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Natural Resource Stewardship and Science

Riparian Monitoring of Wadeable Streams, East Fork Virgin River, Zion National Park

Summary Report, 2008–2012

Natural Resource Report NPS/NCPN/NRR—2015/1021



ON THE COVER

East Fork Virgin River at reach 1, Parunuweap Canyon, Zion National Park, September 2012. NPS photo.

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Summary Report, 2008–2012

Natural Resource Report NPS/NCPN/NRR—2015/1021

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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 about integrated attributes of hydrology, vegetation, and geomorphology on those streams. This information is intended to provide early warning of resource degradation and determine natural variability of wadeable streams.

This report summarizes network monitoring of the East Fork Virgin River in Zion National Park from 2008 to 2012. It outlines goals and objectives of the network's wadeable streams monitoring, methods of the associated protocol, and an overview of the sampling design. This report also presents baseline data on three monitored reaches and examines changes in geomorphology and vegetation resulting from a December 2010 flood event. This flood, which peaked at 3,090 cubic feet per second, was the second-largest flood recorded from 1992 to 2013, and is estimated to be a 25–40 year flood event.

Pre- and post-flood surveys of cross-section transects at reach 1 showed that the flood left substantial deposition on the modern terrace. There was also a significant increase in channel width and a corresponding decrease in floodplain width at this reach. The other two reaches were not surveyed before the flood, but through our vegetation monitoring, we detected a significant increase in the wetted width of the channel at reach 3 after the flood, suggesting the presence of changes similar to those seen at reach 1. Our analysis also suggests that the rising elevation of the modern terrace is causing it to blend with the historic terrace in places so that the two terraces are indistinguishable on surveyed stream cross-sections.

Vegetation response to the flood varied at different reaches. Species richness increased at reaches 1 and 2, while richness and total live cover decreased at reach 3. In addition, the density of Fremont cottonwood (*Populus fremontii*) seedlings increased at reaches 1 and 3 but not at reach 2. The increases in species richness and cottonwood seedling density were expected flood responses. It appears that the decreases in richness and cover at reach 3 were due to (1) erosion of the stream bank that buried or washed away plants, especially obligate wetland graminoids, and (2) damage to Rio Grande seepwillow (*Baccharis salicina*) on the floodplain; the live cover of this plant was reduced more than that of any other species. The lack of increase in cottonwood seedling density at reach 2 likely occurred because there were fewer suitable locations for germination at this reach, which had higher cover of bedrock and dense shrubs adjacent to the channel than reaches 1 and 3.

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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 southwestern bird species 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 have recorded 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 rivers and streams through enhanced water supply, flooding, and erosional and depositional processes (Brinson et al. 1981).

At the same time, upland disturbance processes, across a range of scales, impose direct and indirect effects on riparian ecosystems. 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, 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 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 semi-arid 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).
- **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 the intensity and frequency of disturbances (Hupp and Osterkamp 1985; Bendix 1994). These diverse alluvial surfaces support a wide range of riparian plant and animal communities.

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 observed recovery of upland ecosystems in arid and semi-arid regions, where productivity is typically lower and plant recruitment is slower and more episodic (Scott et al. 2005).

High rates of recovery in riparian ecosystems result primarily from adequate moisture, which supports relatively high rates of productivity; high linear connectivity, which allows for rapid re-colonization of disturbed sites from upstream and downstream refugia; and disturbance-adapted species, whose life-history characteristics allow them to re-establish and re-colonize quickly after 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 Protocol goals and objectives

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

Determine status and trends in surface and groundwater dynamics, including:

- depth to alluvial groundwater
- surface flow
- permanence of stream flow

Determine status and trends in geomorphic processes as reflected in channel and floodplain form, including:

- floodplain width and elevation
- channel width and depth
- channel planform
- channel slope
- composition of bed material

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
- frequency of invasive species

Data from these objectives will be integrated to produce models (such as stage-geomorphic process relationships) and correlations (such as vegetation assemblage by geomorphic surface and depth to groundwater).

1.3 Resource issues driving riparian monitoring at Zion National Park

Zion National Park (NP) resource management staff identified the East Fork Virgin River (EFVR) as the highest-priority wadeable stream for long-term monitoring in the park, due to its similarities in setting and flow to the highly altered North Fork Virgin River, which runs through Zion Canyon. The EFVR within Zion NP is relatively unaltered compared to the North Fork, and is one of the few stream reaches in the U.S. desert southwest believed to be functioning naturally. Monitoring will help us to understand natural variability of this system and provide early warning of system degradation due to human disturbances, especially from outside the park.

Most of the river and watershed are located upstream of the park in Long Valley, along Highway 89 (Figure 1-1), where much of the water is diverted for municipal use and to irrigate agricultural fields and pastures. The river enters the narrow Parunuweap Canyon about 10 miles east of the park boundary on Bureau of Land Management (BLM) land, then continues west through the Research Natural Area in Parunuweap Canyon in the southern part of the park.

Within the park, the river remains in the canyon, but the valley gradually widens, with substantial alluvial terraces, near the western boundary of the park. A few miles after it exits the park, the EFVR joins the North Fork Virgin River to form the mainstem of the Virgin River, southwest of Springdale, Utah. The EFVR has a length of 74 kilometers (46 mi; PSIC 1974), and a watershed area of 1,051 square kilometers (406 mi^2). Within Zion NP, the EFVR is a partly confined perennial stream with low sinuosity (approximately 1.16). The park contains approximately 17% of the length of the EFVR and 6% of the watershed area.

1.3.1 Hydrology

With the extensive water diversions on the upper EFVR, flows entering Parunuweap Canyon are severely diminished upstream of the park during dry periods. However, the majority of flow in the lower EFVR within Zion NP is attributable to accretion of groundwater from the Navajo Sandstone formation (Boyle et al. 1993), and only 3.9% of mean annual streamflow is removed by irrigation and other uses (Sharrow 2013). A water rights agreement, signed in 1996, protects stream and spring water rights within the park, created a groundwater protection zone within two miles of the park boundary, and limits impoundments upstream of the park (USDOI 1996).

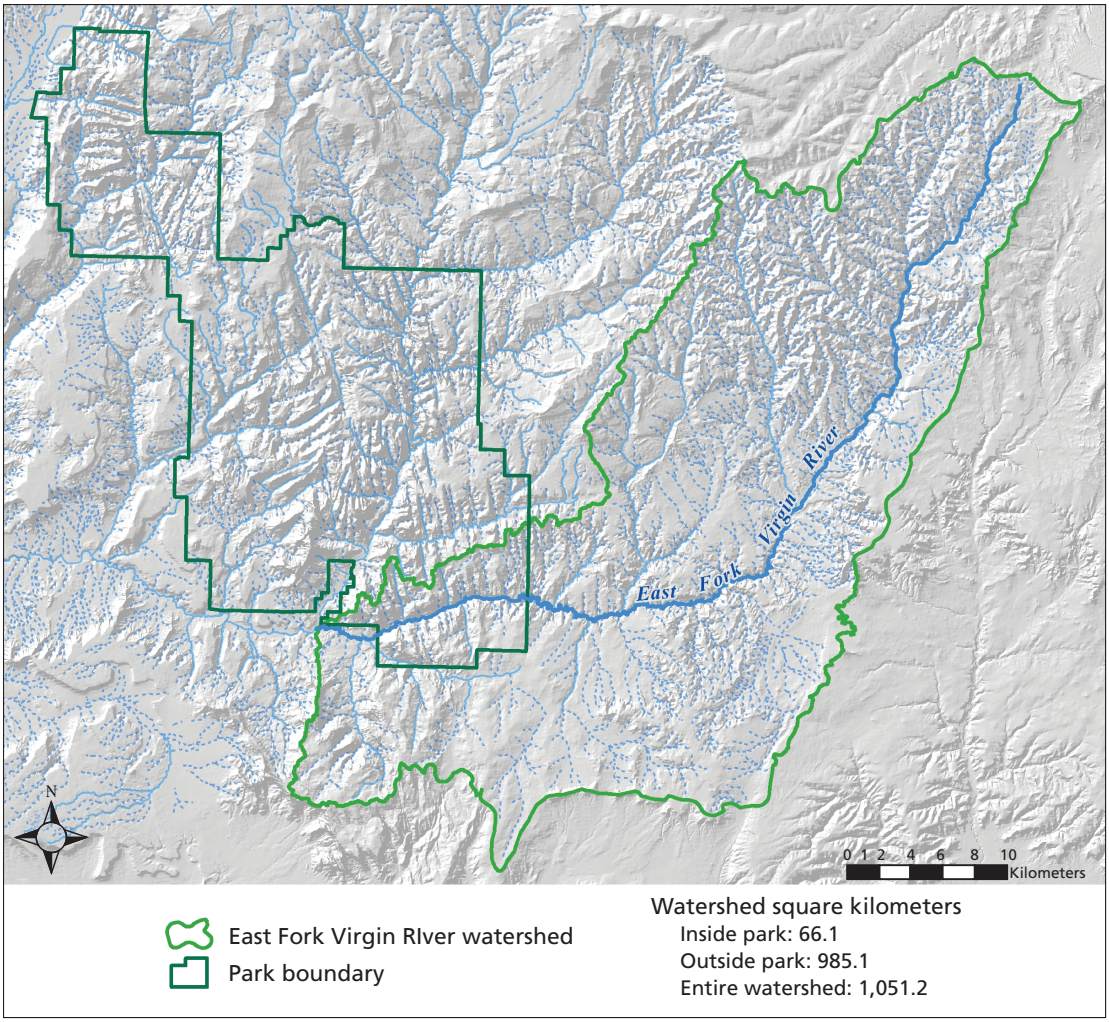


Figure 1-1. Watershed area, East Fork Virgin River.

The near-exclusion of large impoundments upstream of the park preserves natural regimes of floods and sediment transport, which is significant for the river's geomorphology. Due to the consistently flowing springs in Parunuweap Canyon, the EFVR within the park has relatively stable perennial base flow, with an average daily mean flow of 57 cubic feet per second (cfs), and base flow between 30 and 45 cfs. Snowmelt usually occurs between early March and mid-April, with an average peak of approximately 180 cfs. Peak flows for the year usually coincide with storm systems rather than snowmelt runoff, including short-duration, high-intensity monsoonal storms in the summer months and longer-duration, Pacific storm fronts that can develop in the fall and winter months.

1.3.2 Geomorphology

Periods of erosion and deposition along the EFVR are well documented and follow regional erosion and deposition cycles in the southwestern U.S. (Hereford et al. 1995). Erosion occurs during wetter periods with higher streamflow, while deposition occurs during drier periods with lower streamflow. Individual peak streamflow events play a much smaller role in this cycle than longer-term climate patterns. These cycles have created four distinct terraces in the section of the EFVR within the park (Figure 1-2).

The latest cycle of prehistoric erosion on the EFVR occurred from approximately 1200 to 1400 A.D. and ended the prehistoric occupation of Parunuweap Canyon that began around 800 A.D. (Hereford et al. 1995). The terrace that remains from this period (prehistoric terrace) is confined to the margins of the alluvial valley about 6–10 meters (m) above the modern terrace and is located mainly at the lower end of Parunuweap Canyon (Figure 1-2).

After about 1400, a long period of deposition occurred, including during the first 20 years of European settlement in the area, from 1862 until around 1883. Historical documents and photographs indicate that the EFVR had a shallow, narrow, meandering channel with an extensive floodplain at the time of settlement (Hereford et al. 1995). Alluvial terraces near the western park boundary were used for agriculture during this time. The terrace that remains from this period (settlement terrace) is located about 2–4 m below the prehistoric terrace (Hereford et al. 1995; Figure 1-2).

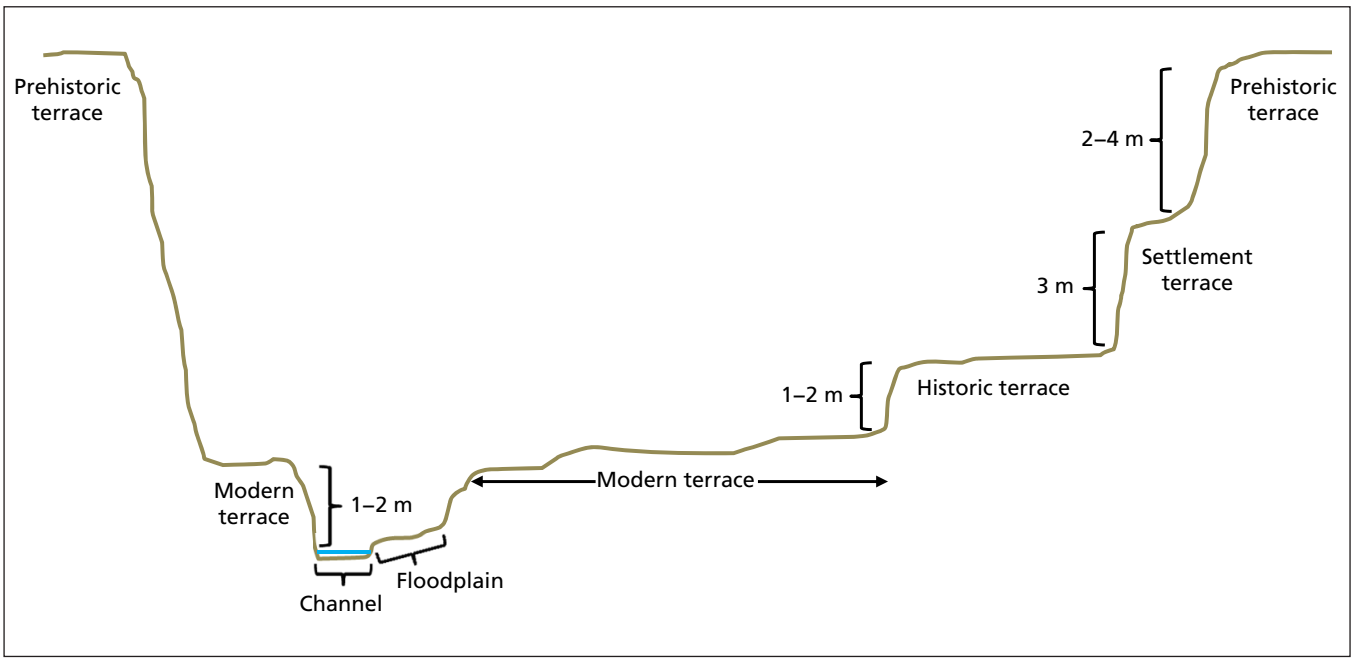


Figure 1-2. Conceptual diagram of terraces described by Hereford and others (1995) on the East Fork Virgin River, Zion National Park. The settlement terrace was the active alluvial terrace during a period of deposition from 1400 to 1883, and was used for agriculture by early European settlers in Parunuweap Canyon. The historic terrace is an abandoned channel occupying meander-like features in the settlement terrace. This feature is a remnant of the historic period of erosion, from 1883 to 1940. Above both of these terraces is the prehistoric terrace, which remains from the most recent prehistoric period of erosion, from 1200 to 1400.

The historic period of erosion began in 1883, and was likely exacerbated by overgrazing of sheep and cattle in the region that coincided with a wet period (Hereford et al. 1995). In the late 1800s, there was downcutting of up to 24 m on the EFVR, followed by extensive channel widening (Hereford et al. 1995). The terrace that remains from this period (historic terrace) is an abandoned channel that occupies meander-like features eroded into the settlement terrace. The historic terrace is about 3 m below the settlement terrace and 1–2 m above the modern terrace, and typically has steep surface breaks on either side (Hereford et al. 1995; see Figure 1-2).

Since 1940, the EFVR has remained predominantly in a cycle of deposition. Within Zion NP, the EFVR currently has a narrow channel and floodplain. The modern terrace is 1–2 m above the channel and floodplain and is typically separated from the channel and floodplain by steep cutbanks (Hereford et al. 1995; see Figure 1-2).

1.3.3 History of modern human use

After livestock grazing was discontinued in the 1930s (Webb et al. 2007), the primary visitors to Parunuweap Canyon inside Zion NP were hikers, though these were very few after the 1980s, when restrictions on access through adjacent private lands greatly limited numbers. In October 1991, the U.S. Geological Survey (USGS) installed a gaging station (09404900) on the EFVR within the park, located about 1,200 m (0.75 mi) upstream of the western park boundary.

The National Park Service designated most of the canyon a Research Natural Area in 2001. Since then, the area has been closed to everyone except federal and state agencies performing natural and cultural resource monitoring and certain park staff, such as those performing annual removal of tamarisk (*Tamarix* spp.) and Russian olive (*Elaeagnus angustifolia*). Additionally, the stretch of the EFVR inside the park and 5.2 river miles upstream of the park on BLM land was designated a Wild and Scenic River in 2009.

1.4 Study objectives

The purpose of this report is (1) to present baseline data for three reaches monitored on the EFVR in Zion National NP from 2008 to 2012, and (2) to examine changes in the geomorphology and vegetation on the EFVR resulting from a 25–40 year flood event in December 2010.

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

2.1.1 Sampling frame delineation

The EFVR runs through Zion NP for 12.3 kilometers (km). Prior to sampling, NCPN staff determined that only 10.3 km of the river were accessible for riparian monitoring. The two kilometers of the EFVR nearest the eastern boundary of the park were only accessible by ascending pourovers and large boulders that required advanced climbing moves, so this section was not included in the sampling frame for riparian monitoring.

Within the accessible stretch of the EFVR in Zion NP, we decided to limit monitoring to areas along the stream with alluvial terrace development. This excluded sections of the stream constrained on both sides by bedrock, colluvium, or a combination of the two. Monitoring was limited to alluvial reaches because these are the areas where change can be detected in our timeframe for monitoring (50–100 years). Change occurs much more slowly in reaches constrained by bedrock and colluvium, and our sampling methods are not designed to detect these types of changes.

The geologic spatial dataset for Parunuweap Canyon included detailed mapping of alluvial terraces in addition to the standard geologic map units (NPS 2006). After field testing the accuracy of this dataset, we decided to use it to mask out sections of the stream that were constrained by bedrock and colluvium on both sides. This eliminated four small sections within the sampling frame and a longer section on the upstream side of what was considered accessible. The EFVR is constrained completely by bedrock and colluvium from the eastern end of the sampling

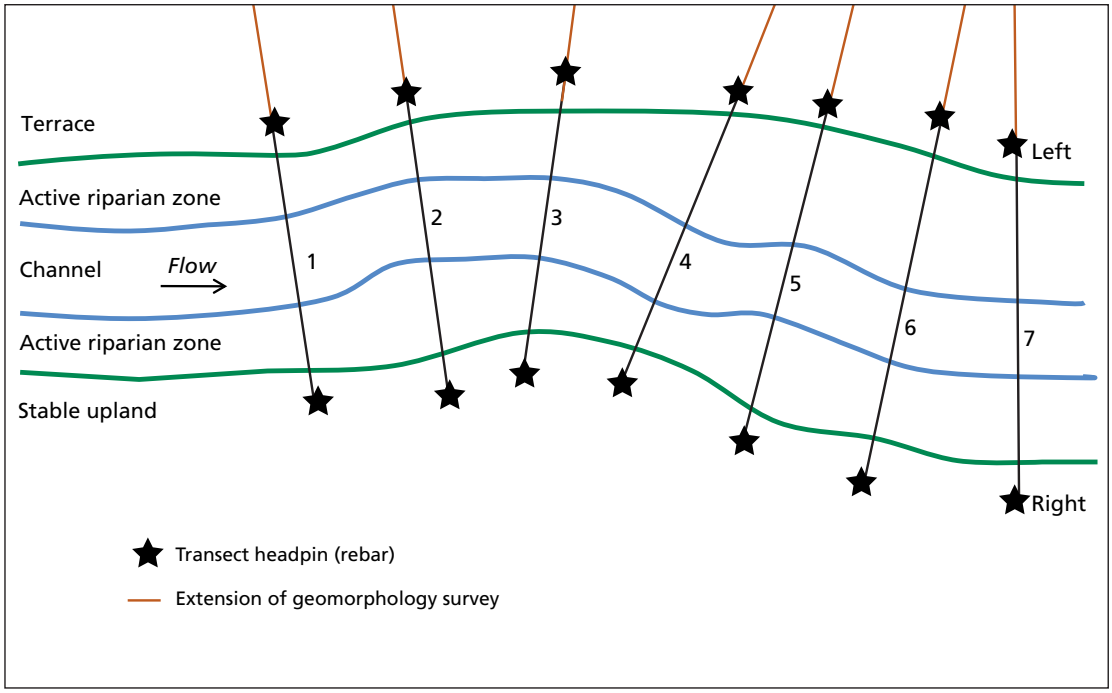


Figure 2-1. Example of a riparian monitoring reach with seven equidistant cross-section transects. The centroid is transect 4. Star symbols indicate locations of headpins, and the green line represents the upland-riparian zone boundary. Vegetation transects sample the active riparian zone, while geomorphology transects extend to a stable upland surface.

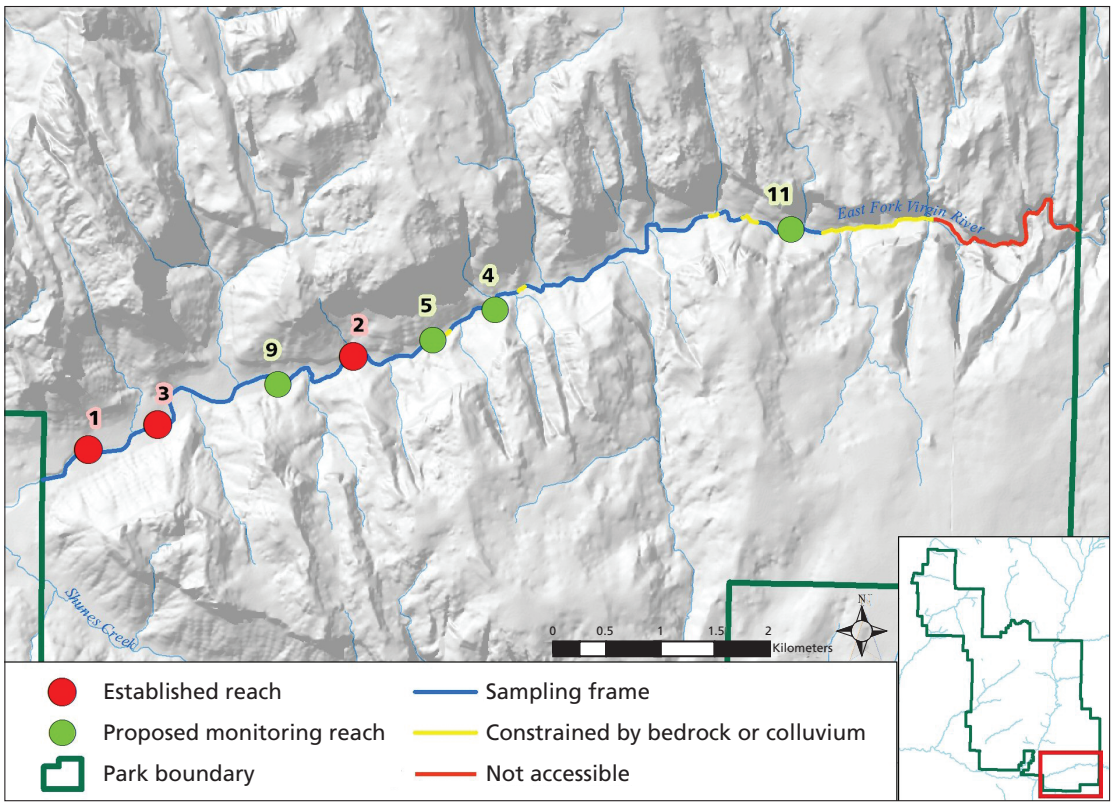


Figure 2-2. Overview map of monitoring reaches on the East Fork Virgin River, Zion National Park, including the reaches established and monitored from 2008 to 2012.

frame to the eastern park boundary.

The final sampling frame for the EFVR (Figure 2-2) included 9.2 km of the stream, starting at the western park boundary. Within this length, a total of 0.4 km was masked out of the four sections constrained by bedrock and colluvium on both sides. This left a length of 8.8 km in the sampling frame, which is 85% of the accessible length of the EFVR.

2.1.2 Monitoring reach selection

Monitoring reaches were selected using the GRTS (Generalized Random Tessellation Stratified) 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 15 possible monitoring reaches in the sampling frame. Reaches were visited ahead of time to ensure that they were suitable for long-term monitoring and were rejected if they contained major tributaries (>10% of the watershed), major spring inputs at the surface, >25% constriction by bedrock or colluvium, or significant cultural sites. Monitoring reaches were then established in ascending order of reach number to maintain the spatial balance of the survey design.

2.1.3 Revisit design

Vegetation and geomorphology monitoring occur at all reaches, and 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 seven reaches are scheduled to be monitored on the EFVR, and vegetation is sampled during the growing season at two reaches each year (Figure 2-3). Vegetation is sampled for two consecutive years at each reach to tease out inter-annual differences due to factors within the range of natural variability, such as temperature, precipitation, and flow, and to better estimate trends. After two years of sampling, the reach is then rested for five years. Geomorphology surveying occurs during leaf-off (i.e., the time when deciduous vegetation is dormant and does

not have any leaves present) between the two growing seasons when vegetation is sampled, so that 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 15-minute intervals by data loggers at the one reach where they are installed, and by the nearby USGS gaging station. Information from the data loggers is collected three times a year, along with manual measurements of surface flow and groundwater. Transects with wells are surveyed every year.

