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Effects of a livestock exclosure on channel morphology and vegetation along Long Creek in Lake County, Oregon

ABSTRACT

Livestock grazing in the western United States has lead to riparian ecosystem and stream channel degradation. Establishing fenced-off exclosures is a common management strategy that aims to passively restore these areas, however, relatively few studies have assessed the evolution of exclosed reaches over time. We evaluated temporal trends in channel form and riparian vegetation along a 4.2 km reach of Long Creek (drainage area of 180 km^2), a tributary to Sycan Marsh in western Lake County, Oregon. The Nature Conservancy implemented reduced livestock grazing along this reach in 1996 and complete exclosure in 1999. Based on previous studies that documented vegetation establishment and subsequent sediment accumulation on channel banks, we hypothesized that the channel would have narrowed and vegetation would have re-established after eleven years of cattle exclosure.

In October 2011, we surveyed seven previously-established cross sections and compared channel geometry in 2011 to surveys conducted since 1990. We also took photos at these locations and compared them to historical images. We found no consistent trend in channel morphology, but two cross sections demonstrated narrowing, one of which was likely driven by reduced flow velocity from a downstream beaver dam. Vegetation had successfully established along the streambanks, but in addition to the riparian species, upland lodgepole pines were also abundant along the channel and on the floodplain.

Our results suggest that beavers should be encouraged so their dams will increase overbank flow and discourage the invasion of upland plant species. We also propose improvements in monitoring methods to ensure repeatability of cross-sections over an extended monitoring period.

INTRODUCTION

Almost 50% of the land in the eleven western United States (Montana, Wyoming, Colorado, New Mexico, and states westward) are used for grazing (Lubowski et al. 2006). In these semi-arid states, riparian ecosystems make up only 1% of the land area, but support 70 to 80% of the region's native species (Bunn 2011). For many of the same reasons that native animals prefer riparian ecosystems – water, shade, thermal cover, and quality and variety of vegetation– livestock also demonstrate a strong preference for this environment (Kauffman and Krueger 1984).

The direct physical impacts of livestock on riparian zones include the removal of vegetation from streambanks, prevention of growth of woody seedlings, and bank modification through the chiseling of hooves and the collapse under excess weight (Kondolf 1993). These physical impacts often lead to changes in the morphology of grazed stream channels, often resulting in wide and shallow channels. Trampling of wetland and valley-bottom sediments may also reduce infiltration, increasing runoff and peak flows. Channel morphology directly influences ecological conditions of streams such as water temperature, water velocity, water aeration, nutrient cycling, and substrate conditions (Beschta and Platts 1986, McDowel and Magilligan 1997). Therefore, channel form can be used as an indicator of overall stream health and a measure of restoration success (Kondolf 1993).

The practice of fencing off livestock from riparian areas has become a common management strategy for mitigating stream degradation. These "exclosures" are a form of passive restoration that allows the stream to recover on its own without any human-aided reconstruction (Kondolf 1993).

There are two general approaches to evaluating changes in channel morphology: a time comparison in which measurements are taken before and after a change in management, and a space for time substitution in which measurements taken some period after exclosure establishment are compared with measurements on a similar reach outside the exclosures (McDowel and Magilligan 1997). The former method is superior as it is a direct documentation of the same reach over time, however, the latter is more common because baseline data is not always collected when the exclosures are first established.

A number of studies have assessed the changes in channel morphology due to livestock exclosures. Many of these studies demonstrate increased low-flow depth, pool area, pool depth, and decreased bankfull width and width to depth ratio (McDowel and Magilligan 1997, Nagle and Clifton, 2003). Results on low-flow depth have been less consistent than the other metrics (Clary et al. 1996, McDowel and Magilligan 1997). Generally, the older the exclosure, the more pronounced the morphological changes have been (Kondolf 1993, McDowel and Magilligan 1997).

The main mechanism driving these observed changes in channel form is the re-establishment of vegetation along the banks. Roots provide resistance to erosion, and vegetation slows water velocity, causing sediment deposition. As sediment builds up between the vegetation along the banks, the channel narrows and deepens (Kandolf, 1993, Nagle and Clifton 2003).

The purpose of this study is to document changes in channel morphology following eleven years of livestock exclosure in the Long Creek watershed in western Lake County, Oregon. We evaluated temporal trends in channel form and riparian vegetation of Long Creek to assess the extent to which cattle exclosure can alter physical and ecological systems. We hypothesized that the channel would have narrowed and vegetation would have re-established itself over the eleven years.

STUDY AREA AND METHODS

Long Creek is located in the headwaters of the Klamath Basin at the Great Basin-Klamath Basin border, within the East Cascades/Modoc Plateau Ecoregion (Bienz, unpublished) (Figure 1). The Long Creek watershed is 10713 ha. Maximum elevation of the watershed is on Yamsay Mountain at 2,486m and the lowest elevation is in Sycan Marsh at 1,523m. Average precipitation for the watershed is 69cm per year and the average precipitation where Long Creek enters Sycan Marsh is 49cm. Streamflow is dominated by spring snowmelt. Average base flow at the USFS 27 road is $0.34 m^3/s$ (C.Bienz, The Nature Conservancy, personal communication, October 2011).

