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Riparian Monitoring of Wadeable Streams at Courthouse Wash, Arches National Park

Summary Report, 2010–2019

Natural Resource Report NPS/NCPN/NRR—2021/2321



ON THE COVER

Courthouse Wash upstream of the park road, Arches National Park. NPS/Rebecca Weissinger.

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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 Courthouse Wash in Arches National Park (NP) from 2010 to 2019. The focus of this report is to (1) present geomorphology and vegetation data from five reaches monitored in Courthouse Wash from 2010 to 2015, and (2) examine patterns in water availability at one monitoring reach from November 2010 to December 2019. Vegetation sampling and geomorphology surveys were suspended in 2016 due to budget cuts; this report presents baseline data for future comparisons.

The NCPN has five monitoring reaches located between the inflow of Sevenmile Canyon, a major tributary, and the terminus of Courthouse Wash, at the Colorado River. Two reaches (2, 5) are located in Upper Courthouse Wash, and three (1, 4, 7) in Lower Courthouse Wash. Hydrologic monitoring wells are installed only at Reach 1. During our monitoring period, which included drought years in 2012 and 2018 and a wetter-than-average period from fall 2013 to 2014, groundwater levels showed steep declines corresponding to the start of the growing season each year. Hot, dry summers and falls in 2012, 2018, and 2019 showed the deepest troughs in groundwater levels. Active monsoon years helped elevate summer and fall groundwater levels in 2013 and 2014. Continued monitoring will help us better understand the relationship of climate and water availability at this reach.

A geomorphic survey was completed once for reaches 2, 4, and 7, and twice for reaches 5 and 1. Powerful floods during our monitoring period resulted in aggradation of the channel in reaches 5 and 1, which were first surveyed in March 2013. Flooding in September 2013 resulted in an average of 0.24 meters of deposition found in the channel thalweg at Reach 1 in March 2014. Storm events in May 2014 caused additional aggradation. In March 2015, an average of 0.41 meters of deposition was recorded in the channel thalweg at Reach 5, with 0.32 meters of deposition between the vegetation transect headpins compared to the 2013 data.

The riparian vegetation recorded at our monitoring reaches is consistent with an open-canopy Fremont cottonwood woodland with a diverse understory. Canopy closure ranged from 29% to 52%. Measurements were sensitive enough to detect a 10% reduction in canopy closure at Reach 5 during a pest infestation in June 2013. Canopy closure subsequently rebounded at the reach by 2015. Total obligate and facultative wetland cover ranged from 7% to 26%. Fremont cottonwood seedlings, saplings, and overstory trees were present at all reaches, indicating good potential for future regeneration of the canopy structure. These data can serve as a baseline for comparison with future monitoring efforts.

One area of management concern is that exotic-plant frequency and cover were relatively high in all monitoring reaches. Exotic cover ranged from 2% to 30%. High exotic cover was related to years with high cover of annual brome grasses. High cover of exotic grasses is associated with increased wildfire risk in southwestern riparian systems, which are not well-adapted to fire. Managers should be prepared for this increased risk following wet winters that promote annual brome grass cover.

Beaver activity was noted throughout bedrock-constrained reaches in Courthouse Wash. Beaver activity can reduce adjacent woody riparian vegetation cover, but it also contributes to maintaining a higher water table and persistent surface water. Climate change is likely to be an increasingly significant stressor in Courthouse Wash, as hotter, drier conditions decrease water levels and increase drought stress for vegetation. The expansion of beaver activity in the

system may increase resilience to climate change in bedrock-constrained reaches of Courthouse Wash. Overall, the heterogeneity of the Courthouse Wash system should continue to support patches of surface water and riparian vegetation even as drought conditions increase.

Even during a relatively short time period, NCPN monitoring metrics have proven to be sensitive to changes in vegetation, geomorphology, and hydrology at our monitoring reaches. Reinstating monitoring as funding permits will allow NCPN to track changes over time in this important riparian ecosystem.

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1 Introduction

Riparian zones occupy a tiny fraction of the desert southwest landscape, yet they contribute disproportionately to regional biodiversity (Gregory et al. 1991, Naiman and Decamps 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 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.

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 worked with network park staff to select resources that can be used as "vital signs" to indicate the health of park ecosystems, including the riparian area of Courthouse Wash in Arches National Park (NP). Courthouse Wash contributes a bright ribbon of green to a landscape otherwise dominated by slickrock. The wash contains scarce resources, such as surface water and tree canopy, providing unique habitats and a corridor for wildlife movement. The area has been prized by indigenous peoples, early ranchers, and now by park visitors searching for a backcountry experience.

In cooperation with park staff, the NCPN initiated long-term riparian monitoring in Courthouse Wash in 2010. The overall goal of 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 (Weissinger et al. 2018). This is the first report on data from this effort at Arches National Park. The results will serve as a baseline for future monitoring efforts. They can also serve as an important check on the current status of the health of the Courthouse Wash system in the face of increasing park visitation and accelerating climate change.

1.1 Purpose and scope

The purpose of this report is to present and evaluate baseline riparian monitoring data collected from 2010 to 2019 at five permanent monitoring reaches in Courthouse Wash at Arches National Park. Each reach consists of seven transects oriented perpendicular to the channel. The transects represent cross-sections of the riparian zone. Vegetation data were collected during 2–3 years from 2010 to 2015. Geomorphic surveys were completed 1–2 times during the same period. Collection of these data has since been suspended for budgetary reasons. Hydrologic data were collected continuously, at 15-minute intervals, in two wells at one monitoring reach from November 2010 to December 2019.

Specific objectives of riparian monitoring in Courthouse Wash are to describe status and trends in:

- Groundwater levels
- Geomorphic processes as reflected in channel and floodplain form, including:
    - channel planform
    - channel slope
    - composition of bed material
- Vegetation dynamics, including:
    - species richness
    - plant cover by life form and wetland status
    - basal area and density of woody species
    - canopy closure
    - frequency of invasive species

Several important geomorphic metrics are not included in this report. We did not attempt to determine 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 U.S., and especially difficult to determine for sand-dominated systems, such as Courthouse Wash.

1.2 Conceptual model of Colorado Plateau wadeable streams

By definition, 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. 1988a). Multiple studies on the Colorado Plateau have recorded change in geomorphic processes and riparian structure coincident with climate-related shifts in regional precipitation patterns (Hereford 1984, Hereford et al. 1996, Allred and Schmidt 1999) and land-use changes (Poff et al. 1997). Riparian ecosystems are directly influenced by rivers or streams 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, debris flow and landslide disturbances directly impinge on narrow riparian zones in steep terrain. At larger scales, indirect effects of climate change and land-use practices (such as grazing and land-clearing, which degrade upland soil stability and reduce vegetation cover) alter 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 uses of land and water across a range of spatial scales.

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 stormflow 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 (Emmett 1974, Elliott et al. 1999, 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 U.S. 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 (Hupp and Osterkamp 1985, Bendix 1994). 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 re-establish and re-colonize quickly following disturbance. These characteristics, along with the predominance of woody vegetation, contribute significantly to regional species richness (γ-diversity) by serving as habitat for plant and animal species not found in surrounding uplands (Brinson et al. 1981, Sabo et al. 2005, Hylander 2006, Sabo and Soykan 2006).

1.3 Study area

Arches National Park is located in southeastern Utah, near the town of Moab. Courthouse Wash is one of two major drainages in the park (Figure 1-1). It originates outside the park. Within the park, Courthouse Wash is a dynamic, heterogenous system centered around an intermittent stream with surface flow and groundwater inputs that vary spatially and temporally. The geomorphology of the channel depends on the width of the canyon. It ranges from wide, braided reaches dominated by sand to narrow, constrained reaches with limited adjacent surfaces. The wide, braided section roughly corresponds to the inflow of Sevenmile Canyon, downstream to the park road (Scenic Drive), which we denote as Upper Courthouse Wash (UCW) in this report. This section has a wide, braided sand channel with adjacent cutbanks and alluvial terraces. It is partially supported by inflows from the unconfined Entrada aquifer. Downstream of the park road, the Navajo Sandstone emerges at the surface, and the channel is constrained between narrow bedrock walls. The canyon-bound, constrained section, which is partially supported by the confined Navajo aquifer, runs from the park road to the outflow of Courthouse Wash at the Colorado River, which we denote as Lower Courthouse Wash (LCW). The bedrock aquifers contribute water to the valley-fill aquifer that supports the riparian zone, which can also be recharged by surface flows. Riparian vegetation consists of a Fremont cottonwood (*Populus fremontii*) overstory, with coyote willow (*Salix exigua*) and a mix of mesic forbs and grasses in the understory. The NCPN has five monitoring reaches located between the inflow of Sevenmile Canyon and the terminus at the Colorado River. Reaches 2 and 5 are located in Upper Courthouse Wash, upstream of the park road. Monitoring reaches 7, 1, and 4 are located in Lower Courthouse Wash.

1.3.1 Current land use and resource concerns

Of the 421 km^2 watershed, over 70% (302 km^2) lies upstream of the park boundary (see Figure 1-1). Courthouse Wash originates primarily on Bureau of Land Management (BLM) land, with some private and state-owned inholdings. Outside the park, the watershed is crisscrossed by heavily used 4×4, off-highway vehicle, and mountain-bike trails. Livestock grazing is also permitted. Pockets of state land allow dispersed camping that is largely unregulated. Private developments include a gas station, two developed campgrounds, a restaurant, and a museum complex. Additional undeveloped private inholdings remain in the watershed. US Highway 191 roughly bisects the watershed and runs from north to south, while State Highway 313 runs west from US 191 near Sevenmile Canyon. Sevenmile Canyon contributes about 20% of the watershed area.

Despite the recreational and livestock use common in the watershed upstream of the park boundary, Courthouse Wash within the park is fairly isolated from upstream effects during most flow conditions. Upstream of

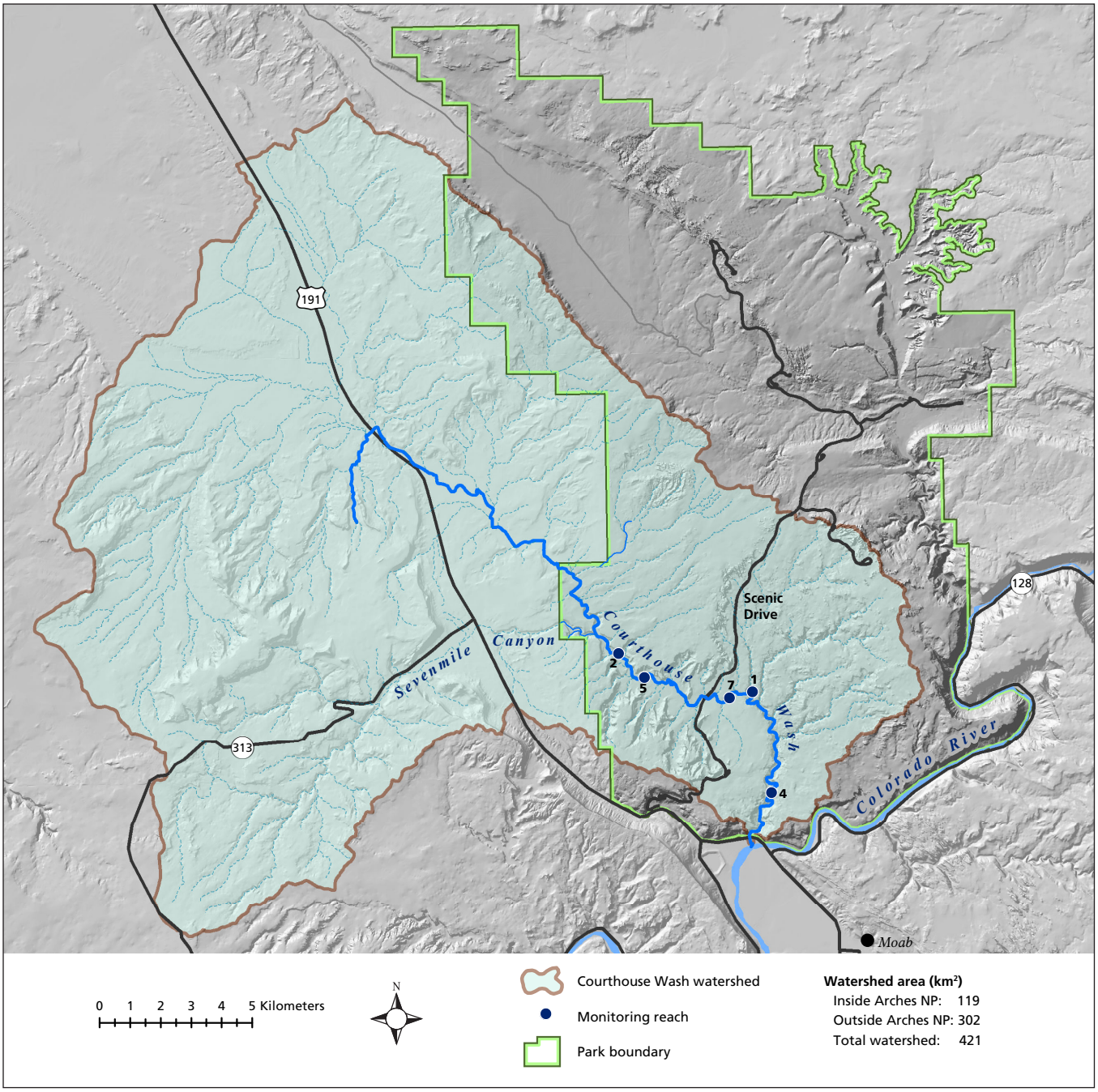


Figure 1-1. Watershed area (km²) of Courthouse Wash, Arches National Park.

the park, Courthouse Wash and Sevenmile Canyon are mostly dry washes that primarily flow during precipitation events. US 191 and a natural knickpoint in Sevenmile Canyon create barriers to passage at that tributary entrance. A boundary fence at the Courthouse Wash entrance to the park discourages entry by off-highway vehicles and livestock, but trespass cattle occasionally enter the park and can be difficult to locate and remove. Trespass vehicles are quickly thwarted by thick riparian vegetation.

Within the park, Courthouse Wash contains both natural and cultural resources and has active recreation zones. Upper Courthouse Wash has several designated backcountry campsites and an unmaintained trail system. An unmaintained hiking trail also runs from the park road downstream through Lower Courthouse Wash to US 191. Courthouse Wash exits the park, flows under a bridge on US 191, and enters the Colorado River just north of Moab, Utah.

Park resource concerns include (1) a potential reduction of groundwater inputs due to withdrawals outside the park, (2) the establishment of exotic invasive species, particularly those that can increase fire risk, such as tamarisk and cheatgrass, (3) the legacy effects of retired livestock grazing, (4) unnatural erosion and gullying caused by the erosion of hiking paths and social trails during high-intensity precipitation and flow events, and (5) the long-term effects of climate change on riparian habitat and surface-water availability.

1.3.2 Climate

Arches National Park has a mean January low temperature of -6.4°C (20.4°F), and a mean July high temperature of 37.3°C (99.1°F). The area is considered semiarid, with mean annual precipitation of 206 millimeters (8.1 in). Precipitation tends to be somewhat evenly distributed throughout the year, with the exception that June is consistently the driest month. Precipitation in July–October is attributable to the North American monsoon (hereafter, "monsoon"), but this source of precipitation has high inter-annual variability because the Colorado Plateau is situated at the monsoon's northernmost distribution (Schwinning et al. 2008). Pacific fronts bring precipitation during winter and spring months.

1.3.3 Hydrology

Surface flow and bio-available groundwater are spatially and temporally variable throughout Courthouse Wash. Overall, bedrock-constrained reaches in Courthouse Wash with bedrock groundwater inputs and/or beaver dams have the most persistent surface water. In wider alluvial reaches, surface water can be rare and may only occur immediately following precipitation events. Seasonal monsoon storms and longer-duration Pacific storm fronts can cause rapid, high-intensity flooding that ranges from hours to days in length. With varying influences of surface and groundwater, hydrologic dynamics in Courthouse Wash are complex and highly localized.

The majority of bio-available water in the system is derived from bedrock groundwater inputs. Groundwater entering the Courthouse Wash system falls conceptually into three zones from upstream to downstream: the confined Entrada, unconfined Entrada represented by the Moab Tongue (also called the Moab Member of the Curtis Formation), and the confined Navajo aquifers. Each aquifer differs in its water quantity and quality and its potential responsiveness to withdrawals and climate change. These bedrock aquifers feed the valley-fill aquifer that supports the riparian zone along Courthouse Wash. The valley-fill aquifer is also recharged by surface-flow events.

Upstream of the park and emerging at a spring in the channel at the northwestern park boundary, the confined Entrada aquifer (overlain by impermeable surface materials) contains groundwater that is thousands of years old (Kirby et al. 2013). Monitoring of springflow and water quality at Upper Courthouse Boundary Spring reported a median flow of 0.03 cfs (cubic feet per second) from 2001 to 2005, and a median specific conductance of 585 µS/centimeter from 2005 to 2011 (Weissinger and Moran 2015). This ancient aquifer underlies much of the area adjacent to the park to the north and west, and groundwater withdrawals in

this area could potentially affect springflow within the park. A 2015 water-rights agreement with the State of Utah prohibits new wells from withdrawing water from this aquifer. A deep-groundwater monitoring well was installed in 2013 upgradient from Courthouse Wash to assist in monitoring the confined Entrada aquifer.

Within the park, outcrops of the Moab Tongue signal a rapid transition to the unconfined Entrada aquifer, which feeds springs in Sevenmile Canyon and the upper section of Courthouse Wash. Springs emerge at the contact line of the Moab Tongue and the underlying main body of the Entrada Formation. Age dating at springs in the unconfined Entrada aquifer suggests the water is mostly younger than 50 years old (Kirby 2007, Masbruch et al. 2010). Springflow monitoring at three springs showed varying responses to climate from 2001 to 2015 (Weissinger et al. 2016). Summary statistics characterizing the springs are shown in Table 1-1.

Groundwater in Lower Courthouse Wash is fed by a small outcrop of Navajo Sandstone connected to a much larger, confined Navajo aquifer, which regionally dips from the northwest down to the Colorado River. No age dating has been done in this section, but regionally, the confined Navajo aquifer often has ages of up to 20,000 years, and an age of greater than 5,000 years is very reasonable (S. Kirby, pers. comm., April 2021). Water-quality monitoring occurs in Lower Courthouse Wash, near the downstream edge of the Navajo aquifer. From 2000 to 2019, the median flow recorded during monthly water-quality visits was 0.13 cfs. Zero flow was recorded on 8 of 104 visits. Median pH was 8.21, median specific conductance 898 µS/cm, and water temperature 13.3°C.

The U.S. Geological Survey operated stream gage 09183000 in Lower Courthouse Wash from roughly 1950 to 1955, and 1966 to 1989. An overview of daily mean discharge at the site indicates an abundance of low-flow days that would be characteristic of groundwater discharge (Figure 1-2). Precipitation-derived surface flows are infrequent and are not sufficient to sustain riparian vegetation; flash floods are the primary geomorphic driver in the system. The gage recorded an annual peak flow of >2,000 cfs for 14 years from 1966 to 1989, despite a mean daily flow of 1.8 cfs at the gage during the same period. The estimated peak flow of record is over 12,000 cfs (Figure 1-3).

1.3.4 Geology and geomorphology

Courthouse Wash enters the park at the transition from outcrops of the Salt Wash Member of the Morrison Formation to the Moab Tongue. As it moves downcanyon, the main body of the Entrada Sandstone begins to emerge, and perennial springs are common at the contact point between the two layers (Figure 1-4). The canyon widens to include a broad floodplain (<400 m wide) (Figure 1-4, Qa1) that is fringed by quaternary alluvial terraces with pronounced cutbanks often more than two meters high (Figure 1-4, Qa2). Two NCPN monitoring reaches are located in the wide-floodplain section of Upper Courthouse Wash. The braided, meandering channel can rework or migrate with relatively low-intensity flood events.

At the park road, the canyon narrows again as the petrified dunes of the Navajo Sandstone emerge and gradually form higher cliffs as the canyon moves downstream. The narrow canyon limits channel meandering, leading to greater potential for channel

Table 1-1. Median flow and water-quality characteristics recorded at springs emerging from the unconfined Entrada aquifer system in Upper Courthouse Wash, Arches National Park.

Site	Flow (cfs)	pH	Specific conductance (µS/cm)	Water temperature (°C)
Sleepy Hollow Spring	0.018	8.3	245	13.4
Sevenmile Boundary	0.011	7.9	248	11.2
Poison Ivy Spring	0.005	8.5	226	15.3

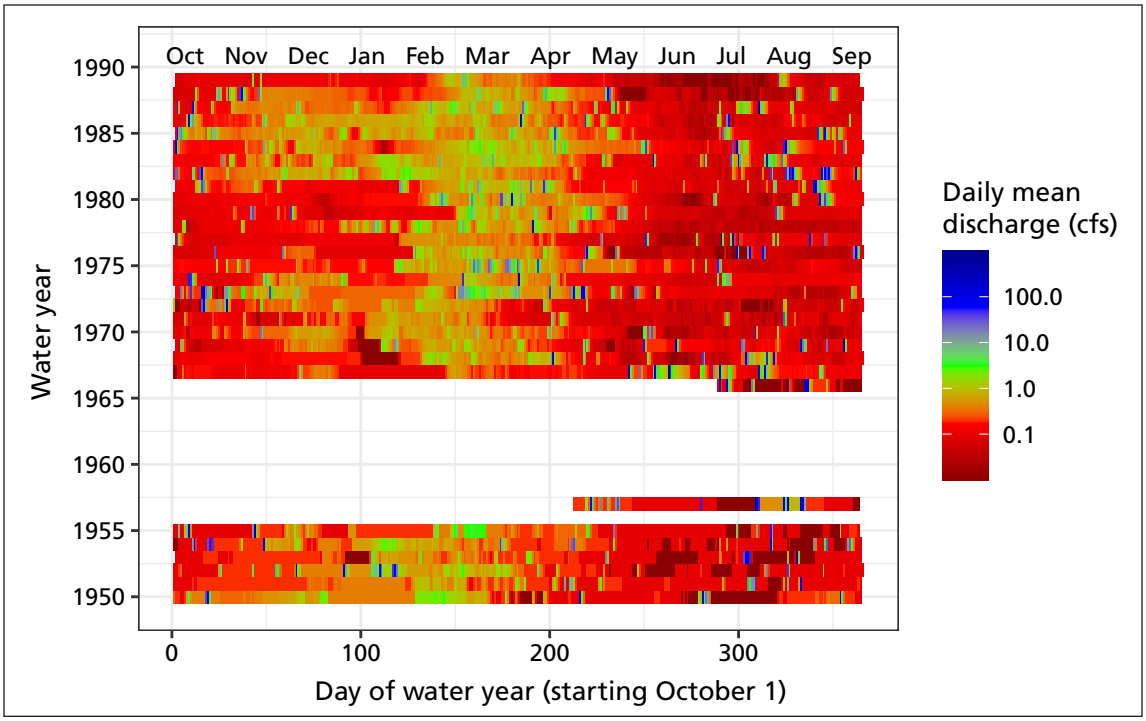


Figure 1-2. Daily mean discharge at the historic gage 09183000 in Lower Courthouse Wash, 1950–1989.

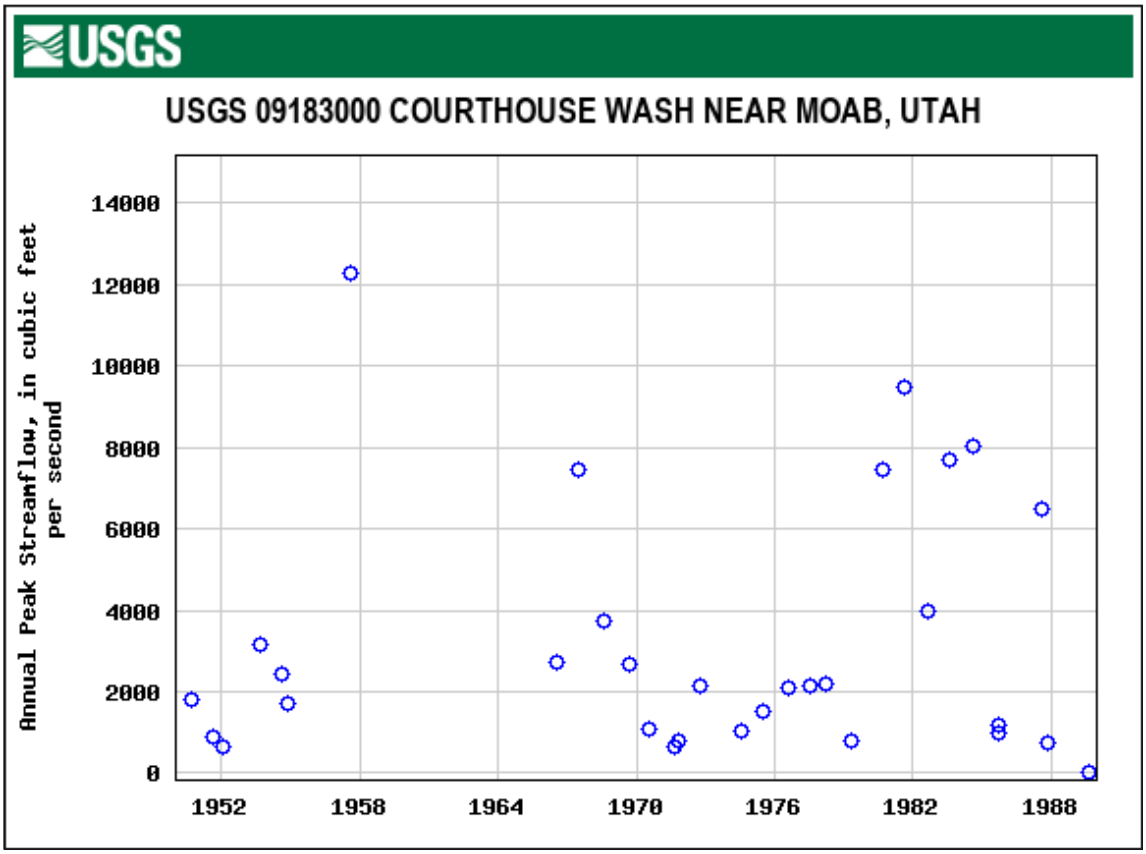


Figure 1-3. Annual peak flows recorded at the historic gage 09183000 in Lower Courthouse Wash, 1950–1989. Graph accessed at nwis.waterdata.usgs.gov.