Reach	Year sampled									
	1	2	3	4	5	6	7	8	9	10
1	X	X						X	X	
2		X	X						X	X
3			X	X						X
4				X	X					
5					X	X				
9						X	X			
11							X	X		

Figure 2-3. Reaches are scheduled to be sampled each year based on a seven-year rotating-panel revisit design for long-term riparian vegetation monitoring on the East Fork Virgin River, Zion National Park. Two reaches are sampled each year, and seven unique reaches are sampled over seven years.

2.1.4 Reaches monitored from 2008 to 2012

For the first three years of monitoring, reaches were, for the most part, established and monitored according to our long-term monitoring design (Table 2-1). Riparian monitoring of the EFVR was initiated in 2008, with the establishment of reach 1 (Figure 2-4) and vegetation monitoring at this reach. Reach 1 was also surveyed in spring 2009. In summer 2009, reach 2 (Figure 2-5) was established and vegetation was monitored at reaches 1 and 2. In summer 2010, reach 3 (Figure 2-6) was established and vegetation was monitored at reaches 2 and 3. One instream well and two riparian wells were established at reach 3 in October 2010, near the existing USGS stream gaging station.

In December 2010, an approximately 25–40 year flood event occurred on the EFVR (D. Sharrow, pers. comm.), with peak flows around 3,090 cfs. To better evaluate the changes caused by the flood, we decided to revisit the reaches that were already established, rather than continue establishing new reaches on the river (Table 2-1). In summer 2011, vegetation was monitored at reaches

Table 2-1. Elevation, location, mean transect length, type of visit, and years visited for each monitoring reach, East Fork Virgin River, Zion National Park, 2008–2012.

Reach	Elevation (m)	Reach centroid UTM coordinates*		Mean transect length (m)*	Type of visit	Years visited				
		Northing	Easting			2008	2009	2010	2011	2012
1	1,189	4114612	325456	58.6	Vegetation	X	X		X	X
					Geomorphology		X			X
					Hydrology					
2	1,220	4115474	327906	37.0	Vegetation		X	X		X
					Geomorphology					X
					Hydrology					
3	1,198	4114853	326099	35.9	Vegetation			X	X	
					Geomorphology				X	
					Hydrology			X	X	X

* NAD83 Zone 12

**Mean of current transect lengths. Some transects were lengthened so that the headpins would be in more stable locations after the December 2010 flood.

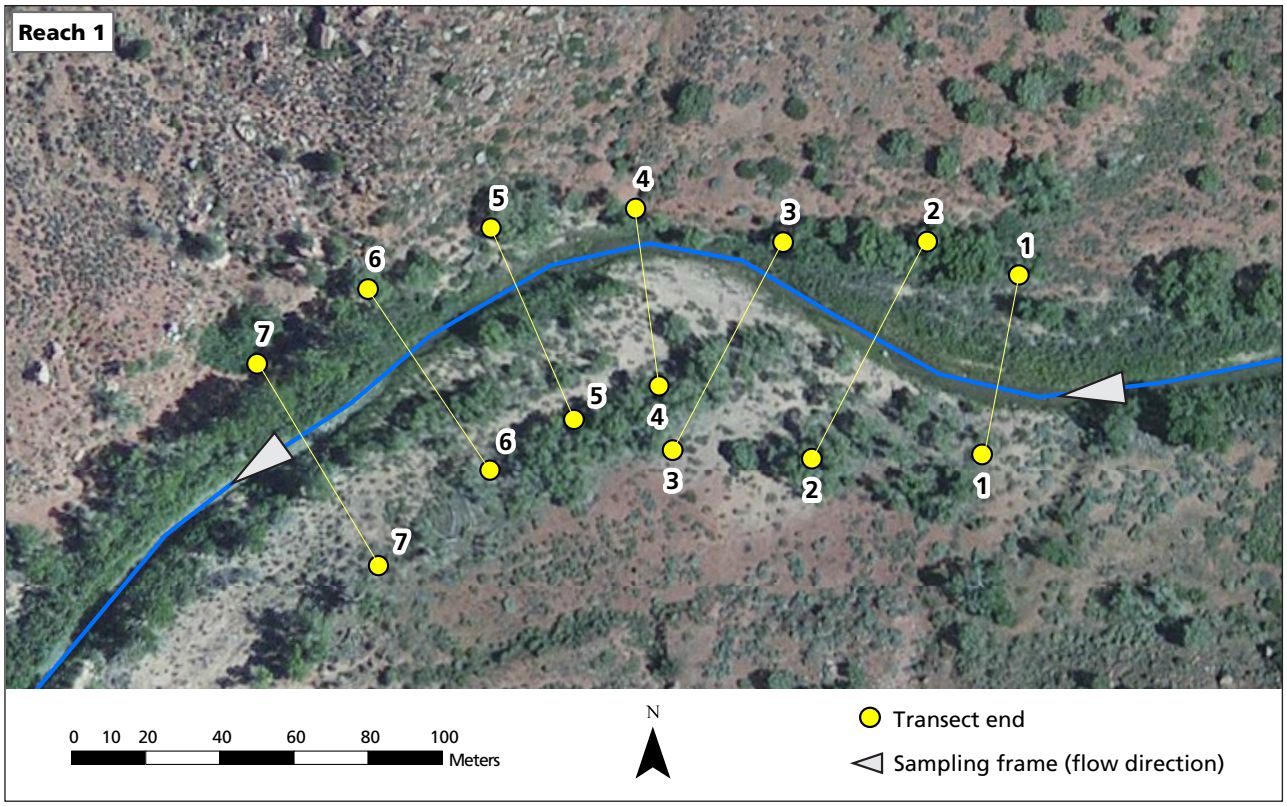


Figure 2-4. Transects at reach 1, East Fork Virgin River, Zion National Park.

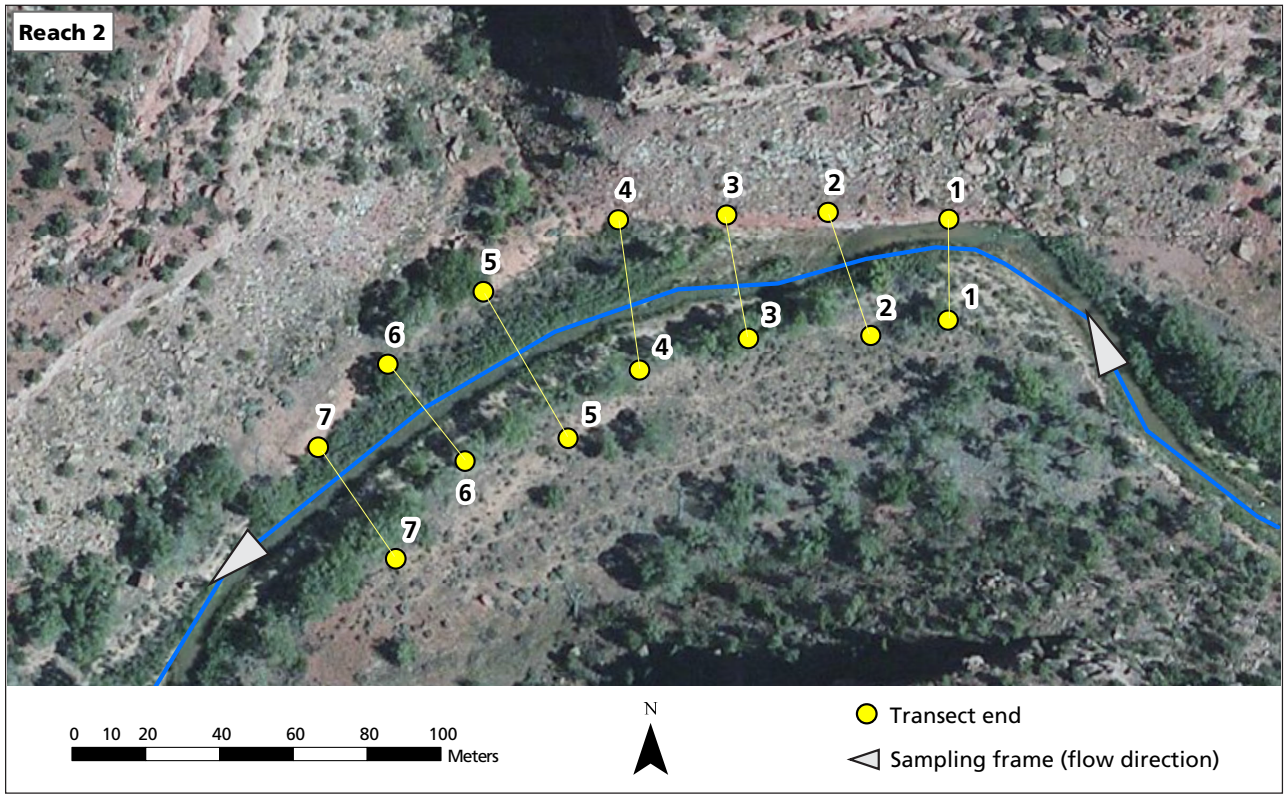


Figure 2-5. Transects at reach 2, East Fork Virgin River, Zion National Park.

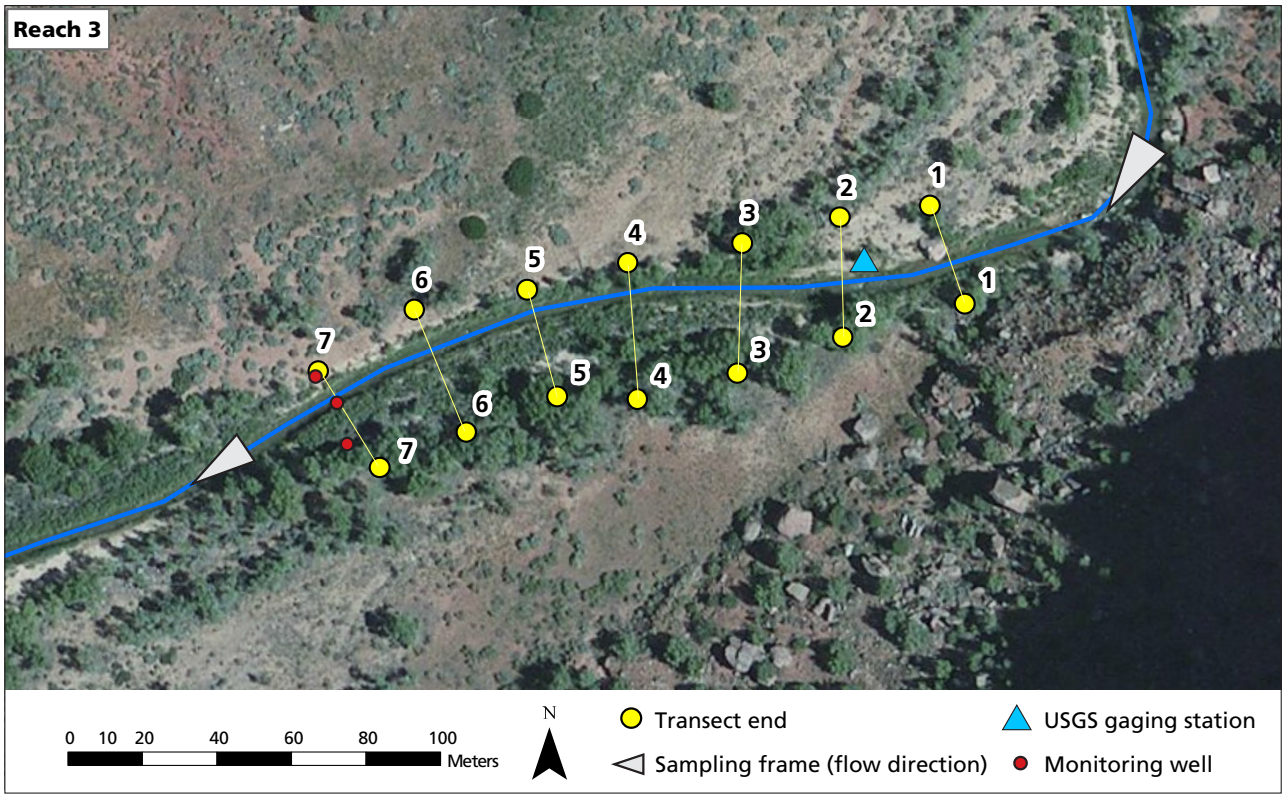


Figure 2-6. Transects at reach 3, East Fork Virgin River, Zion National Park, with monitoring wells and the U.S. Geological Survey gaging station.

1 and 3; reach 3 was surveyed that fall. The following spring, reach 2 was surveyed and reach 1 was resurveyed. Vegetation at reaches 1 and 2 were monitored in summer 2012.

Many headpins were buried or washed away in the flood and had to be replaced or relocated. This caused us to re-evaluate their placement and move headpins to more stable locations where appropriate. Four transects at reach 1, all seven transects at reach 2, and one transect at reach 3 were lengthened after the flood. In some cases, this affected our ability to make before-and-after comparisons; these instances are noted in the text.

2.2 Sampling procedures

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). Kevlar taglines, marked at 1-m intervals, were strung between the headpins and used to guide transect tape placement and surveying.

2.2.1 Hydrologic measurements

Stream stage and groundwater elevations were measured in one instream well and two riparian wells installed along transect 7 of reach 3, near the existing USGS gaging station (see Figure 2-6). Each well contains a pressure transducer that records these data at 15-minute intervals. A barometric pressure transducer is also co-located with the hydrologic infrastructure. Data from hydrologic monitoring equipment were downloaded, and manual measurements of water level and flow were recorded during periodic site visits.

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 were typically too cold for the field crew to perform this measurement during stream-channel surveys. (Pebble counts re-

quire an observer to submerge his/her arm up to the shoulder to grab a pebble at the bottom of the stream.) Stream-channel surveys were performed at each reach using a total station. For each transect, data were recorded at 1-m intervals along the tagline, at the edge of flowing or standing water, and at any significant slope-break points to provide a reasonably accurate depiction of topography. The thalweg was surveyed at 1-m intervals throughout the reach to capture important channel features. Locations of survey control points, headpins, and hydrologic monitoring equipment were also recorded.

2.2.3 Vegetation measurements

A point-intercept method was used to record percent cover of understory and ground-cover attributes at 0.5-m intervals along each transect (Figure 2-7). Density and diameter at breast height (dbh) of trees were recorded by species in a 5-m belt centered on each transect. In 2008, seedlings (<2.5 cm dbh) were recorded in a 1-m belt upstream of each transect instead of in the 5-m belt. Overstory canopy closure was recorded along each transect at 10-m intervals using a concave spherical densiometer. Beginning in 2011, frequency of exotic species was recorded in quadrats of 1 m^2, placed every five meters along the transects. All trees ≥25 centimeters 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.

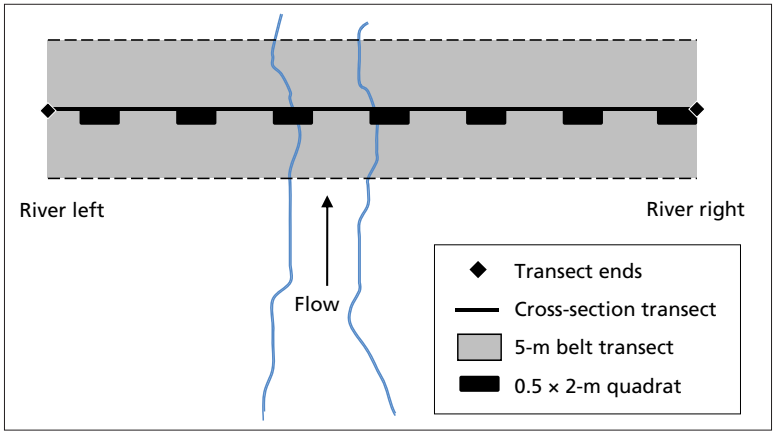


Figure 2-7. Locations of vegetation sampling along each permanent cross-section transect. Understory vegetation was sampled using a point-intercept method along each cross-section transect. Tree density was recorded in a 5-m belt transect, and exotic plant frequency was sampled in 1-m^2 quadrats.

2.3 Data summary, quality checks, and statistical procedures

2.3.1 Hydrology data

Hydrologic data were barometrically compensated and adjusted to match the manual water-level measurement taken during each site visit. Compensated and adjusted hydrologic data were imported into the Aquarius database 3.6, where data corrections were applied, such as deleting erroneous data, identifying ice effects, and adjusting for sensor drift. Additional datasets were derived from the corrected water-elevation data to create time series of stage in the site's permanent datum and depth to groundwater using ground-surface elevations recorded during geomorphic surveys. Final, approved datasets, including 15-minute data and daily mean data, were summarized and analyzed using the Aquarius whiteboard tool. USGS gaging-station data were summarized and analyzed using R 3.1.3 (R Core Team 2015). Additional quality assurance details for the hydrologic data may be found in Appendix A.

In December 2010, a large flood event buried the instream well and changed ground-surface elevations near the riparian groundwater wells in reach 3. No elevation data for the wells or ground surface were taken prior to the flood, and the first topographic survey was completed in October 2011. Thus, analysis of groundwater depth prior to the flood is not possible. We assume that surface elevations outside the channel remained stable from immediately post-flood until the time of the first survey.

2.3.2 Survey data

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 reaches 2 and 3 use this arbitrary coordinate system. For reach 1, survey data were translated and rotated to georeferenced coordinates collected using handheld GPS units. Figures that display elevations at reach 1 were based on the datum

NAD83 (2011) UTM Zone 12N.

A figure of the stream cross-section was created for each transect. These figures were used to determine channel width, channel depth, floodplain width, and elevation of the floodplain above the thalweg. Bankfull, defined as "the elevation where flows overtop the active channel and spread across an adjacent floodplain," is typically created by flows that "are moderate, frequent events with recurrence intervals between 1 and 2 years" (Moody et al. 2003). Although the location of bankfull is easily determined in many streams, this location can be particularly difficult to determine for streams in the southwestern U.S. We estimated bankfull using topographic break points in the stream cross-sections and ensured that these locations were roughly consistent among transects at each reach based on the channel area of each cross-section.

Channel width was determined using the horizontal distance between bankfull on either side of the channel. Channel depth was estimated by taking the difference between the elevation of bankfull and the average elevation of the channel surveyed at approximately every meter. The bankfull width-to-depth ratio was calculated by dividing channel width by channel depth. The floodplain (<10-year) was delineated using the first topographic break point above bankfull where the channel became less steep. In most cases, the floodplain was narrow and did not form a flat surface next to the channel. The elevation of this floodplain above the thalweg was calculated by subtracting the mean elevation of the floodplain from the mean elevation of the channel bottom. Terraces on the cross-sections were described using guidelines from Hereford and others (1995) and a Zion NP geologic spatial dataset that mapped these terraces (NPS 2006).

For reach 1, the only reach surveyed both before and after the flood, changes in channel width, channel depth, floodplain width, and floodplain elevation before and after the flood were analyzed in R 3.0.2 (R Core Team 2013) using Wilcoxon signed-rank tests and an alpha of 0.05. The change in channel area before and after the flood was determined for each transect at reach 1 using WinXSPRO (Hardy et al. 2005).

For each reach, the survey data were used to create a figure of the stream's longitudinal profile and the water-surface level at each transect. The channel slope of each reach was calculated by subtracting the elevation of the lowest water surface (at transect 7) from the highest water surface (at transect 1). Sinuosity was also calculated for each reach by dividing the total reach length by the straight-line distance between the thalweg at transects 1 and 7. A statistical test was not performed on channel slope or sinuosity because our sample size (n=1) was too low to detect changes after the flood.

2.3.3 Vegetation and pebble count data

Only cover and 5-m belt tree data were used to calculate richness because these were the only measures taken in all five years of monitoring. 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. Pebble count data were summarized using the diameter of streambed particles in the 50th and 84th percentiles (d50 and d84).

Summaries and statistical analyses of pebble counts and all vegetation measures were performed in R 3.0.2 (R Core Team 2013). All data were summarized using the plyr package (Wickham 2011), and the pebble-count data were additionally summarized using the matrixStats package (Bengtsson 2013). Reach census data were manipulated using the reshape package (Wickham 2007), and the distribution of trees by size class was plotted with ggplot2 (Wickham 2009).

2.3.4 QA/QC and data limitations

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

For most measurements, reach-level values

before and after the flood are presented in this report. When comparisons were not made before and after the flood, data from the most recent monitoring visit are presented. For example, data on exotic frequency were not collected before 2011; thus, we were not able to make any comparisons before and after the flood for this measure. Cover of the dominant exotic species was compared, instead. Before-and-after the flood comparisons were also not made for the reach census because any changes to this metric were confounded by substantial increases in transect lengths at two of the reaches.

Only three reaches were established at the time of this analysis, and we determined that a sample size of three was not large enough to detect statistically significant changes over the entire sampling frame. Instead, data were summarized by transect, and statistical tests were performed on each reach separately. Data were summarized to transect means before and after the flood for each reach. Pre-flood measurements (before) were the means of measurements at a reach collected in 2008–2010. Post-flood measurements (after) were the means of measurements at a reach collected in 2011–2012. Wilcoxon signed-rank tests were performed on these values, using an alpha of 0.05.

3 Results

3.1 Hydrology

3.1.1 Surface water

Comparing USGS gaging station data for calendar years (CY) 2008–2012 to the period of record (CY1992–2012) showed that the near-peak (i.e., second-highest) flow of record, in 2010, was followed by above-average flow in spring 2011 (Figure 3-1), creating ideal recruitment conditions for native cottonwood and willow species that rely on bare areas with fine sediments and slow spring drawdowns of water levels.

The 20-year median hydrograph was characterized by a daily mean flow of 57 cfs (Table 3-1), with base flow conditions from November to February, and a small rise in flow corresponding to spring runoff in March and April. The median three-day high spring flow for the 20-year period of record was 102 cfs, occurring on a median date of March 6. The median date for the spring center of volume to pass was March 22. Flow levels dropped from May through October, coinciding with the growing season. The seven-day average low flow with a 10-year return interval (7Q10), a measure of hydrologic drought, was 30.8 cfs, as calculated from the gaging-station record using a Log Pearson Type III model. The largest spikes in flow were caused by precipitation events that can occur at any time of year but occurred primarily during the second half of the year. The 20-year median total annual volume was 0.046 km^3.

Long- and short-term monitoring metrics for the USGS gage data are reported in Table 3-1. Instream stage data collected at 15-minute intervals from the NCPN monitoring well indicated that the December 2010 flood reached a maximum stage of 998.36 m (all elevations were referenced to the site's permanent datum, arbitrarily set to 1,000.28 m). Mean flood stage was 997.38 m (Figure 3-2).

Monitoring metrics for instream stage are presented in Table 3-2. Data were summarized for the 2011 calendar year and growing season (May 1–October 31), when vegetation is most reliant on water levels. (Data from 2010 were not included in this table because wells were not installed until October 17 of that year and there were no associated survey data for this time period. Likewise, data from 2012 were omitted from this table because data from January 1 to September 5 were missing for that year.)

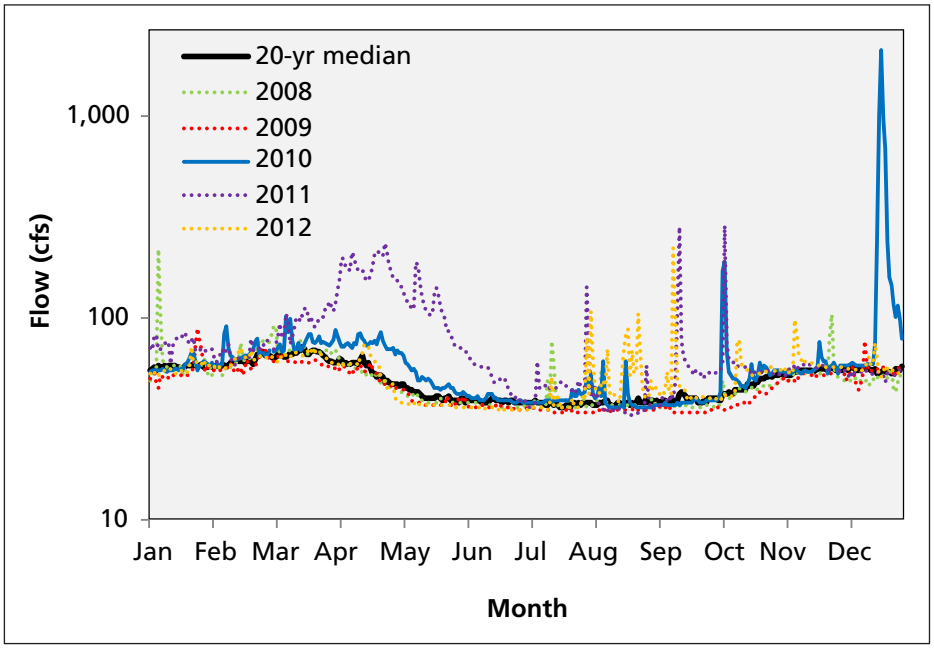


Figure 3-1. Annual hydrographs for 2008–2012, compared to the 20-year median daily mean flow (1992–2012), East Fork Virgin River near Springdale, Utah (USGS gage 09404900).

Table 3-1. Long-term discharge amount and timing metrics for the sampling period and period of record using USGS gaging station data (09404900), East Fork Virgin River near Springdale, Utah.

