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Natural Resource Stewardship and Science

Riparian Monitoring of Wadeable Streams at Armstrong Canyon, Natural Bridges National Monument

Summary Report, 2010–2018

Natural Resource Report NPS/NCPN/NRR—2019/1947



ON THE COVER

Armstrong Canyon near Owachomo Bridge, Natural Bridges National Monument. NPS/Amy Washuta.

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Summary Report, 2010–2018

Natural Resource Report NPS/NCPN/NRR—2019/1947

Prepared by
Dana L. Witwicki
Rebecca Weissinger
Northern Colorado Plateau Network
National Park Service
P.O. Box 848
Moab, UT 84532

Editing and Design
Alice Wondrak Biel
Northern Colorado Plateau Network
National Park Service
P.O. Box 848
Moab, UT 84532

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Executive Summary

The goal of Northern Colorado Plateau Network (NCPN) riparian monitoring of wadeable streams is to provide park managers with status and trend information on integrated hydrologic, geomorphologic, and vegetative attributes of these areas. This information is intended to provide early warning of resource degradation and determine natural variability of wadeable streams.

This report summarizes NCPN monitoring of Armstrong Canyon in Natural Bridges National Monument (NM) from 2010 to 2018. It outlines goals, methods, sampling design, and objectives of the network's wadeable streams monitoring. The goals of this report are to (1) present baseline vegetation and geomorphology data from four reaches (1, 2, 4, and 5) monitored in Armstrong Canyon from 2010 to 2014, (2) examine changes in geomorphology and vegetation resulting from multiple large flood events in September 2013 at the two reaches monitored before and after the floods, and (3) evaluate flood-stage data collected from 2014 to 2018.

Armstrong Canyon is a primarily ephemeral drainage the cuts through the Cedar Mesa sandstone, with bedrock often constraining the channel on at least one side. Straighter, narrower sections of canyon are common; these reaches have higher flood power and limited alluvial and vegetation development. Most of our repeat measurements in Armstrong Canyon occurred at this type of reach, similar to reaches 1 and 5. Changes at these locations tend to be stochastic, making longer-term trends more difficult to detect. More-substantial terraces and less bedrock are present at large bends in the canyon, similar to reaches 2 and 4, but there are relatively few areas like this in Armstrong Canyon.

Surveys of cross-section transects at Reach 5 conducted before and after the September 2013 floods showed some cutting in the channel (widening, deepening, or both) and some deposition on the floodplain along most transects. However, much of the surveyed cross-sections remained the same between years. Pebble counts showed that sand and gravels were also scoured from this reach. Repeat geomorphic surveys were not conducted at any other reaches, but repeat pebble counts at Reach 1 showed little to no change in particle-size distribution before and after the floods. Overall, changes in vegetation after the flash floods of September 2013 seemed minor, considering that flows were powerful enough to wash large trees down the canyon and perch one of them over three meters above the channel.

Vegetation was monitored before and after the floods at two reaches, and changes varied by reach. The main differences detected after the September 2013 floods were a reduction in the number of forb species present at Reach 5, a reduction of forb cover at Reach 1, and a reduction in the frequency of exotic species at Reach 5. Sediment deposition on the floodplain probably buried some forbs and exotic grasses, while flood waters may have washed away plants or part of the seedbank. A relatively rapid recovery of these species is expected because they are adapted to disturbance. Larger floods are well known to promote germination of cottonwood seedlings in riparian areas of the Southwest, and density of cottonwood seedlings increased 60 times after the floods at Reach 1—but not at all at Reach 5. However, cover of narrow-leaved cottonwood doubled after the floods at Reach 5, most likely due to increases in foliage on established seedlings and saplings.

Hydrologic data collection did not begin until spring 2014, and the data are highly variable in response to local weather patterns. Flash floods were common from 2014 to 2018, while more sustained flows from snowmelt were uncommon. The longest dry period within a water year at Reach 5 ranged from 23 to 214 days. The highest stage recorded in September 2017 was about 2.7 meters higher than the channel thalweg. This maximum recorded stage is similar to that indicated by flood debris at transects near the hydrologic sensor (2.4–3.0 meters higher than the channel thalweg) from the September 2013 flood.

Overall, there are many armored and scoured surfaces within Armstrong Canyon that are resistant to changes from flash floods. In addition, vegetation within the canyon appears to be well adapted to flash floods, and we detected fewer changes than expected after the September 2013 floods.

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1 Introduction

1.1 Background

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

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. 1988). Studies on the Colorado Plateau record change in geomorphic process 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 a river or a stream 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. For example, at finer scales, debris flow and landslide disturbances impinge directly 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 channel processes, which 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 land- and water-use activities 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 hydrographs with little or no base flow (Scott et al. 2005).
- **Active erosional and depositional processes.** The high, flashy peak flows and high sediment loads of Colorado Plateau streams can cause vertical aggradation of floodplains and channel incision that progressively disconnects riparian surfaces from surface flow in adjacent channels, creating terraces. Remnant terrace sequences from across the arid and semiarid western U.S., including the Colorado Plateau, record several climatically driven valley cut-and-fill cycles during the Holocene period (i.e., within the last 10,000 years) coincident with wetter and drier climate periods (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 reestablish 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).

1.2 Goals and objectives of the protocol

The overall goal of NCPN riparian monitoring of wadeable streams is to determine long-term trends in hydrologic, geomorphic, and vegetative properties of wadeable streams in the context of changes in other ecological drivers, stressors, and processes. Specific objectives of the riparian monitoring in Armstrong Canyon are to:

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

Depth to alluvial groundwater is not monitored in Armstrong Canyon due to shallow bedrock underlying the channel throughout much of the canyon. In addition, 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 ephemeral streams, such as Armstrong Canyon.

1.3 Resource issues driving riparian monitoring at Natural Bridges NM

Resource management staff selected Armstrong Canyon, one of two major drainages in the monument, for riparian monitoring of wadeable streams at Natural Bridges National Monument (NM; Figure 1-1). This canyon originates outside the monument, on Bureau of Land Management (BLM) land used primarily for backcountry recreation. It contains no notable threats from upstream uses. Within the park, Armstrong Canyon empties into White Canyon, the other main canyon in the monument and a major drainage in southeast Utah, ending in Lake Powell. Armstrong Canyon is an ephemeral stream that flows

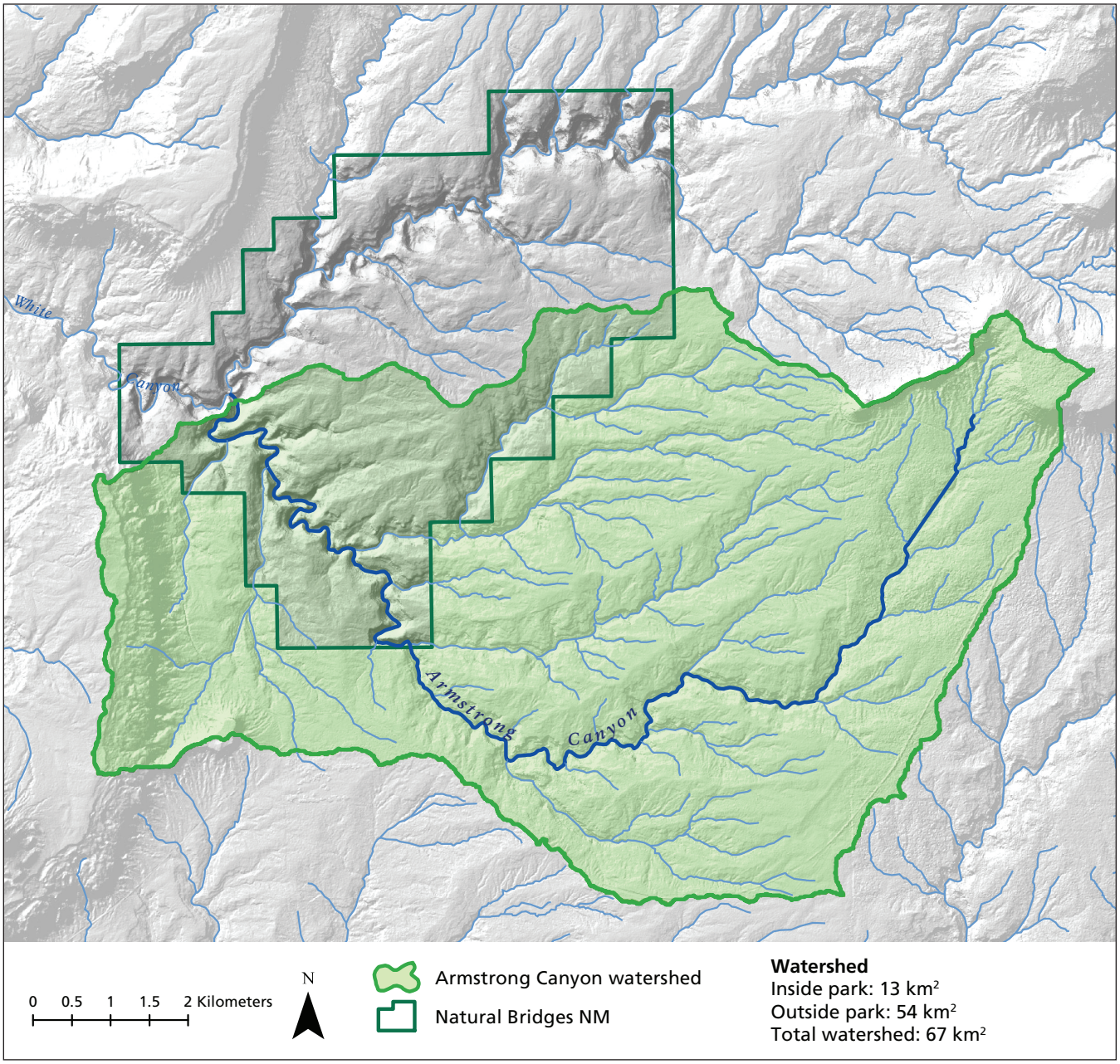


Figure 1-1. Watershed area (km²) of Armstrong Canyon, Natural Bridges National Monument.

after large precipitation events and contains some small perennial pools. It is susceptible to violent flash flooding because most of the canyon is bedrock-constrained, and it has high sinuosity (approximately 1.92). Due to its relatively small drainage area, flash flooding in Armstrong Canyon should generally be less severe than in White Canyon. Armstrong Canyon has a length of 20 kilometers (12.4 mi) and a watershed area of 67 km^2 (25.9 mi^2; see Figure 1-1). The monument contains approximately 37% of the length of Armstrong Canyon and 19% of the watershed area.

Monitoring helps us understand natural variability, especially changes related to flash floods, and provides early warning of system degradation due to human disturbances, especially from outside the park. It can also help detect new exotic plant species and shed light on the dynamics of exotic species within Armstrong Canyon.

1.3.1 Climate

Natural Bridges NM has a mean January low temperature of -6.9°C (19.5°F) and a mean July high temperature of 31.5°C (88.7°F). The area is considered semiarid, with mean annual precipitation of 312 millimeters (12.3 in). Precipitation tends to be somewhat evenly distributed throughout the year, with the exception that June is consistently the driest month. Precipitation in July–September (or sometimes even into October) is attributable to the North American Monsoon (hereafter, "monsoon"), but this precipitation source has high interannual 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.

1.3.2 Geomorphology

Armstrong Canyon is a shallow, narrow canyon cut within the Cedar Mesa Sandstone. It is approximately 60–75 meters (197–246 ft) deep and 15–75 meters (49–246 ft) wide along the canyon bottom (i.e., including the channel, floodplain, and any terraces between the bedrock walls). For most of its length, the channel is constrained by bedrock on one side. Alluvial surfaces, including the channel and floodplain, tend to be less distinct than for perennial streams in the region. When flash floods occur, they tend to scour the width of all surfaces below the uplands (i.e., everything below walls or high terraces).

1.3.3 Hydrology

For most of the year, Armstrong Canyon does not having flowing surface water. Snowmelt often causes a short run-off period during the spring, but most flows are directly attributable to seasonal monsoon storms and longer-duration Pacific storm fronts that can cause rapid, high-intensity flooding that ranges from hours to days in length. As such, hydrologic dynamics in Armstrong Canyon are highly stochastic and primarily related to climate variables, such as storm frequency and intensity.

The dominant geologic outcrop at Natural Bridges NM is Cedar Mesa sandstone, which serves as the primary aquifer in the monument (Thornberry-Ehrlich 2004). However, most springflow emerges from distinct seeplines in the cliff walls (Martin 2000) and does not contribute to instream flows. Some canyon reaches with greater development of riparian vegetation may have subsurface groundwater inputs. A few pools in Armstrong Canyon are considered perennial (Schelz and Moran 2005), but these pools likely consist of a perched shallow alluvial aquifer over bedrock rather than an intersection with a deeper groundwater source (D. Sharrow, pers. comm.). Surface-water dynamics dominate groundwater dynamics in this system.

1.4 Study objectives

The purposes of this report are to (1) present baseline vegetation and geomorphology data from four reaches monitored in Armstrong Canyon from 2010 to 2014, (2) examine changes in geomorphology and vegetation resulting from multiple large flood events in September 2013 at the two reaches that were monitored before and after the floods, and (3) to evaluate flood-stage data collected from 2014 to 2018.

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 to provide inference to the entire sampling frame of the stream within the park.

2.1.1 Sampling frame delineation

Armstrong Canyon runs through Natural Bridges NM for 7.4 kilometers (4.6 mi). Established hiking trails enter the canyon at Owachomo Bridge and Kachina Bridge, providing access to all areas of the canyon with <3 kilometers (<1.9 mi) hiking distance. An analysis of the watershed area of Armstrong Canyon (total area of 67 km^2) confirmed that all tributaries have relatively small watersheds; the largest tributary, Tuwa Canyon, has a watershed of 14 km^2. The entire stretch of Armstrong Canyon within Natural Bridges NM 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 10 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 five ac-

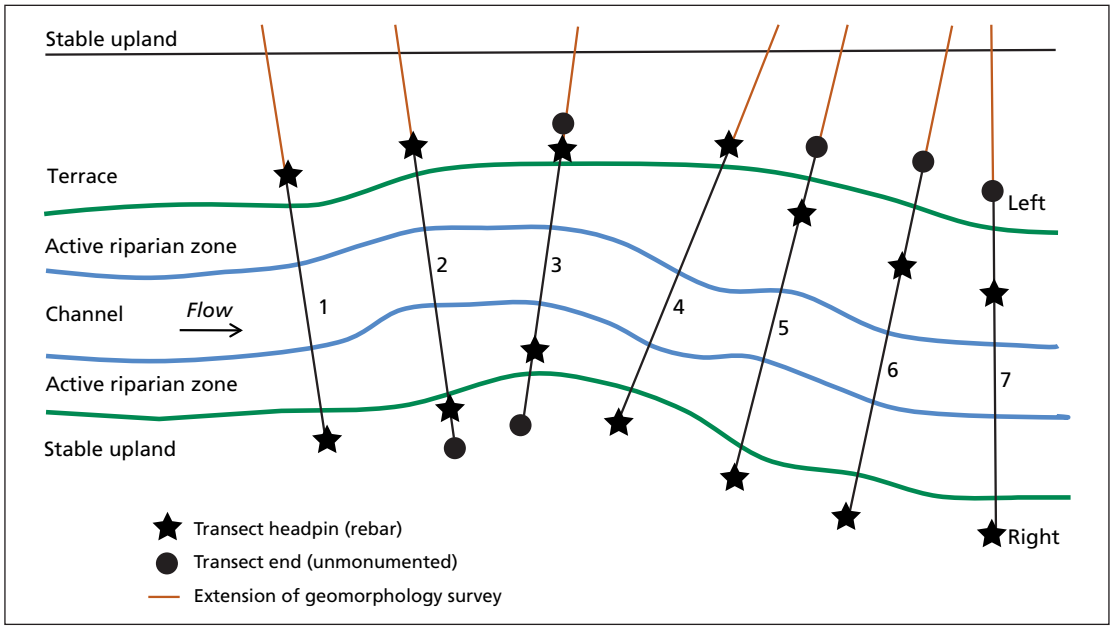


Figure 2-1. Example of a riparian monitoring reach with seven equidistant cross-section transects. Star symbols indicate locations of headpins. Black circles indicate the locations of transect endpoints that cannot be monumented due to bedrock or highly unstable surfaces. The green line represents the upland/riparian zone boundary, and "4" is the location of the reach centroid. Geomorphology transects extend to a stable upland surface.

ceptable monitoring reaches (in ascending order of reach number) were selected for long-term monitoring (Figure 2-2). Reach 3 was rejected for long-term monitoring because it was located at the confluence of Tuwa and Armstrong canyons (i.e., approximately midway between reaches 5 and 6) and thus contained a major tributary.

2.1.3 Revisit design

Vegetation and geomorphology monitoring occur at all reaches. A rotating panel-revisit design was used to increase the overall sample size. The revisit design attempts to balance the need for observing inter-annual 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 five reaches were scheduled to be monitored in Armstrong Canyon, with vegetation sampled during the growing season at two reaches each year (Table 2-1). Two reaches are sampled each year, with five unique reaches sampled over five years. The sampling order of the five reaches was changed (i.e., they are not sequentially sampled from 1 to 6) so that two reaches located very close together were not sampled in the same year (see Figure 2-2 and Table 2-1). In the revisit design, vegetation is sampled at each reach for two consecutive years to tease out year-to-year differences due to temperature, precipitation, flow, and other factors, and to better estimate trends. After two years

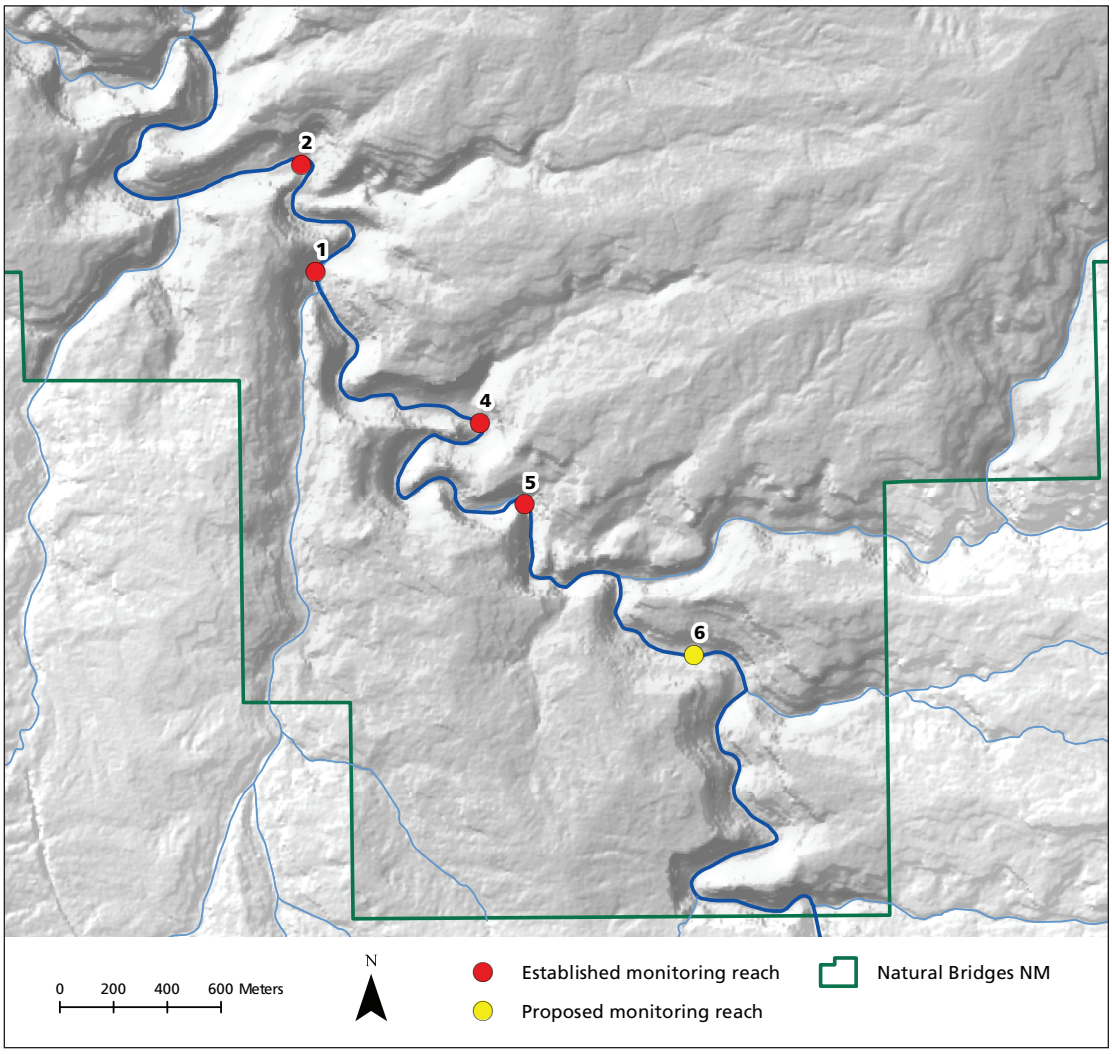


Figure 2-2. Overview map of monitoring reaches in Armstrong Canyon, Natural Bridges National Monument, including the reaches established and monitored from 2010 to 2018. Monuments were established at Reach 6, but this reach has not yet been monitored.

of sampling, the reach is then rested for three years. Geomorphology surveying occurs during leaf-off between the two growing seasons when vegetation is sampled so it can be linked to both years of data when no major flood events occur. 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 in an in-channel well casing with a pressure transducer. Reach 5 was selected for hydrologic monitoring due to its accessibility, the presence of a relatively straight section of channel for instrumentation, and the presence of a boulder suitable for mounting the well casing. Water levels are recorded at 15-minute intervals. Information from the data loggers, as well as manual water level measurements, are collected 2–4 times each year. Transects with loggers are surveyed every year.

2.1.4 Reaches monitored, 2010–2018

For the first three years of monitoring, reaches were, for the most part, established and monitored according to our long-term monitoring design (Table 2-2). Riparian monitoring in Armstrong Canyon was initiated in September 2010, with the establishment of reaches 1 and 5, and vegetation monitoring at these reaches. In June 2011, Reach 2 was established and vegetation was monitored at reaches 2 and 5. Reaches 1 and 5 were surveyed in October 2011, and Reach 2 was surveyed in March 2012. In June 2012, Reach 4 was established and vegetation was monitored at reaches 2 and 4. Figure 2-3 shows each monitored reach.

There was no monitoring in Armstrong Canyon in 2013, due to the federal government budget sequestration and related budget cuts. Anticipating future budget cuts, and wanting to document any changes from the flash floods of September 2013, we decided not to continue establishing new reaches in 2014. Instead, we revisited reaches 1 and 5. Geomorphology at Reach 5 was re-surveyed in March 2014, and vegetation was monitored at reaches 1 and 5 in June 2014. A pressure transducer that measures stage of instream flow was installed at Reach 5 in March 2014 (Figure 2-3). Monuments were installed at the transect ends of Reach 6 during the June 2014 visit, but this reach has not been sampled to date.

Table 2-1. Five-year rotating-panel revisit design for long-term monitoring of riparian vegetation in Armstrong Canyon, Natural Bridges National Monument.

Reach #	Year sampled*									
	1	2	3	4	5	6	7	8	9	10
1	✓	–	–	–	✓	✓	–	–	–	✓
5	✓	✓	–	–	–	✓	✓	–	–	–
2	–	✓	✓	–	–	–	✓	✓	–	–
4	–	–	✓	✓	–	–	–	✓	✓	–
6	–	–	–	✓	✓	–	–	–	✓	✓

*Actual sampling differed from this approach due to budget cuts and a large flood in 2013.

From 2015 to 2018, riparian monitoring at Natural Bridges NM became a lower priority for the Southeast Utah Group national parks, and vegetation and geomorphology monitoring at the park were cut due to budget and personnel limitations. 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 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). On some transects, permanent bedrock markers were also added so transects could be relocated if a headpin washed away. Kevlar taglines marked at one-meter intervals were strung between the headpins and used to guide transect-tape placement and surveying.

2.2.1 Hydrology measurements

One instream flood frequency recorder was installed in a vented PVC well casing bolted

Table 2-2. Elevation, location, mean transect length, type of visit, and years visited for each monitoring reach in Armstrong Canyon, Natural Bridges National Monument, 2010–2018.

Reach[a]	Elevation (m)[b]	Reach centroid UTM coordinates[c]		Reach length (m)	Mean transect length[d] (cm)	Type of visit	Years visited[e]							
		Northing	Easting				2010	2011	2012	2014	2015	2016	2017[f]	2018
1	1,757	4160992	586010	180	26.7	vegetation	✓	–	–	✓	–	–	–	–
						geomorphology	–	✓	–	–	–	–	–	–
						hydrology	–	–	–	–	–	–	–	–
2	1,749	4161391	585958	206	46.7	vegetation	–	✓	✓	–	–	–	–	–
						geomorphology	–	–	✓	–	–	–	–	–
						hydrology	–	–	–	–	–	–	–	–
4	1,768	4160431	586621	222	60.2	vegetation	–	–	✓	–	–	–	–	–
						geomorphology	–	–	–	–	–	–	–	–
						hydrology	–	–	–	–	–	–	–	–
5	1,780	4160127	586788	180	26.6	vegetation	✓	✓	–	✓	–	–	–	–
						geomorphology	–	✓	–	✓	–	–	–	–
						hydrology	–	–	–	✓	✓	✓	✓	✓

aReach 3 was rejected and therefore was not monitored. Data have not been collected from Reach 6 due to the monitoring rotation and budget cuts.

bElevation from 5 m Digital Elevation Model (Utah Automated Geographic Reference Center).