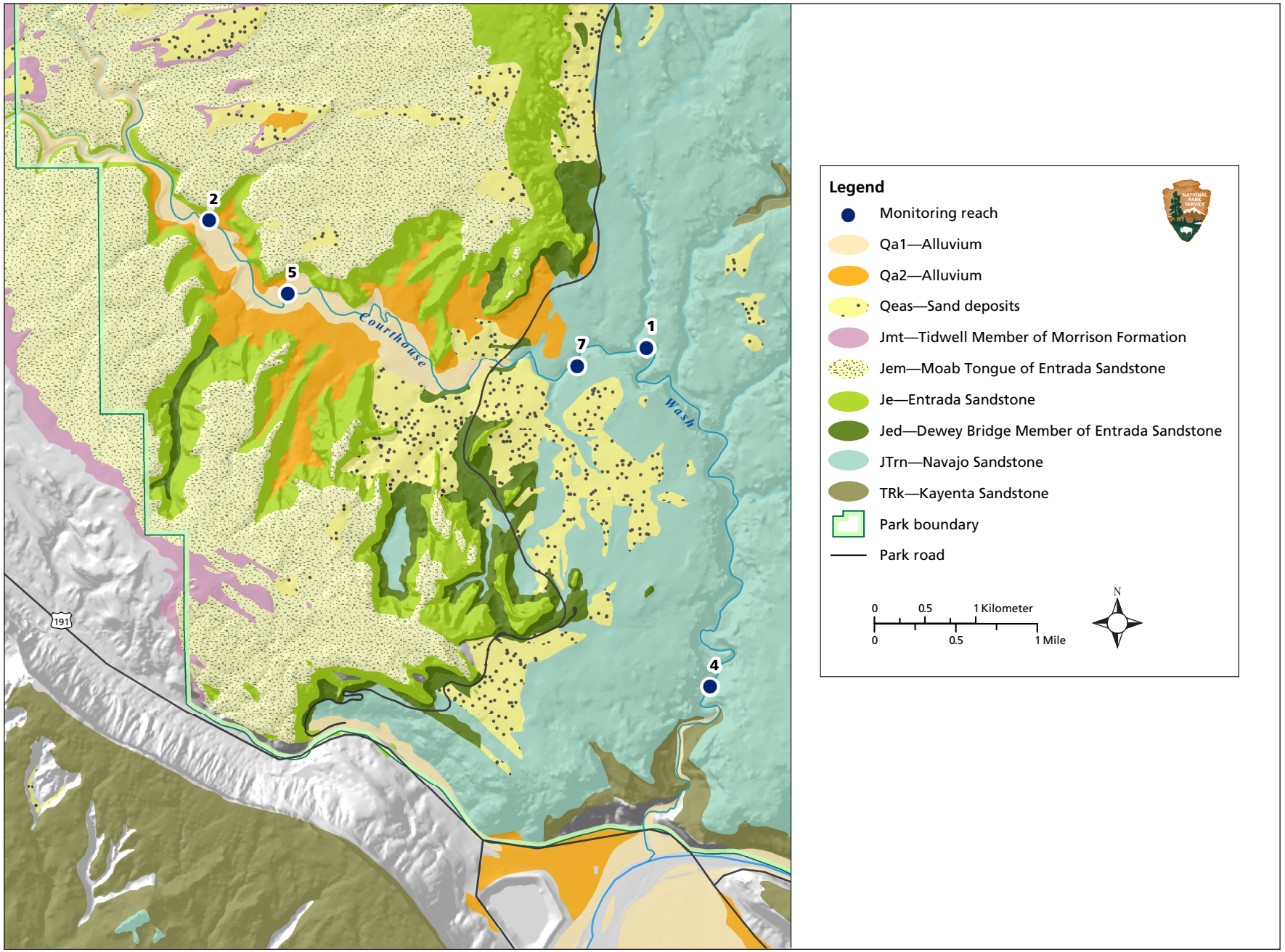


Figure 1-4. Geologic formations in the vicinity of Courthouse Wash, with permanent monitoring reaches noted.

incision during flood events. However, the narrow channel width also promotes establishment of beaver dams, which can serve to slow sediment. Only a few quaternary terrace remnants remain, with most of the alluvial surface subject to flooding during the most intense storm events. Three monitoring reaches are located in this constrained section of Lower Courthouse Wash. The Kayenta Formation briefly outcrops downstream of the monitoring reaches, before the wash enters the Colorado River.

1.3.5 Vegetation and historic grazing

Vegetation in Courthouse Wash is classified primarily as a riparian woodland of Fremont cottonwood with an open canopy and multi-aged stands (Coles et al. 2009). In younger cottonwood stands, the understory consists of mesic herbaceous species. Older cottonwood stands often have upland shrubs and herbaceous species. The braided channels contain sparse but distinctive shrub communities dominated by rubber rabbitbrush (*Chrysothamnus nauseosus*). Coyote-willow shrublands are also common on the banks of Courthouse Wash, sometimes with a tamarisk (*Tamarix* spp.) component. Adjacent alluvial upland areas include greasewood (*Sarcobatus vermiculatus*) flats on lower surfaces, and basin big sage (*Artemisia tridentata*) shrubland and an upland shrub herbaceous complex on terraces. In narrow canyon reaches, the surrounding bedrock supports a sparse pothole and jointed-sandstone woodland dominated by pinyon pine (*Pinus edulis*) and Utah juniper (*Juniperus utahensis*).

Historic photos from Upper Courthouse Wash show an increase in riparian vegetation from the 1930s and 1940 to more recent times (Figures 1-5 and 1-6). Historic photos (photo A in both figures) show a broad, sandy channel with a mostly barren floodplain and sparse shrub cover on adjacent surfaces. Rephotography from 1988 and 2006 (photo B in both figures) shows a comparatively narrowed, scoured channel and abundant riparian vegetation. Several cohorts of cottonwoods are visible. Similar patterns of channel narrowing and vegetation growth have been noted throughout the southwestern U.S. (Webb et al. 2007).

Livestock grazing occurred within the Courthouse Wash area as early as 1875, and was noted as a concern in 1941 (NPS archivist P. Briggs, pers. comm., April 2021), years after the establishment of Arches National Monument in 1929. Prior to 1943, no permits were required to graze within the monument, and records are sparse (Purcell 2019). At the introduction of formal permitting in 1943, historic maps indicate a state inholding in the Courthouse Wash area with an unspecified number of livestock. Elsewhere in the monument, permits allowed trailing and livestock watering for thousands of domestic sheep, and grazing permits for cattle.When Arches National Park was established in 1971, allotments in Courthouse Wash permitted grazing by several hundred cow-calf pairs (Purcell 2019). Grazing was discontinued in 1982, but a boundary fence was not completed until 1998 due to the difficulty and expense of installing fencing across bedrock. Trespass cattle were common in Courthouse Wash until the boundary fence was installed. They are still occasionally problematic.

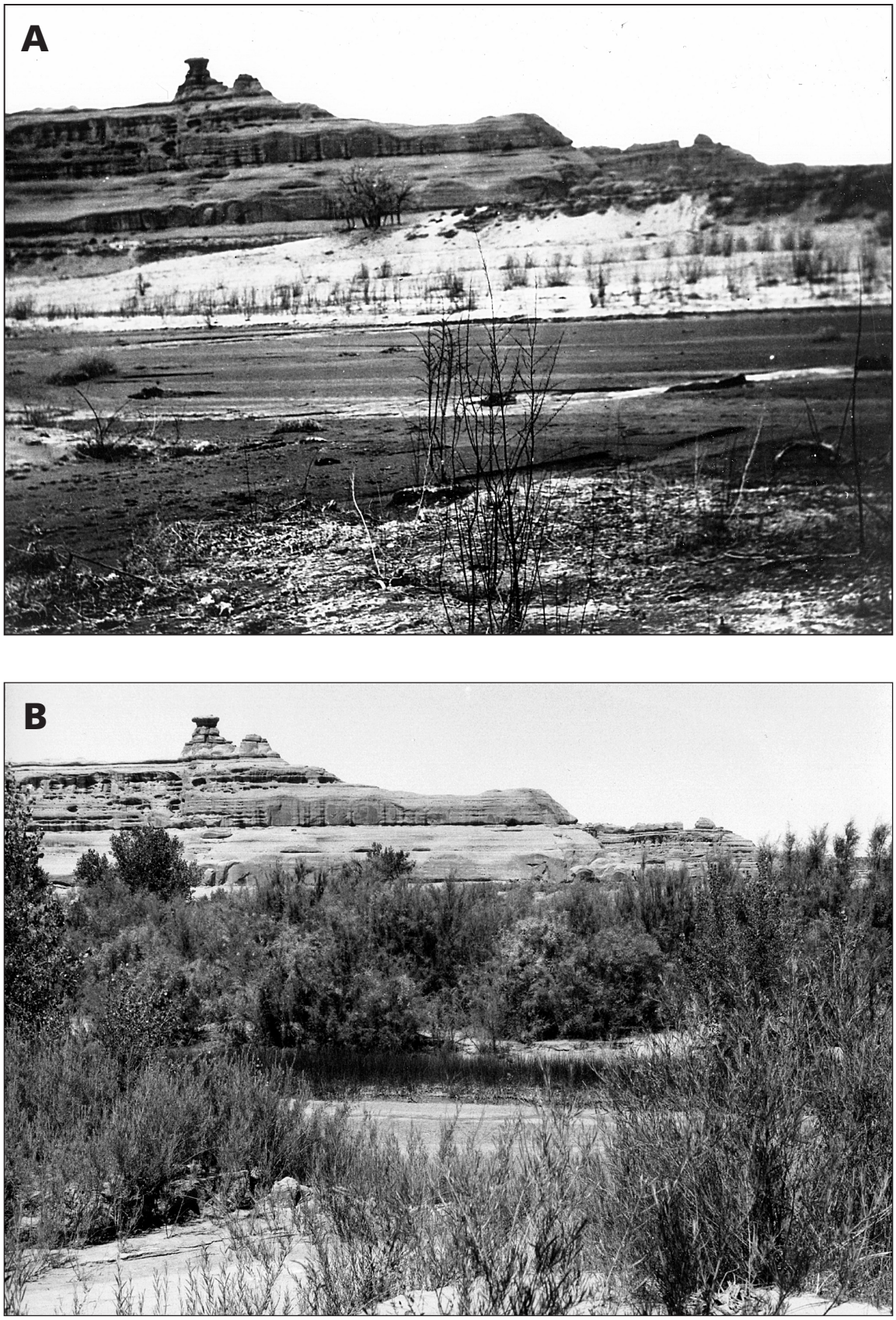


Figure 1-5. Historic photo match from the 1930s (A) and 1988 (B) in Upper Courthouse Wash. Photos from NPS archives, Arches National Park.



Figure 1-6. Historic photo match from 1940 (A) and 2006 (B) in Upper Courthouse Wash. Photos courtesy www.usgs.gov/apps/sbsc-historical-photos/sites/13.

2 Methods

2.1 Sampling design

The sampling unit for 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 (see Section 2.1.2) in order to provide inference to the entire sampling frame of the stream within the park.

2.1.1 Sampling-frame delineation

Analysis of the watershed area of Courthouse Wash (total area of 421 km^2) indicates that a significant tributary, Sevenmile Canyon, contributes approximately 20% of the total watershed area. Because only a short stretch of Courthouse Wash lies within the park upstream of the junction with Sevenmile Canyon, the 15.2-kilometer (9.4-mi) stretch of Courthouse Wash downstream of Sevenmile Canyon within Arches NP was selected as the target population and sampling frame for riparian monitoring.

2.1.2 Monitoring reach selection

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 14 possible monitoring reaches in the sampling frame. Reaches were visited ahead of time to ensure they were suitable for long-term monitoring. They were rejected if they contained major tributaries (>10% of the watershed), major side-canyon spring inputs, >25% bedrock channel, or significant cultural sites. To maintain the spatial balance of the survey design, the first seven acceptable monitoring

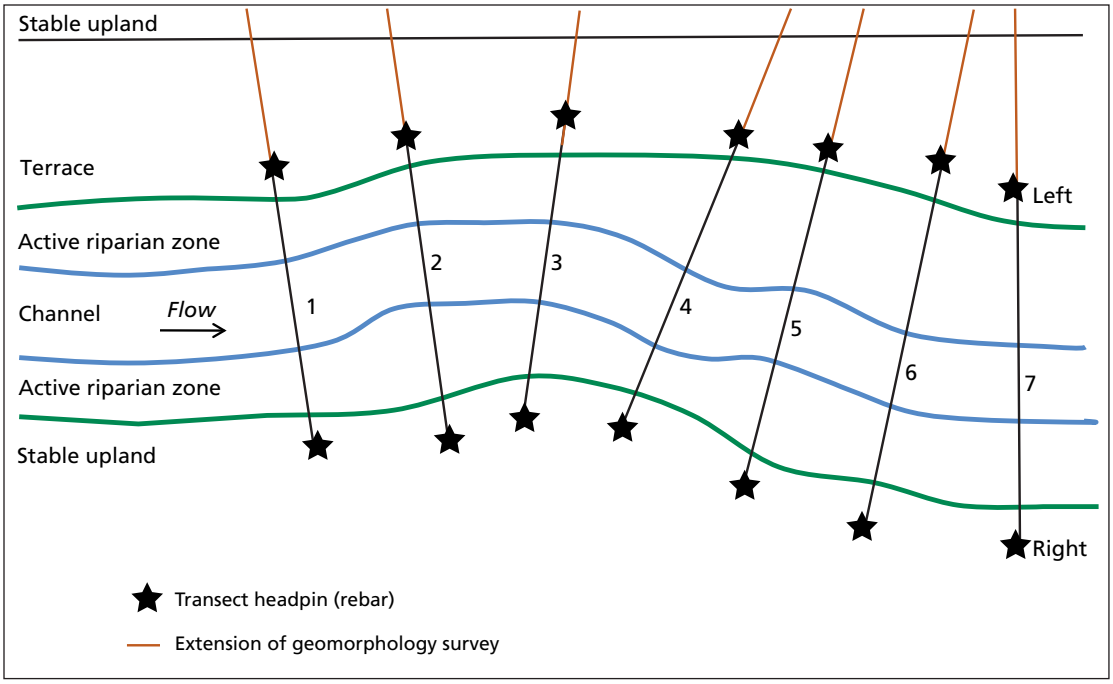


Figure 2-1. Example of a riparian monitoring reach with seven equidistant cross-section transects. Star symbols indicate locations of headpins. The green line represents the upland/riparian zone boundary, and "4" is the location of the reach centroid. Geomorphology transects extend to a stable upland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

reaches (in ascending order of reach number) were selected for long-term monitoring (Figure 2-2). Reaches 2 and 5 are in Upper Courthouse Wash, while reaches 7, 1, and 4 are in Lower Courthouse Wash. Reach 3 was rejected for monitoring because over half the channel was bedrock. Reach 6 was rejected because it contained spring inputs. Reaches 8 and 9 were not monitored due to budget cuts.

2.1.3 Revisit design

Vegetation and geomorphology monitoring occurred at all reaches. A rotating-panel revisit design (Figure 2-3) was used to increase the overall sample size. The revisit design attempts to balance the need for observing interannual variability with the need to maximize replication (Woodward 2004). The total number of reaches sampled was limited by affordable effort and the length of the sampling frame, rather than by variability of vegetation.

A total of seven reaches were scheduled to be monitored in Courthouse Wash, with vegetation sampled during the growing season at two reaches each year (see Figure 2-3). The original sampling order (1–8, sequentially) was changed so that two reaches located very close together were not

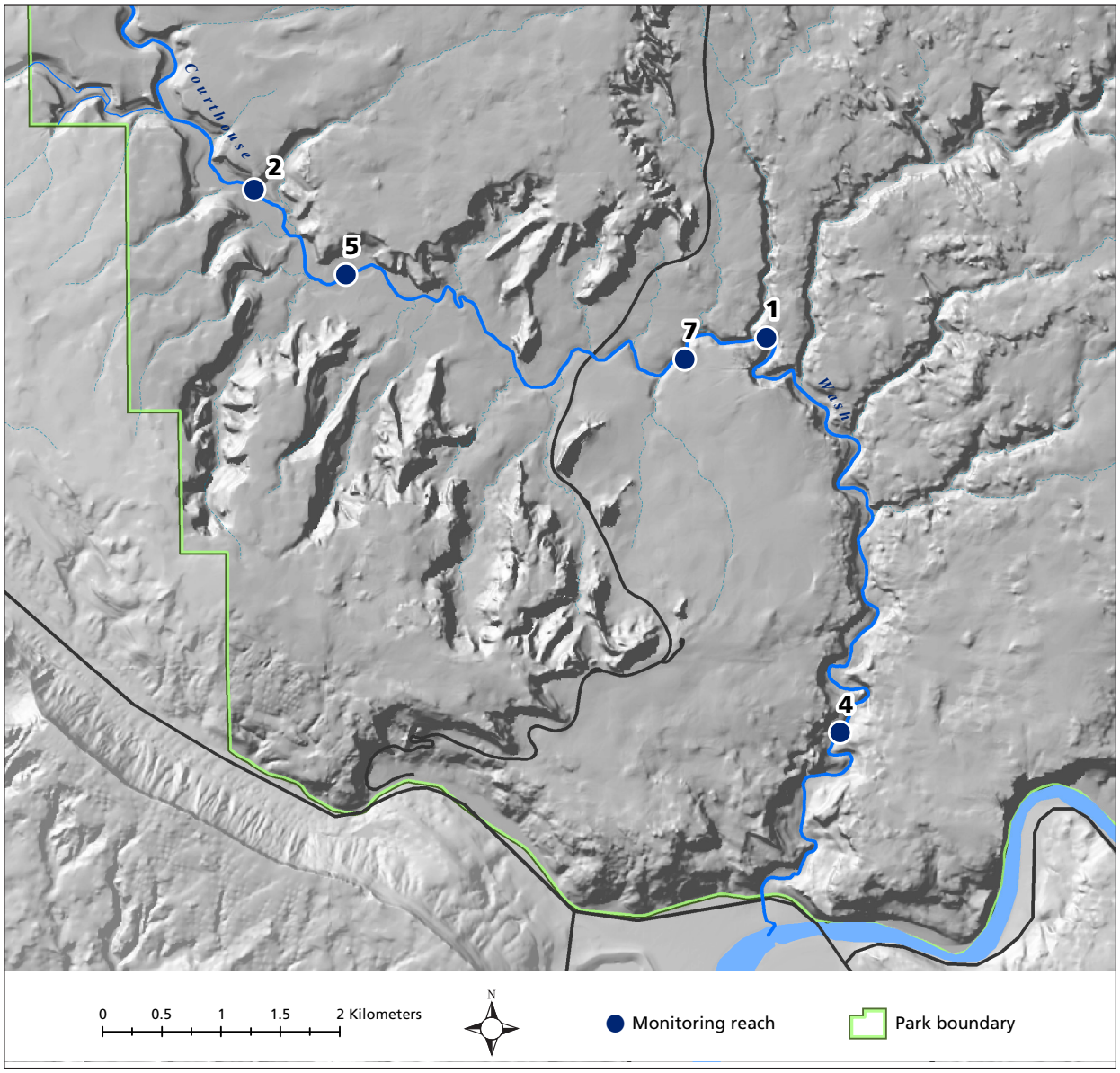


Figure 2-2. Overview map of established monitoring reaches in Courthouse Wash, Arches National Park.

Reach #	Year sampled													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	X	–	–	–	–	–	X	X	–	–	–	–	–	–
2	X	X	–	–	–	–	–	X	X	–	–	–	–	–
7	–	X	X	–	–	–	–	–	X	X	–	–	–	–
5	–	–	X	X	–	–	–	–	–	X	X	–	–	–
4	–	–	–	X	X	–	–	–	–	–	X	X	–	–
8	–	–	–	–	X	X	–	–	–	–	–	X	X	–
9	–	–	–	–	–	X	X	–	–	–	–	–	X	X

Figure 2-3. Reaches proposed for sampling each year, based on the seven-year rotating-panel revisit design for long-term monitoring of riparian vegetation in Courthouse Wash, Arches National Park. Two reaches are sampled each year, with seven reaches sampled over seven years. Actual sampling differed from this approach due to budget cuts and a large flood in 2013. "X" = sampled. "–" = not sampled.

sampled in the same year. In the proposed revisit design, vegetation is sampled for two years in a row at each reach to tease out year-to-year differences due to factors such as temperature, precipitation, and flow, and to better estimate trends. After two years of sampling, the reach is then rested for five years.

Geomorphology surveying occurs between the two growing seasons when vegetation is sampled, so it can be linked to both seasons of data. Sampling some part of a stream each year allows us to detect the effects of major flood events within one year after they occur.

Hydrologic measurements are taken at one reach using an in-channel well and a riparian-zone well with pressure transducers. Reach 1 (see Figure 2-2) was selected for hydrologic monitoring due to its accessibility and the presence of a relatively straight section of channel for instrumentation. Water levels are recorded at 15-minute intervals. Information from the dataloggers, as well as manual water-level measurements, are collected 4–6 times a year. Transects with loggers are surveyed every year.

2.1.4 Reaches monitored from 2010 to 2019

For the most part, reaches were established and monitored according to our long-term monitoring design from 2010 to 2014 (Table 2-1).

- **September 2010:** Riparian monitoring initiated in Courthouse Wash. Reaches 1 and 2 established, vegetation monitored.
- **November 2010:** Hydrologic monitoring wells installed at Reach 1.
- **April 2011:** Geomorphic surveys attempted. Only Reach 2 is successfully surveyed.
- **May 2011:** Reach 2 revisited, Reach 7 established; vegetation monitored in June.
- **March 2012:** Reach 7 surveyed.
- **May 2012:** Reach 5 established. Vegetation monitored at reaches 7 and 5.
- **March 2013:** Reaches 1 and 5 surveyed. Federal sequester triggers automatic budget cuts in all US government programs, requiring a reduction in NCPN field effort.
- **May 2013:** Reach 4 established. Vegetation monitored at reaches 5 and 4.
- **September 2013:** A major storm system causes substantial geomorphic change at previously established monitoring reaches. Anticipating future budget cuts and wanting to document any changes from the recent flash floods, we decide not to continue establishing new reaches in 2014.
- **2014:** Reaches 4 and 1 revisited. Geomorphology is surveyed in March and vegetation monitored in May. Monuments installed at the transect ends of Reach 8 (not sampled to date). Addi-

Table 2-1. Elevation, location, mean transect length, type of visit, and years visited for each monitoring reach in Courthouse Wash, Arches National Park, 2010–2019, from upstream (US) to downstream (DS).

Reach (US to DS)[A]	Elevation (m)[B]	Reach centroid UTM coordinates (NAD83 Zone 12)		Reach length (m)	Mean veg transect length[C] (m)	Type of visit	Years visited[D]									
		Northing	Easting				2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
2	1,274	4280075	618927	360	86.7	vegetation	Sep	May	–	–	–	–	–	–	–	–
2	1,274	4280075	618927	360	86.7	geomorphology	–	Apr	–	–	–	–	–	–	–	–
2	1,274	4280075	618927	360	86.7	hydrology	–	–	–	–	–	–	–	–	–	–
5	1,268	4279356	619801	360	99.2	vegetation	–	–	May	Jun	–	May	–	–	–	–
5	1,268	4279356	619801	360	99.2	geomorphology	–	–	–	Mar	–	Mar	–	–	–	–
5	1,268	4279356	619801	360	99.2	hydrology	–	–	–	–	–	–	–	–	–	–
7	1,252	4278643	622662	204	35.3	vegetation	–	Jun	May	–	–	–	–	–	–	–
7	1,252	4278643	622662	204	35.3	geomorphology	–	–	Mar	–	–	–	–	–	–	–
7	1,252	4278643	622662	204	35.3	hydrology	–	–	–	–	–	–	–	–	–	–
1	1,248	4278821	623349	180	41.2	vegetation	Sep	–	–	–	May	–	–	–	–	–
1	1,248	4278821	623349	180	41.2	geomorphology	–	–	–	Mar	Mar	–	–	–	–	–
1	1,248	4278821	623349	180	41.2	hydrology[E]	–	Y	Y	Y	Y	Y	Y	Y	Y	Y
4	1,224	4275490	623975	200	31.1	vegetation	–	–	–	Jun	May	–	–	–	–	–
4	1,224	4275490	623975	200	31.1	geomorphology	–	–	–	–	Feb	–	–	–	–	–
4	1,224	4275490	623975	200	31.1	hydrology	–	–	–	–	–	–	–	–	–	–

[A]Reaches 3 and 6 were rejected. Reaches 8 and 9 were accepted but never had data collected due to the monitoring rotation and budget cuts.
[B]Elevation from 5-meter Digital Elevation Model (Utah Automated Geographic Reference Center).
[C]Mean of vegetation transect lengths. At Reach 1, the length of one vegetation transect differed by 0.2 meters from 2010 to 2015. At Reach 2, one transect differed by 2.7 meters from 2010 to 2011, due to erosion of a cutbank.
[D]"Y" = sampled. "–" = not sampled.
[E]Wells were installed in November 2010. Usable well surveys occurred in 2013–2015 and 2018–2019.

tional deposition is noted throughout Courthouse Wash following many active storm systems.

- **2015:** Reach 5 resampled, with a survey in March and vegetation sampling in May.

Due to budget cuts from 2016 to 2019, and after subsequent conversations with park staff, vegetation and geomorphology monitoring at the park was suspended. Hydrologic monitoring continued during these years, with the hope that vegetation and geomorphology monitoring would resume in the future.

2.2 Sampling procedures

All sampling follows procedures outlined in Weissinger and others (2018). The reach length and distance between the 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 end points (see Figure 2-1). Kevlar taglines marked at one-meter intervals were strung between the headpins and used to guide transect-tape placement and surveying.

2.2.1 Hydrology measurements

One instream well and one groundwater well were installed on November 2, 2010, at Reach 1 along Transect 2, using a slotted well point and galvanized steel risers. The instream well (Figure 2-4) was installed 4.8 meters from the canyon-right wall in or near the active channel zone, depending on channel geomorphology over time, characterized by a scoured sandy channel with encroaching willow vegetation. The groundwater well (Figure 2-5) was established 28.9 meters from the canyon-right wall on a relatively stable alluvial surface characterized by rabbitbrush and upland grasses.

At installation, the instream well measured 1.56 meters from the top of the well casing to the inside of the well point. After groundwater levels dipped below the well in 2012, the well was deepened to 2.27 meters on July 10, 2013. Sediment deposition from the large flood in September 2013 buried the well, which was gradually uncovered by subsequent flow events. A 61-centimeter riser was added on June 20, 2014, bringing the total instream well length to 2.85 meters. The groundwater well has remained at a total length of 4.83 meters since installation.



Figure 2-4. Courthouse Wash instream monitoring well (see yellow circle), Reach 1, Transect 2, facing upstream, November 2010.



Figure 2-5. Courthouse Wash groundwater monitoring well (see yellow circle), Reach 1, Transect 2, facing the channel, November 2010.

Surveys at Reach 1 have consistently struggled to attain the desired quality goal of less than 6 millimeters in elevation. Autolevel surveys on June 20, 2014, performed before

and after the instream riser was added, likely provide the most accurate relative elevation data for the wells. Well elevations from surveys in 2015 and 2018 ranged from 7 to 14 millimeters higher than the June 20, 2014 elevation. However, the 2019 survey was within 6 millimeters of the June 20, 2014 measurement for both wells, suggesting the well elevations likely have remained stable over time.

Water elevation is recorded at 15-minute intervals by a pressure transducer inside the vented well casing. A barometric-pressure transducer is co-located with the hydrologic infrastructure. Data from hydrologic-monitoring equipment are downloaded and manual water-level measurements are recorded during periodic site visits 4–6 times per year. The depth from the top of the well casing to the ground surface is also recorded during each site visit.

2.2.2 Geomorphology measurements

Channel geomorphology was monitored primarily through pebble counts to measure particle-size distribution, along with stream-channel cross-sections and a thalweg profile. Pebble counts were conducted at each transect by measuring the b-axis (middle dimension) of 60 particles within the channel. Particles less than two millimeters were recorded as <2 mm. Bedrock was recorded as >1,000 mm. Pebble counts were performed each time vegetation was monitored because air and water temperatures are typically too cold to perform this measurement during geomorphic surveys.

Stream-channel surveys were performed at each reach using a Nikon Nivo 3.M total station. For each transect, data were recorded at one-meter intervals along the tagline, at the edge of flowing or standing water, and at any significant slope-break points, to provide a depiction of topography. The thalweg (i.e., the deepest part of the channel) was surveyed at one-meter intervals throughout the reach to capture important channel features. Locations of survey control points, headpins, hydrologic-monitoring equipment, and notable flood debris were also recorded in the survey. Any time hydrologic monitoring equipment was surveyed, a cross-section transect was also surveyed in that location (i.e., at Reach 1/Transect 2) using the same methods as for the permanent monitoring transects.

2.2.3 Vegetation measurements

A point-intercept method was used to record percent cover of understory and ground-cover attributes at 0.5-meter intervals along each transect (Figure 2-6). Density and diameter at breast height (dbh) of trees were recorded by species in a 5-meter belt centered on each transect. Overstory canopy closure was recorded along each transect at 10-meter 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 trees ≥25 cm dbh within the reach were tagged and dbh was measured. In addition, instream and riparian disturbances were described, and the presence of exotic species was recorded during a timed reach walk.