	Sampling period					Period of record
Discharge metric	**2008**	**2009**	**2010**	**2011**	**2012**	**1992–2012**
Mean daily mean flow (cfs)	49	46	69	75	52	57
Median daily mean flow (cfs)	46	45	55	58	53	51
Minimum daily mean flow (cfs)	36	34	36	33	35	26
Maximum daily mean flow (cfs)	219	89	2,120	287	222	2,120
Maximum instantaneous flow (cfs)	684	135	3,090	1,830	1,660	3,100
7-day average low flow (cfs)	36	34	36	33	35	27
7-day low flow median date	9/26/2008	9/27/2009	9/1/2010	8/27/2011	7/4/2012	9/19/2002
3-day average high flow (cfs)	129	80	1367	217	124	1,367
3-day high flow median date	1/7/2008	1/25/2009	12/22/2010	4/25/2011	9/13/2012	12/22/2010
Spring peak (cfs)	91	71	102	235	74	
Spring peak timing (Feb 15–Jun 1)	3/1/2008	2/24/2009	3/7/2010	4/24/2011	4/14/2012	
Winter-spring center of volume (Jan–Jun)	3/16/2008	3/20/2009	3/25/2010	4/10/2011	3/19/2012	
Total annual volume (km^3)	0.044	0.041	0.062	0.067	0.046	

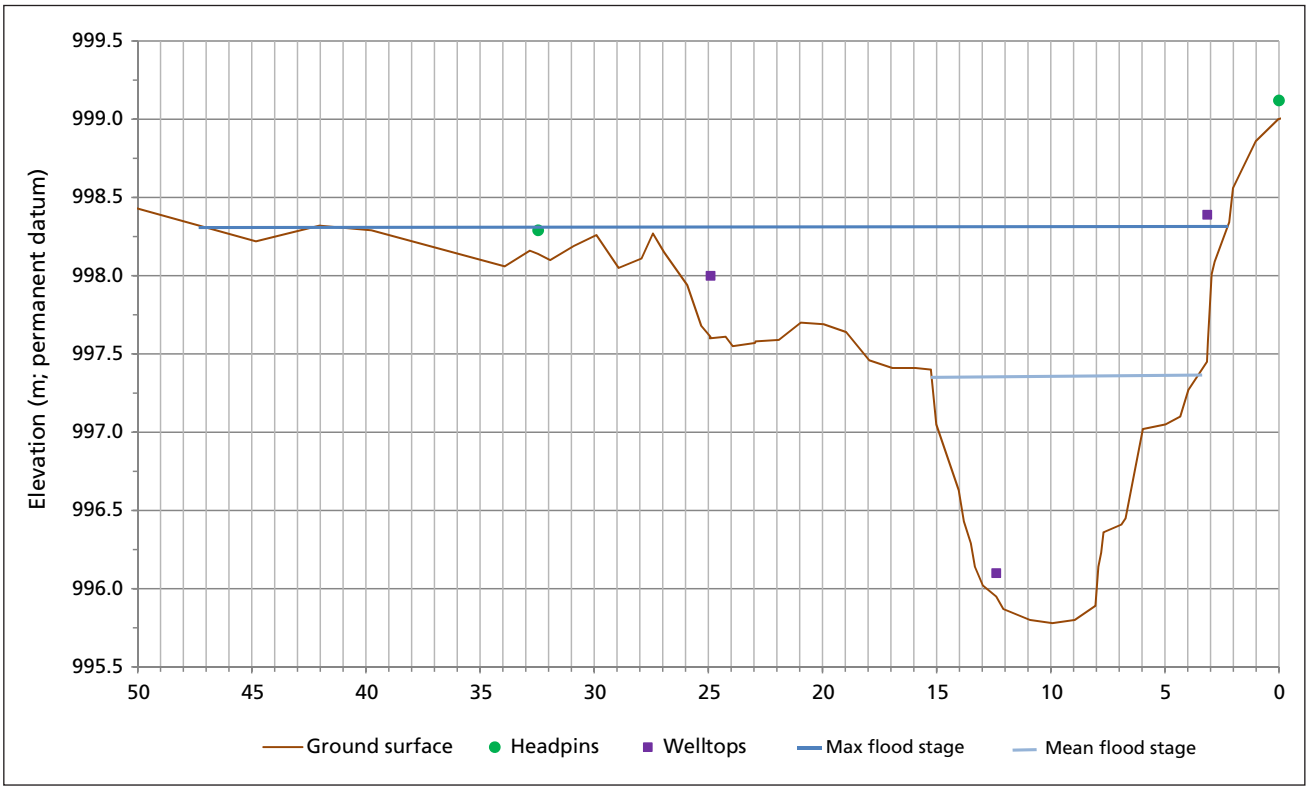


Figure 3-2. Maximum and mean flood stage of December 2010 event relative to reach 3, transect 7 cross-section survey data recorded in October 2011, East Fork Virgin River, Zion National Park. Note that the x-axis is displayed with numbers descending in order to match the locations along the transect for vegetation monitoring.

Table 3-2. Stage metrics using daily mean of instream well, 2011.

Time period	Stage metric (m)				Range
	Mean daily	Median daily	Minimum daily	Maximum daily	
Calendar year (Jan. 1–Dec. 31)*	996.42	996.38	996.09	996.75	0.66
Growing season (May 1–Oct. 31)	996.34	996.33	996.11	996.65	0.54

*Data missing, 12/9–12/31

Water elevations are given in the site's permanent datum.

3.1.2 Groundwater

Riparian groundwater wells responded to the 2010 flood and remained elevated for several months following the event (Figure 3-3). The right riparian well is located on a slightly lower surface than the left riparian well, and right-well water elevations tracked closely with the instream well. The right riparian well is also in a largely unvegetated area, while the left riparian well is located in an area with cottonwood trees. Note that the water elevation for the left riparian well tends to be lower than the right riparian well during the hot summer months, when evapotranspiration is at its highest.

Depth to groundwater tended to be less at the right riparian well than at the left riparian well (Figure 3-4 and Table 3-3), indicating a shallower water table at the right riparian well. The range of depths over time was greater at the left well than at the right well. Data were summarized for the 2011 calendar year and growing season (May 1–October 31). (Data from 2010 were not included in this table because wells were not installed until October 17 of that year and there were no associated survey data for this time period. Likewise, data from 2012 were omitted from this table because data from January 1 to September 5 were missing for that year.)

3.2 Geomorphology

3.2.1 Cross-section survey

The channel had a mean width of 8.5 m and a mean depth of 0.8 m in the most recent survey data (Table 3-4). The floodplain (<10-year) was usually distinct in the cross-sections, with a mean width of 5.4 m and a mean elevation of 0.9 m above the thalweg (Table 3-4, Appendix B). The modern terrace was present and clearly delineated in all surveyed cross-sections (Appendix B). Historic terraces were clearly delineated in many of the cross-sections, but there were many areas delineated as "historic terrace" on the Zion geology GIS layer (NPS 2006) that did not contain a clear surface break between the modern and historic terraces in our cross-sections (see Figure B-1 for an example). Settlement and prehistoric terraces were also present at numerous cross-sections. Elevation guidelines from Hereford and others (1995) were used to distinguish these when data from the Zion geology GIS layer were not consistent with the elevations in our cross-sections.

There was ample evidence of deposition at reach 1 after the flood (Figure 3-5). Sediment was deposited on the modern terrace at all transects, with deposits as deep as 0.5 m in places (see Appendix B). The channel bed was also much higher and shifted to the left at transects 1 and 2 after the flood (Appendix B, Figures B-1 and B-2). At these two transects, the elevation of the stream surface increased to higher than the elevation of the thalweg before the flood (Appendix B, Figures B-1 and B-2). Overall, we detected a decrease in the vertical distance between the thalweg and the <10-year floodplain ($p=0.046$; Table 3-4). There was also evidence that the channel widened after the flood ($p=0.015$) at the expense of the <10-year floodplain, which narrowed ($p=0.015$) after the flood at reach 1 (see Table 3-4, Figure 3-6). Our analysis in WinXSPRO showed that the area under our stream cross-sections at reach 1 had indeed increased at each transect after the flood by a mean of 9.6 m^2 (sd 5.5).

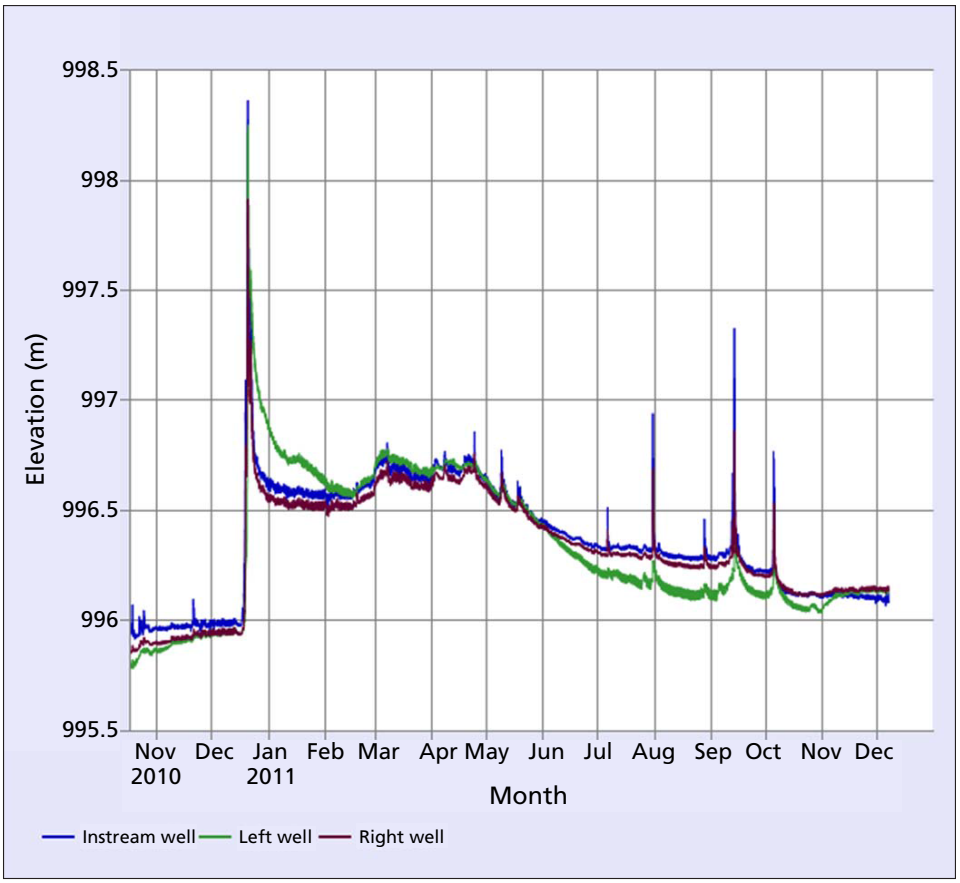


Figure 3-3. Water elevation referenced to the site's permanent datum for all three wells at reach 3, East Fork Virgin River, Zion National Park. Note the December 2010 flood event, which increased water elevations over the following year.

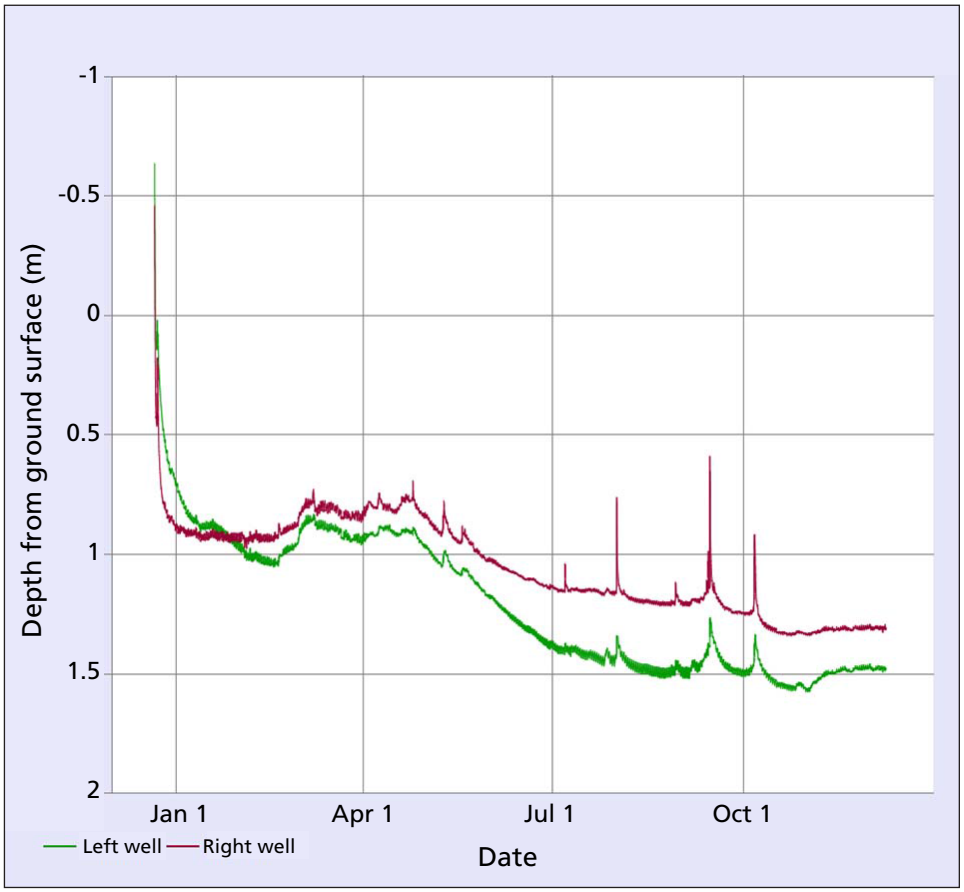


Figure 3-4. Depth to water from the ground surface for left and right riparian wells using October 2011 survey elevations, reach 3, transect 7, East Fork Virgin River, Zion National Park. On the y-axis, zero represents the ground surface and negative numbers represent flooding above the ground surface. Data are presented from the peak of the December 2010 flood, as ground-surface elevations prior to the flood are unknown.

Table 3-3. Long-term depth to groundwater metrics by calendar year and growing season, using daily mean of riparian wells, 2011.

Well	Depth to groundwater (m)								Range (m)	
	Mean daily		Median daily		Minimum daily		Maximum daily			
	Calendar year	Growing season	Calendar year	Growing season	Calendar year	Growing season	Calendar year	Growing season	Calendar year	Growing season
Left well	1.22	1.37	1.31	1.42	0.69	0.96	1.56	1.56	0.87	0.60
Right well	1.06	1.14	1.10	1.15	0.76	0.84	1.33	1.33	0.58	0.50

Calendar year: Jan. 1–Dec. 31
Growing season: May 1–Oct. 31
**Data missing, 12/9–12/31

Table 3-4. Summary of stream-channel characteristics at monitoring reaches before and after the flood, East Fork Virgin River, Zion National Park.

Parameter	Reach 1 (210 m)		Reach 2 (180 m)		Reach 3 (180 m)		Mean*
	Before (2009)	After (2012)	Before (2009)	After (2012)	Before (2010)	After (2011)	
Channel slope (m/km)	8.0	9.6	-	7.0	-	5.9	7.5
Channel width (m)	***8.3***	***9.4***	-	7.8	-	8.4	8.5
Channel depth (m)	0.7	0.7	-	0.8	-	0.9	0.8
Bankfull width to depth ratio	11.6	15.8	-	11.4	-	9.9	12.3
Floodplain width (m)	***7.7***	***5.7***	-	6.6	-	4.0	5.4
Floodplain elevation above the thalweg (m)	***1.0***	***0.8***	-	1.0	-	1.1	0.9
Sinuosity	1.13	1.14	-	1.02	-	1.01	1.06
Diameter of the 50th percentile streambed particle (mm)	26	23	25	25	18	1	22
Diameter of the 84th percentile streambed particle (mm)	94	99	110	87	87	50	78

*Mean of measurements taken after the flood
Reaches 2 and 3 were not surveyed before the flood.
Values in bold italics were significantly different before and after the flood ($p<0.05$). A statistical test was not performed on channel slope or sinuosity.



Figure 3-5. East Fork Virgin River in Parunuweap Canyon near reach 2, Zion National Park, August 2008 (left) and July 2011 (right). The large amount of sand deposited by the December 2010 flood is apparent in the later photo.

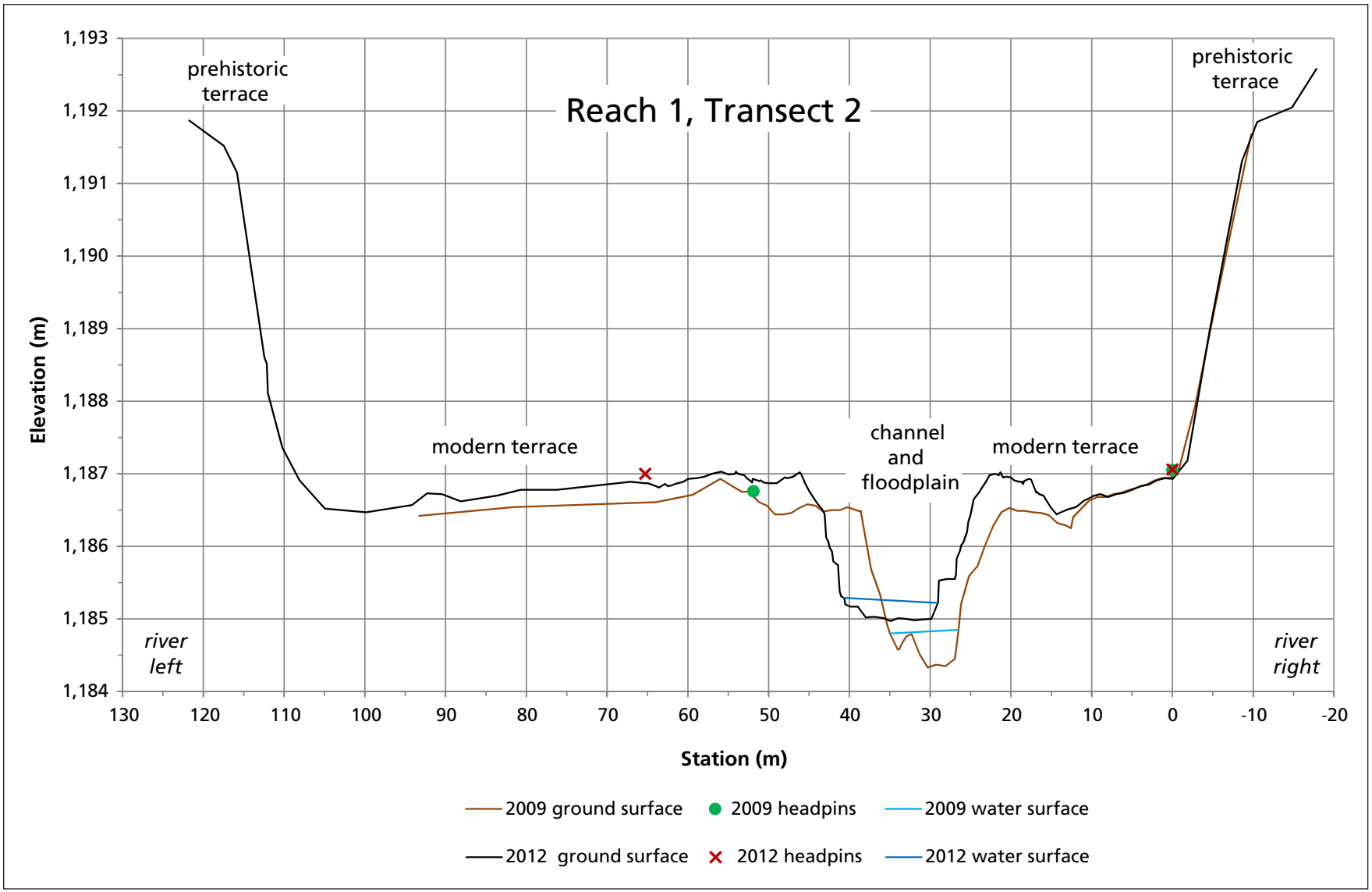


Figure 3-6. Cross-section of reach 1 at transect 2 looking downstream, East Fork Virgin River, Zion National Park, 2009 and 2012. Terraces were identified using the guidelines in Hereford and others (1995). Note that the x-axis is displayed with numbers descending in order to match the locations along the transect for vegetation monitoring.

3.2.2 Profile survey

Overall, the reaches had a mean channel slope of 7.5 m/km (see Table 3-4, Figures 3-7, 3-8, 3-9). Reach 1 was the steepest and reach 3 had the gentlest channel slope. At reach 1, channel slope increased from 8.0 m/km in 2009 to 9.6 m/km in 2012, due to deposition in the upstream part of the reach (see Figure 3-7).

The reaches had a mean sinuosity of 1.06 (see Table 3-4). The sinuosity of reaches 2 and 3 (1.02 and 1.01 respectively) was much lower than the sinuosity of reach 1 (1.14), which was more similar to the overall sinuosity of the EFVR in Zion NP (1.16). There was very little difference in sinuosity at reach 1 before and after the flood (1.13 in 2009 versus 1.14 in 2012).

3.2.3 Pebble count

The distribution of particle sizes was similar at all three reaches, consisting primarily of sand, coarse gravel, and cobbles (Figure 3-10). Overall, the reaches had a mean d50 (see Section 2.3.3) of 22 mm, which classifies the EFVR as a gravel-bed stream with a bimodal grain-size distribution. The mean d84 for all of the reaches was 78 mm (see Table 3-4). We did not detect any differences in stream particle size distribution before and after the flood at any reach using the d50 or d84 metrics (see Table 3-4). However, there was a notable increase in the percent of fines (i.e, sand and finer particles) in 2011 (Figure 3-10). By 2012, the distribution of particle sizes was once again similar to the distribution before the flood (Figure 3-10).

3.3 Vegetation

3.3.1 Species richness

A total of 79 species were detected at the three reaches we monitored in Zion NP from 2008 to 2012. Total species richness increased after the flood at reaches 1 and 2 (p=0.046 and 0.035, respectively) and decreased after the flood at reach 3 (p=0.049; Table 3-5). There were few differences detected in richness by lifeform, except a greater number of forbs at reach 1 after the flood (p=0.033) and a lower number of perennial grasses at reach 3 after the flood (p=0.021; Table 3-5). The only difference in richness by wetland status was a decrease in the number of obligate wetland species at reach 3 after the flood (p=0.031; Table 3-6).

Each year, recorded species are compared to the NPSpecies database to determine first-time observations in Zion NP. One new native species, American bugleweed (*Lycopus americanus*), was detected in 2010. A voucher was created for this species and for two other species, northern scouring rush (*Equisetum variegatum*) and knotgrass (*Paspalum distichum*), that were previously detected in the park but did not have vouchers.

Although Zion NP only has populations of one federally listed threatened or endangered plant species within its borders, at least 189 plants of special conservation concern exist within the park (Fertig and Alexander 2009). Four of these species, Welsh's aster (*Aster welshii*), northern scouring rush, knotgrass, and arrowweed (*Pluchea sericea*), were detected during sampling.

3.3.2 Overstory canopy closure and vegetation cover

There were no significant differences in overstory canopy closure before and after the flood at any reach (Table 3-7). Reach 3 had less live vegetation cover after the flood (both native [p=0.046] and non-native vegetation cover [p=0.015), but total vegetation cover at this reach and live and total vegetation cover at the other two reaches were similar before and after the flood (Tables 3-7 and 3-8).

Cover by lifeform was generally the same before and after the flood. The two exceptions were higher total forb cover at reach 1 after the flood (p=0.046) and lower live and total perennial grass cover at reach 3 after the flood (p=0.015; Table 3-7). Cover by wetland status was also similar before and after the flood for most reaches and wetland types. At reach 3, there was lower live and total cover of facultative wetland species after the flood (p=0.015; Table 3-9).

The decrease in cover at reach 3 appeared to be primarily due to a significant reduction in live (11.8% vs 4.4%) and total (19.1% vs

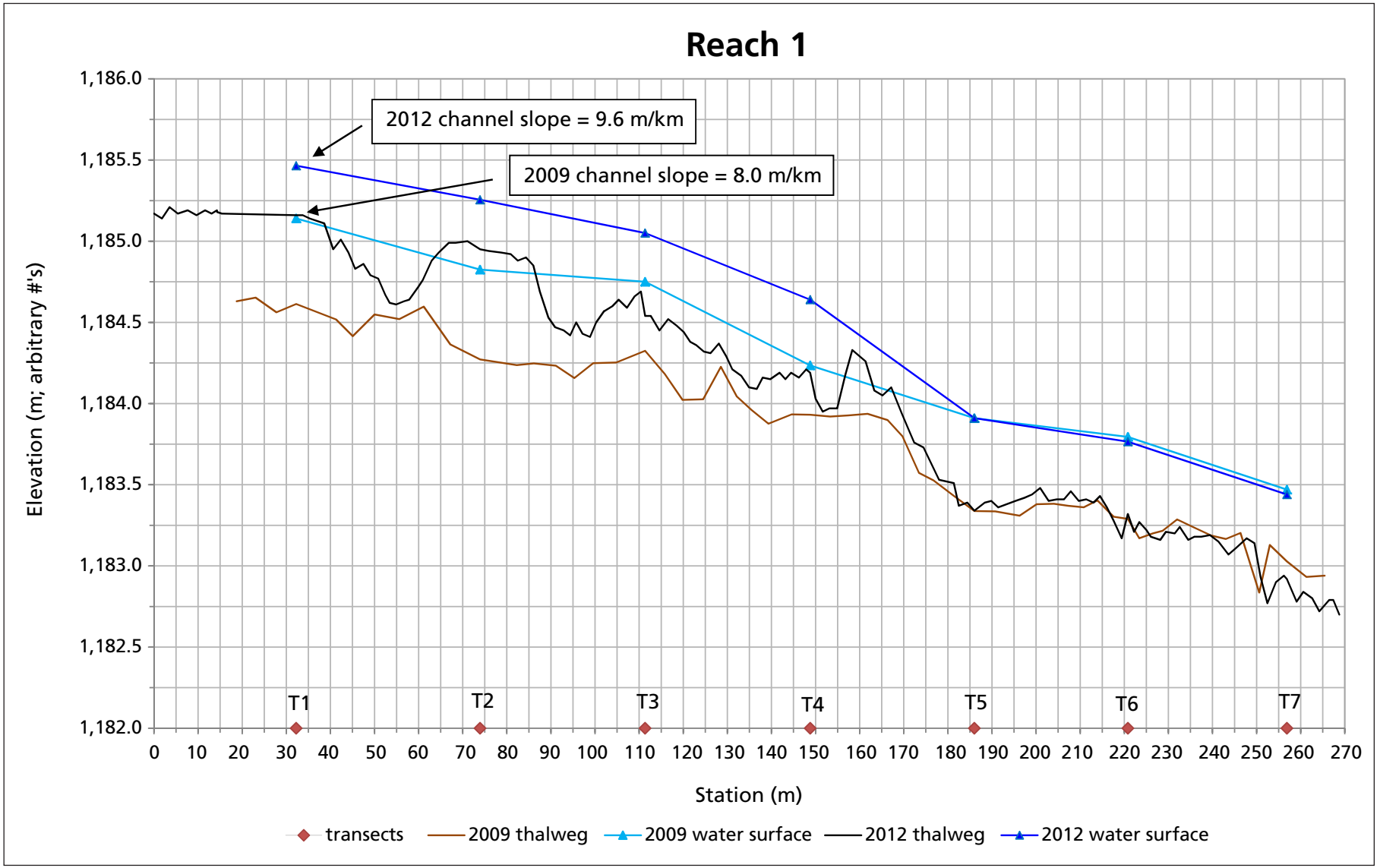


Figure 3-7. Longitudinal profile of reach 1 (February 2009 and March 2012), East Fork Virgin River, Zion National Park. The elevation of the thalweg is plotted for the length of the reach. The elevation of the water surface was surveyed on the left and right sides of the channel where each transect crossed (T1–T7); this was used to determine the channel slope of each reach.