[c]NAD83 Zone 12.

[d]Mean of current transect lengths. At Reach 1, the length of two transects decreased by 2–4 meters in 2014.

[e]No sampling was done in 2013, due to the federal budget sequestration and budget cuts.

[f]No transect surveys were done in 2017.

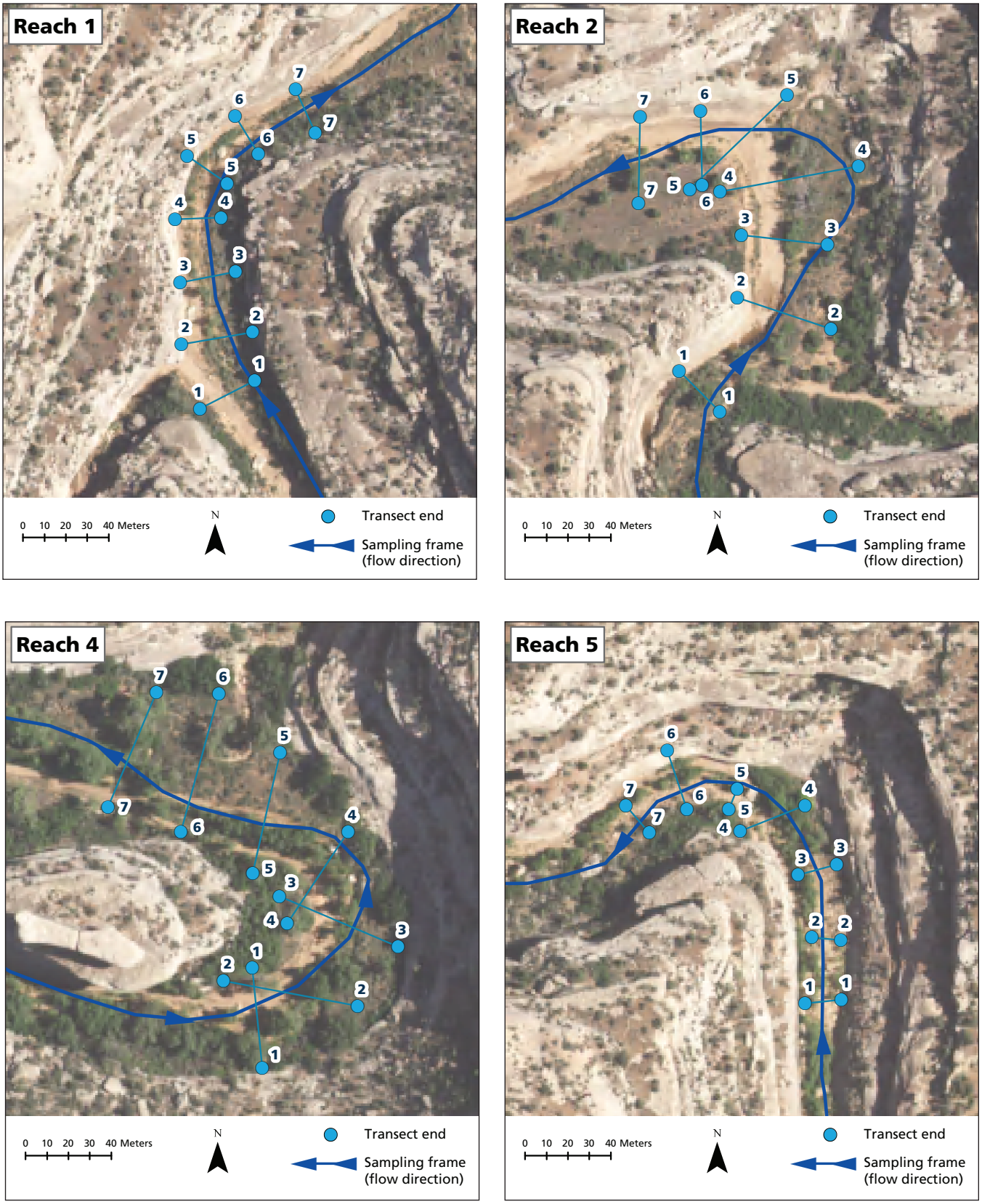


Figure 2-3. Reaches 1, 2, 4, and 5 in Armstrong Canyon, Natural Bridges National Monument.



Figure 2-4. Flood-frequency installation at Reach 5, Armstrong Canyon, Natural Bridges National Monument.

to the downstream side of an in-channel boulder near Transect 2 of Reach 5 (Figure 2-4). Due to the presence of shallow bedrock in the channel, a hydrologic monitoring well could not be installed. Surveys of the well casing and control points in 2015, 2016, and 2018 indicate the well-casing elevation has remained stable over time. A pressure transducer hangs inside the well casing, with the sensor approximately 18.4 centimeters higher than the channel thalweg. The casing is mounted in a section of channel where water pools, and water can persist after the canyon stops flowing.

The pressure transducer records water elevation at 15-minute intervals. 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 2–4 times per year.

2.2.2 Geomorphology measurements

Geomorphology was measured primarily through pebble counts and stream-channel surveys. Pebble counts were conducted at each transect to monitor particle-size distribution within the channel. Pebble counts were performed each time vegetation was monitored because air and water temperatures are typically too cold to perform this measurement during surveys.

Stream-channel surveys were performed at each reach using a 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 throughout the reach at one-meter intervals 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 this location (e.g., at Reach 5 between transects 1 and 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 groundcover attributes at 0.5-meter intervals along each transect (Figure 2-5). Density and diameter at breast height (dbh) of trees were recorded by species in a five-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 of ≥25-centimeter 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.

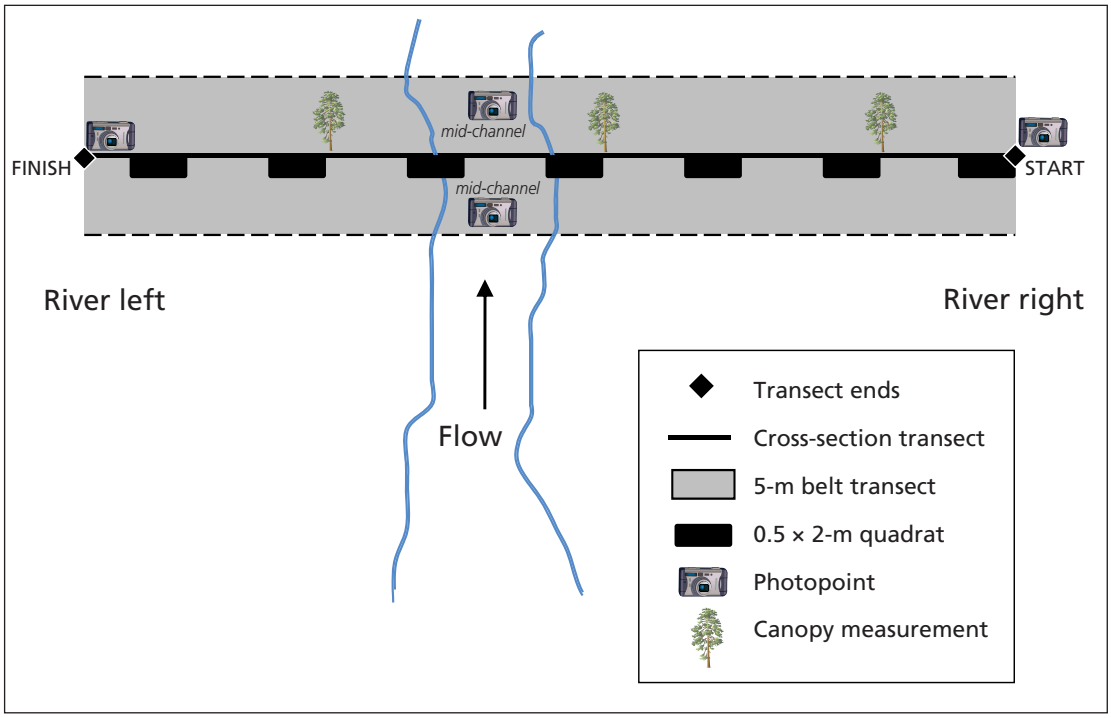


Figure 2-5. Locations of vegetation sampling along each permanent cross-section transect. Understory vegetation is sampled using a point-intercept method at 0.5-meter intervals along the cross-section. Canopy closure is sampled at 10-meter intervals on the cross-section. Seedling, sapling, and overstory tree density is recorded in a five-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.

2.3 Data summary, quality checks, and statistical procedures

2.3.1 Climate data

Because hydrologic monitoring did not begin until April 2014, climate data were summarized to better understand the drivers of changes in geomorphology and vegetation in the reaches. Climate data from the National Weather Service Cooperative Observer Network (COOP) station located at the Natural Bridges NM Visitor Center (station ID #426053) were 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 2018 (start of 2019 water year). Any month with more than three days of precipitation or five days of temperature missing was marked as N/A. There were no missing months of data for precipitation, but several missing months for temperature. In addition, daily precipitation totals were evaluated to look for possible high-flow events that occurred before the hydrologic monitoring equipment began operating.

2.3.2 Hydrology data

Hydrologic data were barometrically compensated and adjusted to match the manual water-level measurement taken during each site visit. If the logger was dry during the site visit, then the measurement was set to the elevation of the logger sensor, approximately 18.4 centimeters above the channel bottom. Compensated and adjusted hydrologic data were imported into the Aquarius database 3.10, where data corrections were applied, such as deleting dry periods, identifying ice effects, and adjusting for sensor drift. A complete list of corrections is provided in Appendix A. The corrected water-elevation data were then converted to the site's permanent datum. Final, approved datasets are publicly available at the National Park Service's Aquarius web portal (https://irma.nps.gov/aqwebportal/). Data were summarized and analyzed using R 3.5.1 (R Core Team 2018). Flood peaks were counted visually as any hydrologic peak separated by more than 12 hours from another hydrologic peak. When possible, flood peaks were confirmed by comparing the presence of a peak to the daily precipitation record. However, because of

the distance between the monitoring reach and the location of the COOP weather station, precipitation records do not always predict the presence of a flood peak.

2.3.3 Survey data

For hydrologic monitoring, acceptable survey errors were <1 centimeter vertically and <5 centimeters horizontally. For geomorphology, acceptable survey errors were <3 centimeters vertically and <5 centimeters horizontally. Any time errors exceeded these amounts, the source of the error was determined and the survey was re-done until it fell within an acceptable level.

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. For all reaches, survey data were collected in an arbitrary, local coordinate system. Figures that display elevations at all reaches use this arbitrary coordinate system. 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 unmonumented transect endpoints (when present). For Reach 5, the only reach that was resurveyed after the September 2013 floods, flood debris surveyed in March 2014 was included in the cross-section figures to estimate stage of the floods, because hydrologic monitoring instrumentation was not yet installed.

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 at Reach 5, transect stations were shifted by the mean difference of transect locations between visits, which lined up the middle transects fairly well. As they move away from the center of the reach, the transects line up less well on the profile figure due to a longer (i.e., windier) thalweg surveyed in 2011. The transects were placed in the same locations in 2011 and 2014.

When water was present at all transects of a reach (e.g., at Reach 2), the channel slope was calculated by subtracting the elevation of the lowest water surface (at transect 7) from the elevation of the highest water surface (at transect 1). This is the standard method NCPN uses to calculate channel slope for wadeable streams. When water was not present at all transects of a reach (e.g., at reaches 1 and 5), the channel slope was calculated by subtracting the elevation of the thalweg of the lowest transect (at transect 7) from the elevation of the thalweg of highest transect (at transect 1). The water levels at transects 1 and 7 at Reach 2 were very shallow (see Figure 3-5), so measurements of channel slope using the alternative method for ephemeral streams should be comparable to the standard method, at least for the three reaches monitored during this study.

Sinuosity was calculated for each reach by dividing the total reach length by the straight-line distance between the thalweg at transects 1 and 7.

2.3.4 Vegetation and pebble-count data

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

Species richness by lifeform and wetland status was calculated using species detected while sampling plant cover, seedling and tree density, the reach census, and exotic frequency. Species-richness data were not calculated for 2010, when exotic frequency was not collected, making that year not comparable with other years (i.e., the number of species would likely be underestimated 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 was 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 were calculated from data collected in the one-meter and five-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 binned and summed by size class and species.

For all measurements in this section, data were summarized by reach. No statistical tests were performed in this initial data summary because there were not enough data to detect trends, and meaningful before-and-after comparisons were difficult to delineate without the accompanying hydrologic data for the same time period. 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) and figures were created with ggplot2 (Wickham 2016).

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

The length of two transects decreased 2–4 meters at Reach 1 in 2014. The crew was unable to determine if this was due to a recording error during the earlier visit or if something moved along the transects to create additional slack in the tape. In some cases, this affected our ability to make comparisons between visits. Instances in which this was potentially an issue are noted in the text.

3 Results

3.1 Climate

In the nine months before our initial monitoring at Natural Bridges NM (September 2010), there were six months when precipitation was higher than average (Figure 3-1). In addition, high daily precipitation totals occurred in December 2009 and August 2010 (Table 3-1).

The 2013 monsoon was wetter than average (see Figure 3-1), especially during the first two weeks of September. These same storms did a great deal of damage to roads, houses, and other infrastructure on the Colorado Front Range. Three of the highest daily precipitation totals from 2009 to 2018 occurred during the 2013 monsoon—including the two wettest days, on September 10 and 15, 2013 (see Table 3-1).

Two droughts occurred during our monitoring period. The first occurred between June 2011 and June 2012, when precipitation was lower than normal for most months (see Figure 3-1). The second drought occurred between March 2017 and September 2018, when precipitation was lower than normal

Table 3-1. Ten highest daily-precipitation totals, Natural Bridges National Monument COOP climate station, 2009–2018.

Date	Precipitation in cm (in)
09/10/2013	5.08 (2.0)
09/15/2013	3.89 (1.5)
12/08/2009	3.28 (1.3)
09/09/2014	3.05 (1.2)
08/01/2010	3.02 (1.2)
08/24/2012	2.84 (1.1)
08/27/2013	2.64 (1.0)
10/07/2018	2.59 (1.0)
08/04/2016	2.41 (1.0)
09/15/2017*	2.31 (0.9)

*Our hydrological sensor recorded the peak flow of record on 9/14/17. The precipitation that caused it fell on that day but was recorded at the climate station the following morning (9/15/2017).

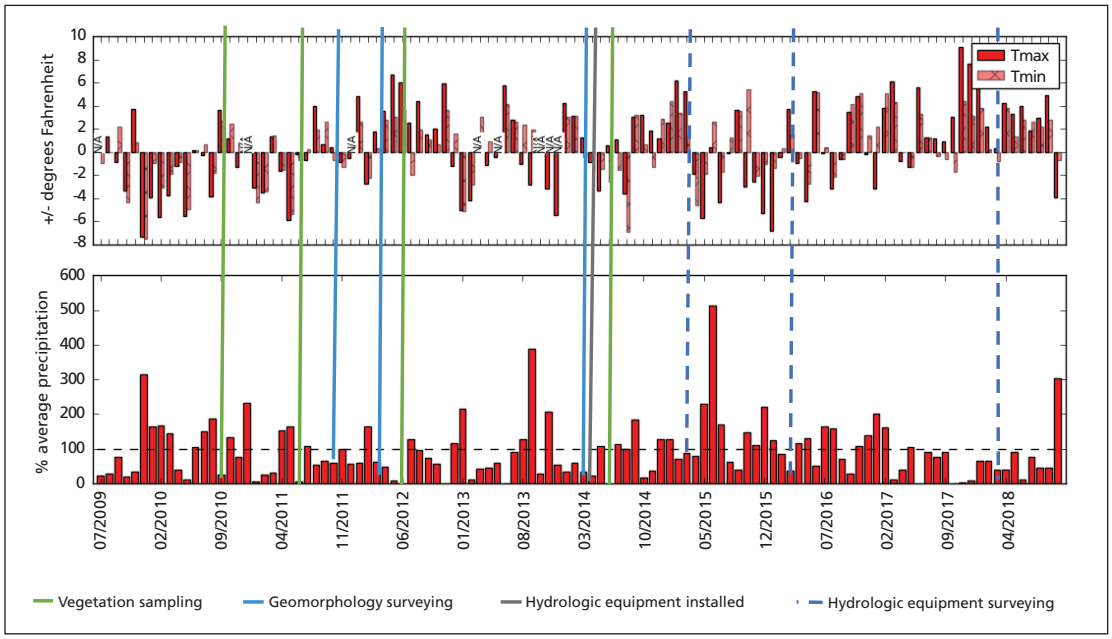


Figure 3-1. Departures from the 30-year average (1981–2010) for minimum temperature, maximum temperature, and precipitation from July 2009 (start of monsoon season the year before NCPN monitoring began) to October 2018 (start of 2019 water year) at Natural Bridges National Monument COOP climate station 426053. Vertical lines show months when sampling occurred. Any month with more than three days of precipitation or five days of temperature missing was marked as N/A.

Table 3-2. Total precipitation by water year, Natural Bridges National Monument COOP climate station, 2009–2018.

Water year	Precipitation in cm (in.)
2009	19.6 (7.7)
2010	37.3 (14.7)
2011	28.2 (11.1)
2012	25.4 (10.0)
2013	38.3 (15.1)
2014	27.9 (11.0)
2015	33.2 (13.1)
2016	39.5 (15.6)
2017	28.5 (11.2)
2018	13.4 (5.3)

for 16 consecutive months (see Figure 3-1) and very low for the 2018 water year (Table 3-2).

3.2 Hydrology

Due to shallow bedrock in the channel, the hydrologic sensor is positioned about 18.4 centimeters above the channel thalweg, in an area where water pools. Surface flows must be higher than this elevation to be recorded by the sensor, and periods of pooled vs. flowing conditions cannot be assessed with our data. Flood peaks can be distinguished visually due to their steep rise and fall. Occasionally, multiple peaks can occur during a single flood event because of discrepancies in when individual tributaries begin to flow. Because most flood events are of short duration, we used a separation of 12 hours between peaks as a cutoff to distinguish individual flow events.

The presence of surface water above the elevation of the pressure-transducer sensor at Reach 5 varied widely (Figure 3-2) and responded to local precipitation (Table 3-3). Flow events can occur during any time of year, although annual peak flows commonly occur during the seasonal monsoon period. The peak flow of record was 1,978.68 meters on September 14, 2017, when flood water rose 2.5 meters above the sensor (Figure 3-3). Prolonged wet periods in the winter and spring (November–April) are due to a pool in the logger location that is able to persist over time because of low evapotranspiration in addition to surface-flow events, sometimes including spring snowmelt. The number of

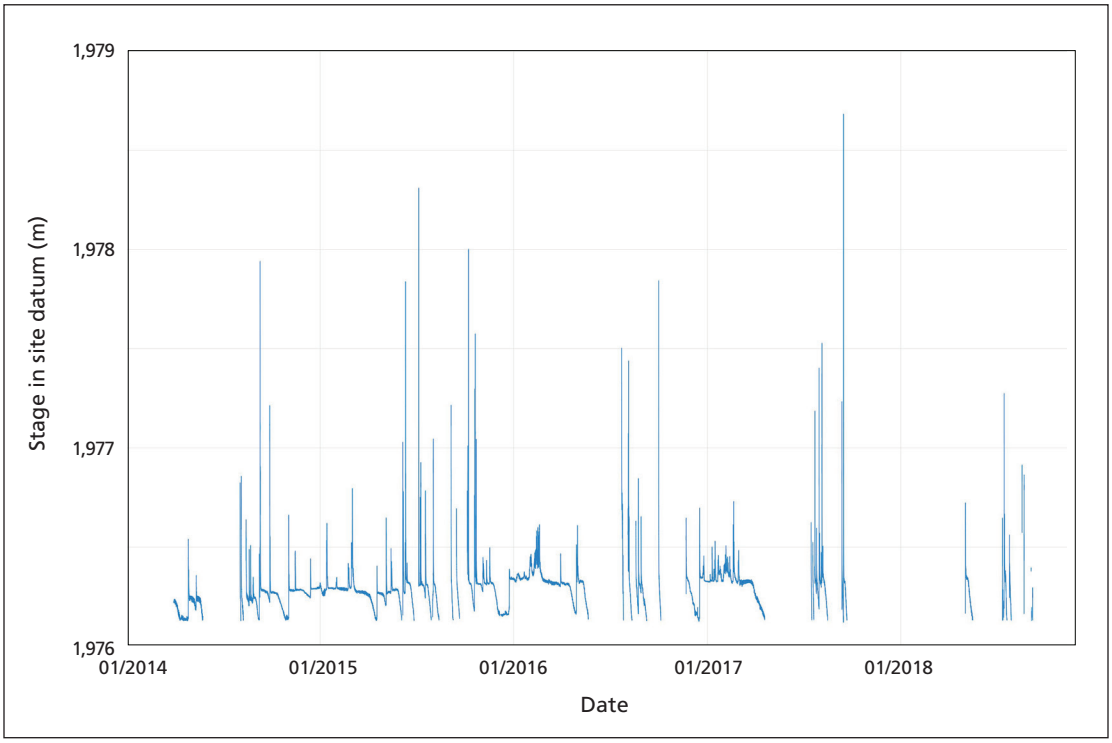


Figure 3-2. Water elevation at Reach 5 recorded in the permanent datum (m), April 2014–September 2018, Armstrong Canyon, Natural Bridges National Monument. Periods when the water elevation fell below the sensor elevation of 1,976.13 meters are shown as gaps in the record.

Table 3-3. Hydrologic summary by water year (October–September) as recorded at the Natural Bridges National Monument COOP climate station, located at the visitor center.

Water year	Precipitation (cm)	Cumulative wet days (days in year)	Longest dry period (days)	Number of peaks	Peak instantaneous stage (m)	Peak stage date
2015	33.2	312.8 (365)	22.7	33	1,978.31	7/5/2015
2016	39.5	258.2 (366)	62.7	32	1,978.00	10/7/2015
2017	28.5	189.6 (365)	87.6	52	1,978.68	9/14/2017
2018	13.4	24.5 (365)	213.9	13	1,977.27	7/14/2018

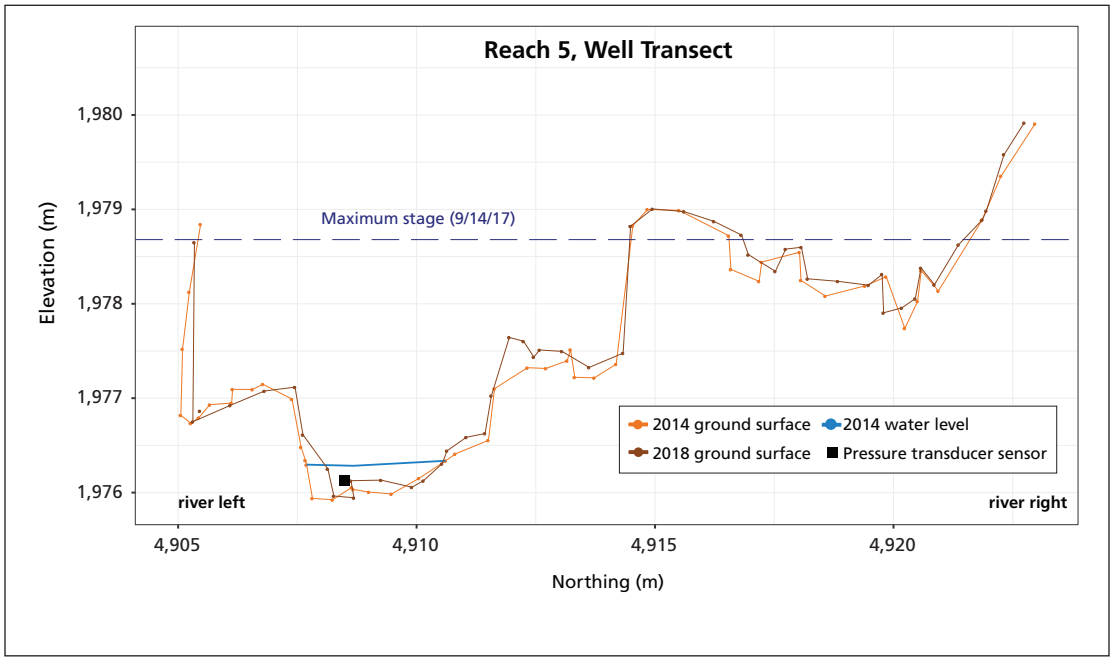


Figure 3-3. Maximum instantaneous flood stage for water years 2015–2018, recorded September 14, 2017, along hydrologic cross-section transect at Reach 5 (between transects 1 and 2), Armstrong Canyon, Natural Bridges National Monument. Survey data were recorded in March 2014 and March 2018. No water was present along the transect in the 2018 survey.

wet days is more closely related to monthly precipitation in the warmer months of the pre-monsoon (May–June) and monsoon (July–October) seasons (Figure 3-4) than during winter. Water year 2018 was one of the driest on record, with no persistent pool over the winter, no spring run-off recorded, a seven-month dry period from October through April, and only 13 flood peaks.