Long Creek historically diverged into three channels before entering Sycan Marsh between cross-sections R1S4 and R3S1 (Figure 3). To manage irrigation deliveries, Long Creek water was diverted into the North Fork for irrigation, and the South Fork of Long Creek no longer received flow. In 2008, a change in water rights allowed The Nature Conservancy to rewater the South Fork, which now carries approximately 60% of the Long Creek discharge to Sycan Marsh and substantially reduces the discharge through Reach 4.

Long Creek is the last remaining of three historic bull trout (Salvelinus confluentus) spawning streams within the Sycan Marsh tributaries. Redband trout (Oncorhychus mykiss (Pop.19), Native Miller Lake lamprey (Lampetra minima), tui chub (Siphateles bicolor), endemic Happy (tui) minnow (Siphateles bicolor obesus) and Klamath speckled dace (Rhinichthys osculus klamathensis), and non-native brook trout (Salvelinus fontinalis) are also present. Extensive livestock grazing in the lower reaches of Long Creek occurred during the 1900's, before The Nature Conservancy acquired 9.6 km along Long Creek and implemented passive restoration through decreased livestock grazing in 1995 and total exclusion in 1999 (C.Bienz, The Nature Conservancy, personal communication, October 2011). Historically, riparian and wetland systems in this area did not receive extensive ungulate grazing.

We interviewed Craig Bienz, Director of the Sycan Marsh Preserve, on October 1st, 2011 to gain a historical perspective of management practices and Long Creek conditions prior to our assessment. Craig Bienz provided historical cross-section survey data, stream temperatures, and photos of the study site over time. This data was collected along three study reaches which will be referred to as Reach 1, Reach 3, and Reach 4. Craig's knowledge of the site and wisdom accumulated through the restoration process provided a great introduction and contributed countless insights towards understanding the project.

Cross-Section Surveys

Repeat cross-section surveys quantify aggradation or degradation as well as channel migration and narrowing or widening. The Nature Conservancy established monuments (steel rebar posts in the ground) and surveyed twelve cross-sections of the mainstem Long Creek and adjacent floodplains in 1990, prior to cattle exclosure. Nature Conservancy volunteers and staff repeated some of the cross section surveys in 1996, 2002, and 2003 (Table1). In October 2011, we resurveyed relative position and elevation along seven of the cross-sections established in 1990 (Figure 3). Additional cross sections were not used due to problems locating historical data, trouble finding cross sections, and time constraints. The surveys were conducted during base flow ($0.51 m^3/s$) using an autolevel, tripod, rod, and survey tape.

Ideally, survey monuments are immobile points and are far enough from the channel so that channel erosion or deposition will not remove or obscure the monuments. Unfortunately, the previous surveys along Long Creek used the ground surface next to rebar monuments as the fixed reference points. This method introduces some uncertainty because the ground surface elevation may change over time and may vary on different sides of the rebar. For example, a substantial change such as 20 cm of aggradation across the floodplain, channel, and banks would not be detected because there would be no relative change between floodplain and channel elevations. During our visit in 2011, no evidence of recent deposition was observed near any monuments except Reach 1 Section 4. Ultimately, Reach 1 Section 4 was not included in our analysis because of this uncertainty, and uncertainty regarding the monument locations that were apparently moved prior to 2011. Additionally, our survey of Reach 1 Section 2 was not included in our analysis because data from prior surveys could not be located. Although not surveyed in 2011, we include results from an additional cross section (Reach 3, Section 3) because historical data were available.

Photographic Monitoring

The Nature Conservancy completed photomonitoring at all seven of the repeated cross-sections in 1990, 1996, 2003, and 2008 to track vegetation re-establishment following livestock exclosure. They took photos of the right bank, left bank, upstream, and downstream orientations. With the previous photos in hand, we re-photographed each orientation at the seven cross-section locations to see if a change in vegetation structure was evident along Long Creek channel banks over the eleven years of livestock exclosure.

RESULTS

Cross Section Surveys

Of the six cross sections evaluated in this study, four had measurable channel change. The channel at Reach 3 Section 3 and Reach 4 Section 2 demonstrated widening and incision. At Reach 3 Section 3, the channel incised 0.1m between 1990 and 1996 (Figure 4). From 1996 to 2002 the channel downcut another 0.1m, and the right bank eroded 0.8m. In all, Reach 3 Section 3 downcut 0.2m and widened by 0.8m from 1990 to 2002. Reach 4 Section 2 incised 0.1m from 1990 to 1996 and has not incised or aggraded since 1996 (Figure 5). The right bank has not changed; the left bank retreated 0.4m from 1990 to 2002 and an additional 0.9m from 2002 to 2011. In all, the channel at Reach 4 Section 2 downcut 0.1m (10% change) and widened 1.4m (10% change).

