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Riparian Monitoring of Wadeable Streams on the Fremont River, Capitol Reef National Park, 2009–2021

Natural Resource Report NPS/NCPN/NRR—2023/2584



ON THE COVER

Fremont River, Capitol Reef National Park. NPS/Amy Washuta.

Riparian Monitoring of Wadeable Streams on the Fremont River, Capitol Reef National Park, 2009–2021

Natural Resource Report NPS/NCPN/NRR—2023/2584

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Executive Summary

The goal of Northern Colorado Plateau Network (NCPN) riparian monitoring is to determine long-term trends in hydrologic, geomorphic, and vegetative properties of wadeable streams in the context of changes in other ecological drivers, stressors, and processes. This information is intended to provide early warning of resource degradation and determine natural variability of wadeable streams.

This report summarizes NCPN monitoring of the Fremont River in Capitol Reef National Park (NP) from water years 2009 to 2021. The focus of this report is to (1) examine patterns in water availability at one monitoring reach from 2010 to 2021, and (2) present geomorphology and vegetation data from four reaches monitored from 2009 to 2021. Vegetation sampling and geomorphology surveys were completed at varying intervals throughout the time period; this report looks at changes within single reaches and establishes a baseline for future comparisons.

There are four monitoring reaches established on the Fremont River: (1) F-01, approximately 2.5 kilometers upstream of a knickpoint (sharp change in channel slope) and associated waterfall that emerged following construction of State Highway 24 in 1964, (2) F-07, in a large oxbow that was cut off due to the highway construction, (3) F-04, approximately 1.5 kilometers downstream of the knickpoint, and (4) F-14, approximately 4.8 kilometers downstream of the knickpoint. Geomorphic and vegetation surveys took place at all reaches. Hydrologic monitoring occurred only at F-01.

From 2001 to 2021, the entire range of flows recorded at a gaging station on the Fremont River upstream of the park near Bicknell, Utah, decreased, with the steepest decreases occurring in the highest flow percentiles. Continuous hydrologic monitoring at reach F-01 in the park from 2010 to 2021 showed perennial flows in the Fremont River, with lower flows during the irrigation season (April 1–October 31). The irrigation season was also characterized by greater evapotranspiration, which may be exacerbated in the future due to higher air temperatures.

Lower observed inputs and greater evapotranspiration suggest the Fremont River is at risk for progressively lower flows over time. While overbank flows occurred infrequently in the monitoring reach, inhibiting cottonwood recruitment, groundwater levels remained shallow enough to support mature cottonwood trees. Protecting spring snowmelt flows of 94 cfs (the average annual maximum 14-day rolling mean at reach F-01), or greater should maintain the current wetland vegetated zone. Maintaining the hydrologic record was challenging due to high-magnitude flood events and turbid flows; the park should consider a gaging station for an accurate discharge record.

Geomorphic surveys showed net sediment deposition at reaches F-01 and F-14 in the channels, banks, and floodplains from 2009 to 2021, with more deposition occurring earlier in the study period. A large flood event in 2013 resulted in high flows and deposition of close to one meter at F-01. Only localized erosion occurred, and thalweg surveys showed that stream channels were either stable or increasing in elevation. Reach F-07, the abandoned oxbow, exhibited little geomorphic change over the study period.

Riparian vegetation was characteristic of a Fremont cottonwood woodland, with canopy closure up to 30% and a mixed understory of shrubs and herbaceous species. Obligate wetland vegetation cover of 5%–10% was present at reaches F-01, F-04, and F-14. Reach F-07, in the oxbow, has transitioned to an upland system, with little to no canopy cover and no obligate wetland species. While mature cottonwoods were present in reaches F-01, F-04, and F-14, there was limited evidence of seedlings or saplings graduating into larger size classes. Cottonwood seedlings are primarily resprouts from beaver-browsed trees, although one seedling recruitment event was observed in 2014, following high flows in late 2013. Protecting some

cottonwoods with chicken wire may help protect the larger size classes and maintain a mixed-age woodland.

Exotic plant species cover was less than 10% in reaches F-01, F-04, and F-14. Efforts to control Russian olive (*Eleagnus angustifolia*) along the Fremont River appear to have been successful in these reaches. In reach F-07, exotic plant cover ranged from 9% to 25%, with notable spikes in Russian thistle (*Salsola tragus*) and cheatgrass (*Bromus tectorum*) in 2010 and 2011, respectively.

Management recommendations for this report are:

- Advocate for maintaining spring snowmelt flows of 94 cfs or greater in the NCPN monitoring reach. Policy goals to achieve this could include excluding additional upstream reservoirs and diversions and maintaining the state-managed irrigation season, which currently begins on April 1.
- If a high-accuracy discharge record is desired, investigate the placement of a gaging station within the park or the re-establishment of the Caineville gaging station downstream of the park boundary.
- Protect young cottonwoods from beaver herbivory and release older mature trees from chicken wire if it is restricting growth and/or the trees are being girdled.
- Continue control of Russian olive and tamarisk.
- Advocate for restoration of the abandoned oxbow, where riparian function has been lost.

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1 Introduction

1.1 Background

Riparian zones occupy a tiny fraction of the desert southwest landscape, yet they contribute disproportionately to regional biodiversity (Gregory et al. 1991; Naiman and Décamps 1997). It is estimated that over 60% of species found in arid-region riparian areas are not found in adjacent upland habitats (Sabo et al. 2005). Approximately 77% of amphibian, 80% of mammal, and 90% of bird species in the US Southwest routinely use riparian areas for food, water, or cover (Brown et al. 1977).

In addition, southwestern riparian zones are key stopovers for many North American migratory bird species (Skagen et al. 1998). Riparian vegetation contributes litter and woody debris to aquatic ecosystems, creating the foundation for in-stream food webs (Vannote et al. 1980). Other key riparian ecosystem services include improving water quality via sediment trapping (Pearce et al. 1998; Tabacchi et al. 1998), preventing erosion through bank stabilization (Beeson and Doyle 1995; Simon and Collison 2002), and reducing flood power (Birkeland 2002). The aesthetic qualities of riparian areas also make them attractive to park visitors.

1.2 Conceptual model of Colorado Plateau wadeable streams

Riparian ecosystems are situated where upland and aquatic systems meet. As such, they are potentially sensitive indicators of landscape-level environmental change (Naiman et al. 1988). Numerous studies on the Colorado Plateau have recorded change in geomorphic processes and riparian structure coincident with climate-related shifts in regional precipitation patterns (Allred and Schmidt 1999; Hereford 1984; Hereford et al. 1996) and land-use changes (Poff et al. 1997). Rivers and streams directly influence riparian ecosystems through enhanced water supply, flooding, and erosional and depositional processes (Brinson et al. 1981).

At the same time, upland disturbance processes impose direct and indirect effects on riparian ecosystems across a range of scales. At finer scales in steep terrain, debris flow and landslide disturbances directly impinge on narrow riparian zones. At larger scales, land-use practices (such as grazing and land-clearing) and indirect effects of climate change (such as increased frequency and severity of fire, and loss of biological soil crusts) degrade upland soil stability and reduce vegetation cover, altering the delivery of water and sediment to receiving streams (Trimble and Mendel 1995). This, in turn, alters the rate, magnitude, and direction of the channel processes that ultimately structure and maintain riparian ecosystems (Frissell et al. 1986).

Consistent, long-term monitoring of key physical and biological elements of riparian ecosystems can provide important insights into the effects of human use of land and water across a range of spatial scales. The Northern Colorado Plateau Network (NCPN) collects and analyzes long-term ecological monitoring data to provide national parks with scientific information to inform decisionmaking. NCPN staff have worked with park staff to select resources that can be used as "vital signs" to indicate the health of park ecosystems, including the riparian area of the Fremont River at Capitol Reef National Park (NP).

Relatively healthy, naturally functioning riparian ecosystems of the Colorado Plateau are characterized by the following elements:

- **Surface-flow variability.** Given the potential for high-intensity rainfall events, steep terrain, thin and patchy soils, exposures of relatively impermeable bedrock, and sparse vegetation, the hydrographs of streams originating within the Colorado Plateau are typified by relatively high-magnitude, short-duration, temporally unpredictable storm-flow hydrographs with little or no base flow (Scott et al. 2005).
- **Active erosional and depositional processes.** The high, flashy peak flows and high sediment loads of Colorado Plateau streams can cause vertical aggradation of floodplains and channel incision that progressively disconnects riparian surfaces from surface flow in

adjacent channels, creating terraces. Remnant terrace sequences from across the arid and semiarid western U.S., including the Colorado Plateau, record several climatically driven valley cut-and-fill cycles during the Holocene period (i.e., within the last 10,000 years) coincident with wetter and drier climate periods (Elliot et al. 1999; Emmett 1974; Miller et al. 2004). Land uses that exacerbate erosion can also contribute to channel incision.

- **Relatively shallow alluvial groundwater.** Water from surface flow and associated shallow alluvial aquifers is essential to the persistence of most low-elevation woody riparian species in the southwestern US. Thus, an integrated understanding of surface and alluvial groundwater flows, and their interactions, is fundamental to understanding establishment and survival processes of existing riparian and wetland ecosystems (Winter 1999; Woessner 2000).
- **Diverse alluvial surfaces.** Variations in surface flow, depth to alluvial groundwater, topography, and valley setting create cross-valley gradients of moisture availability and disturbance intensity and frequency (Bendix 1994; Hupp and Osterkamp 1985). These diverse alluvial surfaces support a wide range of riparian plant and animal communities, including some invasive exotic plant species.

A hallmark of riparian ecosystems on the Colorado Plateau is their resilience to frequent and sometimes intense physical disturbances. Rapid recovery of the structural and functional elements of riparian ecosystems following disturbance is distinct from the recovery of upland ecosystems in arid and semiarid regions, where productivity is typically lower and plant recruitment is slower and more episodic (Scott et al. 2005). High rates of recovery in riparian ecosystems result primarily from *adequate moisture*, which supports relatively high rates of productivity; *high linear connectivity*, which allows for rapid re-colonization of disturbed sites from upstream and downstream refugia; and *disturbance-adapted species*, whose life-history characteristics allow them to reestablish and re-colonize quickly following disturbance.

These characteristics, along with the predominance of woody vegetation, contribute significantly to species richness across communities by serving as habitat for plant and animal species not found in surrounding uplands (Brinson et al. 1981; Hylander 2006; Sabo et al. 2005).

1.3 Purpose and scope

The overall goal of NCPN riparian monitoring of wadeable streams is to determine long-term trends in hydrologic, geomorphic, and vegetative properties of wadeable streams in the context of changes in other ecological drivers, stressors, and processes. At Capitol Reef NP, specific objectives of riparian monitoring in the Fremont River are to:

- Determine status and trends in surface water and shallow groundwater,
- Determine status and trends in geomorphic processes as reflected in channel and floodplain form, including channel planform, channel slope, and composition of bed material, and
- Determine status and trends in vegetation dynamics, including species richness, plant cover by lifeform and wetland status, basal area and density of woody species, canopy closure, and frequency of invasive species.

We do not attempt to determine some common geomorphic metrics, including channel width, channel depth, floodplain width, or elevation of the floodplain above the thalweg (i.e., the deepest part of the channel) for the reach cross-sections. The topographic breaks used to determine these surfaces are difficult to determine for streams in the southwestern US, including the Fremont River.

This report (1) presents and evaluates vegetation and geomorphic monitoring data collected at four reaches in the Fremont River from 2009 to 2021, (2) presents hydrologic data collected at one reach from

2010 to 2021, and (3) identifies significant high-flow events and evaluates their impacts on vegetation and geomorphology.

1.4 Study area

The Fremont River watershed (HUC #14070003) covers approximately 5,063 square kilometers, originating from headwater streams in the high plateaus surrounding Fish Lake in Fish Lake National Forest, northwest of Capitol Reef NP (Figure 1-1). In the upper portion of the watershed, the river is stored in Fish Lake, and then Johnson Valley and Mill Meadow reservoirs. Dams were constructed at Johnson Valley in 1899, and Mill Meadow in 1954 (UDEQ 2002). At Mill Meadow, the majority of surface water is diverted for irrigation from April 1 to October 31 (UDEQ 2002). Surface flow is restored further downstream as springs and major tributaries enter the main channel before the river enters the park.

Capitol Reef National Park was designated to protect the Waterpocket Fold, a 145-ki-

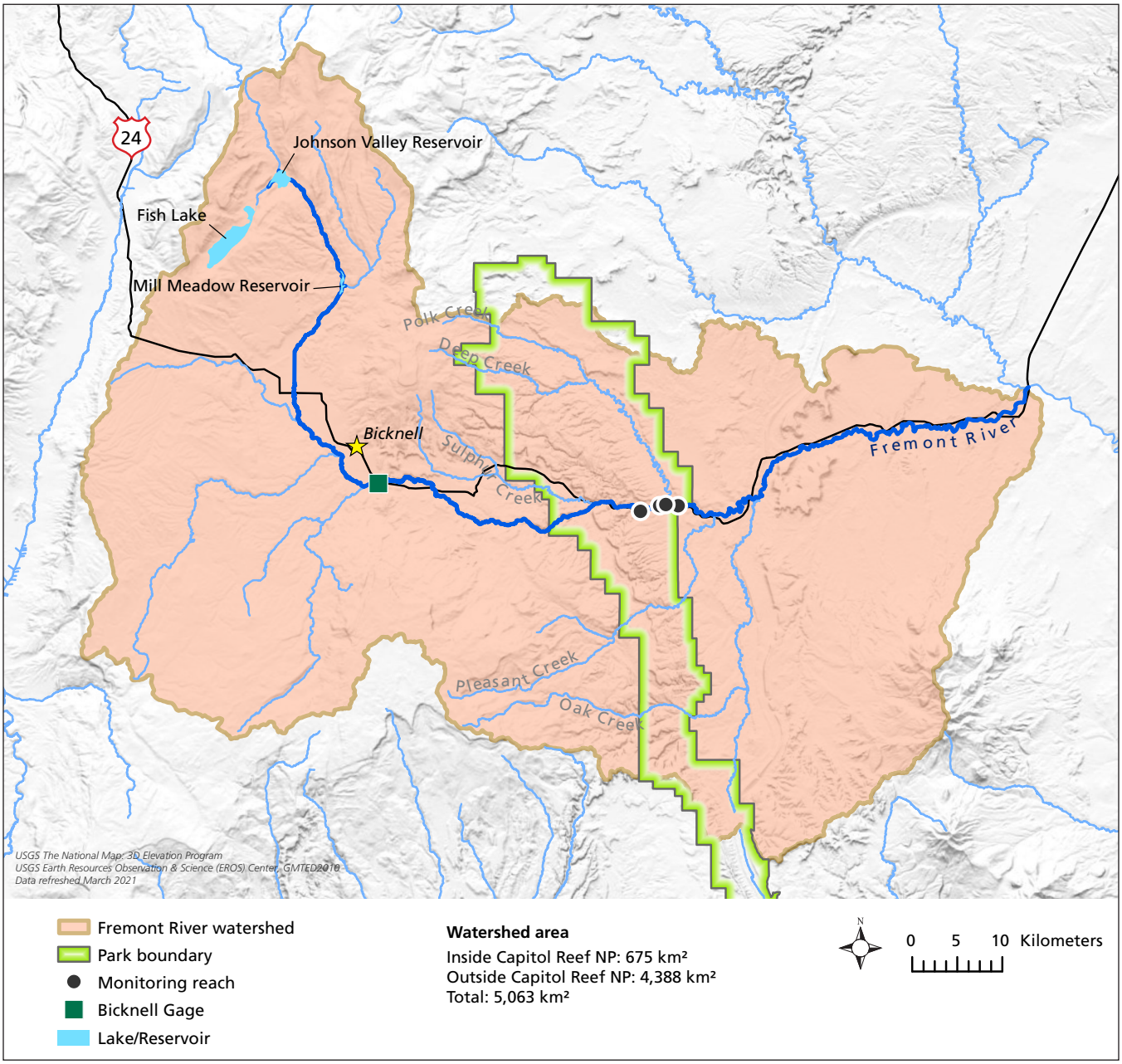


Figure 1-1. Capitol Reef National Park in the context of the Fremont River watershed.

lometer, eastward-dipping monocline that is the largest exposed such feature in North America. The Fremont River bisects the Waterpocket Fold from west to east, traveling 21 kilometers through the park. Within this segment, water is diverted in the Fruita Rural Historic District to irrigate historic fruit orchards. From Fruita to the eastern park boundary, Utah State Highway 24 constrains the river channel to the north side of the highway. Because of the proximity of the Fremont River to the highway, it receives moderate recreational use from visitors walking on social trails at roadside pullouts. The riparian zone receives heavy recreational use at the popular Hickman Bridge trailhead, located adjacent to the river.

Resource concerns related to the Fremont River in Capitol Reef NP include:

1) maintaining instream flows that support riparian and aquatic ecosystems,
2) downcutting at the knickpoint and geomorphic changes to the channel upstream and downstream,
3) impacts to the watershed from activities within the park, including orchard management and recreational use,
4) water-quality concerns resulting from upstream sources, and
5) managing the concerns listed above in the context of climate projections that predict higher temperatures and uncertainty in future precipitation (Battaglin et al. 2020).

1.4.1 Climate

Capitol Reef NP has an arid climate, with average annual precipitation totals of 20 centimeters as recorded at park headquarters from 1980 to 2020. Average July maximum temperature is 32.8°C (91°F); average minimum temperature in January is −6.7°C (20°F). The North American Monsoon brings precipitation to the park in the form of brief but intense rainstorms in the summer months (July–September), often resulting in localized flooding in the Fremont River or its tributaries. At higher elevations of the Fremont River watershed in Fish Lake National Forest, most precipitation falls as snow in the winter months, ranging from 40 to 76 centimeters.

1.4.2 Hydrology

The US Geological Survey (USGS) measures flow on the Fremont River at USGS gaging station 09330000 (hereafter referred to as the Bicknell gage), approximately 34 kilometers upstream of the NCPN F-01 monitoring reach (see Figure 1-1). The watershed area upstream of the gage is 1,945 km^2. The daily mean discharge hydrograph shows higher winter flows, corresponding to the non-irrigation season of November–March (Figure 1-2). In most years, there is only a minor spring increase in flow due to snowmelt, as indicated by the 25th to 75th percentiles, shown in green. However, above the 75th percentile, there can be snowmelt peaks in March and April. In roughly 5% of years, peaks are higher and last longer, sometimes lingering into June. Spring is followed by declining water levels through summer, corresponding to irrigation withdrawals and increased evapotranspiration. Monsoonal storms in late summer and early fall can cause flash flooding events. The monsoonal flooding regime experienced at the monitoring reach is different from that recorded at the Bicknell gage, which is situated in a wide alluvial valley, rather than a constricted canyon.

Within Capitol Reef NP, the river becomes naturally constrained by bedrock canyons. The river enters in a gorge through the Kaibab Limestone and subsequently cuts through the younger to older rock formations of the Waterpocket Fold, including the Moenkopi Formation, Kayenta Formation, and the Navajo Sandstone (Graham 2006) (Figure 1-3). The Moenkopi Formation is a minor local aquifer and supports the park's public water supply well for the Fruita developed area (Struthers et al. 2022). The Navajo Sandstone is a major regional aquifer, supporting springs that drain into or toward the Fremont River within the park, often where the river contacts the underlying Kayenta Formation (Cudlip and Kunkle 2004). Quaternary alluvium in the Fremont River valley bottom supports a shallow alluvial aquifer replenished by river water and precipitation (see Figure 1-3).

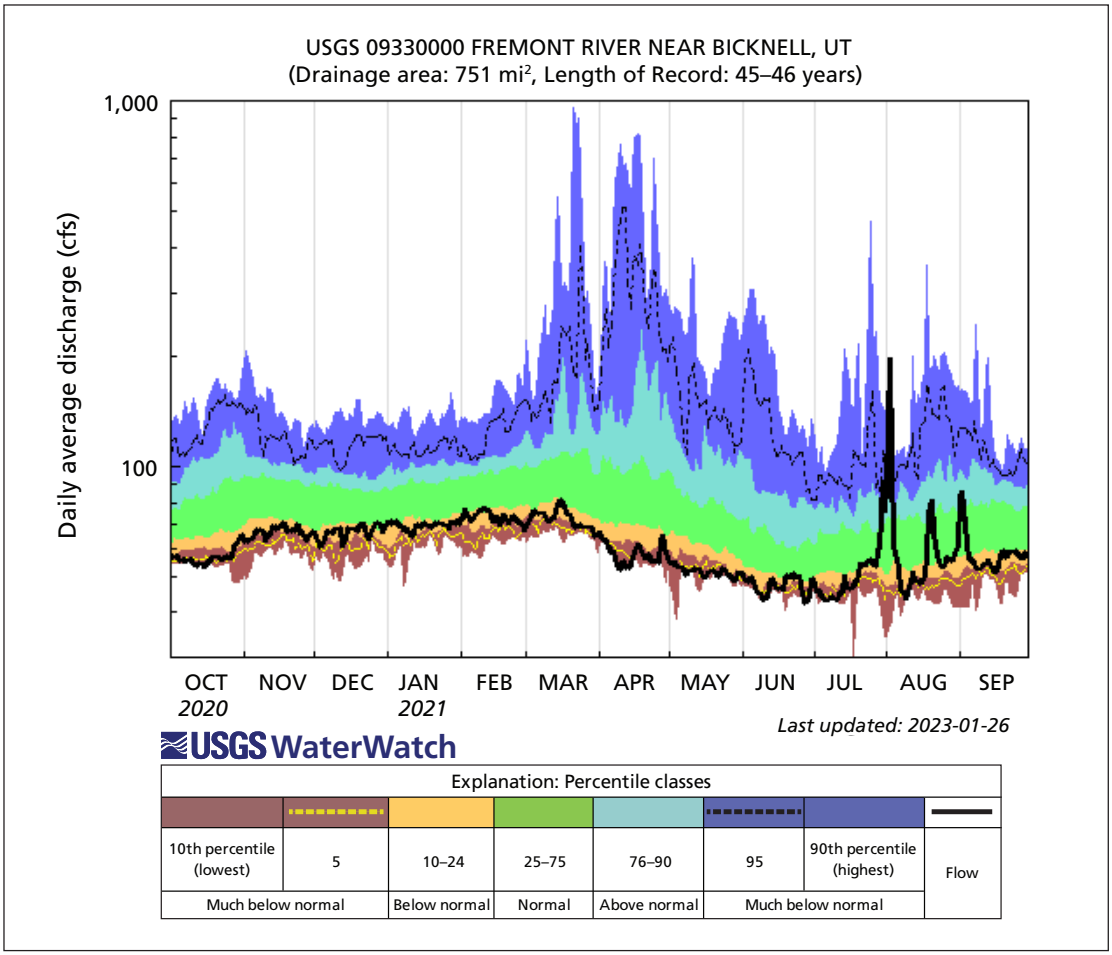


Figure 1-2. Streamflow-duration hydrograph for the Fremont River near Bicknell, Utah (Gage 09330000), comparing water year 2021 (October 2020–September 2021) to percentiles for the 45-year period of record. Downloaded from https://waterwatch.usgs.gov/ on 1/26/2023.