2.3 Data summary, quality checks, and statistical procedures

2.3.1 Climate data

Climate data from the National Weather Service Cooperative Observer Network (COOP) station located at the Arches NP Visitor Center (station ID # 420336) was accessed via ClimateAnalyzer.org. Monthly precipitation and temperature were compared to 30-year averages (1981–2010) from July 2009 (start of monsoon season the year before NCPN monitoring began) to October 2019 (start of 2020 water year). Any month missing more than three days of data for precipitation (2 months) or five days of data for temperature (5 months) was marked as N/A. In addition, daily precipitation totals were evaluated to look for possible high-flow events.

2.3.2 Hydrology data

NCPN 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 3.10, where data corrections were applied, such as adjusting

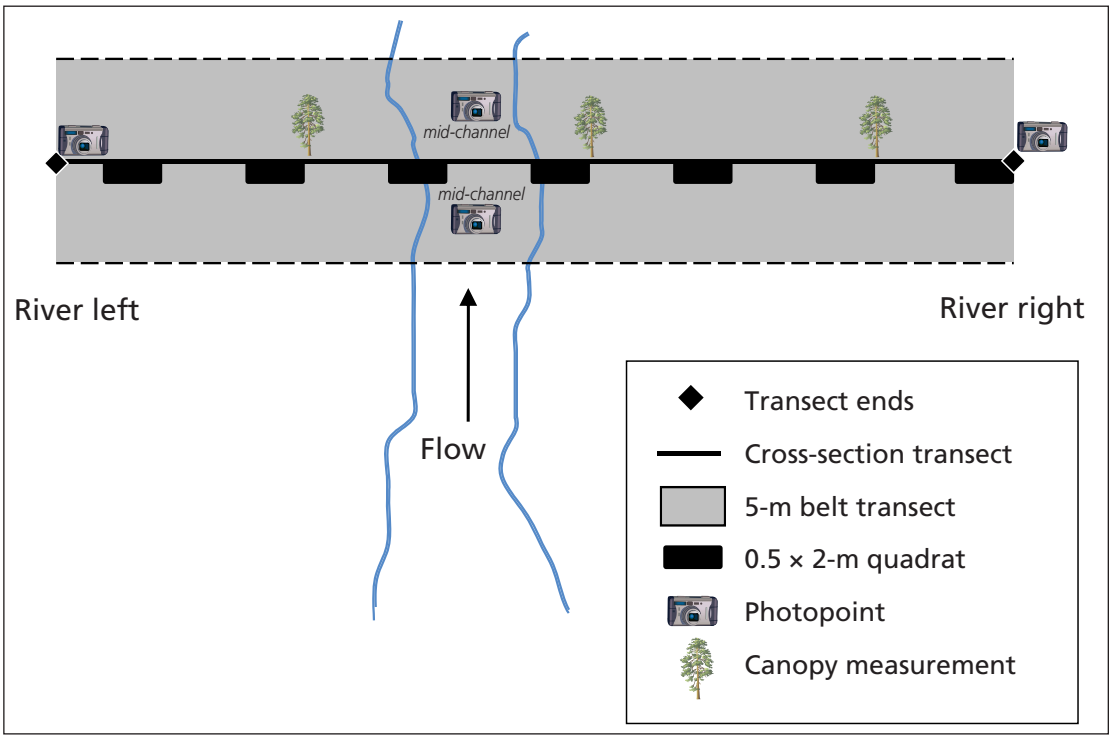


Figure 2-6. Locations of vegetation sampling along each permanent cross-section transect. Understory vegetation was sampled using a point-intercept method at 0.5-meter intervals along the cross-section. Canopy closure was sampled at 10-meter intervals on the cross-section. Seedling, sapling, and overstory tree density was 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.

for sensor drift. Short-term gaps of several hours, such as those during site visits, were linearly interpolated. Longer-term gaps remained unfilled, with the exception of several weeks during a drought period in 2012, when water levels dipped below the logger in the instream well. Due to the close association between instream and groundwater well levels, the groundwater-well data were used to interpolate water levels for the instream well during the drought periods of August 1–23 and September 3–12, 2012.

The corrected water-level data were then converted to the site's permanent datum (see Section 2.3.3). 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 depth-to-water from the ground surface using surveyed ground-surface elevations and manual ground-surface measurements from site visits. Final, approved datasets with associated metadata are publicly available at the National Park Service's Aquarius web portal (https://irma.nps.gov/aqwebportal/). Data were summarized using R 3.5.2 (R Core Team 2018) and the tidyverse (Wickham et al. 2019) and lubridate (Grolemund and Wickham 2011) packages.

2.3.3 Survey data

For hydrologic monitoring infrastructure, acceptable survey errors were <1 vertical centimeter and <5 horizontal centimeters. For geomorphology, acceptable survey errors were <3 vertical centimeters and <5 horizontal centimeters. Surveys that exceeded these errors were not included in this report.

Survey data collected with the total station were imported into Excel, where they were quality-checked, summarized, and used to make figures. Survey data were translated and rotated with Traverse PC software. Because benchmarks with true elevations are not available near our monitoring reaches, survey data were collected in a local datum established at each site ("site datum") during the first site survey. A site datum is an abstract coordinate system with a reference point assigned to an arbitrary elevation

that is used to start all subsequent surveys. Figures that display "elevations" at reaches in this report all use this site datum. Final figures for this report were created in R (R Core Team 2018).

Along each permanent transect and the hydrologic transect, survey data were used to create a figure of the stream cross-section, including surface topography, the level of surface water (when present), headpins, and unmarked transect endpoints (when present). For each reach, survey data were also used to create a figure of the stream's longitudinal profile and the level of the surface water at each transect. To line up the thalweg between visits, transect stations were shifted by the mean difference of transect locations between visits, which lined up the middle transects fairly well. Moving away from the center of the reach, the transects line up less well on the profile figure. Note that the transect locations are permanently marked and do not change over time.

Reach slope was calculated in two ways. The water slope is the standard slope measurement for perennial streams. However, water was not present during all survey events at all reaches. 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 surveyed distance between the two transects. Channel slope was calculated as the most-upstream surveyed thalweg elevation not located in a pool minus the most-downstream surveyed thalweg elevation not located in a pool, divided by the total length of the surveyed thalweg.

Sinuosity was calculated for each reach between transects 1 and 7 by dividing the distance recorded during the thalweg profile by the straight-line distance estimated using ArcGIS. A change in thalweg elevation between two survey events was calculated by averaging all thalweg measurements between transects 1 and 7 for each survey event, then subtracting the average thalweg elevation from the most recent survey from the earlier survey.

2.3.4 Vegetation and pebble count data

Quality assurance and quality control (QA/QC) procedures were performed for all data. They included domain-checking in data-entry procedures, checks for missing values, and logic checks.

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

Species richness by lifeform and wetland status were calculated using species detected while sampling plant cover, seedling and tree density, the reach census, and exotic frequency. Because exotic frequency was not collected in 2010, species-richness data from this year were not calculated because they likely underestimated the number of species compared with other years. *Tamarix* and *Opuntia* spp. were counted as species for richness because NCPN cannot identify these more finely in the field. All other genera and unknown species were excluded from species-richness calculations.

Percent cover of surface features and vegetation by lifeform, nativity, wetland status, and species were calculated from point-intercept data. 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.

Seedling, sapling, and tree density was calculated from data collected in the 1-meter and 5-meter belts. Basal area of trees was also calculated using the dbh of saplings and overstory trees in the belt transects. Trees in the overstory census were combined and summarized by size class and species.

For all measurements presented in this report, data were summarized by reach. No statistical tests were performed in this initial data summary because there were not enough data to detect trends. Summaries of pebble counts and all vegetation measures were performed in R 3.5.1 (R Core Team 2018). Data were summarized using the dplyr package (Wickham et al. 2018). Figures were created with ggplot2 (Wickham 2016).

3 Results

3.1 Climate

Climate is recorded by water year (WY; October 1–September 30) as measured at Arches National Park's National Weather Service COOP climate station. A wetter-than-average period occurred from WY2014 to WY2016 (Figure 3-1). Six of the 10 largest precipitation events from 2009 to 2019 occurred between September 2013 and June 2015—including the two largest storm events, in May and August 2014 (Table 3-1). Two droughts occurred during the monitoring period. From December 2011 to November 2012, precipitation was lower than normal for 12 consecutive months. Total precipitation was very low for the 2012 water year (Table 3-2). Total precipitation in WY2018 was also well below average.

Table 3-1. Ten highest daily precipitation totals from 2009 to 2019, Arches National Park.

Date	Precipitation in cm (in.)
05/11/2014	3.23 (1.3)
08/14/2014	3.10 (1.2)
08/22/2018	2.95 (1.2)
06/06/2015	2.92 (1.2)
09/10/2013	2.61 (1.0)
09/28/2014	2.59 (1.0)
10/12/2013	2.41 (1.0)
02/13/2018	2.03 (0.8)
07/20/2017	1.98 (0.8)
10/26/2011	1.96 (0.8)

3.2 Hydrology

Only Reach 1, in Lower Courthouse Wash (valley fill with contributions from the confined Navajo aquifer) has monitoring wells. Water levels at Reach 1 are strongly seasonal, with elevated levels in the winter and steep declines as the growing season begins and evapotranspiration increases (Figure 3-2). Water levels for the instream and groundwater wells track each other closely, indicating good hydraulic connectivity throughout the transect. Water levels are very similar during drawdown, with the exception of discrete

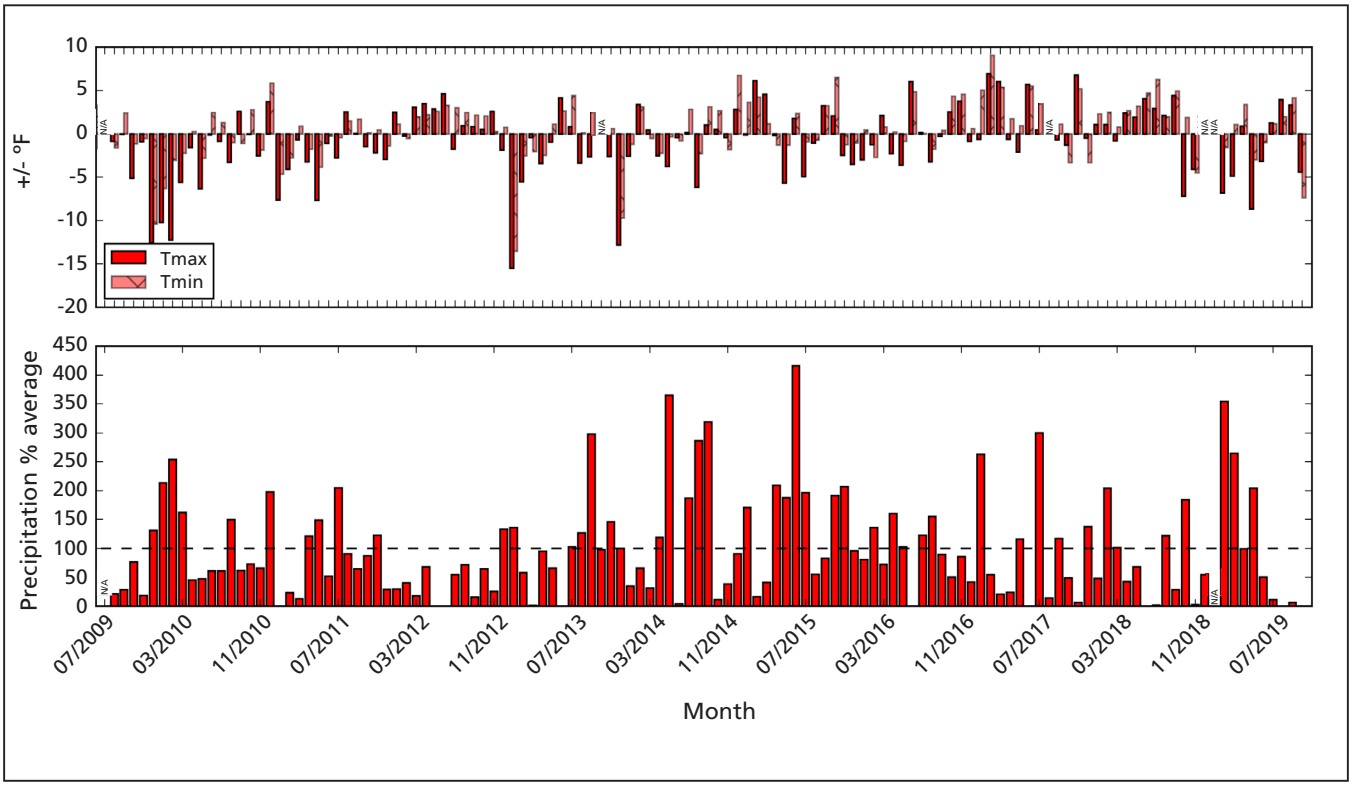


Figure 3-1. Departure from the 30-year average (1981–2010) for maximum temperature (Tmax), minimum temperature (Tmin), and precipitation from July 2009 (start of monsoon season the year before NCPN monitoring began) to October 2019 (start of 2020 water year) at the Arches National Park COOP climate station. Months missing more than 3 days of precipitation data and/or 5 days of temperature data are marked as N/A.

Table 3-2. Total precipitation by water year from 2009 to 2019, Arches National Park.

Water year	Precipitation in cm (in.)
2009	NA[A]
2010	22.6 (8.9)
2011	20.3 (8.0)
2012	10.9 (4.3)
2013	21.6 (8.5)
2014	35.3 (13.9)
2015	24.9 (9.8)
2016	28.2 (11.1)
2017	19.8 (7.8)
2018	14.7 (5.8)
2019	24.6 (9.7)

[A]Missing data for May–July 2009.

precipitation events, seen as rapid spikes in the instream water level. While usually subsiding within a few hours, these flow events often also cause a bump in groundwater levels that can be sustained for a surprisingly long period. The stream switches from a gaining reach from about January to July (as groundwater drains toward the channel) to a losing reach from about August to December (as channel water drains towards the riparian zone; Figure 3-3).

3.2.1 Instream water levels

From March 2011 to April 2014, discharge measurements were recorded during each field visit using a Baski 8" portable flume, for a total of 22 measurements. Discharge ranged from 0 to 0.12 cfs. Zero-flow days accounted for half of the field visits. Flow measurements were discontinued in May 2014, due to the dynamic nature of the channel and a lack of stable channel control.

The sand channel at Reach 1 often fills or cuts with flood events, making it difficult to determine whether recorded water levels are above ground or below ground. Gaps in the survey dataset also complicate interpretations of water levels. When surveys are completed, they are conducted in the spring. Most channel-changing floods occur during a few months in the fall, most often during September and October. As such, the springtime elevation is probably representative of most of the water year and, while imprecise, may be a useful marker for the relative abundance of surface water in the reach over time. For the four water years with survey data, the number of days with values above the minimum surveyed channel elevation ranged from 148 to 329 (Table 3-3). The 10 highest-

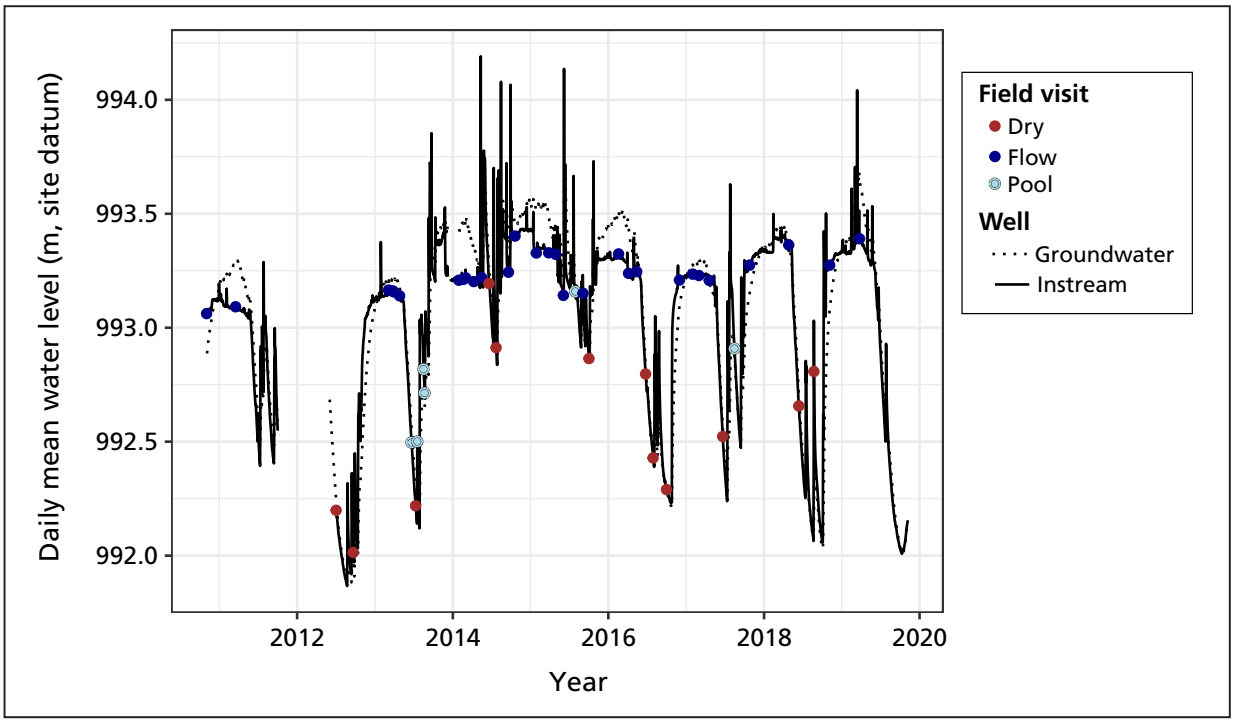


Figure 3-2. Daily mean water level (m, site datum) of the instream and groundwater wells, 2011–2019, Reach 1, Lower Courthouse Wash, with channel status noted on field visits.

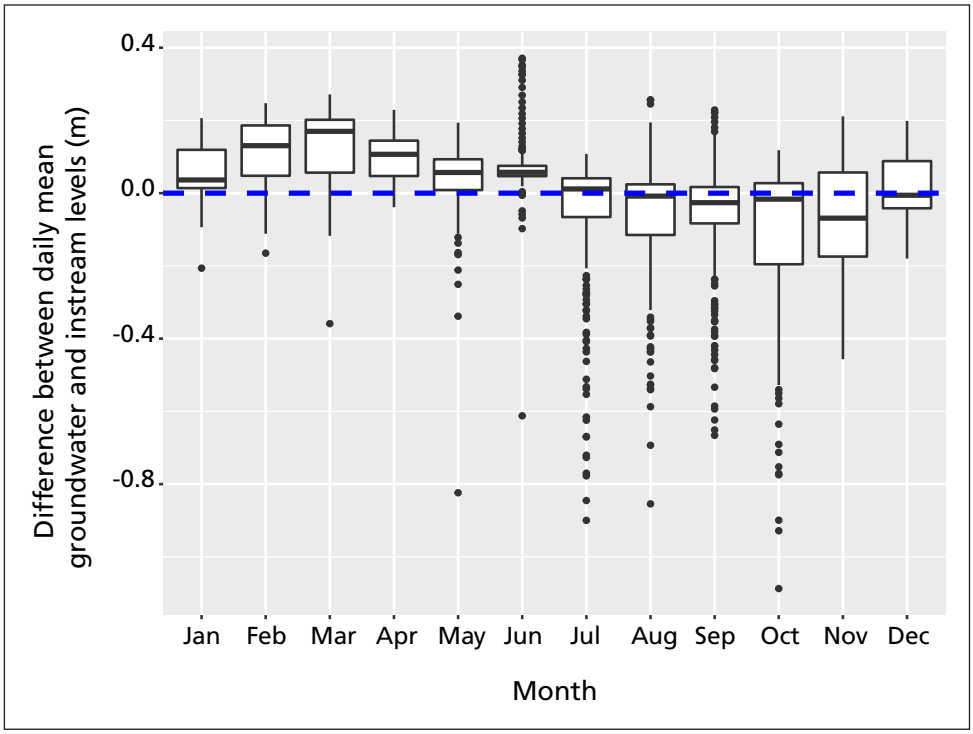


Figure 3-3. Differences in daily mean groundwater and instream levels for each month. Boxes represent the 25th, 50th (center line), and 75th percentile values. Whiskers extend to 1.5 times the interquartile range. Values beyond the whiskers are represented as dots. Values greater than zero indicate a gaining reach, when groundwater levels are higher than instream levels. Values less than zero indicate a losing reach, when surface water events can recharge groundwater levels.

Table 3-3. Surveyed channel elevations at Reach 1, Transect 2, where the instream well is located, with number of days when the daily mean water level was above or below the minimum surveyed channel elevation in the site datum.

Water year	Survey date	Average channel elevation (m)	Minimum channel elevation (m)	Days above minimum	Days below minimum	Total days
2013	3/3/2013	993.13	993.05	193	164	357
2014	3/1/2014	993.15	993.08	329	23	352
2018	3/20/2018	993.46	993.33	148	217	365
2019	2/12/2019	993.34	993.24	239	126	365

stage flood events in the period of record all occurred after a significant flood event in September 2013 initiated an active period of channel deposition and erosion from storms that continued through June 2015 (Table 3-4). Some, but not all, of these high-stage events matched the highest precipitation events recorded at the Arches visitor center weather station (see Table 3-1).

Flood events are important aquatic disturbances that can recharge the valley-fill aquifer. Because flash floods are often rapid, they are muted in the daily mean record. To estimate flood frequency, we calculated the change in daily mean stage. Increases of >0.01 meter were visually associated with hydrograph peaks, but some small flood events were still missed (Figure 3-4). Flood frequency varied from 10 to 35 events per year, with a median of 24 (Table 3-5).

3.2.2 Groundwater levels

The ground surface at the groundwater well is much more stable than the instream channel surface, as confirmed by survey data and measurements from the top of the well casing during each site visit. Groundwater levels are consistently deeper than 2.5 meters below the ground surface and often over 3 meters below the ground surface during the summer and fall (Figure 3-5).

3.2.2.1 Trends in groundwater levels

A LOESS smooth of depth-to-groundwater over time (Figure 3-6) suggests (1) a dip in groundwater depth corresponding to

Table 3-4. The ten highest 15-minute stage events at Reach 1, Transect 2, with maximum recorded stage.

Date	Maximum 15-minute stage (m, site datum)
8/14/2014	996.13
6/6/2015	995.76
10/23/2015	995.18
9/9/2014	995.13
7/26/2017	995.07
6/11/2015	994.86
8/4/2014	994.73
7/25/2017	994.65
5/11/2014	994.63
9/28/2014	994.57

Table 3-5. Number of events per water year when daily mean stage rose by more than 0.01 meter, Reach 1, Transect 2.

Water year	Number of events
2013	35
2014	26
2015	24
2016	24
2017	23
2018	10
2019	27

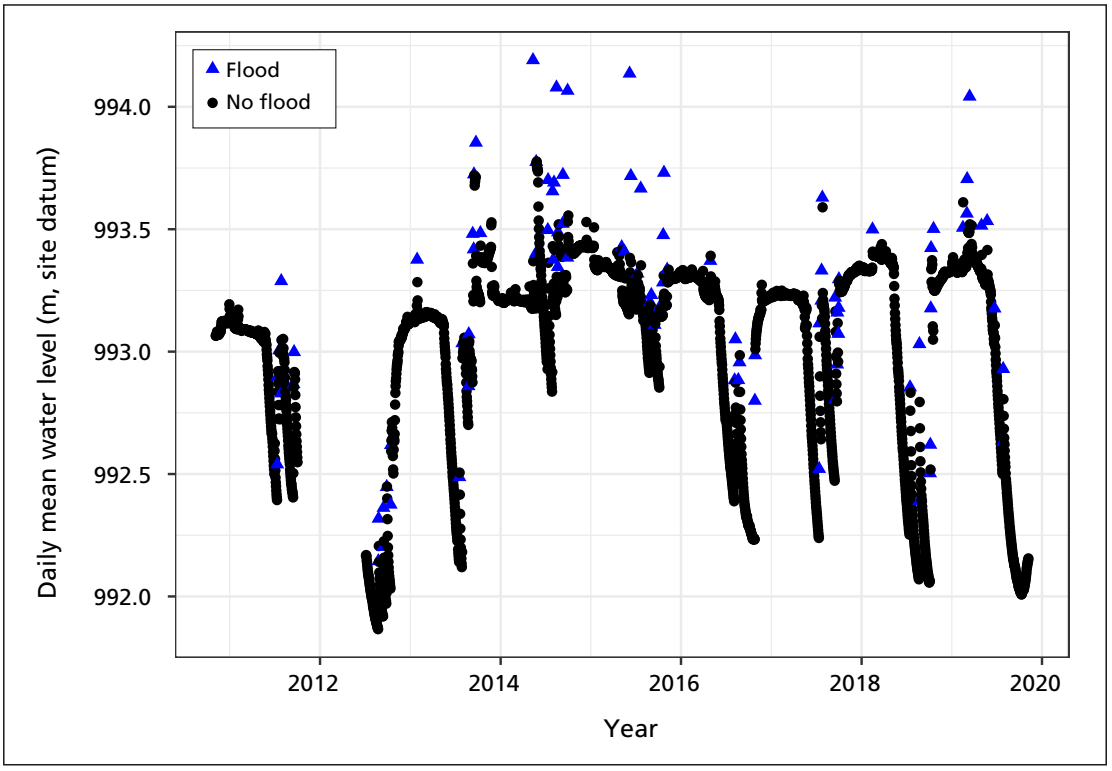


Figure 3-4. Flood events when the daily mean stage increased by more than 0.01 meter from the previous day.

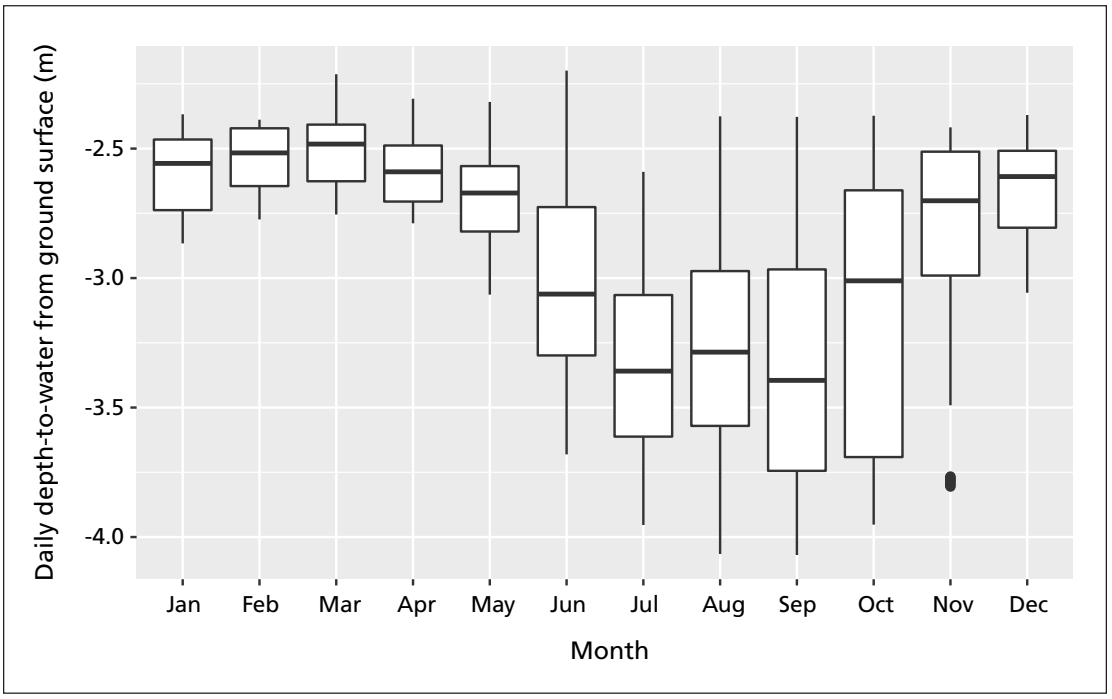


Figure 3-5. Mean daily depth-to-water (m) by month at the groundwater well, Reach 1, Lower Courthouse Wash, 2011–2019. Boxes represent the 25th, 50th (center line), and 75th percentile values. Whiskers extend to 1.5 times the interquartile range.