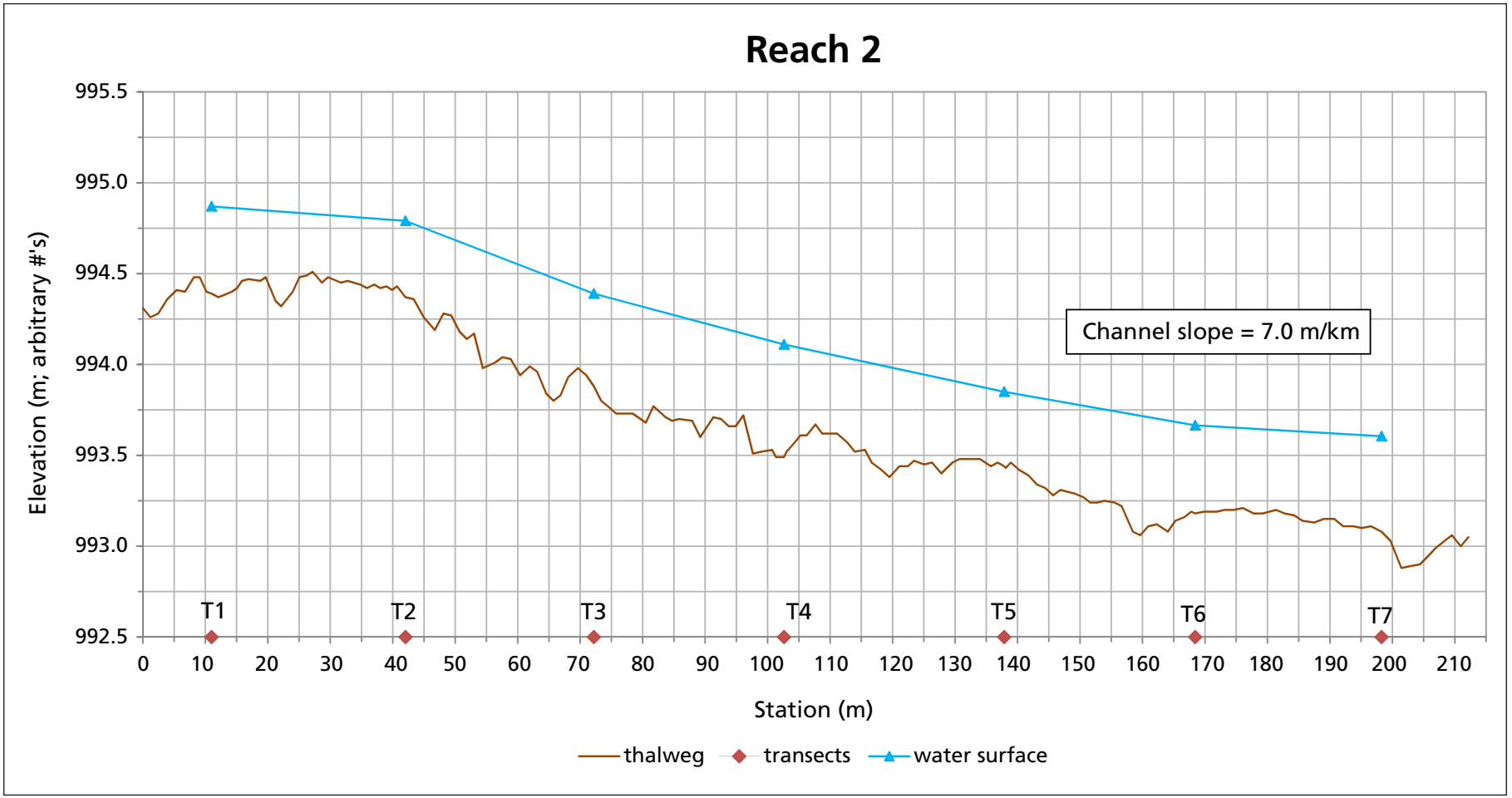


Figure 3-8. Longitudinal profile of reach 2 (March 2012), East Fork Virgin River, Zion National Park. The elevation of the thalweg is plotted for the length of the reach. The elevation of the water surface was surveyed on the left and right sides of the channel where each transect crossed (T1–T7); this was used to determine the channel slope of each reach.

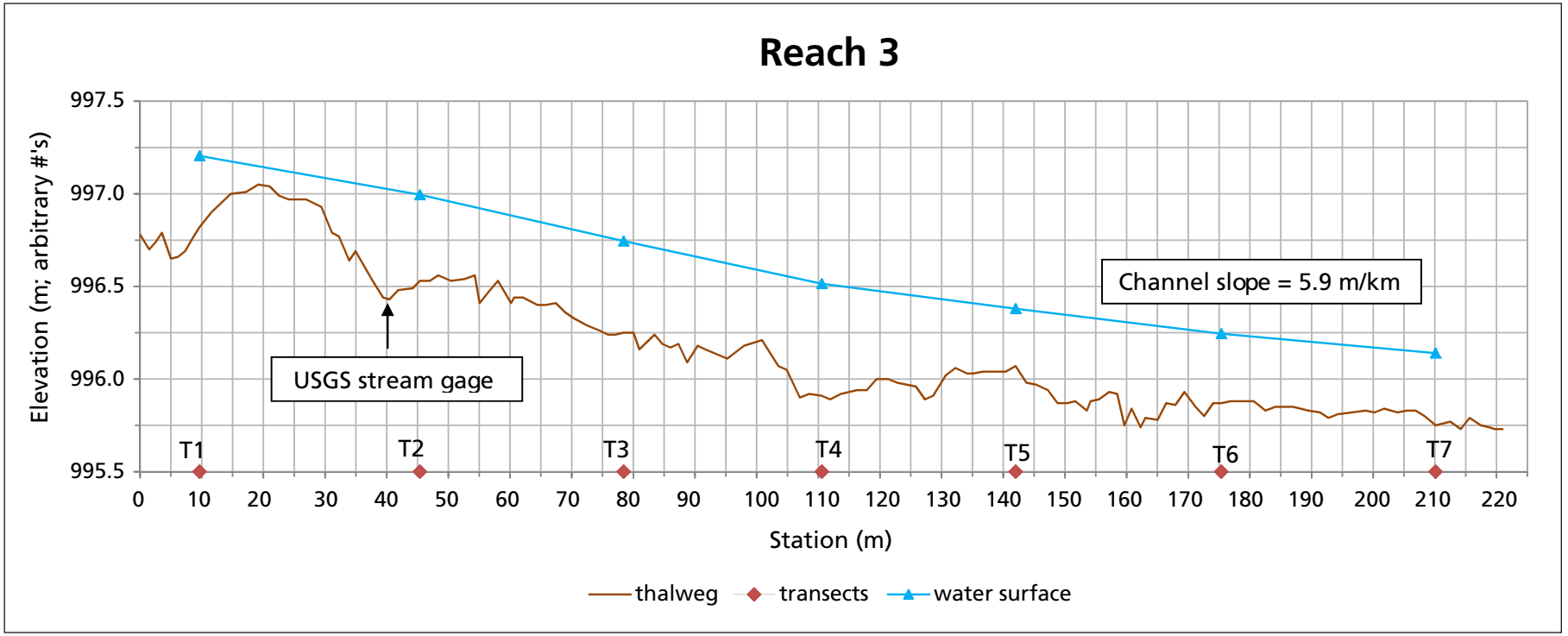


Figure 3-9. Longitudinal profile of reach 3 (October 2011), East Fork Virgin River, Zion National Park. The elevation of the thalweg is plotted for the length of the reach. The elevation of the water surface was surveyed on the left and right sides of the channel where each transect crossed (T1–T7); this was used to determine the channel slope of each reach. The approximate location of the USGS stream gage is included.

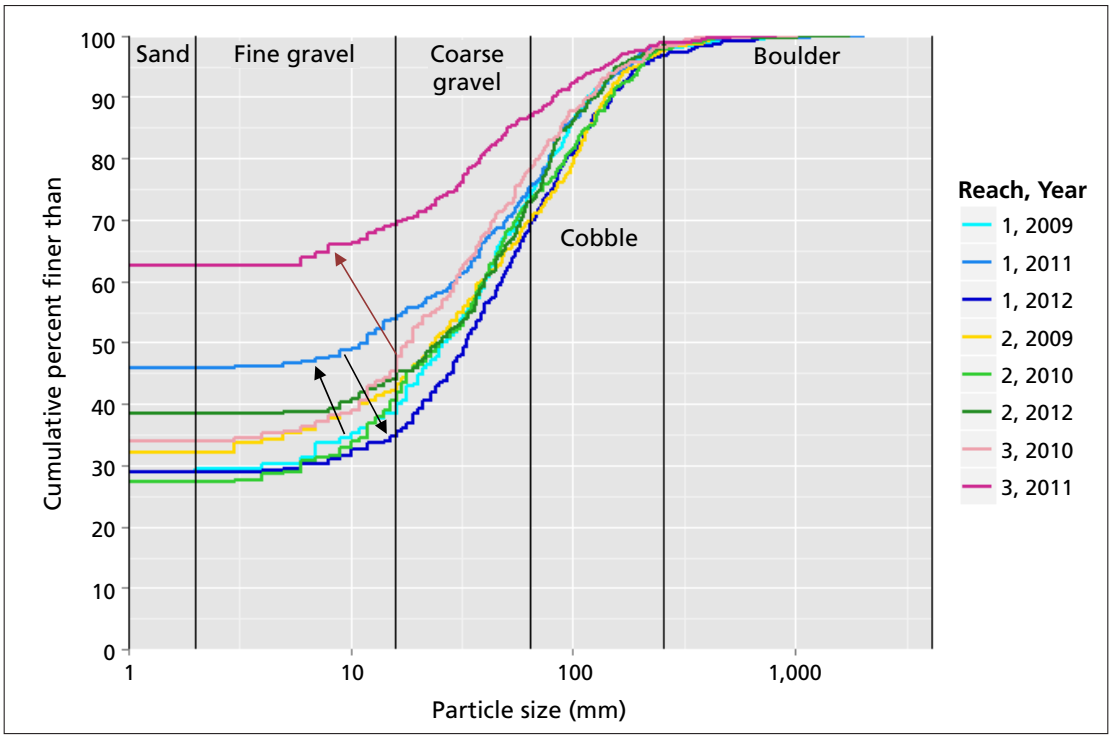


Figure 3-10. Particle size distribution of the channel surface at each reach for each year of sampling, East Fork Virgin River, Zion National Park, 2009–2012. Particle size distribution was sampled using pebble counts; small, black arrows indicate temporal sequence of observations at reach 1; small, brown arrow indicates temporal sequence of sampling at reach 3. Classification of sand, gravel, cobble, and boulder is based on the Wentworth scale.

Table 3-5. Total number of species detected (total exotic species) per reach by lifeform before and after the flood, East Fork Virgin River, Zion National Park.

	Reach 1		Reach 2		Reach 3	
Parameter	Before (2008, 2009)	After (2011, 2012)	Before (2009, 2010)	After (2012)	Before (2010)	After (2011)
Total	***29*** (4)	***30*** (6)	***27*** (6)	***35*** (9)	***30*** (7)	***19*** (3)
Tree	5 (1)	3 (0)	4 (1)	4 (1)	3 (0)	3 (0)
Shrub	10 (1)	8 (0)	5 (0)	5 (0)	4 (0)	5 (0)
Perennial grass	9 (1)	8 (2)	10 (2)	14 (3)	***9*** (2)	***5*** (1)
Annual grass	1 (1)	2 (2)	2 (2)	3 (3)	1 (1)	1 (1)
Forb/Herb	***5*** (1)	***7*** (2)	6 (1)	6 (2)	11 (4)	4 (1)
Fern	1 (0)	2 (0)	2 (0)	3 (0)	2 (0)	1 (0)

Summary only includes point-intercept and 5-m belt data since these were collected in all reaches in all years.
Values in bold italics were significantly different before and after the flood ($p<0.05$).

Table 3-6. Number of plant species detected per reach by wetland status before and after the flood, East Fork Virgin River, Zion National Park.

Wetland status	Reach 1		Reach 2		Reach 3	
	Before (2008, 2009)	After (2011, 2012)	Before (2009, 2010)	After (2012)	Before (2010)	After (2011)
Obligate wetland	6	4	7	6	***9***	***4***
Facultative wetland	8	8	8	8	8	7
Facultative	5	6	4	6	3	3
Facultative upland	2	3	3	5	6	1
Upland	9	10	6	9	4	4

*Summary only includes point-intercept and 5-m belt data since these were collected in all reaches in all years.
Values in bold italics were significantly different before and after the flood ($p<0.05$).

Table 3-7. Percent overstory canopy closure and percent cover of vegetation by lifeform before and after the flood, East Fork Virgin River, Zion National Park.

Parameter	Type	Reach 1		Reach 2		Reach 3	
		Before (2008, 2009)	After (2011, 2012)	Before (2009, 2010)	After (2012)	Before (2010)	After (2011)
Percent							
Overstory canopy closure		29.8	35.1	42.3	35.1	33.8	32.2
Percent cover							
Total*	Live	23.9	22.9	24.8	24.5	***28.9***	***22.6***
	Total	30.6	31.8	36.9	33.7	37.2	35.2
Tree	Live	2.2	1.8	2.3	2.3	2.6	3.2
	Total	3.0	2.3	2.8	3.1	3.3	4.2
Shrub	Live	17.4	16.1	17.3	15.8	16.7	13.0
	Total	22.6	22.2	26.4	22.8	25.0	23.8
Perennial grass	Live	4.5	3.6	4.8	4.3	***10.4***	***4.8***
	Total	5.0	4.7	6.5	5.8	***10.8***	***4.8***
Annual grass	Live	0.1	0.2	0.4	0.4	0.2	0
	Total	0.7	3.2	2.5	3.5	0.4	1.4
Forb/Herb	Live	1.0	2.3	2.3	3.3	3.0	1.8
	Total	***1.0***	***2.6***	2.8	3.3	3.0	2.0
Fern	Live	0.2	0.2	0.5	0.8	1.4	1.4
	Total	0.2	0.2	0.5	1.0	1.4	1.4

*Vegetation cover was recorded below 2 m in 2008 and below 1.5 m in all other years. Beginning in 2011, shrubs taller than 1.5 m were also recorded.
Values in bold italics were significantly different before and after the flood ($p<0.05$).

Table 3-8. Percent cover of vegetation by nativity and reach before and after the flood, East Fork Virgin River, Zion National Park.

		Reach 1		Reach 2		Reach 3	
Nativity	Type	Before (2008, 2009)	After (2011, 2012)	Before (2009, 2010)	After (2012)	Before (2010)	After (2011)
Native	Live	22.8	22.0	23.3	23.5	***27.8***	***22.4***
	Total	28.7	28.9	33.9	30.7	36.2	33.6
Non-native	Live	1.3	1.2	2.9	2.1	***3.9***	***0.6***
	Total	1.9	4.0	5.0	5.4	4.1	2.2

*Vegetation cover was recorded below 2 m in 2008 and below 1.5 m in all other years. Beginning in 2011, shrubs taller than 1.5 m were also recorded.

Values in bold italics were significantly different before and after the flood ($p<0.05$).

Table 3-9. Percent cover of vegetation by wetland indicator and reach before and after the flood, East Fork Virgin River, Zion National Park.

		Reach 1		Reach 2		Reach 3	
Wetland status	Type	Before (2008, 2009)	After (2011, 2012)	Before (2009, 2010)	After (2012)	Before (2010)	After (2011)
Obligate wetland	Live	6.2	5.3	6.4	6.8	9.6	10.8
	Total	6.4	6.1	8.2	9.3	10.4	12.6
Facultative wetland	Live	11.7	12.1	14.6	14.2	***19.3***	***10.0***
	Total	16.8	17.1	24.1	19.5	***27.2***	***19.4***
Facultative	Live	3.6	3.5	3.6	2.9	2.0	1.2
	Total	4.5	5.3	4.2	3.9	2.4	2.0
Facultative upland	Live	0.7	0.8	1.1	1.2	1.4	0
	Total	0.7	1.2	1.2	1.4	1.4	0.2
Upland	Live	2.9	2.9	1.6	2.1	1.6	2.2
	Total	3.6	5.4	3.7	5.4	1.8	3.6

*Vegetation cover was recorded below 2 m in 2008 and below 1.5 m in all other years. Beginning in 2011, shrubs taller than 1.5 m were also recorded.

Values in bold italics were significantly different before and after the flood ($p<0.05$).

13.2%) cover of the facultative wetland species, Rio Grande seepwillow (*Baccharis salicina*), after the flood (p=0.036 and 0.046, respectively).

3.3.3 Exotic species

There was a significant reduction in live (2.4% vs 0.6%) and total (2.6% vs 0.6%) cover of redtop (*Agrostis stolonifera*), an exotic perennial grass (p=0.036), after the flood at reach 3. Total cheatgrass (*Bromus tectorum*) cover was between 1.4 and 3.5%, and did not change significantly after the flood at any reach. Percent cover of other exotic species detected at the reaches was less than 1% and was not significantly different before or after the flood.

Frequency of exotic plant species was also relatively low at the most recent monitoring visit (Table 3-10). In addition to the exotic plant species detected through our frequency measures, Russian olive was detected at reach 1 and tamarisk was detected at reaches 1 and 2 through our cover measurements.

Lists of all exotic species detected at each monitoring visit and descriptions of the number of plants, size of invasions, and approximate locations are available on request.

3.3.4 Tree density and basal area

Density of live Fremont cottonwood (*Populus fremontii*) seedlings, saplings, and overstory trees before and after the flood is shown in Table 3-11 for each reach. Seedling density increased dramatically at reaches 1 and 3 after the flood (p=0.046 and 0.036, respectively). We did not detect any differences before and after the flood in sapling or overstory tree density at any reach, or in seedling density at reach 2.

A few other tree species were detected in the 5-m belt, but there were so few trees of these species that we did not make any comparisons before or after the flood. Velvet ash (*Fraxinus velutina*) was detected at all reaches. Russian olive, Utah juniper (*Juniperus osteosperma*), two-needle pinyon (*Pinus edulis*), and Goodding's black willow (*Salix gooddingii*) were also present in at least one of the reaches.

A significant increase in the basal area of live trees (all species combined) was detected at reach 2 after the flood (p=0.036; Table 3-11). This result is likely an artifact of increased transect length at reach 2 after the flood (see Discussion for a detailed explanation of this issue).

3.3.5 Reach census

Nearly all of the trees detected in the reach census were Fremont cottonwoods. The only other species detected was one Goodding's black willow, at reach 2, in the 25–30 cm dbh class. Reach 1 had about three times as many Fremont cottonwoods as the other two reaches (Figure 3-11).

Because many transects were lengthened after the flood at reaches 1 and 2, tree-census data were not compared before and after the flood at these reaches. At reach 3, where only one transect was lengthened by about 4 m, there were no changes to the number or size distribution of large cottonwood trees after the flood.

3.3.6 Surface features

Fines and litter were the dominant surface cover at all reaches (Table 3-12). The flood caused fines cover to double and litter cover to decrease by about the same amount (p=0.015). Biological soil crust cover was also significantly reduced by the flood at reach 1 (p=0.031). In addition, the flood increased the wetted channel width (% cover of water) at reach 3 (p=0.015).

3.4 Other disturbances

There were few other disturbances noted by the crew outside of the flood events detailed in the hydrology section of the results. Cut stems of tamarisk and/or Russian olive from park exotic plant control efforts and light browsing of native woody species by beaver were noted at all of the reaches.

Table 3-10. Frequency of exotic plant species detected by lifeform and reach, East Fork Virgin River, Zion National Park.

Scientific name	Common name	Duration	Frequency of detection (%)		
			Reach 1	Reach 2	Reach 3
Graminoid					
Agrostis stolonifera	redtop	perennial	1.1	2.1	0
Bromus diandrus	ripgut brome	annual	0.6	0	0.3
Bromus rubens	red brome	annual	0.7	0.2	0
Bromus tectorum	cheatgrass	annual	6.9	3.3	3.1
Festuca pratensis	meadow fescue	perennial	0	0.2	0
Forb					
Melilotus species	sweetclover		1.9	1.4	3.1
Salsola species	Russian thistle	annual	1.9	0.7	1.4
Sisymbrium altissimum	tumble mustard	annual	0	0	0.6

Data from the most recent visit are presented (2012 for reaches 1 and 2 and 2011 for reach 3).

Table 3-11. Density of live Fremont cottonwood (*Populus fremontii*) seedlings, saplings, and overstory trees, and basal area of all live trees before and after the flood, East Fork Virgin River, Zion National Park.

Vegetation type	Reach 1		Reach 2		Reach 3	
	Before (2008, 2009)	After (2011, 2012)	Before (2009, 2010)	After (2012)	Before (2010)	After (2011)
Density (trees/ha)						
Seedling (<2.5 cm)	***700***	***2,257***	843	410	***162***	***5,141***
Sapling (2.5–15.0 cm)	136	85	62	70	129	116
Overstory tree (>15 cm)	83	102	95	124	146	135
Basal area (m^2/ha)*						
Live trees	4.9	5.9	***3.5***	***5.9***	7.8	7.9

*Increases in overstory cottonwood density and basal area of live trees at reaches 1 and 2 are likely due to increases in transect length after the flood and not due to large increases in growth at these reaches. See the discussion section of the report for more information. Values in bold italics were significantly different before and after the flood ($p<0.05$).

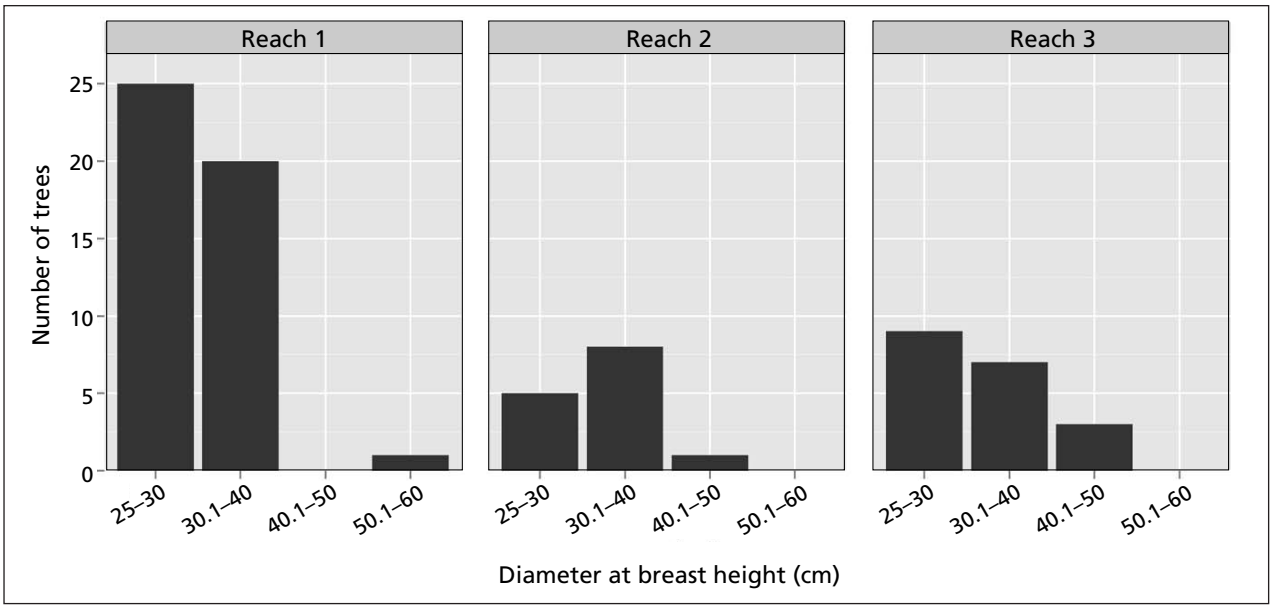


Figure 3-11. Number of Fremont cottonwood (*Populus fremontii*) trees by size class with ≥25 cm diameter at each reach, East Fork Virgin River, Zion National Park. Data from the most recent visit are presented (2012 for reaches 1 and 2, and 2011 for reach 3).