A small perennial tributary, Sulphur Creek, enters the Fremont River near the park's visitor center. Dry washes, including Spring Canyon and Grand Wash, also enter the river upstream of the monitoring reach, and may contribute to high flows during monsoonal flash flooding. The river continues eastward from the park boundary to its confluence with the Dirty Devil River near Hanksville, Utah, at an elevation of 1,300 meters.

The Fremont River is fully appropriated, meaning all water is allocated to water-right holders. Diversions are common upstream of the park. The park maintains an 8-cfs (cubic feet per second) water right for irrigating orchards and pastureland. Downstream water users hold senior water rights that total 23.5 cfs. These downstream water rights represent the minimum instream flows that should occur in the park during the irrigation season unless drought measures are in place.

1.4.3 Geology and geomorphology

Capitol Reef National Park is in the northern half of the Colorado Plateau. This area is characterized by uplifted Mesozoic to Paleozoic sedimentary-rock formations with deep canyons cut by the Colorado River and its tributaries, including the Fremont River (USDA 2022). Outside the park, in the upper Fremont watershed, volcanic activity in the Tertiary and Quaternary ages formed numerous plateaus and flat-topped mountains, including the Fish Lake hightop and Thousand Lake Mountain, where the Fremont River originates. Dropping in elevation to the east and south, the river passes through Rabbit Valley, which has a thick alluvium layer of sands, gravel, silts, and clays, prior to entering the park (see Figure 1-3) (UDEQ 2002).

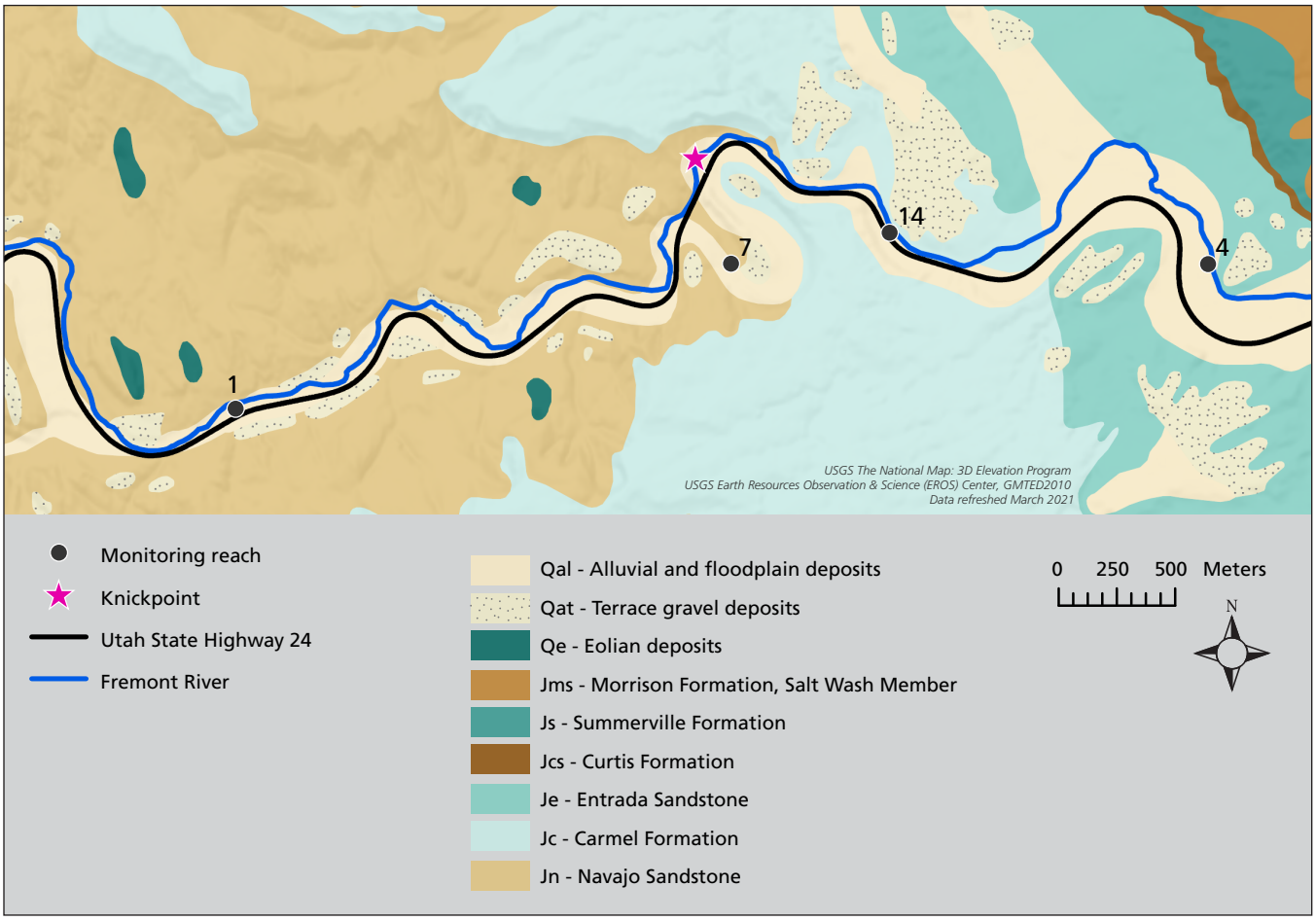


Figure 1-3. Geology of the area surrounding Fremont River monitoring reaches.

During construction of State Highway 24 through Capitol Reef NP in 1964, a large channel meander was cut off from the Fremont River, and surface flow diverted to the north side of the highway. This alteration to the channel resulted in a rapidly eroding knickpoint (sharp change in channel slope) and associated waterfall in the Navajo Sandstone, with an abandoned oxbow above it (see reach 7 in Figure 1-3). Monitoring reaches in the park are in the constricted Navajo Sandstone canyon above the knickpoint, the abandoned oxbow, and a similarly constricted canyon downstream, in the Carmel Formation (see Figure 1-3). The river's alluvial valley bottom also contains Quaternary-age terrace gravel deposits frequently found adjacent to the modern floodplain.

Channel narrowing and incision are apparent throughout the extent of the Fremont River in Capitol Reef NP. Photos taken prior to 1950 show a wide, braided channel with little to no vegetation. Later photos show a narrower, deeper channel, with banks stabilized by mature Fremont cottonwood (*Populus fremontii*), coyote willow (*Salix exigua*), and common reed (*Phragmites australis*). Photos taken by researcher Charles Kay in 2009, and NCPN staff in 2022, show additional instances of channel straightening (Kay 2011; Figures 1-4, 1-5).

1.4.4 Vegetation

The narrow band of riparian vegetation along the Fremont River in Capitol Reef NP is primarily classified as Fremont Cottonwood Woodland Complex. The Fremont cottonwood overstory is usually found on terraces above the streambed, with canopy closure often 40% or less. Mature stands have an understory of mixed upland shrub species, including rabbitbrush (*Chrysothamnus nauseosus*) and Basin big sagebrush (*Artemisia tridentata*). Younger stands have coyote willow. Vegetation in these woodlands varies depending on frequency of



Figure 1-4. Historical photo match looking northwest up the Fremont River. Photopoint is located slightly downstream of the Hickman Bridge trailhead. Photo at left taken by former superintendent Charles Kelley, ca. 1950; middle photo taken by Charles Kay in 2009 (photoplate HM-6 in Kay 2011). The photo at right was relocated and taken by Rebecca Weissinger (NCPN) in 2022. The wide, braided river channel greatly narrowed and incised since 1950, with additional straightening occurring from 2009 to present. Previously unvegetated streambanks are now stabilized primarily by coyote willow and common reed.

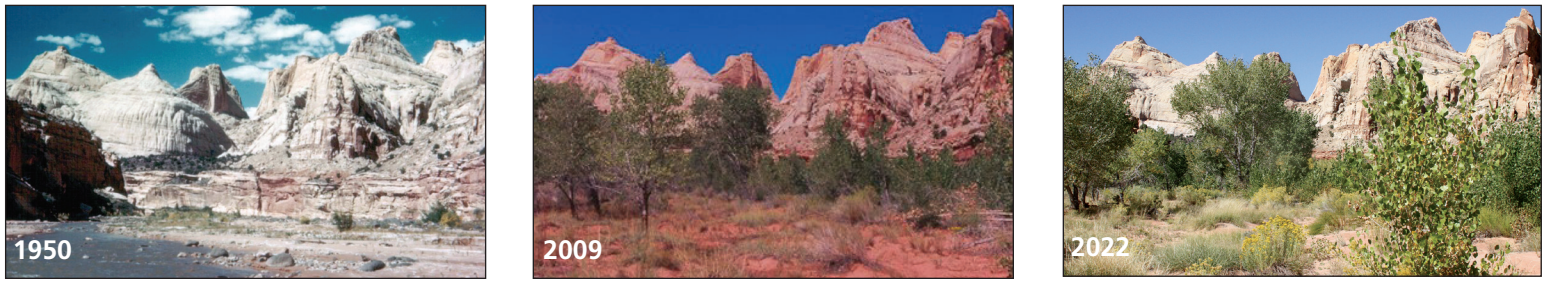


Figure 1-5. Historical photo match looking northwest up the Fremont River. Photopoint is located slightly downstream of the Hickman Bridge trailhead. Photo at left taken by former superintendent Charles Kelley, ca. 1950; middle photo taken by Charles Kay in 2009 (photoplate HM-14 in Kay 2011). The photo at right was relocated and taken by Rebecca Weissinger (NCPN) in 2022. In the present-day photos, the river channel is no longer visible; it is located to the far right in the photo frame. The braided river channel has been replaced with a terrace of Fremont cottonwood and upland shrub species, including rabbitbrush and basin big sagebrush. In the bottom photo, surface litter has been recently scoured and replaced with freshly deposited sand. A new young cottonwood is visible in the foreground.

flooding and associated scour or deposition in the floodplain (Coles et al. 2009).

Tamarisk (*Tamarisk* sp.) and Russian olive (*Eleagnus angustifolia*) are both exotic woody plants that can invade riparian areas and disrupt ecosystem function (Poff et al. 2011). Vegetation mapping efforts (Coles et al. 2009) recorded that the Fremont Cottonwood Woodland Complex was often invaded by tamarisk, and the park's 2004 Water Resources Management Plan (Cudlip and Kunkle 2004) describes tamarisk and Russian olive as dominating riparian vegetation downstream of the knickpoint.

Historical photos show that where the river has channelized, vegetation on the remaining terraces often includes facultative or upland species, such as rabbitbrush, alkali sacaton (*Sporobolus airoides*), saltgrass (*Distichlis spicata*), and Basin big sagebrush (see Figures 1-4, 1-5). Along the streambanks, coyote willow and common reed can be dense (Kay 2011; see Figure 1-4).

2 Methods

2.1 Sampling design

The sampling unit for NCPN riparian monitoring of wadeable streams is a stream reach. Measurements of vegetation and physical drivers are co-located at each reach. A reach is 180–360 meters in length, with seven equally spaced transects that run perpendicular to the channel (Figure 2-1). The reach, as defined here, is intended to be a representative portion of a stream segment. Stream segments are typically thousands of meters in length and represent relatively uniform sets of physical, chemical, and biological conditions within a stream (Fitzpatrick et al. 1998). Stream segments are analogous to valley segments as defined in the process-oriented, hierarchical geomorphic classification of Montgomery and Buffington (1993, 1998). Reaches were selected for monitoring using a survey design intended to provide inference to the entire sampling frame of the stream within the park. However, limitations to sampling effort (described below) mean that inference is now only made to individual reaches.

2.1.1 Sampling frame

Initially, the entire length of the Fremont River as it runs through the park (21 km) was selected as the target population, with stratification into six sections that reflected similarities in geology and management:

1. the **Fremont Gorge,** which cuts into the Kaibab Limestone and undivided Cutler Group,
2. the **managed area** through the historic district,
3. the constricted Navajo Sandstone canyon along the highway **above the knickpoint**,
4. the **oxbow** that formed following construction of Utah Highway 24,
5. a constricted sandstone canyon **below the knickpoint**, similar to that above the knickpoint but through the Carmel Formation, and
6. the **Lower Fremont** River, where the geology opens into a wider alluvial valley.

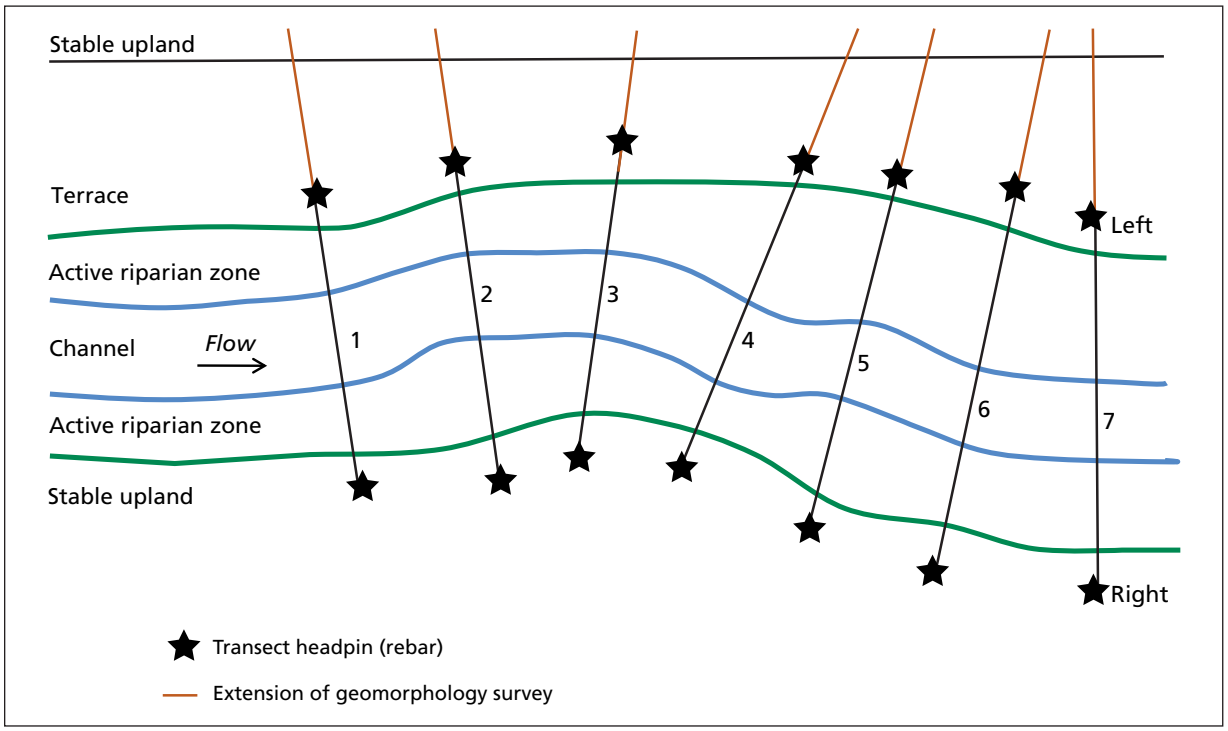


Figure 2-1. Example of a riparian monitoring reach with seven equidistant cross-section transects. Star symbols indicate locations of headpins. The green line represents the upland/riparian zone boundary, and "4" is the location of the reach centroid. Geomorphology transects extend to a stable upland surface.

Monitoring reaches were selected using the Generalized Random Tessellation Stratified (GRTS) method (Stevens and Olsen 2004) to create a spatially balanced design within the sampling frame. The spsurvey 2.0 package (Kincaid and Olsen 2008) in R 2.8.1 (R Core Team 2008) was used to create an ordered list of centroids for 10 possible monitoring reaches in the sampling frame. Twenty additional reaches were identified to account for the possibility of rejected reaches. Reaches could be rejected if they contained major tributaries, were bedrock-constricted (no more than 25% of the reach) or had significant archeological concerns.

2.1.2 Revisit design and reaches monitored, 2009–2021

Vegetation and geomorphology monitoring occur at all reaches, while hydrology monitoring occurs at a single reach. Pilot monitoring was not conducted at Capitol Reef NP because affordable effort and the length of the sampling frame were greater limiting factors than the variability of vegetation. A rotating panel-revisit design was originally proposed to increase the overall sample size (Weissinger et al. 2018). The initial revisit design sampled three reaches per year, and a total of 10 reaches over five years. Reaches F-01 (above the knickpoint), F-07 (oxbow), and F-14 (below the knickpoint) were established in 2009 (Table 2-1, Figure 2-2). Vegetation and geomorphology surveys were completed in 2010 and 2011. In 2012, reach F-04 (Lower Fremont) was established, and vegetation and geomorphology were monitored.

After the first few field seasons, it was determined that it was not feasible to sample three reaches per year for vegetation and geomorphology, due to time constraints and the 2013 federal budget sequestration. As a result, NCPN prioritized sampling of three reaches that were already established and were of the greatest management interest to the park: F-01, F-07, and F-14. After 2013, F-01, F-07, and F-14 were sampled for vegetation and geomorphology when the budget allowed (see Table 2-1).

In 2010, hydrologic monitoring was initiated, with the installation of instream and groundwater wells at F-01. This monitoring has continued every year (with some gaps due to flood damage). In 2021, reaches F-01, F-07, and F-14 were all sampled for vegetation and geomorphology to support an external research project at the request of park staff. Vegetation sampling took place on June 24–28, 2009, August 3–5, 2010, August 4–9, 2011, August 2–4, 2012, June 18–21, 2014, June 14, 2018, and May 27–29, 2021.

Riparian monitoring remains a high priority for park managers at Capitol Reef NP, but the future frequency of vegetation and geomorphology monitoring will depend on ongoing discussions with park staff. Hydrologic monitoring will continue annually.

2.1.3 Sampling procedures

All sampling followed procedures outlined in Weissinger and others (2018). The reach length and distance between transects were determined by the width of the active riparian zone. Permanent transects were established perpendicular to the channel and marked with rebar (i.e., headpins), usually at the endpoints. On some transects, permanent bedrock markers were also added so transects could be relocated if a headpin washed away. Kevlar taglines marked at one-meter intervals were strung between the headpins and used to guide transect-tape placement and surveying.

2.1.4 Hydrology measurements

Hydrologic monitoring occurs only at reach F-01. Stream stage and groundwater elevations are measured in one instream surface-water installation and two riparian shallow groundwater wells installed along transect 1 of reach F-01. Reach F-01 was selected for hydrologic monitoring due to its first position in the spatially balanced sampling design and the presence of a relatively straight section of channel for instrumentation. The monitoring reach has a relatively even-depth, rectangular channel with elevated banks. Water levels are recorded at 15-minute intervals. Information from the data loggers, as well as manual measurements, are collected 4–6 times each year. Transects with loggers are surveyed every year.

Table 2-1. Elevation, location, mean transect length, years visited, and type of visit for each monitoring reach on the Fremont River, Capitol Reef National Park, 2009–2021.

Reach	Location	Elevation (m)	UTM-N	UTM-E	Reach length (m)	Mean transect length (m)	Year	Vegetation	Geomorphology	Hydrology
F-01	above the knickpoint	1,579	4236811	483754	240	61.1	2009	X	X	–
							2010	X	–	X
							2011	X	–	X
							2012	–	–	X
							2013	–	–	X
							2014	X	X	X
							2015	–	–	X
							2016	–	–	X
							2017	–	–	X
							2018	X	X	X
							2019	–	–	X
							2020	–	–	X
							2021	X	X	X
F-07	oxbow	1,554	4237434	485884	300	51.3	2009	X	X	–
							2010	X	–	–
							2011	X	–	–
							2021	X	X	–
F-14	below the knickpoint	1,536	4237568	486566	180	26.8	2009	X	X	–
							2010	X	–	–
							2011	X	–	–
							2012	X	–	–
							2014	X	X	–
							2021	X	X	–
F-04*	Lower Fremont	1,520	4237433	487934	390	93.1	2012	X	–	–

*Retired after 2013 due to time constraints and the 2013 federal budget sequestration.

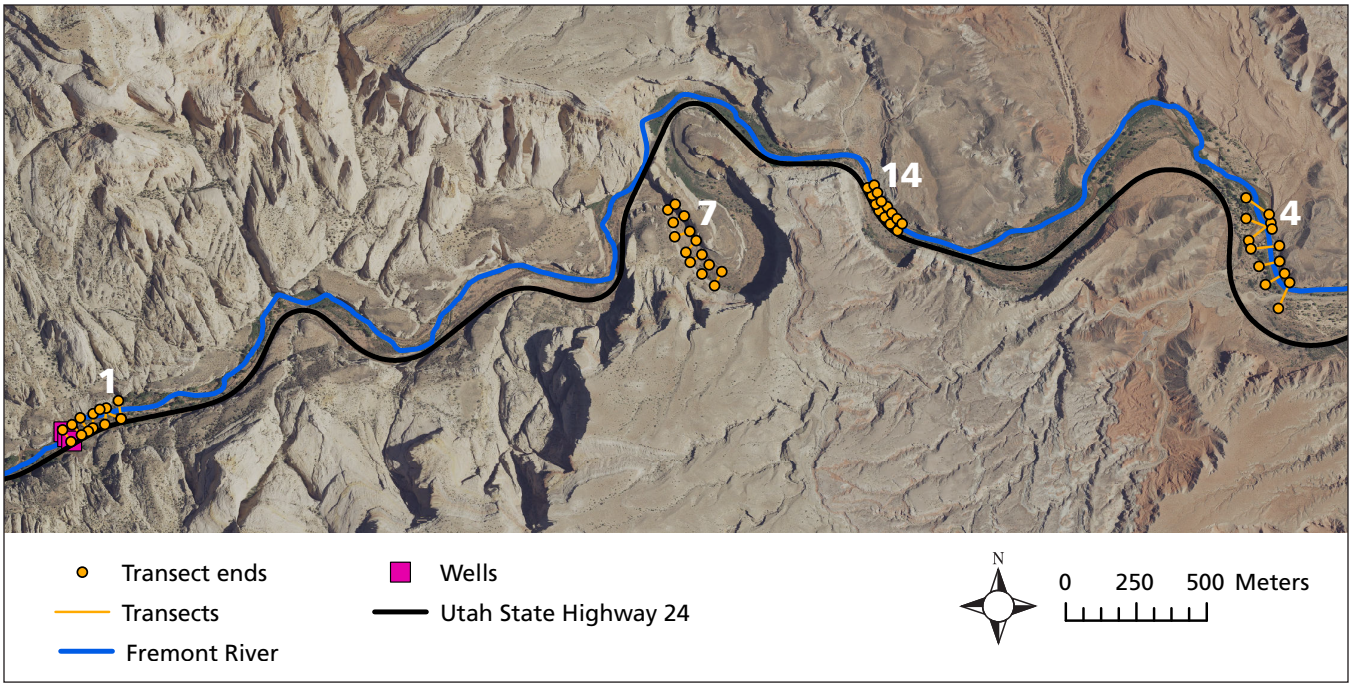


Figure 2-2. Locations of NCPN monitoring transects and hydrologic installations.