3.3 Geomorphology

3.3.1 Cross-section survey

Only Reach 5 was surveyed multiple times during our monitoring. The second survey, in March 2014, occurred after large flash floods in September 2013. The differences between data from 2014 and earlier years helps give us insight on the type and magnitude of geomorphic changes caused by large flood events. Reaches 1 and 2 were each surveyed one time. A general description of the cross-sections of each reach is provided.

Reach 5 is one of the narrower reaches we monitored (see Table 2-2), with bedrock walls on both sides of the survey transects (see Figure 2-4). Flood debris surveyed in 2014 was approximately 2–4 meters above the channel (2.4 m above the thalweg at Transect 1 and 3.0 m above the thalweg at Transect 2, the two transects nearest to the hydrologic equipment; Appendix B), suggesting that the maximum stage of the September 2013 floods was similar or possibly even higher than the maximum stage recorded by the hydrologic monitoring equipment in September 2017.

Changes in channel cross-sections after the large flash floods of September 2013 varied by transect (Appendix B). Overall, much of the surveyed cross-sections remained the same between 2011 and 2014. Along Transect 1, the main channel and three smaller side channels were cut deeper in 2014 compared to 2011. At Transect 6, the channel was also cut deeper, and the main channel appeared to switch locations to a channel approxi-

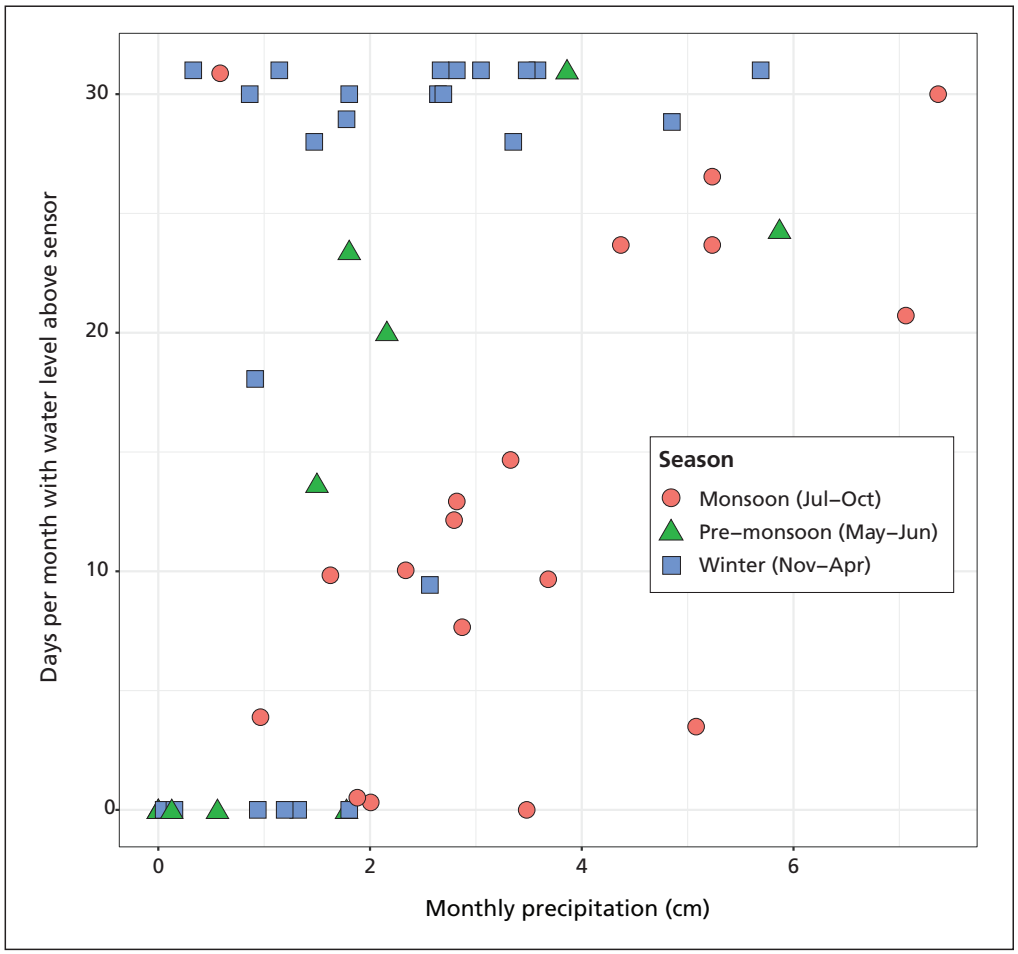


Figure 3-4. Number of wet days per month and amount of monthly precipitation, Armstrong Canyon, Natural Bridges National Monument, May 2014–September 2018. Monthly wet days are related to monthly precipitation in the pre-monsoon and monsoon period, but water is more likely to persist during winter months, even with low precipitation. Wet periods only include water levels above the hydrologic-sensor elevation, about 18.4 centimeters above the channel bottom.

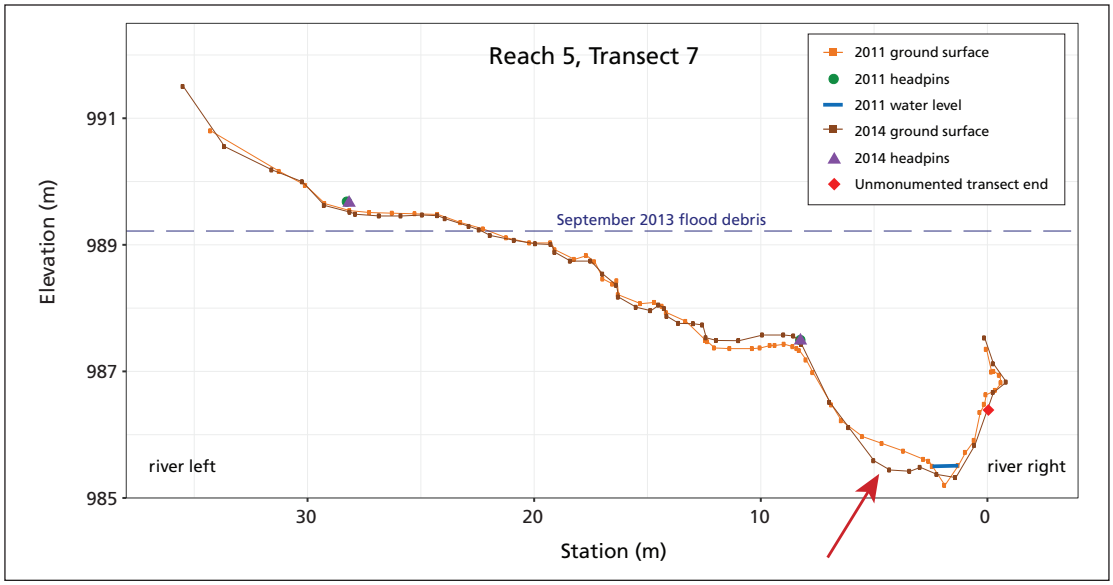


Figure 3-5. Cross-section of Reach 5, Transect 7, looking downstream, Armstrong Canyon, Natural Bridges National Monument, 2011 and 2014. No water was present in 2014. A blue dashed line shows the elevation of debris from the September 2013 floods detected during the 2014 survey. Note that the x-axis is displayed with numbers descending in order to match vegetation-monitoring locations along the transect.

mately eight meters away in 2014 compared to 2011. On transects 3–7, the main channel was wider in 2014 than in 2011. At Transect 7, there was a substantial amount of scouring associated with the widening—nearly 0.5 m of scouring on the left side of the channel (see red arrow in Figure 3-5). There was some deposition on the terraces at transects 3–6, as well as a large deposit on the right side of the channel at Transect 1 in 2014. There was almost no cutting or deposition along Transect 2. Repeat photos from 2014 show that a large cottonwood trunk was washed into the reach (Figure 3-6), most likely during the flash floods of September 2013.

Reach 1 is one of the narrower reaches we monitored (see Table 2-2). The channel is located on river left, against a bedrock wall, for most of the transects (Appendix B). There is a low terrace on the right side of the reach along some transects. No water was present when the reach was surveyed in October 2011.

Reach 2 is located on a sharp left turn in the canyon (see Figure 2-3). The channel moves from river left in the upstream part of the reach to river right in the downstream part of the reach (see Appendix B). This reach is wider and has longer transects than reaches



Figure 3-6. Photo (facing downstream) of Reach 5, Transect 4, Armstrong Canyon, Natural Bridges National Monument, June 2011 (left) and June 2014 (right). The channel surface and shrubs changed little after high-flow events in September 2013, but a large cottonwood trunk was washed into the reach and is apparent in the later photo. NPS photos.

1 and 5 (see Table 2-2). All transects have substantial terraces on one or both sides (Appendix B), and a small side channel enters the reach between transects 1 and 2 (see Figure 2-3). There was standing water at all of the transects when this reach was surveyed in March 2012.

3.3.2 Profile survey

Overall, the reaches had a mean channel slope of 10.1 meters per kilometer (Table 3-4, Figure 3-7). Reach 5 was the steepest (mean of 18.1 m/km across visits). Reach 2 had the gentlest channel slope (5.1 m/km). At Reach 5, channel slope was similar in 2011 and 2014 (18.9 m/km and 17.3 m/km, respectively; see Table 3-4, Figure 3-7).

The reaches had a mean sinuosity of 1.56 (see Table 3-4). The sinuosity of reaches 1 and 5 (1.27 and 1.34, respectively) was much lower than the sinuosity of Reach 2 (2.06), which was more similar to the overall sinuosity of Armstrong Canyon in Natural Bridges NM (1.92). The sinuosity at Reach 5 was nearly identical between visits (1.35 in 2010 versus 1.34 in 2014). Reach 4 was not surveyed due to budget cuts and prioritization.

3.3.3 Pebble count

The distribution of particle sizes was similar at all three reaches, consisting primarily of sand and gravel (Figure 3-8). Overall, the reaches had a mean d50 of 4 millimeters (see Table 3-4), which classifies Armstrong Canyon as a gravel-bed stream with a bimodal grain-size distribution. The mean d84 for all reaches was 54 millimeters (see Table 3-4). The only notable difference in particle sizes among the reaches was for d84, which was much higher for Reach 5 than for the other reaches (see Table 3-4).

There was a notable decrease in the percent of sand and gravels at Reach 5 in 2014 (after the September 2013 floods) compared to 2010 and 2011 (see Figure 3-8), and d50 increased from 1 in 2010 and 2011 to 9 in 2014 (see Table 3-4). Reach 1, which was also monitored in 2010 and 2014, had very little change in particle sizes over this period of time, including a slight increase in the percent of sand and gravels (see Figure 3-8). The percent of fines at Reach 2 decreased from 2011 to 2012 (see Figure 3-8), but it is not clear if this was related to a high-flow event.

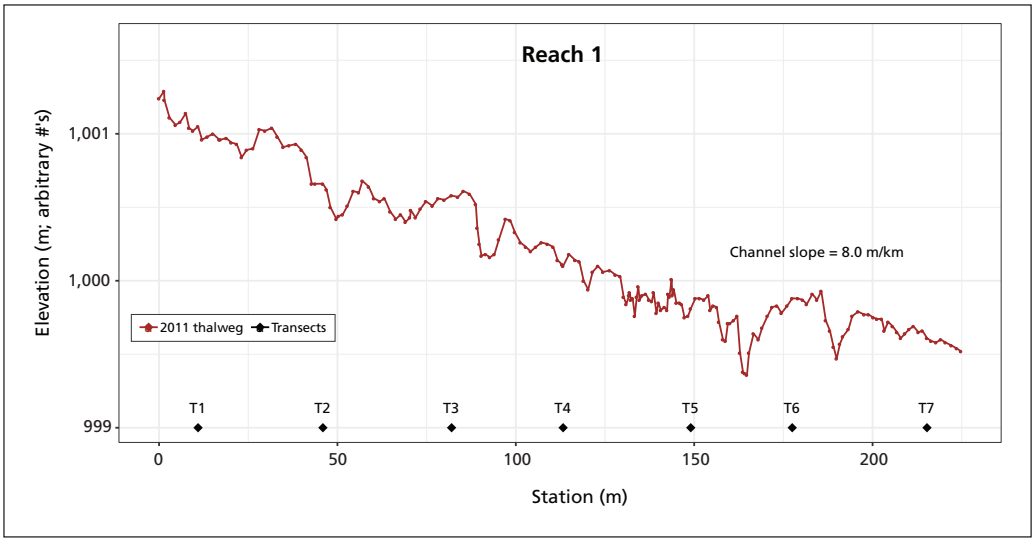
Table 3-4. Summary of stream-channel characteristics at monitoring reaches, Armstrong Canyon, Natural Bridges National Monument.

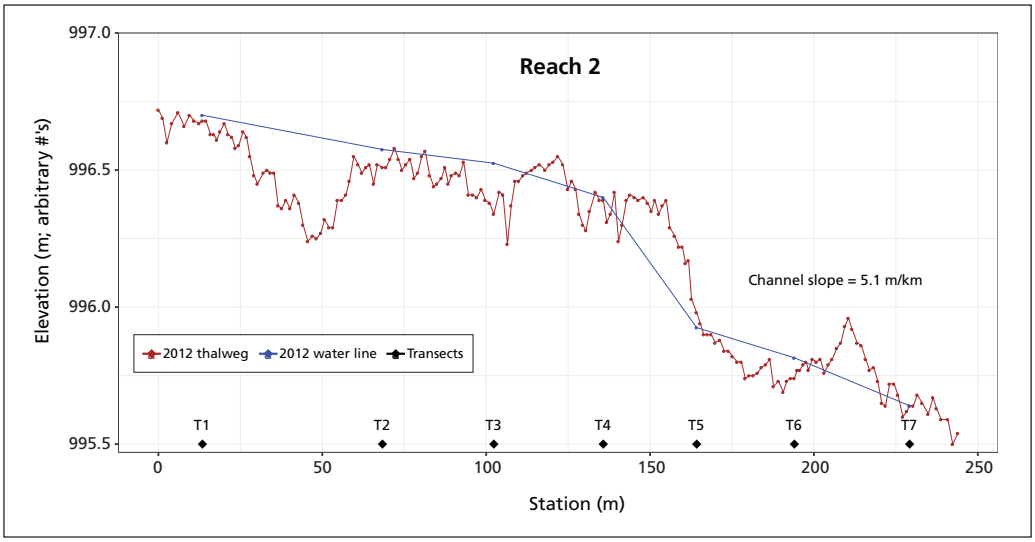
Parameter	Year	Reach 1	Reach 2	Reach 4[a]	Reach 5	Mean[b]
Channel slope (m/km)	2011	8.0	–	–	18.9	
	2012	–	5.1	NA	–	10.1
	2014	–	–	–	17.3	
Sinuosity	2011	1.27	–	–	1.35	
	2012	–	2.06	NA	–	1.56
	2014	–	–	–	1.34	
Diameter of 50th percentile streambed particle (mm)	2011	1[c]	–	–	1	
	2012	–	6	1	–	4
	2014	–	–	–	9	
Diameter of 84th percentile streambed particle (mm)	2011	35[c]	–	–	137	
	2012	–	27	23	–	54
	2014	–	–	–	130	

[a]Because Reach 4 was not surveyed, data for channel slope and sinuosity are not available. Data on particle diameter are collected during vegetation monitoring.

[b]Mean of most recent measurements at each reach.

[c]Collected during 2010 vegetation monitoring.





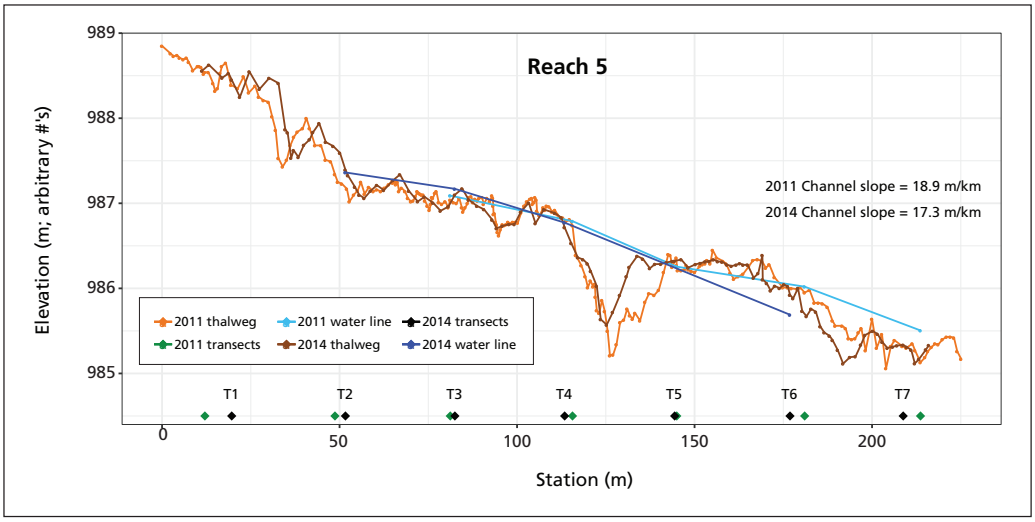


Figure 3-7. Longitudinal profile of Reach 1 (October 2011), Reach 2 (March 2012), and Reach 5 (October 2011 and March 2014), Armstrong Canyon, Natural Bridges National Monument. The elevation of the thalweg is plotted for the length of each reach. The elevation of the water surface was surveyed on the left and right sides of the channel where each transect crossed. This was used to determine the channel slope of reaches where water was present on all transects (e.g., Reach 2). At Reach 5, there was a longer (i.e., windier) thalweg between the transects in 2011 compared to 2014. Therefore, the surveyed locations do not line up as well as they move out from the center transects. Also at Reach 5, Transect 6, the water level surveyed on the cross-section was in a lower pocket not connected with the main thalweg. This makes it appear as though the water level is below the surface in the figure.

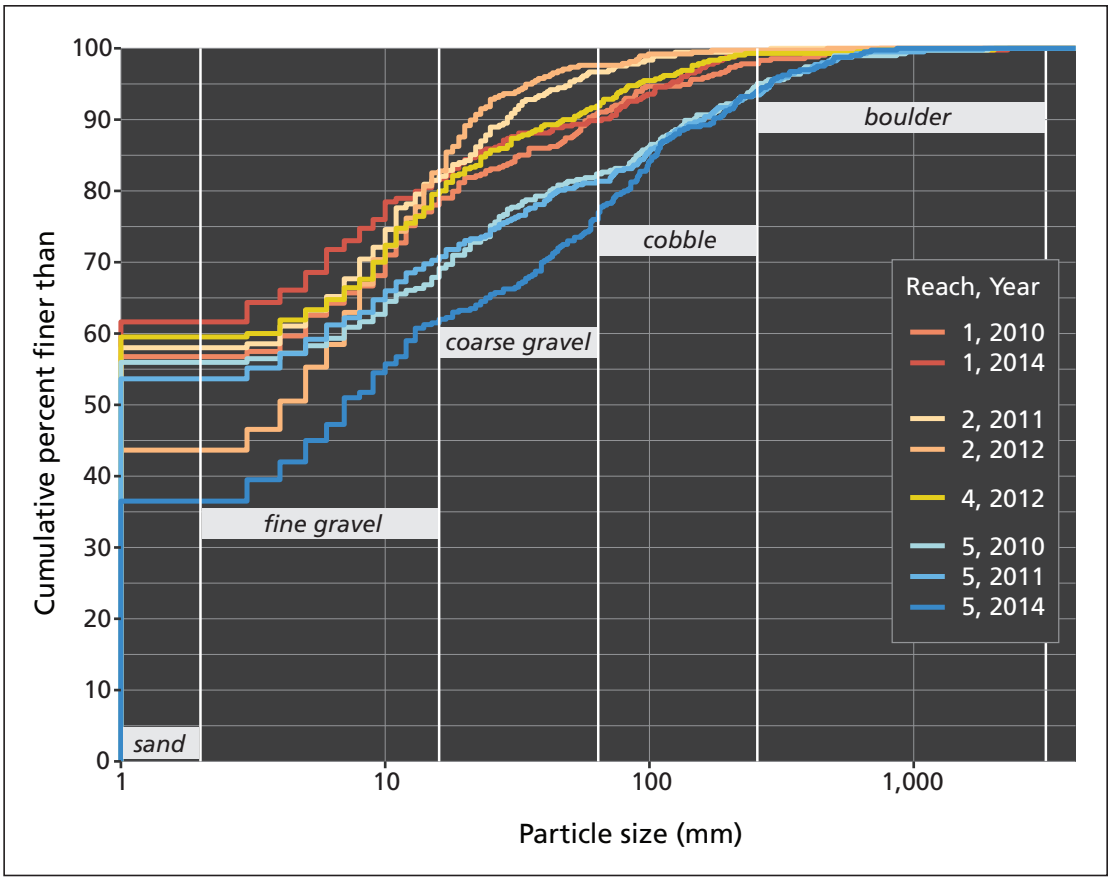


Figure 3-8. Particle-size distribution of the channel surface at each reach for each year of sampling, Armstrong Canyon, Natural Bridges National Monument, 2010–2014. Particle-size distribution was sampled using pebble counts. Classification of sand, gravel, cobble, and boulder is based on the Wentworth scale.

3.4 Vegetation

3.4.1 Species richness

A total of 76 species were detected at the four reaches monitored in Natural Bridges NM from 2010 to 2014. Total species richness ranged from 28 to 41 species per reach, and richness by lifeform was relatively similar among reaches (Table 3-5). Reach 2 had a 25% reduction in the total number of species detected from 2011 to 2012. At Reach 5, half as many forb species were detected in 2014 (after the September 2013 floods) than in 2011. Reach 1 had fewer total wetland species (obligate and facultative) than the other reaches (Table 3-6).

Each year, recorded species are compared to the NPSpecies database to determine first-time observations in Natural Bridges NM. One new exotic species, cultivated wheat (*Triticum aestivum*), was detected during wadeable streams monitoring in 2012. Western goldenrod (*Euthamia occidentalis*), a previously unconfirmed species, was also detected at multiple reaches in multiple years. Vouchers have not been created for these species yet, but we will attempt to collect and mount them when we find appropriate specimens.

Although Natural Bridges NM has no populations of federally listed threatened or endangered plant species within its borders, at least 21 plants of special conservation concern exist within the park (Fertig 2009). None of these species was detected during riparian monitoring.

3.4.2 Overstory canopy closure and vegetation cover

Overstory canopy closure and total percent cover of vegetation were lower at reaches 1 and 2, and highest at Reach 4 (Table 3-7). Reach 5 had a much higher percent cover of trees than the other reaches (Table 3-8), while Reach 4 had a much higher percent

Table 3-5. Number of plant species detected per reach by lifeform, Armstrong Canyon, Natural Bridges National Monument.

Parameter	Year	Reach 1	Reach 2	Reach 4	Reach 5
Tree	2011	–	5	–	5
	2012	–	3	3	–
	2014	4	–	–	6
Shrub	2011	–	5	–	5
	2012	–	9	12	–
	2014	10	–	–	8
Perennial grass	2011	–	13	–	8
	2012	–	7	10	–
	2014	7	–	–	8
Annual grass	2011	–	3	–	1
	2012	–	2	2	–
	2014	3	–	–	1
Forb/Herb	2011	–	14	–	11
	2012	–	10	13	–
	2014	11	–	–	5
Fern	2011	–	1	–	0
	2012	–	0	0	–
	2014	0	–	–	0
Total	2011	–	41	–	30
	2012	–	31	40	–
	2014	35	–	–	28

Table 3-6. Number of plant species detected per reach by wetland status, Armstrong Canyon, Natural Bridges National Monument.

Wetland status	Year	Reach 1	Reach 2	Reach 4	Reach 5
Obligate wetland	2011	–	1	–	3
	2012	–	2	2	–
	2014	2	–	–	3
Facultative wetland	2011	–	8	–	4
	2012	–	6	4	–
	2014	1	–	–	6
Facultative	2011	–	6	–	4
	2012	–	4	5	–
	2014	7	–	–	3
Facultative upland	2011	–	10	–	5
	2012	–	7	9	–
	2014	6	–	–	5
Upland	2011	–	16	–	14
	2012	–	12	20	–
	2014	19	–	–	11

Table 3-7. Percent overstory canopy closure, Armstrong Canyon, Natural Bridges National Monument.

Year	Reach 1	Reach 2	Reach 4	Reach 5
2010	8.9	–	–	14.9
2011	–	9.4	–	21.8
2012	–	9.1	32.3	–
2014	10.2	–	–	21.0

Table 3-8. Percent cover of vegetation by lifeform, Armstrong Canyon, Natural Bridges National Monument.