Table 3-12. Percent cover of surface features by reach before and after the flood, East Fork Virgin River, Zion National Park.

	Reach 1		Reach 2		Reach 3	
Surface feature	**Before (2008, 2009)**	**After (2011, 2012)**	**Before (2009, 2010)**	**After (2012)**	**Before (2010)**	**After (2011)**
Water	11.9	11.5	17.4	16.1	***11.0***	***13.8***
Fines (0.1–2 mm)	***28.8***	***58.9***	***24.8***	***48.4***	***24.8***	***58.0***
Fine gravel (>2–16 mm)	0	0.1	0.6	0.2	0.2	0
Coarse gravel (>16–64 mm)	0	0.7	0.4	1.2	0.4	0.8
Cobble (>64–256 mm)	0.2	0.4	0.8	0.8	0.6	0.8
Boulder (>256 mm)	0.5	0.2	0.2	0	0.4	0.6
Bedrock	0	0	0.1	2.7	0	0
Biological soil crust	***6.4***	***0.2***	2.0	0	5.5	0.8
Litter	***5.03***	***26.9***	***51.0***	***29.4***	***54.1***	***24.2***
Woody debris	0.4	0.3	0.5	1.0	1.0	0.2

Values in bold italics were significantly different before and after the flood ($p<0.05$).

4 Discussion

4.1 Geomorphology

The surveys at reach 1 showed that the channel became wider and shallower after the December 2010 flood, and remained this way for over a year after the flood (see Table 3-4). Although we do not have survey data from before the flood for the other two reaches, it is possible to infer changes in the channel width by looking at changes in the wetted width (% surface cover of water) using cover data from point-intercept sampling. Our surface-cover data from point-intercept sampling show a significant increase in the wetted width of the stream at reach 3 after the flood (see Table 3-12). It is likely that this increase in wetted width was associated with an increase in overall channel width, especially because we detected an increase in channel width at reach 1 (even though an increase in the wetted width was not apparent).

To the degree that response to a single flood event can indicate a pattern, our data support that the EFVR is still currently in a cycle of deposition, which tends to occur during drier periods with fewer large flood events. Data from regional weather stations indicate that annual precipitation has been highly variable throughout the region over the last 100 years. However, the region has heated up markedly in recent decades, and many temperature variables are now regularly above their historic range of variability (Witwicki 2013; Garfin et al. 2014; Monahan and Fisichelli 2014). Although the current cycle of deposition does not seem to be associated with decreased precipitation, increased temperature can affect the water balance of watersheds by increasing evaporation of soil moisture and transpiration by vegetation (McCabe and Wolock 2011), and this has been demonstrated in a water-balance model developed specifically for Zion NP (D. Thoma, pers. comm.).

Alluvial deposits from the flood in December 2010 increased the elevation of the modern terrace, which is becoming indistinguishable from the historic terrace in some of the surveyed cross-sections (i.e., there is no longer a distinct cutbank separating these two terraces; see Appendix B, Figure B2 for an example). Although we attempted to distinguish the modern and historic terraces on our surveyed cross-sections, they should be interpreted with this caveat. It is still possible to distinguish these two terraces by analyzing the alluvial deposits that comprise them (Hereford et al. 1995), but this is beyond the scope of our monitoring protocol.

4.2 Vegetation

After the flood, we did not detect any significant changes for most of the vegetation metrics. This indicates that this riparian system is generally resilient and able to effectively adapt to disturbance. In metrics for which we did detect changes, the changes seen were not consistent at all reaches. The flood generally seemed to benefit disturbance-adapted riparian species and new colonizers at reaches 1 and 2, where species richness increased significantly after the flood (see Table 3-5).

In contrast, the post-flood changes detected at reach 3 were much more destructive to vegetation. After the flood, the width of the wetted channel increased at this reach (see Table 3-12). Vegetation along the streambank and in the narrow floodplain were most affected. Species richness at reach 3 decreased after the flood (see Table 3-5), and the decrease in obligate wetland graminoid species, such as *Carex* and *Eleocharis* species, was especially notable along the streambank (see Table 3-6). There were also significant decreases in live and total perennial grass cover at this reach (see Table 3-7), driven primarily by the decrease in redtop, a non-native facultative wetland species commonly found along the streambank (see Table 3-9). Additionally, the flood decreased total live vegetation cover at reach 3 (see Table 3-7), especially Rio Grande seepwillow, a native facultative wetland species, which had significant decreases in live cover (see Table 3-9). Because they are adapted to disturbance, a relatively rapid recovery of these species is expected.

It should be noted that reach 3 was only sampled in 2011 (the growing season after the flood), while reach 1 was sampled in 2011 and 2012, and reach 2 was only sampled in 2012. Although it is possible that the decreas-

es in richness and cover at reach 3 could be due to timing of sampling and our methods of analysis, we believe this is unlikely. The significant increase in wetted channel width at reach 3 suggests that parts of the streambank were scoured away during the flood. This idea is supported by the decrease in the number of obligate wetland species and in total cover (i.e., including dead parts of the plant) of redtop, both of which are found primarily along the streambank. The wetted channel width and vegetation cover at reach 1 were similar between monitoring visits in 2011 and 2012, additionally supporting the supposition that reach 3 truly experienced more streambank erosion that the other two reaches.

Larger floods are well known to promote germination of cottonwood seedlings in Southwestern riparian areas (Cooper et al. 1999; Friedman and Lee 2002; Scott et al. 1997), and the elevated groundwater levels shown in our hydrologic data would be expected to support increased recruitment. We saw an expected increase of Fremont cottonwood seedlings at reaches 1 and 3; however, we did not detect any increase at reach 2. In general, tree density and surface and vegetation cover at reach 2 were similar to that at the other two reaches. One possible explanation for the discrepancy in cottonwood increase at reach 2 is that there were fewer available fine sediment surfaces for seedling establishment at this reach. There is bedrock adjacent to the channel at a couple of the transects, and dense shrubs next to the channel at numerous transects. It seems unlikely that we simply missed an increase in seedling density at reach 2 by waiting to sample this plot until the 2012 growing season, because seedling density was found to be over 100 percent higher at reach 1 in both 2011 and 2012 (after the flood), as compared to 2008 or 2009 (before the flood).

Overall, the increase in cottonwood seedling density after the flood was encouraging, but we will need to continue to monitor how well they survive over time. Cottonwood recruitment is a concern in the main canyon of the North Fork of the Virgin River, where seedling survival is insufficient to sustain the cottonwood population over time (Steen-Adams 2002). Levees that channelize the river in this area, and high rates of herbivory by deer, are thought to be largely responsible for the decline. Because both the hydrology and predator-prey relationships of the EFVR in Zion NP are relatively unaltered compared to those in the main canyon of the North Fork of the Virgin River, sufficient levels of cottonwood regeneration may be possible on the EFVR.

4.3 Issues with variable transect length for long-term monitoring

Our protocol allows for changes in transect length, and we realized that adjustments were necessary after the flood buried or washed away many of our headpins. Most of our understory vegetation measurements should be minimally affected by changes in transect length, but tree measurements, such as density and basal area, have the potential to be affected more significantly. Cottonwood trees germinate in the floodplain and tend to form linear bands running parallel to the channel. When transects are lengthened to allow staff to place headpins on more stable surfaces, they may cross additional bands of cottonwoods, artificially increasing density and basal area of trees compared to earlier measurements.

Although no significant differences in tree density were detected as the result of this process, a significant increase in basal area was detected at reach 2 (see Table 3-11). After the flood, the lengths of all **seven** transects at reach 2 were increased (compared to four transects at reach 1 and one transect at reach 3). The increase in basal area recorded at reach 2 is likely due to an increase in transect length (a mean increase of 7 m per transect at this reach), rather than a substantial increase in the diameter of cottonwood trees at this reach. This issue needs to be considered in the analysis any time there is a substantial change in transect lengths between the time periods being examined. The impact of these changes should decrease over time as headpins are moved to more stable locations.

Similarly, the number of trees detected in the reach census was, in part, related to the

length of the transects and the locations of the headpins. Although more trees were detected in the reach census at reach 1, this reach had a longer mean transect length than reaches 2 or 3 (59 m compared to 37 m and 36 m; see Table 2-1 and Figure 3-9). Therefore, the reach census data should be compared within each reach over time, but should not be compared among the reaches. Density and basal area derived from the 5-m belt data are more appropriate metrics for comparing trees among reaches.

4.4 Statistics

Because our overall goal was to provide inference to the entire length of the EFVR within our sampling frame, we used a survey design to select monitoring reaches. Our preliminary analyses confirmed that a sample size of three reaches is not large enough to detect changes throughout the whole sampling frame. Thus, we analyzed each reach separately for this report and found that the reaches responded differently to the flood in a number of ways. Examining each reach separately still provides useful information, with each reach acting as an indicator site, but this 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). It may be more difficult than originally thought to have a sample size of seven reaches in future analyses, and the long-term revisit design will need to continue to be evaluated, especially considering the issues we are currently experiencing regarding access into Parunuweap Canyon.

4.5 Recommendations for future monitoring

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 on a river in the same year, so that results are more comparable and measurements can be directly attributed to flows during the previous year (versus several previous years). If this happens, the remainder of the monitoring scheduled on this river, at other wadeable streams, or on other protocols may need to be altered to balance the workload.

Rare flood events can inundate areas that initially appeared to be above the limits of a conceivable flood. Thus, headpins should always be placed in the most stable locations available to limit loss and burial. If transect lengths are altered in the future, it would be worth tracking whether trees are found along the previous location of the transect or the lengthened portion so the data are comparable between years.

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 similarly to our upland monitoring protocol to add consistency between the protocols for the crew. At the time, however, we did not realize that this would create descending numbers along the x-axes of our stream cross-section figures (see Figure 3-6 and Appendix B).

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Appendix A: Hydrologic Data, 2010–2012

A.1 Well and piezometer installation

For convenience, the use of "wells" in this appendix (and in the report) can be understood to incorporate both wells and piezometers. Wells and piezometers are composed of 1¼" galvanized steel pipe. Each well point is 3 feet long (0.91 m) and is screened with 60-gauge metal mesh suitable for screening out coarse sand. Wells were installed manually using a post pounder. Two different types of wells were installed at Reach 3, Transect 7 by the NCPN on October 17, 2010: an instream monitoring well and two riparian groundwater piezometers.

The instream well has a screened, 3-foot (0.91 m) well point and at least one screened, 3-foot (0.91 m) galvanized steel riser (Figure A-1). The uppermost riser of the instream well is a solid galvanized steel riser with holes drilled into the sides. This riser was wrapped in filter fabric to reduce siltation inside the well during installation, but the filter fabric washed away over time. Due to this design, the instream installation began to fill with sediment, which has introduced an unknown amount of noise to instream stage records over time. The instream well was driven to a depth that would secure the well in place during flood events and minimize its profile above the water column.

The riparian groundwater piezometers have a screened, 3-foot (0.91 m) well point and solid galvanized steel risers in 2–3 foot sections (0.61–0.91 m; Figures A-2 and A-3). Riparian piezometers were driven to a depth of at least one meter lower than the groundwater table encountered during installation. A small hole was drilled on the downstream side of the uppermost riser to vent the well to the atmosphere. No well log is available from the installation, but cutbanks at the site suggest that the riparian piezometers are in coarse alluvium with no confining layers.

A notch was filed into the lip of the uppermost riser of each installation as a permanent measuring point. Manual water-level measurements were taken from the measuring point on the top of the well casing to the water's surface inside the well. Pressure transducers were suspended from the well caps using Kevlar cord.

Wells were installed along a permanent, monumented monitoring transect that corresponds to NCPN's vegetation and geomorphology measurements (Figure A-4). The wells are located approximately 180 m downstream of USGS gaging station 09404900, East Fork Virgin River, near Springdale, Utah (Figures A-4 and A-5). There are no notes to indicate why NCPN's monitoring wells were located downstream of, rather than adjacent to, the USGS gage. The gage is just downstream of a significant bend in the channel, and floodplain area is limited on the river left side, so the installation may have been put downstream to allow access to a wider floodplain.



Figure A-1. Installing the instream well at ZION P-03.

Instream well
Lat: 37.16361 N, Long: -112.95952 W
Northing: 4114819.871, Easting: 326014.731 UTM Zone 12, NAD 83
Depth of well: 1.81 m



Figure A-2. River right riparian piezometer. Photo taken after 2010 flood event.

Right piezometer
Lat: 37.16367 N, Long: -112.95959 W
Northing: 4114827.292, Easting: 326008.668 UTM Zone 12, NAD 83
Depth of piezometer: 3.95 m



Figure A-3. River left riparian piezometer. Photo taken after 2010 flood.

Left piezometer
Lat: 37.16350 N, Long: -112.95948 W
Northing: 4114808.215, Easting: 326017.753 UTM Zone 12, NAD 83
Depth of piezometer: 3.49 m

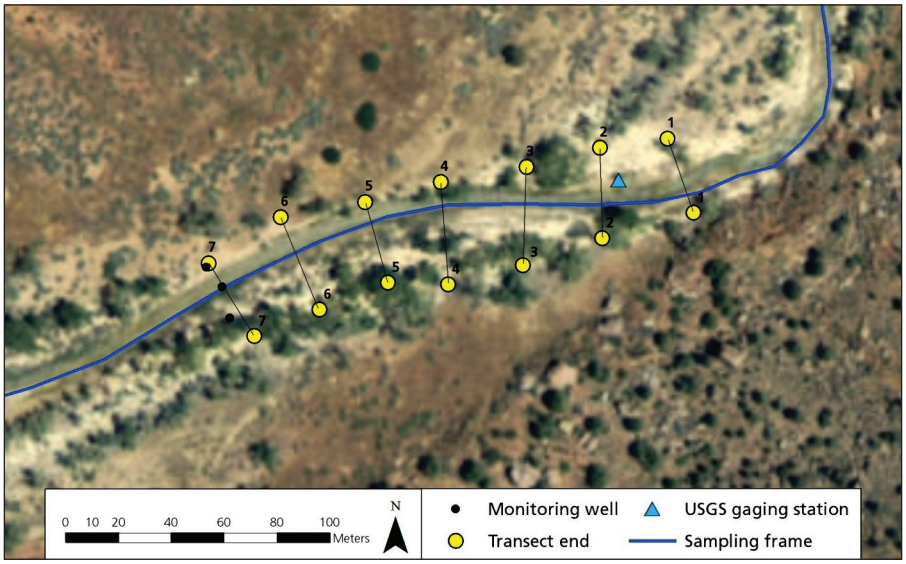


Figure A-4. Overview of NCPN monitoring reach ZION P-03 with permanent vegetation and geomorphology monitoring transects, well locations, and USGS gaging station.



Figure A-5. USGS gage 09404900 located near transect 2 in ZION P-03. Photo courtesy USGS.

1.2 History of levels

Surveys of well elevations and ground-surface elevations next to the well measuring points were taken with a Nikon Nivo 3.M total station and a SpectraPrecision data collector with Survey Pro software (version 4.9.2). The Nikon Nivo 3.M has an angle precision of 3 seconds, which translates to an estimated horizontal and vertical accuracy of +/- 0.01 cm over 500 meters. Intrasurvey errors by NCPN at the East Fork Virgin River averaged a horizontal accuracy of +/-0.014 m and vertical accuracy of +/- 0.003 m over 25–48 m of distance.

The first survey of well elevations for ZION P-03 took place on 10/25/2011, about one year after the wells were established. During this survey, the survey crew recorded elevations on top of the well caps rather than on top of the well casings. A second survey on 2/28/2013 recorded elevations for both the top of the well caps and the top of the well casings. We calculated the difference between the two 2013 measurements and subtracted it from the 2011 well-cap elevations to create calculated top-of-casing elevations for 2011 (Table A-1), and the maximum difference between a 2013 measured well elevation and a 2011 calculated well elevation was 0.02 m. Due to the potential for calculation errors, we use the top-of-casing elevations from the 2013 survey as the baseline elevations for converting hydrologic data into the site datum. Elevations are referenced to the site's permanent datum, Control Point 2 (CP2), with an arbitrary assigned elevation of 1,000.28 m.

1.3 Site visits, well maintenance, and manual water level measurements

Site visits were scheduled to occur in spring, summer, and fall of each year. Manual water-level measurements were recorded to the nearest 0.1 cm (0.001 m) using a Solinst Model 101 water level meter. Continuous water levels were recorded using Solinst Gold leveloggers with an estimated accuracy of 0.3 cm (0.003 m). During each site visit, the depth to the bottom of the well was measured and compared to the installation depth to detect sediment build-up within the well. If more than 6 cm of sediment was present, then the well was purged using a manual foot pump to remove the sediment.

Because of staff turnover, regular field visits did not occur in 2011 and 2012 (see Tables A-2 and A-3). A data gap exists for each well from 12/9/2011 to 9/5/2012. In this report, we focus our discussion of well data on the short, post-flood period in 2010 and all of 2011.

A flood event on December 21, 2010 overtopped all three monitoring wells, reworked the channel in ZION P-03, and covered the instream monitoring well with sediment. After the flood, the channel bottom slowly scoured. The instream well was still buried during a site visit on 3/14/2011. By 10/24/2011, the channel had scoured down enough that the instream well emerged, but the well was packed full of sediment. The ground surface recorded next to the instream well was 9 cm lower during the survey in 2013 than in 2011. Due to staff turnover, the instream well was not redeveloped until 9/4/2012.

1.4 Hydrologic data corrections for 2010–2012

Raw logger water-level data were barometrically compensated and adjusted to match the manual water level recorded at the beginning of the period using Solinst Levelogger software verson 4.0.3. Data were imported into the Aquarius platform, version 3.x, distributed by Aquatic Informatics. Logger water levels at the end of the record were compared to manual water level measurements from the site visit at the end of the record. If the logger measurement differed by more than 0.5 cm (0.005 m), a drift correction was applied so that the logger data would match the manual water level measurement. A history of drift corrections applied to each datalogger record for ZION P-03 is included in Table A-4.

Corrected data were used to build derived datasets in Aquarius v. 3.x. Water levels were subtracted from each well's elevation in the site's permanent datum to create a time series of water elevations that can be compared across wells. The ground-surface elevations recorded in the 2011 and 2013 total station

Table A-1. History of levels for wells and control points at ZION P-03.

	Control point				Left riparian well			Right riparian well			Instream well			
Date	CP-1	CP-2	CP-3	CP-4	TOC	Datum Corr.	GS[1]	TOC	Datum Corr.	GS[1]	TOC	Datum Corr.	GS[1]	Closure error[2]
10/25/2011	1003.90	1000.28	1003.94	1003.43	997.97		997.61	998.36		997.45	996.08		995.95	0.00
2/28/2013	1003.90	1000.28	1003.94	1003.43	997.96	0.00	997.60	998.35	0.00	997.44	996.08	0.00	995.87	0.02

Elevations are reported in meters relative to the site's arbitrary datum.

CP – Control Point, stable monumented location (e.g., rebar or a survey marker)

TOC – Top of well casing

GS – Ground surface next to well

[1] – Not a stable surface; elevation expected to change

[2] - Closure error – Difference in elevation recorded for a single, stable location at the beginning and end of a survey. If the survey included more than one job, the maximum closure error is presented here.

Table A-2. Manual water-level measurement (cm) in wells during each field visit, referenced to the top of the well casing.

Date	Water level (cm)			Comments
	Instream well	Left well	Right well	
10/17/2010	-11.6	-219.1	-250.3	Installation; no times recorded for water level measurements
3/14/2011		-122.6	-168.8	Instream well buried; staff leaves
10/24/2011	4.0	-191.8	-223.1	Instream well uncovered; new staff
12/08/2011	1.0	-183.0	-221.0	Equipment malfunction–dataloggers not downloaded or reprogrammed; staff leaves
6/11/2012		-205.2	-232.5	New staff; no times recorded for water level measurements
9/4/2012	4.0	-204.5	-234.0	Instream well redeveloped

Positive numbers indicate that the water elevation was higher than the well casing.

Table A-3. Manual water-level measurements referenced to the site datum (m), with stage and discharge recorded by the USGS gaging station.

Date	USGS gage			Instream well		Left well		Right well	
	Time	Stage (ft)	Discharge (cfs)	Time	Stage (m)	Time	Stage (m)	Time	Stage (m)
10/17/2010	–	–	–	–	995.96	–	995.77	–	995.84
3/14/2011	12:45	5.72	98	–	–	13:00	829.16	12:45	996.66
10/24/2011	16:00	5.27	57	16:10	996.12	15:48	996.04	15:30	996.12
12/08/2011	11:00	5.24	49	11:10	996.09	11:15	996.13	11:08	996.14
6/11/2012	–	–	–	–	–	–	995.91	–	996.02
9/4/2012	11:00	5.09	41	11:05	996.12	9:55	995.92	9:25	996.01

Times are reported in Mountain Standard Time.

Table A-4. Water-level corrections applied to each datalogger record, 2010–2012.

Start date	End date	Instream	Left riparian well	Right riparian well
10/17/2010	12/21/2010	Pre-flood data	Pre-flood data; no ground elevations known; depth to groundwater not calculated	Pre-flood data; no ground elevations known; depth to groundwater not calculated
12/21/2010	3/14/2011	Well buried; no manual measurement possible; no correction possible	+2.3 cm; applied back to 12/21/2010	+1.3 cm; applied back to 12/21/2010
3/14/2011	10/24/2011	+5.4 cm; applied back to 12/21/2010	<0.5 cm; no correction applied	+0.7 cm
10/24/2011	12/08/2011	-6.1 cm	-5.1 cm	-0.9 cm
12/08/2011	9/4/2012	Missing data	Missing data	Missing data
9/4/2012	2/28/2013	-4.7 cm; data not summarized in report	-2.8 cm; data not summarized in report	-1.6 cm; data not summarized in report

surveys were applied to the water elevations of the groundwater monitoring piezometers to calculate a depth-to-groundwater time series for each piezometer. Changes in ground-surface elevations were applied to the peak stage associated with large flood events, during which ground surfaces are assumed to have changed. No ground-surface elevations were available prior to the 2010 flood, so the depth-to-groundwater time series begin at the peak of the 2010 flood, rather than in October 2010.

1.5 Changes to methods based on 2010–2012 data and field effort

To improve data quality assurance and control, several changes have been made to NCPN hydrologic monitoring. In 2013, three manual water-level measurements were added before downloading data and before redeploying the datalogger. Taking three measurements ensures that water levels are stable within the well. Taking measurements before and after downloading data ensures that the manual measurement times correspond as closely as possible to the end and beginning of datalogger records.

Also in 2013, we added a measurement from the top of the well casing at the measuring point notch to the ground surface so that information on the ground surface elevation is available more frequently than site surveys would allow. Total station surveys of well elevations and well cross-sections are now taken annually rather than on a rotating basis that coincided with vegetation sampling at the reach.

Appendix B: Cross-sections of Stream Reaches

Appendix B figures begin on next page. 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.

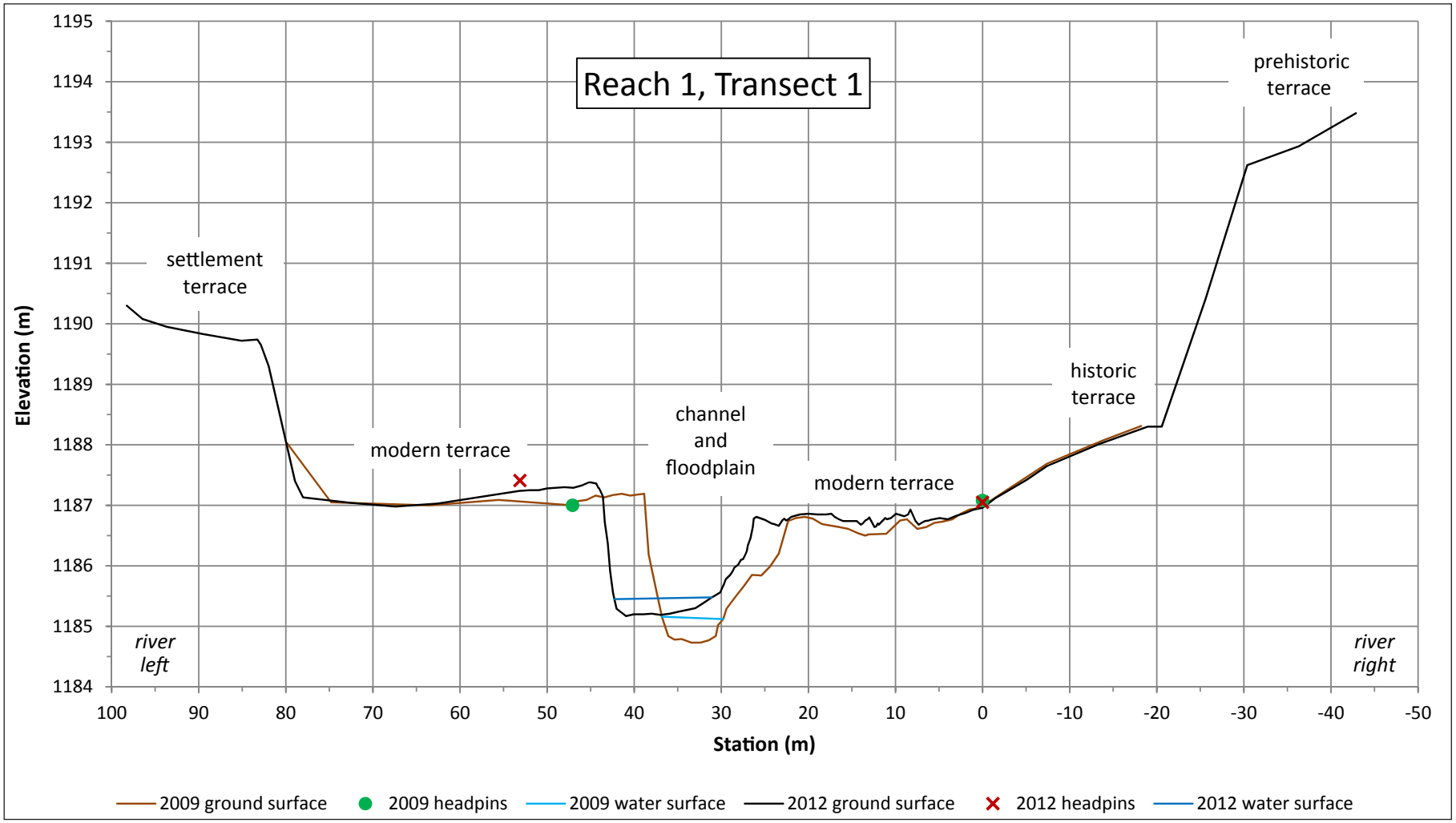


Figure B1. Cross-section of reach 1 at transect 1 looking downstream, East Fork Virgin River, Zion National Park, 2009 and 2012. The historic terrace delineated by the Zion geology GIS layer (NPS 2006) from approximately 50 m to 85 m on river left was not present in this cross-section, and the settlement terrace on river left was not mapped on the GIS layer.