For convenience, the use of "wells" in this report can be understood to incorporate all hydrologic infrastructure, including wells, piezometers, stilling wells, and more-temporary installations. Water elevation and water temperature were recorded at 15-minute intervals by a submersed pressure transducer inside each vented well casing. A barometric pressure transducer was hung above the water level to correct for atmospheric-pressure fluctuations. Data from hydrologic monitoring equipment were downloaded and manual water-level measurements recorded during periodic site visits 4–6 times per year. The depth from the top of the well casing to the ground surface was also recorded during each site visit. A discharge measurement and instream water temperature were taken using a SonTek Flowtracker acoustic doppler velocimeter with equal-increment sampling across the channel.

The initial installation of hydrologic infrastructure occurred in October 2009, with pressure transducers installed in April 2010. Wells were composed of 1¼" galvanized steel pipe, with a three-foot-long well point screened with 60-gauze metal mesh suitable for screening out coarse sand. The wells were driven to a depth of approximately one meter below the groundwater level or channel bottom. The river-left shallow groundwater well has remained intact over time. Both the instream well and the river-right shallow groundwater well have been replaced since the original installation.

The instream and river-right wells were irreparably damaged by a flood event in September 2013 and replaced in June 2014. Because the river-right well was moved upgradient, away from the channel several meters from the previous installation, water elevations are likely to differ by several centimeters before and after 2014 due to the slope of groundwater away from the channel. The June 2014 instream installation, installed on the opposite bank from the prior 2009 instream installation, was irreparably damaged in a flash flood just a few months later. The current instream installation, an open-bottomed metal casing attached to a T-post driven into the channel bottom, was established in October 2014, a few centimeters from the 2009 installation. Instream water-level data should be comparable over time. Detailed information on all installations is available in Appendix A.

2.1.5 Geomorphology measurements

Channel geomorphology was measured during geomorphology and hydrologic surveys. Geomorphology and hydrologic

surveys were performed conducted prior to spring peak flows, using a Nikon Nivo 3.M total station. All survey coordinates were collected in UTM NAD83, Zone 12. Baseline survey elevations were tied to pre-existing benchmarks (reach F-14) or by first comparing handheld GPS coordinates of installed control points collected in the field with USGS 7.5-minute Topographic Quadrangle maps. The GPS coordinate that best matched the 7.5-minute map was then used to establish survey elevations at reaches F-01 and F-07. Local scale factors were applied during surveying to match baseline surveys.

Surveyors collected ground elevations along all reach transects and the channel thalweg (i.e., the deepest part of the channel), as well as elevations of installed transect headpins, control points, and wells. Along each transect, ground elevations were measured at one-meter intervals, at the edge of flowing or standing water, and at any significant slope-break points. The thalweg was surveyed throughout the reach. For the hydrologic surveys, surveyors collected elevations of installed control points and wells. In addition, they collected ground elevations along the nearest reach transect (i.e., transect 2 at reach F-01). Elevations of flood debris were measured when and where they occurred along transects during geomorphic and hydrologic surveys.

Pebble counts were conducted to measure particle-size distribution within the stream channel by measuring the b-axis (middle dimension) of 60 particles along regularly spaced intervals. Particles less than two millimeters were recorded as 1-mm. Particles that could not be collected (e.g., due to large size or interment) were measured along their exposed b-axis. Because air and water temperatures were typically too cold to perform this measurement during spring, pebble counts were performed during summer vegetation monitoring. Therefore, bed material may have been altered by high spring flows and differ from the particle-size distribution when surveys were completed.

2.1.6 Vegetation measurements

Vegetation sampling took place during late spring or early summer, when plants were fully leafed out. A point-intercept method was used to record percent cover of understory and ground-cover attributes at 0.5-meter intervals along each transect (see Figure 2-1). Density and diameter at breast height (dbh) of trees were recorded by species in a five-meter belt centered on each transect (Figure 2-3). Overstory canopy closure was recorded along each transect at 10-meter

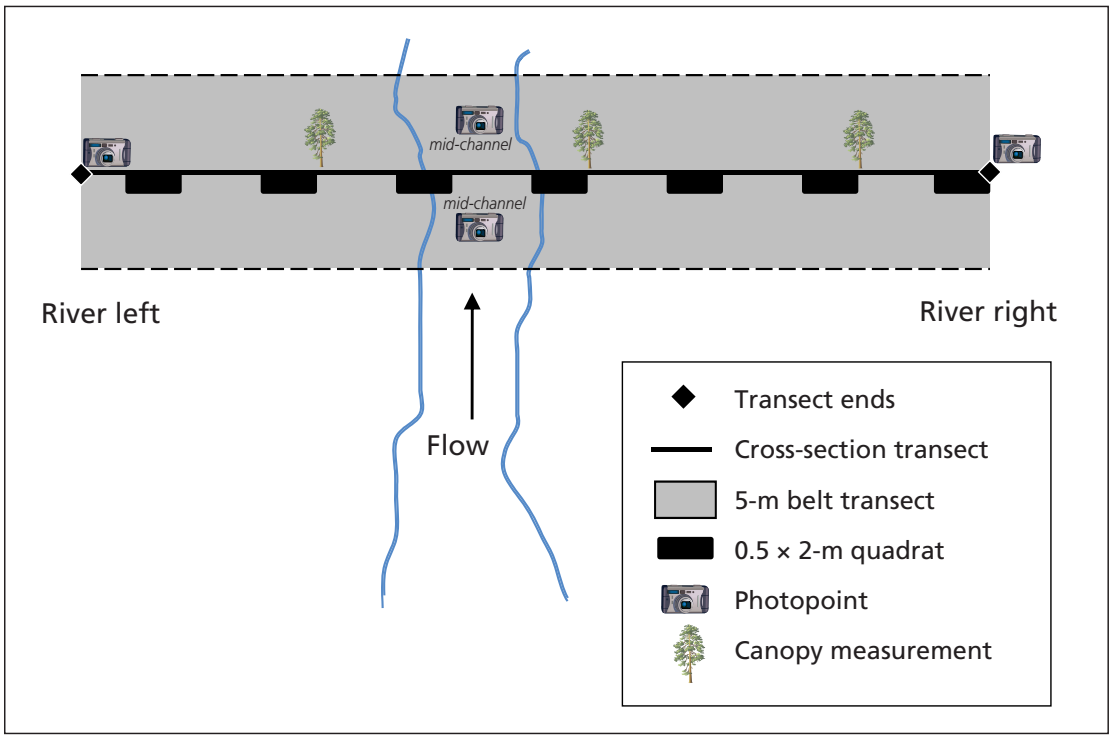


Figure 2-3. Locations of vegetation sampling along each permanent cross-section transect. Understory vegetation is sampled using a point-intercept method at 0.5-meter intervals along the cross-section. Canopy closure is sampled at 10-meter intervals on the cross-section. Seedling, sapling, and overstory tree density is recorded in a 5-meter belt transect. Exotic plant frequency is sampled in 0.5 × 2-meter quadrats. A census of large-diameter trees occurs at the reach scale.

intervals using a concave spherical densiometer. Beginning in 2011, frequency of exotic species was recorded in 1-m^2 quadrats placed every five meters along the transects. All overstory trees of ≥25-centimeter dbh within the reach were tagged and dbh was measured. In addition, instream and riparian disturbances were described and exotic species recorded during a timed plant walk.

2.2 Data summary, quality checks, and statistical procedures

2.2.1 Climate data

Climate data were summarized to better understand the context and drivers of change in hydrology, geomorphology, and vegetation. We looked at (1) local precipitation data from the Capitol Reef NP visitor center, (2) the Standardized Precipitation-Evapotranspiration Index (SPEI) drought index at the visitor center, and (3) drought conditions from the US Drought Monitor for the Fremont River watershed.

Climate data from the National Weather Service Cooperative Observer Network (COOP) station located at the Capitol Reef visitor center (station ID #421171) were accessed via Climate Analyzer. Cumulative monthly precipitation was calculated, and months with more than three days of missing data were removed from the dataset.

A timeseries of the one-year SPEI was accessed from Climate Engine and used to identify wet and dry periods (Huntington et al. 2017; Vicente-Serrano et al. 2010). The SPEI incorporates the impact of temperature by using the difference between precipitation (P) and potential evapotranspiration (PET); therefore, negative values indicate dry conditions and positive values indicate wet conditions. The SPEI is standardized relative to a reference period (1981–2016), and values are standard deviations away from the long-term average. Values greater or less than two standard deviations away from the long-term average are rare, and considered extremely wet or dry conditions.

Finally, a timeseries of drought for the Fremont River watershed was accessed from the US Drought Monitor (USDM 2023). Drought is presented as the percent of the total watershed area at a given drought class: D0–Abnormally Dry, D1–Moderate Drought, D2–Severe Drought, D3–Extreme Drought, D4–Exceptional Drought. Drought classes are cumulative, meaning that if an area is at D4, it is also at D0, D1, D2, and D3.

2.2.2 Hydrology data

Hydrologic data were barometrically compensated and adjusted to match the manual water-level measurement taken during each site visit. Compensated and adjusted hydrologic data were imported into the Aquarius database, where data corrections were applied, such as adjusting for sensor drift. Short-term gaps of several hours, such as those during site visits, were linearly interpolated. Final, approved datasets with associated metadata are publicly available at the National Park Service's Aquarius web portal (https://irma.nps.gov/aqwebportal/).

The corrected water-level data were then converted to the site's permanent datum. The 15-minute data were aggregated to a daily mean for each day with more than 90% of datapoints available. Groundwater data were also converted to a depth-to-water from the ground surface using surveyed ground-surface elevations and manual ground-surface measurements from site visits.

Discharge was derived from the instream water-level data through the creation, in cooperation with the NPS Water Resources Division, of a stage-discharge rating curve using paired manual measurements of stage and discharge. Because discharge was measured infrequently from 2010 to 2013, a robust rating curve could not be developed for this period. The current rating curve includes 41 paired stage-discharge measurements from December 2014 to September 2021, with measured discharge ranging from 22.3 to 92 cfs. In winter, ice effects can cause rapid fluctuations in the recorded stage. For ice-affected data, we replaced noisy winter data when water temperatures were near or below zero with linear interpolated daily means. We present a daily mean discharge record from October 2014 to September 2021.

Because of the relatively short, interrupted nature of NCPN's hydrologic dataset, we do not analyze hydrologic data for trends over time, but summarize data and compare them to management-relevant thresholds using R software with the tidyverse and lubridate packages (Grolemund and Wickham 2011; R Core Team 2022; Wickham 2016). Monthly and annual statistics were calculated for all time periods with >90% of daily means available and for the irrigation (April 1–October 31) and non-irrigation (November 1–March 31) seasons. To estimate the timing and magnitude of spring snowmelt, we calculated a rolling 14-day average of daily mean stage and daily mean discharge. Daily mean discharge was compared to the contemporary cumulative downstream water right of 23.5 cfs. Instantaneous water temperature was compared to the state water-quality standard for warmwater aquatic fish, of 27°C. We also explored a linear-regression relationship between daily mean discharge at F-01 and the Bicknell gage (see Section 1.4.2).

For historic context of inputs into the system, we used a Mann-Kendall analysis with a Theil-Sen slope estimator (Helsel et al. 2020) to detect statistical changes over a 20-year period across the range of daily mean discharge at the Bicknell gage. The Mann-Kendall test is a non-parametric test for monotonic change over time using annual data. To create the quantile Kendall plot, Mann-Kendall statistics are run for each quantile, beginning with the minimum daily mean discharge and proceeding through the maximum daily mean discharge. Slope estimates are calculated on the logarithm of the discharge data and then transformed to express the trend in percent per year (Hirsch 2022). The p-value for the Mann-Kendall test is computed using the adjustment for serial correlation implemented in the zyp package (Bronaugh and Werner 2019). Mann-Kendall analyses were performed with the EGRET package (Hirsch and de Cicco 2015) using code modified from that published by Hirsch (2022).

2.2.3 Survey data

Acceptable survey errors during hydrologic surveys followed established US Geological Survey protocols and were limited to <1 vertical centimeter. For geomorphology surveys, acceptable survey errors were <5 vertical centimeters.

Survey data collected with the total station were imported into Excel, where they were quality-checked and summarized. Survey data were translated and rotated with Traverse PC software. Final figures for this report were created in R 4.2.0.

Along each transect, survey data were used to create a figure of the stream cross-section ground-surface topography. Geomorphic survey data were also used to create the stream's thalweg profile. While transect locations are permanently installed and did not change over time, figures of thalweg surveys show misalignment of transects across surveys. This is due to the thalweg's varying location and form across surveys (i.e., the thalweg may be, or may be observed to be, more or less sinuous from one survey to the next). To line up the thalweg across visits, figures of transect profiles were centered on transect 4. Moving away from the center of the reach, the transects line up less well on the profile figure.

Reach slope was calculated in two ways. The water slope is the standard slope measurement for perennial streams. For reaches where water was present across all surveys, the water slope was calculated as the elevation of the water level at transect 1 minus the elevation of the water level at transect 7, divided by the length of the channel between these two transects. However, water was absent in reach F-07 during all surveys. Channel (i.e., thalweg) slope was calculated as the thalweg elevation at transect 1 minus the thalweg elevation at transect 7, divided by the length of the thalweg between these two transects.

Sinuosity was calculated for each reach between transects 1 and 7 by dividing the thalweg distance recorded between these transects during the thalweg profile by the straight-line distance between the upstream- and downstream-most thalweg points. Mean thalweg elevations were calculated by averaging thalweg measurements at each of

the seven transect crossings collected during each survey event.

Particle-size distribution of the channel surface was determined using the pebble-count data. The diameter of streambed particles at the 50th and 84th percentiles (d50 and d84) were calculated.

2.2.4 Vegetation data

Quality-assurance and quality-control (QA/QC) procedures were performed for all data. These included restricting values in the database to valid names and measures where possible, verification of data entry, checks for missing values, and range and logic checks (Weissinger et al. 2018).

Percent cover of surface features and vegetation was calculated from point-intercept data. Vegetation was examined by functional group (i.e., lifeform), nativity, and wetland status. Vegetation was grouped rather than examining individual species responses because groups of similar species perform unique functions in the riparian ecosystem. Live cover included photosynthetic and live woody tissue. Total cover additionally included dead plants, dead parts of live plants, and senescent tissue that was alive earlier in the growing season.

Species richness was calculated using species detected while sampling plant cover, seedling and tree density, the overstory tree census, and exotic frequency. Because exotic-frequency data were not collected until 2011, species richness was calculated beginning in that year. Tamarisk and pricklypear (*Opuntia* sp.) were counted as species for richness because NCPN cannot identify these more specifically in the field. All other genera and unknown species were excluded from species-richness calculations. Species detected in the timed plant walk were not included in the richness calculation because it is a non-repeatable measure. However, unique exotic species detected were reported.

Canopy closure—which describes the proportion of the sky covered by vegetation, and influences light and temperature in the understory (Jennings et al. 1999)—was summarized at the reach level.

Seedling, sapling, and tree density were calculated from data collected in the five-meter belt. Size-class delineation for tree species was 0–2.5 centimeters for seedlings, 2.51–15 centimeters for saplings, and >15 centimeters for trees. Basal area was calculated using the dbh of saplings and trees in the belt transects. Dbh and crown health of trees ≥25cm dbh (referred to as overstory trees to distinguish from those sampled in the five-meter belts) were recorded in the reach census, and these are. Overstory trees in the reach census were binned and summed by size class, species, and status (dead or alive).

For all measurements in this section, data were summarized by reach. No statistical tests were performed in this data summary because there were not enough data to detect trends for the study area. Summaries of pebble counts and all vegetation measures were performed in R 4.2.0. Data were summarized using the dplyr package. Figures were created with ggplot2.

3 Results

3.1 Climate

Precipitation measured at the Capitol Reef visitor center showed several large events during the monitoring period (Figure 3-1). In September 2013, cumulative monthly precipitation was 132 millimeters. This month also produced the highest daily total in the period of record (beginning in 1967), at 47 millimeters, recorded on September 11, 2013. Only one other month in the record had a similar precipitation total: October 2006 (133 mm). All other monthly precipitation totals recorded were at or below 90 millimeters. Other large events during the monitoring period occurred in July 2011 (90 mm), July 2021 (86 mm) and August 2010 (81 mm). Months excluded due to missing data were February, March, and May 2011.

The SPEI, which incorporates the impact of temperature on precipitation inputs to the system, shows the intensity and duration of drought at the Capitol Reef visitor center (see Figure 3-1). SPEI results show dry conditions at the beginning and end of the monitoring period, with extremely dry conditions at the end of 2018 and first half of 2021. However, short periods of extreme wetness also occurred in early 2014 and mid-2016.

At a larger scale, the Fremont River watershed experienced varying levels of drought for much of the monitoring period (see Figure 3-1). Drought conditions were relatively mild until 2018, when progressively worsening drought occurred in most of the watershed through 2022. In 2021, when vegetation was sampled, approximately 90% or more of the watershed was in "Exceptional Drought" (USDM 2023).

However, results show that regional-scale drought is not always directly reflected locally. The SPEI for the Capitol Reef visitor center shows a relatively long dry period from 2008 to 2010, when regional drought was at its lowest levels or absent. In 2012–2013, when the entire watershed was in Severe Drought, the SPEI showed a somewhat dry period, but of a lower duration and intensity than at the watershed level. These disparities likely reflect the localized nature of monsoonal storms on the Colorado Plateau.

3.2 Hydrology

Hydrology results are reported by water year (WY), which extends from October 1 to September 30 of the following year (e.g., water year 2015 began on 10/1/2014 and ended on 9/30/2015.)

3.2.1 Discharge

Daily mean discharge at the F-01 monitoring reach ranged from 16.5 to 118 cfs (Figure 3-2), with a median value of 60 cfs and an interquartile range of 36–79 cfs. Because dangerous stream conditions exist at higher flows, no wading discharge measurements were taken above 92 cfs. While the channel is roughly rectangular, changes in the relationship between stage and discharge outside of this measured range are likely. Our stage-discharge rating curve may underestimate flows above 92 cfs. Average daily mean discharge was 42 cfs during the irrigation season (n = 1,471 days) and 81 cfs during the non-irrigation season (n = 1,055). Monthly and annual means are summarized in Table 3-1.

Twenty-five days in the discharge record had a daily mean discharge below 23.5 cfs, the contemporary cumulative water right for water users downstream of the park boundary. All of the daily mean discharges below this threshold occurred during the irrigation season: 6/2016 (1 day), 6/2017 (6 days), 8/2018 (4 days), 7/2019 (13 days), and 5/2020 (1 day). Daily means recorded at the Bicknell gage for the same days ranged from 44.5 to 61 cfs.

A linear regression of daily mean discharge suggests that during the non-irrigation season, daily mean discharge at the Bicknell gage is a fairly good predictor of daily mean discharge at the F-01 monitoring reach (Figure 3-3; F-statistic: 3,135 on 1 and 1,053 df, $p < 0.001$, $R^2 = 0.75$). Irrigation-season flows were not well-correlated.

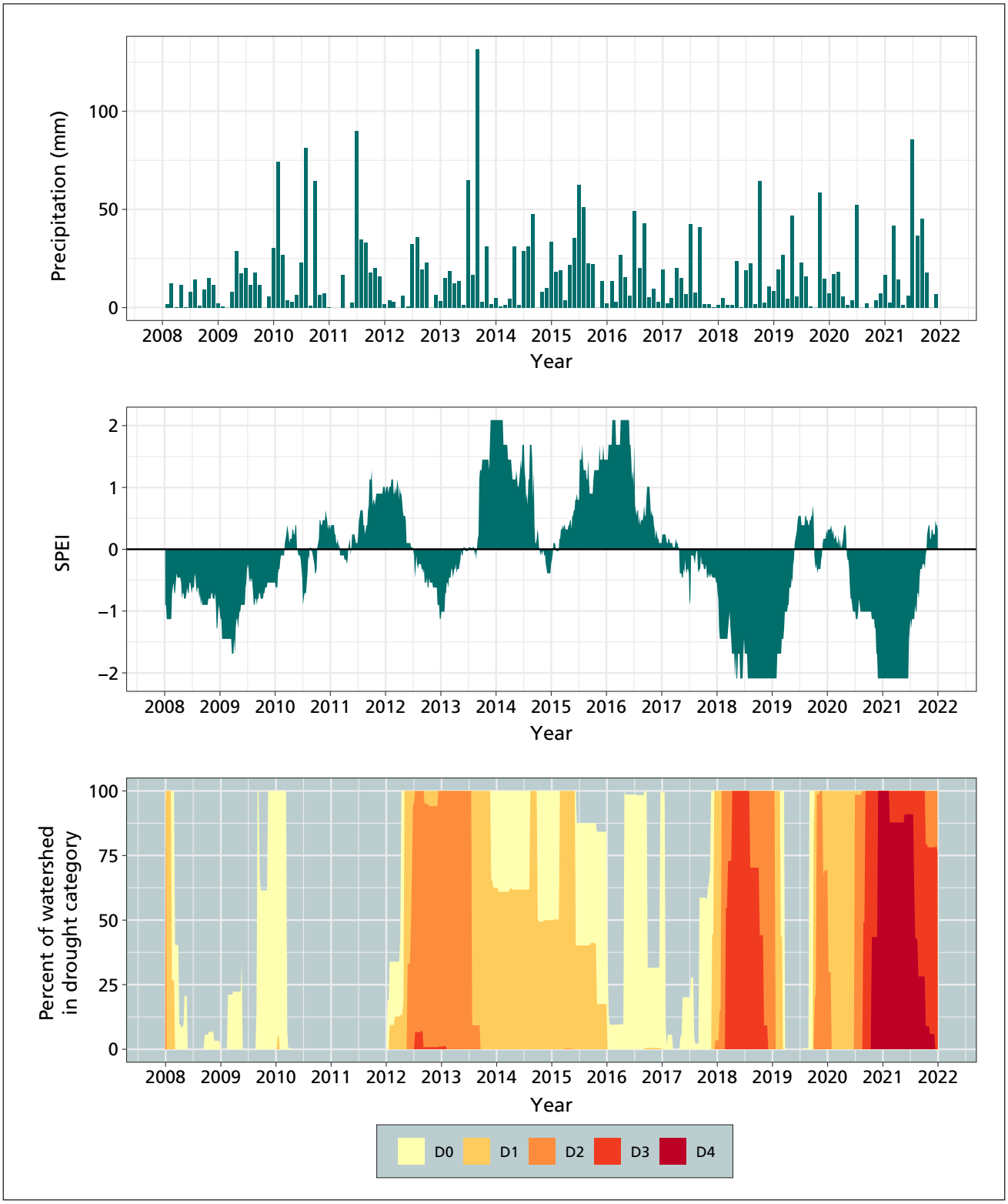


Figure 3-1. Precipitation and drought in the Fremont River watershed, 2008–2022.