Parameter	Year	Live (Total) vegetation			
		Reach 1	Reach 2	Reach 4	Reach 5
Tree (percent cover)	2010	0.5 (0.8)	–	–	7.8 (7.8)
	2011	–	1.2 (2)	–	7.8 (8.1)
	2012	–	1.7 (1.7)	1.7 (1.9)	–
	2014	0.3 (0.3)	–	–	14.3 (14.6)
Shrub (percent cover)	2010	7.5 (10.4)*	–	–	10.3 (11.9)*
	2011	–	6.7 (7.8)	–	13.8 (14.3)
	2012	–	5.8 (7.7)	23.3 (31)	–
	2014	12.4 (14.5)	–	–	10.3 (12.2)
Perennial grass (percent cover)	2010	7.3 (9.1)	–	–	5.7 (6.8)
	2011	–	9.7 (13.2)	–	4.6 (6.8)
	2012	–	6.6 (11.8)	5.2 (9.5)	–
	2014	8.6 (11.3)	–	–	4.3 (5.7)
Annual grass (percent cover)	2010	0 (0)	–	–	0 (0)
	2011	–	1.7 (3.1)	–	0.5 (0.5)
	2012	–	0.2 (4.3)	0.1 (3.4)	–
	2014	0.5 (5.1)	–	–	0 (0.5)
Forb/Herb (percent cover)	2010	9.1 (9.9)	–	–	10.0 (10.8)
	2011	–	3.7 (6.7)	–	6.5 (8.9)
	2012	–	2.6 (4.1)	4.4 (8.6)	–
	2014	5.6 (6.2)	–	–	4.1 (7.3)
Fern (percent cover)	2010	0 (0)	–	–	0 (0)
	2011	–	0.2 (0.2)	–	0 (0)
	2012	–	0 (0)	0 (0)	–
	2014	0 (0)	–	–	0 (0)
Total (percent cover)	2010	22.3 (27.3)	–	–	32.4 (35.4)
	2011	–	21.8 (30.1)	–	30.3 (34.3)
	2012	–	17.0 (28.1)	32.8 (47.8)	–
	2014	24.7 (31.7)	–	–	31.1 (37.3)

*In 2010, shrub cover was not recorded above 1.5 m. These data may not be comparable to those for other years.

cover of shrubs than the other reaches. Otherwise, cover by lifeform was relatively similar among the reaches. Live cover of trees at Reach 5 nearly doubled from 2011 to 2014 (7.8% vs. 14.3%, respectively). This was due to large increases in live cover of narrow-leaved cottonwood (*Populus angustifolia*; 5.4% in 2011 vs. 10.0% in 2014) and box-elder (*Acer negundo*; 1.1% in 2011 vs. 2.7% in 2014). At Reach 1, forb cover, including many different species, decreased by 33% or more from 2010 to 2014.

Overall, cover of native and exotic species was similar among visits to each reach (Table 3-9). In reaches 2 and 5, live cover of exotic species tended to be higher in 2011 than in other years these reaches were sampled. Higher total cover of exotic species at Reach 1 in 2014 and Reach 2 in 2012 was primarily dead cheatgrass (*Bromus tectorum*) that was alive earlier in the growing season.

Reach 4 had higher cover of wetland species (obligate and facultative) than the other reaches (15.3% for Reach 4 vs. 1.8–9.4% for the other reaches; Table 3-10). Cover of obligate wetland species doubled from 2010 to 2014 at Reach 1, which was due to increases in cover of coyote willow (*Salix exigua*). This may have been a response to the September 2013 floods, or it could have been due to a change in sampling methods (shrub cover above 1.5 m height was not sampled in 2010).

Table 3-9. Percent cover of native and exotic vegetation, Armstrong Canyon, Natural Bridges National Monument.

Plant type	Year	Live (Total) vegetation			
		Reach 1	Reach 2	Reach 4	Reach 5
Exotic perennial grass	2010	0.0 (0.0)	–	–	0.0 (0.0)
	2011	–	0.8 (0.8)	–	0.8 (0.8)
	2012	–	0.2 (0.6)	0.6 (2.7)	–
	2014	0.3 (0.3)	–	–	1.1 (1.1)
Exotic annual grass	2010	0.0 (0.0)	–	–	0.0 (0.0)
	2011	–	1.7 (3.1)	–	0.5 (0.5)
	2012	–	0.2 (4.3)	0.1 (3.4)	–
	2014	0.5 (4.8)	–	–	0 (0.5)
Exotic forb	2010	1.8 (1.8)	–	–	0.5 (0.5)
	2011	–	0.6 (0.9)	–	1.1 (1.1)
	2012	–	0.5 (0.8)	0.4 (1.0)	–
	2014	0.0 (0.0)	–	–	0.3 (0.3)
All exotic	2010	1.8 (1.8)	–	–	0.5 (0.5)
	2011	–	2.9 (4.4)	–	2.4 (2.4)
	2012	–	0.8 (5.5)	1.1 (6.7)	–
	2014	0.8 (5.1)	–	–	1.4 (1.9)
All native	2010	20.5 (25.5)*	–	–	30.8 (34.1)*
	2011	–	19.6 (27.1)	–	29.2 (33.2)
	2012	–	16.1 (23.3)	32.5 (44.8)	–
	2014	24.2 (28.0)	–	–	28.9 (35.1)

*In 2010, shrub cover was not recorded above 1.5 meters. These data may not be comparable to those for other years.

Table 3-10. Percent cover of vegetation by wetland status, Armstrong Canyon, Natural Bridges National Monument.

Wetland status	Year	Reach 1	Reach 2	Reach 4	Reach 5
Obligate wetland	2010	1.8 (2.3)*	–	–	5.1 (5.4)*
	2011	–	1.4 (1.4)	–	6.2 (6.5)
	2012	–	1.2 (1.2)	4.4 (4.5)	–
	2014	4.8 (5.1)	–	–	3.8 (4.1)
Facultative wetland	2010	0 (0)	–	–	3.2 (3.2)
	2011	–	4 (5.4)	–	3.2 (4.1)
	2012	–	3.7 (4.6)	10.9 (16.9)	–
	2014	0 (0)	–	–	4.9 (5.1)
Facultative	2010	4.4 (6.0)*	–	–	9.5 (10.0)*
	2011	–	3.2 (4.9)	–	8.9 (8.9)
	2012	–	2.9 (4.6)	6.4 (8.6)	–
	2014	4.8 (5.6)	–	–	13.8 (14.6)
Facultative upland	2010	6.5 (7.3)	–	–	2.2 (3.0)
	2011	–	2.6 (3.7)	–	3.5 (4.3)
	2012	–	1.4 (4.0)	3.7 (7.1)	–
	2014	4.3 (6.2)	–	–	3.5 (4.6)
Upland	2010	11.4 (13.8)*	–	–	12.2 (14.1)*
	2011	–	11.8 (17.5)	–	11.9 (14.3)
	2012	–	7.5 (15.8)	10.1 (18.2)	–
	2014	13.4 (19.1)	–	–	6.5 (11.4)

*In 2010, shrub cover was not recorded above 1.5 meters. These data may not be comparable to those for other years.

3.4.3 Exotic species

A total of 20 exotic plant species were detected at the four reaches monitored in Natural Bridges NM from 2010 to 2014. Cheatgrass, sweet-clover (*Melilotus* species, including *M. alba* and *M. officinalis*), and Kentucky bluegrass (*Poa pratensis*) were the most frequently detected exotic species (27.3–58.3%, 13.6–28.9%, and 1.5–21.1%, respectively) of quadrats sampled along each transect at a reach; Table 3-11). At Reach 5, smaller frequencies of exotic-plant species were detected in 2014 (after the September 2013 floods) than in 2011 for all species.

Tamarisk (*Tamarix* sp.) was the only exotic tree species detected. It was found in low amounts at each reach (i.e., detected in one reach for exotic frequency, but observed during the timed walk at all reaches). Four additional species were detected during the timed walk: African mustard (*Malcomia africana*), alfalfa (*Medicago sativa*), common dandelion (*Taraxacum officinale*), and cultivated wheat. 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.

Table 3-11. Percent frequency of exotic plant species detected by lifeform and reach, Armstrong Canyon, Natural Bridges National Monument.

Type	Scientific name	Common name	Duration	Year*	Reach 1	Reach 2	Reach 4	Reach 5
Shrub	*Tamarix* sp.	tamarisk	Perennial	2011	–	0	–	0
				2012	–	1.5	0	–
				2014	0	–	–	0
Grass	*Agropyron cristatum*	crested wheatgrass	Perennial	2011	–	1.5	–	0
				2012	–	0	4.8	–
				2014	2.6	–	–	0
Grass	*Agrostis stolonifera*	redtop	Perennial	2011	–	0	–	7.9
				2012	–	0	0	–
				2014	0	–	–	2.6
Grass	*Bromus japonicus*	Japanese chess	Annual	2011	–	10.6	–	0
				2012	–	12.1	15.5	–
				2014	5.1	–	–	0
Grass	*Bromus* sp.	brome	Annual	2011	–	1.5	–	0
				2012	–	1.5	0	–
				2014	0	–	–	0
Grass	*Bromus tectorum*	cheatgrass	Annual	2011	–	27.3	–	39.5
				2012	–	36.4	58.3	–
				2014	48.7	–	–	31.6
Grass	*Poa pratensis*	Kentucky bluegrass	Perennial	2011	–	1.5	–	21.1
				2012	–	3.0	8.3	–
				2014	7.7	–	–	15.8
Grass	*Polypogon monspeliensis*	rabbitfoot-grass	Annual	2011	–	1.5	–	0
				2012	–	0	0	–
				2014	0	–	–	0
Forb	*Erodium cicutarium*	stork's-bill	Annual	2011	–	1.5	–	0
				2012	–	0	0	–
				2014	0	–	–	0
Forb	*Lactuca serriola*	prickly lettuce	Annual	2011	–	0	–	2.6
				2012	–	0	0	–
				2014	0	–	–	0

Table 3-11. Percent frequency of exotic plant species detected by lifeform and reach, Armstrong Canyon, Natural Bridges National Monument, cont.

Type	Scientific name	Common name	Duration	Year*	Reach 1	Reach 2	Reach 4	Reach 5
Forb	*Melilotus alba*	white sweet-clover	Annual	2011	–	0	–	0
				2012	–	0	1.2	–
				2014	0	–	–	0
Forb	*Melilotus officinalis*	yellow sweet-clover	Biennial	2011	–	7.6	–	2.6
				2012	–	4.5	8.3	–
				2014	0	–	–	0
Forb	*Melilotus* sp.	sweetclover	–	2011	–	13.6	–	28.9
				2012	–	22.7	17.9	–
				2014	20.5	–	–	21.1
Forb	*Polygonum aviculare*	yard knotweed	Annual	2011	–	0	–	0
				2012	–	1.5	0	–
				2014	0	–	–	0
Forb	*Ranunculus testiculatus*	bur buttercup	Annual	2011	–	0	–	2.6
				2012	–	0	0	–
				2014	0	–	–	0
Forb	*Salsola tragus*	Russian-thistle	Annual	2011	–	4.5	–	0
				2012	–	22.7	6.0	–
				2014	7.7	–	–	0
Forb	*Sisymbrium altissimum*	tumble mustard	Annual	2011	–	1.5	–	0
				2012	–	1.5	0	–
				2014	0	–	–	0
Forb	*Tragopogon dubius*	yellow salsify	Biennial	2011	–	0	–	2.6
				2012	–	0	0	–
				2014	2.6	–	–	0

*Exotic frequency data were not collected before 2011.

3.4.4 Tree density and basal area

Seedling density varied by species and changed dramatically between some years (Table 3-12). Sapling and overstory tree density (Tables 3-13 and 3-14) and basal area (Table 3-15) were similar between visits to each reach except where noted below.

Reaches 2 and 4 had the highest basal area of trees (see Table 3-15), consisting primarily of Fremont cottonwood (*Populus fremontii*) and lance-leaf cottonwood (*P. intercurrens*), a hybrid of Fremont cottonwood and narrow-leaved cottonwood (*P. angustifolia*), at Reach 2. There was a dramatic increase in density of cottonwood seedlings, including lance-leaf cottonwood, Fremont cottonwood, and other cottonwood seedlings that could not be identified to species, at Reach 2 from 2011 to 2012 (see Table 3-12).

Considering all species and size classes combined, Reach 1 contained a lower density of trees than the other reaches. This reach had seedlings and some saplings of cottonwood species, but all overstory trees at this reach were upland species: Utah juniper (*Juniperus osteosperma*) and two-needle pinyon (*Pinus edulis*). Density of overstory trees and basal area (see Tables 3-14, 3-15) were lower at this reach in 2014 compared to 2011, but this difference may be an artifact of decreasing the length of two transects at the 2014 visit. Seedlings of cottonwood species at this reach were 20 times higher in 2014 (after the September 2013 floods) than in 2010 (see Table 3-12).

Reach 5 had a lower basal area of trees than the other reaches, and no overstory trees were detected in density sampling (see Tables

Table 3-12. Density (trees/ha) of live seedlings (<2.5 cm) by species, Armstrong Canyon, Natural Bridges National Monument.

Scientific name	Common name	Year	Reach 1	Reach 2	Reach 4	Reach 5
Acer negundo	boxelder	2010	0	–	–	86
		2011	–	18	–	590
		2012	–	12	0	–
		2014	0	–	–	472
Juniperus sp.	juniper species	2010	0	–	–	0
		2011	–	0	–	0
		2012	–	0	5	–
		2014	21*	–	–	21
Juniperus osteosperma	Utah juniper	2010	10	–	–	0
		2011	–	6	–	0
		2012	–	0	0	–
		2014	0*	–	–	11
Pinus edulis	two-needle pinyon	2010	10	–	–	11
		2011	–	0	–	11
		2012	–	0	0	–
		2014	11*	–	–	0
Populus x intercurrens	lance-leaf cottonwood	2010	0	–	–	129
		2011	–	428	–	204
		2012	–	783	81	–
		2014	0	–	–	333
Populus angustifolia	narrow-leaved cottonwood	2010	0	–	–	740
		2011	–	0	–	1,738
		2012	–	0	57	–
		2014	86	–	–	1,481
Populus fremontii	Fremont cottonwood	2010	10	–	–	0
		2011	–	0	–	0
		2012	–	12	413	–
		2014	21	–	–	0
Populus sp.	cottonwood species	2010	0	–	–	0
		2011	–	0	–	0
		2012	–	330	427	–
		2014	492	–	–	86

*Changes in density at Reach 1 may be due to decreases in transect length and not due to loss of live trees at this reach. See Section 3.4.4 for more information.

Table 3-13. Density (trees/ha) of live saplings (2.5–15.0 cm) by species, Armstrong Canyon, Natural Bridges National Monument.

Scientific name	Common name	Year	Reach 1	Reach 2	Reach 4	Reach 5
Acer negundo	boxelder	2010	0	–	–	118
		2011	–	79	–	129
		2012	–	79	0	–
		2014	0	–	–	139
Juniperus sp.	juniper species	2010	0	–	–	0
		2011	–	0	–	0
		2012	–	0	0	–
		2014	0	–	–	0
Juniperus osteosperma	Utah juniper	2010	10	–	–	0
		2011	–	0	–	0
		2012	–	0	0	–
		2014	21*	–	–	0
Pinus edulis	two-needle pinyon	2010	31	–	–	0
		2011	–	0	–	0
		2012	–	0	0	–
		2014	11*	–	–	0
Populus x intercurrens	lance-leaf cottonwood	2010	0	–	–	21
		2011	–	86	–	32
		2012	–	92	19	–
		2014	0	–	–	64
Populus angustifolia	narrow-leaved cottonwood	2010	0	–	–	236
		2011	–	0	–	279
		2012	–	0	0	–
		2014	21	–	–	354
Populus fremontii	Fremont cottonwood	2010	0	–	–	0
		2011	–	0	–	0
		2012	–	0	109	–
		2014	0	–	–	0
Populus sp.	cottonwood species	2010	0	–	–	0
		2011	–	0	–	0
		2012	–	0	0	–
		2014	0	–	–	0

*Changes in density at Reach 1 may be due to decreases in transect length and not due to loss of live trees at this reach. See Section 3.4.4 for more information.

Table 3-14. Density (trees/ha) of live overstory trees (>15 cm) by species, Armstrong Canyon, Natural Bridges National Monument.

Scientific name	Common name	Year	Reach 1	Reach 2	Reach 4	Reach 5
Acer negundo	boxelder	2010	0	–	–	0
		2011	–	0	–	0
		2012	–	0	0	–
		2014	0	–	–	0
Juniperus sp.	juniper species	2010	0	–	–	0
		2011	–	0	–	0
		2012	–	0	0	–
		2014	0	–	–	0
Juniperus osteosperma	Utah juniper	2010	21	–	–	0
		2011	–	0	–	0
		2012	–	0	0	–
		2014	11*	–	–	0
Pinus edulis	two-needle pinyon	2010	10	–	–	0
		2011	–	0	–	0
		2012	–	0	0	–
		2014	0*	–	–	0
Populus x intercurrens	lance-leaf cottonwood	2010	0	–	–	0
		2011	–	12	–	0
		2012	–	12	0	–
		2014	0	–	–	0
Populus angustifolia	narrow-leaved cottonwood	2010	0	–	–	0
		2011	–	0	–	0
		2012	–	0	0	–
		2014	0	–	–	0
Populus fremontii	Fremont cottonwood	2010	0	–	–	0
		2011	–	6	–	0
		2012	–	6	28	–
		2014	0	–	–	0
Populus sp.	cottonwood species	2010	0	–	–	0
		2011	–	0	–	0
		2012	–	0	0	–
		2014	0	–	–	0

*Changes in density at Reach 1 may be due to decreases in transect length and not due to loss of live trees at this reach. See Section 3.4.4 for more information.

Table 3-15. Basal area (m^2/ha) of live trees by species, Armstrong Canyon, Natural Bridges National Monument.

Scientific name	Common name	Year	Reach 1	Reach 2	Reach 4	Reach 5
Acer negundo	boxelder	2010	0	–	–	0.2
		2011	–	0.2	–	0.2
		2012	–	0.1	0	–
		2014	0	–	–	0.3
Juniperus sp.	juniper species	2010	0	–	–	0
		2011	–	0	–	0
		2012	–	0	0	–
		2014	0	–	–	0
Juniperus osteosperma	Utah juniper	2010	2.7	–	–	0
		2011	–	0	–	0
		2012	–	0	0	–
		2014	1.8*	–	–	0
Pinus edulis	two-needle pinyon	2010	0.2	–	–	0
		2011	–	0	–	0
		2012	–	0	0	–
		2014	0*	–	–	0
Populus x intercurrens	lance-leaf cottonwood	2010	0	–	–	0
		2011	–	1.6	–	0.1
		2012	–	1.7	0.1	–
		2014	0	–	–	0.1
Populus angustifolia	narrow-leaved cottonwood	2010	0	–	–	0.5
		2011	–	0	–	0.6
		2012	–	0	0	–
		2014	0	–	–	0.9
Populus fremontii	Fremont cottonwood	2010	0	–	–	0
		2011	–	4.1	–	0
		2012	–	4.0	7.4	–
		2014	0	–	–	0
Populus sp.	cottonwood species	2010	0	–	–	0
		2011	–	0	–	0
		2012	–	0	0	–
		2014	0	–	–	0

*Changes in basal area at Reach 1 may be due to decreases in transect length and not due to loss of live trees at this reaches. See Section 3.4.4 for more information.

3-14, 3-15). Seedlings and saplings at this reach were mostly narrow-leaved cottonwood and boxelder (*Acer negundo*) and also some lanced-leaved cottonwood (see Tables 3-12, 3-13). There were no notable changes in density or basal area at this reach in 2014 compared to earlier visits, but seedling density of narrow-leaved cottonwoods more than doubled from 2010 to 2011.

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 3-9).

Overstory trees at reaches 2 and 4 were all cottonwoods (*Populus* species, including Fremont cottonwood, narrow-leaved cottonwood, and lance-leaf cottonwood), and included Fremont cottonwoods in all size classes (see Figure 3-9). Some of the largest Fremont cottonwoods that NCPN has sampled during wadeable-streams monitoring occurred in these reaches, with dbh's of greater than 100 centimeters. There were very few overstory trees present at reaches 1 and 5. These trees were primarily upland species, including two-needle pinyon and Utah juniper, in smaller size classes (see Figure 3-9).

3.4.6 Surface cover

Fines and litter were the dominant surface cover at all reaches (Table 3-16). There was very little change in cover of surface features between monitoring visits.

3.5 Other disturbances

The hiking trail through Armstrong Canyon runs either through the wash or on higher terraces throughout all of the reaches. Flood debris was noted at all reaches, but its age could not always be determined. At the June 2010 visit, a recent, smaller flood was noted at the reaches. At the June 2014 visit, debris and impacts from the large floods in September 2013 were apparent. Cut stems of tamarisk from park exotic-plant control efforts were also noted at Reach 2 in 2012.

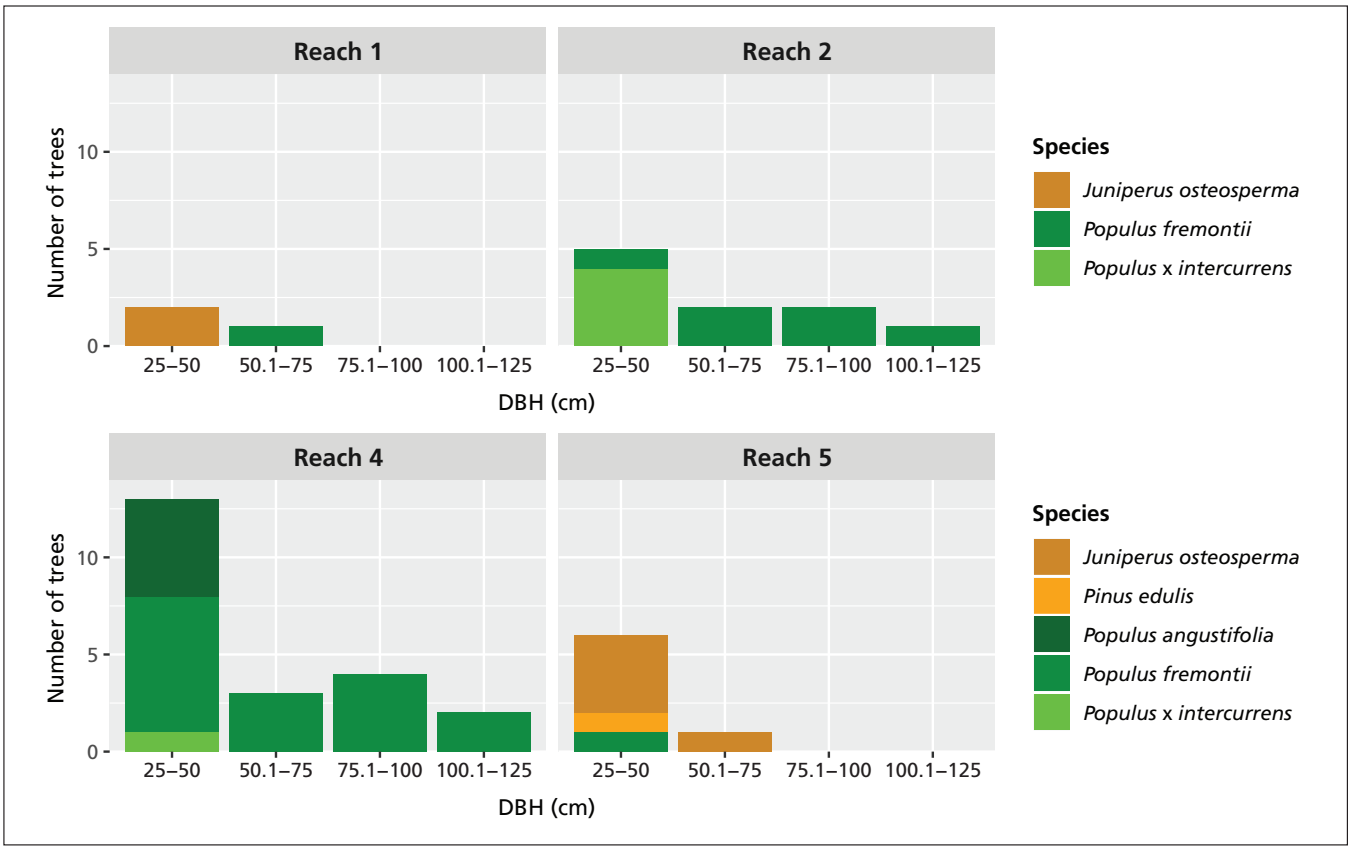


Figure 3-9. Number of lives trees by size class and species with ≥25 cm dbh at each reach, Armstrong Canyon, Natural Bridges National Monument. Data from the most recent visit are presented (2014 for reaches 1 and 5 and 2012 for reaches 2 and 4).

Table 3-16. Percent cover of surface features, Armstrong Canyon, Natural Bridges National Monument.