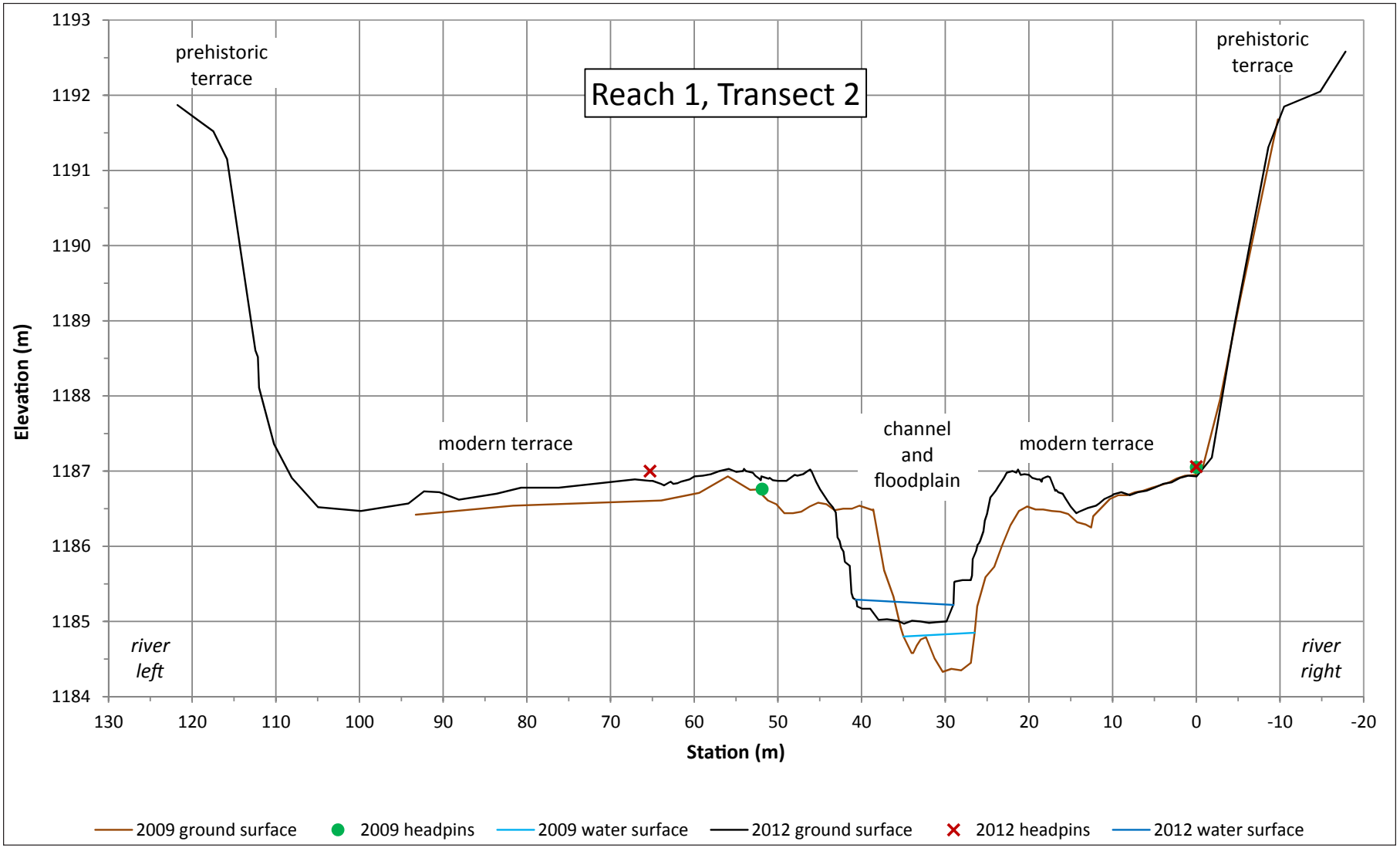


Figure B2. Cross-section of reach 1 at transect 2 looking downstream, East Fork Virgin River, Zion National Park, 2009 and 2012. The historic terrace delineated by the Zion geology GIS layer (NPS 2006) from approximately 55 m to 105 m on river left was not present in this cross-section.

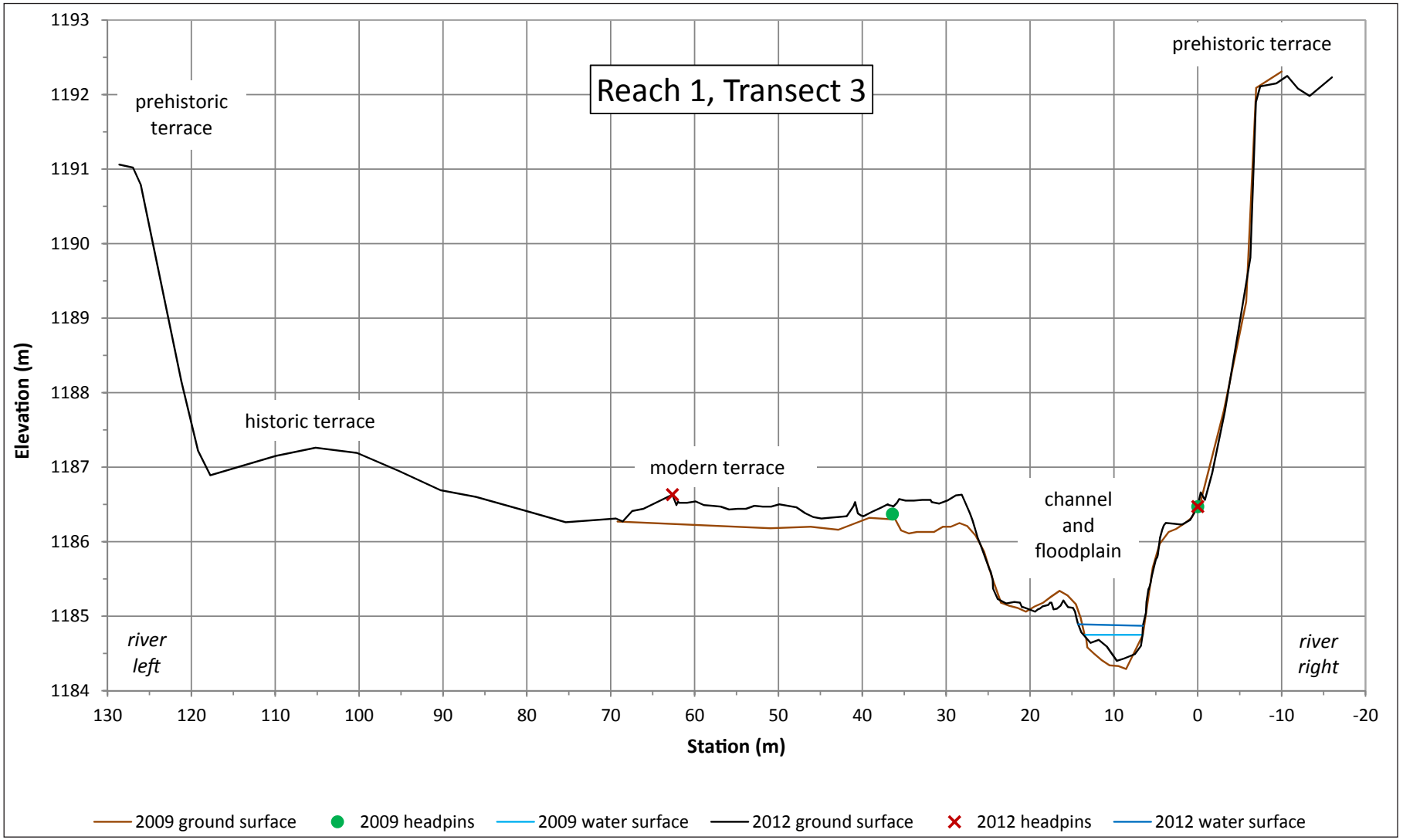


Figure B3. Cross-section of reach 1 at transect 3 looking downstream, East Fork Virgin River, Zion National Park, 2009 and 2012.

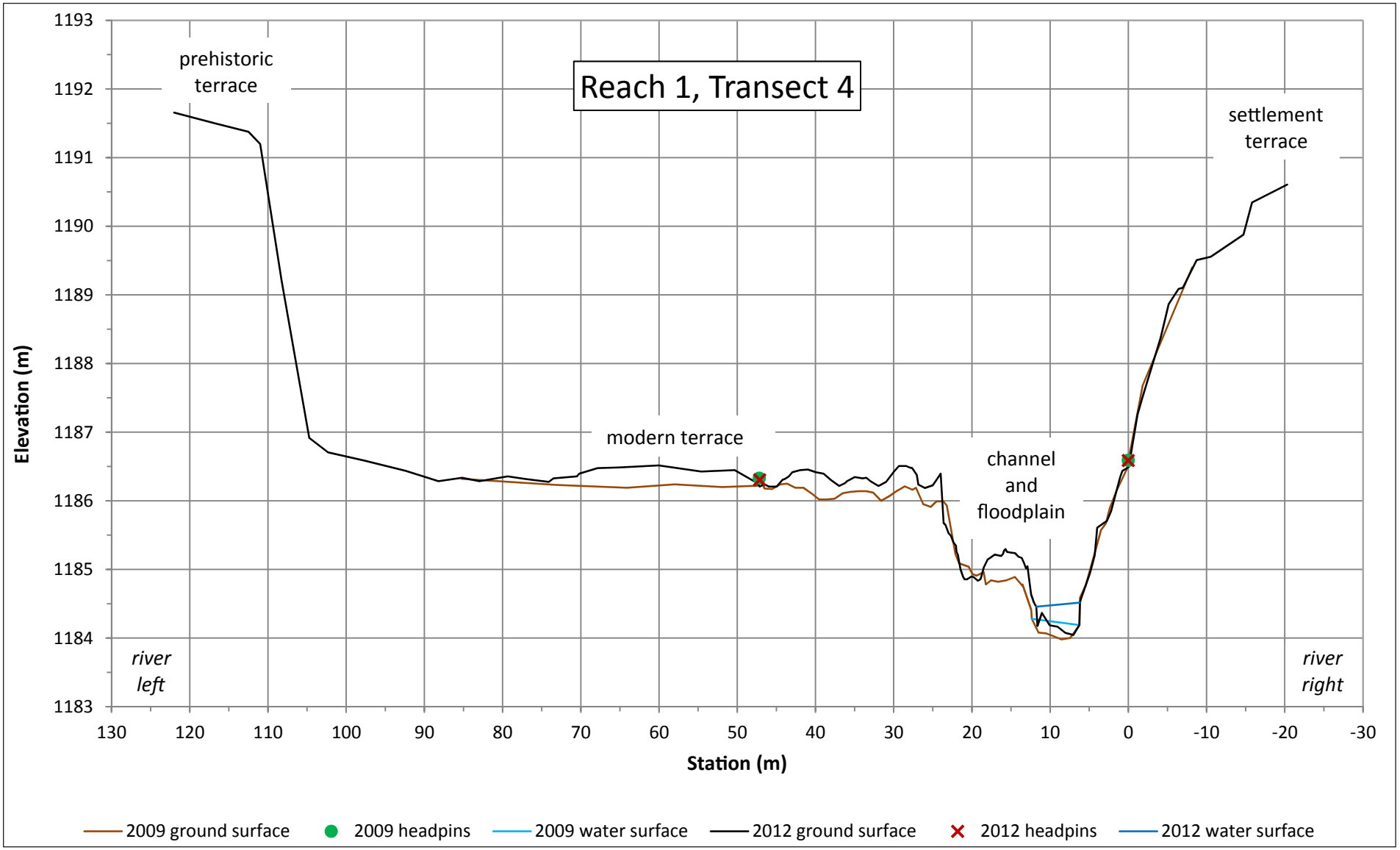


Figure B4. Cross-section of reach 1 at transect 4 looking downstream, East Fork Virgin River, Zion National Park, 2009 and 2012. The historic terrace delineated by the Zion geology GIS layer (NPS 2006) from approximately 65 m to 105 m on river left was not present in this cross-section.

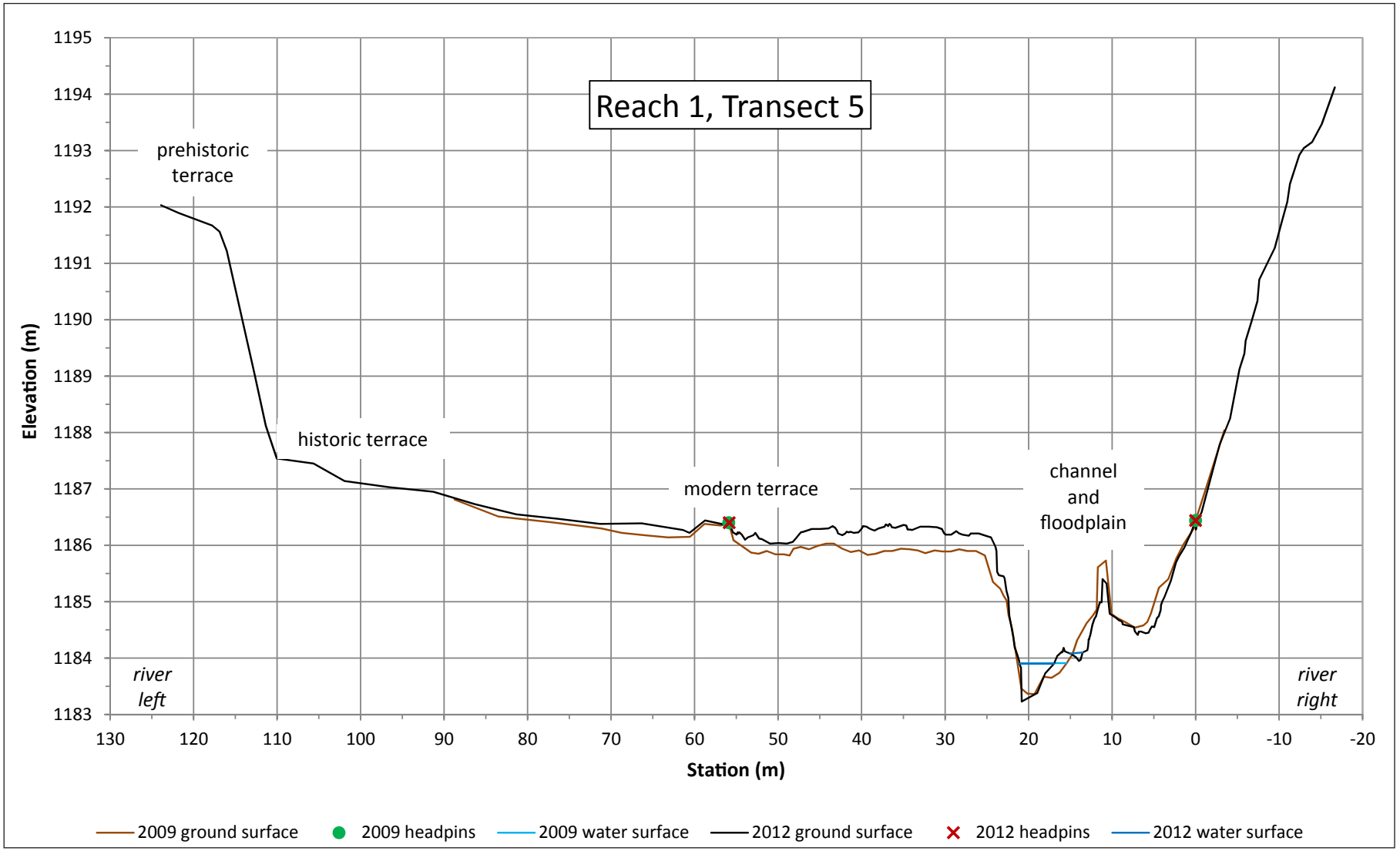


Figure B5. Cross-section of reach 1 at transect 5 looking downstream, East Fork Virgin River, Zion National Park, 2009 and 2012.

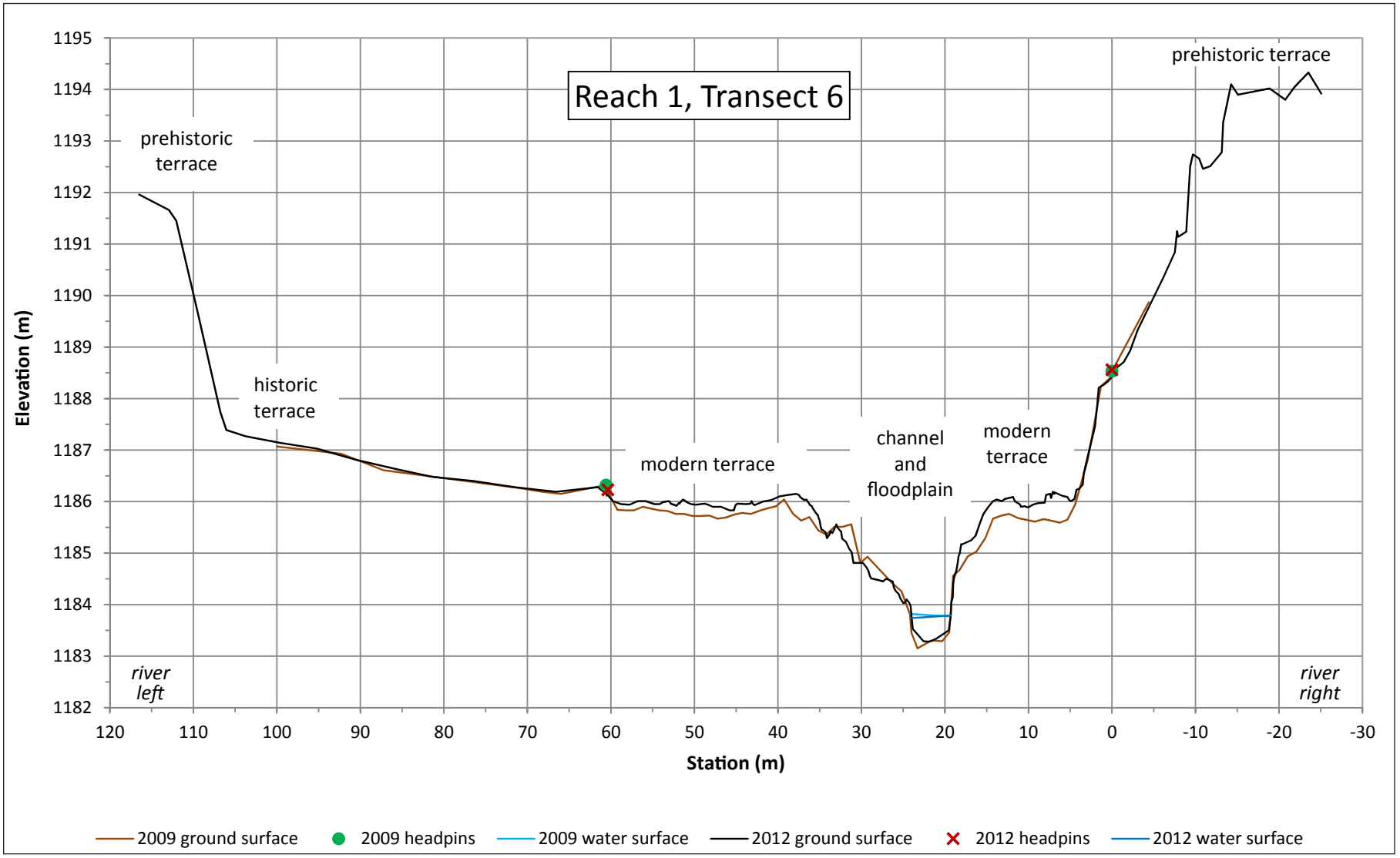


Figure B6. Cross-section of reach 1 at transect 6 looking downstream, East Fork Virgin River, Zion National Park, 2009 and 2012.

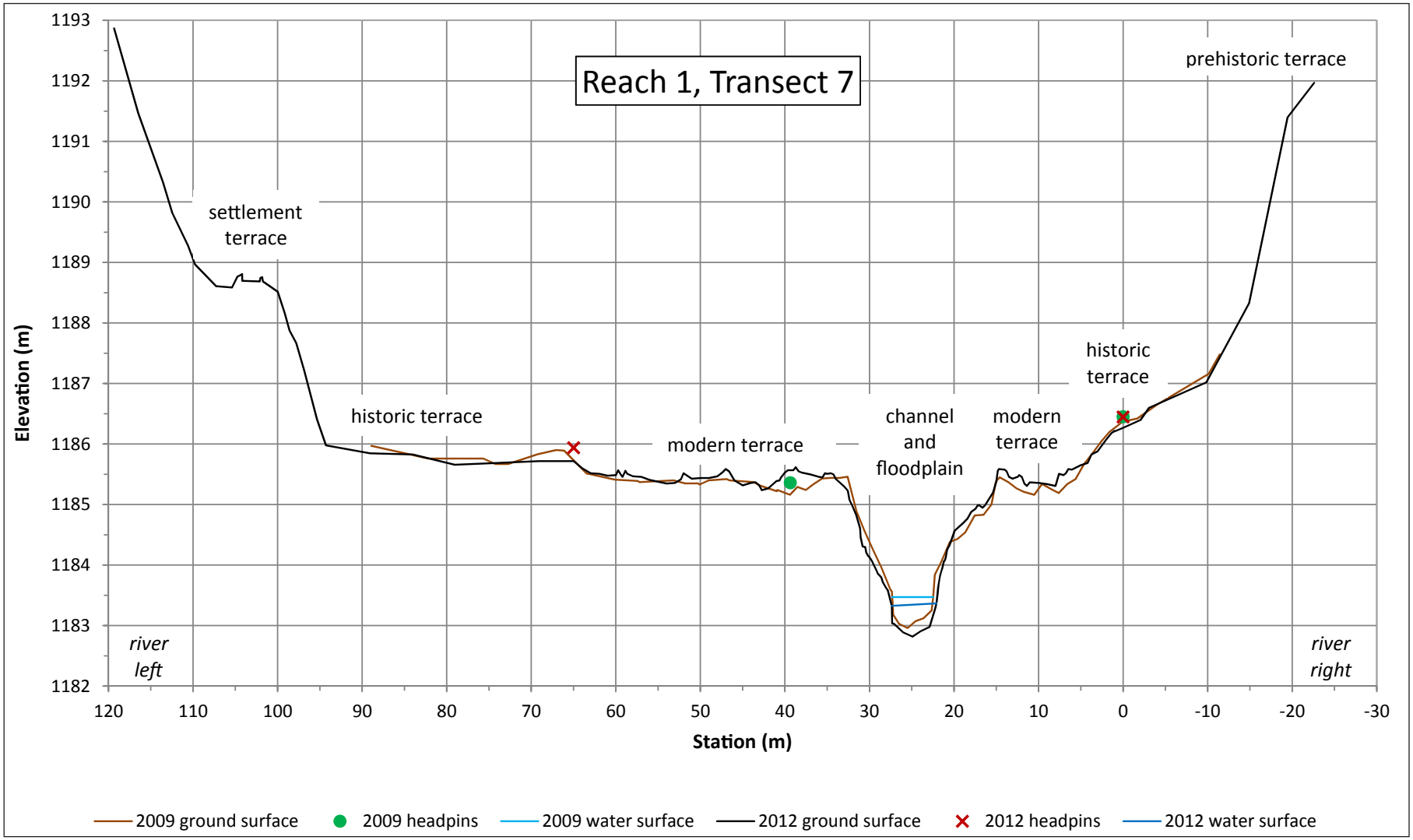


Figure B7. Cross-section of reach 1 at transect 7 looking downstream, East Fork Virgin River, Zion National Park, 2009 and 2012. The settlement terrace on river left was not mapped on the Zion geology GIS layer (NPS 2006).