Top: Cumulative monthly precipitation at the Capitol Reef visitor center (COOP Station ID 421171, accessed 1/17/2023).

Middle: 1-year Standardized Precipitation-Evapotranspiration Index at the Capitol Reef visitor center. SPEI is an index of precipitation minus potential evapotranspiration represented as standard deviations from the 1981–2016 reference period. An SPEI of ≥2 is considered extremely wet, while ≤–2 indicates extreme drought. Data were accessed via Climate Engine (app.climateengine.com, 1/17/2023; Abatzoglou 2013).

Bottom: Percent of the Fremont River watershed area in drought. Data are from the US Drought Monitor (droughtmonitor.unl.edu, accessed 1/17/23). Categories follow the Drought Monitor convention: D0–Abnormally Dry, D1–Moderate Drought, D2–Severe Drought, D3–Extreme Drought, D4–Exceptional Drought.

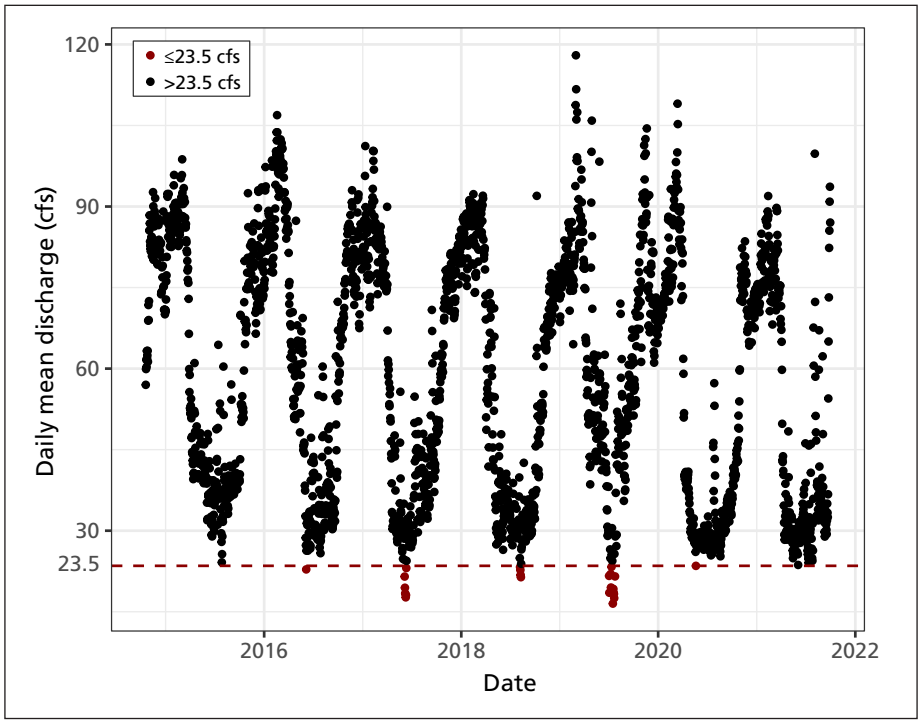


Figure 3-2. Daily mean discharge above and below 23.5 cfs (the contemporary cumulative water right for water users downstream of the park boundary) at the F-01 (above the knickpoint) monitoring reach, WY2015–2021.

Table 3-1. Average daily mean discharge (cfs) by month and water year at the F-01 monitoring reach for periods with >90% of days available, WY2015–2021.

Water year	Oct*	Nov	Dec	Jan	Feb	Mar	Apr*	May*	Jun*	Jul*	Aug*	Sep*	Annual
2015	NA	85	79	85	89	83	47	42	36	38	38	40	60
2016	60	80	78	86	93	93	63	57	32	33	40	39	63
2017	68	84	80	82	87	79	49	33	28	39	38	46	59
2018	57	76	79	83	85	86	59	40	35	31	30	32	58
2019	50	67	74	77	80	92	64	56	45	25	48	54	61
2020	67	87	71	72	81	90	43	29	28	33	30	33	55
2021	45	75	71	77	81	78	40	29	31	33	44	47	54
Mean	58	79	76	80	85	86	52	41	34	33	38	42	59

*Irrigation season.

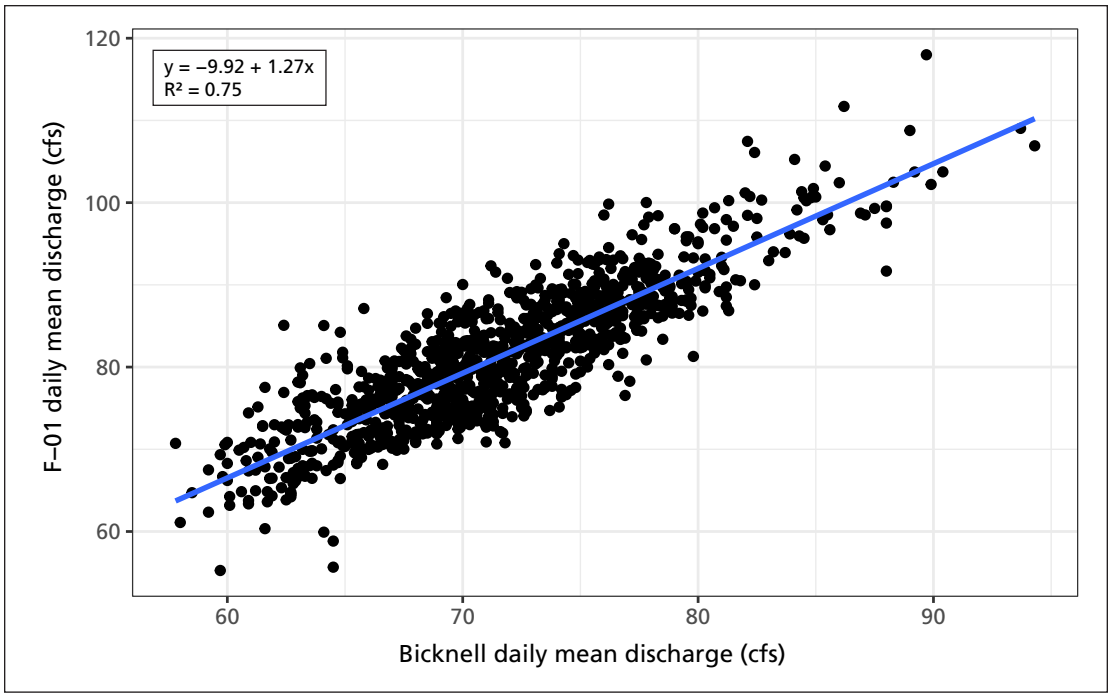


Figure 3-3. During the non-irrigation season of November–March, daily mean discharge recorded at the Bicknell gage was well-correlated with daily mean discharge at reach F-01 (above the knickpoint) in WY2015–2021.

Daily mean discharge at the Bicknell gage decreased over all quantiles from WY2001 to WY2021. The steepest declines were noted in the 90th percentile non-exceedance (i.e., flow value is likely not to be exceeded 90% of the time during the water year) and higher flows; in other words, the cfs of the highest 10% of flows each year have decreased the most. In Figure 3-4, each plotted point represents the 20-year trend for a flow statistic expressed as a percent change over time. The left-most point is the trend, using all the lowest daily mean discharges for each year over the period of record. The next point to the right is the trend associated with the second-lowest discharge each year, and so on. From minimum to maximum discharges, every value showed a statistically significant decline at either p = 0.05 or p = 0.1, indicating a decreasing discharge trend across the entire range of flows at the Bicknell gage.

3.2.2 Overbank flows

Using geomorphic survey data, overbank flows at transect 1, reach F-01 occurred at stages of ~1,580.15 meters or higher from October 2014 to July 2021. The instream well recorded stages higher than this threshold on five days: 8/3/2016, 8/26/2016, 8/1/2019, 7/23/2020, and 7/27/2020. Flows above this stage lasted for 15–45 minutes in duration. While it is likely that this elevation does not precisely match overbank flows, it suggests that overbank flows at this monitoring reach are infrequent and of short duration. Overbank flows in other locations depend on local channel geomorphology and may occur more frequently.

3.2.3 Wetland vegetation sustaining flows

Auble and others (2005) suggested that wetland vegetation at Capitol Reef NP is supported on surfaces that are inundated for at least two weeks every two years. We estimated this elevation in our monitoring reach using a maximum 14-day rolling daily mean stage, which could be calculated for eight years of the instream record (Table 3-2). A significant flood event in September 2013 increased the elevation of the channel bottom in the reach, which increases the stage of water flowing in the channel. Flooding in August 2021 also aggraded the channel bottom and changed the stage-discharge relationship. For these reasons, WY2015–2020 were used to calculate the average

14-day daily mean high stage of 1,578.79 meters. The average 14-day rolling daily mean discharge calculated from the stage-discharge curve for the same period was 94 cfs (Table 3-3). These sustained higher flows usually occurred in mid- to late March, during snowmelt conditions, and prior to the beginning of the irrigation season on April 1.

Comparing a cross-section surveyed in 2019 to a photograph of transect 1 in 2020 (Figure 3-5) suggests that herbaceous perennial wetland vegetation occurred on the gently sloping bank between surveyed elevations of 1,578.39 and 1,578.85 meters. On the bank above the gently sloping bottom, herbaceous perennial wetland vegetation continued up a steep slope to an elevation of about 1,579.59 meters, perhaps through capillary action. However, on the opposing cutbank, a similar elevation had patchy to no herbaceous perennial wetland vegetation. Higher-elevation surfaces had some woody riparian species, but the understory was mostly xeric. At F-01 transect 1, herbaceous perennial wetland vegetation ranged from about −0.4 meters below to 0.8 meters above the average WY2015–2020 maximum 14-day rolling mean stage.

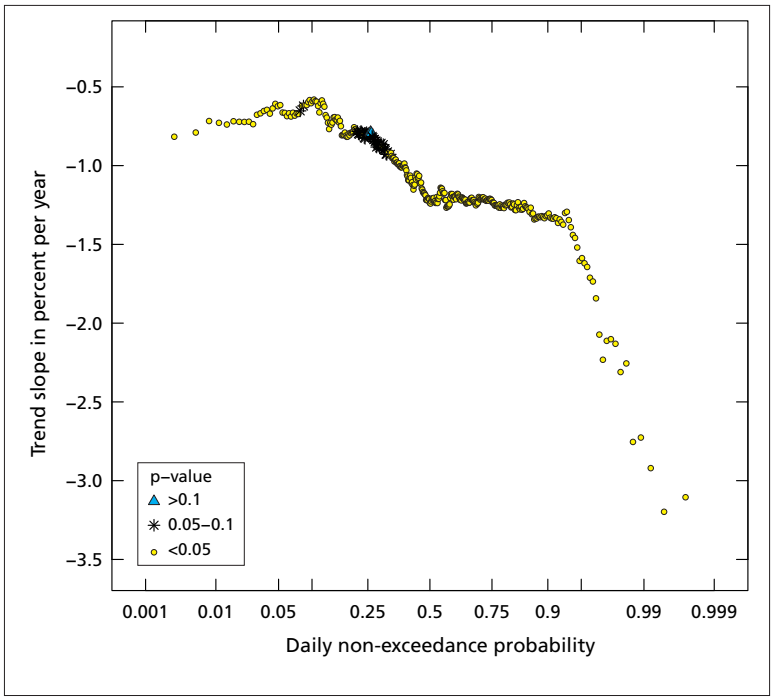


Figure 3-4. Daily mean discharges at the Bicknell gage decreased across almost all flow quantiles from WY2001 to WY2021. The x-axis represents a daily flow non-exceedance probability, with minimum flows to the left and maximum flows to the right. The y-axis represents the trend slope over the 20-year period associated with each quantile's Mann-Kendall test. Statistical p-values <0.05 for the Mann-Kendall test are represented with a yellow dot, while p-values between 0.05 and 0.1 are represented with a black asterisk. There were no p-values greater than 0.1.

Table 3-2. Water years with >90% of daily means available to calculate a maximum 14-day rolling daily mean stage at F-01 (above the knickpoint), Fremont River, Capitol Reef NP, 2011–2021.

Water year	Date	Yearly maximum rolling 14-day daily mean stage (m)
2011	3/26/2011	1,578.66
2015	1/18/2015	1,578.79
2016	3/13/2016	1,578.77
2017	2/15/2017	1,578.79
2018	3/24/2018	1,578.77
2019	3/14/2019	1,578.80
2020	3/15/2020	1,578.80
2021	8/13/2021	1,578.87

Table 3-3. Water years with >90% of daily means available to calculate a maximum 14-day rolling daily mean flow at F-01 (above the knickpoint), Fremont River, Capitol Reef NP, 2015–2021.

Water year	Date	Yearly maximum rolling 14-day daily mean flow (cfs)
2015	3/10/2015	92
2016	3/12/2016	100
2017	2/14/2017	92
2018	3/23/2018	89
2019	3/13/2019	99
2020	3/14/2020	96
2021	2/14/2021	86

NPS/CAROLYN HACKBARTH



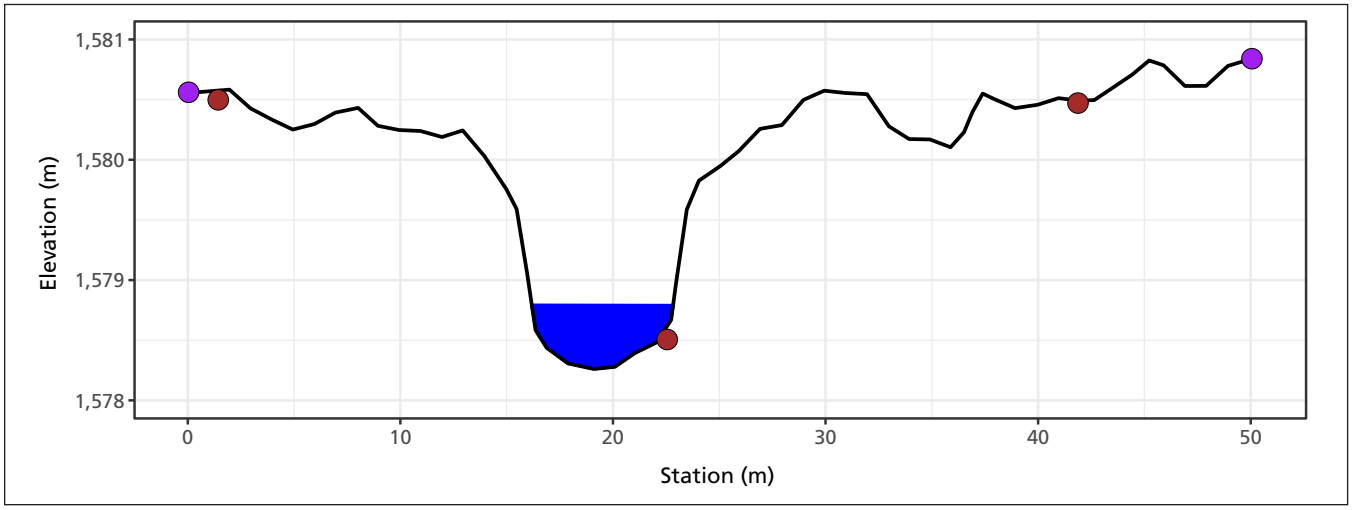


Figure 3-5. (Top) View of F-01 (above the knickpoint) transect 1 looking upstream, May 2020, and (bottom) and average 14-day maximum rolling daily mean stage (blue line) for WY2015–2020, plotted on the F-01 transect 1 channel cross-section surveyed in March 2019. Black line is ground surface, brown points are wells, and purple points are headpins. River right is at Station 0, the equivalent of facing upstream.

3.2.4 High water temperatures

Water temperatures were generally below the Utah state water quality standard of 27°C for warmwater aquatic life (Figure 3-6). The daily mean water temperature never exceeded the state water-quality standard, and only five days had instantaneous (15-minute) records of >27°C: four in June 2016 and one in July 2018. On June 5, 2016, high water temperatures corresponded to a daily mean flow of less than 23.5 cfs.

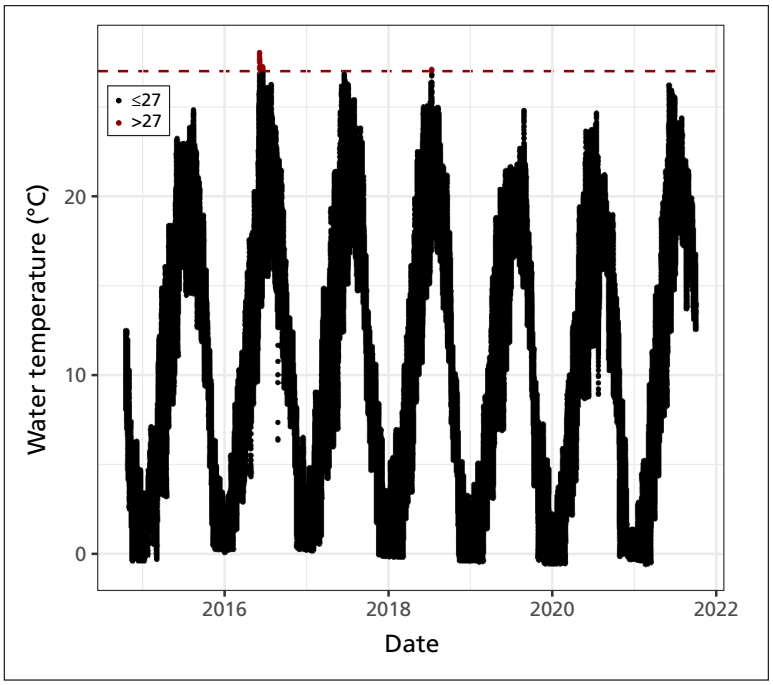


Figure 3-6. Instantaneous (15-minute) instream water temperature above and below 27°C at F-01 (above the knickpoint) over time.

3.2.5 Groundwater levels and relationships with surface water

Depth to groundwater was generally more than 1.5 meters below the ground surface at both the left and right wells (Figure 3-7). The average daily mean depth to groundwater during the irrigation season was −2.01 meters for the left well (n = 2,192) and −2.11 meters for the right well (n = 1,598). During the non-irrigation season, the left well daily mean depth averaged −1.82 meters (n = 1,479), and the right well averaged −1.94 meters (n = 1,058).

Daily variation in groundwater levels during the irrigation season had means of 0.04 and 0.03 meters in the left and right wells, respectively. During the non-irrigation season, the mean of daily variation was 0.02

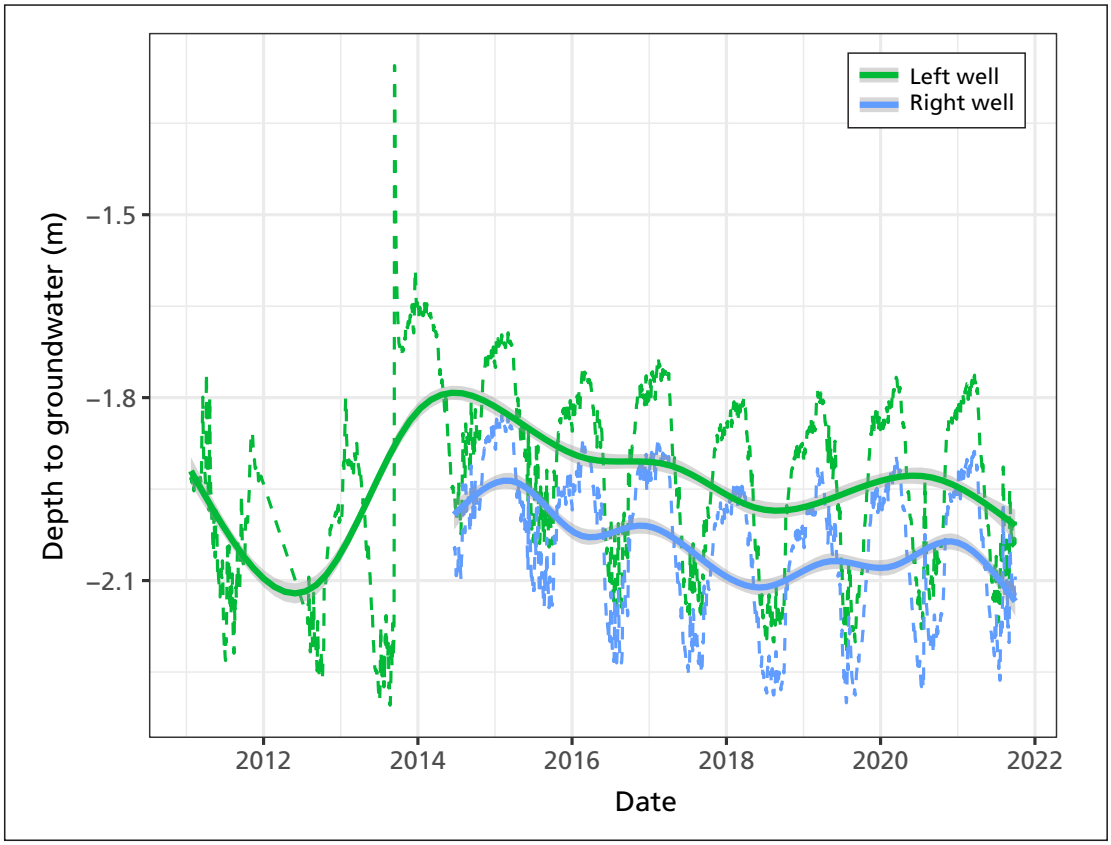


Figure 3-7. Depth to groundwater at the left and right well at reach F-01 (above the knickpoint), with a LOESS smooth showing trends over time. The right well was sheared off by flooding in September 2013 and replaced in a new location in June 2014. Data from the two installations are not equivalent; more recent data are presented.

meters for both wells. Monthly variation is described in Figure 3-8.

Instream water levels were consistently higher than water levels in the groundwater wells (Figure 3-9), indicating this is a losing reach without noticeable groundwater inputs. A sharp increase in stage associated with the September 2013 flood event can be noted in the left well record (the only well that remained intact during this flood event). The aggradation of large cobbles in the channel during this event resulted in a modest but sustained step increase in stage, even though groundwater levels trended downward from 2014 to 2021.

Instream stage continued to increase, with additional aggradation in the channel from subsequent flood events. In a well-connected system, groundwater stage would be expected to move relatively in tandem with instream stage. It is unclear why groundwater stage remained relatively flat-to-decreasing while the instream stage was increasing.

3.3 Geomorphology

3.3.1 Cross-section surveys

Transect 1 at reach F-01 was surveyed a total of 10 times between 2009 and 2021, including during hydrologic and geomorphic surveys, and with three surveys in 2014 alone. Geomorphology surveys of all transects at each reach were conducted four times at reach F-01, twice at reach F-07, and three times at reach F-14.