By contrast, the channel at Reach 3 Section 1 and Reach 4 Section 3 narrowed over the monitoring period. At Reach 3 Section 1 the channel narrowed from 7.6m to 7.1m (10% change) from 1996 to 2011 (Figure 7), but bed elevation and channel depth remained the same. The channel of Reach 4 Section 3 progressively narrowed, aggraded, and deepened as a result of sediment deposition in the channel and on the floodplain from 1990 to 2011 (Figure 6). In 1990 the Reach 4 Section 3 channel was 7.2m wide and 0.4m deep. By 2011 the channel had deepened to 0.7m (75% change) and narrowed to 6.5m (10% change).A beaver dam is now present just downstream of cross section Reach 4 Section 3. The pond extends up to the cross section.

The other two sections included in this analysis did not have any measurable change. Reach 1 Section1 had no channel change between surveys in 1990 and 2011 (Figure 8). Reach 1 Section 3 had no channel change between surveys in 2003 and 2011 (Figure 9).

Photographic Monitoring

The extent of riparian vegetation from 1990 (nine years before livestock exclosure) to 2011 (eleven years after livestock exclusion) increased substantially within all sampled reaches. Photomonitoring shows a significant increase in riparian vegetation from 1990 to 1996, a period when there were changes in the timing and intensity of cattle grazing. During this period, riparian vegetation became established along the streambank. Then from 1996 to 2003 willow density increased. At cross-section Reach 1 Section 1, the channel banks in 1990 were heavily grazed with evidence of cattle chiseling along the outer banks. Vegetation was consumed down to stubble grasses (Figure 10). In contrast, the 2011 photos show a marked increase in native riparian willows and upland conifers along the channel banks. Photopoints taken at cross-sections Reach 1 Section 2, Reach 1 Section 3, Reach 3 Section1, and Reach 4 Section 3 illustrate a similar trend of dense riparian and upland species establishing along both stream banks (Figure 11-15). At many cross-section locations, the floodplain is visible from across the channel for approximately 120 feet in 1990 before willows, alders, and lodgepole pines (Pinus contorta) line the channel banks in 2011. The rapid encroachment of lodgepole pines is most notably shown at cross-section R1S3 from 1991 to 2003 (Figure 16).

DISCUSSION

Channel Morphology

In this study we found no consistent trend in channel morphology. Although channel narrowing was the expected result based on previous literature, there may be several reasons why we did not observe this consistently. Most importantly, the exclosure is only eleven years old. Older exclosures often demonstrate more pronounced morphological changes than younger exclosures (Kondolf 1993, McDowel and Magilligan 1997). Stream reaches that had been exclosed from livestock for 68 (Platts 1981) and 48 (Clifton 1989) years demonstrated significant narrowing and decrease in width to depth ratio, whereas a reach that was exclosed for 24 years did not narrow significantly (Kondolf, 1993). On the other hand, some reaches showed signs of narrowing just a few years after being exclosed (McDowel and Magilligan 1997). Therefore, although the literature demonstrates a general trend toward channel narrowing after a reach has been exclosed from livestock, channel morphology seems very much dependent on local conditions in the first 25 years and it can take close to 50 years for channels to show significant narrowing.

Moreover, we do not know the extent to which the channel had been widened by cattle. Photos from 1990 indicate near-barren and eroding banks, but we do not know the rate of erosion or how much widening there had been.

Geomorphically effective flows and adequate sediment load are both necessary for the channel to narrow. If suspended sediment concentrations are small, narrowing may be a very slow process. Substantial narrowing was observed at Reach 4 Section 3, however. This cross section was located just upstream of a beaver dam (Figure 17). The beaver dam decreases the flow velocity which provides the opportunity for sediment deposition along the banks (Butler and Malanson, 1995). The fact that we observed a significant build up of sediment on the right bank of this cross section could be evidence that there is an adequate supply of sediment for channel narrowing to occur.

It is important to note that logging and grazing occur in upstream parts of the watershed. Upstream logging and grazing can increase both runoff and sediment yields (Bilotta et al.2007, Blackburn 1983, Chin 2006, Meehan and Platts 1978). The smaller the exclosed area is, relative to grazed area, the more likely it is that modified flow and sediment regimes will affect the restored reach (Kondolf 1993). As the Nature Conservancy's exclosure is only 4.45km^2, while the grazed area of the Long Creek watershed is 107km^2, upstream impacts may play a significant role in Long Creek's channel morphology. Increased runoff may lead to a widened or incised channel depending on bed armoring and relative resistance to erosion of bed and bank material (Schumm 1969; Simon and Castro 2005); or, increased fine sediment yield could lead to channel narrowing by providing abundant material to be trapped by bank vegetation. For small streams, such as Long Creek, the direct physical impact of livestock on the channel banks is likely to have a more dominant effect than the erosive forces from increased flow. Thus, "if the banks are vegetated and free from physical impact of livestock hooves, small streams can be expected to narrow eventually to something approaching their overbank width" (Kondolf 1993). An analysis of flow and sediment transport may provide insight into the rate at which narrowing will occur and is recommended for further study.