Surface feature	Year	Reach 1	Reach 2	Reach 4	Reach 5
Water	2010	4.4	–	–	2.4
	2011	–	1.2	–	0
	2012	–	0	0	–
	2014	0	–	–	0
Fines (0.1–2 mm)	2010	52.5	–	–	38.1
	2011	–	46.0	–	48.1
	2012	–	40.3	31.3	–
	2014	58.9	–	–	47.3
Fine gravel (>2–16 mm)	2010	5.5	–	–	5.4
	2011	–	5.8	–	6.8
	2012	–	9.2	4.3	–
	2014	3.8	–	–	6.8
Coarse gravel (>16–64 mm)	2010	5.7	–	–	7.3
	2011	–	3.1	–	4.3
	2012	–	2.6	1.9	–
	2014	3.5	–	–	4.1
Cobble (>64–256 mm)	2010	2.9	–	–	4.9
	2011	–	1.5	–	4.6
	2012	–	1.2	0.6	–
	2014	5.4	–	–	6.5
Boulder (>256 mm)	2010	4.2	–	–	14.3
	2011	–	0	–	15.9
	2012	–	0.2	2.4	–
	2014	3.2	–	–	15.4
Bedrock	2010	1.3	–	–	3.2
	2011	–	5.7	–	1.1
	2012	–	4.9	0	–
	2014	2.4	–	–	1.1
Biological soil crust	2010	0.5	–	–	0.3
	2011	–	3.1	–	0
	2012	–	2.8	0.4	–
	2014	1.6	–	–	0
Litter	2010	20.8	–	–	23.5
	2011	–	29.6	–	18.1
	2012	–	36.3	57.1	–
	2014	21.2	–	–	18.6
Woody debris	2010	0.3	–	–	0
	2011	–	1.2	–	0.3
	2012	–	0.6	0.1	–
	2014	0	–	–	0

4 Discussion

Our monitoring provides insight on the frequency and duration of large flow events in Armstrong Canyon, geomorphic changes caused by these events, and vegetation response following large flow events. The most notable limitation of our monitoring effort thus far is the minimal temporal overlap between our hydrologic monitoring (2014–2018) with vegetation and geomorphology monitoring (2010–2014). Thus, we do not have a site-specific hydrologic record for the years when vegetation and geomorphology were monitored, and we were not able to integrate these three components as well as we had hoped. Our analysis of the climate record (see Table 3-1, Figure 3-1), in combination with reports of high-flow events from the park, gives us insight on the major flash-flood events during these years. Given this information, we draw the following general conclusions about Armstrong Canyon from our data and discuss ideas for improving riparian monitoring in the canyon.

4.1 Hydrology

Hydrologic data indicate that flow events in the canyon are strongly related to local precipitation, and flash floods are common. The highest-stage floods tend to occur during the monsoon season, but flow events are possible throughout the year. Unsurprisingly, surface water persists longer when evapotranspiration is low (i.e., in cooler months).

Hydrologic flows at Natural Bridges NM are not significantly affected by upstream land uses or management at this time. About 19% of the watershed is protected within the monument, and much of the remainder of the watershed is on federally managed public lands. A small portion, about 2.7% of the watershed, is state trust land that could be sold and privately developed. No changes in land use or management are anticipated at this time.

As such, the current flow regime is primarily related to climate, with flowing conditions mostly corresponding to local precipitation and persistent pooled conditions dependent upon evapotranspiration. Precipitation is highly variable in the Southwest, and climate variability makes the detection of long-term trends more difficult. It is unknown how long the data record would need to be in order to detect long-term trends in flood frequency and wetted duration at Natural Bridges NM.

4.2 Geomorphology and surface cover

Straighter, narrower sections of canyon, similar to reaches 1 and 5, are more representative of Armstrong Canyon overall (see Figure 2-3), but changes at these locations tend to be stochastic, and longer-term trends can be difficult to detect. Most of our repeat measurements in Armstrong Canyon occurred at this type of reach. More substantial terraces and less bedrock are present at large bends in the canyon, similar to reaches 2 and 4. There are relatively few areas like this in Armstrong Canyon.

Flood events can scour sand and gravels out of the channel, as was evident from the particle-size distribution data after the September 2013 floods at Reach 5 (see Table 3-4, Figure 3-8). Yet Reach 1 had slight increases in sand and fine gravel after the 2013 floods, suggesting that there was deposition at this reach after the floods. Reach 5 has a higher channel slope than the other surveyed reaches (see Table 3-4) and was one of the narrower reaches monitored. These factors could have increased the power of floodwaters at this reach during high flows and increased scouring.

There was also evidence of channel cutting (i.e., channel widening, deepening, or both) on all but one channel cross-section at Reach 5 (see Figure 3-5; Appendix B), and some sediment was deposited on the floodplain. However, much of the surveyed cross-sections remained the same after the floods (Appendix B), attesting to how strongly armored many of the geomorphic surfaces are within Armstrong Canyon. We did not see evidence that the channel cut into higher terraces during the 2013 flash floods. However, our only repeat survey was at a Reach 5, which was armored by bedrock on both sides. Terraces are more prominent features at reaches 2 and 4 (see Figure 2-3; Appendix B), and repeat sur-

veys of these two reaches would tell us more about changes in terrace geomorphology in Armstrong Canyon. Prehistoric archeological artifacts may exist on high terraces, and could be threatened if the terraces were cut away during high-flow events.

Despite the scouring that occurred after the September 2013 floods, surface cover at reaches 1 and 5 in 2014 was very similar to that in earlier years of monitoring (see Table 3-16).

4.3 Vegetation

Overall, changes in vegetation after the flash floods of September 2013 seemed minor, considering that flows were powerful enough to wash large trees down the canyon and perch them over three meters above the channel. This demonstrates both the resilience and effectiveness of disturbance adaptations of plants in this riparian system.

The main differences in vegetation detected after the September 2013 floods were a reduction in the number of forb species present at Reach 5 (see Table 3-5), a reduction of forb cover at Reach 1 (see Table 3-8), and a reduction in the frequency of exotic species at Reach 5 (see Table 3-11). Deposition of sediment on the floodplain (Appendix B) probably buried some forbs and exotic grasses, while flood waters may have washed away plants or part of the seedbank. A relatively rapid recovery of these species is expected because they are adapted to disturbance.

Tree species also appear to have responded to the flood through increased cottonwood seedling germination at Reach 1 (see Table 3-12) and higher narrow-leaved cottonwood cover at Reach 5 (see Table 3-8). Larger floods are well known to promote germination of cottonwood seedlings in riparian areas of the Southwest (Cooper et al. 1999, Friedman and Lee 2002, Scott et al. 1997), yet we did not detect any increase in cottonwood seedlings at Reach 5 after the September 2013 floods (see Table 3-12). One possible explanation is that there were fewer fine-sediment surfaces available for seedling establishment at this reach than at the others (see Figure 3-8, Table 3-16). This same pattern of variable cottonwood recruitment was observed at monitoring reaches on the East Fork Virgin River at Zion National Park after a large flood event in 2010 (Witwicki and Weissinger 2015). Absent any decrease in sapling or overstory tree density of riparian species after the September 2013 floods, increases in cottonwood-seedling density suggest that riparian vegetation is sustainable under current climatic conditions.

It should be noted that only two of the four monitoring reaches in Armstrong Canyon were sampled in 2014, after the September 2013 floods. Data from reaches 2 and 4, which are wider and more terraced (Figure 2-3, Table 2-2), would provide a fuller understanding of how flash floods affect vegetation in Armstrong Canyon.

4.4 Limitations of riparian monitoring in Armstrong Canyon

There are several major limitations to riparian monitoring in Armstrong Canyon that should be considered.

First, vegetation and geomorphology monitoring at Natural Bridges NM has been cut every year from 2015 to 2018. Riparian monitoring in Armstrong Canyon has proved to be the lowest priority of all NCPN monitoring efforts occurring in the Southeast Utah Group. During this time, NCPN staff has continued quarterly hydrologic monitoring visits and maintained the logger that monitors stage.

Second, although high daily precipitation totals are generally indicative of flash-flood events, daily precipitation totals at a weather station are not well correlated with flood stage. Precipitation that falls at other locations within the watershed, and the intensity of the storm (e.g., the high-intensity storms that typically occur during the monsoon), both influence flood stage within the canyon and are not captured by the daily precipitation totals at the weather station. Thus, we have little understanding of the magnitude of flash floods that occurred from 2010 to 2013, other than our approximation of stage of the September 2013 floods using heights of surveyed flood debris.

Third, there are significant limitations to the interpretability and usefulness of the hydrologic data. Because the logger is mounted 18.4 centimeters above the channel bottom due to bedrock, low flows can be missed. The persistent pool in the logger location also means that flowing versus pooled conditions cannot be parsed out. Loggers are affected by drying, and corrections need to be applied to almost every flood peak (see Appendix A). Sedimentation of the loggers can also affect the flood-recession limb of the hydrograph in a way that is difficult to correct with confidence. Overall, the data are noisier than they would be if they were from loggers placed in perennial systems, or from a well or piezometer that goes below the ground surface. Corrected water levels are less certain than in other systems monitored by NCPN.

Fourth, there are many armored and scoured surfaces within Armstrong Canyon that are resistant to changes from flash floods, and vegetation in the canyon appears to be well adapted to flash floods. Fewer changes than expected were detected after the September 2013 floods.

4.5 Recommendations for future monitoring

Concurrent monitoring of hydrology, geomorphology, and vegetation, as originally intended, would provide a more complete understanding of the riparian system in Armstrong Canyon. To enhance the analysis of significant hydrologic events, specifically large floods, deviations from the monitoring schedule should be made to permit measurements at all reaches in the same year, so that results are more comparable and measurements can be directly attributed to flows during the previous year (versus several years). If this happens, the remainder of the monitoring scheduled at Armstrong Canyon, at other wadeable streams, or on other protocols may need to be altered to balance the work load.

Some options are available for improving quality of the hydrologic data, depending on management priorities and questions. The logger could be moved to a location that does not pool so flowing conditions are better captured. However, such a location would increase the risk of losing the logger during flash-flood events and would not alleviate problems with drying and sedimentation. More frequent field visits would allow greater certainty in data corrections by more accurately pinpointing which flow events require which corrections. An automated camera could be placed that would take periodic photos to record whether there is flow in the channel, but this would add a fair amount of data management and infrastructure to the project. A crest-stage gage would provide more reliable estimates of peak flood stage, but would not provide information on flood duration and could miss subsequent flood events if not promptly reset.

It may also be worthwhile to reverse the numbering along each transect so that zero is on river left instead of river right. The transect-numbering scheme was set up similar to that of NCPN's upland-monitoring protocol to add consistency between the protocols for the crew. At the time, however, we did not realize this would create descending numbers along the x-axes of our stream cross-section figures (see Figure 3-5 and Appendix B).

We used a survey design to select monitoring reaches for Armstrong Canyon because our overall goal was to provide inference to the entire length of the canyon within our sampling frame. Our preliminary analyses on the East Fork Virgin River in Zion National Park (Witwicki and Weissinger 2015) confirmed that 3–4 reaches is not an adequate sample size to detect changes throughout the whole sampling frame. Thus, each reach was analyzed separately in that report, and we found the reaches responded differently to a major flood in a number of ways. In our preliminary look at data from Armstrong Canyon, reaches—and even transects within reaches—appeared to be responding differently to large flash floods.

For any future riparian monitoring in Armstrong Canyon, we would analyze the data by looking at each reach separately. In this type of analysis, each reach acts as an indicator site, which does not allow for the same level of inference as a survey design (i.e., inference to the entire length of the stream within the sampling frame). The long-term revisit design would need to be re-evaluated in light of this and any other changes in monitoring priorities.

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Appendix A. Data Corrections Applied to Hydrologic Time Series

Data corrections are applied to the hydrologic data to delete dry periods when the water level was below the logger sensor, remove ice-affected data, and apply corrections due to flood effects, including sedimentation and drying of the sensor. These corrections make important assumptions about how the logger responds to flood events:

- If the logger signal dips below the dry depth on the recession limb of a flood, then a drift correction is applied from the flood peak to the end of the recession limb, setting the end of the recession limb to the dry elevation or the pool elevation, if the elevation remains stable after the recession limb.
- If the ending logger measurement does not match up to the manual water level measurement, then a correction is applied so that the ending logger measurement matches.
- If there is an obvious jump or break in the data, then an offset correction is applied as appropriate.
- If there is no obvious jump or break, then a drift correction is applied back to the most recent flood peak.
- Dry periods are noisy and can fluctuate around 1 cm from the dry depth. The beginning and ending of dry periods are marked as best as possible, and the region is deleted.

A complete and uncorrected time series is maintained in the Aquarius database.

Table A-1. Data corrections applied to hydrologic time series.

From time	To time	Comment
2014-03-30 17:00:00	2014-04-11 08:15:00	Drift Correction with value of 0.800cm; set end to dry elevation of -58.5 cm
2014-05-11 17:30:00	2014-05-24 07:45:00	Drift Correction with value of 0.300cm; end set to dry elevation of -58.5 cm
2014-05-24 10:15:00	2014-08-02 16:00:00	Delete Region; sensor above water level
2014-08-02 16:15:00	2014-08-04 03:00:00	Drift Correction with value of 2.000cm; end set to dry elevation of -58.5 cm
2014-08-04 02:45:00	2014-08-04 21:00:00	Delete Region; sensor above water level
2014-08-04 21:45:00	2014-08-08 21:00:00	Drift Correction with value of 2.200cm; end set to dry elevation of -58.5 cm
2014-08-08 21:30:00	2014-08-13 18:15:00	Delete Region; dry
2014-08-13 22:45:00	2014-08-26 11:45:00	Drift Correction with value of -1.600cm; end set to manual water level measurement
2014-08-26 11:45:00	2014-08-26 13:15:00	Fill Data Gaps (Linear) with gap resample rate of 15.00 min; field visit
2014-08-27 07:30:00	2014-09-06 07:15:00	Drift Correction with value of 1.600cm; end set to match continuing logger record
2014-10-28 09:15:00	2014-10-28 12:00:00	Delete Region; unexplained spike
2015-03-02 16:15:00	2015-03-12 11:00:00	Drift Correction with value of -0.900cm; end set to manual water level measurement
2015-03-12 11:00:00	2015-03-12 11:45:00	Fill Data Gaps (Linear) with gap resample rate of 15.00 min; field visit
2015-03-25 12:15:00	2015-03-26 10:15:00	Fill Data Gaps (Linear) with gap resample rate of 15.00 min; unexplained spikes
2015-03-25 13:45:00	2015-03-25 13:45:00	Delete Region; unexplained spike
2015-03-25 15:45:00	2015-03-25 15:45:00	Delete Region; unexplained spike
2015-03-26 09:15:00	2015-03-26 09:30:00	Delete Region; unexplained spike
2015-05-05 12:15:00	2015-06-03 15:45:00	Drift Correction with value of 3.400cm; end set to dry elevation of -58.5 cm
2015-06-03 16:00:00	2015-06-05 16:00:00	Delete Region; sensor above water level
2015-06-23 14:15:00	2015-06-23 15:00:00	Fill Data Gaps (Linear) with gap resample rate of 15.00 min; field visit
2015-06-23 15:00:00	2015-06-27 08:00:00	Drift Correction with Calibration Drift value of 0.000cm and Fouling Drift value of 1.200cm
2015-06-27 07:45:00	2015-07-05 18:15:00	Delete Region; sensor above water level
2015-07-18 11:30:00	2015-07-29 12:45:00	Drift Correction with Calibration Drift value of 0.000cm and Fouling Drift value of 3.000cm

Table A-1. Data corrections applied to hydrologic time series, cont.

From time	To time	Comment
2015-07-29 10:45:00	2015-07-31 23:45:00	Delete Region; sensor above water level
2015-08-02 09:00:00	2015-08-13 03:45:00	Drift Correction with Calibration Drift value of 0.000cm and Fouling Drift value of 2.200cm
2015-08-13 03:30:00	2015-09-04 21:00:00	Delete Region; water level below sensor
2015-09-04 21:30:00	2015-09-09 00:15:00	Drift Correction with Calibration Drift value of 0.000cm and Fouling Drift value of 3.200cm
2015-09-08 11:15:00	2015-09-09 00:00:00	Fill Data Gaps (Linear) with gap resample rate of 14.00 min
2015-09-08 11:15:00	2015-09-09 00:00:00	Delete Region; noisy, probably from drying
2015-09-09 00:30:00	2015-09-15 01:45:00	Delete Region; water level below sensor
2015-09-15 05:15:00	2015-09-18 11:15:00	Drift Correction with value of -0.500cm; end set to manual water level measurement
2015-09-18 11:15:00	2015-09-18 12:00:00	Fill Data Gaps (Linear) with gap resample rate of 15.00 min; field visit
2015-09-18 13:15:00	2015-09-20 21:00:00	Drift Correction with Calibration Drift value of 0.000cm and Fouling Drift value of 1.700cm
2015-09-18 13:15:00	2015-09-20 21:00:00	Offset Correction with value of 0.500cm
2015-09-20 18:45:00	2015-10-05 10:45:00	Delete Region; water level below logger sensor
2015-09-20 21:00:00	2015-09-22 02:15:00	Fill Data Gaps (Linear) with gap resample rate of 14.00 min
2015-09-20 21:00:00	2015-09-22 02:15:00	Delete Region; noisy, probably from drying
2015-09-20 21:30:00	2015-09-22 02:15:00	Delete Region; noisy, probably from drying
2015-12-05 23:00:00	2015-12-06 11:45:00	Delete Region; ice effects
2015-12-06 12:00:00	2015-12-08 02:45:00	Delete Region; ice effects
2015-12-06 22:00:00	2015-12-07 12:15:00	Delete Region; ice effects
2016-02-19 13:45:00	2016-03-19 08:15:00	Drift Correction with Calibration Drift value of 0.000cm and Fouling Drift value of -1.400cm; applied after ice effects
2016-03-19 08:15:00	2016-03-19 10:30:00	Fill Data Gaps (Linear) with gap resample rate of 15.00 min; field visit
2016-03-19 09:12:00	2016-05-04 11:26:00	Drift Correction with Calibration Drift value of 0.000cm and Fouling Drift value of 0.600cm; adjust to manual measurement
2016-05-04 11:15:00	2016-05-04 12:15:00	Fill Data Gaps (Linear) with gap resample rate of 15.00 min; field visit
2016-05-04 12:15:00	2016-05-21 00:15:00	Drift Correction with Calibration Drift value of 0.000cm and Fouling Drift value of 1.900cm; applied drift to where it goes dry
2016-05-21 00:45:00	2016-07-22 17:15:00	Delete Region; water level below sensor
2016-07-22 17:30:00	2016-07-26 05:15:00	Offset Correction with value of 40.500cm; logger sensor covered with sediment on 8/1/16 field visit; adjusted to flood peak
2016-07-26 05:15:00	2016-08-03 23:45:00	Delete Region; water level below sensor
2016-08-04 00:00:00	2016-08-11 10:45:00	Offset Correction with value of 1.800cm; set ending value to dry measurement of -58.5 cm
2016-08-11 11:00:00	2016-08-18 17:30:00	Delete Region; water level below sensor
2016-08-18 17:45:00	2016-09-08 08:15:00	Offset Correction with value of 0.800cm; set ending value to dry measurement of -58.5 cm
2016-09-08 08:30:00	2016-09-30 16:30:00	Delete Region; water level below sensor
2016-09-30 16:45:00	2016-10-04 21:00:00	Offset Correction with value of 2.400cm; set ending value to dry measurement of -58.5 cm
2016-10-04 21:15:00	2016-10-05 22:00:00	Delete Region; noise while logger stabilizes to dry measurement
2016-10-05 22:15:00	2016-11-21 13:30:00	Delete Region; water level below sensor
2016-12-23 01:00:00	2017-03-02 12:30:00	Offset Correction with value of -1.600cm; set ending value to manual field measurement;
2017-03-02 12:30:00	2017-03-02 13:45:00	Fill Data Gaps (Linear) with gap resample rate of 15.00 min; field visit

Table A-1. Data corrections applied to hydrologic time series, cont.

From time	To time	Comment
2017-03-02 13:45:00	2017-04-19 01:30:00	Drift Correction with vallue of 3.000cm; ending value set to logger elevation of -58.5 cm
2017-04-19 01:30:00	2017-07-15 14:30:00	Delete Region; water level below sensor
2017-04-19 01:45:00	2017-09-22 09:15:00	Offset Correction with value of 0.900cm; set to logger elevation of -58.5 cm
2017-07-15 14:45:00	2017-07-16 20:30:00	Drift Correction with value of 1.000cm; ending elevation set to logger elevation of -58.5 cm
2017-07-16 20:30:00	2017-07-18 18:45:00	Delete Region; water level below sensor
2017-07-20 10:00:00	2017-07-20 14:45:00	Offset Correction with value of 1.000cm; ending elevation set to logger elevation of -58.5 cm
2017-07-20 15:00:00	2017-07-22 03:15:00	Delete Region; water level below sensor
2017-08-05 01:45:00	2017-08-15 15:45:00	Drift Correction with value of 2.400cm; end set to dry elevation of -58.5 cm
2017-08-15 16:00:00	2017-09-11 14:00:00	Delete Region; water level below sensor
2017-09-14 15:00:00	2017-09-21 06:00:00	Drift Correction with value of 2.500cm; end set to dry elevation of -58.5 cm
2017-09-21 06:15:00	2017-09-22 09:15:00	Delete Region; water level below sensor
2017-09-22 10:00:00	2018-05-02 22:30:00	Delete Region; logger above water level
2018-05-03 00:15:00	2018-05-16 14:15:00	Offset Correction with value of 2.000cm; end of flow set to -58.5 cm
2018-05-16 14:45:00	2018-07-11 16:45:00	Delete Region; water level below logger sensor
2018-07-11 17:15:00	2018-07-11 20:00:00	Offset Correction with value of 7.600cm applied to flood peak. Set dry elevation to -58.5 cm
2018-07-11 20:15:00	2018-07-11 20:30:00	Delete Region; logger adjustment due to drying
2018-07-11 20:45:00	2018-07-12 15:15:00	Delete Region; water level below logger sensor
2018-07-12 15:30:00	2018-07-12 17:45:00	Offset Correction with value of 4.000cm to flood peak; set dry elevation to -58.5 cm.
2018-07-12 18:00:00	2018-07-12 18:15:00	Delete Region; logger adjustment due to drying.
2018-07-12 18:30:00	2018-07-13 23:45:00	Delete Region; water level below logger sensor
2018-07-14 22:00:00	2018-07-20 05:45:00	Offset Correction with value of 1.700cm applied to flood peak. Dry elevation set to -58.5 cm.
2018-07-20 06:00:00	2018-07-20 18:30:00	Delete Region; logger adjustment due to drying.
2018-07-20 18:45:00	2018-07-24 18:00:00	Delete Region; water level below logger sensor
2018-07-24 18:30:00	2018-07-28 06:45:00	Offset Correction with value of 2.500cm applied to flood peak. Dry elevation set to -58.5 cm.
2018-07-28 07:15:06	2018-08-17 16:00:00	Delete Region; water level below logger sensor
2018-08-17 18:15:00	2018-08-21 12:45:00	Delete Region; logger affected by wet mud on sensors; deleted from slope break on flood recession to beginning of next flood rise
2018-08-21 13:00:00	2018-08-28 13:00:00	Offset Correction with value of 44.800cm; logger affected by mud; set beginning of flood rise to logger sensor elevation
2018-08-21 18:30:00	2018-09-03 17:45:00	Delete Region; logger affected by mud on logger sensors; deleted from flood peak to next flood rise
2018-09-03 19:45:00	2018-09-04 17:45:00	Delete Region; logger affected by wet mud on sensors
2018-09-03 19:45:00	2018-09-07 06:15:00	Offset Correction with value of -20.200cm; logger affected by wet mud on sensors
2018-09-05 00:15:00	2018-09-06 14:15:00	Delete Region; loggers affected by wet mud on sensors
2018-09-06 14:30:00	2018-09-06 18:30:00	Offset Correction with value of 6.200cm; loggers affected by wet mud on sensors
2018-09-06 18:45:00	2018-09-12 15:15:00	Delete Region; loggers affected by wet mud on sensors

Appendix B. Cross-sections of Stream Reaches

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

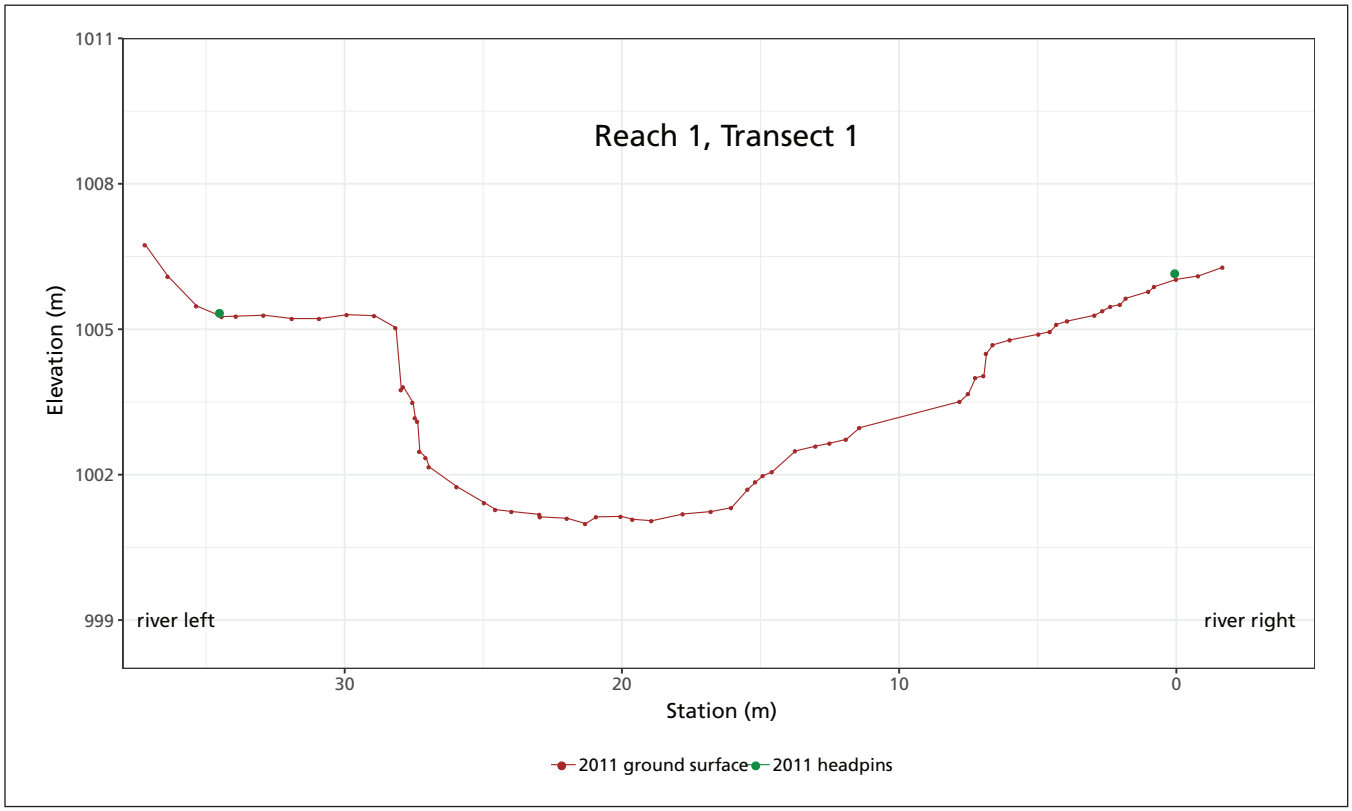


Figure B1. Cross-section of Reach 1, Transect 1, looking downstream, Armstrong Canyon, National Bridges National Monument, 2011.