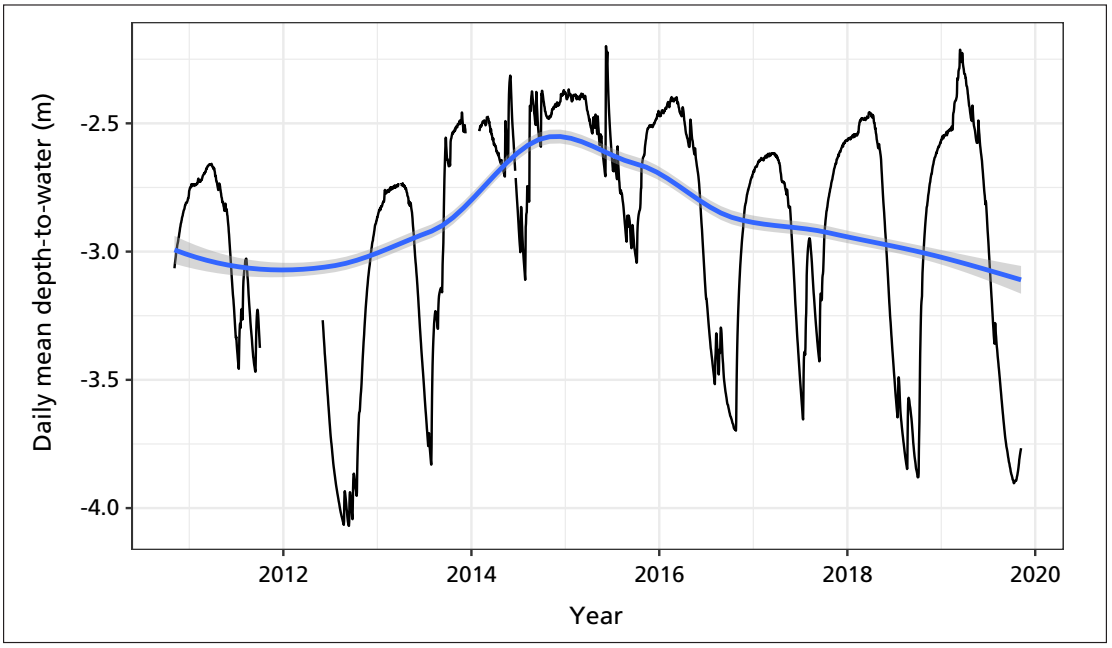


Figure 3-6. Trend in depth-to-water using a LOESS smooth.

drought conditions in 2012, and (2) elevated groundwater depths during the active storm period from fall 2013 to spring 2015, particularly during the growing-season drawdown period. This pattern suggests that monsoon storms may play a key role in keeping groundwater levels closer to the ground surface during the growing season. Depth-to-water has trended downward again since 2016.

3.3 Geomorphology

3.3.1 Cross-section survey

Only reaches 5 and 1 were surveyed multiple times during this monitoring. Both were surveyed for the first time in March 2013. Reach 1 was resurveyed in March 2014, and Reach 5 was resurveyed in March 2015. September 2013–June 2015 was a particularly active period, with many large flood events. The differences between survey visits during this period give us insight on the type and magnitude of geomorphic changes caused by large flood events. Reaches 2, 4, and 7 were each surveyed one time. A general description of the cross-sections of each reach is provided.

3.3.1.1 Upper Courthouse Wash

Reach 2 (Figure 3-7) was surveyed in April 2011. It is characterized by a wide, braided channel bordered by quaternary alluvial terraces with unstable cutbanks. The average width between cutbanks was 210 meters. Channels on both canyon-left and canyon-right in this bottomland had flowing water during the survey event. Although there is no repeat survey data for this reach, crews noted that one vegetation transect needed to be lengthened by 2.7 meters from 2010 to 2011 due to erosion of the cutbank by the channel.

Reach 5 (Figure 3-8) also has a wide, braided channel, with an average width in 2013 of 304 meters between alluvial-terrace cutbanks. Field notes from 2015 indicate the channel had migrated by about 30 meters, and that most vegetation-transect headpins were buried in sediment. Cross-sections showed deposition across much of the braided channel area, with an average of 0.32 meters of deposition between the headpins from March 2013 to March 2015 (Appendix A).

3.3.1.2 Lower Courthouse Wash

At Reach 7 (Figure 3-9), beaver ponds were noted as newly established at transects 1 and 7 during the survey in March 2012. The channel is constrained on both sides by narrow canyon walls, with a narrow, scoured channel adjacent to a canyon wall and usually a gently sloping alluvial surface to the opposite canyon wall.

Reach 1 (Figure 3-10) is similarly constrained by canyon walls. It includes a sharp bend near transects 5 and 6. The reach showed minor to no deposition on alluvial terraces and no migration of the channel location from 2013 to 2014 (Appendix A). Transect 1 is influenced by a side canyon entering the main wash. This transect showed over a meter of scouring in the side-canyon channel, but scouring transitioned to a few centimeters of deposition as the cross-section approached the main channel of Courthouse Wash between March 2013 and March 2014. Transects 2–7 showed some deposition on alluvial surfaces near the channel, transitioning to no change moving further from the channel.

Reach 4 (Figure 3-11) is a bit wider than reaches 7 and 1, with alluvial terraces on alternating sides of the canyon at the upstream and downstream ends. Field notes from vegetation sampling in May 2011 indicated that a beaver dam located approximately 20 meters downstream of Transect 7 had pooled water upstream past Transect 1. Vegetation and geomorphology sampling were postponed because of the beaver-dam pool. When the reach was next visited for vegetation sampling in June 2013, the crew noted that the beaver dam was gone. By the time of the survey visit in February 2014, the crew noted "impressive trenching" from the floods in fall 2013. A spring was emerging where the channel had scoured down to bedrock in one section. Cross-sections from the February 2014 visit indicated a more incised channel than at other monitoring reaches.

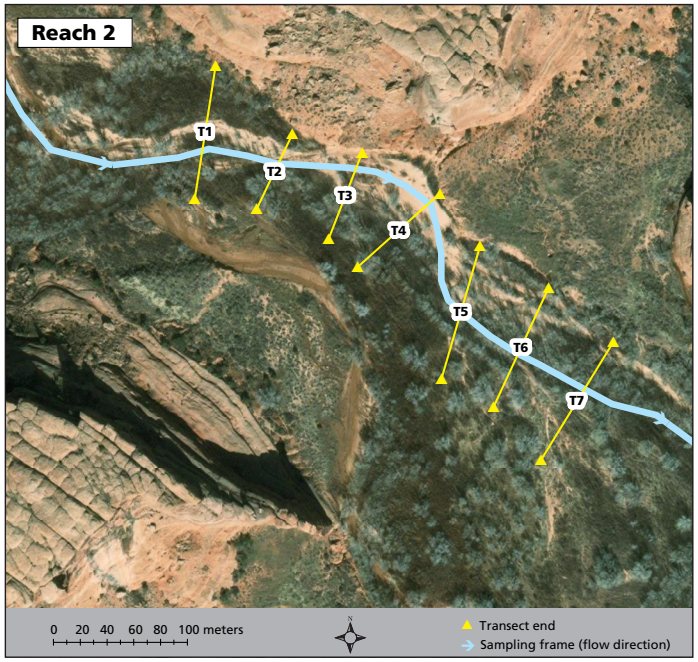




Figure 3-7. *Left,* aerial imagery of monitoring reach 2 in Upper Courthouse Wash, showing the location of monitoring transects and the broad, braided channel. *Right,* representative mid-channel photo taken during vegetation monitoring at Reach 2 (September 2010).

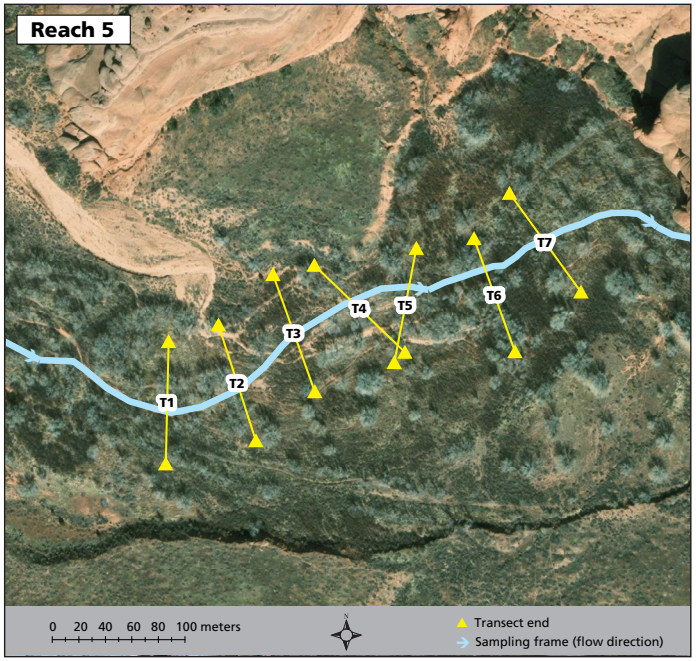




Figure 3-8. *Left,* aerial imagery of monitoring reach 5 in Upper Courthouse Wash, showing the location of monitoring transects and the broad, braided channel. *Right,* representative mid-channel photo taken during vegetation monitoring at Reach 5 (June 2013).

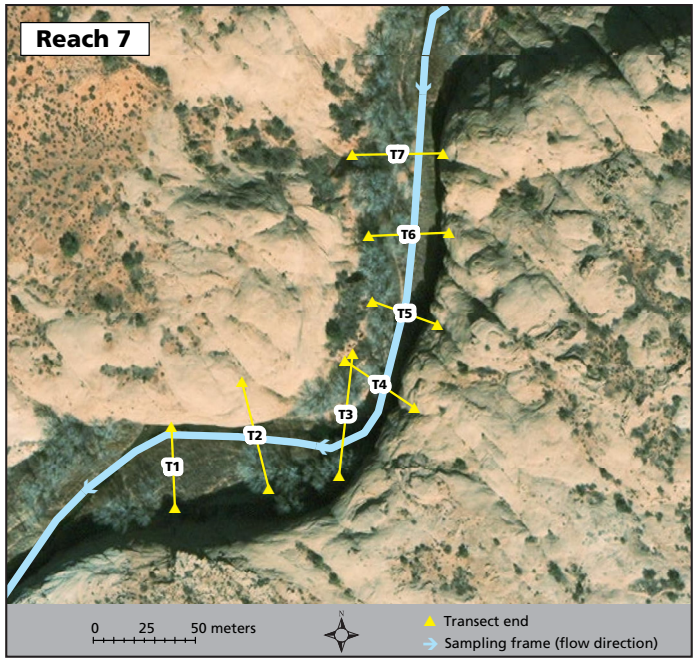




Figure 3-9. *Left,* aerial imagery of monitoring reach 7 in Lower Courthouse Wash, showing the location of monitoring transects and the narrow, bedrock-constrained channel. *Right,* representative mid-channel photo taken during vegetation monitoring at Reach 5 (June 2011).

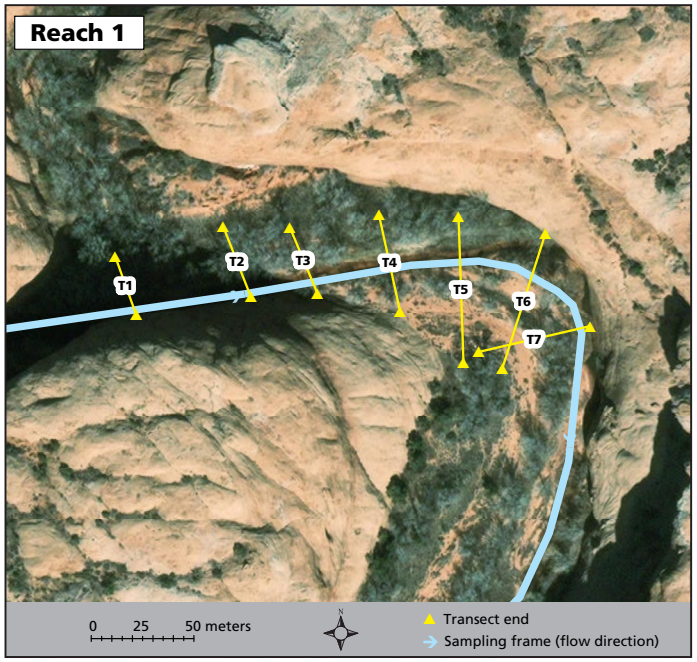




Figure 3-10. *Left,* aerial imagery of monitoring reach 1 in Lower Courthouse Wash, showing the location of monitoring transects and the narrow, bedrock-constrained channel. *Right,* representative mid-channel photo taken during vegetation monitoring at Reach 5 (May 2014).

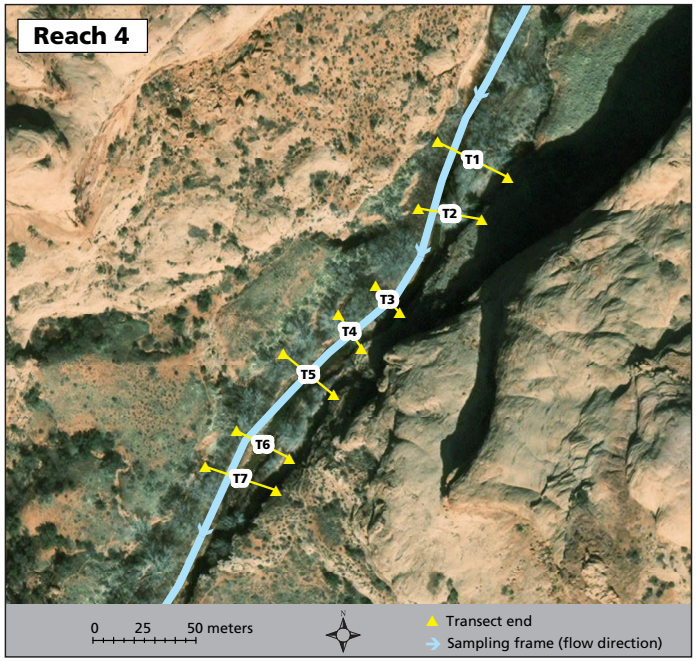




Figure 3-11. *Left,* aerial imagery of monitoring reach 4 in Lower Courthouse Wash, showing the location of monitoring transects and the narrow, bedrock-constrained channel. *Right,* representative mid-channel photo taken during vegetation monitoring at Reach 5 (June 2013).

3.3.2 Profile survey

Overall, the reaches, excluding Reach 5, had a median water slope of 3 m/km (Table 3-6). The median thalweg slope was 4 m/km. Channel slopes were similar at reaches 1 and 5 before and after the September 2013 flood event.

The reaches had a mean sinuosity of 1.29 using the most recent survey data (see Table 3-6). The sinuosity at Reach 5 increased following flood events, from 1.10 in 2013 to 1.17 in 2015. Sinuosity at Reach 1 was similar between repeat visits (1.29 in 2013 versus 1.31 in 2014). Both Reach 5, in Upper Courthouse Wash, and Reach 1, in Lower Courthouse Wash, showed significant deposition in the channel following flood events in 2013 and 2014. The mean thalweg elevation increased 0.41 meters at Reach 5 between 2013 and 2015 (Figure 3-12), and 0.24 meters at Reach 1 between 2013 and 2014 (Figure 3-13).

A knickpoint was present in Reach 5 during both surveys, but its location in 2015 was downstream of the 2013 location. Field notes indicated frequent geomorphic change in the channel at Reach 1, with a pool at Transect 7 present in 2010, absent in March 2014, present in early May 2014, and then absent again five days later, after a flood event. The same

Table 3-6. Summary of stream-channel characteristics at monitoring reaches, Courthouse Wash, Arches National Park.

Parameter	Year	Upper Courthouse		Lower Courthouse		
		Reach 2	Reach 5	Reach 7	Reach 1	Reach 4
Water slope (m/km)	2011	3	–	–	–	–
	2012	–	–	7	–	–
	2013	–	N/A	–	4	–
	2014	–	–	–	2	3
	2015	–	N/A	–	–	–
Thalweg slope (m/km)	2011	3	–	–	–	–
	2012	–	–	6	–	–
	2013	–	5	–	4	–
	2014	–	–	–	3	4
	2015	–	6	–	–	–
Sinuosity	2011	1.44	–	–	–	–
	2012	–	–	1.39	–	–
	2013	–	1.10	–	1.29	–
	2014	–	–	–	1.31	1.13
	2015	–	1.17	–	–	–
Diameter of the 50th percentile streambed particle (mm)[A]	2010	<2	–	–	<2	–
	2011	<2	–	<2	–	–
	2012	–	<2	<2	–	–
	2013	–	<2	–	–	<2
	2014	–	–	–	<2	<2
	2015	–	<2	–	–	–
Diameter of the 84th percentile streambed particle (mm)[A]	2010	<2	–	–	9	–
	2011	<2	–	<2	–	–
	2012	–	<2	<2	–	–
	2013	–	<2	–	–	<2
	2014	–	–	–	<2	>1,000
	2015	–	<2	–	–	–

[A]Data on particle diameter are collected during vegetation monitoring, which does not always happen the same year as the surveys.

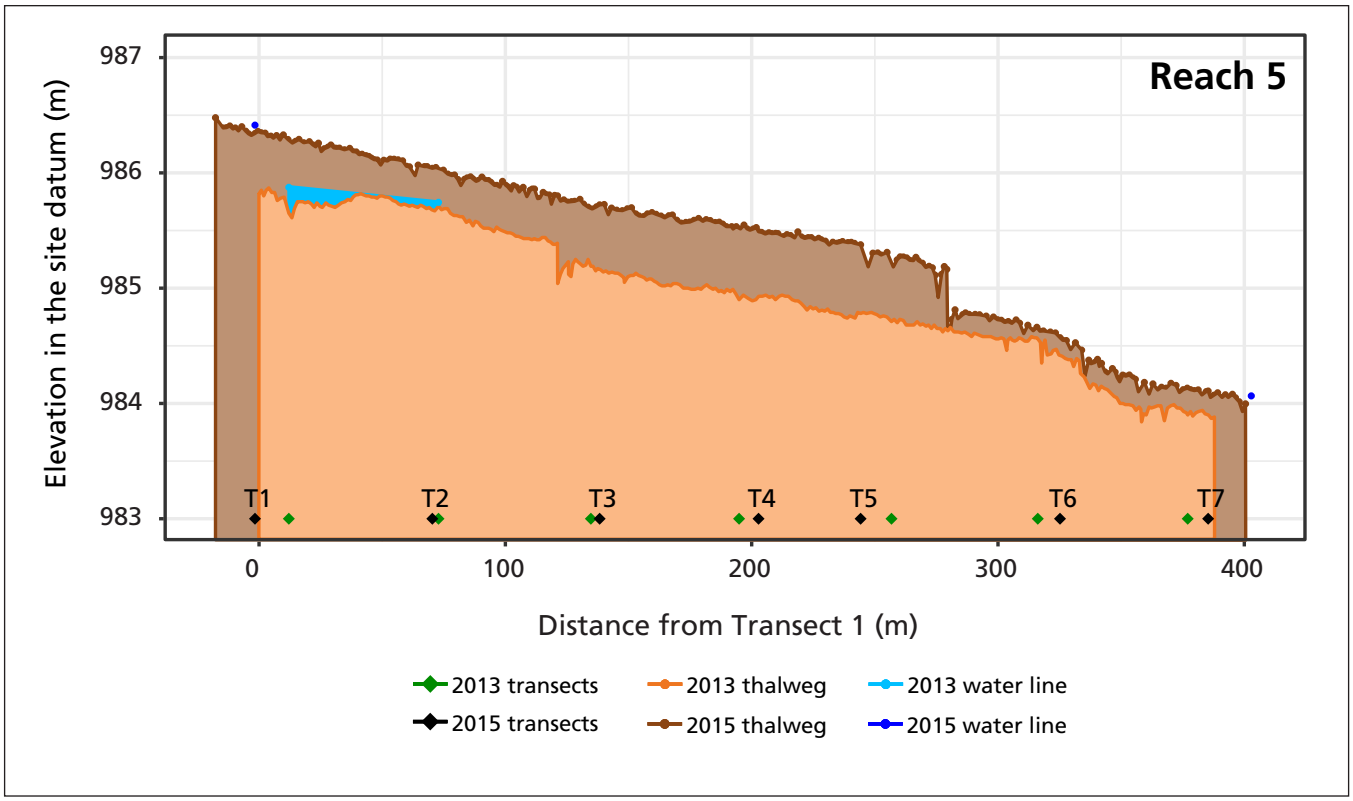


Figure 3-12. Channel thalweg profile at Reach 5, Upper Courthouse Wash, in 2013 and 2015.

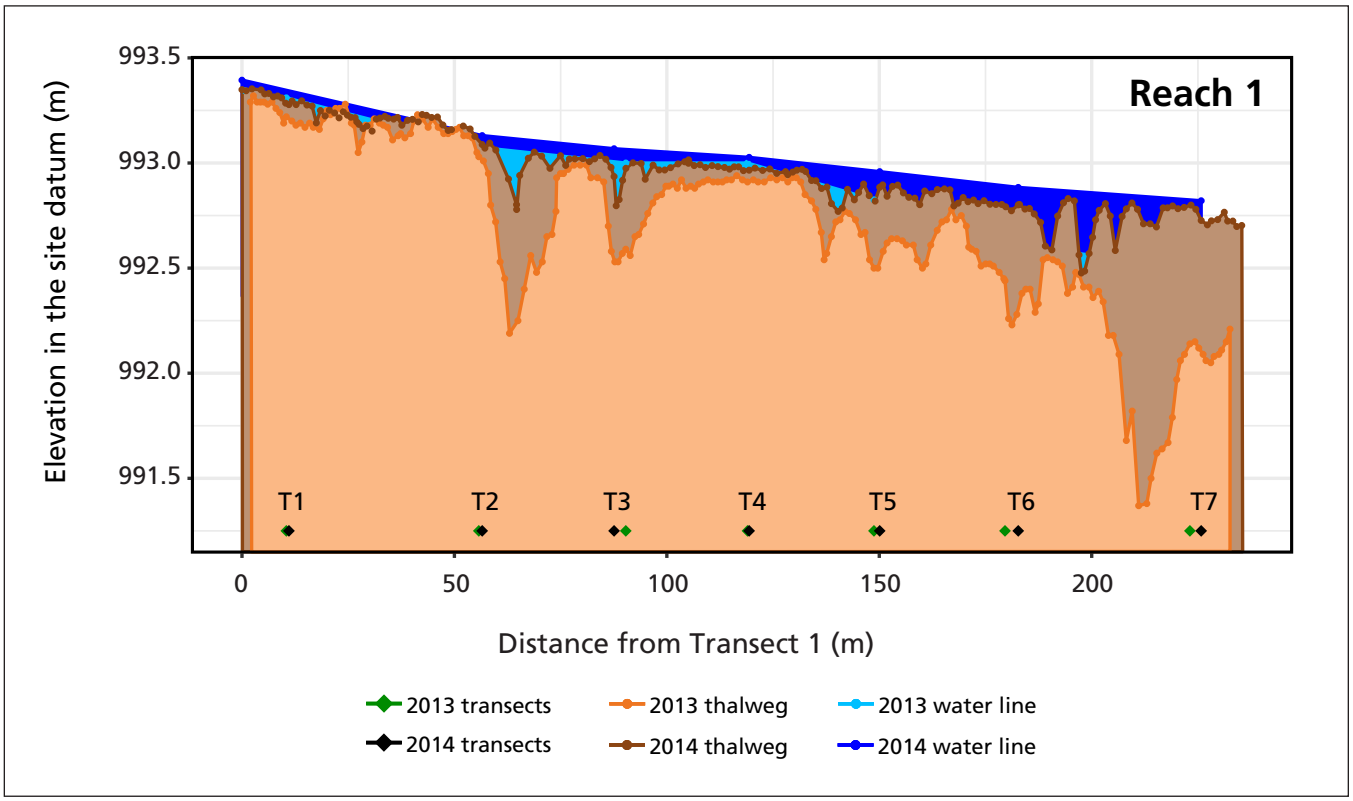


Figure 3-13. Channel thalweg profile at Reach 1, Lower Courthouse Wash, in 2013 and 2014.

storm system deposited 75 centimeters of sand at the instream well in Reach 1.

3.3.3 Pebble count

Courthouse Wash is dominated by sand. All reaches had a d50 of <2 millimeters. Most reaches also had a d84 of <2 millimeters (see Table 3-6). Repeat samples from Reach 1 moved from a d84 of 9 millimeters in 2010 to a d84 of <2 millimeters in 2014, which was consistent with deposition in the channel noted in the 2014 geomorphic surveys. At Reach 4, the d84 moved from <2 millimeters (sand) in 2013 to >1,000 millimeters (bedrock) in 2014. While we do not have full geomorphic surveys for this reach in 2014, this pattern would be consistent with scouring from flood events, and with field notes as noted above.

3.4 Vegetation

3.4.1 Species richness

A total of 92 species were detected at the five reaches monitored in Arches NP from 2010 to 2015. Total species richness ranged from 26 to 47 species per reach. Richness by lifeform was relatively similar among reaches for most lifeforms (Table 3-7). Forb/herb richness was higher in Upper Courthouse Wash reaches than in Lower Courthouse Wash reaches, likely due to the greater area sampled. Reaches 7 and 4 (LCW) tended to have higher wetland species richness (obligate and facultative) and lower upland species richness than UCW reaches (Table 3-8), likely reflecting the limited amount of upland area in Lower Courthouse Wash and the periodic presence of beaver dams in these reaches. Reach 2 (UCW) had a 25% reduction in the total number of species detected from 2011 to 2012 (see Table 3-7). At Reach 5 (UCW), there were half as many forb species detected in 2014 (after the September 2013 floods) than in 2011.

Each year, recorded species are compared to the NPSpecies database to determine first-time observations in Arches NP. Two species new to the park were vouchered during wadeable streams monitoring: ditch polypogon (*Polypogon interruptus*) and an exotic species, yard knotweed (*Polygonum aviculare*).

Although Arches NP has no populations of federally listed threatened or endangered plant species within its borders, at least 32 plants of special conservation concern exist within the park (Fertig 2009). One of these, gumweed aster (*Grindelia fastigiata*), was recorded in four of the monitoring reaches. Another, lemon scurf-pea (*Psoralideum lanceolatum*), was recorded at one monitoring reach.

3.4.2 Overstory canopy closure and vegetation cover

Overstory canopy closure and total percent cover of vegetation were lowest at Reach 1 (LCW) (Tables 3-9 and 3-10). While most reaches had fairly consistent perennial cover over time, Reach 5 (UCW) had variable canopy closure, tree cover, and total cover, with lower values in 2013 that corresponded to a beetle infestation and cottonwood defoliation event noted in June of that year. Values at Reach 5 rebounded by 2015. An apparent increase in shrub and total cover at Reach 2 (UCW) from 2010 to 2011 was likely due to a change in sampling methods (shrub cover above 1.5 m height was not sampled in 2010). This change corresponded to a 10% reported increase in coyote willow.

Overall, total exotic cover was relatively high compared to total native cover. Total exotic cover ranged from 2% to 30%, while total native cover ranged from 17% to 43% (Table 3-11). Changes in exotic cover over time were generally related to exotic annual grasses, particularly cheatgrass (*Bromus tectorum*) and Japanese chess (*Bromus japonicus*). Reaches in Upper Courthouse Wash tended to have higher total exotic cover than in Lower Courthouse Wash, likely because of the greater xeric area sampled. Reach 1 (LCW) had the lowest exotic and native cover. Total native cover was higher at reaches 7 and 4 (LCW) than in the UCW reaches.