Between 2009 and 2021, all transects at reach F-01 exhibited sediment deposition across all or most of their lengths. Nearly one meter of sediment was deposited on both the river-left banks and floodplains of transects 5 and 6. More than 80 centimeters of deposition took place on the river-left bank of transect 1 and the floodplain of transect 2 (Figure 3-10). Across all transects, deposition was generally greatest between 2009 and 2014, although sections of transect 1 exhibited greatest deposition between 2019 and 2021.

Localized zones of sediment erosion occurred along transects 2, 5, 6, and 7. The appearance of erosion along transect 2 between 0 and 5 meters was likely not actual erosion, but rather an artifact of missing survey points between 0 and 8 meters in 2009. The river-right banks of transects 5 and 6 exhibited sediment erosion of up to 1.4 and 1.7 meters, while the river-left bank of transect 7 exhibited sediment erosion of up to 85 centimeters. This erosion primarily took place between 2009 and 2014. All channel beds showed progressive deposition in cross-sections except for the river-right side along transect 5, where about 10 centimeters of incision took place between 2018 and 2021. The largest amount of sediment deposition (~85 cm) in the channel took place along the river-right channel bed of transect 6.

There was minimal observed change in ground-surface elevations across all transects in reach F-07 between 2009 and 2021 (Figure 3-11). Transects 1, 2, and 3 exhibited small quantities (~10–20 cm) of localized erosion near their thalwegs, while transects 5, 6, and 7 exhibited nearly identical cross-section profiles. Transect 4 exhibited localized colluvial deposition of up to 36 centimeters at and near the river-right headpin that extended along the transect for 12 meters.

At reach F-14, net sediment deposition was observed across all transects on river left between 2009 and 2021 (Figure 3-12). The largest quantities of sediment deposition took place on the river-left bank of transect 2 (~70 cm of deposition between 2009 and 2021). Sediment deposition also occurred on the river-right channels or banks of transects 1, 3, and 4. Alternatively, sediment erosion occurred on river right across transects 2, 5, 6, and 7. The largest quantity of sediment erosion took place on the river-right bank of transect 2 (~65 cm of erosion between 2009 and 2014). The channel bed appeared stable across most transects, although incision of 10–15 centimeters was observed in the river-right channels of transects 1 and 3.

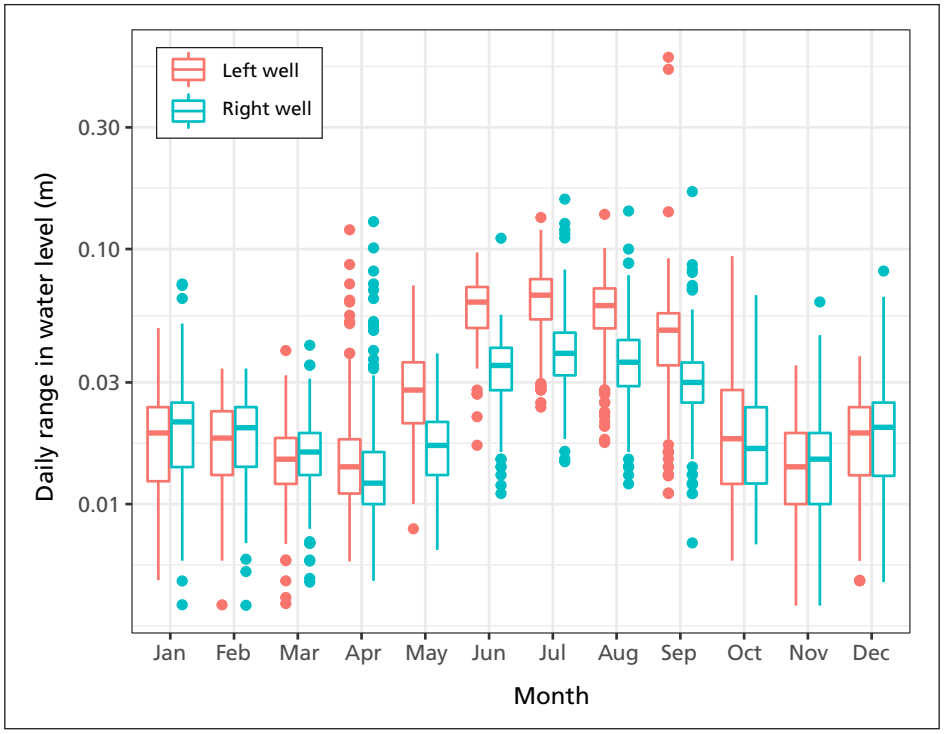


Figure 3-8. Daily range in water level by month recorded in shallow groundwater wells at the F-01 (above the knickpoint) monitoring reach. The boxplot shows the median value as an interior line bounded by a box showing the interquartile range (IQR) of the data. Whiskers represent the range of data within 1.5 × IQR. Dots represent values that lie outside this range.

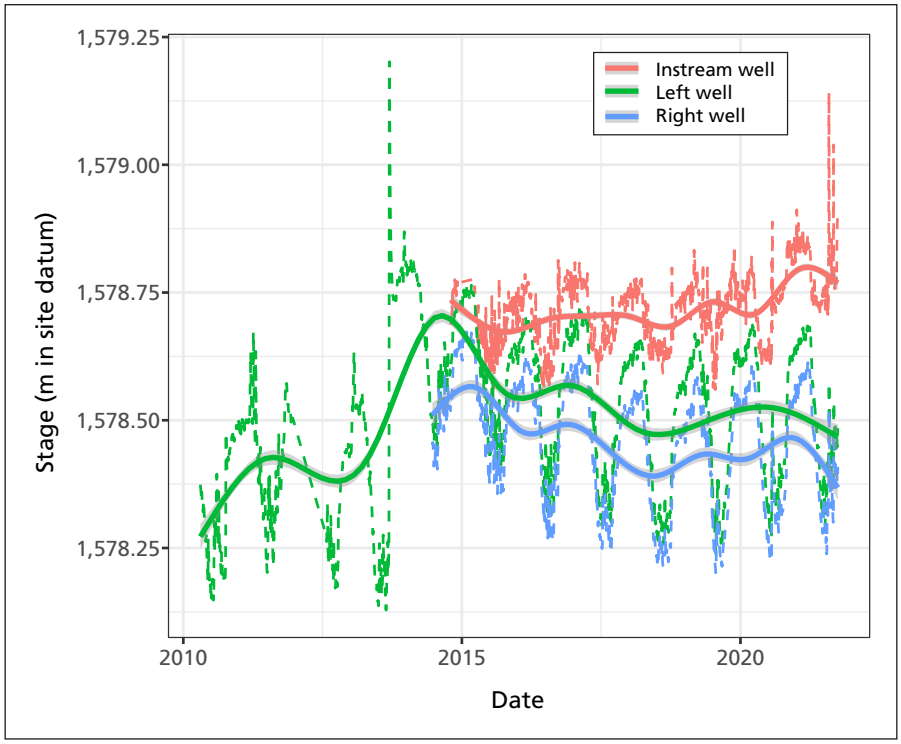


Figure 3-9. Water elevations in the site datum (m) in the instream, left, and right wells over time, with LOESS smooths describing trends over time.

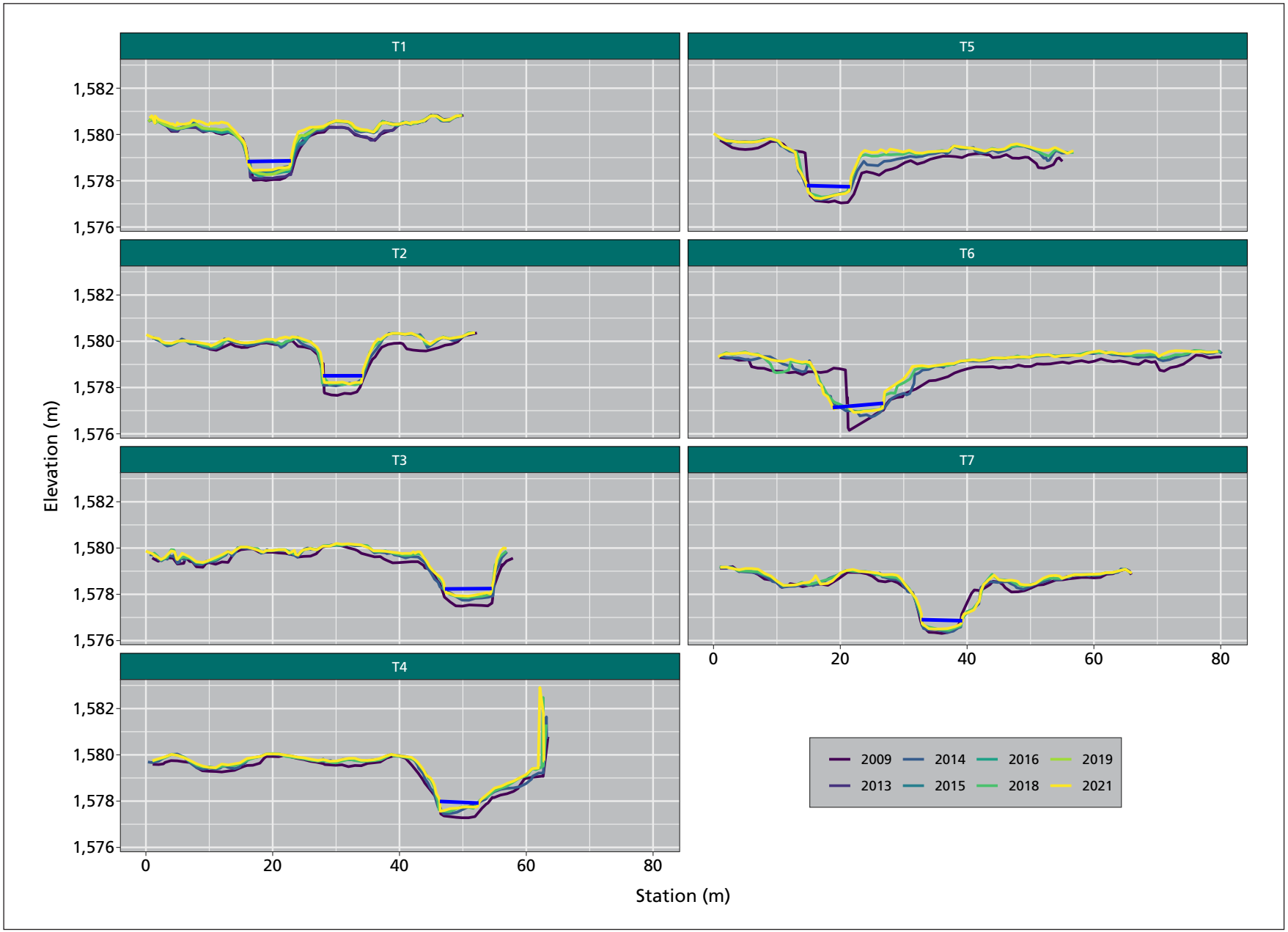


Figure 3-10. Cross-section survey profiles for transects 1–7 at reach F-01 (above the knickpoint). Transect 1 is the upstream end of the reach and Transect 7 is the downstream end. River right is at Station 0, so cross-sections are facing upstream. Transect 1 was surveyed in eight different years during the study period, while transects 2–7 were surveyed in four different years. The water line in 2021 is shown in blue.

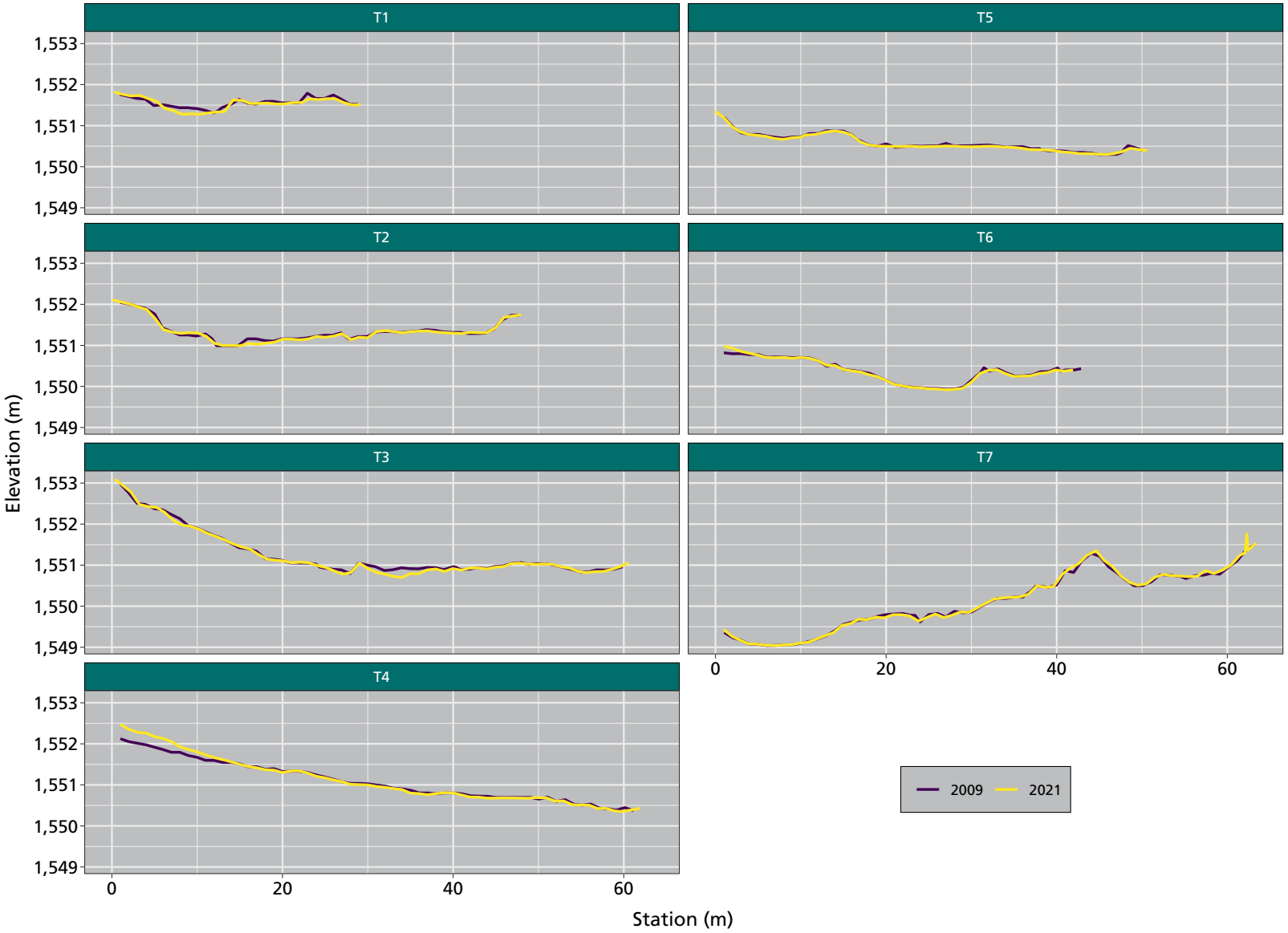


Figure 3-11. Cross-section survey profiles for transects 1–7 at reach F-07 (oxbow). Transect 1 is the upstream end of the reach and Transect 7 is the downstream end. River right is at Station 0, so cross-sections are facing upstream. No water line is shown because this is a dry channel.

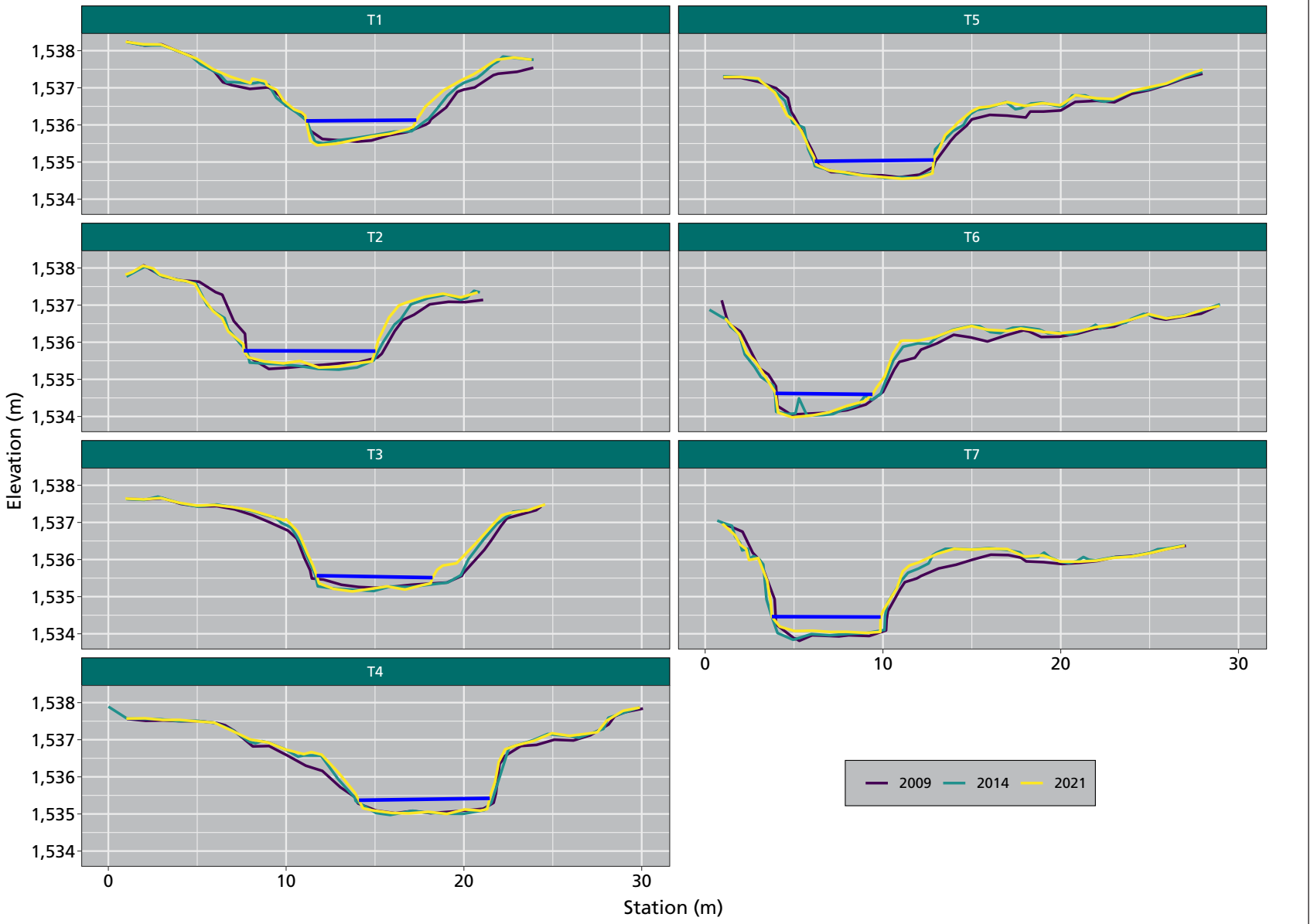


Figure 3-12. Cross-section survey profiles for transects 1–7 at reach F-14 (below the knickpoint). Transect 1 is the upstream end of the reach and Transect 7 is the downstream end. River right is at Station 0, so cross-sections are facing upstream. The water line in 2021 is shown in blue.

3.3.2 *Thalweg surveys*

Thalweg surveys were conducted four times at reach F-01, twice at reach F-07, and three times at reach F-14 (Figure 3-13).

At reach F-01, the mean thalweg elevation increased by 43 centimeters between WY2009 and 2021, with most of this change (29 cm) taking place between 2009 and 2014. Whereas mean thalweg elevation increased across all surveys, zones of localized channel erosion also occurred—most notably between transects 6 and 7 from 2009 to 2014, and transects 4 and 5 from 2018 to 2021. Channel sinuosity showed minimal variation across surveys, ranging from 1.22 in 2018 to 1.26 in 2014 (Table 3-4). The thalweg slope increased by 0.007 meters per meter from 2009 to 2014, decreased by 0.001 m/m between 2014 and 2018, and again increased by 0.009 meters per meter from 2018 to 2021. The water-surface slope progressively increased across surveys.

At reach F-14, mean thalweg elevations varied by only one centimeter among the three surveys and were identical between the 2009 and 2021 survey. Channel sinuosity showed minimal variation across surveys, ranging from 1.07 in 2014 to 1.04 in 2021. A decrease in channel slope measured between the 2009 and 2021 surveys likely resulted from a localized zone of sediment deposition of up to 25 centimeters, concentrated between transects 6 and 7. The water slope was highest in 2021 and lowest in 2014.

At reach F-07, the total thalweg distance between transects 1 and 7 was measured

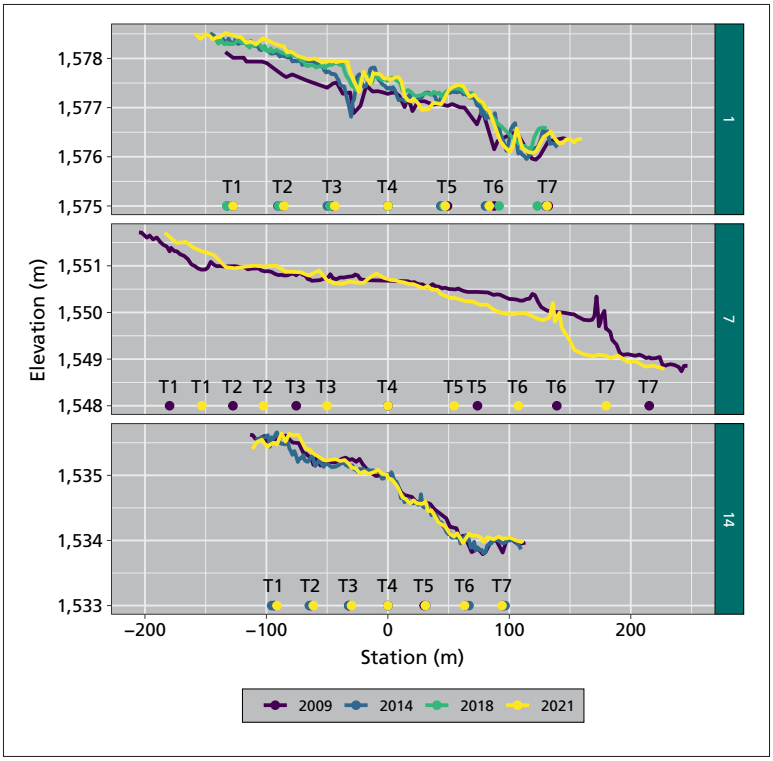


Figure 3-13. Thalweg elevation profile by reach and year. Profiles are centered where they cross transect 4 at each reach. Because observed thalweg length varied by survey, profiles become offset with increasing (or decreasing) distance from transect 4. Transect locations are included at an arbitrary lower elevation to improve interpretation of transect alignment across surveys. Note different scales on y-axis.