Decreased streamflow through Reach 4 Section 3 could also have contributed to channel narrowing. In 2008, water diversion into Reach 4 from the South Fork of Long Creek ceased, leading to a 60% decrease in discharge (C. Bienz, The Nature Conservancy, personnel communication, October 2011). As a result, erosion of the channel walls that leads to channel widening was reduced (Lane 1955, Schumm 1969). The fact that we observed no narrowing at Reach 4 Section 2 is perplexing and suggests a more thorough understanding of the watershed processes is required to understand changes in channel morphology.

Riparian Vegetation

Vegetation response was evident in all sampled reaches of Long Creek. Prior to exclosure, livestock used Long Creek's riparian corridor for succulent forage and drinking water, which depleted natural riparian vegetation and likely led to eroded channel banks. The 21-year record of photopoints clearly illustrates dense growth of low-lying riparian vegetation including re-establishment of willow and alder after livestock were removed. This finding is supported by previous studies that have shown plant recovery after livestock exclosures (Schulz, 1990).

In addition to riparian species, lodgepole pine has also established and spread rapidly on the valley bottom along Long Creek following livestock exclosure (Figure 10). Lodgepole pine is an upland tree that is commonly established in wetland and valley-bottom floodplains in response to channel incision, beaver extirpation, drought, water diversion, or earlier snowmelt, which effectively cause the drier conditions favorable to upland species (Loheide et al. 2009, Rubin et al. 2011). Livestock exclosure also facilitates establishment of lodgepole because cattle prevent seedling establishment through trampling and browsing (Eissenstat et al. 1982). Water consumption by lodgepole may lead to drier conditions, causing a positive feedback of additional lodgepole establishment, and may ultimately direct the ecosystem towards a different trajectory.

Previous studies conducted by The Nature Conservancy also indicated that the historical fire frequency was on a seven to twelve year interval, possibly preventing succession to forest ecosystem. The floodplain has been suppressed from the influence of fire for at least the last 100 years (C.Bienz, personnel communication, October 1, 2011). The Conservancy is planning to harvest lodgepole pine from the riparian area in the winter of 2011. This silvicultural prescription will be followed with prescribed fire in the fall of 2012 (C.Bienz, personnel communication, October 1, 2011). However, lodgepole pine is an aggressive pioneer species that establishes quickly on burned landscapes (Brown 1975). We therefore recommend a lodgepole management strategy that includes consideration of soil moisture, since lodgepole do not tolerate saturated conditions.

How one manages for ecological targets is somewhat beyond the scope of this project however, we would recommend including beavers as part of an adaptive management strategy for controlling lodgepole pine and recovering the hydrologic dynamic that likely existed prior to grazing. Prior to trapping and disruption of riparian vegetation by cattle, beaver populations were likely much higher than the few that are present today (Wohl, 2001). Beaver have a symbiotic relationship with the physical and biological dynamics of valley bottoms. By raising the water table and encouraging fine sediment deposition, beaver prohibit upland species growth (such as lodgepole pine), and promote the growth of willow and alder- species upon which they rely (Westbrook et al., 2006). In some cases, artificial beaver dams have been constructed as a method for raising the water table and promoting willow growth as a precursor to beaver introduction. Beaver are present, though in small numbers, in Long Creek, and we recommend monitoring and promoting the plants and habitat needs of beaver as part of the ongoing lodgepole pine management.

Monitoring Challenges

Monitoring of channel morphology and vegetation change in Long Creek has occurred over a 21-year period. Data collection over such a lengthy duration presents many challenges. First of all, it is often carried out by multiple people. Therefore, it is crucial to organize data so that the results and methods are transparent to future researchers. Otherwise past data sets may be incomprehensible and valuable monitoring results no longer useful. Also, as mentioned, when conducting measurements of cross-sectional data, it is important to ensure the permanence of survey monuments and to set survey monuments away from existing channel banks with sufficient distance to anticipate any future channel migration. The orientation (compass bearing) of the cross-sectional location across the channel should also be noted as dense vegetation overtime can obstruct relocation. The photomonitoring points tracked fairly well over the years, but it again is important to have a compass bearing of each photo from a known location. Cross-sectional photos were generally taken standing at the survey monuments. This position is helpful during the first few years before dense vegetation is established, but once vegetation establishes, channel conditions are less visible.

CONCLUSION

Establishing fenced-off exclosures is a common management strategy that aims to restore degraded channels with less cost, planning, and disturbance then active restoration strategies. This study sought to determine the effects of a long-term livestock exclosure along Long Creek, Oregon by evaluating temporal trends in channel form and riparian vegetation.