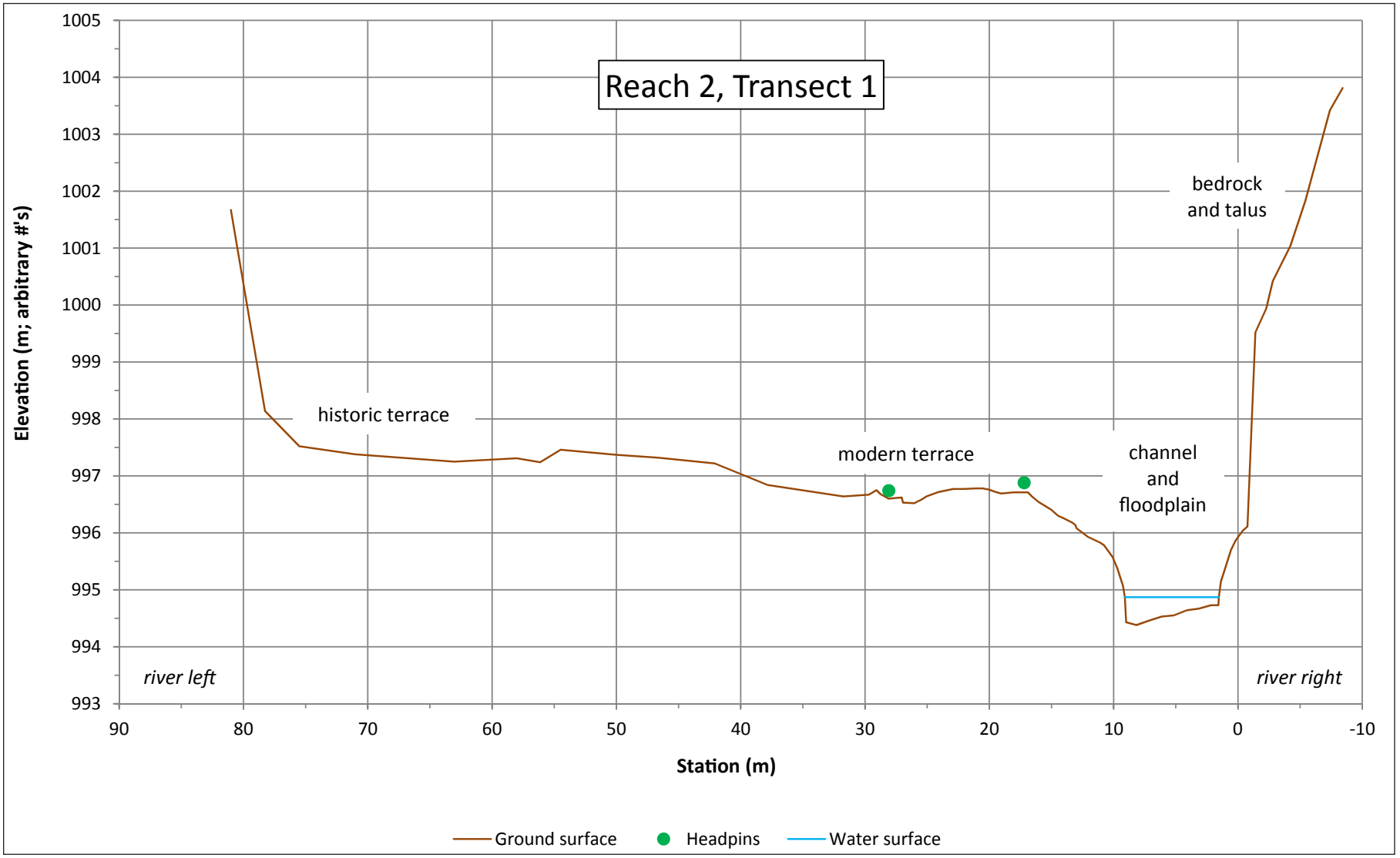


Figure B8. Cross-section of reach 2 at transect 1 looking downstream, East Fork Virgin River, Zion National Park, March 2012.

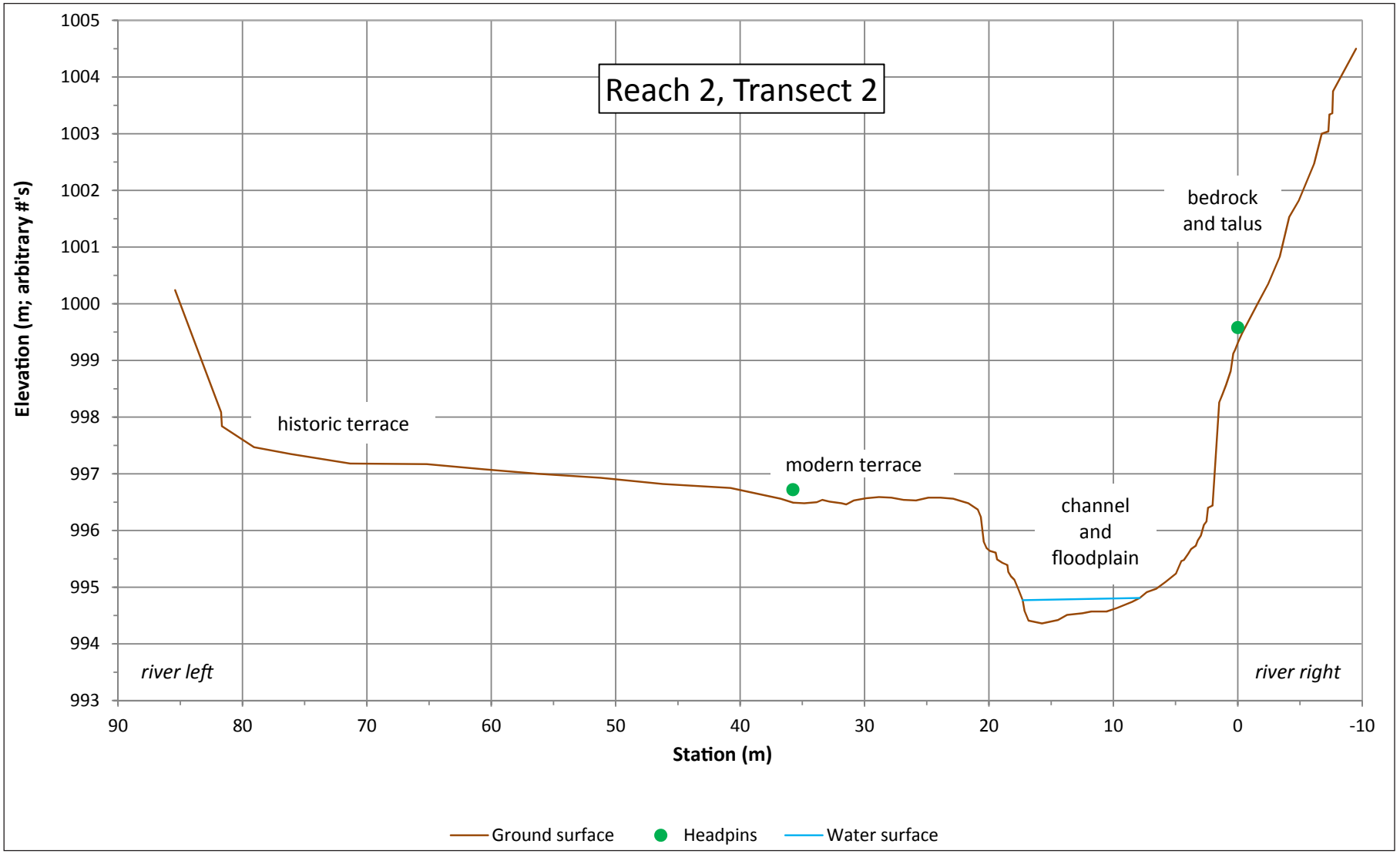


Figure B9. Cross-section of reach 2 at transect 2 looking downstream, East Fork Virgin River, Zion National Park, March 2012.

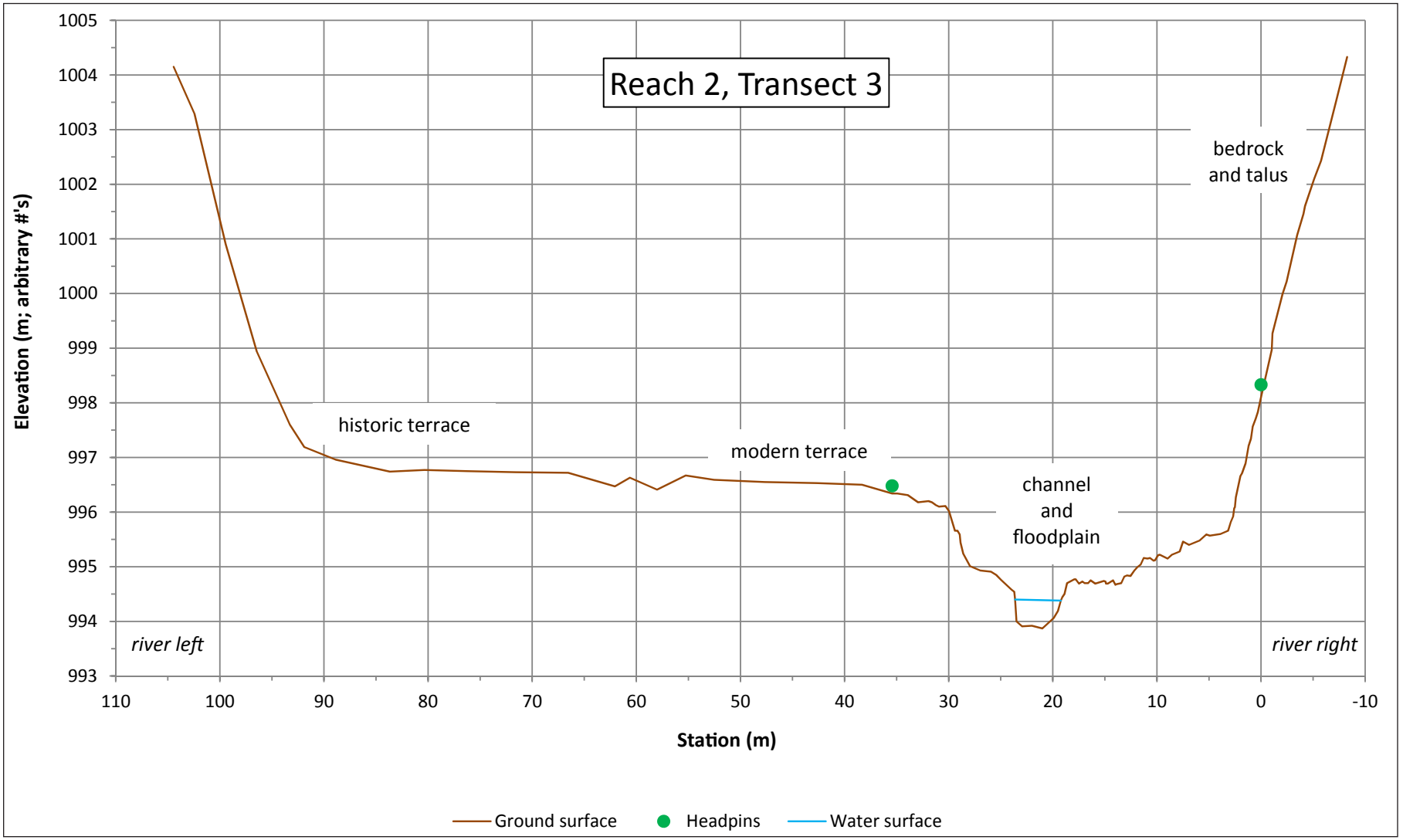


Figure B10. Cross-section of reach 2 at transect 3 looking downstream, East Fork Virgin River, Zion National Park, March 2012. Although there is little difference in elevation between the modern terrace and the historic terrace at this cross-section, the surface break around 65 m corresponded well with the mapped surfaces on the Zion geology GIS layer (NPS 2006).



Figure B11. Cross-section of reach 2 at transect 4 looking downstream, East Fork Virgin River, Zion National Park, March 2012. Although there is little difference in elevation between the modern terrace and the historic terrace at this cross-section, the surface break around 65–75 m corresponded well with the mapped surfaces on the Zion geology GIS layer (NPS 2006).

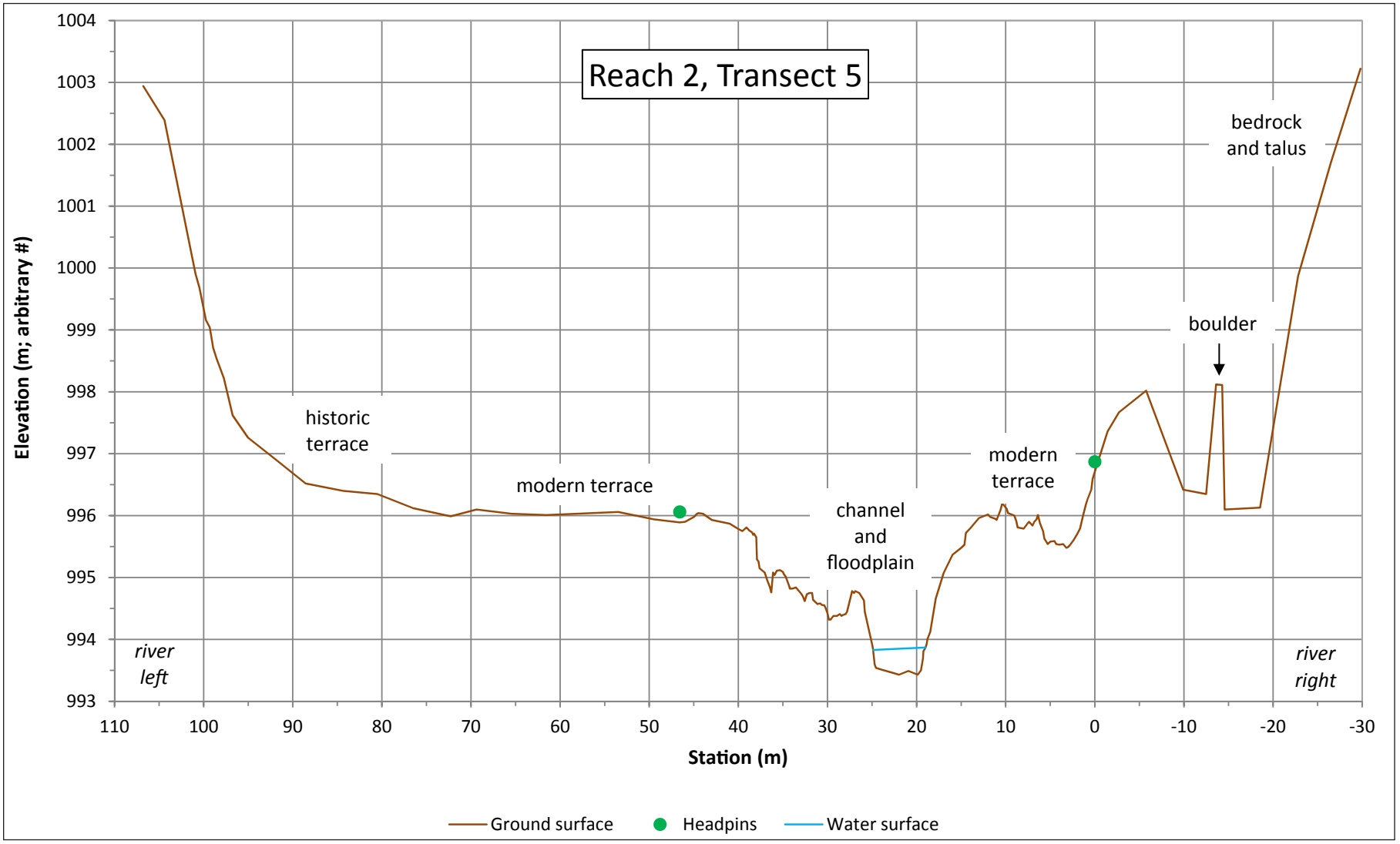


Figure B12. Cross-section of reach 2 at transect 5 looking downstream, East Fork Virgin River, Zion National Park, March 2012.

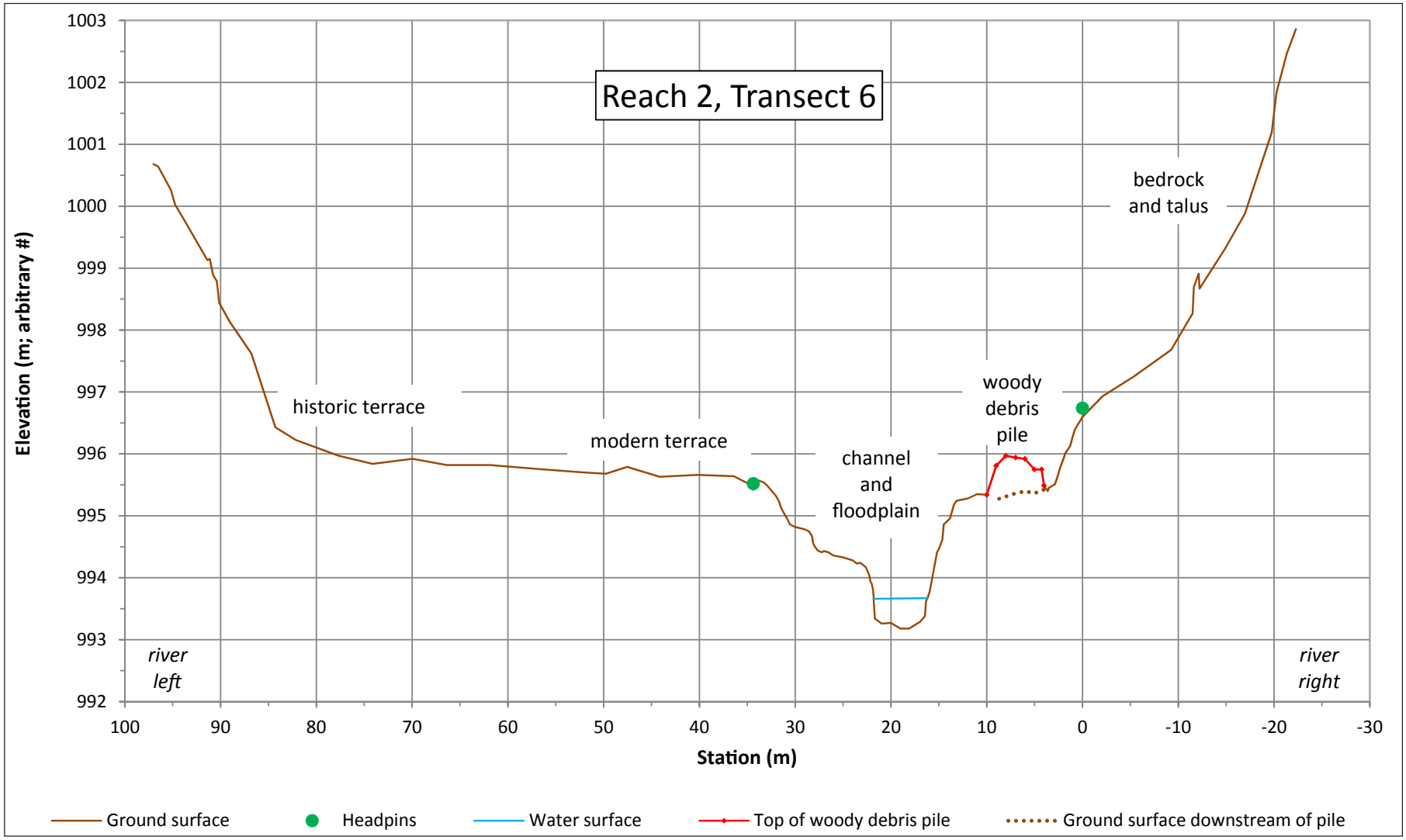


Figure B13. Cross-section of reach 2 at transect 6 looking downstream, East Fork Virgin River, Zion National Park, March 2012. The historic terrace delineated by the Zion geology GIS layer (NPS 2006) from approximately 55 m to 85 m on river left was not distinct in this cross-section.

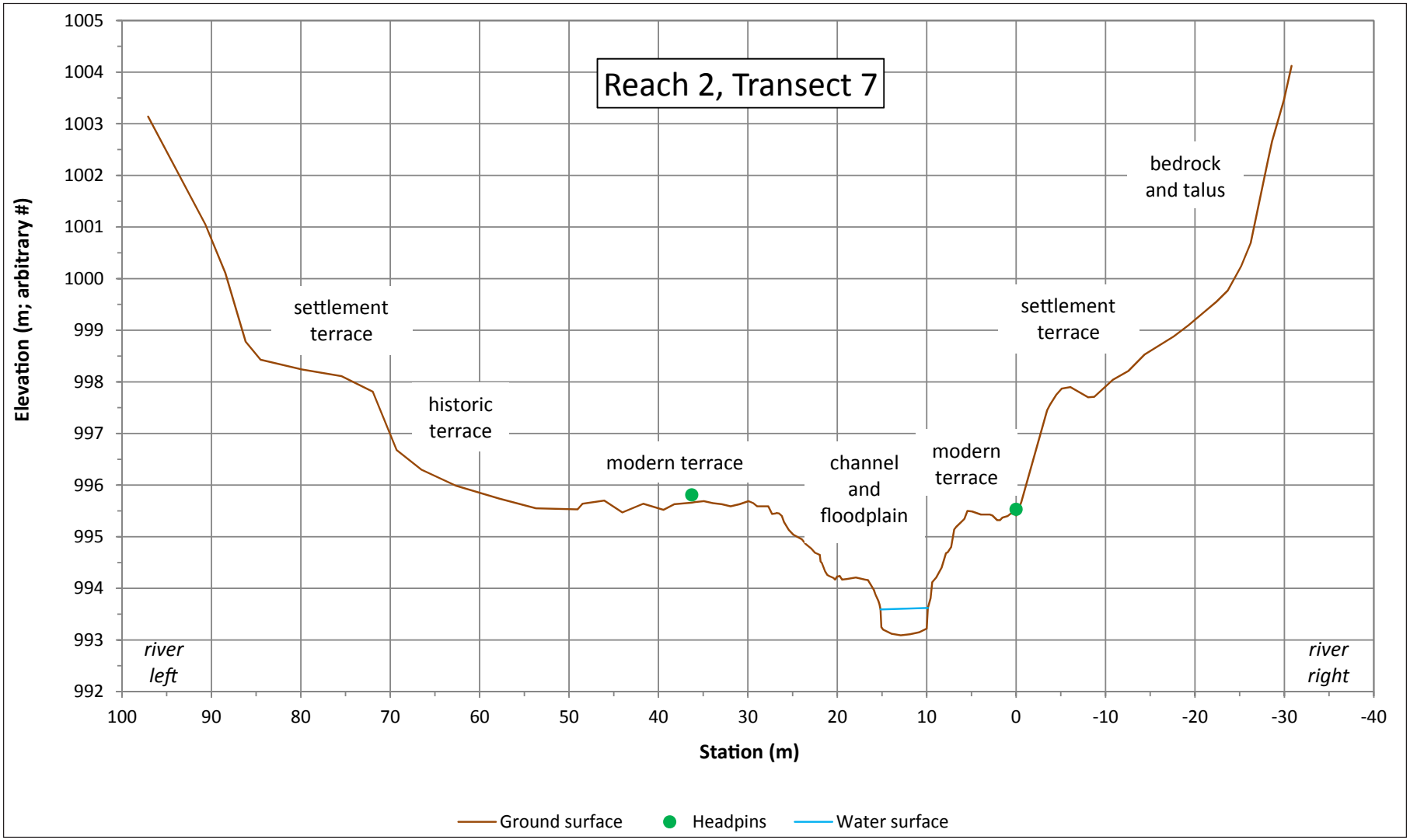


Figure B14. Cross-section of reach 2 at transect 7 looking downstream, East Fork Virgin River, Zion National Park, March 2012. The historic terrace delineated by the Zion geology GIS layer (NPS 2006) from approximately 50–70 m on river left was not distinct in this cross-section. The small settlement terraces on river right and left were not mapped in the Zion geology GIS layer.