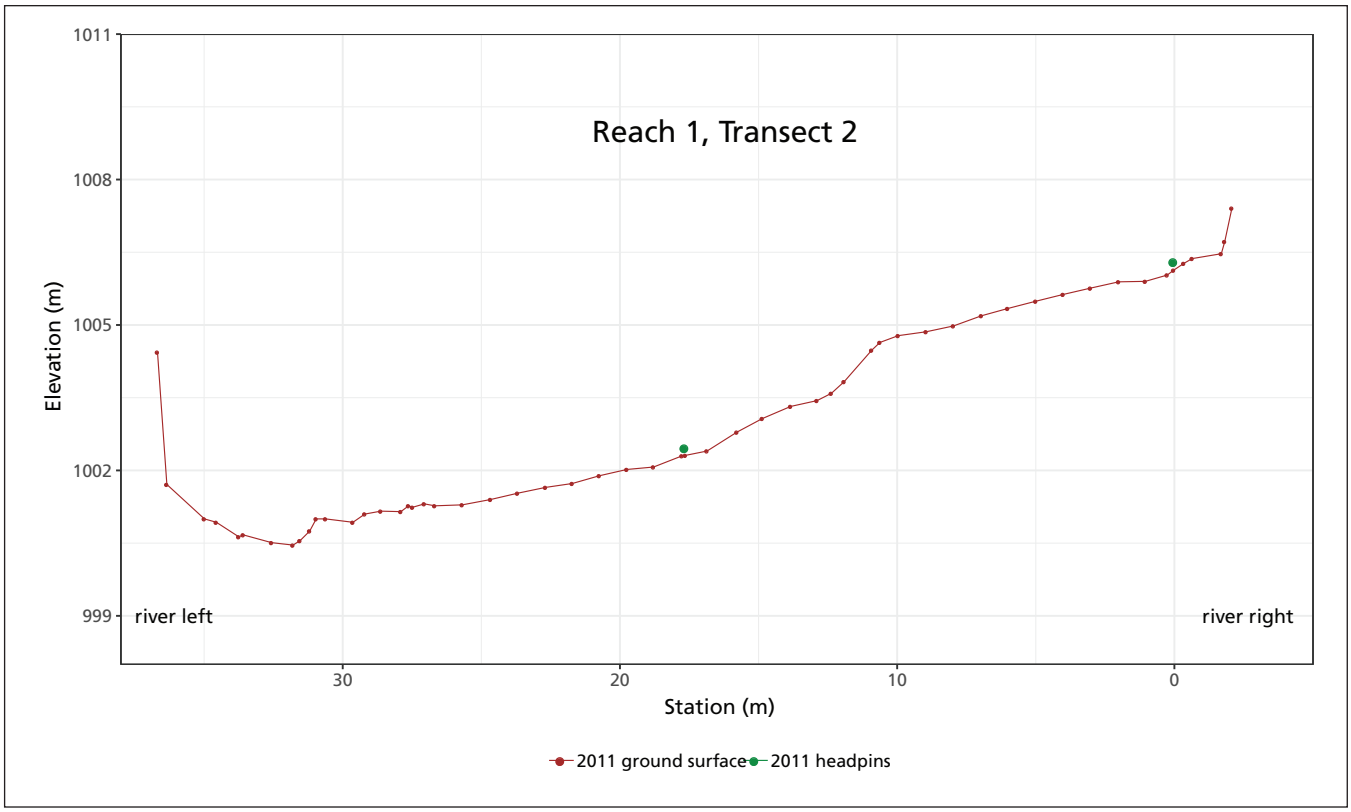


Figure B2. Cross-section of Reach 1, Transect 2, looking downstream, Armstrong Canyon, National Bridges National Monument, 2011.

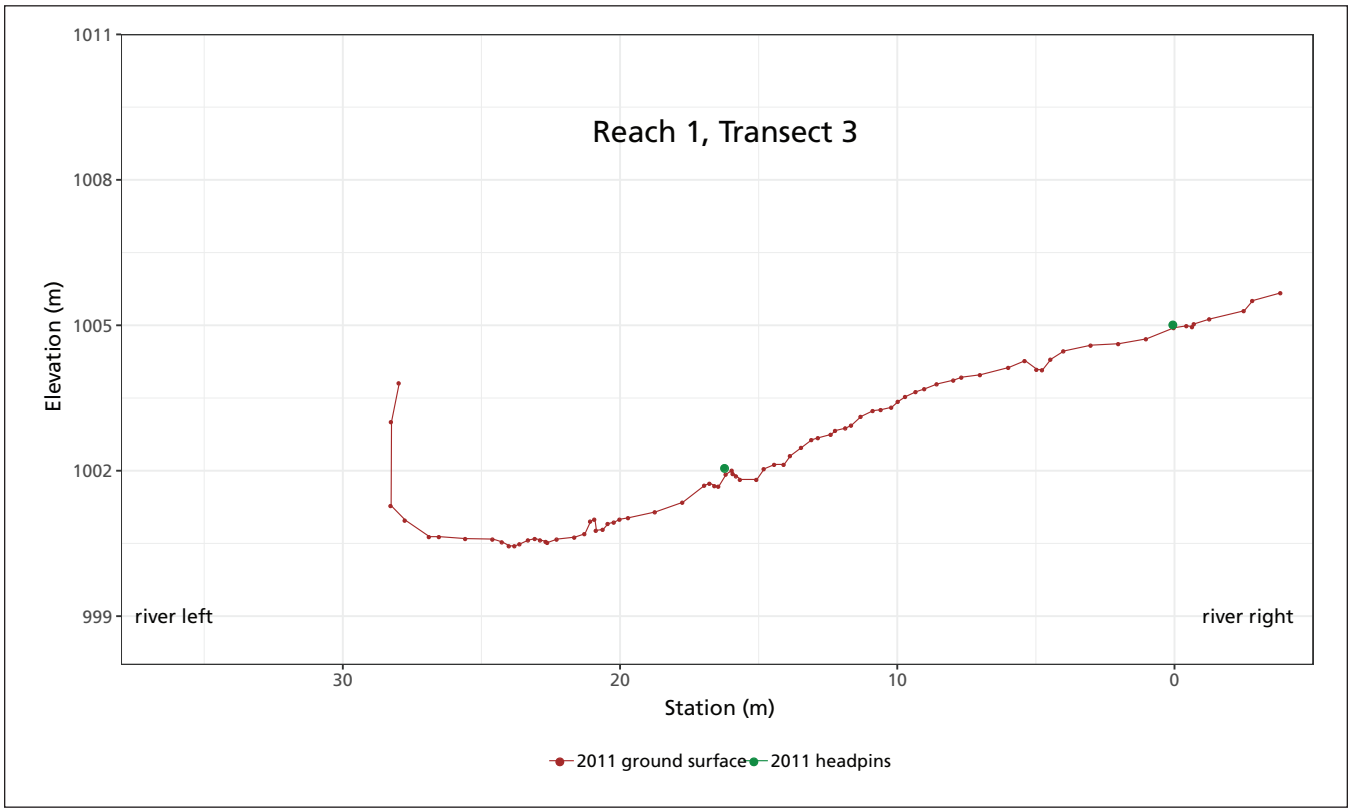


Figure B3. Cross-section of Reach 1, Transect 3, looking downstream, Armstrong Canyon, National Bridges National Monument, 2011.

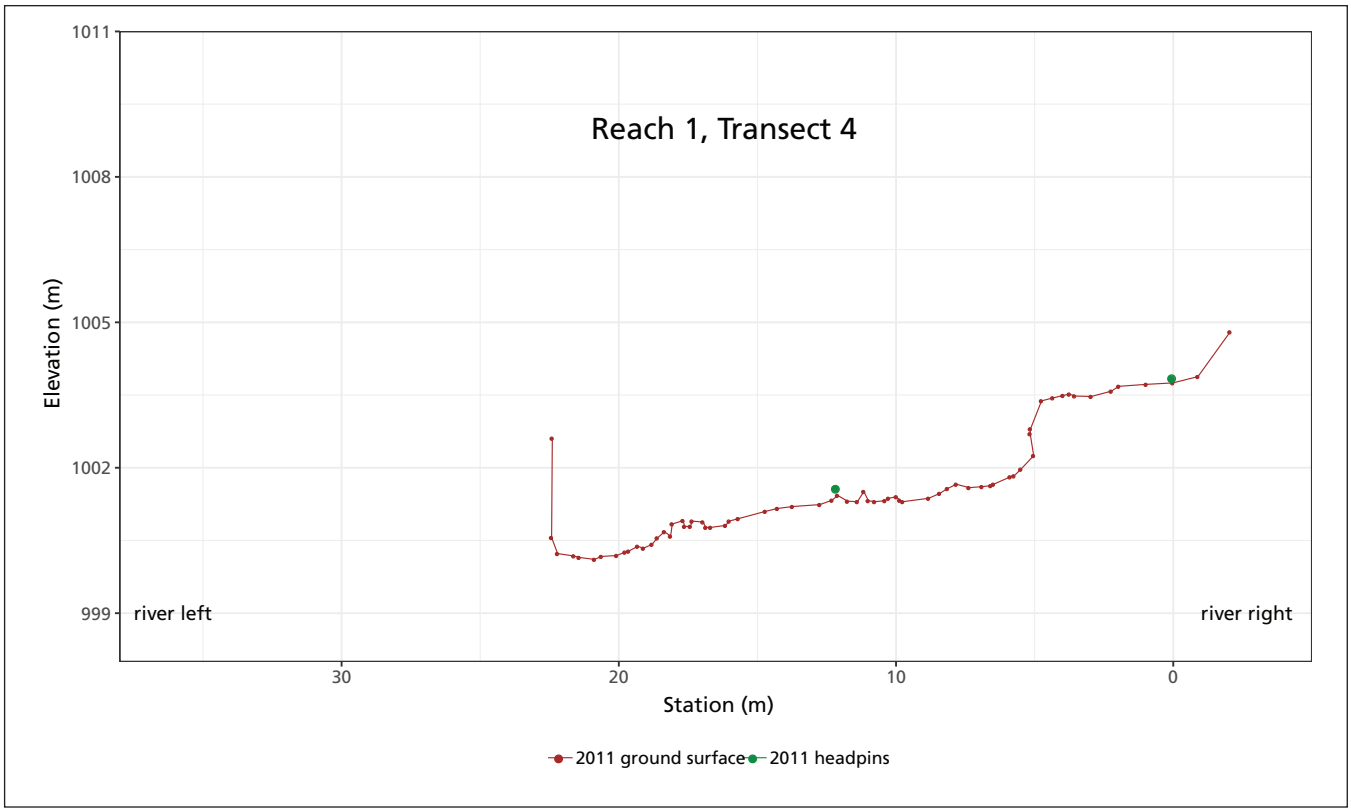


Figure B4. Cross-section of Reach 1, Transect 4, looking downstream, Armstrong Canyon, National Bridges National Monument, 2011.

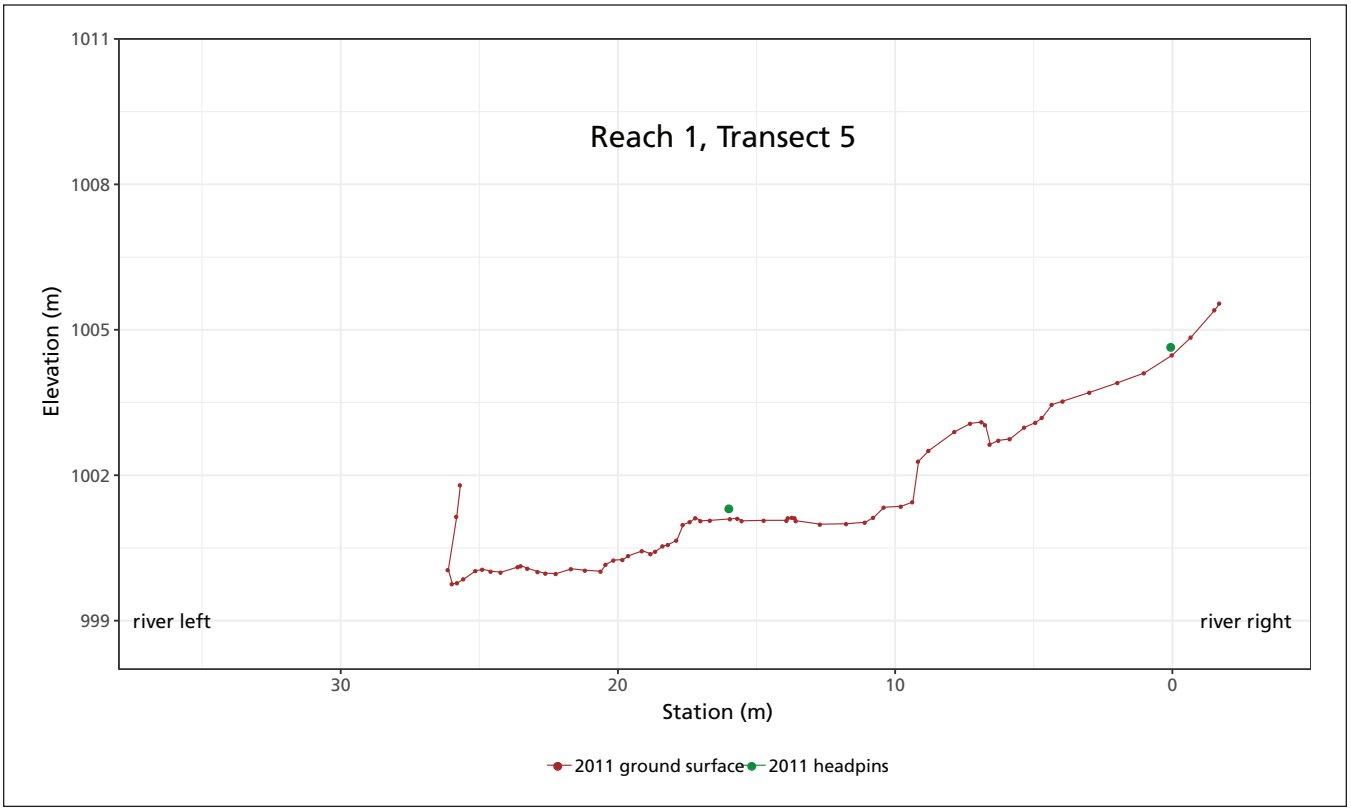


Figure B5. Cross-section of Reach 1, Transect 5, looking downstream, Armstrong Canyon, National Bridges National Monument, 2011.

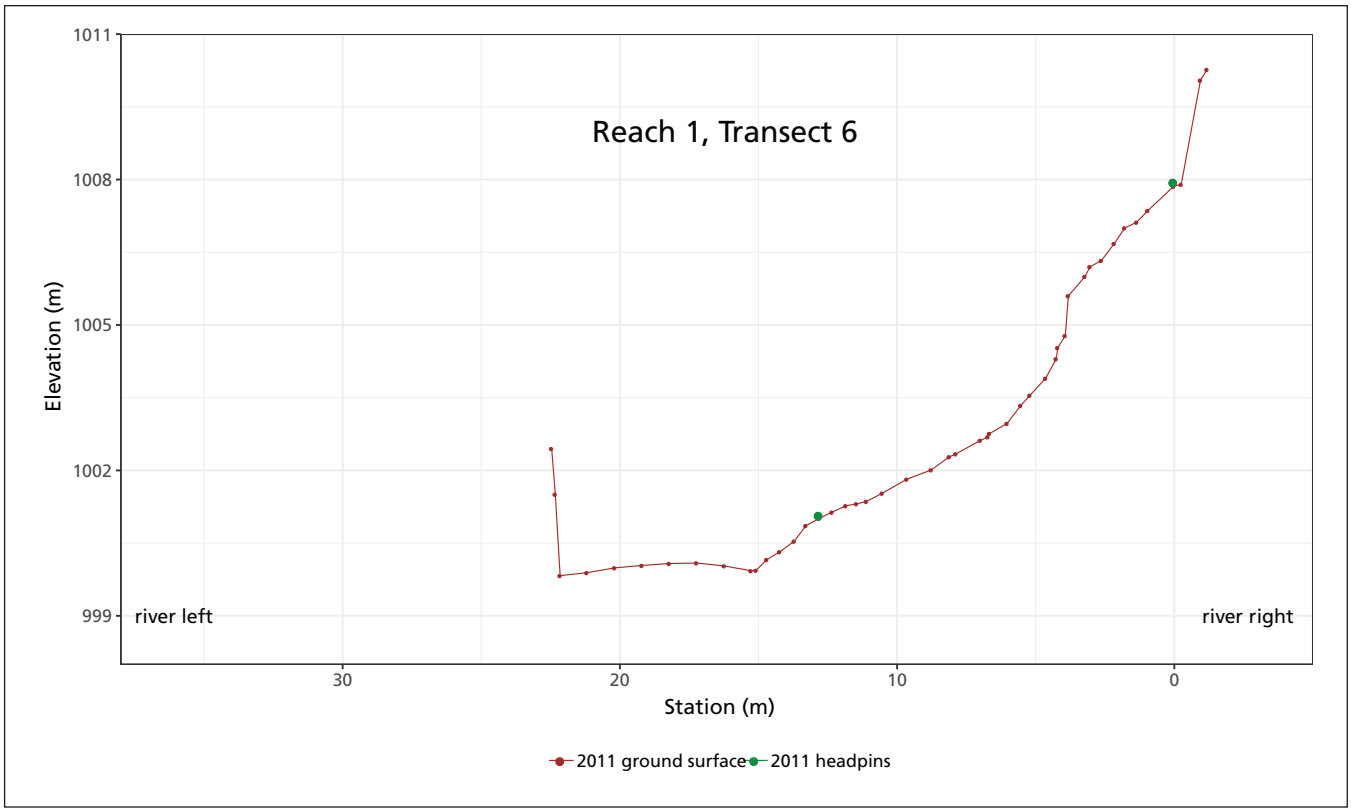


Figure B6. Cross-section of Reach 1, Transect 6, looking downstream, Armstrong Canyon, National Bridges National Monument, 2011.

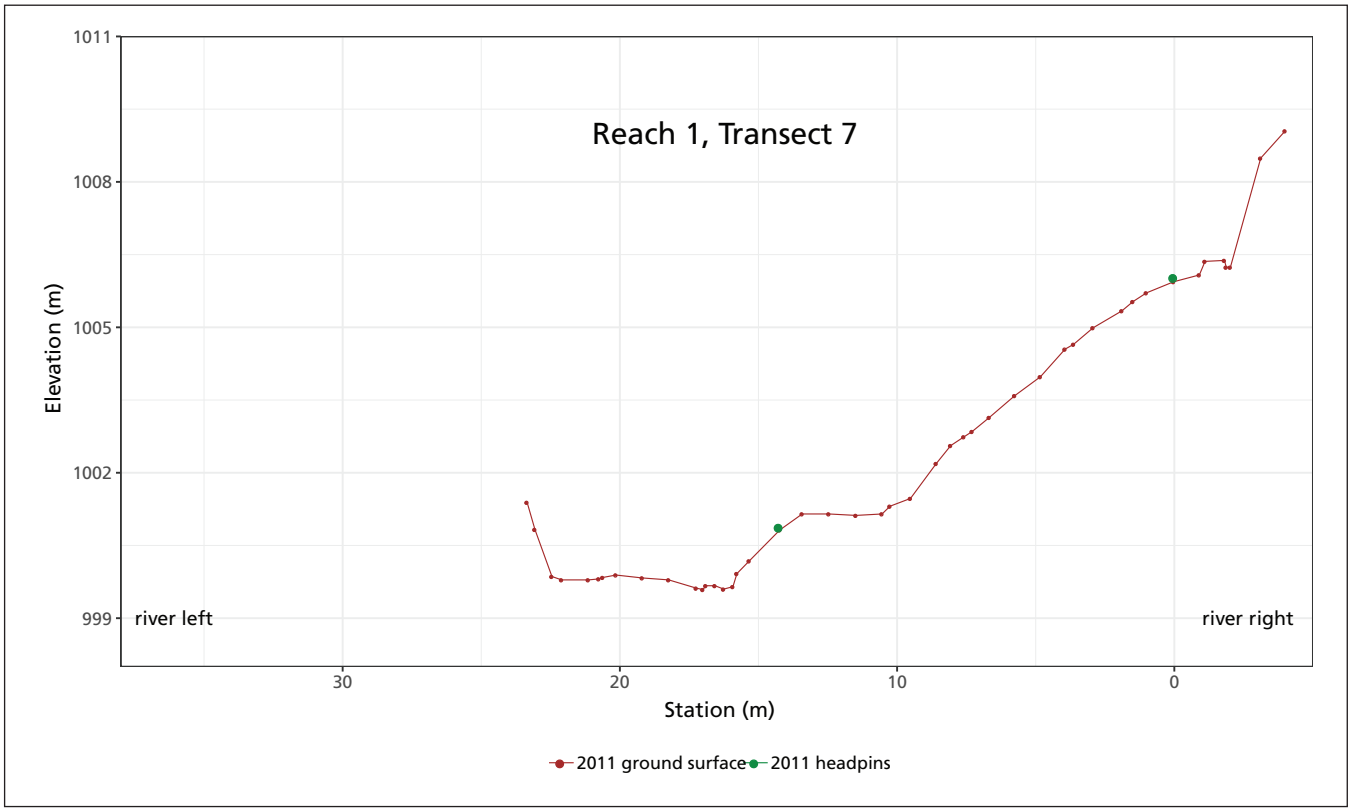


Figure B7. Cross-section of Reach 1, Transect 7, looking downstream, Armstrong Canyon, National Bridges National Monument, 2011.

