755	4138268	37.3714472	-113.1598146

2022 BLM field crew: Jared Dalebout (Utah State Office), Ryan Reese (St. George Field Office), Brandt Reese (Grand Staircase-Escalante National Monument).

2023 BLM field crew: Jared Dalebout (Utah State Office); 2023 NPS field crew: Robyn Henderek, Zachary Warren.
Water quality instrument used by the BLM: YSI Pro Plus in 2022 and YSI Pro 1030 in 2023.

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