Channel morphology varied among the sampled reaches and only narrowed at two of six sections, one of which occurred just upstream of a beaver dam. Vegetation quickly established even before cattle were completely excluded, and the riparian corridor became densely filled with willow, alders, and lodgepole pine. Even though we expected a greater response in channel narrowing, riparian vegetation and decreased livestock trampling are beneficial to the system. We expect that channel narrowing may still occur in coming years as vegetation thickens and beavers further colonize the reach.

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TABLES

Table 1. Summary of available data from Long Creek Cross Sections

Sites	1990	1996	2002	2003	2010	2011
Reach1						
R1S1	X		X			X
R1S3				X		X
Reach3						
R3S1	unused	X	X			
R3S3	X	X	X			X
Reach4						
R4S2	X	X	X			X
R4S3	X	X	X			X

FIGURES

Figure 1. Location of Long Creek within the Klamath Basin.

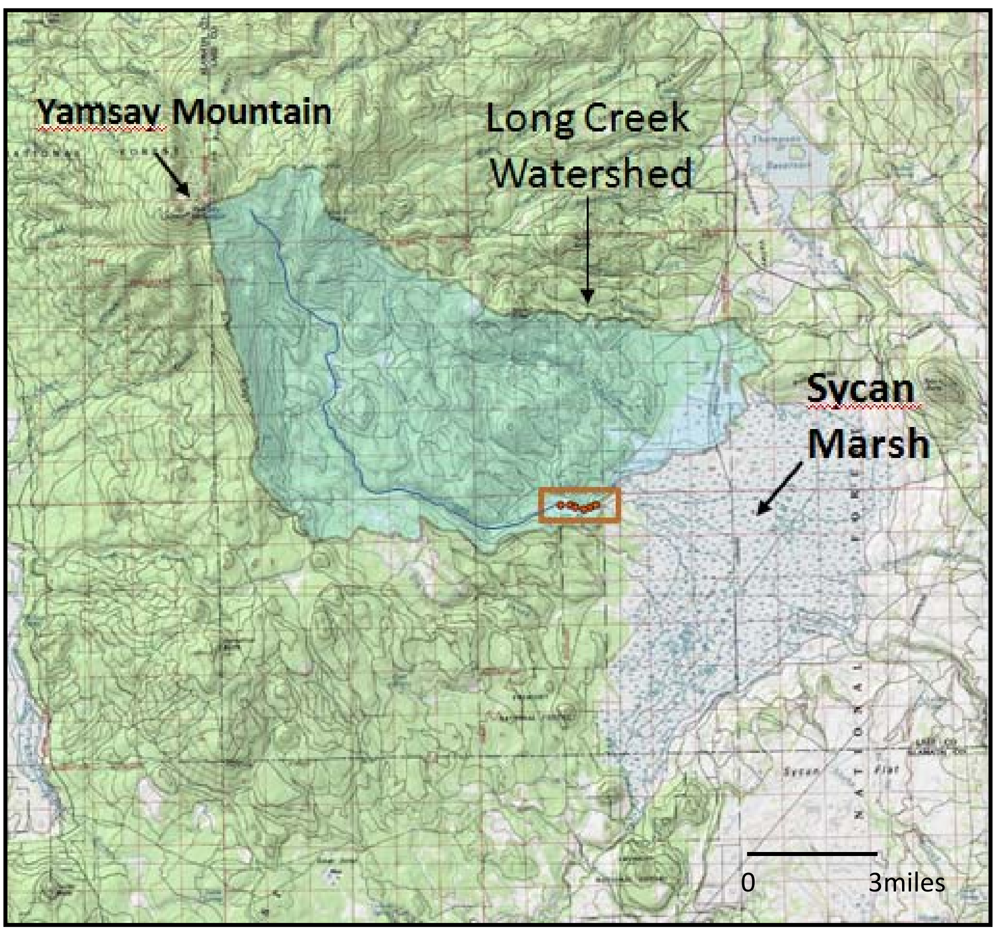
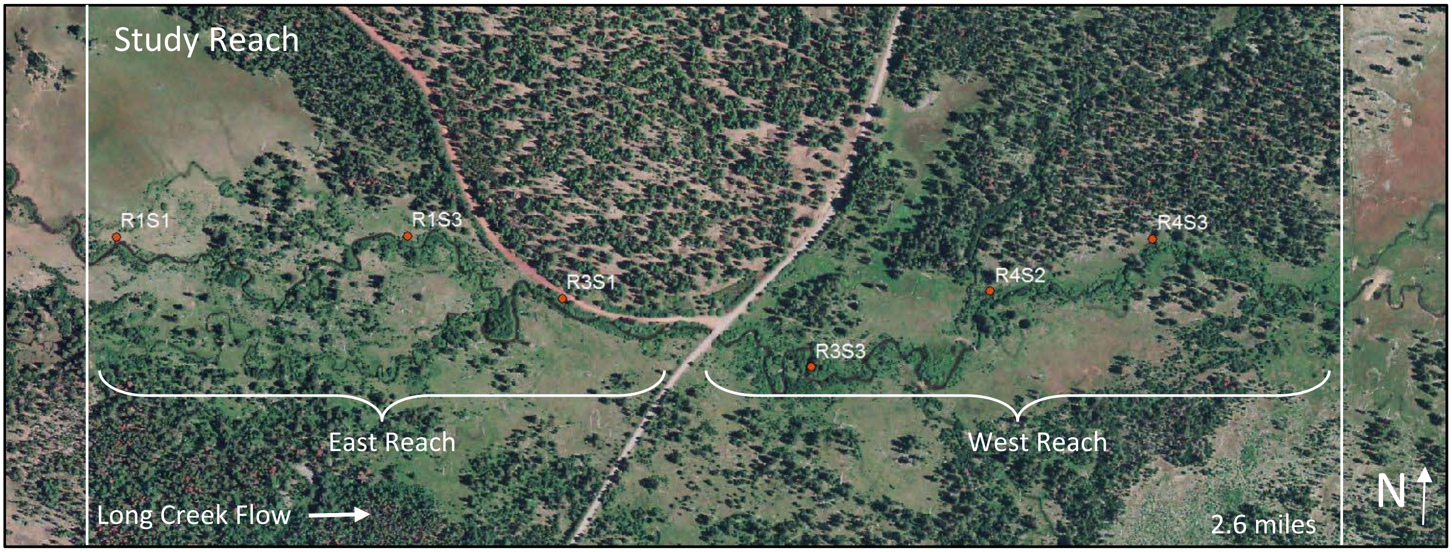