Patterns in native cover were also found in wetland species (obligate and facultative; Table 3-12). Wetland species cover was higher at reaches 7 and 4 (LCW), both of which periodically had beaver dams present. An apparent increase in obligate cover at Reach 2 (UCW) from 2010 to 2011 was likely an

Table 3-7. Number of plant species detected per reach by lifeform, Courthouse Wash, Arches National Park.

Parameter	Year	Upper Courthouse		Lower Courthouse		
		Reach 2	Reach 5	Reach 7	Reach 1	Reach 4
Total	2011	38	–	31	–	–
	2012	–	39	26	–	–
	2013	–	40	–	–	32
	2014	–	–	–	34	33
	2015	–	47	–	–	–
Tree	2011	4	–	4	–	–
	2012	–	3	2	–	–
	2013	–	4	–	–	4
	2014	–	–	–	1	3
	2015	–	3	–	–	–
Shrub	2011	3	–	6	–	–
	2012	–	5	6	–	–
	2013	–	5	–	–	9
	2014	–	–	–	5	8
	2015	–	4	–	–	–
Perennial grass	2011	7	–	7	–	–
	2012	–	9	6	–	–
	2013	–	9	–	–	8
	2014	–	–	–	10	7
	2015	–	9	–	–	–
Annual grass	2011	3	–	3	–	–
	2012	–	3	1	–	–
	2013	–	3	–	–	3
	2014	–	–	–	4	3
	2015	–	5	–	–	–
Forb/Herb	2011	20	–	9	–	–
	2012	–	18	8	–	–
	2013	–	19	–	–	6
	2014	–	–	–	13	9
	2015	–	26	–	–	–
Fern	2011	0	–	1	–	–
	2012	–	1	2	–	–
	2013	–	0	–	–	1
	2014	–	–	–	1	2
	2015	–	0	–	–	–
Vine	2011	1	–	1	–	–
	2012	–	0	1	–	–
	2013	–	0	–	–	1
	2014	–	–	–	0	1
	2015	–	0	–	–	–

Table 3-8. Number of plant species detected per reach by wetland status, Courthouse Wash, Arches National Park.

Parameter	Year	Upper Courthouse		Lower Courthouse		
		Reach 2	Reach 5	Reach 7	Reach 1	Reach 4
Obligate wetland	2011	5	–	3	–	–
	2012	–	2	3	–	–
	2013	–	2	–	–	4
	2014	–	–	–	3	3
	2015	–	3	–	–	–
Facultative wetland	2011	5	–	8	–	–
	2012	–	4	8	–	–
	2013	–	4	–	–	10
	2014	–	–	–	6	8
	2015	–	6	–	–	–
Facultative	2011	7	–	5	–	–
	2012	–	8	5	–	–
	2013	–	8	–	–	3
	2014	–	–	–	4	3
	2015	–	9	–	–	–
Facultative upland	2011	8	–	7	–	–
	2012	–	10	5	–	–
	2013	–	10	–	–	8
	2014	–	–	–	8	10
	2015	–	13	–	–	–
Upland	2011	13	–	8	–	–
	2012	–	15	5	–	–
	2013	–	16	–	–	7
	2014	–	–	–	13	9
	2015	–	16	–	–	–

Table 3-9. Percent overstory canopy closure, Courthouse Wash, Arches National Park.

Parameter	Year	Upper Courthouse		Lower Courthouse		
		Reach 2	Reach 5	Reach 7	Reach 1	Reach 4
Overstory canopy closure	2010	46.5	–	–	33.0	–
	2011	46.9	–	46.1	–	–
	2012	–	40.3	50.2	–	–
	2013	–	29.1	–	–	51.8
	2014	–	–	–	31.7	44.8
	2015	–	35.3	–	–	–

Table 3-10. Live and (total) percent cover of vegetation by life form, Courthouse Wash, Arches National Park.

Parameter	Year	Upper Courthouse		Lower Courthouse		
		Reach 2	Reach 5	Reach 7	Reach 1	Reach 4
Tree	2010	4.7 (5.9)	–	–	1.2 (1.7)	–
	2011	2.1 (3.0)	–	2.8 (3.3)	–	–
	2012	–	2.3 (4.2)	1.2 (1.6)	–	–
	2013	–	0.6 (1.5)	–	–	3.9 (6.0)
	2014	–	–	–	1.2 (2.1)	2.1 (3.0)
	2015	–	1.7 (2.7)	–	–	–
Shrub	2010[A]	9.8 (13.1)	–	–	4.0 (5.6)	–
	2011	20.2 (22.4)	–	16.3 (19.7)	–	–
	2012	–	13.7 (18.3)	16.1 (18.5)	–	–
	2013	–	11.2 (18.3)	–	–	11.8 (13.0)
	2014	–	–	–	3.5 (4.7)	14.8 (18.1)
	2015	–	16.0 (20.9)	–	–	–
Perennial grass	2010	1.7 (2.1)	–	–	6.1 (9.6)	–
	2011	1.0 (1.2)	–	10.8 (17.9)	–	–
	2012	–	4.5 (6.5)	10.8 (15.7)	–	–
	2013	–	2.4 (4.8)	–	–	6.0 (13.7)
	2014	–	–	–	4.5 (7.3)	6.5 (11.3)
	2015	–	8.3 (9.0)	–	–	–
Annual grass	2010	0.7 (0.8)	–	–	0.2 (0.9)	–
	2011	1.2 (1.4)	–	0 (1.4)	–	–
	2012	–	0.6 (11.3)	0.2 (0.4)	–	–
	2013	–	0.1 (26.9)	–	–	1.4 (2.5)
	2014	–	–	–	1.4 (1.9)	5.3 (8.8)
	2015	–	18.0 (20.0)	–	–	–
Forb/Herb	2010	7.6 (8.8)	–	–	7.7 (9.9)	–
	2011	12.2 (12.6)	–	8.7 (9.6)	–	–
	2012	–	6.8 (13.2)	7.3 (9.1)	–	–
	2013	–	5.5 (7.4)	–	–	6.5 (8.8)
	2014	–	–	–	2.3 (3.8)	4.9 (6.2)
	2015	–	11.3 (12.5)	–	–	–
Fern	2010	0 (0)	–	–	0.7 (0.9)	–
	2011	0 (0)	–	1.6 (2.0)	–	–
	2012	–	0.1 (0.1)	1.8 (2.0)	–	–
	2013	–	0 (0)	–	–	3.7 (7.6)
	2014	–	–	–	0 (0.2)	3.2 (4.6)
	2015	–	0 (0)	–	–	–
Vine	2010	0.2 (0.2)	–	–	0 (0)	–
	2011	0.1 (0.1)	–	2.0 (2.2)	–	–
	2012	–	0 (0)	2.2 (2.2)	–	–
	2013	–	0 (0)	–	–	6.2 (6.7)
	2014	–	–	–	0 (0)	5.3 (6.0)
	2015	–	0 (0)	–	–	–
Total	2010	22.6 (27.7)	–	–	18.6 (25.9)	–
	2011	32.4 (35.1)	–	36.2 (46.3)	–	–
	2012	–	25.6 (42.4)	34.1 (41.1)	–	–
	2013	–	18.2 (45.3)	–	–	33.8 (46.8)
	2014	–	–	–	12.2 (18.8)	33.1 (45.1)
	2015	–	44.6 (48.7)	–	–	–

[A]In 2010, shrub cover was not recorded above 1.5 m in height. These data may not be comparable to those from other years.

Table 3-11. Live and (total) percent cover of native and exotic vegetation, Courthouse Wash, Arches National Park.

Parameter	Year	Upper Courthouse		Lower Courthouse		
		Reach 2	Reach 5	Reach 7	Reach 1	Reach 4
Exotic perennial grass	2010	0 (0)	–	–	0 (0)	–
	2011	0 (0)	–	0.4 (0.4)	–	–
	2012	–	0 (0)	0.2 (0.2)	–	–
	2013	–	0 (0)	–	–	0.5 (0.9)
	2014	–	–	–	0.2 (0.2)	0.9 (0.9)
	2015	–	0.1 (0.1)	–	–	–
Exotic annual grass	2010	0.7 (0.8)	–	–	0.2 (0.9)	–
	2011	1.2 (1.4)	–	0 (1.4)	–	–
	2012	–	0.6 (11.3)	0.2 (0.4)	–	–
	2013	–	0.1 (26.9)	–	–	1.4 (2.5)
	2014	–	–	–	1.2 (1.7)	5.3 (8.6)
	2015	–	18.0 (20.0)	–	–	–
Exotic forb	2010	4.9 (5.4)	–	–	0.7 (1.6)	–
	2011	10.5 (10.5)	–	4.9 (5.3)	–	–
	2012	–	0.7 (5.6)	3.9 (4.1)	–	–
	2013	–	0.6 (0.9)	–	–	1.4 (1.4)
	2014	–	–	–	0.2 (0.5)	2.5 (2.5)
	2015	–	5.4 (5.4)	–	–	–
All exotic	2010	7.0 (9.5)	–	–	1.0 (2.6)	–
	2011	13.1 (14.1)	–	5.3 (7.1)	–	–
	2012	–	3.5 (19.4)	4.3 (4.7)	–	–
	2013	–	2.7 (30.3)	–	–	3.9 (7.6)
	2014	–	–	–	1.6 (2.4)	8.1 (12.7)
	2015	–	25.1 (27.4)	–	–	–
All native	2010	16.8 (20.4)	–	–	17.6 (23.5)	–
	2011	22.0 (23.9)	–	33.3 (42.9)	–	–
	2012	–	23.0 (28.9)	31.1 (37.6)	–	–
	2013	–	15.9 (24.6)	–	–	31.0 (41.4)
	2014	–	–	–	10.8 (16.7)	27.5 (36.1)
	2015	–	26.6 (31.7)	–	–	–

Table 3-12. Live and (total) percent cover of vegetation by wetland status, Courthouse Wash, Arches National Park.

Parameter	Year	Upper Courthouse		Lower Courthouse		
		Reach 2	Reach 5	Reach 7	Reach 1	Reach 4
Obligate wetland	2010[A]	7.5 (8.8)	–	–	1.4 (3.0)	–
	2011	17.6 (18.6)	–	13.0 (13.8)	–	–
	2012	–	8.1 (9.8)	11.2 (12.4)	–	–
	2013	–	6.0 (9.2)	–	–	12.7 (14.8)
	2014	–	–	–	1.6 (1.7)	12.5 (13.4)
	2015	–	12.8 (15.3)	–	–	–
Facultative wetland	2010*	5.2 (8.3)	–	–	5.9 (7.8)	–
	2011	2.1 (4.4)	–	15.4 (23.6)	–	–
	2012	–	3.4 (5.9)	16.3 (21.3)	–	–
	2013	–	3.4 (6.2)	–	–	13.7 (23.1)
	2014	–	–	–	3.1 (5.4)	11.3 (17.1)
	2015	–	5.9 (7.3)	–	–	–
Facultative	2010*	4.0 (4.7)	–	–	2.4 (3.0)	–
	2011	3.9 (4.1)	–	3.5 (5.1)	–	–
	2012	–	7.8 (9.7)	4.1 (5.7)	–	–
	2013	–	4.3 (6.8)	–	–	1.2 (3.0)
	2014	–	–	–	0.5 (0.9)	1.2 (1.9)
	2015	–	2.4 (4.5)	–	–	–
Facultative upland	2010*	5.5 (6.1)	–	–	4.0 (5.6)	–
	2011	11.0 (11.2)	–	9.1 (10.0)	–	–
	2012	–	5.0 (11.2)	7.3 (7.5)	–	–
	2013	–	3.5 (4.9)	–	–	9.3 (10.6)
	2014	–	–	–	2.1 (2.8)	9.3 (10.9)
	2015	–	13.2 (14.0)	–	–	–
Upland	2010*	2.4 (3.0)	–	–	5.9 (9.6)	–
	2011	2.3 (2.8)	–	1.2 (3.3)	–	–
	2012	–	3.9 (15.8)	0.8 (1.6)	–	–
	2013	–	2.7 (29.8)	–	–	2.3 (3.9)
	2014	–	–	–	5.2 (8.5)	6.7 (10.9)
	2015	–	19.6 (22.0)	–	–	–

[A]In 2010, shrub cover was not recorded above 1.5 meters. These data may not be comparable to those from other years.

artifact of the increased reporting of coyote willow due to a change in sampling methodology noted above.

3.4.3 Exotic species

A total of 25 exotic plant species were detected at the five reaches monitored in Arches NP from 2010 to 2015. Cheatgrass and sweetclover (*Melilotus* species, including *M. alba* and *M. officinalis*) were the most frequently detected exotic species (31–95% and 14–68%, respectively, of quadrats sampled along each transect at a reach). The exotic tree, Russian-olive (*Elaeagnus angustifolia*), was noted at three reaches, though over time it decreased in cover at reaches 5 (UCW) and 4 (LCW). Field crews noted slash piles of Russian-olive at Reach 4 in June 2013. Tamarisk (*Tamarix* sp.) was the only exotic shrub species detected, with about 5% cover in reaches 2 and 5 (UCW). Tamarisk was absent from reaches in Lower Courthouse Wash. Ripgut brome (*Bromus diandrus*) was newly noted in both LCW reaches visited in 2014. Data on the frequency of each species at each reach are available in Appendix B (Table B1). Lists of all exotic species detected at each monitoring visit, and descriptions of the number of plants, size of invasions, and approximate locations, are available on request.

3.4.4 Tree density and basal area

Seedling density varied by species and changed dramatically between some years (Table 3-13). Russian-olive seedlings were noted at all reaches except Reach 1, but few to no saplings were noted (Table 3-14), suggesting seedling survival may be poor. Cottonwood seedlings were common at all reaches, although numbers may be inflated due to the difficulty of distinguishing between cottonwood and willow seedlings. The presence of cottonwood saplings at all reaches indicates that successful cottonwood recruitment is ongoing throughout the monitoring reaches. Boxelder (*Acer negundo*) was not noted as an overstory species in any monitoring reach, but several seedlings were noted in Reach 4 in 2014, after scouring floods breached a beaver dam at this reach.

Russian-olive sapling density decreased to zero at Reach 5 (Table 3-14). At the same reach, sapling density of Fremont cottonwood decreased from the mid 500s in 2012 and 2013 to 216 in 2015. A cycle of floods starting in fall 2013 may have removed some cottonwood saplings from Reach 5, although similar drops were not noted at reaches 1 and 4, which were sampled in May 2014. Reach 5 also showed an increase in cottonwood trees of >15.0 cm dbh, so some of the saplings recorded in 2013 may have moved into the next size class by 2015.

Overstory trees consisted only of Fremont cottonwood. Overstory tree density (Table 3-15) and basal area (Table 3-16) were similar between visits to each reach. Reach 4 had the highest basal area of trees, despite having a similar density of trees as other reaches.

3.4.5 Reach census

Overstory tree census data at each reach were nearly identical between visits. Therefore, only the most recent year of data is presented (Figure 3-14). Overstory trees at all reaches were all Fremont cottonwoods. Reaches 2 and 5 (UCW) had more trees than monitoring reaches in Lower Courthouse Wash, probably due to the larger extent of the channel and floodplain area. There were few trees of >50.0 centimeters dbh at any monitoring reach, and only a few individuals >75.0 centimeters dbh at Reach 4.

3.4.6 Surface features

Fines and litter were the dominant surface cover at all reaches (Appendix B, Table B2). There was very little change in cover of surface features between monitoring visits, other than a decrease in litter and an increase in fines at reaches 5, 7, and 4 after the flood events of 2013 and 2014.

Table 3-13. Density (trees/ha) of live seedlings (<2.5 cm dbh) by species, Courthouse Wash, Arches National Park.

Scientific name	Common name	Year	Upper Courthouse		Lower Courthouse		
			Reach 2	Reach 5	Reach 7	Reach 1	Reach 4
Acer negundo	boxelder	2010	0	–	–	0	–
Acer negundo	boxelder	2011	0	–	0	–	–
Acer negundo	boxelder	2012	–	0	0	–	–
Acer negundo	boxelder	2013	–	0	–	–	0
Acer negundo	boxelder	2014	–	–	–	0	18
Acer negundo	boxelder	2015	–	0	–	–	–
Elaeagnus angustifolia	Russian-olive	2010	0	–	–	0	–
Elaeagnus angustifolia	Russian-olive	2011	493	–	8	–	–
Elaeagnus angustifolia	Russian-olive	2012	–	279	41	–	–
Elaeagnus angustifolia	Russian-olive	2013	–	109	–	–	147
Elaeagnus angustifolia	Russian-olive	2014	–	–	–	0	18
Elaeagnus angustifolia	Russian-olive	2015	–	46	–	–	–
Juniperus spp.	juniper species	2010	3	–	–	0	–
Juniperus spp.	juniper species	2011	10	–	16	–	–
Juniperus spp.	juniper species	2012	–	9	0	–	–
Juniperus spp.	juniper species	2013	–	12	–	–	46
Juniperus spp.	juniper species	2014	–	–	–	7	46
Juniperus spp.	juniper species	2015	–	6	–	–	–
Pinus edulis	two-needle pinyon	2010	0	–	–	0	–
Pinus edulis	two-needle pinyon	2011	23	–	0	–	–
Pinus edulis	two-needle pinyon	2012	–	0	0	–	–
Pinus edulis	two-needle pinyon	2013	–	0	–	–	0
Pinus edulis	two-needle pinyon	2014	–	–	–	0	0
Pinus edulis	two-needle pinyon	2015	–	0	–	–	–
Populus fremontii	Fremont cottonwood	2010	6,014	–	–	1,351	–
Populus fremontii	Fremont cottonwood	2011	5,836	–	2,900	–	–
Populus fremontii	Fremont cottonwood	2012	–	276	20,138	–	–
Populus fremontii	Fremont cottonwood	2013	–	178	–	–	35,264
Populus fremontii	Fremont cottonwood	2014	–	–	–	18,356	4,589
Populus fremontii	Fremont cottonwood	2015	–	22,096	–	–	–
Salix gooddingii	Goodding's black willow	2010	0	–	–	0	–
Salix gooddingii	Goodding's black willow	2011	0	–	8	–	–
Salix gooddingii	Goodding's black willow	2012	–	0	0	–	–
Salix gooddingii	Goodding's black willow	2013	–	0	–	–	0
Salix gooddingii	Goodding's black willow	2014	–	–	–	0	0
Salix gooddingii	Goodding's black willow	2015	–	0	–	–	–

Table 3-14. Density (trees/ha) of live saplings (2.5–15.0 cm dbh) by species, Courthouse Wash, Arches National Park.

Scientific name	Common name	Year	Upper Courthouse		Lower Courthouse		
			Reach 2	Reach 5	Reach 7	Reach 1	Reach 4
Elaeagnus angustifolia	Russian-olive	2010	0	–	–	0	–
Elaeagnus angustifolia	Russian-olive	2011	0	–	0	–	–
Elaeagnus angustifolia	Russian-olive	2012	–	6	0	–	–
Elaeagnus angustifolia	Russian-olive	2013	–	0	–	–	0
Elaeagnus angustifolia	Russian-olive	2014	–	–	–	0	0
Elaeagnus angustifolia	Russian-olive	2015	–	0	–	–	–
Juniperus spp.	juniper species	2010	0	–	–	0	–
Juniperus spp.	juniper species	2011	7	–	0	–	–
Juniperus spp.	juniper species	2012	–	9	0	–	–
Juniperus spp.	juniper species	2013	–	9	–	–	0
Juniperus spp.	juniper species	2014	–	–	–	0	0
Juniperus spp.	juniper species	2015	–	14	–	–	–
Populus fremontii	Fremont cottonwood	2010	429	–	–	423	–
Populus fremontii	Fremont cottonwood	2011	411	–	381	–	–
Populus fremontii	Fremont cottonwood	2012	–	541	308	–	–
Populus fremontii	Fremont cottonwood	2013	–	587	–	–	83
Populus fremontii	Fremont cottonwood	2014	–	–	–	395	119
Populus fremontii	Fremont cottonwood	2015	–	216	–	–	–

Table 3-15. Density (trees/ha) of live overstory trees (>15.0 cm dbh) by species, Courthouse Wash, Arches National Park.

Scientific name	Common name	Year	Upper Courthouse		Lower Courthouse		
			Reach 2	Reach 5	Reach 7	Reach 1	Reach 4
Populus fremontii	Fremont cottonwood	2010	109	–	–	132	–
Populus fremontii	Fremont cottonwood	2011	141	–	178	–	–
Populus fremontii	Fremont cottonwood	2012	–	98	170	–	–
Populus fremontii	Fremont cottonwood	2013	–	115	–	–	110
Populus fremontii	Fremont cottonwood	2014	–	–	–	125	128
Populus fremontii	Fremont cottonwood	2015	–	130	–	–	–

Table 3-16. Basal area (m^2/ha) of live trees by species, Courthouse Wash, Arches National Park.

Scientific name	Common name	Year	Upper Courthouse		Lower Courthouse		
			Reach 2	Reach 5	Reach 7	Reach 1	Reach 4
Populus fremontii	Fremont cottonwood	2010	6.0	–	–	7.1	–
Populus fremontii	Fremont cottonwood	2011	7.7	–	9.6	–	–
Populus fremontii	Fremont cottonwood	2012	–	7.8	9.5	–	–
Populus fremontii	Fremont cottonwood	2013	–	8.5	–	–	21.5
Populus fremontii	Fremont cottonwood	2014	–	–	–	7.7	26.0
Populus fremontii	Fremont cottonwood	2015	–	8.3	–	–	–

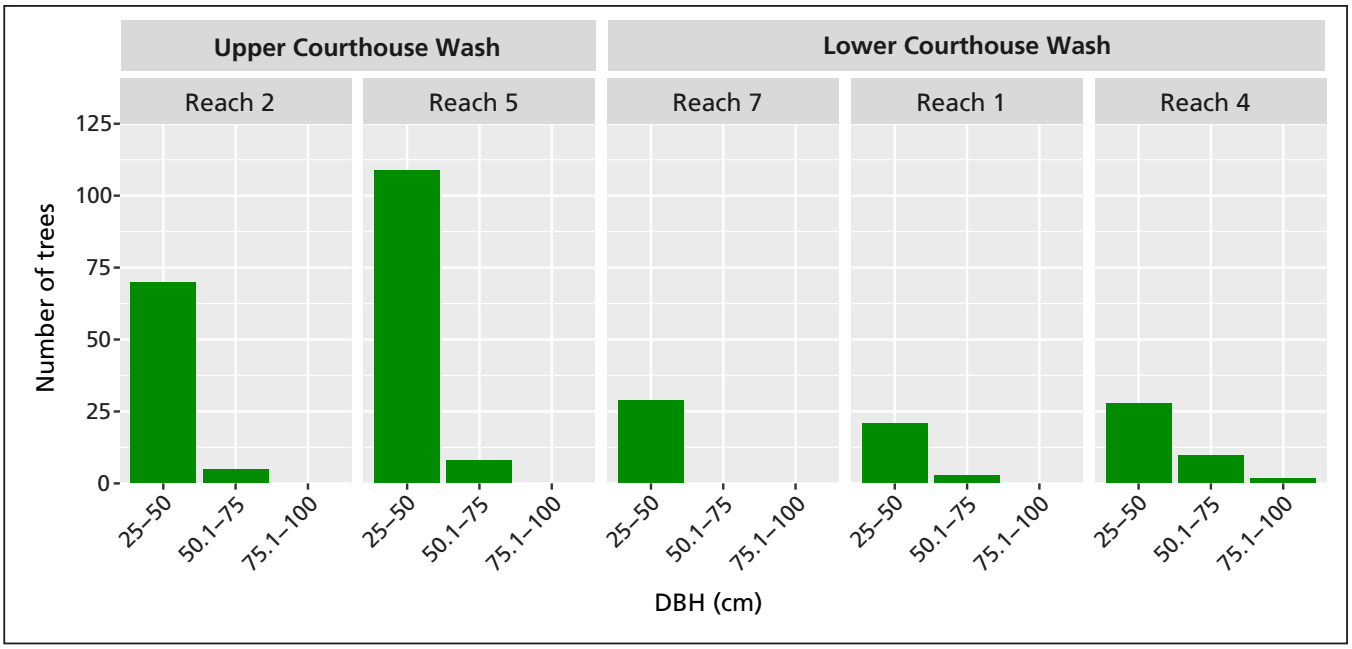


Figure 3-14. Number of live *Populus fremontii* trees by size class with ≥25 cm diameter at each reach, Courthouse Wash, Arches National Park. Data from the most recent visit are presented (2015 for Reach 5, 2014 for reaches 1 and 4, 2012 for Reach 7, and 2011 for Reach 2).

4 Discussion

NCPN monitoring data provide a snapshot of vegetation and geomorphology conditions in Courthouse Wash from 2010 to 2015. Courthouse Wash is a dynamic, heterogenous system with a diverse riparian flora that continues to show good recruitment of the primary overstory species, Fremont cottonwood. A groundwater-protection zone and limited development in contributing aquifers protects groundwater inputs into the system. Natural barriers, park fencing, and a lack of perennial flow help isolate the system within the park from upstream land uses. Recreational uses have had a light footprint. The Courthouse Wash system is dominated by natural processes rather than human effects. Presuming these protections can be maintained, the primary stressors on the system are likely to be climate change and exotic plant invasions.

4.1 Hydrology

Hydrologic data were limited to one reach in Lower Courthouse Wash, due primarily to the logistical difficulty of installing wells in backcountry locations and instrumenting systems with high flood velocities and dynamic sand channels. Ancient groundwater in the confined Entrada and Navajo aquifers creates some stability in bedrock groundwater inputs to the system, while the unconfined Moab Tongue aquifer is likely more closely tied to recent climate (Masbruch et al. 2010). The valley-fill aquifer is also recharged by surface-flow events. NCPN hydrologic data represent a reach in the valley-fill aquifer with contributions from the confined Navajo aquifer. Eight years of data is not sufficient to understand long-term trends in groundwater, but interesting patterns are beginning to emerge.

Data from the instream and groundwater wells track closely, with an elevated base level in the winter and spring. Terrace groundwater levels are higher than instream levels in the reach from roughly December through June. A steep decline in groundwater levels coincides with the beginning of the growing season. This decline continues through the growing season unless flood events recharge the alluvial aquifer. As air temperatures increase, demand from evapotranspiration deepens groundwater levels, with the deepest troughs noted in hotter and drier years, such as 2012, 2018, and 2019 (see Figure 3-1). A similarly strong evapotranspiration signal was noted for the surface flow of springs emerging from the Moab Tongue in Upper Courthouse Wash during an overlapping period (Weissinger et al. 2016). As the growing season lengthens and air temperatures increase due to climate change, it is likely that increased evapotranspiration will result in a lower water table and increasing drought stress during summer and fall.

The exception to these hot, dry years are active monsoon years, when flash floods can recharge the valley-fill aquifer. Large flood events from fall 2013 to spring 2015 helped elevate summer and fall groundwater levels relative to drier years. These floods can reach from canyon wall to canyon wall in the constrained bedrock section of Lower Courthouse Wash (Figure 4-1). Channel aggradation from the September 2013 flood and again in May 2014 diminished the dif-

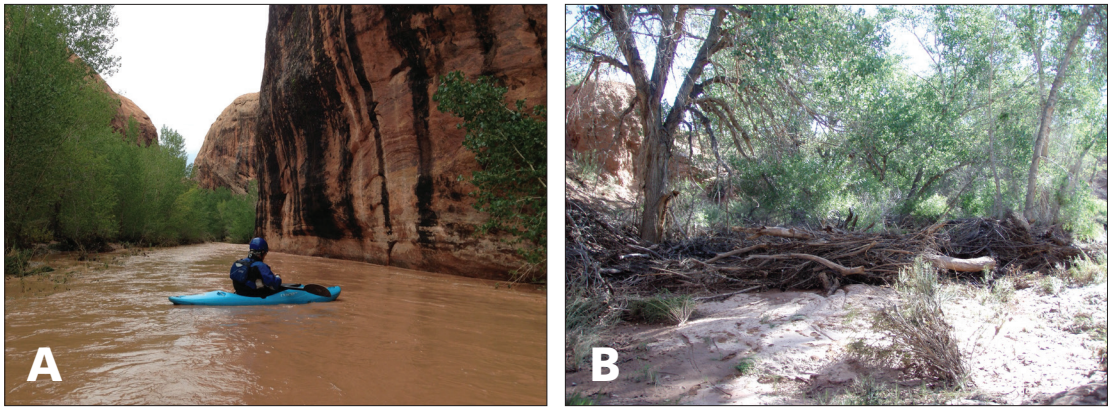


Figure 4-1. Examples of wall-to-wall flooding (A) and off-channel flood debris (B) from flooding in Lower Courthouse Wash in 2013 and 2014.

ference in elevation between the riparian terrace and the channel, which can reduce groundwater loss to the channel. The establishment of a beaver dam just upstream of Reach 1, noted in January 2015 and completed by March 2015, may also have helped maintain a higher water table during this period, although the dam had washed away by September 2015. Monsoon precipitation is unpredictable, but climate-change models suggest a weakening of the monsoon is likely (Pascale et al. 2017). Monsoon recharge may be less common in the future.