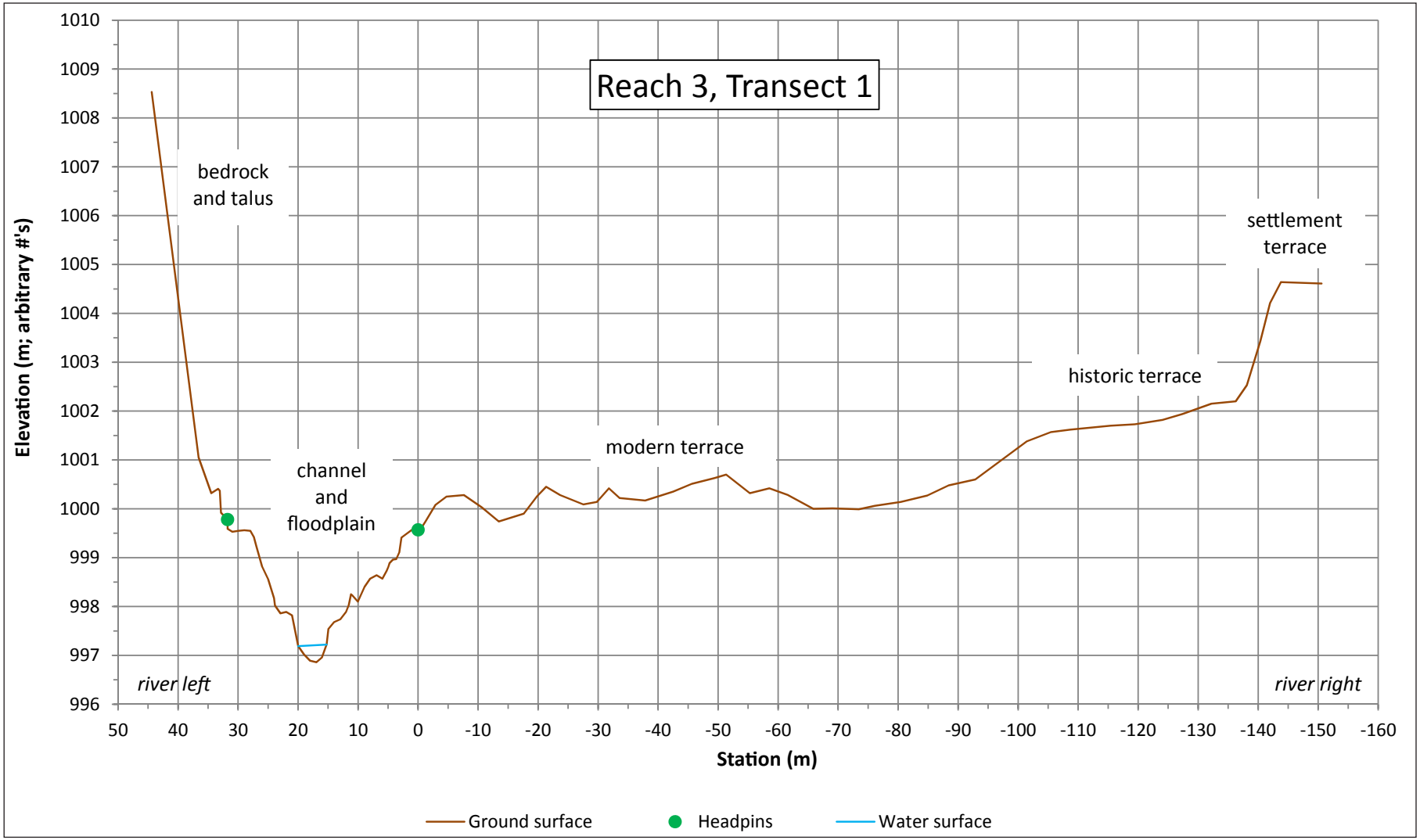


Figure B15. Cross-section of reach 3 at transect 1 looking downstream, East Fork Virgin River, Zion National Park, October 2011.

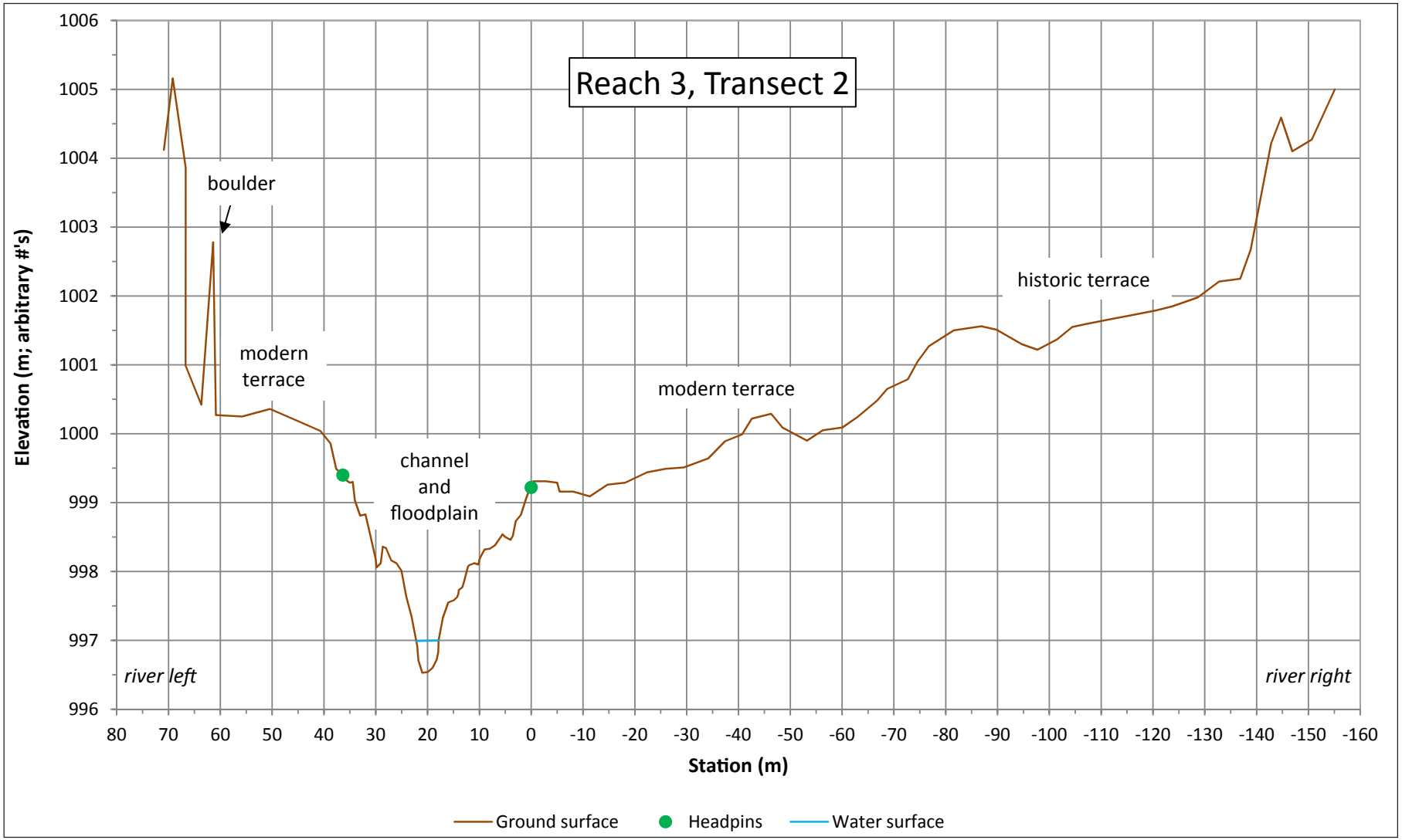


Figure B16. Cross-section of reach 3 at transect 2 looking downstream, East Fork Virgin River, Zion National Park, October 2011.

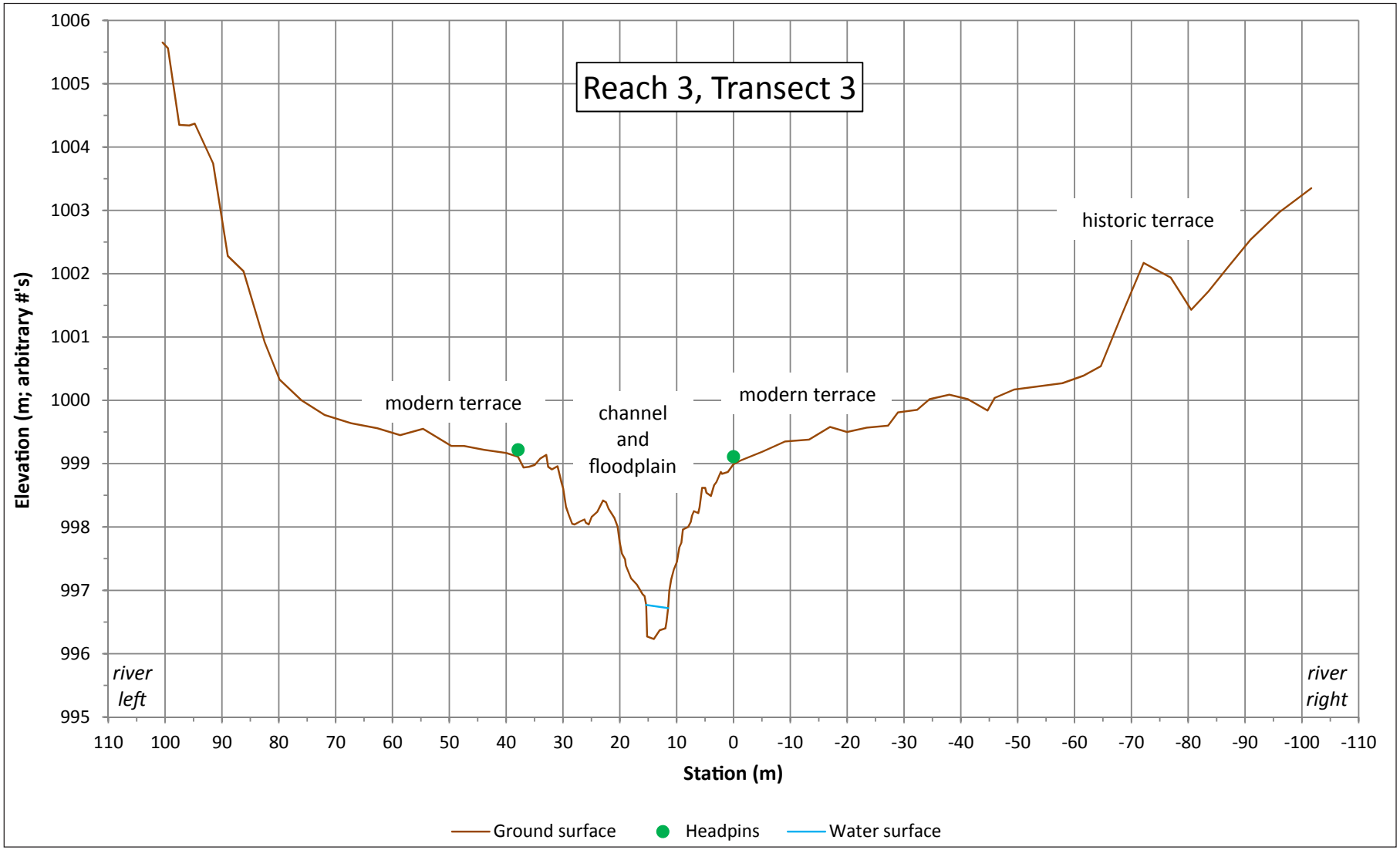


Figure B17. Cross-section of reach 3 at transect 3 looking downstream, East Fork Virgin River, Zion National Park, October 2011.

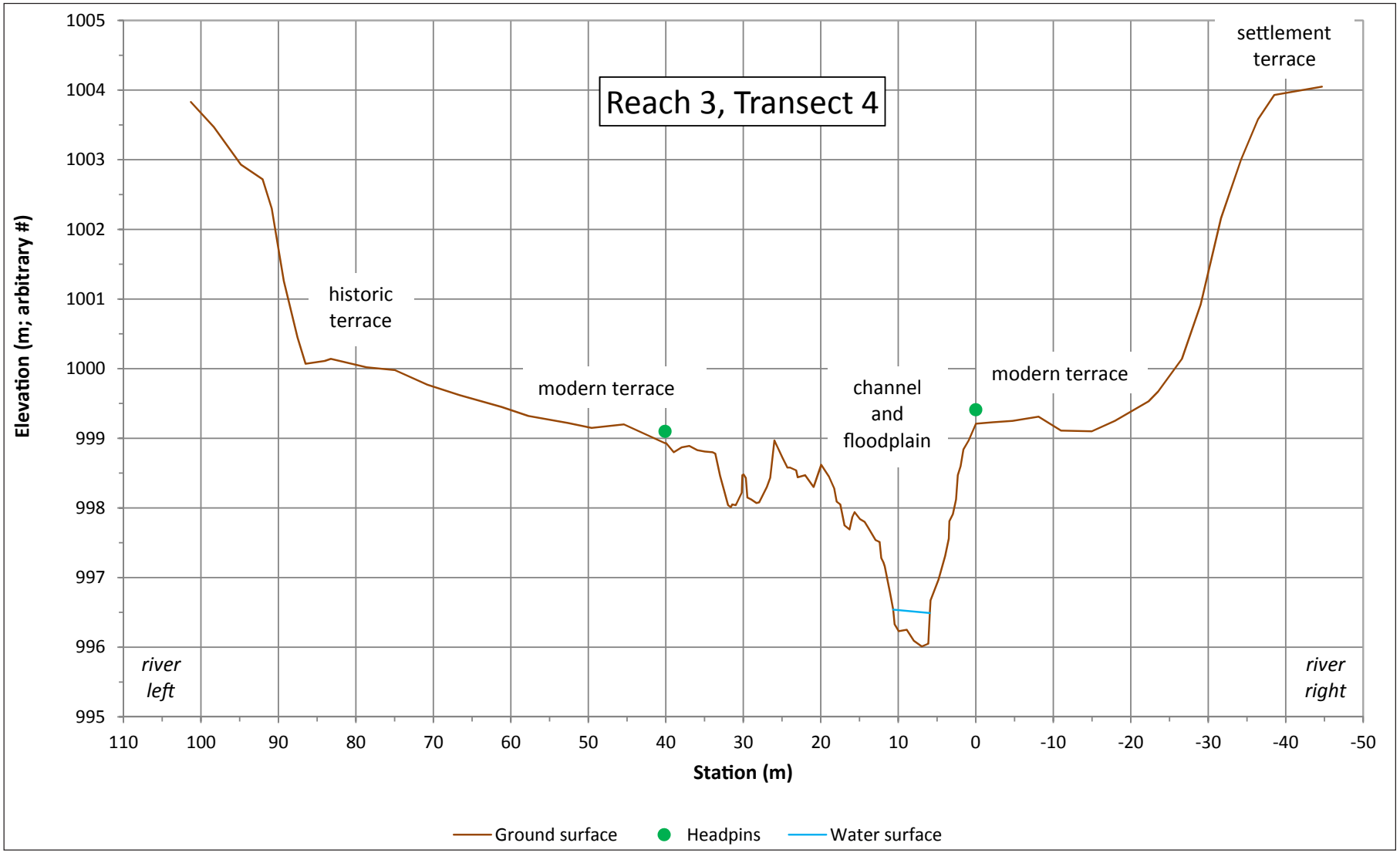


Figure B18. Cross-section of reach 3 at transect 4 looking downstream, East Fork Virgin River, Zion National Park, October 2011. The historic terrace on river left was not mapped on the Zion geology GIS layer (NPS 2006).

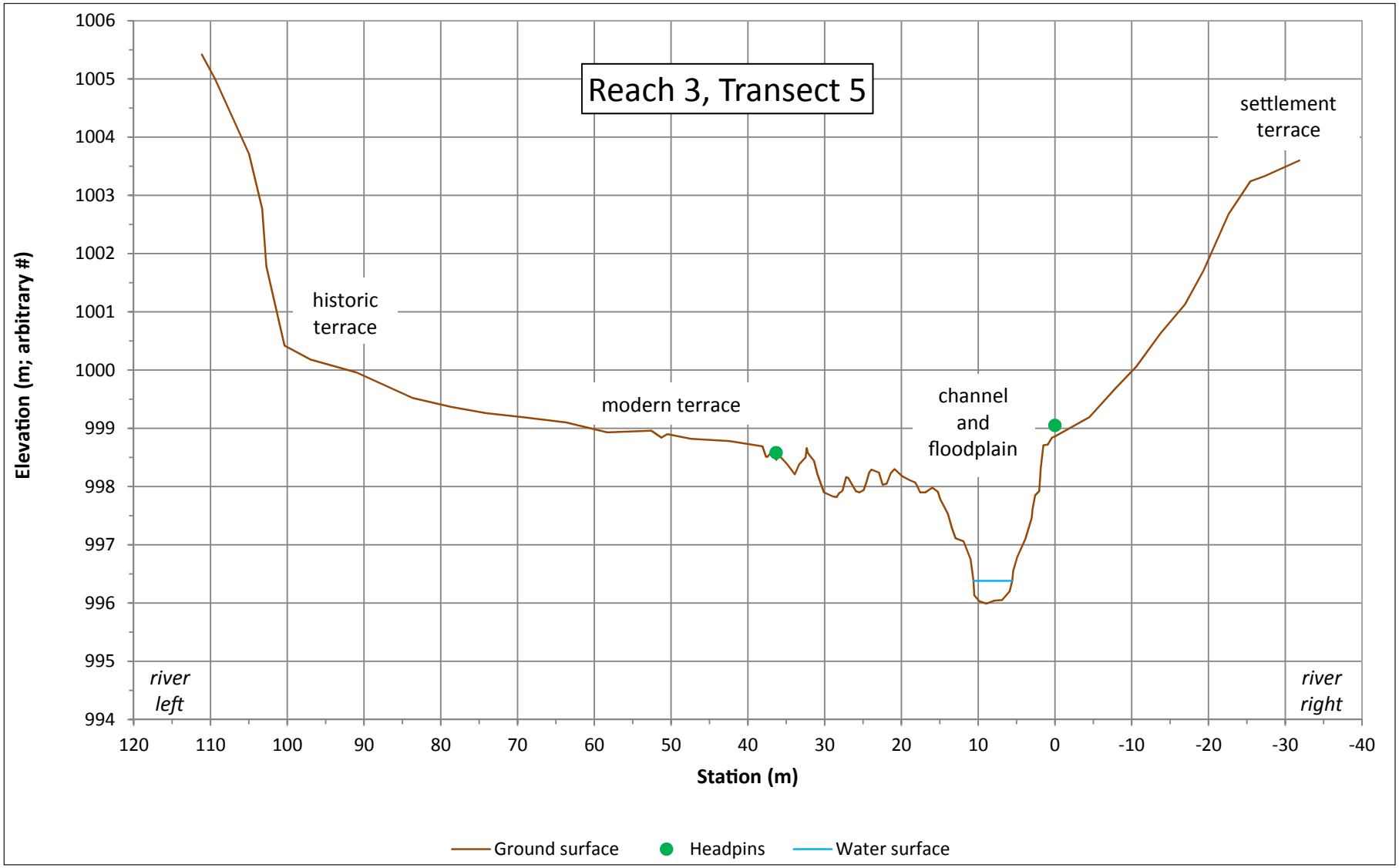


Figure B19. Cross-section of reach 3 at transect 5 looking downstream, East Fork Virgin River, Zion National Park, October 2011. There appears to be a remnant of a historic terrace on river left from about 90–100 m that was not mapped on the Zion geology GIS layer (NPS 2006).

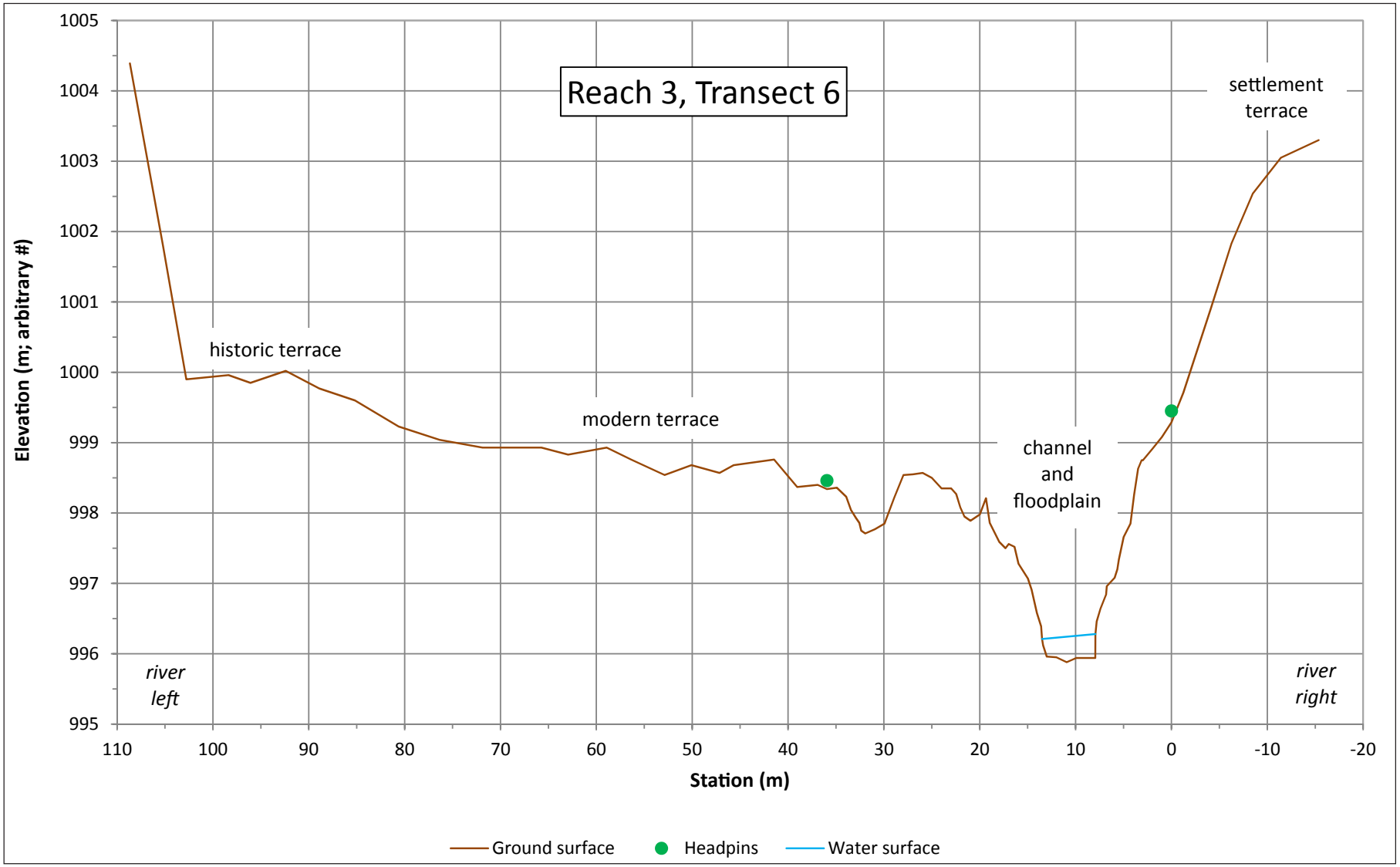


Figure B20. Cross-section of reach 3 at transect 6 looking downstream, East Fork Virgin River, Zion National Park, October 2011. The historic terrace on river left was not mapped on the Zion geology GIS layer (NPS 2006).

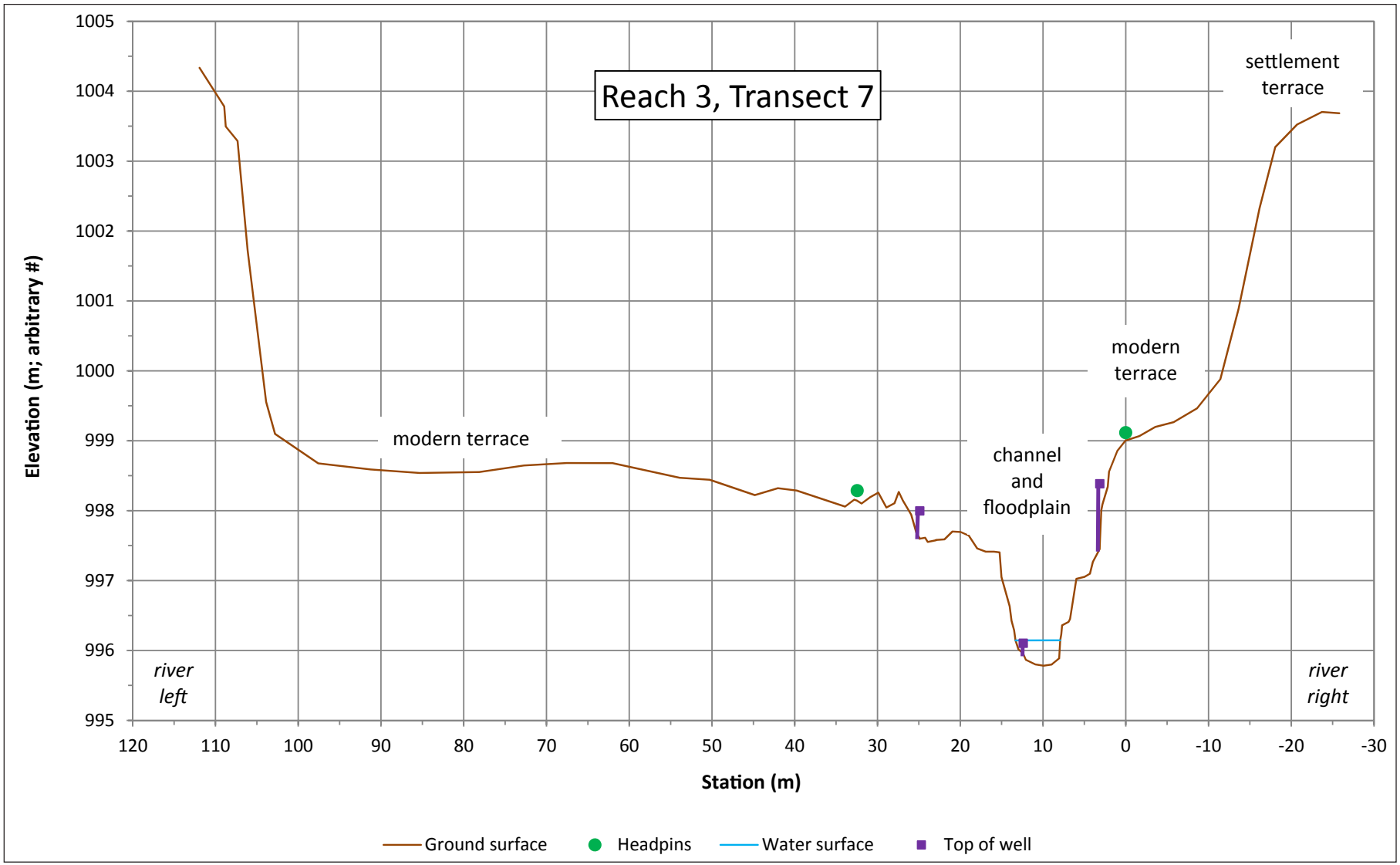


Figure B21. Cross-section of reach 3 at transect 7 looking downstream, East Fork Virgin River, Zion National Park, October 2011.

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

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U.S. Department of the Interior

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