Figure 2. Local Long Creek watershed with respect to Yamsay Mountain and Sycan Marsh.



Photomonitoring and cross-section locations

East Reach

West Reach

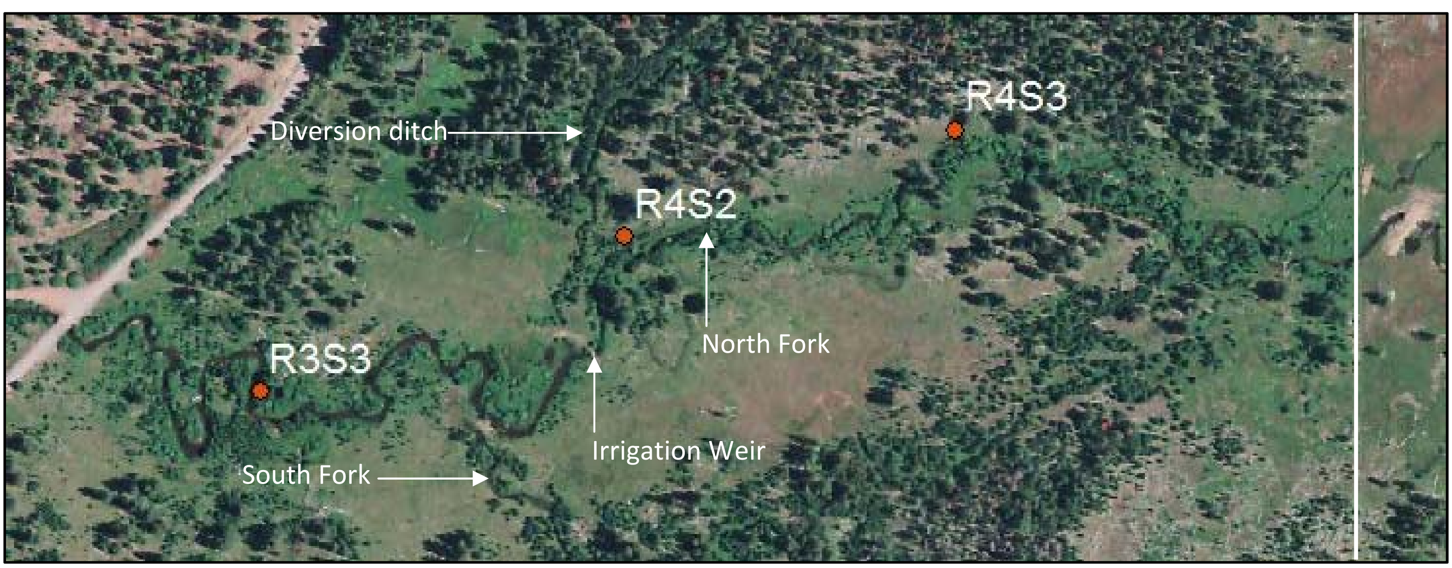


Figure 3. Location of cross-section surveys and photomonitoring along Long Creek.