4.2 Geomorphology

Survey data and field notes indicate that both erosion and deposition are active processes in the Courthouse Wash system. These dynamics are characteristic of sand-dominated watersheds in arid systems (Jaeger et al. 2017). Similar to systems throughout the arid southwest (Webb et al. 2007), Upper Courthouse Wash has previously gone through a significant erosion cycle, as evidenced by the incision of the current braided channel several meters below the adjacent alluvial terraces. Monitoring reaches in both Upper and Lower Courthouse Wash with survey data before and after an active storm period from fall 2013 to 2014 showed aggradation in the channel.

In Lower Courthouse Wash, the narrow confines of the canyon allow beavers to build dams, creating pools that can provide persistent surface water and raise groundwater levels both upstream and downstream of the dam. Beaver dams can also slow flood waters, which helps retain sediment. However, the magnitude of flash floods in the Courthouse Wash also frequently breaches beaver dams. Failure of beaver dams could lead to channel incisions that can continue to be cut upstream. Channel incision is a concern because it can cause groundwater levels to drop on adjacent surfaces, leaving the water less accessible for many riparian plant species. An example of this can be found upstream of monitoring Reach 1 (Figure 4-2), but the long-term consequences of such a breach are yet to be determined.

Beaver populations were extirpated or reduced in the region in the 1800s, and their population continues to recover (Naiman et al. 1988b). Anecdotally, beaver activity in Courthouse Wash increased in the 2000s, with beaver colonizing the system from the Colorado River and continuing to move upstream in Courthouse Wash to the northwestern park boundary and small, spring-fed tributary alcoves. There was beaver activity in or near all of the monitoring reaches in Lower Courthouse Wash during our

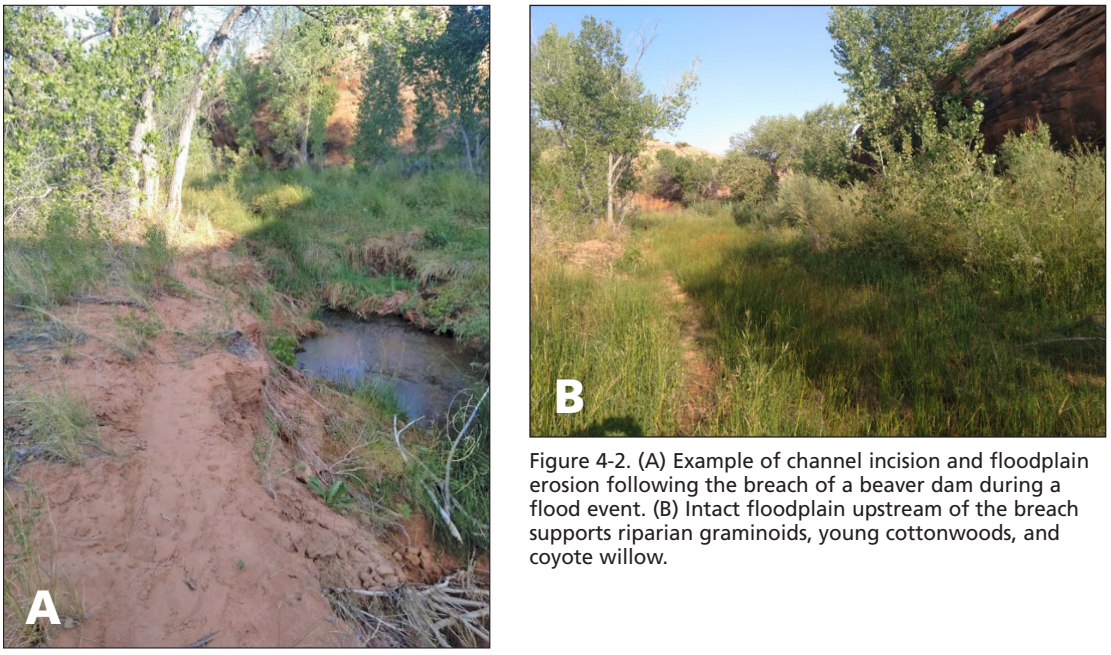


Figure 4-2. (A) Example of channel incision and floodplain erosion following the breach of a beaver dam during a flood event. (B) Intact floodplain upstream of the breach supports riparian graminoids, young cottonwoods, and coyote willow.

period of record. Some of the beaver dams noted while hiking to and from monitoring reaches have had stable locations over time, but the dams near our monitoring reaches have all breached at least once.

Local effects of beaver activity can be significant. Beavers can quickly fell large numbers of cottonwood and willow, while woody regrowth is episodic and slow. Dam breaches can also create channel-incision events and knickpoints with the potential to continue to erode upstream, into previously unaffected riparian habitat. Within a mosaic of riparian habitat, however, beaver activity can be highly beneficial. Beaver dams create pools that can provide persistent surface water and raise groundwater levels both upstream and downstream of the dam. Beaver dams can also slow low-magnitude flood waters. This helps retain sediment, and can help aggrade channels and fill arroyos (Webb et al. 2007). Beavers are likely to help maintain ecosystem resilience in Courthouse Wash in the face of climate change by maintaining pockets of surface water and high groundwater tables during droughts.

At a smaller scale, human effects can create unnatural erosion events. Field crews have noted gullying along social trails in Upper Courthouse Wash that funnel rain during intense storm events. This gullying can lead to incision, and can endanger cultural resources on the quaternary alluvial terraces next to the wash. Encouraging visitors to hike in the wash, rather than on adjacent surfaces, could help lessen the footprint and erosive potential of social trails.

4.3 Vegetation

Overall, NCPN monitoring reaches show the hallmarks of a diverse, sustainable riparian area very different from from the sparsely vegetated landscape recorded in historic photos in the 1930s and 1940s (see figures 1-5 and 1-6). Riparian canopy and understory species were present at all monitoring reaches and were the dominant cover type, except for Reach 1, which had relatively low obligate and facultative wetland cover. The presence of seedlings and saplings in all monitoring reaches indicates good potential for regeneration of the Fremont cottonwood overstory into the future.

One area of management concern is that exotic plant frequency and cover were relatively high in all monitoring reaches. High exotic cover, particularly of species that contribute to fuel loading, is associated with increased fire risk in southwestern riparian systems (Busch 1995, USFWS 2002). Fremont cottonwoods, in particular, are not fire-adapted and have shown high post-fire mortality with little resprouting (Higgins 1981). Of particular concern are non-native fuels, such as tamarisk and annual brome grasses. Arches National Park has actively removed tamarisk and Russian-olive at high-density sites in Courthouse Wash. Our data suggest these programs have helped keep both species at low cover in NCPN monitoring reaches.

Annual brome grasses, however, are more difficult to control. Their cover and height varies based on precipitation in winter and early spring. Dense cover of exotic annual grasses after wet periods increases the fire risk in Courthouse Wash. Natural ignitions are still likely to be limited, because lightning strikes typically hit the canyon rims, and low cover in surrounding upland systems reduces the risk that fire will carry to the riparian bottomland. To reduce the risk of human ignitions, it may be prudent to check backcountry campsites for high annual brome cover in wet years, even though campfires are not allowed at these sites.

Drought stress on Fremont cottonwoods has already been noted on several occasions in Courthouse Wash. Groundwater depths on the terrace at Reach 1 were consistently below the level needed to sustain cottonwood health. Reach 1 also had the lowest cover of riparian vegetation of any monitoring reach. Field crews have noted that older cottonwoods on higher surfaces at Reach 1 have begun to drop limbs and have poor canopy health, while younger cottonwoods nearer the channel still maintain a healthy canopy.

Drought stress can decrease the resilience of riparian vegetation to other stressors, as well. In June 2013, a cottonwood leaf beetle

outbreak occurred in Courthouse Wash. Trees in a dry channel section of Upper Courthouse Wash had more defoliation than trees in a wetted channel section of Lower Courthouse Wash (Figure 4-3). At Reach 5 (UCW), overstory canopy closure dropped by one quarter compared to the previous year, from 40% to 29%, during this pest outbreak. The effects of this outbreak seemed short-lived, as canopy closure rebounded to 35% at Reach 5 in 2015.

4.4 Future monitoring and conclusions

Vegetation and geomorphology monitoring has been suspended in Courthouse Wash since 2015, due to budget constraints. Two of the proposed seven monitoring reaches were never established for the same reasons. We used a survey design to select monitoring reaches for Courthouse Wash because our overall goal was to provide inference to the entire length of Courthouse Wash within the sampling frame. However, previous analyses on the East Fork of the Virgin River in Zion National Park (Witwicki and Weissinger 2015) using the same monitoring protocol confirmed that five reaches is an insufficient sample size to detect changes throughout the whole sampling frame. For this reason, moving forward, each reach will be compared to itself over time. This updated sampling design provides flexibility to sample reaches periodically, as funding allows, rather than requiring a strict revisit schedule.

Vegetation and geomorphology metrics both proved sensitive to changes from floods and pest infestations noted during the initial monitoring visits. Baseline data from 2010 to 2015 can provide a valuable comparison for future monitoring efforts when they are resumed. Retaking historic photos and overview photos of monitoring reaches would also help provide a record of change over time. Maintaining the hydrologic record at Reach 1 should be a high priority to better understand the effects of climate on water availability in the system.

Arches National Park managers have prioritized protecting groundwater systems that feed park aquifers, removing exotic woody vegetation, and repairing the fenceline to exclude trespass cattle in Courthouse Wash. These actions help support a diverse, healthy riparian system in Courthouse Wash. Managers should be prepared for increased wildfire risks in the riparian zone in years with high annual brome cover. Climate change is likely to be an increasingly significant stressor, as hotter, drier conditions decrease water levels and increase drought stress for vegetation. The expansion of beaver activity in the system may increase resilience to climate change in bedrock-constrained reaches of Courthouse Wash. Overall, the heterogeneity of the Courthouse Wash system should continue to support patches of surface water and riparian vegetation, even as drought conditions increase. NCPN monitoring can be useful in tracking riparian-ecosystem health in the future.

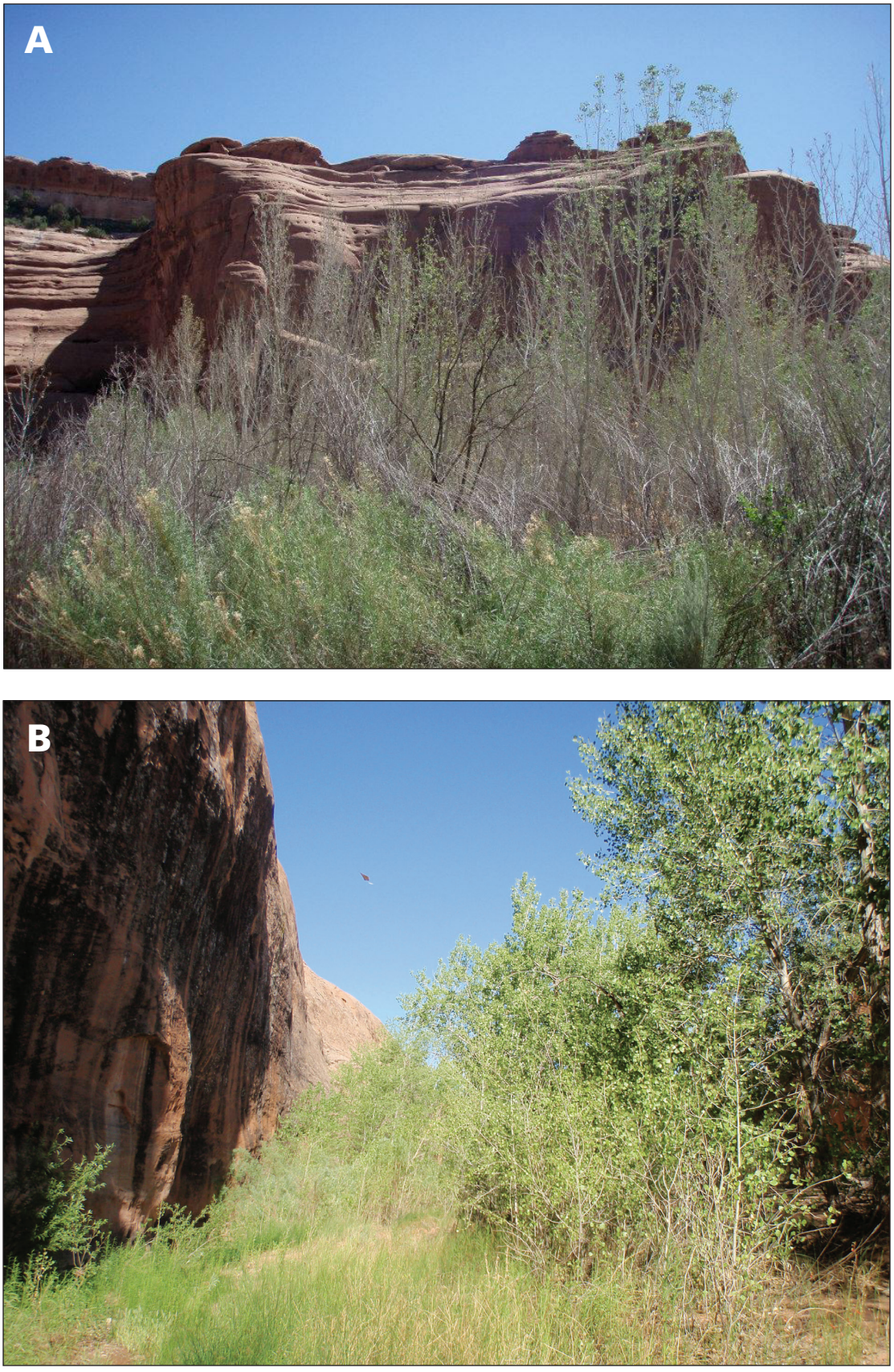


Figure 4-3. Cottonwood-leaf defoliation during a pest outbreak in June 2013 was more significant in dry channel reaches in Upper Courthouse Wash (A) than in wetted channel reaches in Lower Courthouse Wash (B).

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Appendix A. Cross-sections of Stream Reaches

For all figures, note that the x-axis is displayed with descending numbers, in order to match the locations along the transect for vegetation monitoring.

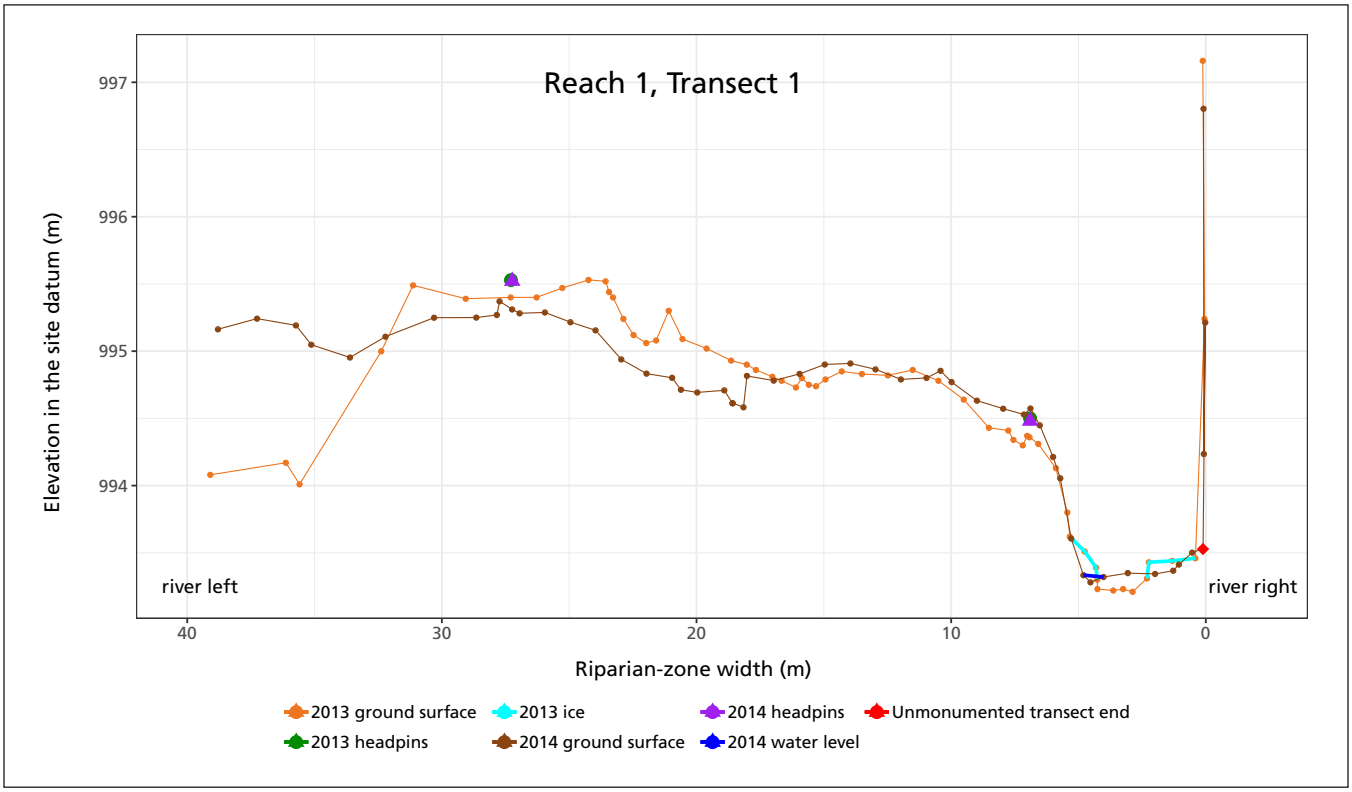


Figure A-1. Cross-section of reach 1 at transect 1 looking downstream, Courthouse Wash, Arches National Park, 2013 and 2014.

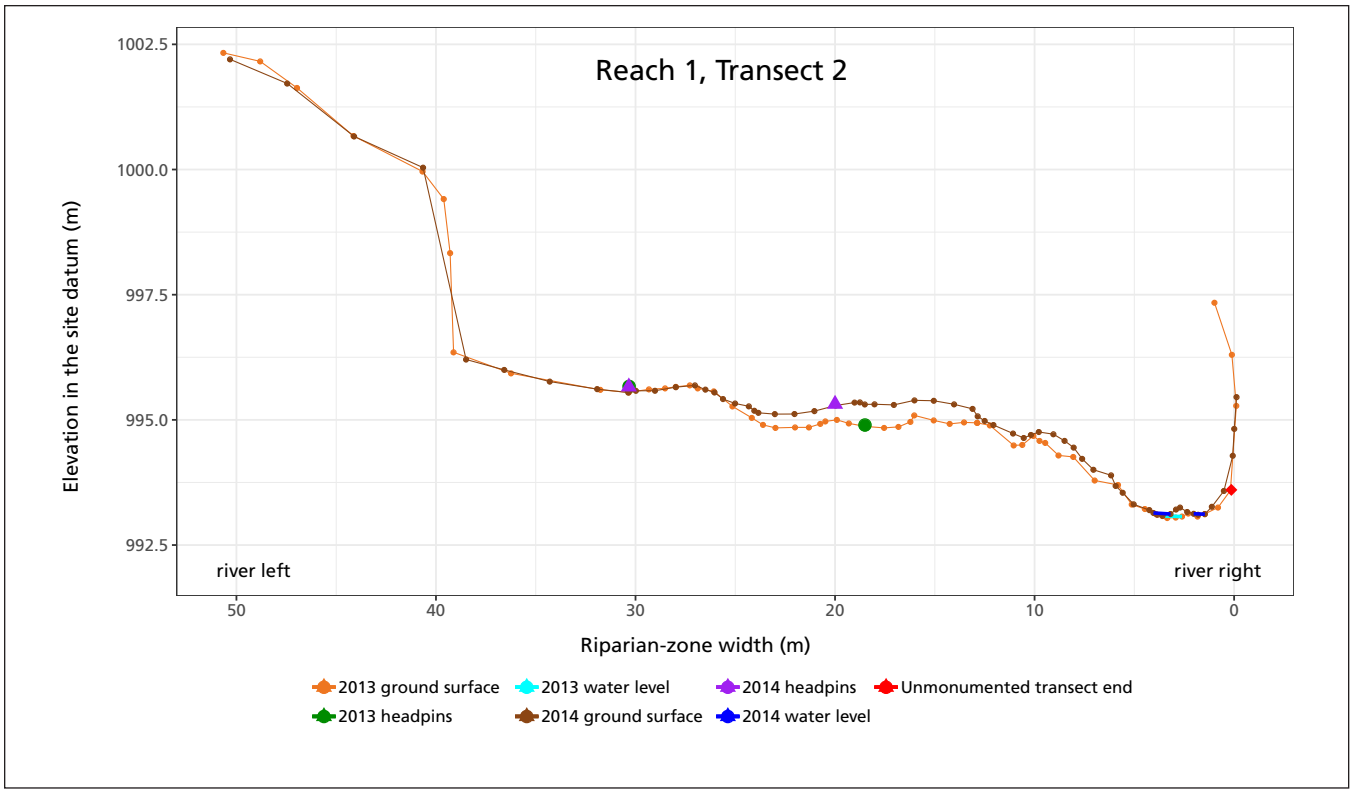


Figure A-2. Cross-section of reach 1 at transect 2 looking downstream, Courthouse Wash, Arches National Park, 2013 and 2014.

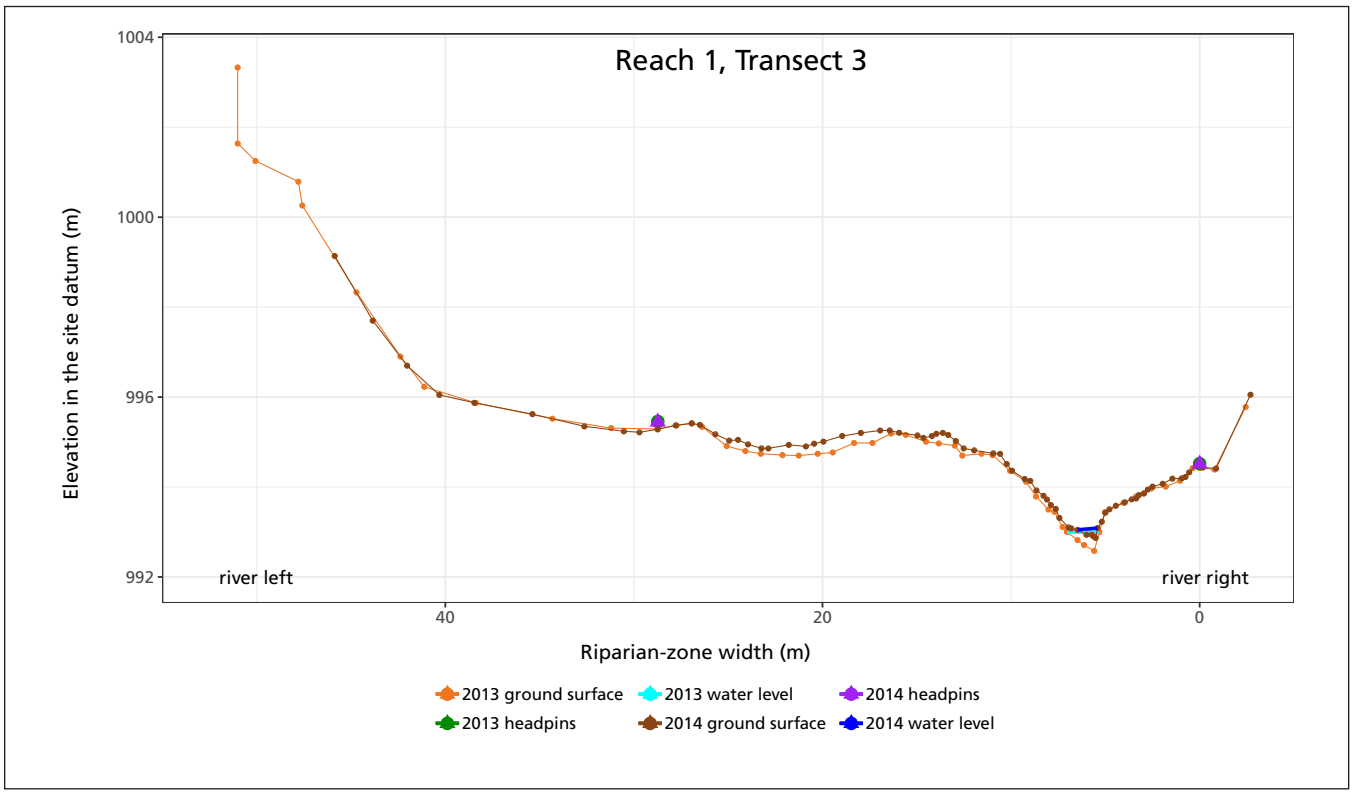


Figure A-3. Cross-section of reach 1 at transect 3 looking downstream, Courthouse Wash, Arches National Park, 2013 and 2014.

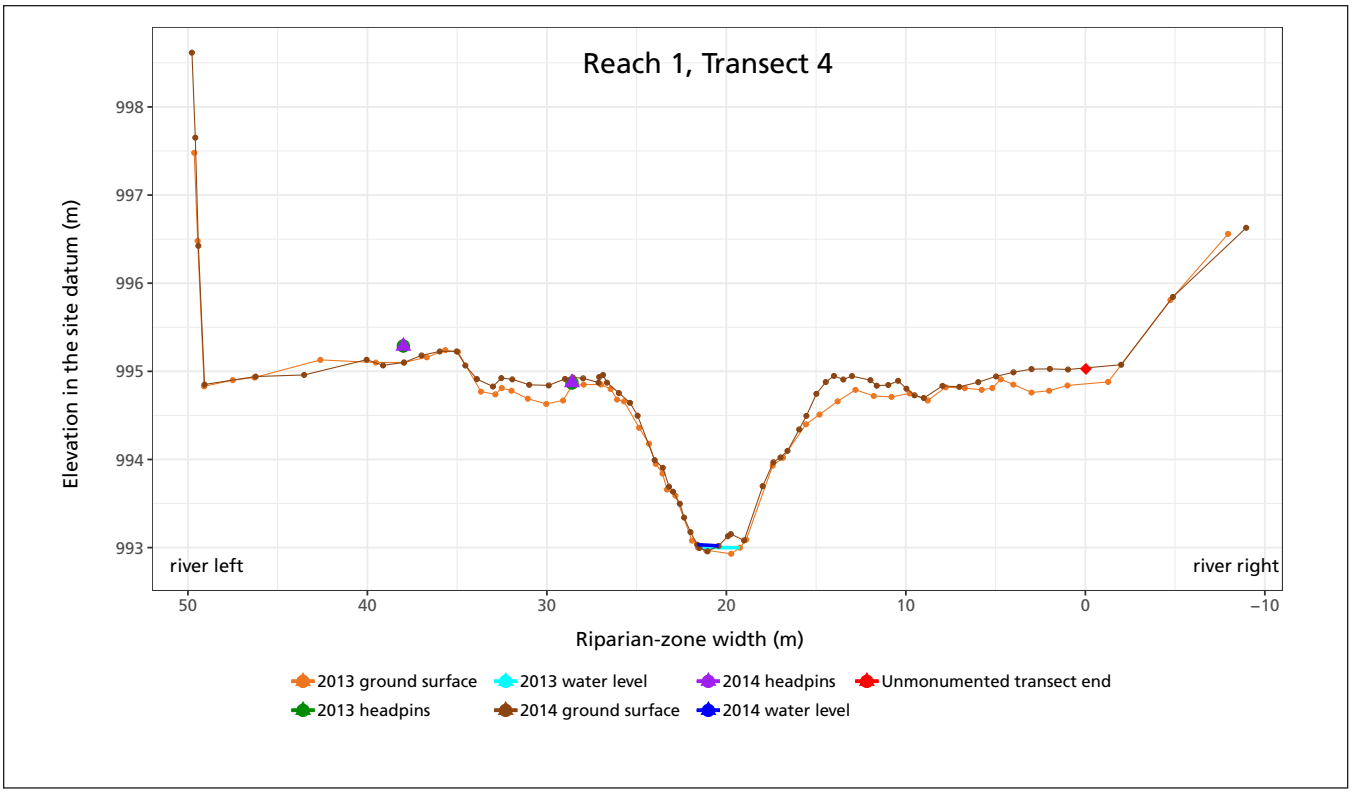


Figure A-4. Cross-section of reach 1 at transect 4 looking downstream, Courthouse Wash, Arches National Park, 2013 and 2014.