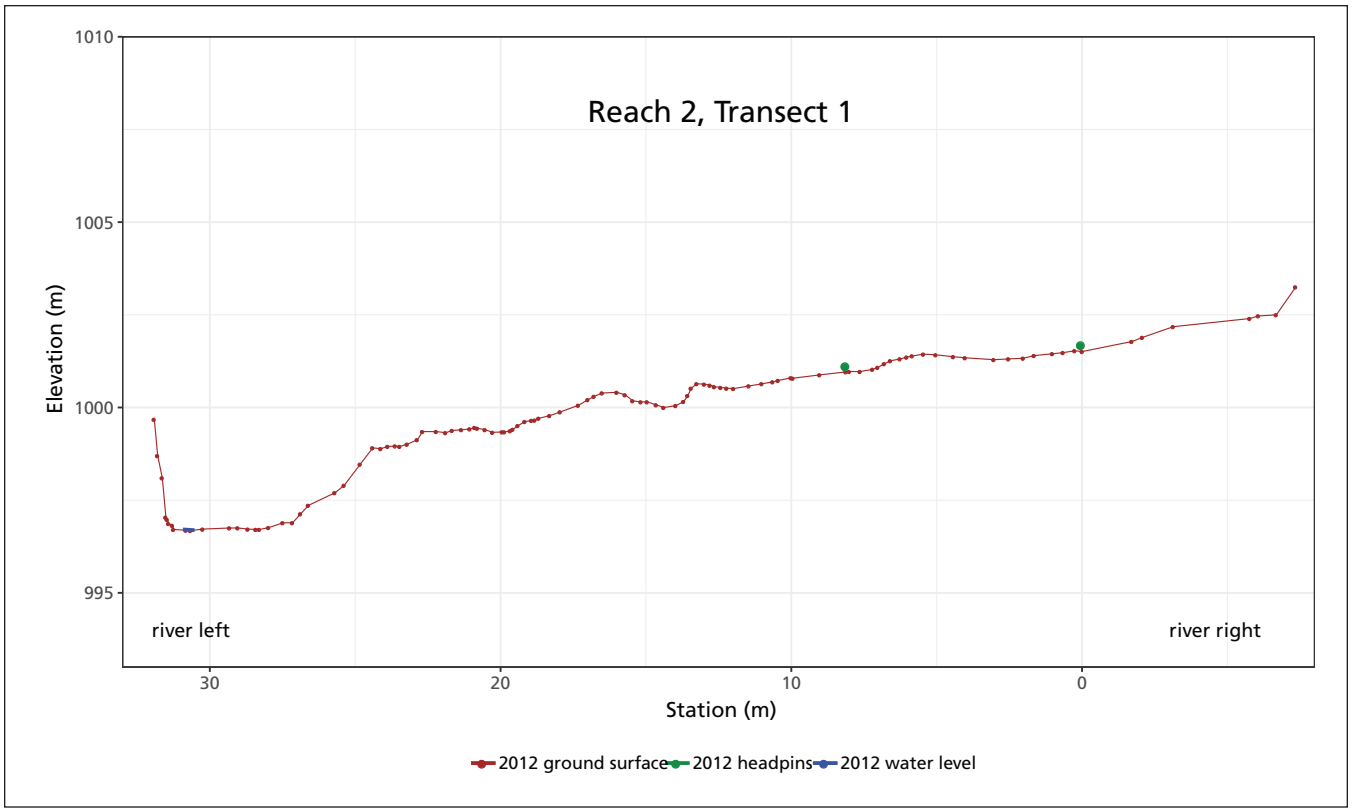


Figure B8. Cross-section of Reach 2, Transect 1, looking downstream, Armstrong Canyon, National Bridges National Monument, 2012.

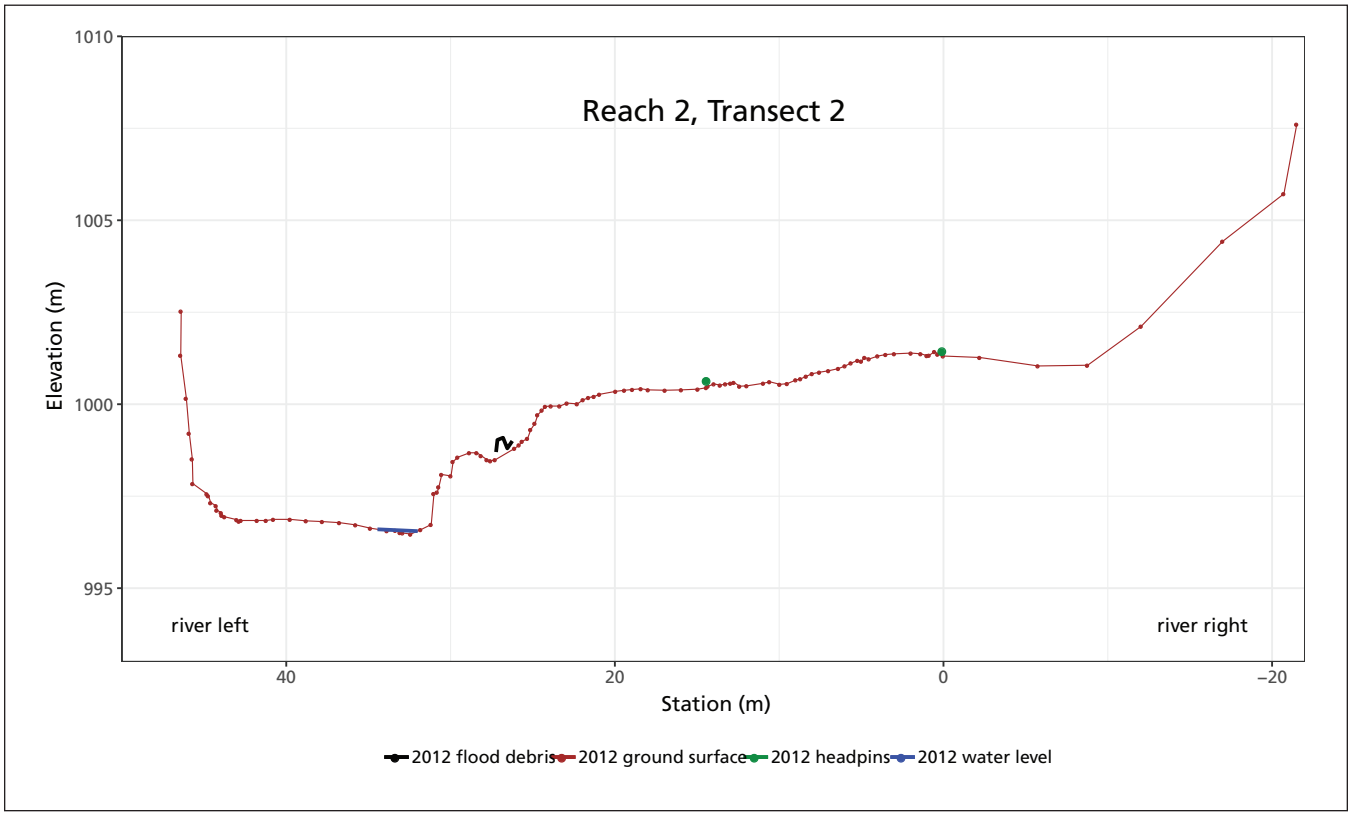


Figure B9. Cross-section of Reach 2, Transect 2, looking downstream, Armstrong Canyon, National Bridges National Monument, 2012.

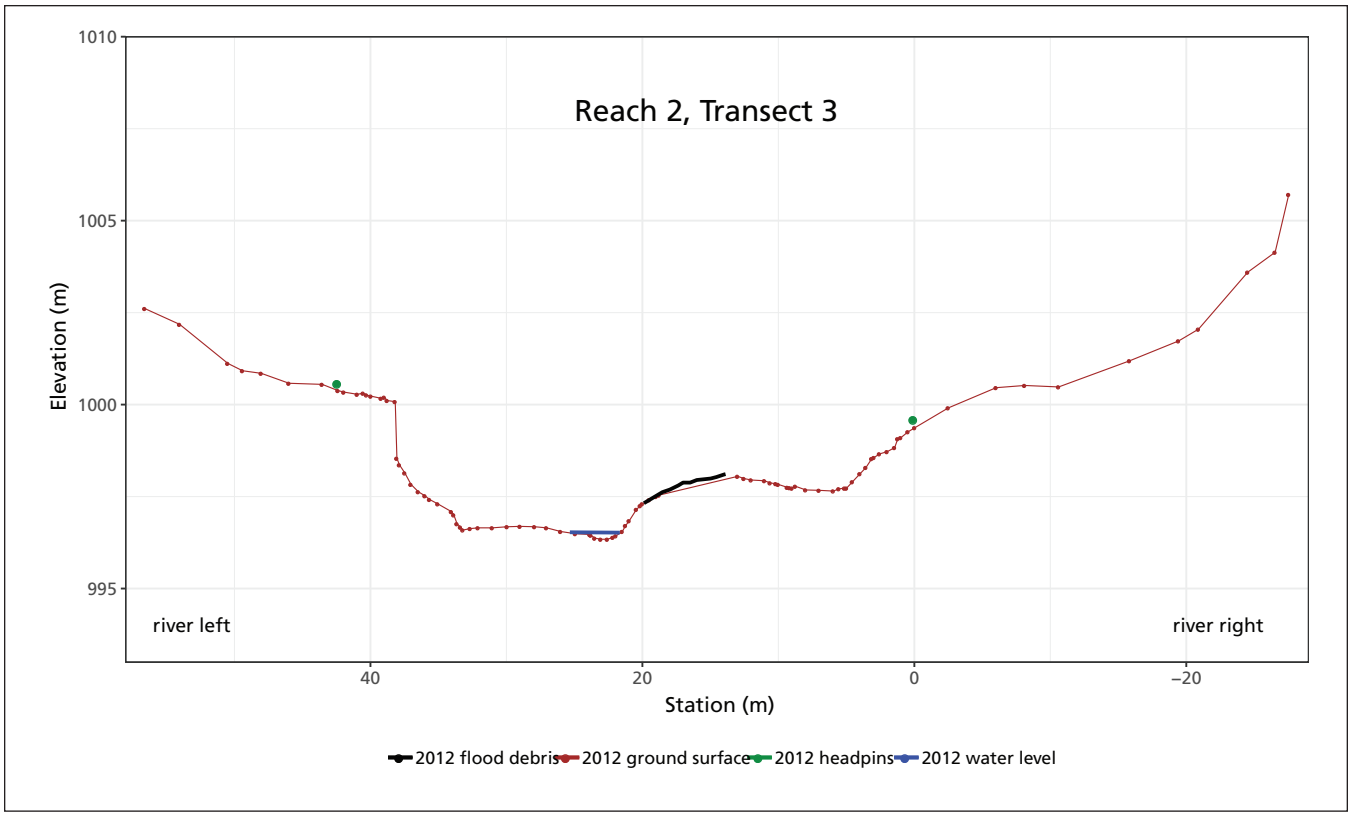


Figure B10. Cross-section of Reach 2, Transect 3, looking downstream, Armstrong Canyon, National Bridges National Monument, 2012.

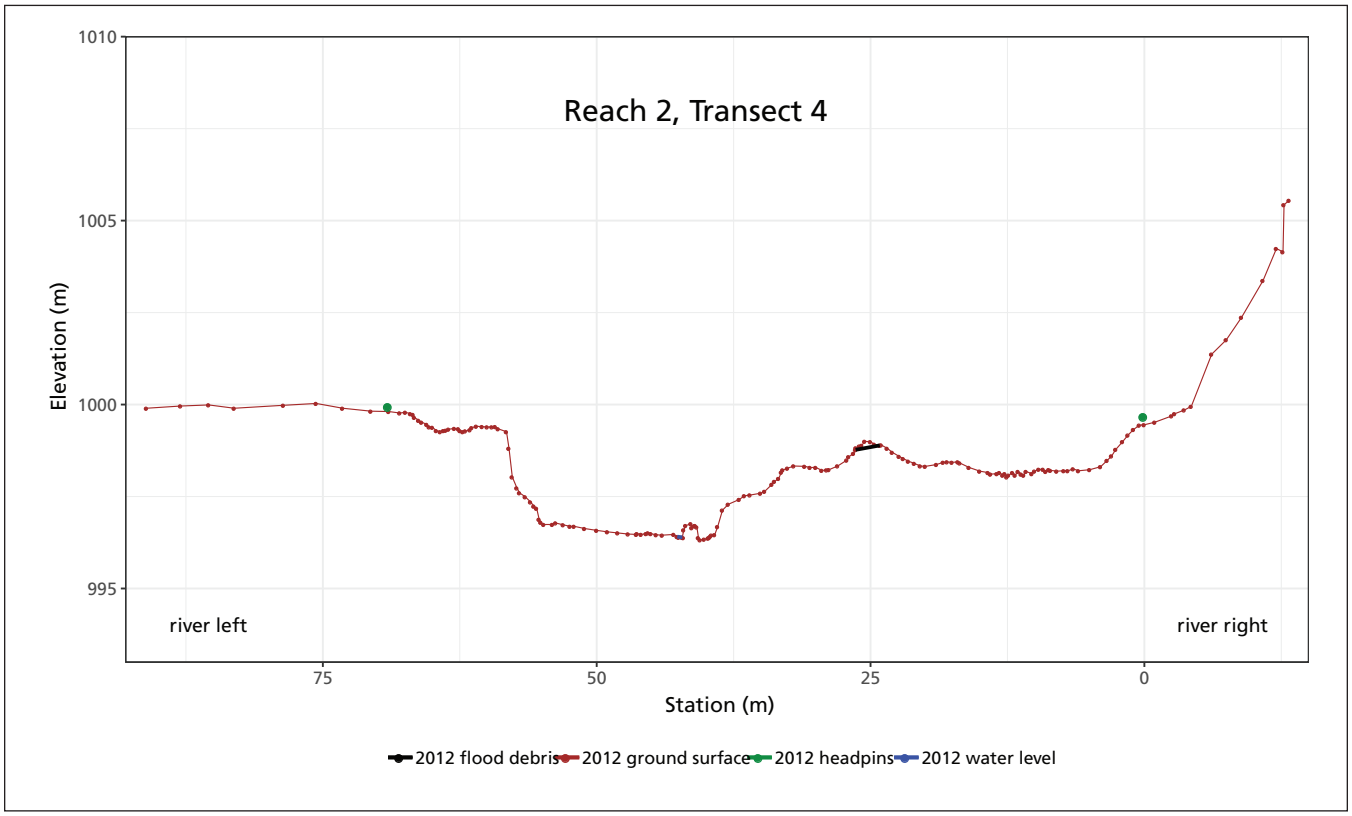


Figure B11. Cross-section of Reach 2, Transect 4, looking downstream, Armstrong Canyon, National Bridges National Monument, 2012.

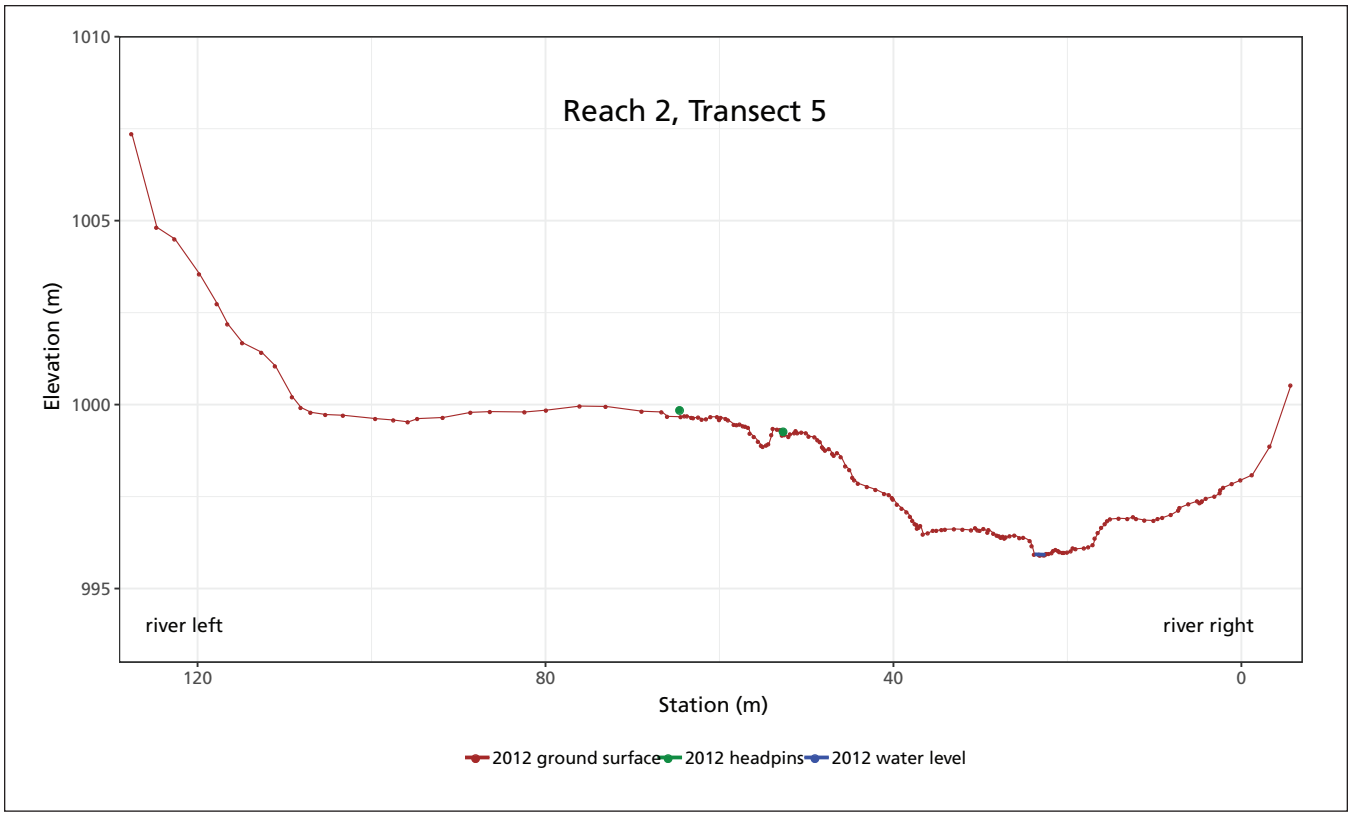


Figure B12. Cross-section of Reach 2, Transect 5, looking downstream, Armstrong Canyon, National Bridges National Monument, 2012.

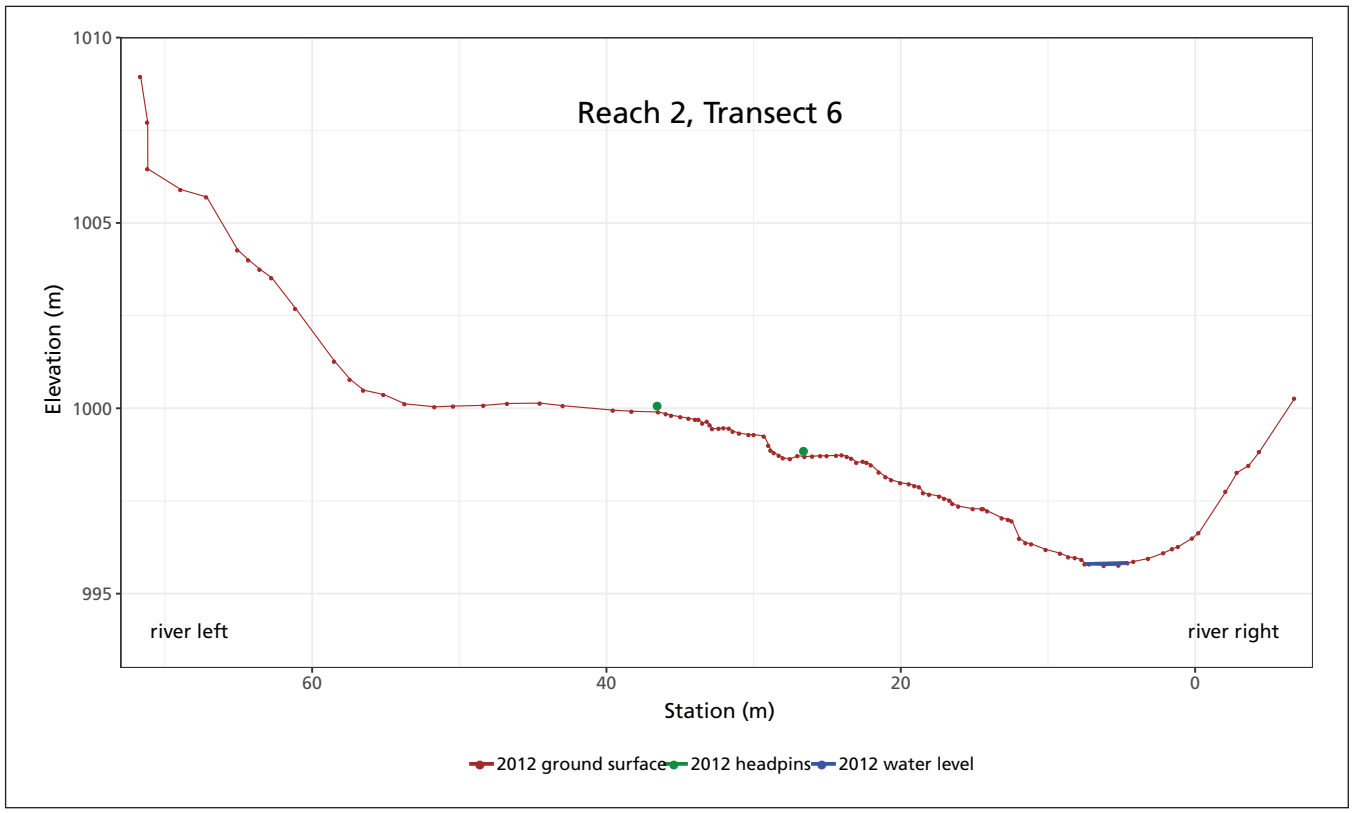


Figure B13. Cross-section of Reach 2, Transect 6, looking downstream, Armstrong Canyon, National Bridges National Monument, 2012.

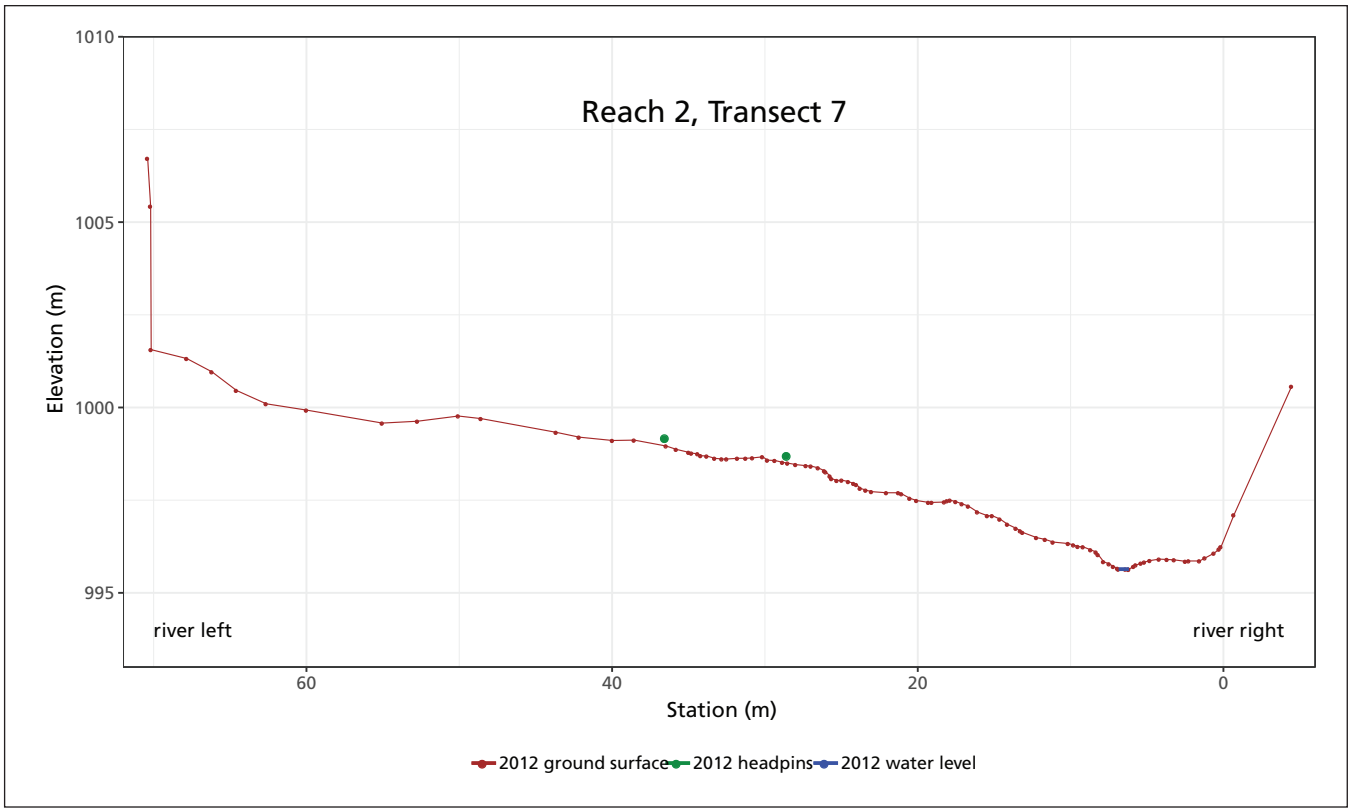


Figure B14. Cross-section of Reach 2, Transect 7, looking downstream, Armstrong Canyon, National Bridges National Monument, 2012.