Table 3-4. Stream-channel water slope, thalweg slope, sinuosity, and mean thalweg elevation.

Parameter	Reach	2009	2014	2018	2021
Water slope (meters/meter)	F-01	0.006	0.007	0.007	0.008
	F-07*	–	–	–	–
	F-14	0.009	0.008	–	0.009
Thalweg slope (meters/meter)	F-01	0.007	0.007	0.007	0.008
	F-07	0.006	–	–	0.007
	F-14	0.009	0.008	–	0.009
Sinuosity	F-01	1.24	1.26	1.22	1.23
	F-07	1.27	–	–	1.07
	F-14	1.05	1.07	–	1.04
Mean thalweg Elevation (m)	F-01	1,577.13	1,577.42	1,577.48	1,577.56
	F-07	1,550.47	–	–	1,550.44
	F-14	1,534.79	1,534.78	–	1,534.79

*Water slope was not measured in reach F-07 (oxbow) because it was dry.

at ~420 meters in 2009, whereas the same distance was measured at ~360 meters in 2021. Observed distances along the thalweg between individual transects of the 2009 and 2021 surveys of reach F-07 ranged from as little as 20 centimeters between transects 2 and 3 to as much as 25 meters between transects 3 and 4. Therefore, channel sinuosity was reduced from 1.27 in 2009 to 1.07 in 2021. This resulted in considerable offset between the 2009 and 2021 thalweg profiles. Mean thalweg elevation decreased slightly, and the thalweg slope increased slightly, between the two surveys. Notably, a historical earthen dam running perpendicular to and across the dry riverbed was observed during both surveys between transects 6 and 7.

3.3.3 Pebble counts

Pebble counts were performed concurrent with vegetation surveys, and therefore had more repeat measurements than geomorphology surveys. Pebble counts at reach F-01 showed a median grain size of 3.3 millimeters or less in all years, and up to 9.3 millimeters in the 84th percentile, indicating that the reach substrate is primarily medium gravel size or smaller (Table 3-5). Median grain size at reach F-14 was slightly larger in most years but always less than 3.9 millimeters, and larger also in the 84th percentile, with grain size up to 15.2 millimeters. Reach F-07 was dominated by sand at all visits. No major changes in grain size that would indicate significant deposition or erosion events across a reach were detected.

3.4 Vegetation

3.4.1 Plant cover

In reaches F-01 and F-14, vegetation cover was generally stable from 2009 to 2021, with total cover ranging from 30% to 44% for reach F-01 and 39%–46% for reach F-14 (Figure 3-14). Live cover was more variable between years (20%–39% in reach F-01 and 23%–41% in reach F-14). In both reaches, total and live cover increased slightly between 2009 and 2011. These increases appeared to be driven by native vegetation from multiple functional groups (Figure 3-15). In reach F-07, total and live cover more than doubled from 2009 to 2010. This was due to a spike in non-native forb cover—primarily Russian thistle (*Salsola* sp.), from 8% in 2009 to 23% in 2010. Live and total cover decreased noticeably at reach F-14 in 2012, which was a relatively hot, dry year (see Figure 3-1). Reaches F-01 and F-14 had higher overall cover than reach F-07, because of higher cover of perennial grasses, shrubs, and trees. The composition of functional groups at reach F-04 was similar to that at reaches F-01 and F-14, but with slightly lower live and total cover. However, F-04 was only sampled once, and in a drought year.

Live and total cover of functional groups, wetland indicator groups, and native and non-native groups tracked each other closely from year to year. Therefore, only total cover is presented here for Figures 3-15, 3-16, and 3-17. In reaches F-01, F-14,

Table 3-5. Median grain size (mm) of stream-channel pebbles, 2009–2021.

Parameter	Reach	2009	2010	2011	2012	2014	2018	2021
D50	1	1.8	2.1	1.6	–	3.3	2.7	3
	7	–	0.1	0.1	–	–	–	0.1
	14	2.4	2.7	2.1	2.6	3.1	–	3.9
D84	1	5.4	6	7.3	–	9.3	8	8.2
	7	–	0.1	0.1	–	–	–	0.1
	14	7.9	9.4	11.3	8.2	15.2	–	11.5

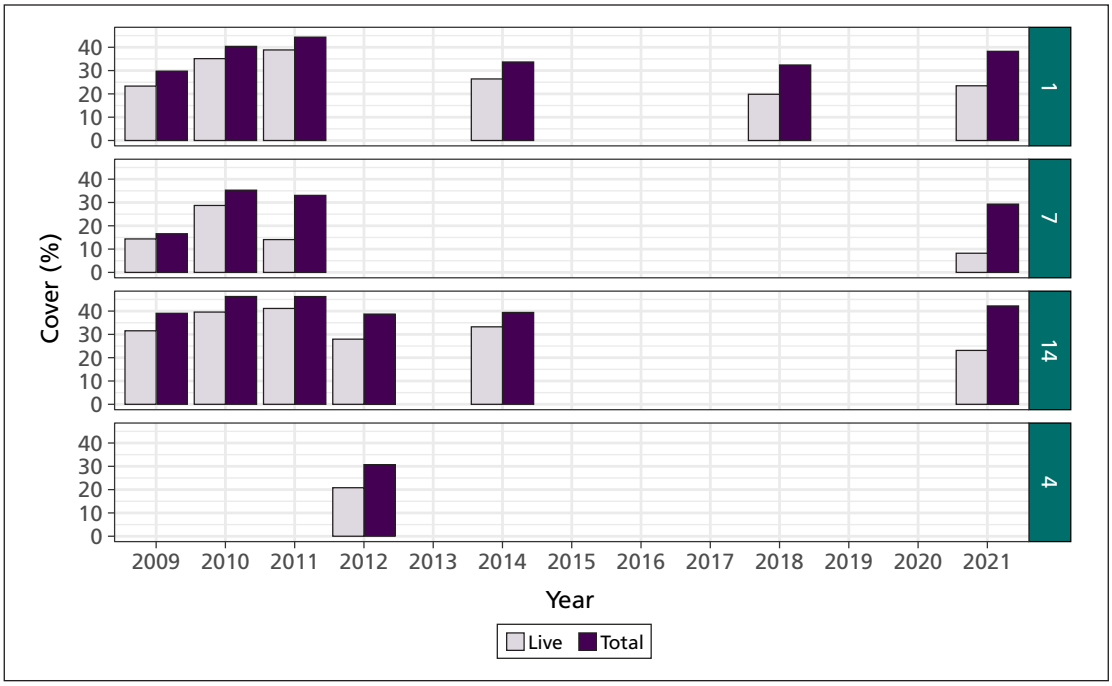


Figure 3-14. Live and total cover of vegetation by reach, 2009–2021.

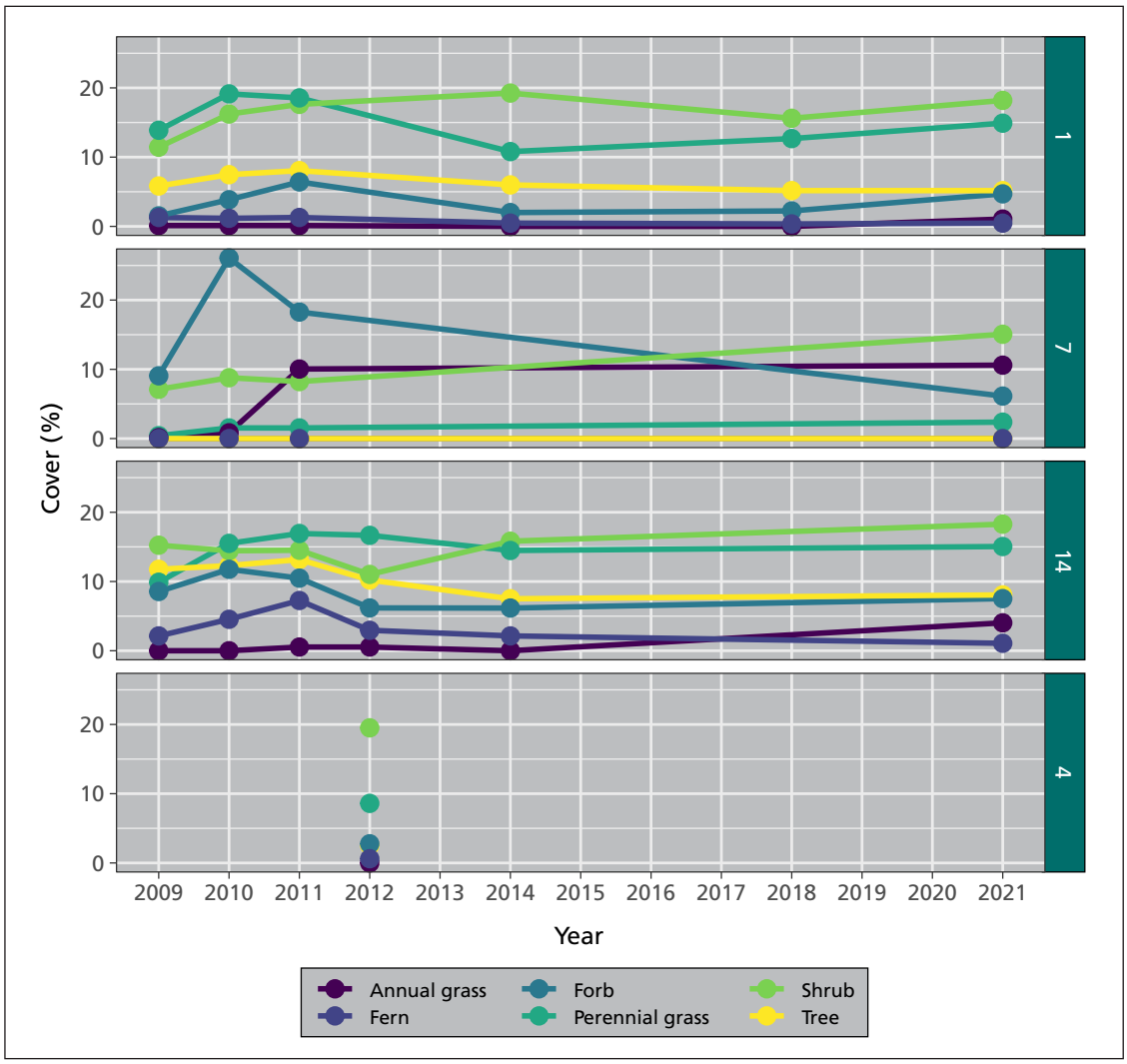


Figure 3-15. Total cover of vegetation by functional group and reach, 2009–2021.

Figure 3-16. Total cover of wetland indicator groups by reach, 2009–2021.

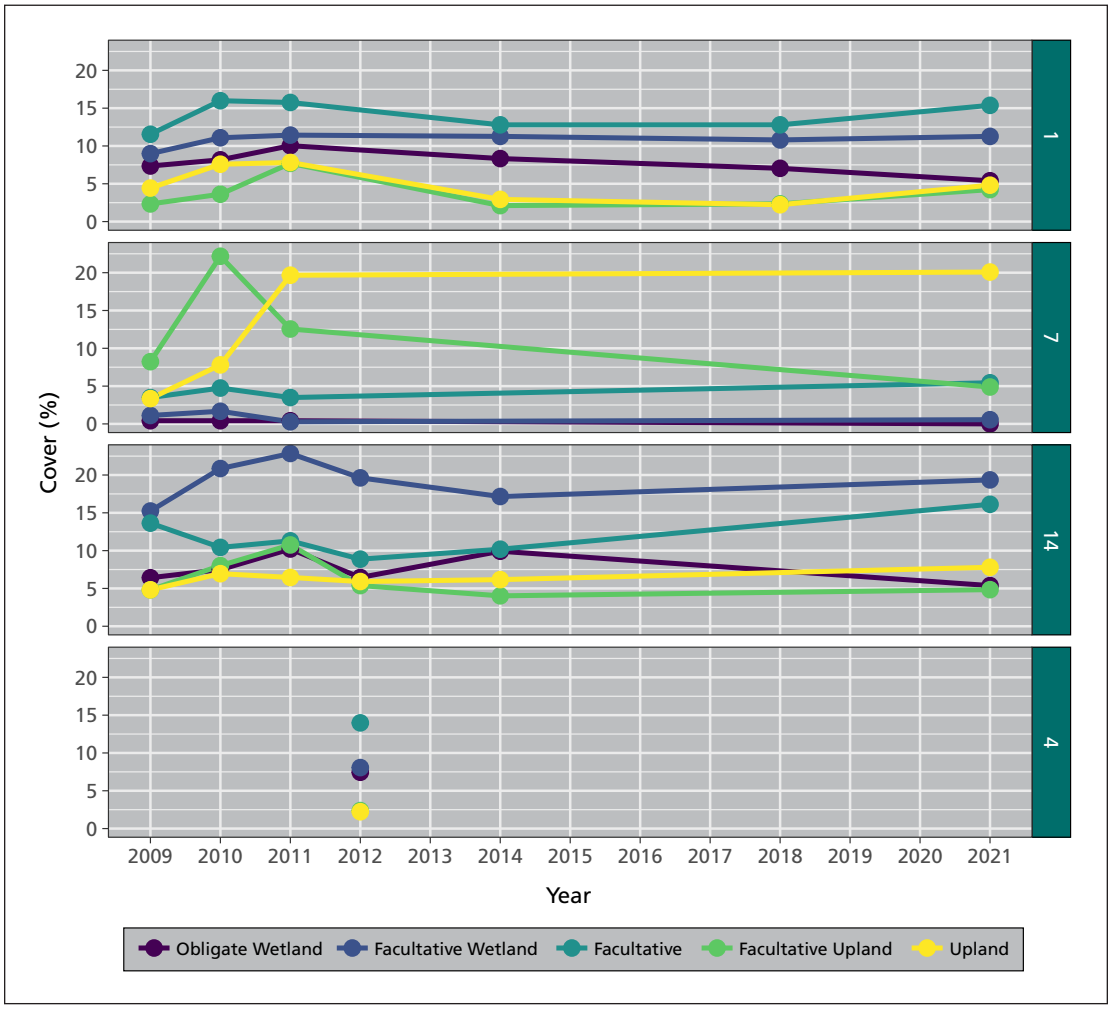


Figure 3-17. Total cover of native and exotic vegetation by reach, 2009–2021.



and F-04, perennial grasses and shrubs had the highest percent cover; these groups were dominated by facultative wetland or facultative species (see Figure 3-16). The dominant shrubs and grasses in these reaches included coyote willow, rabbitbrush, saltgrass, common reed, Indian ricegrass (*Achnatherum hymenoides*), and scratchgrass (*Muhlenbergia asperifolia*) (at reach F-14 only). Ferns, which included the facultative wetland species, scouringrush horsetail (*Equisetum hyemale*) and smooth scouring-rush (*Equisetum laevigatum*), had modest cover (1–7%) in reach F-14 but low cover (<2%) in reach F-01. Annual grasses were low or absent in these reaches but in 2021, annual grass in reach F-14 increased to 4% due to growth of non-native cheatgrass (*Bromus tectorum*). There was a slight decrease in tree cover in reach F-14 from 2011 to 2014, from 13% to 8%.

Reaches F-01, F-04, and F-14 had similar cover of obligate wetland species; however, reach F-14 had greater cover of facultative wetland species, including Fremont cottonwood, scratchgrass, and horsetail (*Equisetum* sp.). This difference was greatest in 2011—but by 2021, the distribution of wetland indicator groups between reaches F-01 and F-14 was very similar. In these reaches, obligate wetland species decreased to their lowest point in the monitoring period in 2021.

Conversely, in the dry oxbow reach (F-07), forbs and shrubs that were primarily upland or facultative upland species dominated. These species included rabbitbrush, four-wing saltbush (*Atriplex canescens*), and the non-native forb, Russian thistle. Trees and ferns were totally absent from the cross-sectional transects in reach F-07. In 2011, the cover of annual grass at reach F-07 increased from <1% to 10% due to a flush of cheatgrass. Cheatgrass cover remained high 10 years later.

3.4.2 Exotic plants

Native species dominated plant cover in reaches F-01, F-04, and F-14 (Figure 3-17). In these reaches, exotic-species cover varied slightly between years but remained below 10% in all years. Common exotic species in these reaches included Russian olive, tamarisk, cheatgrass, redtop (*Agrostis stolonifera*), sweetclover (*Melilotus* sp.), and Russian thistle. Cover of exotic species was much greater in reach F-07, ranging from 9% to 25%. In 2009–2011, exotic plants comprised the majority of total cover in this reach. However, by 2021, native species had a slight majority due to small increases in the native shrubs, rabbitbrush and four-wing saltbush, along with a 10% decrease in Russian thistle.

Both exotic-frequency and point-intercept data showed that reach F-07 had the greatest number of exotic species. However, exotic-frequency data showed that reach F-14 (40%–60%) had higher detections of exotic species than reach F-01 (10%–29%) (Figure 3-18). Exotic-frequency quadrats also detected more unique species than point-intercept data. Over the monitoring period, seven species were detected only in exotic quadrats: bur buttercup (*Ceratocephala testiculata*), lambsquarter (*Chenopodium album*), halogeton (*Halogeton glomeratus*), common plantain (*Plantago major*), yellow salsify (*Tragopogon dubius*), muttongrass (*Poa pratensis*), and spiny-leaf sow-thistle (*Sonchus asper*). An additional 12 exotic species were detected with timed plant walks; a complete list is provided in Appendix B. Because these species were not detected with line-point intercept or frequency quadrats, they are presumed to have low cover in the reaches or be isolated patches.

3.4.3 Species richness

Species richness includes unique species detected during point-intercept, exotic frequency, five-meter belt transects, and the overstory tree census. Because exotic frequency measurements began in 2011, only richness data for 2011–2021 are comparable. Exotic-frequency quadrats detected 1–6 additional species in each reach, so excluding these data would underestimate species richness. Reach size (see Table 2-1) and increased observer experience over time may also impact detection of unique species.

Species richness was lowest in reaches F-04 (23 species) and F-07 (18–25 species) (Figure 3-19). At reach F-14, a consistent number of species (31–33) was detected in

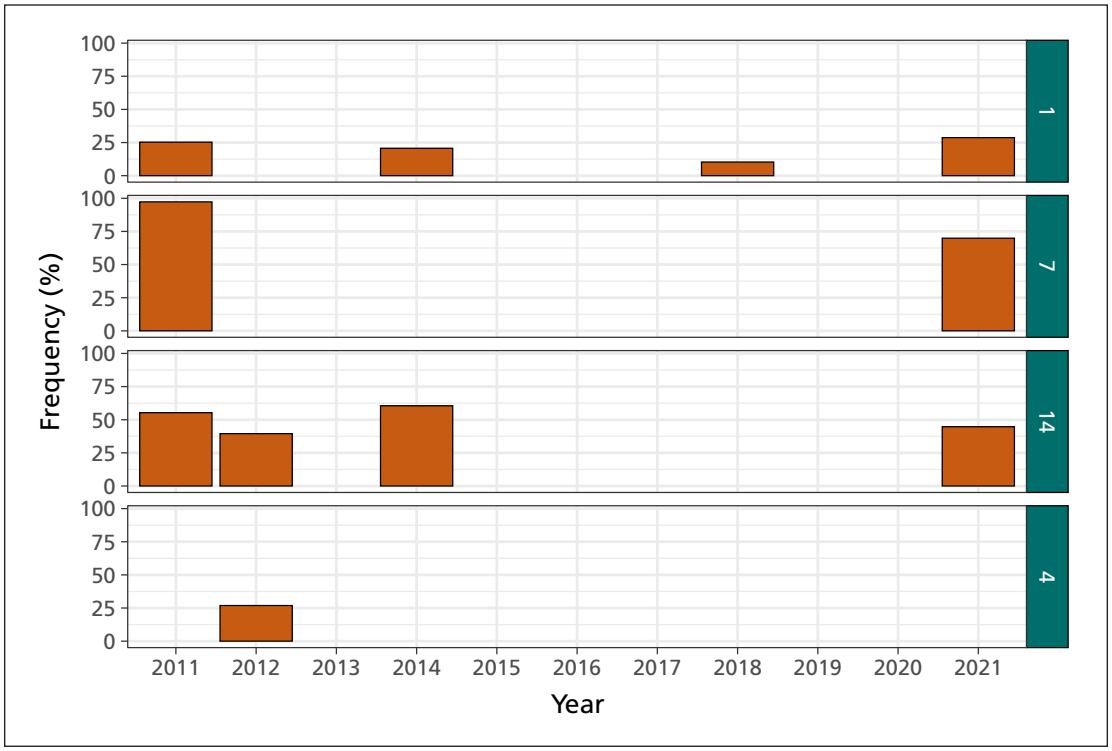


Figure 3-18. Frequency of exotic plant species by reach, 2011–2021.

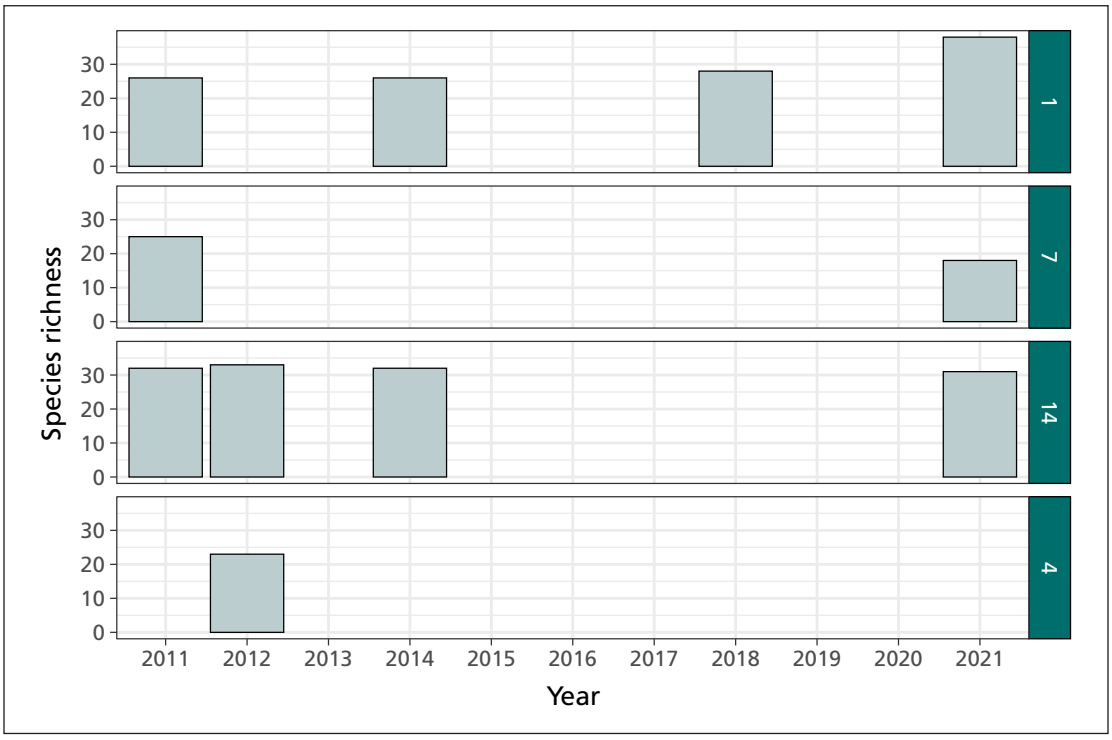


Figure 3-19. Species richness by reach, 2011–2021.

all visits. Reach F-01 had the largest increase in the number of species detected from early in the monitoring period to present: from 26 species in 2011 to 38 species in 2021. New species at this reach in 2021 were a mix of trees, shrubs, forbs, and exotic species.