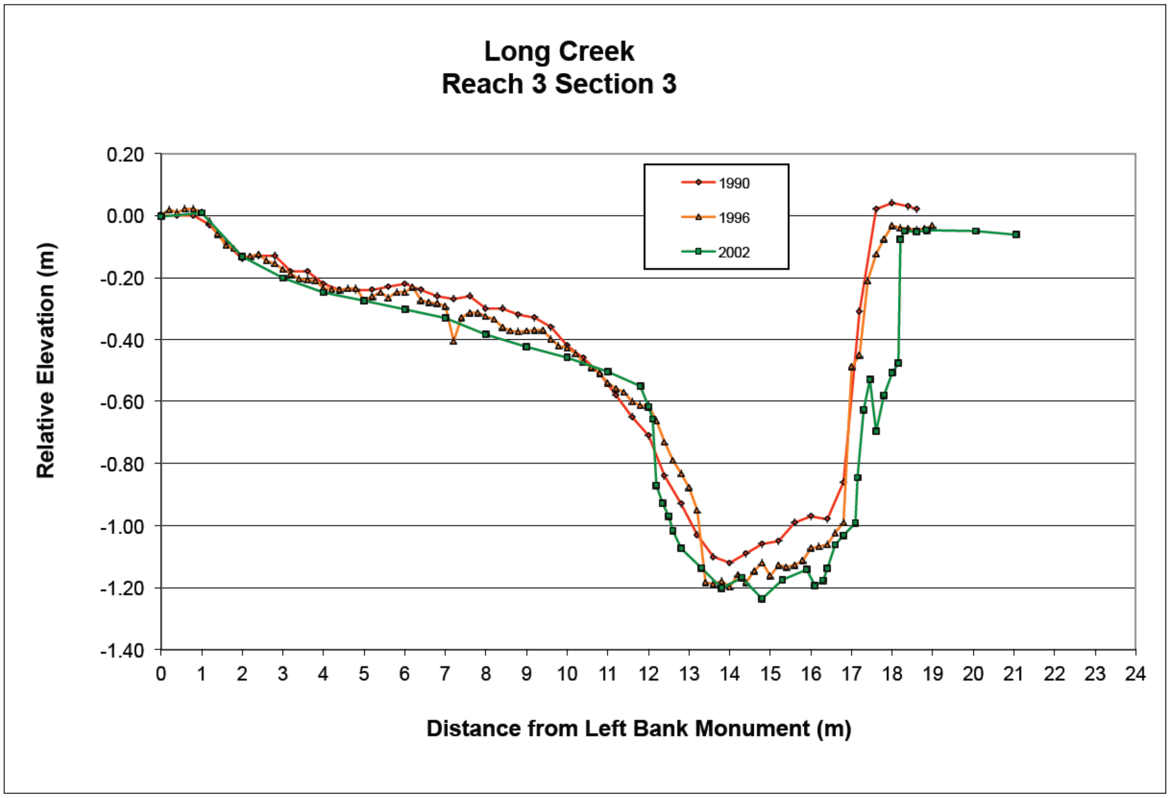


Figure 4. Reach 3 Section 3 incised ~ 0.2m and widened by ~ 0.8m from 1990 to 2002. It was not surveyed in 2011.