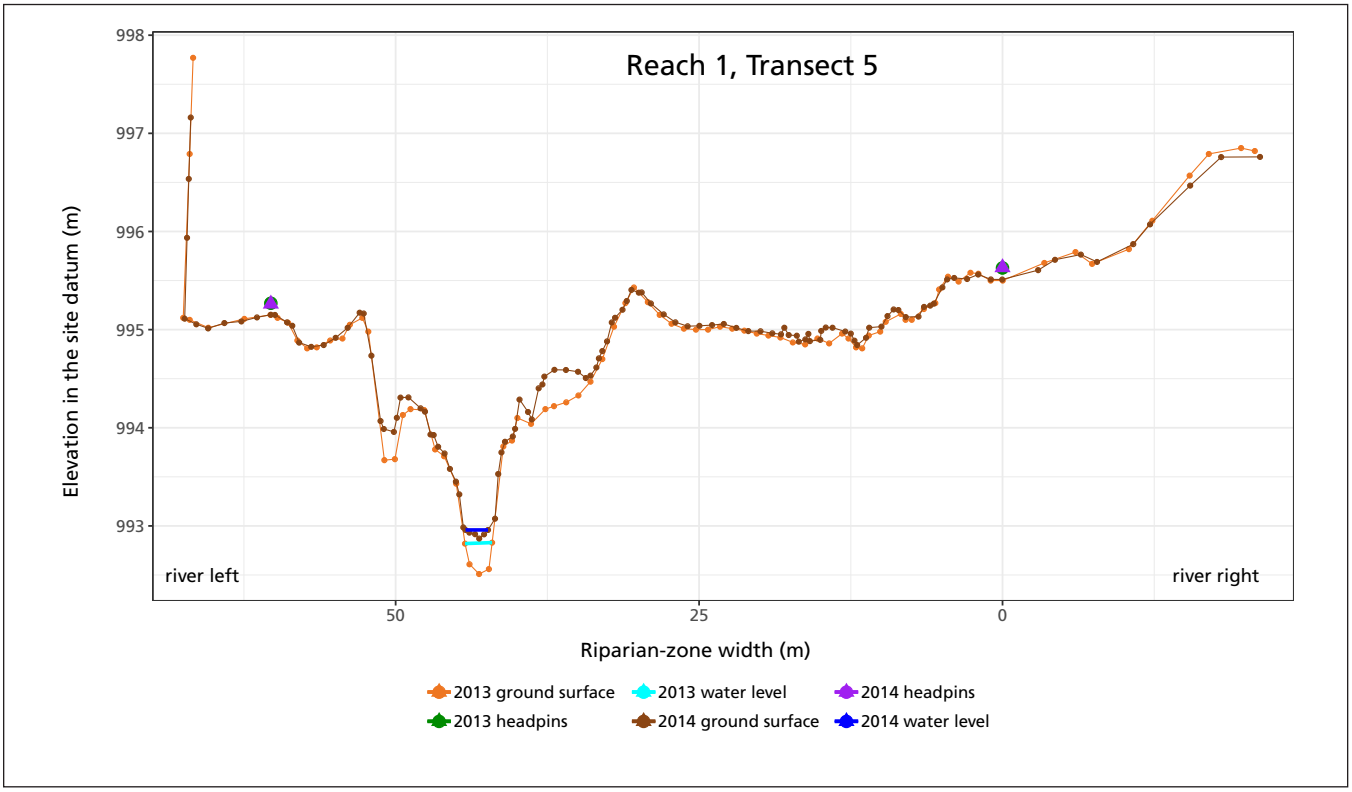


Figure A-5. Cross-section of reach 1 at transect 5 looking downstream, Courthouse Wash, Arches National Park, 2013 and 2014.

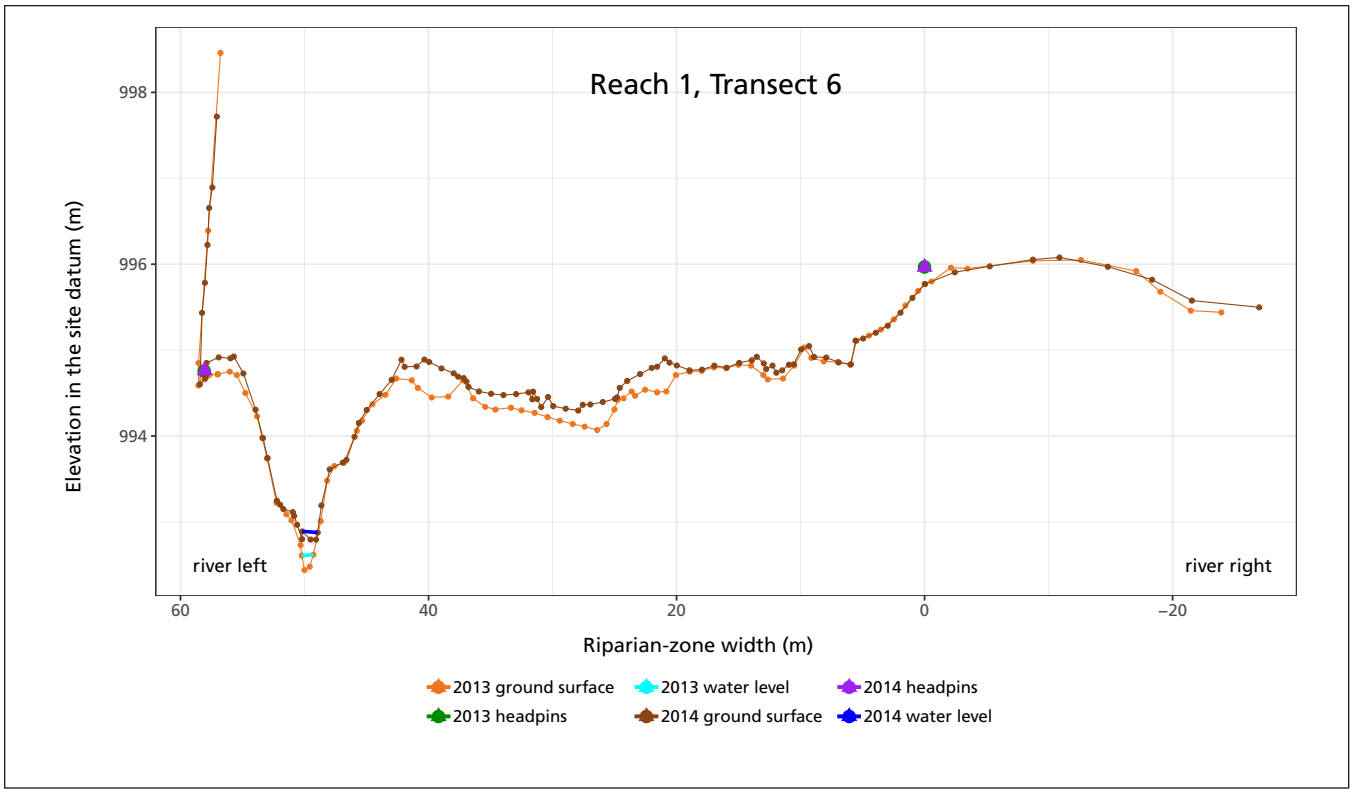


Figure A-6. Cross-section of reach 1 at transect 6 looking downstream, Courthouse Wash, Arches National Park, 2013 and 2014.

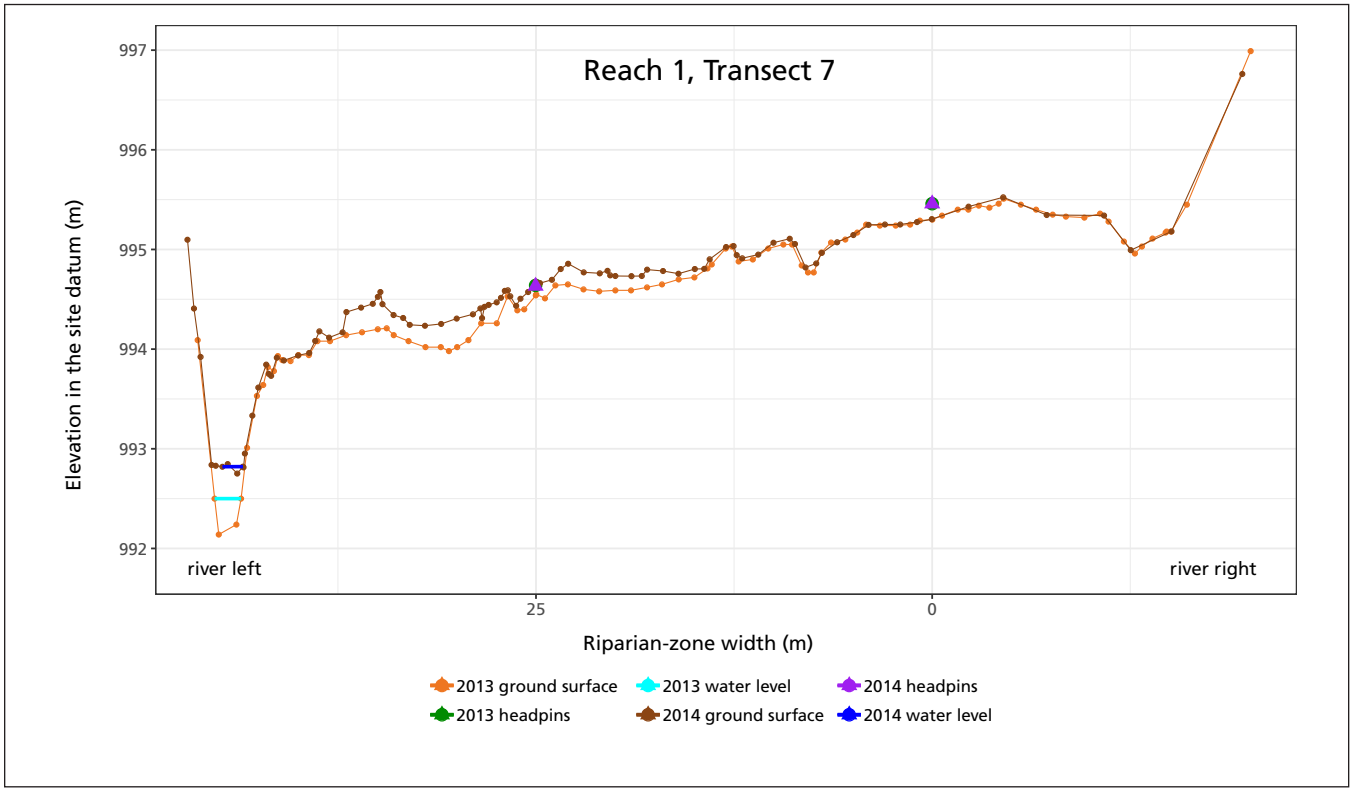


Figure A-7. Cross-section of reach 1 at transect 7 looking downstream, Courthouse Wash, Arches National Park, 2013 and 2014.

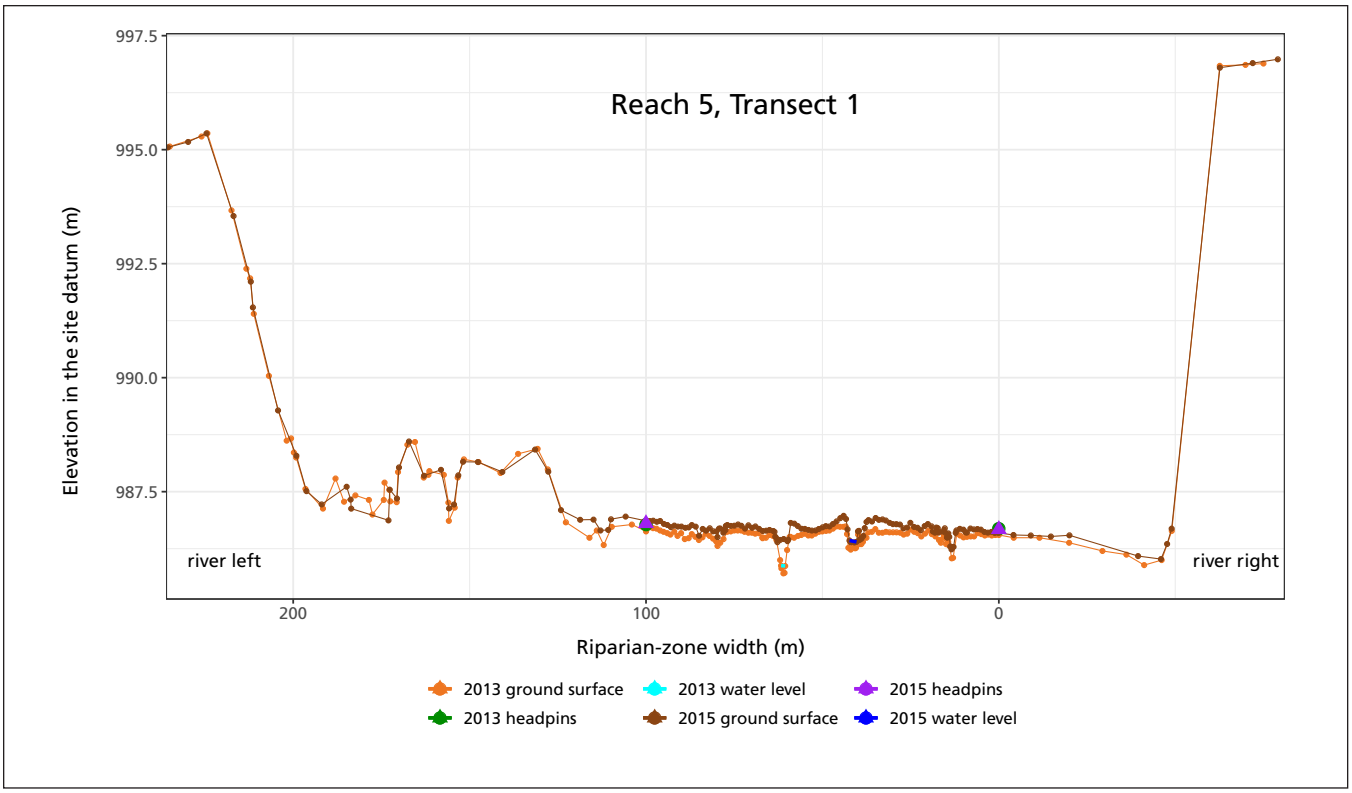


Figure A-8. Cross-section of reach 5 at transect 1 looking downstream, Courthouse Wash, Arches National Park, 2013 and 2015.

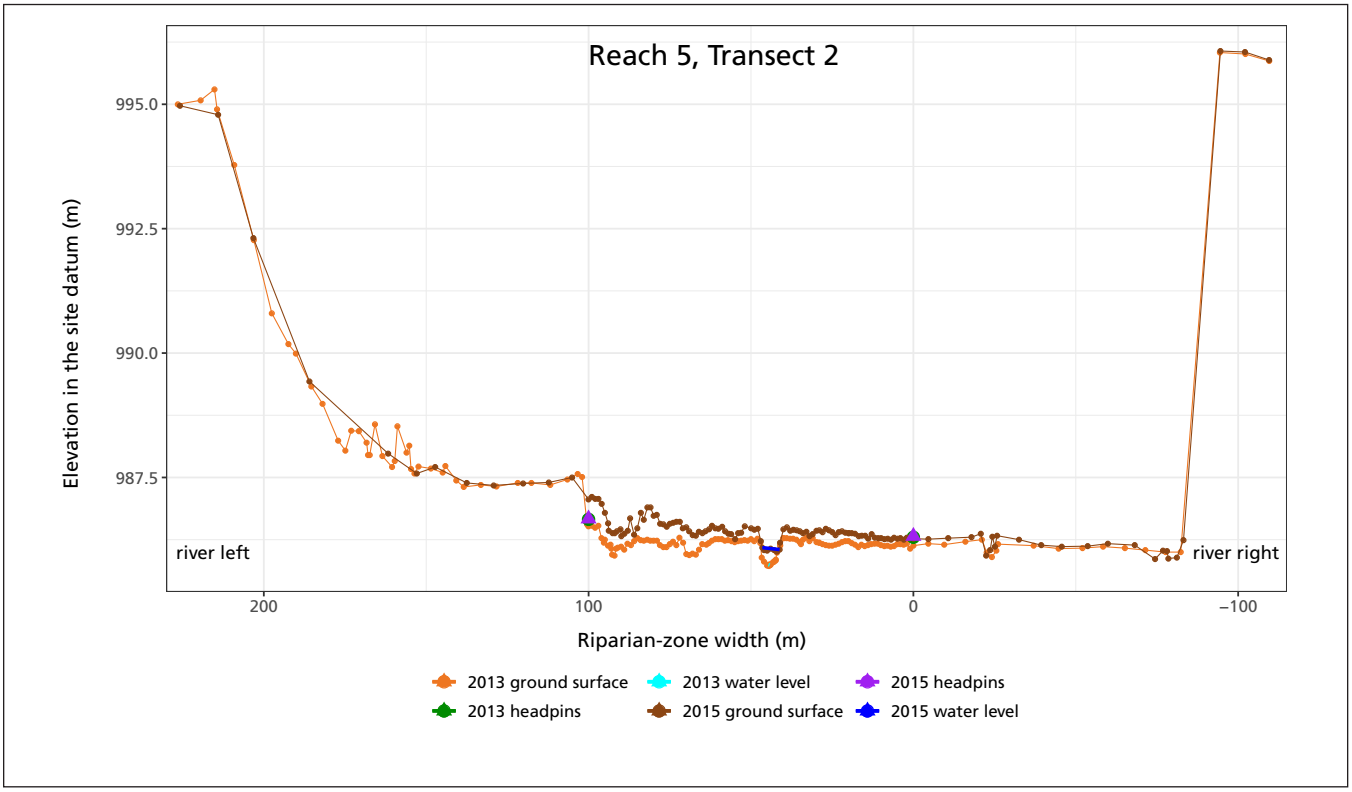


Figure A-9. Cross-section of reach 5 at transect 2 looking downstream, Courthouse Wash, Arches National Park, 2013 and 2015.

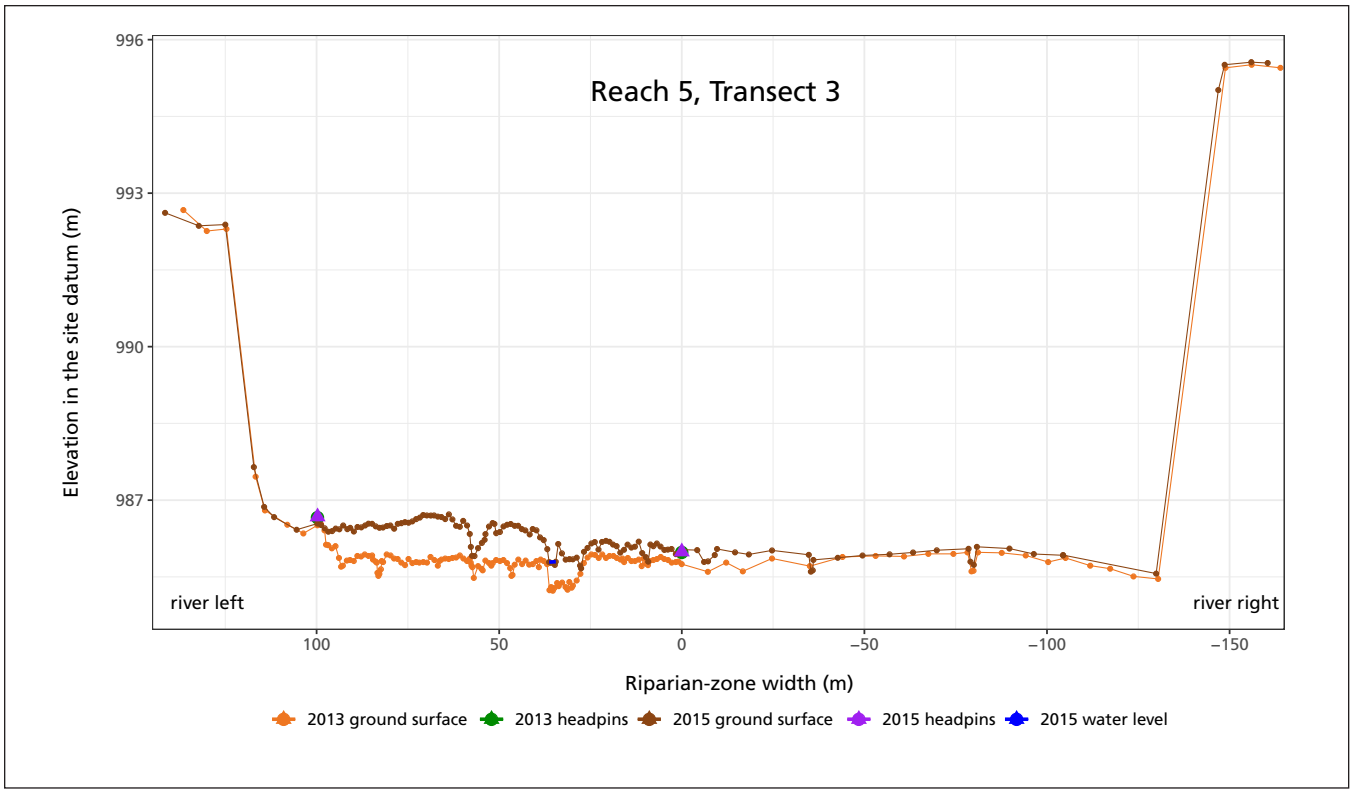


Figure A-10. Cross-section of reach 5 at transect 3 looking downstream, Courthouse Wash, Arches National Park, 2013 and 2015. No water was present in 2013.

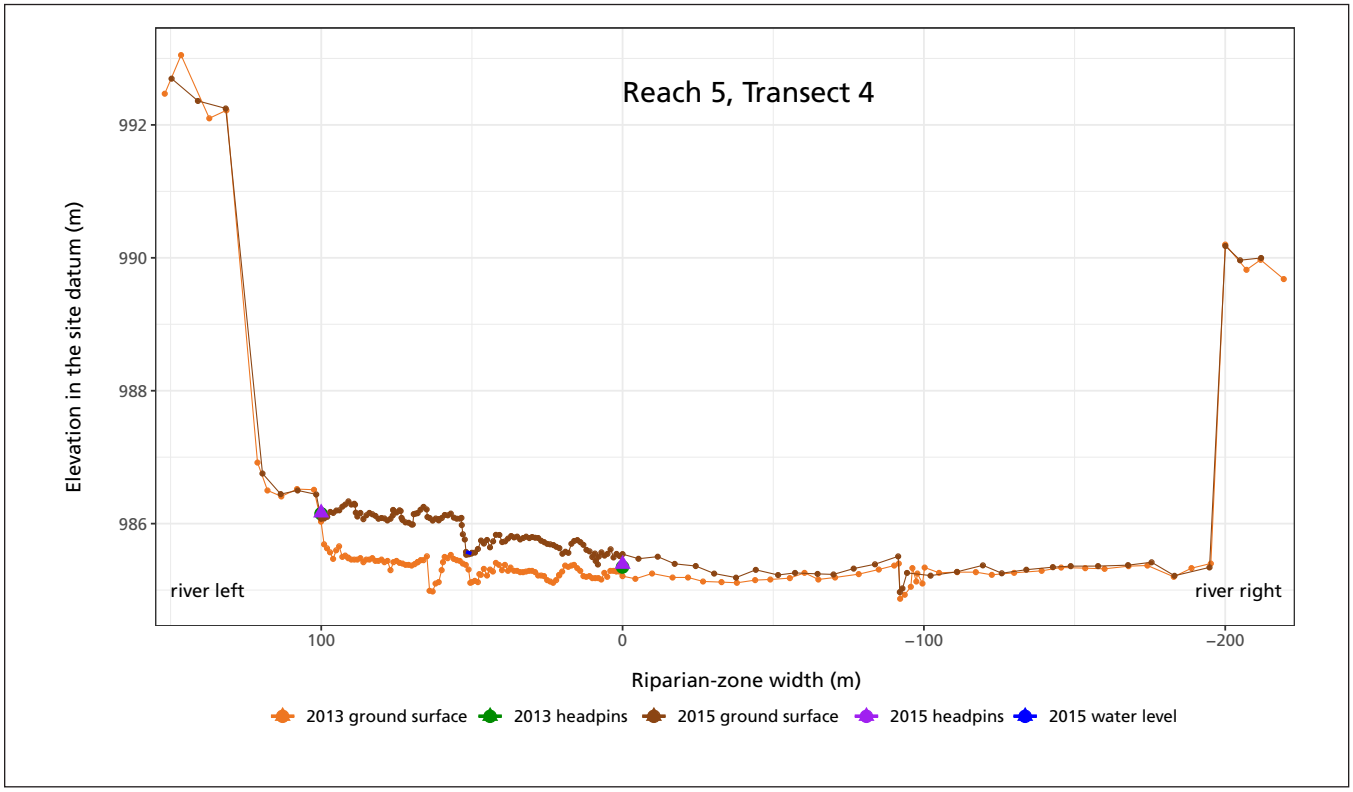


Figure A-11. Cross-section of reach 5 at transect 4 looking downstream, Courthouse Wash, Arches National Park, 2013 and 2015. No water was present in 2013.