3.4.4 Canopy closure

Canopy closure was variable across years and reaches (Figure 3-20). There was higher canopy closure in reach F-01 than in reach F-14, despite lower percent cover of tree species in reach F-01. Canopy closure was comparatively lower in 2021 than in the early years of monitoring. This decrease corresponded to a slight drop in tree percent cover in 2021. Canopy closure in reach F-07, where only a few trees were present, was very low (0.2%).

3.4.5 Seedling, sapling, and tree density and basal area

Across all reaches, the dominant tree was Fremont cottonwood. The exotic, Russian olive, was also present at reaches F-01, F-14, and F-04, but in much lower densities. A small number of additional tree species were detected in the seedling size class: boxelder (*Acer negundo*), two-needle pinyon (*Pinus edulis*), and Goodding's willow (*Salix gooddingii*). Because these species were detected in small numbers (≤6 individual seedlings), they are excluded from Figure 3-21. These species were not detected in the larger size classes in any year.

Density of Fremont cottonwood seedlings ranged from 295 to 14,323 trees per hectare. Saplings ranged from 6 to 352 trees per hectare, and trees (≥15 cm dbh) from 6 to 85 trees per hectare. Identification of Fremont cottonwood seedlings can be difficult due to their similarity to coyote willow in the cotyledon stage. When individuals could not be positively identified, they were not counted, resulting in possible underestimates of Fremont cottonwood seedlings. Fremont cottonwood and Russian olive seedlings also included resprouts from damaged trees, primarily those that were browsed by beaver (although field crews also noted flood damage and chemical treatment as other mechanisms of disturbance).

In 2014, a large number of seedlings (>3,000) in reach F-01 resulted in seedling density an order of magnitude greater than in any other year or reach (14,323 trees/ha).

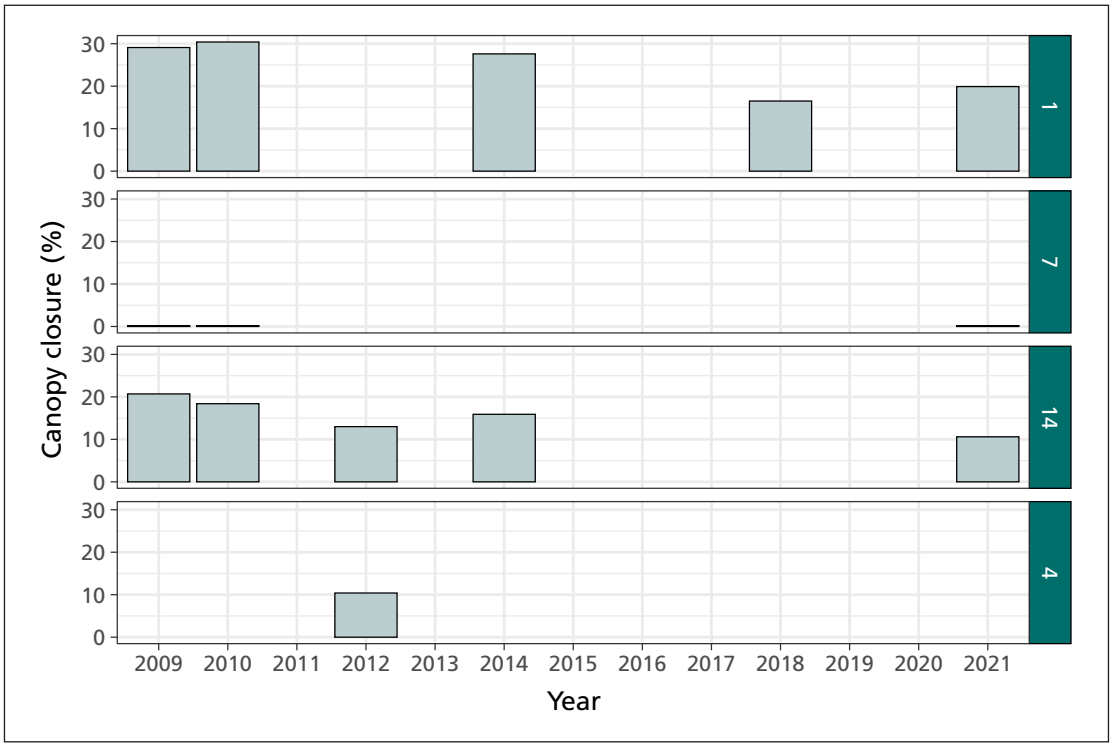


Figure 3-20. Canopy closure by reach, 2009–2021. Canopy-closure measurements were not taken in 2011.

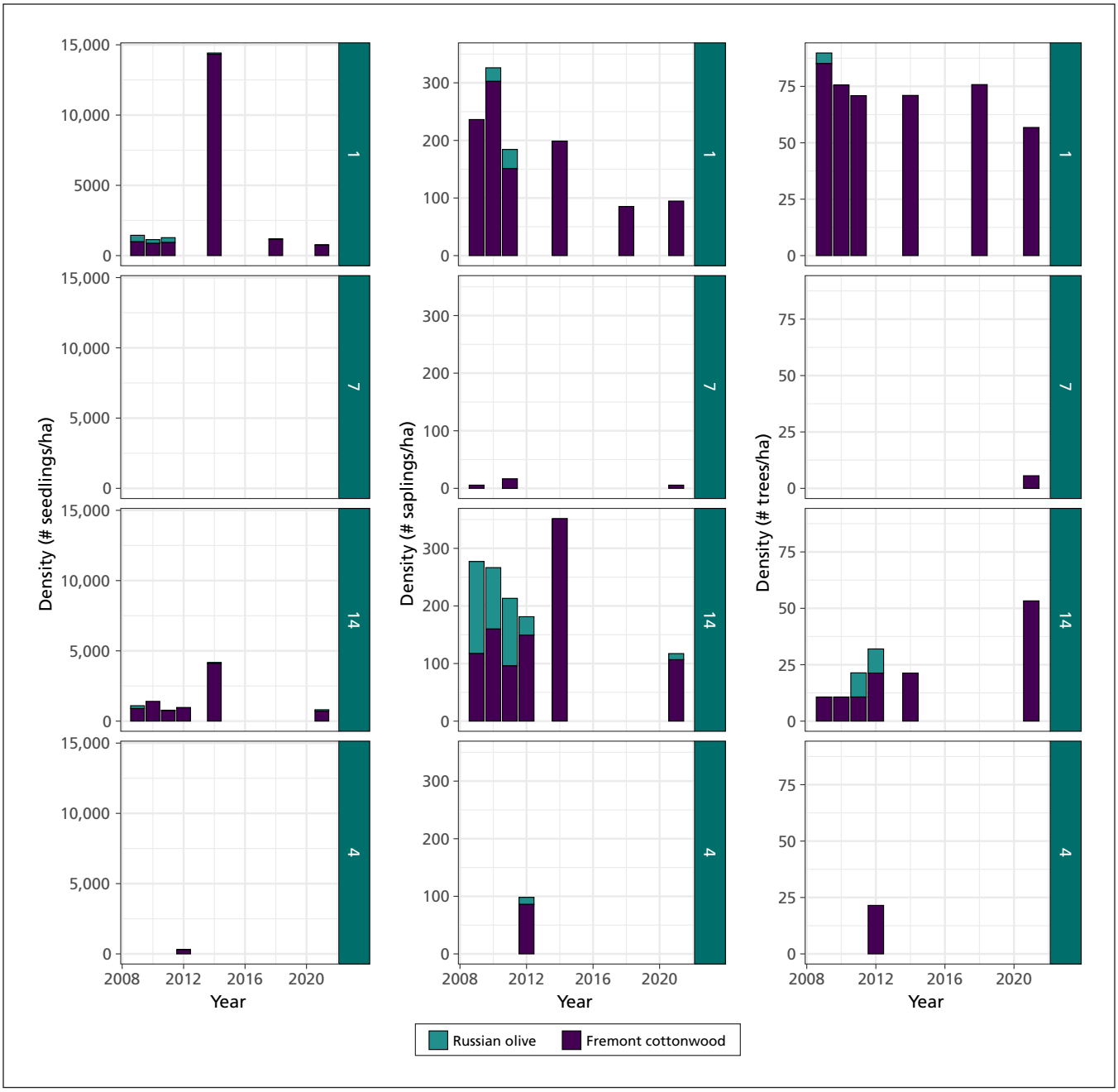


Figure 3-21. Seedling (left), sapling (center), and tree (right) density in 5-meter belt transects by reach, 2009–2021. Note different scales on y-axis for each panel.

Seedling density was also high (4,105 trees/ha) in reach F-14 in the same year, but within the same order of magnitude as in other years and reaches. This recruitment event at reach F-01 in 2014 did not appear to result in establishment of cottonwoods, as sapling and tree densities 4–7 years later (2018 and 2021) were either similar to or lower than in previous years. At reach F-14, seedling and sapling densities were both highest in 2014. A higher density of mature trees at reach F-14 in 2021 may indicate that some of the established saplings were able to advance to the larger size class.

Reach F-14 also had relatively high densities of Russian olive seedlings in 2009–2011 (107–160 trees/ha). However, this species was totally absent in 2014, and there were no mature Russian olive trees present in 2021. Russian olive seedlings were present in all years of sampling, although in relatively low densities in 2021.

At reach F-07, a single mature Fremont cottonwood was present, and a small number (≤3) of saplings were detected over the monitoring period. No tree seedlings of any species were detected in this reach.

At reach F-01, saplings were higher in density but mature trees contributed the greater amount of basal area (Figure 3-22). At reach F-14, this was not the case, with saplings and mature trees contributing similar amounts of basal area. Reach F-01 had the highest density and greatest basal area of trees compared to the other reaches.

3.4.6 Overstory tree census

Because most overstory trees (≥25 cm dbh) on the Fremont River are Fremont cottonwood; this is the only species presented in Figure 3-23. At all reaches, most trees in the census were in the 25–35 centimeter dbh size class. However, reach F-01 had a small number of trees in the largest size class (45.1–50 cm). The largest tree in the monitored reaches (50 cm dbh) occurred at reach F-01.

Three of the overstory trees in reach F-01 died over the 12-year monitoring period. One of these was noted to have been girdled by beaver activity. While cause of death was not noted for the other trees, field crews noted disturbance by insect herbivory, tent caterpillars, and flood debris. In some cases, chicken wire used to protect the trees from beaver activity was now girdling them as they grew larger.



Figure 3-22. Basal area of sapling and trees in the 5-m belt transects, 2009–2021.

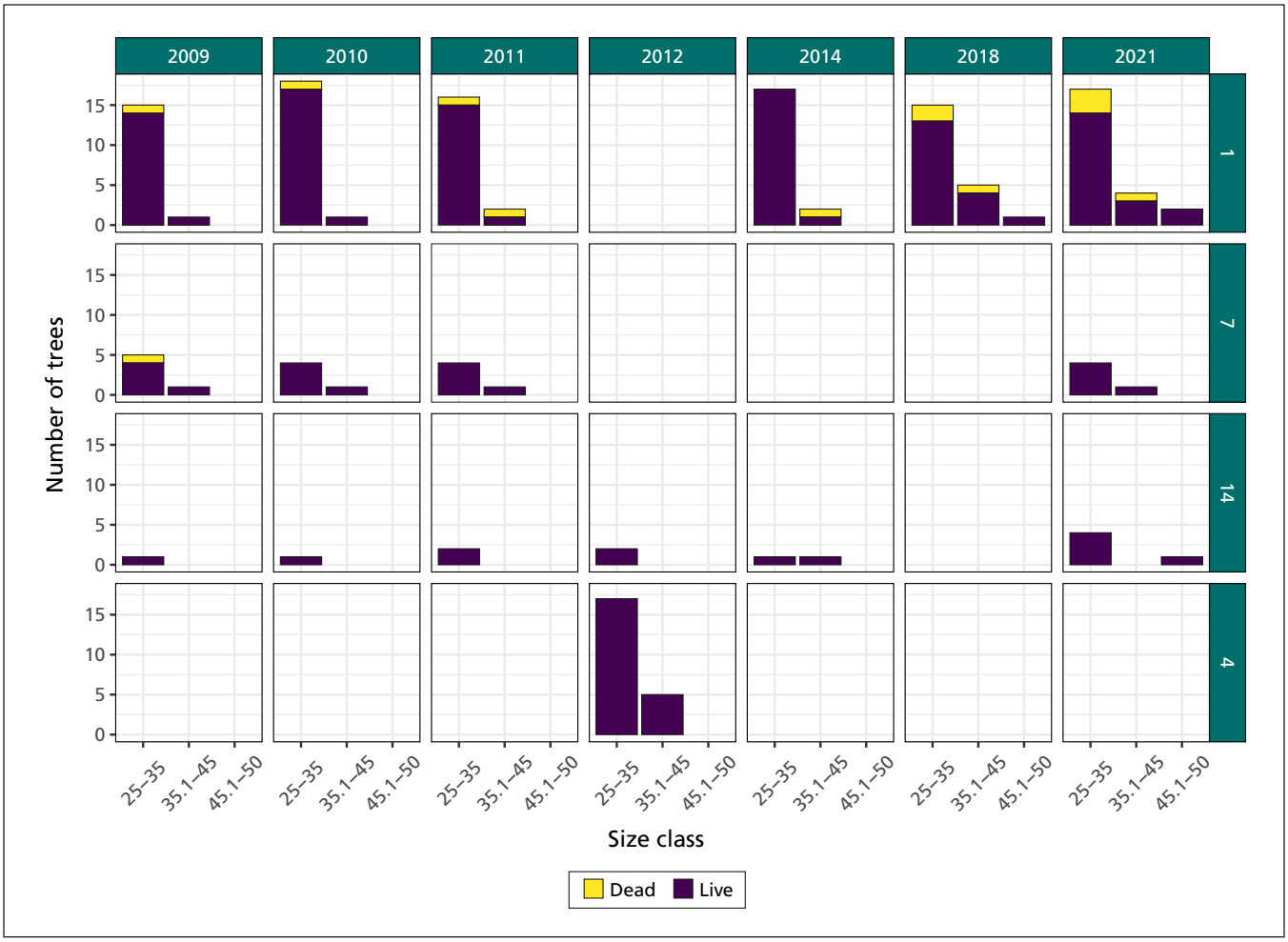


Figure 3-23. Overstory Fremont cottonwood trees by size class, 2009–2021. Note that reaches are of varying size (see Table 2-1).

4 Discussion, Conclusions, and Recommendations

4.1 Discussion

4.1.1 Hydrology

The Fremont River maintained perennial flow from 2009 to 2021, with a strong seasonal signal that corresponded to the irrigation season of April 1–October 31 (see Figure 3-2). This season also coincided with greater evapotranspiration; lower flows during the irrigation season were a result of both anthropogenic withdrawals and natural processes. Flows at the upstream Bicknell gage decreased across all quantiles from WY2001 to WY2021, with flows in the 90th percentile and higher decreasing the most (see Figure 3-4). The potential for lower inputs and higher air temperatures, leading to greater evapotranspiration, suggest the Fremont River is at risk for progressively lower flows over time, as is projected for surface waters throughout the US Southwest due to anthropogenic climate change (Seager et al. 2013).

Overbank flows at F-01 occur infrequently, generally as brief events associated with intense monsoon storms in the late summer and fall. They can cause substantial geomorphic change (see Figure 3-10). Cottonwood recruitment is generally tied to spring overbank-flow events with slow drawdown that can support seedling establishment (Mahoney and Rood 1998), but overbank flows at F-01 do not have the necessary timing or duration to support the regeneration of riparian woody species on higher floodplain surfaces. Groundwater levels averaged about two meters below the surface, well within the <4-meter threshold that supports mature cottonwood trees (Stromberg et al. 1996). Only legacy cottonwood trees remain on these surfaces, and they actively resprout following disturbances, such as beaver browsing.

In a study in the Fremont River gorge, upstream of NCPN's monitoring reaches, Auble and others (2005) found that wetland vegetation occurred on the ground surface at elevations that were inundated for at least two weeks every two years. Their analysis of the duration of high-flow frequency estimated the 14-day high flow to equal about 100 cfs in the gorge. Our data agreed well with this analysis, with an estimated wetland vegetation zone approximately 0.4 meters below and 0.8 meters above the 14-day high flow stage, equivalent to about 94 cfs at the F-01 monitoring reach (see Figure 3-5). These flows generally occurred in March, during snowmelt runoff. To maintain current wetland vegetation in the monitoring reach, it is important to protect these March flows from upstream diversion or capture.

Low-flow days occurred periodically during the irrigation season. Irrigation withdrawals substantially reduced instream flows from April 1 to October 31. From WY2015 to WY2021, there were 25 days with a daily mean discharge less than 23.5 cfs, the contemporary cumulative water right for water users located downstream of the park boundary (see Figure 3-2). Protecting these flows would fulfill water-right obligations to downstream users and help maintain instream flows through the park.

The Fremont River provides habitat for five native fish species, including three species of conservation concern: bluehead sucker (*Catostomus discobolus*), flannelmouth sucker (*C. latipinnis*), and roundtail chub (*Gila robusta)*. Although the State of Utah classifies the Fremont River as a coldwater system, all the native species within Capitol Reef NP are warmwater species (pers. comm., M. Trammell 1/30/2023). Daily mean water temperatures were never higher than the Utah warmwater aquatic standard of 27°C, although some instantaneous measurements were higher than this threshold (see Figure 3-6). Water temperatures remained cool enough to sustain native fish populations, even on low-flow days.

Maintaining a hydrologic record has been challenging on the Fremont River. The magnitude of flash-flood events and their associated turbidity and debris have repeatedly destroyed hydrologic instrumentation. Even under normal flow conditions, there are continued challenges for maintaining a

high-quality data record. Ice can affect the instream record during the winter months, and sedimentation of the instream logger is common throughout the year. Both ice and sedimentation can affect sensor accuracy, with the resulting dataset requiring frequent data corrections. High-flow events cannot be adequately estimated by our stage-discharge rating curve. Maintaining a daily mean discharge dataset will require continued assistance from technical experts in the NPS Water Resources Division to update the F-01 stage-discharge rating curve. Accurate estimates of high flows would require collecting additional calibration data for high-flow events.

4.1.2 Geomorphology

Flow regime, in conjunction with sediment and vegetation dynamics, is the primary driver of river-channel and floodplain form (Fryirs and Brierley 2013; Lane 1954; Leopold et al. 1964; Leopold and Maddock Jr. 1953). At reaches F-01 and F-14, the channel is greatly downcut. However, cross-sections of transects still exhibited considerable geomorphic change across all surveys (see Figures 3-10, 3-12). During the study period, ground elevations increased along most transect channels, banks, and floodplains, as well as most of the channel thalwegs, due to net sediment deposition (see Figure 3-13).

Sediment erosion was localized, occurring along some channels, banks, and sections of the channel thalwegs. Periods of the greatest sediment deposition and erosion appeared to correspond with peak flows, as observed in the hydrologic record. For example, quantities of sediment deposition and erosion were generally greatest between surveys in 2009 and 2014. This corresponded with the timing of the largest observed flood during the study period, in fall 2013. At reach F-01, this flood also destroyed the river-right well and completely buried the instream well in sediment.

Differences in the observed sinuosity of the thalweg across surveys complicated comparative analysis of the thalweg profiles across all reaches. This was particularly problematic at reach F-07, where in 2021, the field crew noted, ". . . the thalweg and right/left bankfulls were very difficult to discern. The thalweg was surveyed although it should be considered as only an approximate observation . . . ." Due to these difficulties, as well as actual changes in thalweg distances at reaches F-01 and F-14, there was considerable offset of transects across surveys (see Figure 3-13). Despite these challenges, it is clear that channel elevations along transects, and thalweg elevations along the channel at reaches F-01 and F-14, largely experienced net sediment deposition over the study period.

However, it is important not to assume net sediment deposition is occurring across the Fremont River through Capitol Reef NP. Reaches F-01 and F-14 represent river lengths of ~260 and 190 meters, respectively, which is only a small fraction of the river's total length through the park. A more intensive study of geomorphic change along a 50-kilometer reach in Grand Canyon National Park by Grams and others (2019) demonstrated that determination of net sediment erosion or deposition was only possible using state-of-the-art bathymetry and topography surveys of high temporal frequency and broad spatial extent, because the majority of geomorphic change occurred in a small percentage of the study area.

Our monitoring demonstrates that geomorphic change is ongoing, and highlights the importance of flood flows in maintaining naturally dynamic riparian systems. The loss of river flow at reach F-07 is an important, albeit extreme, example of the importance of water in maintaining riparian habitat. Due to its location in the abandoned meander, channelized water flow was not observed in reach F-07 during the study period (although brief, intermittent flow resulting from local storm activity was possible). As a result, little geomorphic change occurred in this reach relative to reaches F-01 and F-14 (see Figure 3-11), and what change did occur resulted primarily from colluvial deposition.

4.1.3 Vegetation

Results from vegetation monitoring showed that reaches F-01, F-04, and F-14 are representative of mature riparian systems in the

arid Southwest, dominated by a Fremont cottonwood overstory and a mixed-shrub understory. Historical photos show cottonwood (and willow species) nearly absent from the Fremont River corridor in the early 1900s, but these species are now abundant (Kay 2011, see Figures 1-4, 1-5). This pattern has been observed in other riparian systems in the Southwest. Proposed mechanisms for these increases include altered flood regimes and channelization that have made more area available for colonization by plants (Webb et al. 2007). Despite alteration from historical conditions, vegetation in reaches F-01, F-04, and F-14 had low cover of exotic species. In addition, riparian obligate species were present, along with mixed-age classes of Fremont cottonwood that provide important functions in riparian systems.

Vegetation cover was dense in reaches F-01 and F-14, where total cover was close to or above 40% in some years (see Figures 3-14, 1-4, 1-5). Shrubs included both upland and facultative wetland species, primarily depending on their position relative to the stream channel. In reaches F-01 and F-14, total and live cover, and cover of functional groups, changed little over the monitoring period despite fluctuating wet and dry periods and multiple years of extreme drought, starting in 2018. Riparian systems may be buffered from impacts of drought as long as they retain contact with groundwater (Kibler et al. 2021). However, gaps in monitoring data limited our ability to relate environmental conditions to changes in vegetation cover. Some minor increases in cover in these reaches from 2009 to 2011 may be related to timing of sampling, which occurred in August, rather than late May/June, in 2010 and 2011.