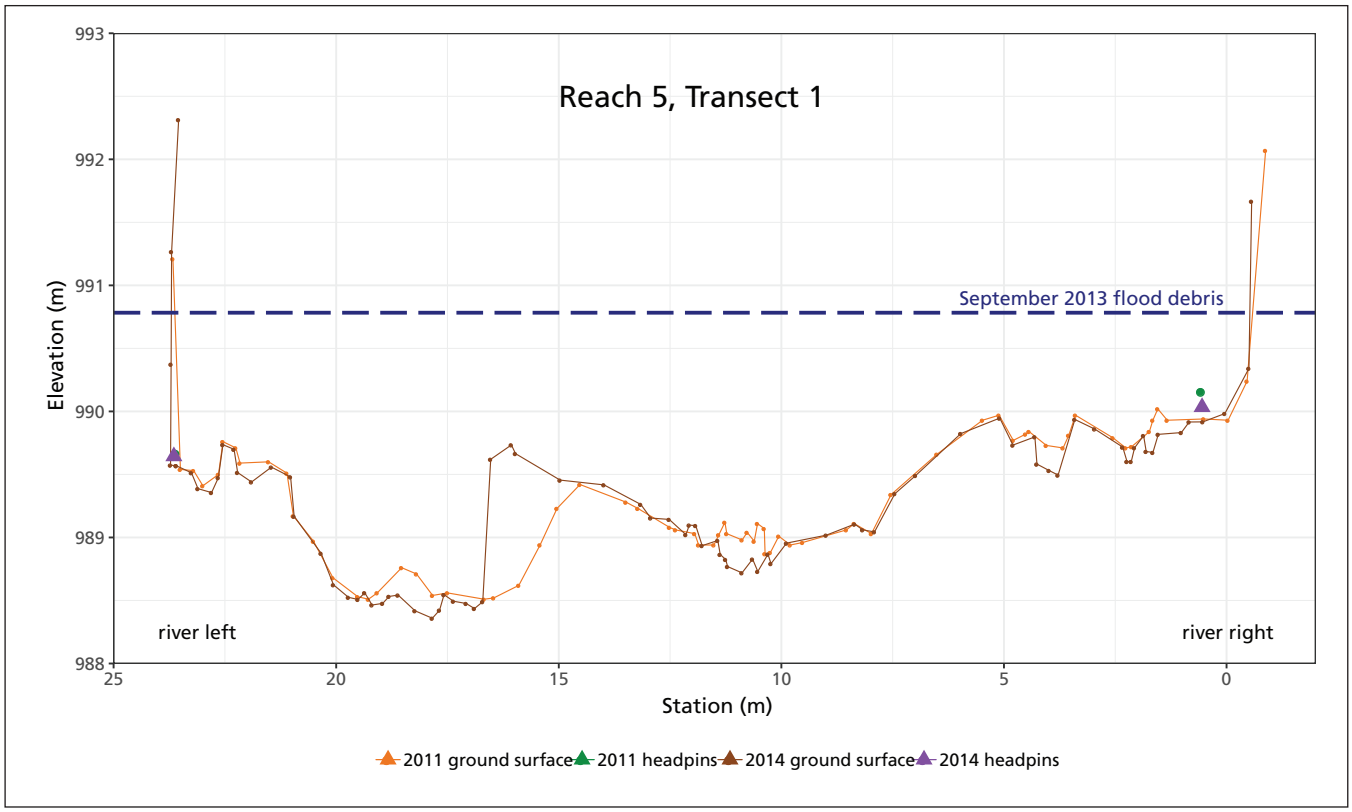


Figure B15. Cross-section of Reach 5, Transect 1, looking downstream, Armstrong Canyon, National Bridges National Monument, 2011 and 2014. No water was present in 2011 or 2014. A blue dashed line shows the elevation of debris from the September 2013 floods detected during the 2014 survey.

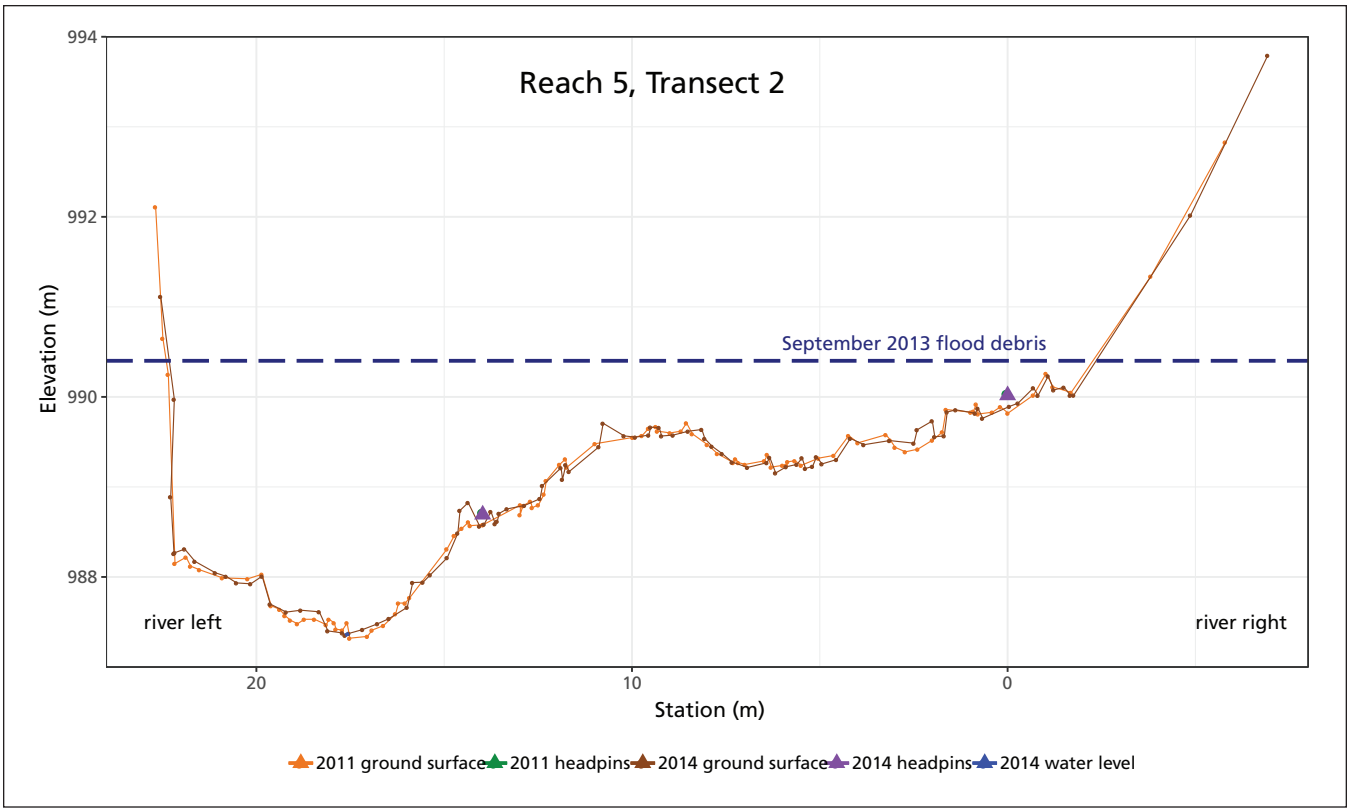


Figure B16. Cross-section of Reach 5, Transect 2, looking downstream, Armstrong Canyon, National Bridges National Monument, 2011 and 2014. No water was present in 2011. A blue dashed line shows the elevation of debris from the September 2013 floods detected during the 2014 survey.

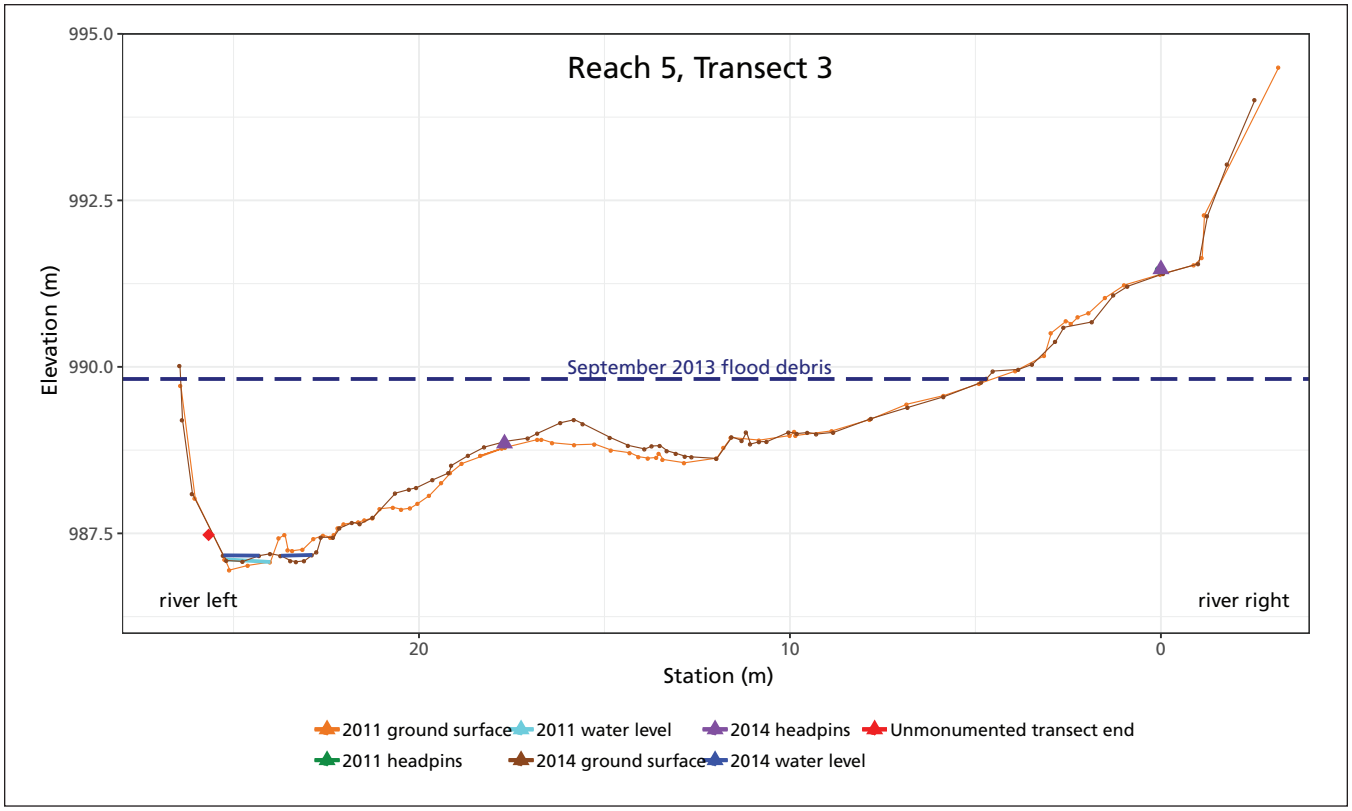


Figure B17. Cross-section of Reach 5, Transect 3, looking downstream, Armstrong Canyon, National Bridges National Monument, 2011 and 2014. A blue dashed line shows the elevation of debris from the September 2013 floods detected during the 2014 survey.

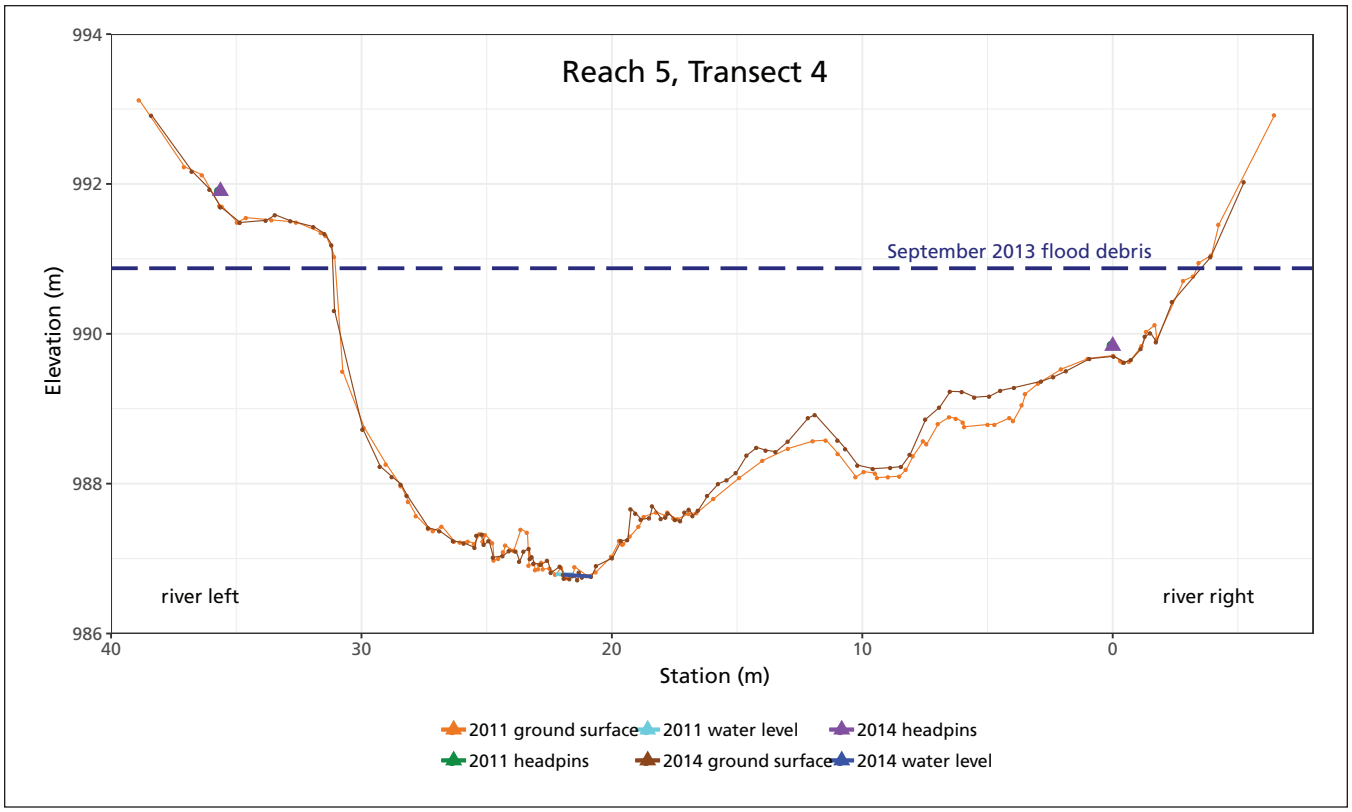


Figure B18. Cross-section of Reach 5, Transect 4, looking downstream, Armstrong Canyon, National Bridges National Monument, 2011 and 2014. A blue dashed line shows the elevation of debris from the September 2013 floods detected during the 2014 survey.

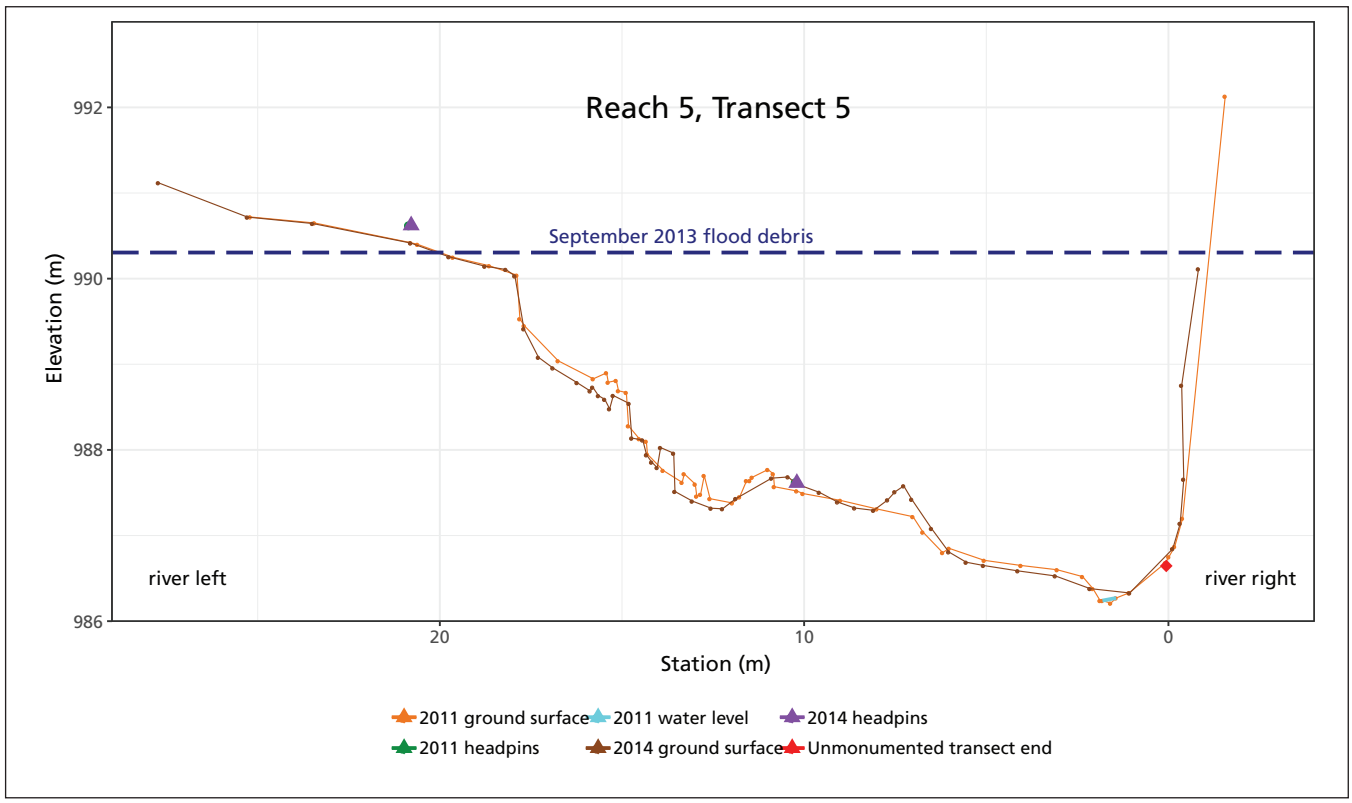


Figure B19. Cross-section of Reach 5, Transect 5, looking downstream, Armstrong Canyon, National Bridges National Monument, 2011 and 2014. No water was present in 2014. A blue dashed line shows the elevation of debris (which on this transect was a large cottonwood trunk) from the September 2013 floods detected during the 2014 survey.

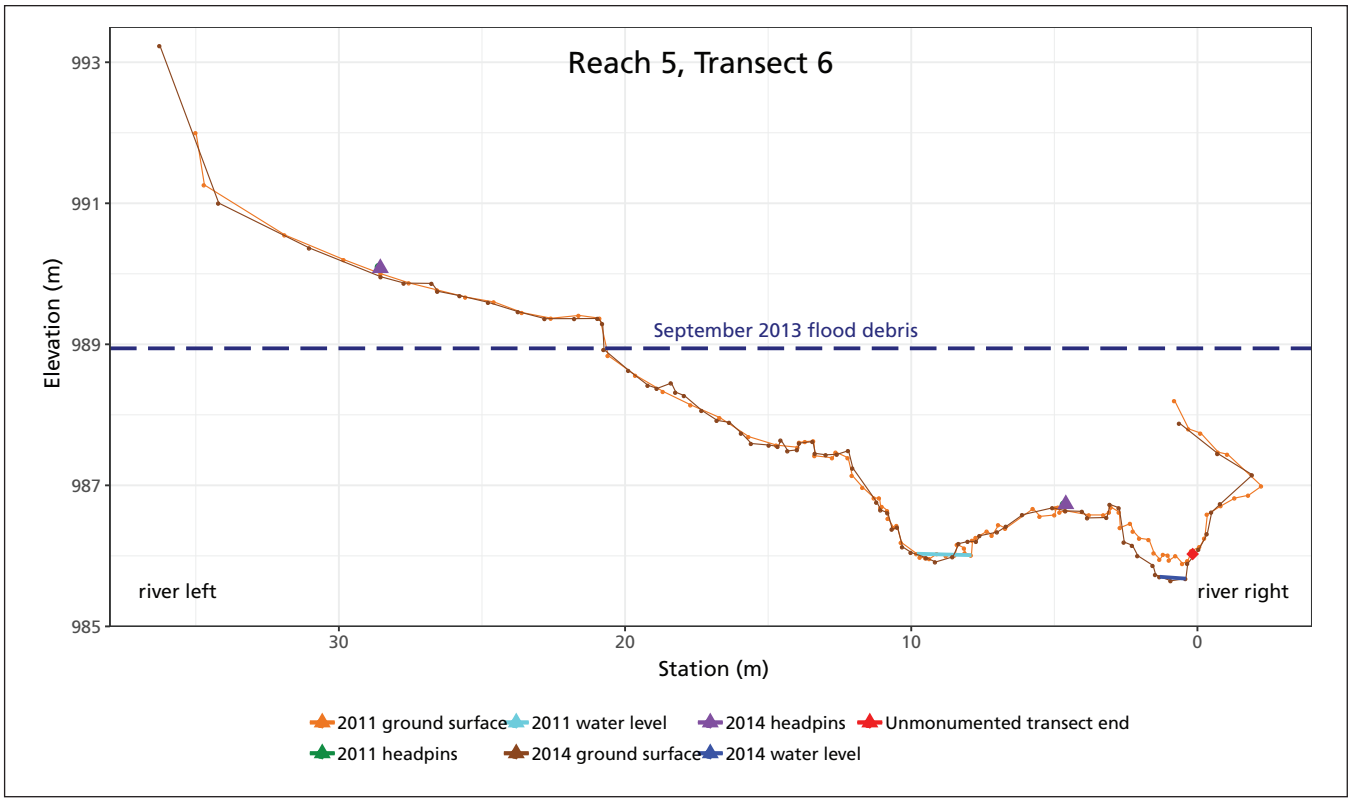


Figure B20. Cross-section of Reach 5, Transect 6, looking downstream, Armstrong Canyon, National Bridges National Monument, 2011 and 2014. A blue dashed line shows the elevation of debris from the September 2013 floods detected during the 2014 survey.

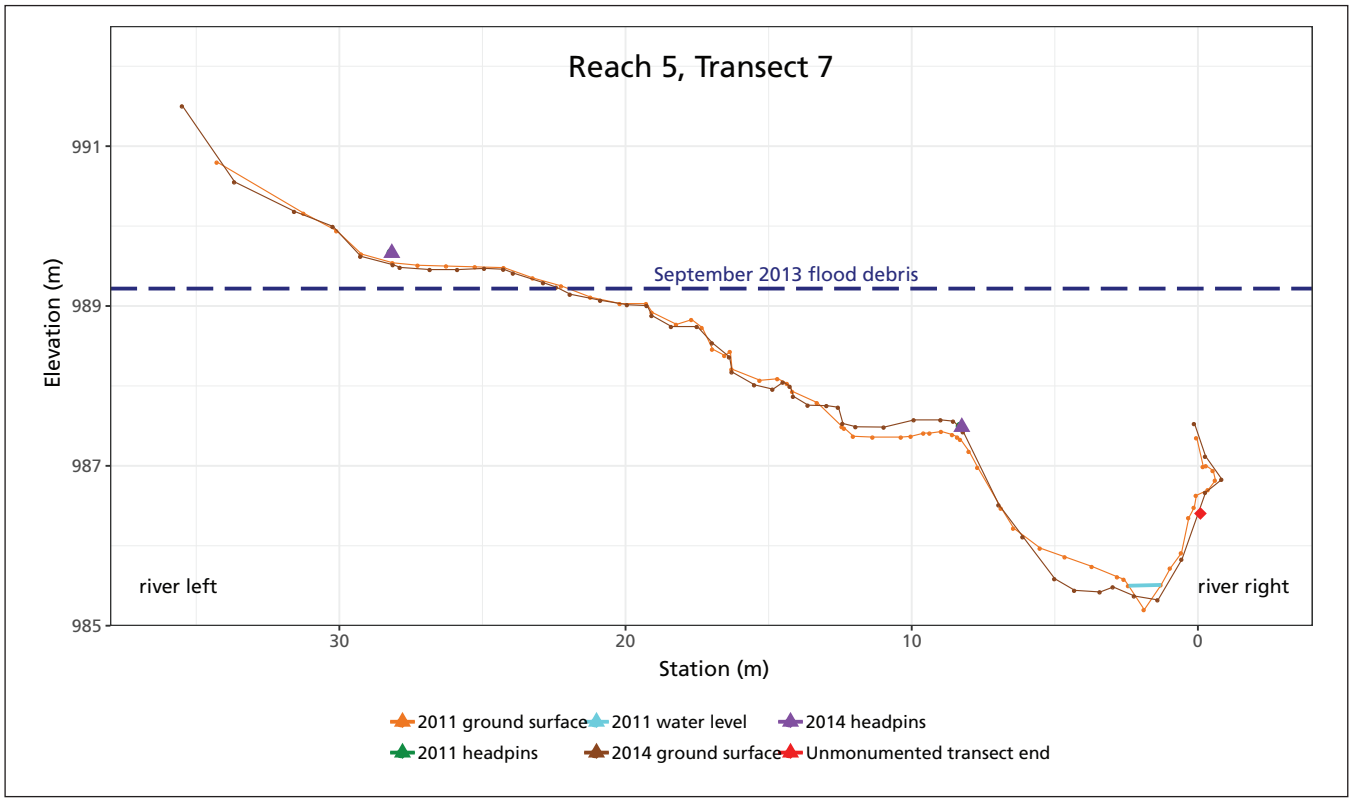


Figure B21. Cross-section of Reach 5, Transect 7, looking downstream, Armstrong Canyon, National Bridges National Monument, 2011 and 2014. No water was present in 2014. A blue dashed line shows the elevation of debris from the September 2013 floods detected during the 2014 survey.

The Department of the Interior protects and manages the nation's natural resources and cultural heritage; provides scientific and other information about those resources; and honors its special responsibilities to American Indians, Alaska Natives, and affiliated Island Communities.

NPS 115/154794, July 2019

National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science
1201 Oak Ridge Drive, Suite 150
Fort Collins, Colorado 80525

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