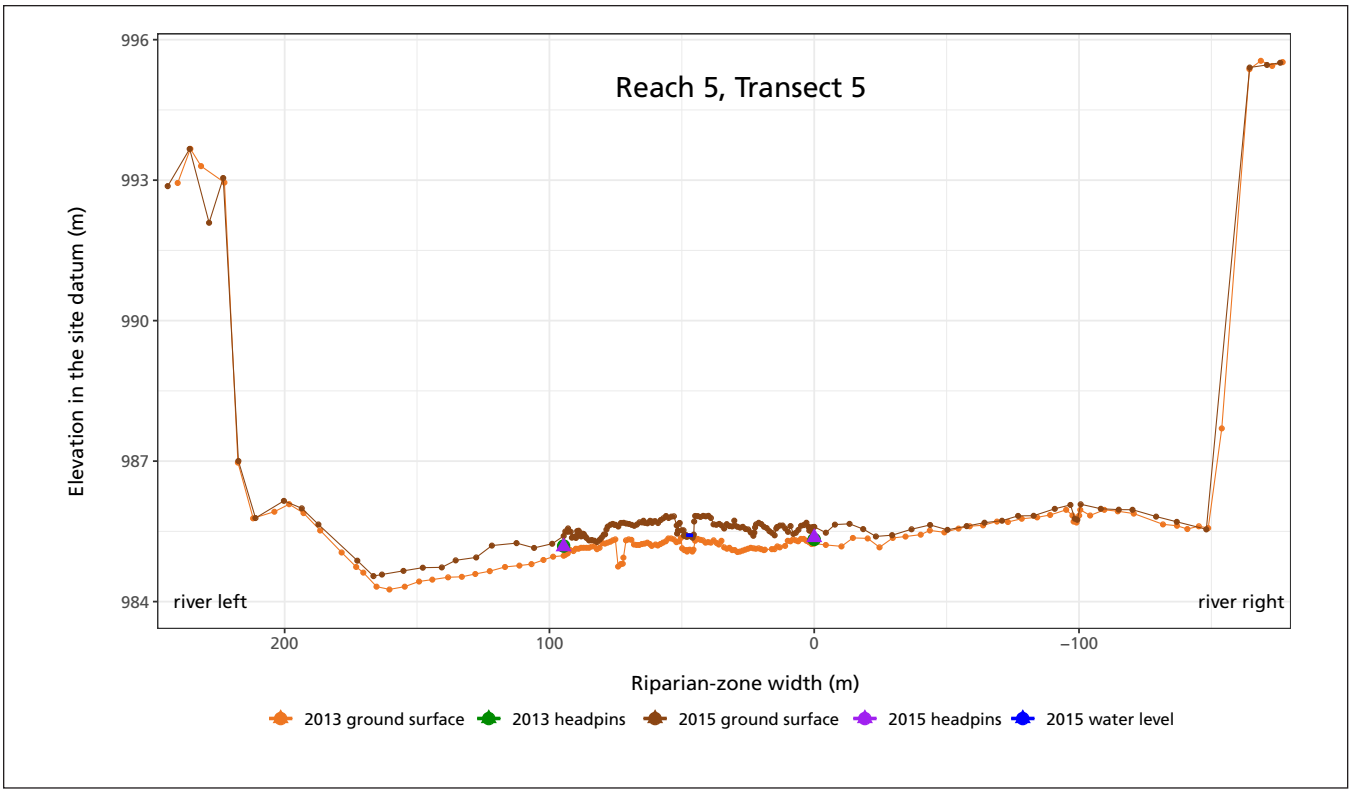


Figure A-12. Cross-section of reach 5 at transect 5 looking downstream, Courthouse Wash, Arches National Park, 2013 and 2015. No water was present in 2013.

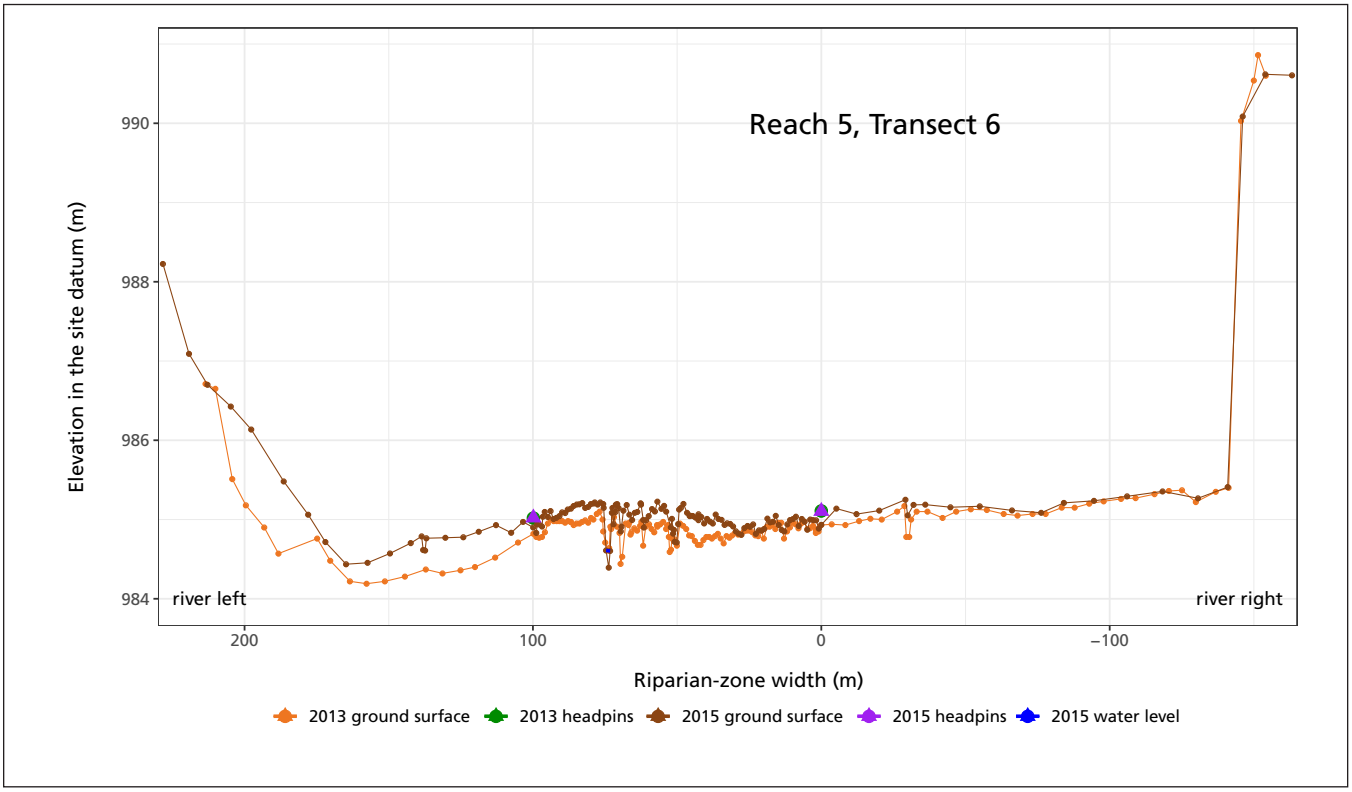


Figure A-13. Cross-section of reach 5 at transect 6 looking downstream, Courthouse Wash, Arches National Park, 2013 and 2015. No water was present in 2013.

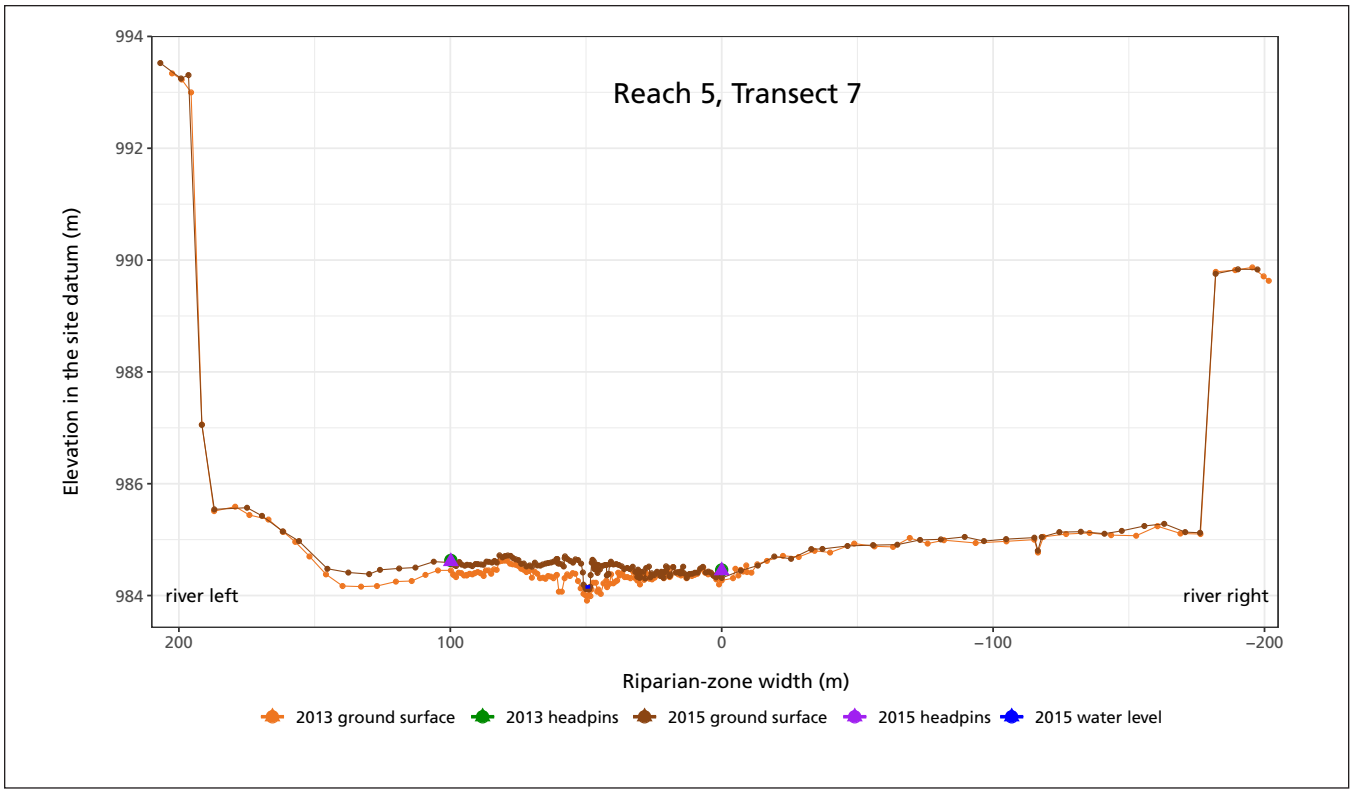


Figure A-14. Cross-section of reach 5 at transect 7 looking downstream, Courthouse Wash, Arches National Park, 2013 and 2015. No water was present in 2013.

Appendix B. Vegetation Data Summaries

Table B-1. Frequency of exotic plant species detected by lifeform and reach, Courthouse Wash, Arches National Park, 2011–2015.

Lifeform	Scientific name	Common name	Duration	Year	Upper Courthouse		Lower Courthouse		
					Reach 2	Reach 5	Reach 7	Reach 1	Reach 4
Tree	*Elaeagnus angustifolia*	Russian-olive	Perennial	2011	3.3	–	0	–	–
Tree	*Elaeagnus angustifolia*	Russian-olive	Perennial	2012	–	1.4	0	–	–
Tree	*Elaeagnus angustifolia*	Russian-olive	Perennial	2013	–	0.7	–	–	2.3
Tree	*Elaeagnus angustifolia*	Russian-olive	Perennial	2014	–	–	–	0	0
Tree	*Elaeagnus angustifolia*	Russian-olive	Perennial	2015	–	0	–	–	–
Shrub	*Tamarix* sp.	Tamarisk	Perennial	2011	5.7	–	0	–	–
Shrub	*Tamarix* sp.	Tamarisk	Perennial	2012	–	4.3	0	–	–
Shrub	*Tamarix* sp.	Tamarisk	Perennial	2013	–	5.0	–	–	0
Shrub	*Tamarix* sp.	Tamarisk	Perennial	2014	–	–	–	0	0
Shrub	*Tamarix* sp.	Tamarisk	Perennial	2015	–	5.0	–	–	–
Grass	*Aegilops cylindrica*	Jointed goatgrass	Annual	2011	0	–	0	–	–
Grass	*Aegilops cylindrica*	Jointed goatgrass	Annual	2012	–	0	0	–	–
Grass	*Aegilops cylindrica*	Jointed goatgrass	Annual	2013	–	0	–	–	0
Grass	*Aegilops cylindrica*	Jointed goatgrass	Annual	2014	–	–	–	0	0
Grass	*Aegilops cylindrica*	Jointed goatgrass	Annual	2015	–	2.2	–	–	–
Grass	*Agrostis stolonifera*	Redtop	Perennial	2011	0	–	7.8	–	–
Grass	*Agrostis stolonifera*	Redtop	Perennial	2012	–	0	5.9	–	–
Grass	*Agrostis stolonifera*	Redtop	Perennial	2013	–	0	–	–	4.5
Grass	*Agrostis stolonifera*	Redtop	Perennial	2014	–	–	–	0	6.8
Grass	*Agrostis stolonifera*	Redtop	Perennial	2015	–	1.4	–	–	–
Grass	*Bromus diandrus*	Ripgut brome	Annual	2011	0	–	0	–	–
Grass	*Bromus diandrus*	Ripgut brome	Annual	2012	–	0	0	–	–
Grass	*Bromus diandrus*	Ripgut brome	Annual	2013	–	0	–	–	0
Grass	*Bromus diandrus*	Ripgut brome	Annual	2014	–	–	–	10.2	18.2
Grass	*Bromus diandrus*	Ripgut brome	Annual	2015	–	0	–	–	–
Grass	*Bromus japonicus*	Japanese chess	Annual	2011	0	–	2.0	–	–
Grass	*Bromus japonicus*	Japanese chess	Annual	2012	–	6.5	0	–	–
Grass	*Bromus japonicus*	Japanese chess	Annual	2013	–	5.8	–	–	22.7

Table B-1 (cont.). Frequency of exotic plant species detected by lifeform and reach, Courthouse Wash, Arches National Park, 2011–2015.

Lifeform	Scientific name	Common name	Duration	Year	Upper Courthouse		Lower Courthouse		
					Reach 2	Reach 5	Reach 7	Reach 1	Reach 4
Grass	*Bromus japonicus*	Japanese chess	Annual	2014	–	–	–	0	31.8
Grass	*Bromus japonicus*	Japanese chess	Annual	2015	–	4.3	–	–	–
Grass	*Bromus tectorum*	Cheatgrass	Annual	2011	36.1	–	35.3	–	–
Grass	*Bromus tectorum*	Cheatgrass	Annual	2012	–	82.7	31.4	–	–
Grass	*Bromus tectorum*	Cheatgrass	Annual	2013	–	95.0	–	–	38.6
Grass	*Bromus tectorum*	Cheatgrass	Annual	2014	–	–	–	52.5	65.9
Grass	*Bromus tectorum*	Cheatgrass	Annual	2015	–	74.1	–	–	–
Grass	*Dactylis glomerata*	Orchard grass	Perennial	2011	0	–	0	–	–
Grass	*Dactylis glomerata*	Orchard grass	Perennial	2012	–	0	0	–	–
Grass	*Dactylis glomerata*	Orchard grass	Perennial	2013	–	0	–	–	0
Grass	*Dactylis glomerata*	Orchard grass	Perennial	2014	–	–	–	0	2.3
Grass	*Dactylis glomerata*	Orchard grass	Perennial	2015	–	0	–	–	–
Grass	*Eremopyrum triticeum*	Annual wheatgrass	Annual	2011	2.5	–	0	–	–
Grass	*Eremopyrum triticeum*	Annual wheatgrass	Annual	2012	–	5.0	0	–	–
Grass	*Eremopyrum triticeum*	Annual wheatgrass	Annual	2013	–	2.2	–	–	0
Grass	*Eremopyrum triticeum*	Annual wheatgrass	Annual	2014	–	–	–	0	0
Grass	*Eremopyrum triticeum*	Annual wheatgrass	Annual	2015	–	4.3	–	–	–
Grass	*Polypogon monspeliensis*	Rabbitfoot-grass	Annual	2011	0.8	–	2.0	–	–
Grass	*Polypogon monspeliensis*	Rabbitfoot-grass	Annual	2012	–	0	0	–	–
Grass	*Polypogon monspeliensis*	Rabbitfoot-grass	Annual	2013	–	0	–	–	6.8
Grass	*Polypogon monspeliensis*	Rabbitfoot-grass	Annual	2014	–	–	–	0	0
Grass	*Polypogon monspeliensis*	Rabbitfoot-grass	Annual	2015	–	2.2	–	–	–
Grass	*Schismus arabicus*	Arabian grass	Annual	2011	0	–	0	–	–
Grass	*Schismus arabicus*	Arabian grass	Annual	2012	–	0	0	–	–
Grass	*Schismus arabicus*	Arabian grass	Annual	2013	–	0	–	–	0
Grass	*Schismus arabicus*	Arabian grass	Annual	2014	–	–	–	10.2	0
Grass	*Schismus arabicus*	Arabian grass	Annual	2015	–	0	–	–	–
Forb	*Bassia hyssopifolia*	Five-horn smotherweed	Annual	2011	12.3	–	0	–	–
Forb	*Bassia hyssopifolia*	Five-horn smotherweed	Annual	2012	–	0	0	–	–

Table B-1 (cont.). Frequency of exotic plant species detected by lifeform and reach, Courthouse Wash, Arches National Park, 2011–2015.

Lifeform	Scientific name	Common name	Duration	Year	Upper Courthouse		Lower Courthouse		
					Reach 2	Reach 5	Reach 7	Reach 1	Reach 4
Forb	*Bassia hyssopifolia*	Five-horn smotherweed	Annual	2013	–	0	–	–	0
Forb	*Bassia hyssopifolia*	Five-horn smotherweed	Annual	2014	–	–	–	0	0
Forb	*Bassia hyssopifolia*	Five-horn smotherweed	Annual	2015	–	0	–	–	–
Forb	*Chenopodium* sp.	goosefoot species	Annual	2011	0.8	–	0	–	–
Forb	*Chenopodium* sp.	goosefoot species	Annual	2012	–	0	0	–	–
Forb	*Chenopodium* sp.	goosefoot species	Annual	2013	–	0	–	–	0
Forb	*Chenopodium* sp.	goosefoot species	Annual	2014	–	–	–	0	0
Forb	*Chenopodium* sp.	goosefoot species	Annual	2015	–	0	–	–	–
Forb	*Descurainia sophia*	Flixweed	Annual	2011	0	–	0	–	–
Forb	*Descurainia sophia*	Flixweed	Annual	2012	–	0.7	0	–	–
Forb	*Descurainia sophia*	Flixweed	Annual	2013	–	1.4	–	–	0
Forb	*Descurainia sophia*	Flixweed	Annual	2014	–	–	–	0	0
Forb	*Descurainia sophia*	Flixweed	Annual	2015	–	0	–	–	–
Forb	*Erodium cicutarium*	Stork's-bill	Annual	2011	0.8	–	0	–	–
Forb	*Erodium cicutarium*	Stork's-bill	Annual	2012	–	0	0	–	–
Forb	*Erodium cicutarium*	Stork's-bill	Annual	2013	–	0	–	–	0
Forb	*Erodium cicutarium*	Stork's-bill	Annual	2014	–	–	–	5.1	0
Forb	*Erodium cicutarium*	Stork's-bill	Annual	2015	–	0.7	–	–	–
Forb	*Halogeton glomeratus*	Halogeton	Annual	2011	0.8	–	0	–	–
Forb	*Halogeton glomeratus*	Halogeton	Annual	2012	–	0	0	–	–
Forb	*Halogeton glomeratus*	Halogeton	Annual	2013	–	0	–	–	0
Forb	*Halogeton glomeratus*	Halogeton	Annual	2014	–	–	–	0	0
Forb	*Halogeton glomeratus*	Halogeton	Annual	2015	–	0	–	–	–
Forb	*Lactuca serriola*	Prickly lettuce	Annual	2011	0	–	0	–	–
Forb	*Lactuca serriola*	Prickly lettuce	Annual	2012	–	1.4	0	–	–
Forb	*Lactuca serriola*	Prickly lettuce	Annual	2013	–	1.4	–	–	0
Forb	*Lactuca serriola*	Prickly lettuce	Annual	2014	–	–	–	0	0
Forb	*Lactuca serriola*	Prickly lettuce	Annual	2015	–	2.9	–	–	–
Forb	*Malcolmia africana*	African mustard	Annual	2011	13.1	–	0	–	–

Table B-1 (cont.). Frequency of exotic plant species detected by lifeform and reach, Courthouse Wash, Arches National Park, 2011–2015.

Lifeform	Scientific name	Common name	Duration	Year	Upper Courthouse		Lower Courthouse		
					Reach 2	Reach 5	Reach 7	Reach 1	Reach 4
Forb	*Malcolmia africana*	African mustard	Annual	2012	–	0	0	–	–
Forb	*Malcolmia africana*	African mustard	Annual	2013	–	0.7	–	–	0
Forb	*Malcolmia africana*	African mustard	Annual	2014	–	–	–	0	0
Forb	*Malcolmia africana*	African mustard	Annual	2015	–	5.0	–	–	–
Forb	*Melilotus officinalis*	Yellow sweet-clover	Biennial	2011	18.0	–	17.6	–	–
Forb	*Melilotus officinalis*	Yellow sweet-clover	Biennial	2012	–	12.9	33.3	–	–
Forb	*Melilotus officinalis*	Yellow sweet-clover	Biennial	2013	–	11.5	–	–	2.3
Forb	*Melilotus officinalis*	Yellow sweet-clover	Biennial	2014	–	–	–	3.4	9.1
Forb	*Melilotus officinalis*	Yellow sweet-clover	Biennial	2015	–	2.9	–	–	–
Forb	*Melilotus* sp.	sweetclover	Biennial	2011	50.0	–	49.0	–	–
Forb	*Melilotus* sp.	sweetclover	Biennial	2012	–	20.9	17.6	–	–
Forb	*Melilotus* sp.	sweetclover	Biennial	2013	–	47.5	–	–	18.2
Forb	*Melilotus* sp.	sweetclover	Biennial	2014	–	–	–	10.2	27.3
Forb	*Melilotus* sp.	sweetclover	Biennial	2015	–	59.7	–	–	–
Forb	*Salsola tragus*	Russian-thistle	Annual	2011	35.2	–	2.0	–	–
Forb	*Salsola tragus*	Russian-thistle	Annual	2012	–	4.3	0	–	–
Forb	*Salsola tragus*	Russian-thistle	Annual	2013	–	5.0	–	–	4.5
Forb	*Salsola tragus*	Russian-thistle	Annual	2014	–	–	–	5.1	2.3
Forb	*Salsola tragus*	Russian-thistle	Annual	2015	–	2.2	–	–	–
Forb	*Sisymbrium altissimum*	Tumble mustard	Annual	2011	0	–	0	–	–
Forb	*Sisymbrium altissimum*	Tumble mustard	Annual	2012	–	0	0	–	–
Forb	*Sisymbrium altissimum*	Tumble mustard	Annual	2013	–	0	–	–	0
Forb	*Sisymbrium altissimum*	Tumble mustard	Annual	2014	–	–	–	0	0
Forb	*Sisymbrium altissimum*	Tumble mustard	Annual	2015	–	0.7	–	–	–
Forb	*Sonchus asper*	Spiny-leaf sow-thistle	Annual	2011	0.8	–	0	–	–
Forb	*Sonchus asper*	Spiny-leaf sow-thistle	Annual	2012	–	0	0	–	–
Forb	*Sonchus asper*	Spiny-leaf sow-thistle	Annual	2013	–	0	–	–	0
Forb	*Sonchus asper*	Spiny-leaf sow-thistle	Annual	2014	–	–	–	0	0
Forb	*Sonchus asper*	Spiny-leaf sow-thistle	Annual	2015	–	0.7	–	–	–
Forb	*Taraxacum officinale*	Common dandelion	Perennial	2011	0.8	–	0	–	–

Table B-1 (cont.). Frequency of exotic plant species detected by lifeform and reach, Courthouse Wash, Arches National Park, 2011–2015.

Lifeform	Scientific name	Common name	Duration	Year	Upper Courthouse		Lower Courthouse		
					Reach 2	Reach 5	Reach 7	Reach 1	Reach 4
Forb	*Taraxacum officinale*	Common dandelion	Perennial	2012	–	0	0	–	–
Forb	*Taraxacum officinale*	Common dandelion	Perennial	2013	–	0	–	–	0
Forb	*Taraxacum officinale*	Common dandelion	Perennial	2014	–	–	–	0	0
Forb	*Taraxacum officinale*	Common dandelion	Perennial	2015	–	0	–	–	–
Forb	*Tragopogon dubius*	Yellow salsify	Biennial	2011	0	–	0	–	–
Forb	*Tragopogon dubius*	Yellow salsify	Biennial	2012	–	0.7	0	–	–
Forb	*Tragopogon dubius*	Yellow salsify	Biennial	2013	–	0	–	–	0
Forb	*Tragopogon dubius*	Yellow salsify	Biennial	2014	–	–	–	0	0
Forb	*Tragopogon dubius*	Yellow salsify	Biennial	2015	–	1.4	–	–	–

Table B-2. Percent cover of surface features, Courthouse Wash, Arches National Park.

Surface feature	Year	Upper Courthouse		Lower Courthouse		
		Reach 2	Reach 5	Reach 7	Reach 1	Reach 4
Water	2010	0	–	–	0	–
Water	2011	0.7	–	3.7	–	–
Water	2012	–	0	8.5	–	–
Water	2013	–	0	–	–	7.2
Water	2014	–	–	–	3.7	8.3
Water	2015	–	0.8	–	–	–
Fines (0.1–2 mm)	2010	73.3	–	–	64.5	–
Fines (0.1–2 mm)	2011	60.0	–	36.8	–	–
Fines (0.1–2 mm)	2012	–	46.0	35.6	–	–
Fines (0.1–2 mm)	2013	–	36.8	–	–	15.0
Fines (0.1–2 mm)	2014	–	–	–	74.7	31.5
Fines (0.1–2 mm)	2015	–	69.9	–	–	–
Fine gravel (>2–16 mm)	2010	0.2	–	–	3.5	–
Fine gravel (>2–16 mm)	2011	0	–	0.2	–	–
Fine gravel (>2–16 mm)	2012	–	0	0	–	–
Fine gravel (>2–16 mm)	2013	–	0.1	–	–	0.5
Fine gravel (>2–16 mm)	2014	–	–	–	1.0	0.5
Fine gravel (>2–16 mm)	2015	–	0	–	–	–
Coarse gravel (>16–64 mm)	2010	0.1	–	–	1.2	–
Coarse gravel (>16–64 mm)	2011	0	–	0	–	–
Coarse gravel (>16–64 mm)	2012	–	0	0	–	–
Coarse gravel (>16–64 mm)	2013	–	0	–	–	0
Coarse gravel (>16–64 mm)	2014	–	–	–	0.3	0
Coarse gravel (>16–64 mm)	2015	–	0	–	–	–
Cobble (>64–256 mm)	2010	0	–	–	0	–
Cobble (>64–256 mm)	2011	0	–	0	–	–
Cobble (>64–256 mm)	2012	–	0	0	–	–
Cobble (>64–256 mm)	2013	–	0	–	–	0
Cobble (>64–256 mm)	2014	–	–	–	0	0
Cobble (>64–256 mm)	2015	–	0	–	–	–
Boulder (>256 mm)	2010	0.2	–	–	0	–
Boulder (>256 mm)	2011	0	–	0	–	–
Boulder (>256 mm)	2012	–	0	0	–	–
Boulder (>256 mm)	2013	–	0	–	–	0
Boulder (>256 mm)	2014	–	–	–	0	0
Boulder (>256 mm)	2015	–	0	–	–	–
Bedrock	2010	0	–	–	0.2	–
Bedrock	2011	0.2	–	0	–	–
Bedrock	2012	–	0	0	–	–
Bedrock	2013	–	0	–	–	0.5
Bedrock	2014	–	–	–	0	1.2

Table B-2 (cont.). Percent cover of surface features, Courthouse Wash, Arches National Park.

Surface feature	Year	Upper Courthouse		Lower Courthouse		
		Reach 2	Reach 5	Reach 7	Reach 1	Reach 4
Bedrock	2015	–	0	–	–	–
Biological soil crust	2010	0.2	–	–	0.2	–
Biological soil crust	2011	0	–	0.6	–	–
Biological soil crust	2012	–	0.1	1.0	–	–
Biological soil crust	2013	–	0.1	–	–	0.2
Biological soil crust	2014	–	–	–	0.2	0
Biological soil crust	2015	–	0.1	–	–	–
Litter	2010	24.6	–	–	29.7	–
Litter	2011	37.9	–	57.7	–	–
Litter	2012	–	51.0	53.7	–	–
Litter	2013	–	57.7	–	–	74.8
Litter	2014	–	–	–	19.0	56.0
Litter	2015	–	25.8	–	–	–
Woody debris	2010	0.1	–	–	0	–
Woody debris	2011	0.2	–	0.2	–	–
Woody debris	2012	–	0.1	0.4	–	–
Woody debris	2013	–	0.2	–	–	0.2
Woody debris	2014	–	–	–	0.2	0.5
Woody debris	2015	–	0	–	–	–

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