Reach F-07, located in the abandoned oxbow, had distinctly different vegetation than the other reaches. The Capitol Reef Water Resources Management Plan (Cudlip and Kunkle 2004) notes that a five-acre wetland persisted in the oxbow until 1993, but further drying had occurred by 1995 (Cudlip and Kunkle 2004). The oxbow and associated wetland provided habitat for the federally listed Ute ladies-tresses (*Spiranthes diluvialis*), as well as muskrat (*Ondatra zibethicus*), leopard frogs (*Rana pipiens*), and other riparian wetland plant species (Cudlip and Kunkle 2004).

Our monitoring confirms the transition to an upland system through the previously noted lack of geomorphic change, as well as the current species composition (see Figures 3-11, 3-16). There has been a complete loss of riparian obligate species at this reach, an almost complete loss of cottonwood trees, and a relatively high proportion of exotic species compared to the other reaches. A large increase in cheatgrass was detected in 2011, and cover remained high in the most recent monitoring year, 2021 (see Figures 3-15, 3-17). Connection to the Fremont River groundwater table may have persisted in the oxbow for some time—but with additional rapid downcutting at the knickpoint, groundwater levels have since lowered and no longer support riparian vegetation, except at the very downstream edge of the oxbow (C. Livensperger, pers. obs.).

As the dominant native tree species in large and small river reaches throughout the Colorado Plateau, Fremont cottonwood play a critical role in structuring riparian communities. At NCPN monitoring reaches, densities of Fremont cottonwood were at the lower reported range for mature stands (50–400+ trees per hectare (Braatne et al. 1996) (see Figure 3-21). Maintenance of these cottonwood forests depends on periodic recruitment, which requires large flood events that deposit fresh alluvium, followed by continued availability of adequate soil moisture (Cooper et al. 1999; Everitt 1995; Stromberg 1997).

One large recruitment event of cottonwood seedlings was observed at reach F-01 in 2014, following very high precipitation in September 2013 and associated sediment deposition (see Figures 3-1, 3-10, 3-21). At F-01, it did not appear that these seedlings survived and contributed to increases in the larger sapling or tree size classes. At F-14, however, mature tree density did increase by 2021 (see Figure 3-21). Even if seedlings survived, field crews noted a lot of beaver activity, which may prevent saplings from growing into larger size classes. One large

tree that died during monitoring was girdled by beavers.

Park staff have made efforts to protect growing cottonwoods by wrapping them with chicken wire. However, field crews also noted that some of these fast-growing trees were now being girdled by chicken wire. While additional recruitment events were not observed, they may have occurred but been missed due to the timing of sampling. In 2010, 2011, and 2012, sampling took place in August, by which point a seedling flush may have been washed out by monsoon floods. Mortality of mature Fremont cottonwood was low, possibly due to the large number of trees protected with chicken wire by park staff.

Control of Russian olive had visible impacts in the monitored reaches, where exotic species cover was below 10% in riparian reaches (see Figure 3-17) and density of Russian olive saplings decreased over time (see Figure 3-21). NPS Invasive Plant Management Team crews regularly treat Russian olive along the Fremont River, which may account for the loss of this species from reach F-14. NCPN field crews doing invasive surveys along State Highway 24 have observed that the park's eastern boundary coincides with a noticeable increase in Russian olive, and the species is also common in the upper Fremont watershed.

Similarly, cover of tamarisk was low in the monitored reaches, likely due to previous control efforts and the presence of the tamarisk beetle (*Diorhabda* spp.). However, NCPN's invasive exotic plant monitoring (Perkins 2022) found that both Russian olive and tamarisk increased along Highway 24 in recent years. Russian olive, in particular, increased downstream of the oxbow. Invasive exotic monitoring takes place along a large stretch of the Fremont River where it follows the highway, whereas results reported here are limited to individual, smaller reaches.

Seven unique exotic species were detected with frequency-quadrat methods that did not show up in line-point intercept data. However, frequency-quadrat detections for reaches F-01 and F-07 were either above 70% or below 30%, limiting the utility of this metric for detecting change over time in future analyses (Elzinga et al. 1998). Timed plant walks were also used to detect exotic species, and although these cannot be used to assess trend over time, they may provide early warning of species of concern.

None of the exotic species detected at Capitol Reef NP were in Class 1 or 2 (the highest priorities for control) on the State of Utah's noxious weed list, which identifies serious threats. Three species detected are listed as Class 3, meaning containment of new or expanded populations is recommended: tamarisk, quackgrass (*Elymus repens*), and common reed. In 2020, samples of common reed were tested and determined to be the native variety of this species (pers. comm, Kelli Quinn, 5/5/2023).

Nine species that are on the park's invasive plant priority list (Perkins 2022) were also detected in the monitoring reaches: tree-of-heaven (*Ailanthus altissima*), asparagus (*Asparagus officinalis*), blue mustard (*Chorispora tenella*), bull thistle (*Cirsium vulgare*), Russian olive, quackgrass, African mustard (*Malcolmia africana*), alfalfa (*Medicago sativa*), and tamarisk. Quackgrass was detected at reach F-14 in 2012 and 2014 but not in more recent years.

4.2 Conclusions

Perennial flows are maintained on the Fremont River in Capitol Reef National Park, but overbank flows at reach F-01 are infrequent. These flows are associated with flash-flood events and are difficult to monitor with the current infrastructure. Runoff from spring snowmelt generally stays within the channel and contributes to the maintenance of wetland vegetation.

Vegetation in reaches F-01, F-14, and F-04 has low cover of exotic species. Riparian obligate species and mixed-age classes of Fremont cottonwood are present, but recruitment of young cottonwoods into larger size classes was limited. Only legacy cottonwood trees remain on higher floodplain surfaces, which may limit system resilience to disturbance.

In reaches F-01 and F-14, net sediment deposition of up to one meter in the floodplain occurred over the monitoring period, and high flows in 2013 deposited considerable sediment at reach F-01. Only localized erosion occurred, and thalweg surveys showed stream channels were either stable or increasing in elevation.

Vegetation and geomorphology observations in individual reaches may not necessarily reflect patterns in the entirety of the Fremont River in Capitol Reef NP. Because the original sample design was not fully realized, reaches should only be compared to themselves over time and comparisons above and below the knickpoint may be misleading.

4.3 Recommendations

Based on the findings in this report, the NCPN makes the following recommendations for monitoring and management of the Fremont River and its associated resources in Capitol Reef National Park.

4.3.1 Monitoring recommendations

1. Monitor vegetation consistently in June to improve interpretation and increase likelihood of capturing cottonwood-recruitment events.
2. Unless a re-routing of the Fremont River occurs, suspend vegetation and geomorphology monitoring at F-07, the oxbow reach. This reach has transitioned to an upland system in which geomorphology and vegetation are less dynamic than at F-01 or F-14.
3. Consider increasing the number of exotic-frequency quadrats if detection of trend in exotic frequency over time is a goal of this monitoring. Otherwise, discontinue this measurement, which overlaps with NCPN's invasive exotic plant monitoring protocol.
4. Inference on status and trend of broader sections of the Fremont River (e.g., above and below the knickpoint) would require establishment and more frequent monitoring of additional reaches, as described in the original sampling design. However, this remains beyond NCPN's current capacity to support. Continue discussions between NCPN and Capitol Reef NP staff to prioritize wadeable streams relative to other NCPN monitoring protocols.

4.3.2 Management recommendations

1. Advocate for maintaining spring-snowmelt flows of 94 cfs or greater in the NCPN monitoring reach. Policy goals to achieve this could include excluding additional upstream reservoirs and diversions and maintaining the state-managed irrigation season, which currently begins on April 1.
2. If a high-accuracy discharge record is desired, then investigate the placement of a gaging station within the park, or the re-establishment of the Caineville gaging station downstream of the park boundary.
3. Protect young cottonwoods from beaver herbivory and release older mature trees from chicken wire if it is restricting growth. Remove chicken wire from cottonwoods that have grown and are being girdled.
4. Continue control of the woody exotic species, Russian olive and tamarisk.
5. Advocate for restoration of the abandoned oxbow, where riparian function has been lost.

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Appendix A. Hydrologic Infrastructure

Instream installation

- Lat: 38.27876 N, Long: –111.18671 W
- Northing: 4236761.445, Easting: 483669.306 UTM Zone 12, NAD 83
- Current depth of installation: 32.6 cm

There have been three instream installations at reach F-01 since the project began in 2010 (Table A-1). The original instream well had a screened, 3-ft (0.91-m) well point and at least one screened, 3-ft (0.91-m) galvanized steel riser (Figure A-1). The instream well was driven to a depth that would secure the well in place during flood events and minimize its profile above the water column. The uppermost riser of the instream well was a solid galvanized steel riser with holes drilled into the sides. This riser was wrapped in filter fabric to reduce siltation inside the well during installation, but the filter fabric washed away over time. Due to this design, the instream installation began to fill with sediment, which introduced an unknown amount of noise to instream stage records over time. A difference in water elevation inside the well and in the stream was first noted on a field visit on August 11, 2013. After unsuccessful attempts to redevelop the well, the logger was removed on September 6, 2013.

A flash flood in September 2013 irretrievably buried the instream well in large cobbles. A staff plate and stilling well were installed in the stream on June 18, 2014 (Figure A-2). The staff plate and stilling well were driven about two feet into the channel, but this was not deep enough to withstand subsequent flooding. A flash flood tilted the staff plate and stilling well on July 31, 2014. This installation was removed.

A new installation was established on October 7, 2014. A T-post was driven into the channel, and a vented casing and logger were attached using hose clamps (Figure A-3). An additional T-post was driven in upstream to catch debris during flood events. This current installation is about 12 cm downstream from the location of the original instream well (Figure A-4). The open-bottomed design allows sediment to enter the casing, which could permit sedimentation to artificially increase the recorded stage.

Table A-1. Elevation and active dates of instream installation at reach F-01, Capitol Reef National Park.

Elevation referenced to site's permanent datum (m)	Start date	End date
1,578.50	4/21/2010	9/6/2013
1,579.35	6/19/2014	8/6/2014
1,578.84	10/8/2014	–





Figure A-1 (left). Instream well at reach F-01, April 2010–September 2013.

Figure A-2 (right). Staff plate and stilling well, June–July 2014.





Figure A-3. Vented casing attached to T-post, October 2014–present.

Figure A-4. Location of the current instream installation (emerging from water at center bottom of photo) to the previous instream well, visible at the channel bottom 12 cm upstream of the current installation in June 2016.

River-left shallow groundwater piezometer

- Lat: 38.27890 N, Long: –111.18684 W
- Northing: 4236776.556, Easting: 483658.394 UTM Zone 12, NAD 83
- Current depth of well: 345.6 cm

The riparian groundwater piezometers (Table A-2) have a screened 3 ft. (0.91 m) well point and solid galvanized steel risers in 2–3 foot (0.61–0.91 m) sections. Riparian piezometers were driven to a depth of at least one meter lower than the groundwater table encountered during installation. A small hole was drilled on the downstream side of the uppermost riser to vent the well to the atmosphere. No well log is available from the October 2009 installation.

The river-left well has remained intact throughout the period of record (Figure A-5).

Table A-2. Elevation and active dates of river-left shallow grandwater piezometer at reach F-01, Capitol Reef National Park.

Piezometer	Elevation referenced to site's permanent datum (m)	Start date	End date
River-left	1,580.60	4/21/2010	–
River-right	1,580.56	4/21/2010	9/6/2013
River-right	1,580.81	6/19/2014	–



Figure A-5. River-left riparian shallow groundwater monitoring well, 2010–present. The well is to the right of the orange flag at bottom right.

River-right shallow groundwater piezometer

- Lat: 38.27865 N, Long: –111.18657 W
- Northing: 4236748.935, Easting: 483681.507 UTM Zone 12, NAD 83
- Current depth of well: 384.5 cm

The original river-right well was driven to a depth of 429 cm (Figure A-6). The September 2013 flash flood that buried the instream well also sheared off the river right well, and the datalogger was lost. A new shallow groundwater well was installed on June 18, 2014 (Figure A-7). Installing the right well required the use of a backhoe due to a layer of large cobbles about 2.5 m below the surface. Substrate at the right well was medium-fine sand with tree roots to 1 m, medium-fine sand with gravel and cobble to 2.5 m, and gravel and large cobble mix with occasional boulders from 2.5 m to the depth of the installation (almost 4 m).



Figure A-6. River-right riparian groundwater monitoring well, April 2010–September 2013.



Figure A-7. River-right riparian groundwater monitoring well, June 2014–present.

Appendix B. Plant Species List

Table B-1. All plant species identified during monitoring at reaches F-01, F-04, F-07, and F-14, Fremont River, Capitol Reef National Park, water years 2009–2021.

Scientific name[1]	Common name	Lifeform	Duration	Nativity	Wetland code[2]
Acer negundo	boxelder	Tree	Perennial	Native	FACW
Achnatherum hymenoides	Indian ricegrass	Graminoid	Perennial	Native	UPL
Agropyron cristatum	crested wheatgrass	Graminoid	Perennial	Non-native	UPL
Agrostis stolonifera	redtop	Graminoid	Perennial	Non-native	FACW
Ailanthus altissima[3]	tree-of-heaven	Tree	Perennial	Non-native	FACU
Alnus incana	gray alder	Shrub	Perennial	Native	FACW
Ambrosia acanthicarpa	bur ragweed	Forb	Annual	Native	FAC
Apocynum cannabinum	common dogbane	Forb	Perennial	Native	FAC
Aristida purpurea	purple three-awn	Graminoid	Perennial	Native	UPL
Artemisia bigelovii	Bigelow's sagebrush	Shrub	Perennial	Native	UPL
Artemisia dracunculus	tarragon	Forb	Perennial	Native	FAC
Artemisia ludoviciana	Louisiana wormwood	Forb	Perennial	Native	FACU
Asclepias speciosa	showy milkweed	Forb	Perennial	Native	FACW
Asparagus officinalis[3]	asparagus	Forb	Perennial	Non-native	FACU
Atriplex canescens	four-wing saltbush	Shrub	Perennial	Native	UPL
Atriplex confertifolia	shadscale	Shrub	Perennial	Native	UPL
Atriplex gardneri	Gardner's saltbush	DwarfShrub	Perennial	Native	FAC
Bouteloua barbata	sixweeks grama	Graminoid	Annual	Native	UPL
Brickellia longifolia	longleaf brickellbush	Shrub	Perennial	Native	FACW
Bromus inermis	smooth brome	Graminoid	Perennial	Non-native	UPL
Bromus japonicus	Japanese chess	Graminoid	Annual	Non-native	UPL
Bromus tectorum	cheatgrass	Graminoid	Annual	Non-native	UPL
Carex nebrascensis	Nebraska sedge	Graminoid	Perennial	Native	OBL
Castilleja linariifolia	Wyoming paintbrush	Forb	Perennial	Native	FAC
Ceratocephala testiculata	bur buttercup	Forb	Annual	Non-native	UPL
Chamaesyce fendleri	Fendler's spurge	Forb	Perennial	Native	UPL
Chamaesyce glyptosperma	ridge-seeded spurge	Forb	Annual	Native	UPL
*Chenopodium albu*m	lambsquarter	Forb	Annual	Non-native	FACU
Chorispora tenella[3]	blue mustard	Forb	Annual	Non-native	UPL
Chrysothamnus linifolius	spear-leaf rabbitbrush	Shrub	Perennial	Native	FACW
Chrysothamnus viscidiflorus	green rabbitbrush	Shrub	Perennial	Native	UPL
Cirsium vulgare[3]	bull thistle	Forb	Perennial	Non-native	FAC
Cleome lutea	yellow beeplant	Forb	Annual	Native	UPL
Comandra umbellata	bastard toadflax	Forb	Perennial	Native	UPL
Conyza canadensis	Canadian horseweed	Forb	Annual	Native	FACW

[1]Plants not identified to species are excluded except for Opuntia sp. and Tamarix sp., which we are only able to identify to genus.
[2]Wetland codes are as follows: FACW–facultative wetland, UPL–upland, FACU–facultative upland, FAC–facultative, OBL–obligate wetland.
[3]Invasive exotic species also found on the current priority list for NCPN's Invasive Exotic Plant Monitoring.

Table B-1, cont. All plant species identified during monitoring from 2009 to 2021 at F-01, F-04, F-07, and F-14.

Scientific name[1]	Common name	Lifeform	Duration	Nativity	Wetland code[2]
Dactylis glomerata	orchard grass	Graminoid	Perennial	Non-native	FACU
Distichlis spicata	desert saltgrass	Graminoid	Perennial	Native	FAC
Elaeagnus angustifolia[3]	Russian-olive	Tree	Perennial	Non-native	FAC
Eleocharis palustris	common spikerush	Graminoid	Perennial	Native	OBL
Elymus canadensis	Canada wildrye	Graminoid	Perennial	Native	FACU
Elymus elymoides	squirreltail	Graminoid	Perennial	Native	UPL
Elymus repens[3]	quackgrass	Graminoid	Perennial	Non-native	FACU
Ephedra torreyana	Torrey's mormontea	Shrub	Perennial	Native	UPL
Equisetum arvense	field horsetail	Fern	Perennial	Native	FAC
Equisetum hyemale	scouringrush horsetail	Fern	Perennial	Native	FACW
Equisetum laevigatum	smooth scouring-rush	Fern	Perennial	Native	FACW
Ericameria nauseosa	rabbitbrush (sp).	Shrub	Perennial	Native	FAC
Eriogonum cernuum	nodding wild buckwheat	Forb	Annual	Native	UPL
Erioneuron pilosum	hairy tridens	Graminoid	Perennial	Native	UPL
Euthamia occidentalis	western goldenrod	Forb	Perennial	Native	OBL
Gaillardia spathulata	Basin blanketflower	Forb	Perennial	Native	UPL
Gutierrezia sarothrae	broom snakeweed	DwarfShrub	Perennial	Native	UPL
Halogeton glomeratus	halogeton	Forb	Annual	Non-native	UPL
Hesperostipa comata	needle-and-thread	Graminoid	Perennial	Native	UPL
Iva acerosa	copperweed	Forb	Perennial	Native	FACU
Juncus balticus var. *montanus*	Baltic rush	Graminoid	Perennial	Native	FACW
Lappula occidentalis	western stickseed	Forb	Annual	Native	UPL
Lolium arundinaceum	tall fescue	Graminoid	Perennial	Non-native	FACW
Lolium pratense	meadow fescue	Graminoid	Perennial	Non-native	FACU
Machaeranthera canescens	hoary aster	Forb	Perennial	Native	UPL
Malcolmia africana[3]	African mustard	Forb	Annual	Non-native	UPL
Medicago sativa[3]	alfalfa	Forb	Perennial	Non-native	FAC
Melilotus alba	white sweet-clover	Forb	Annual	Non-native	FACU
Melilotus officinalis	yellow sweet-clover	Forb	Biennial	Non-native	FACU
Muhlenbergia asperifolia	scratchgrass	Graminoid	Perennial	Native	FACW
Oenothera pallida	pale evening-primrose	Forb	Perennial	Native	UPL
Opuntia sp.	pricklypear	DwarfShrub	Perennial	Native	UPL
Pascopyrum smithii	western wheatgrass	Graminoid	Perennial	Native	FACU
Phalaris arundinacea	reed canary grass	Graminoid	Perennial	Native	OBL
Phragmites australis	common reed	Graminoid	Perennial	Native	FACW
Pinus edulis	two-needle pinyon	Tree	Perennial	Native	UPL
Plantago major	common plantain	Forb	Perennial	Non-native	FAC
Plantago patagonica	woolly plantain	Forb	Annual	Native	UPL
Poa fendleriana	muttongrass	Graminoid	Perennial	Native	UPL

[1]Plants not identified to species are excluded except for Opuntia sp. and Tamarix sp., which we are only able to identify to genus.
[2]Wetland codes are as follows: FACW–facultative wetland, UPL–upland, FACU–facultative upland, FAC–facultative, OBL–obligate wetland.
[3]Invasive exotic species also found on the current priority list for NCPN's Invasive Exotic Plant Monitoring.

Table B-1, cont. All plant species identified during monitoring from 2009 to 2021 at F-01, F-04, F-07, and F-14.

Scientific name[1]	Common name	Lifeform	Duration	Nativity	Wetland code[2]
Poa pratensis	Kentucky bluegrass	Graminoid	Perennial	Non-native	FACU
Polypogon monspeliensis	rabbitfoot grass	Graminoid	Annual	Non-native	FACW
Populus fremontii	Fremont cottonwood	Tree	Perennial	Native	FACW
Portulaca oleracea	common purslane	Forb	Annual	Non-native	FAC
Psoralidium lanceolatum	lemon scurf-pea	Forb	Perennial	Native	UPL
Salix eriocephala	graybark willow	Shrub	Perennial	Native	OBL
Salix exigua	coyote willow	Shrub	Perennial	Native	OBL
Salix gooddingii	Goodding's black willow	Tree	Perennial	Native	FACW
Salsola paulsenii	barbwire Russian-thistle	Forb	Annual	Non-native	FACU
Salsola tragus	Russian-thistle	Forb	Annual	Non-native	FACU
Schoenoplectus pungens	common threesquare	Graminoid	Perennial	Native	OBL
Shepherdia rotundifolia	roundleaf buffaloberry	Shrub	Perennial	Native	UPL
Solidago canadensis	Canada goldenrod	Forb	Perennial	Native	FACU
Sonchus asper	spiny-leaf sow-thistle	Forb	Annual	Non-native	FACU
Sphaeralcea parvifolia	small-leaf globemallow	Forb	Perennial	Native	UPL
Sporobolus airoides	alkali sacaton	Graminoid	Perennial	Native	FAC
Sporobolus contractus	spike dropseed	Graminoid	Perennial	Native	UPL
Sporobolus cryptandrus	sand dropseed	Graminoid	Perennial	Native	FACU
Stanleya pinnata	prince's-plume	Forb	Perennial	Native	UPL
Tamarix sp.[3]	tamarisk	Shrub	Perennial	Non-native	FACW
Taraxacum officinale	common dandelion	Forb	Perennial	Non-native	FACU
Tragopogon dubius	yellow salsify	Forb	Biennial	Non-native	FAC
Trifolium repens	white clover	Forb	Perennial	Non-native	FACU

[1]Plants not identified to species are excluded except for Opuntia sp. and Tamarix sp., which we are only able to identify to genus.
[2]Wetland codes are as follows: FACW–facultative wetland, UPL–upland, FACU–facultative upland, FAC–facultative, OBL–obligate wetland.
[3]Invasive exotic species also found on the current priority list for NCPN's Invasive Exotic Plant Monitoring.

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