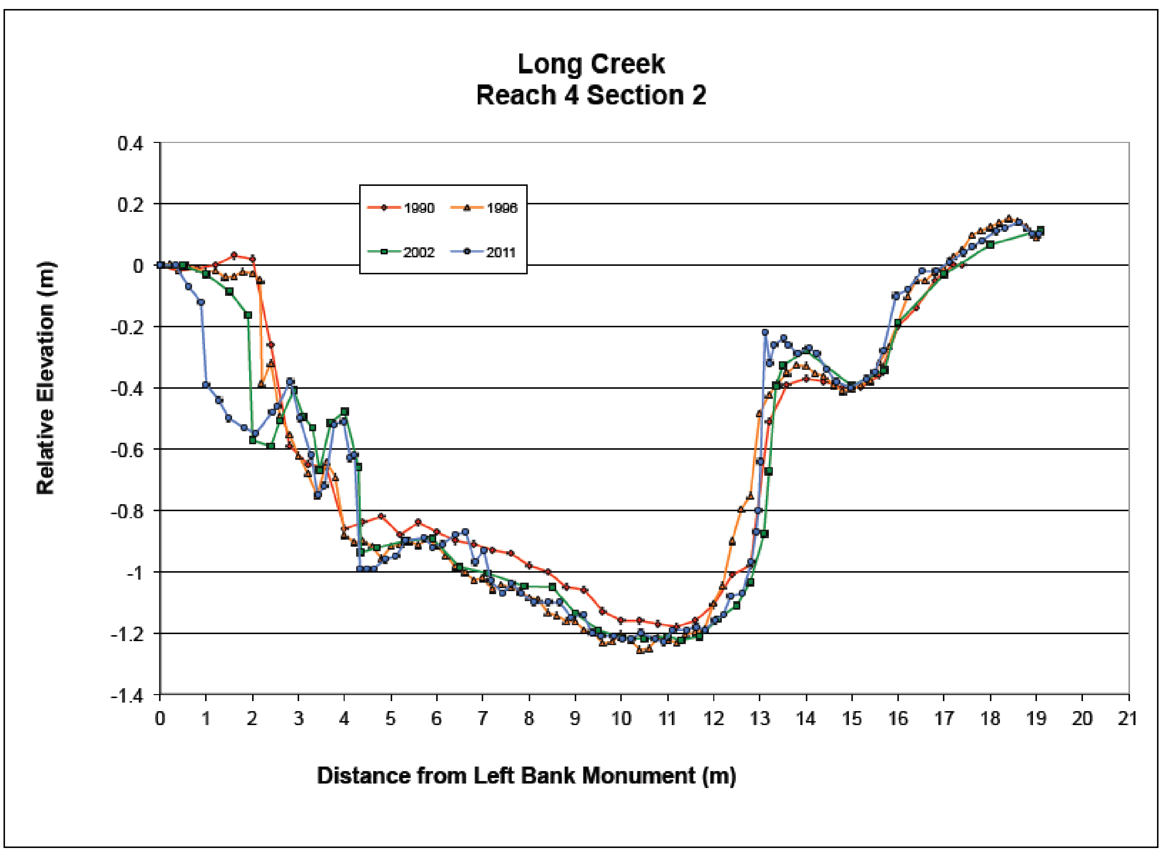


Figure 5. Reach 4 Section 2 incised ~ 0.1m (10% change) and widened ~1.4m (10% change). Surveys were conducted in 1990, 1996, 2002, and 2011.

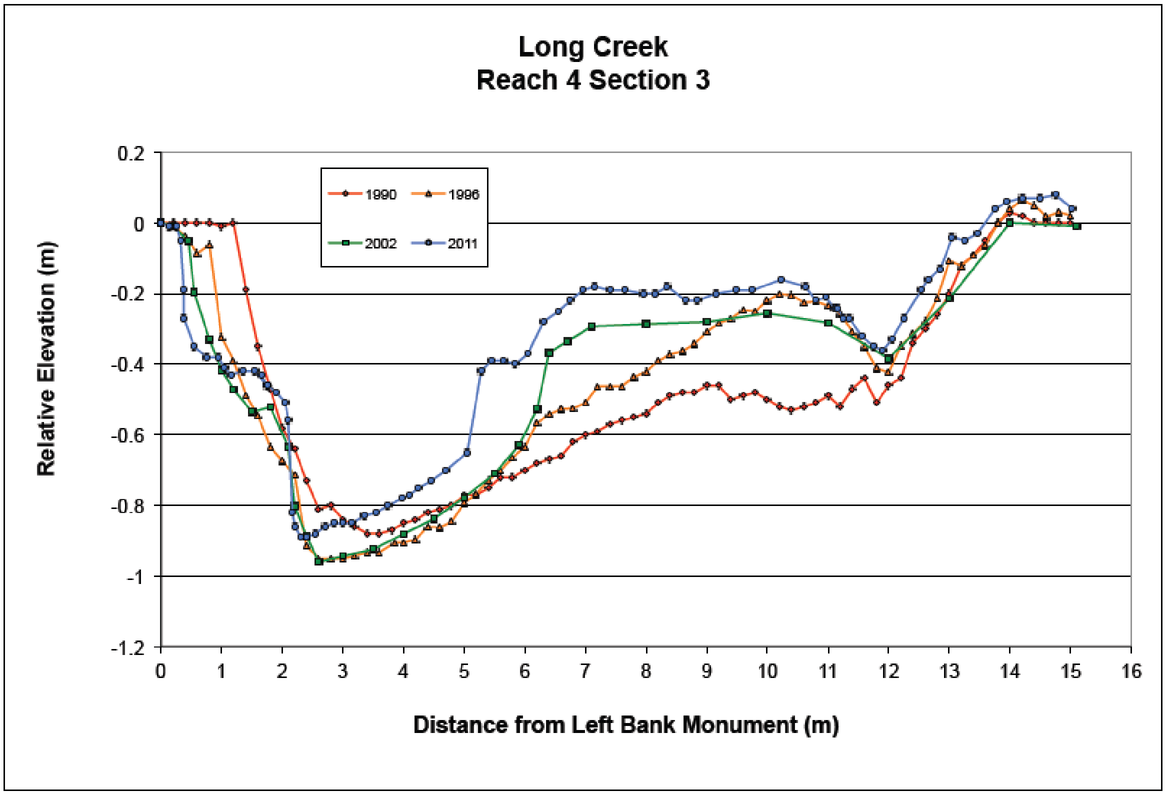


Figure 6. Reach 4 Section 3 exhibited the most substantial change. By 2011 the channel had deepened to ~0.7m (75% change) and narrowed to ~6.5m (10% change). A beaver dam, now present just downstream of the cross section, is the likely cause of the channel change.

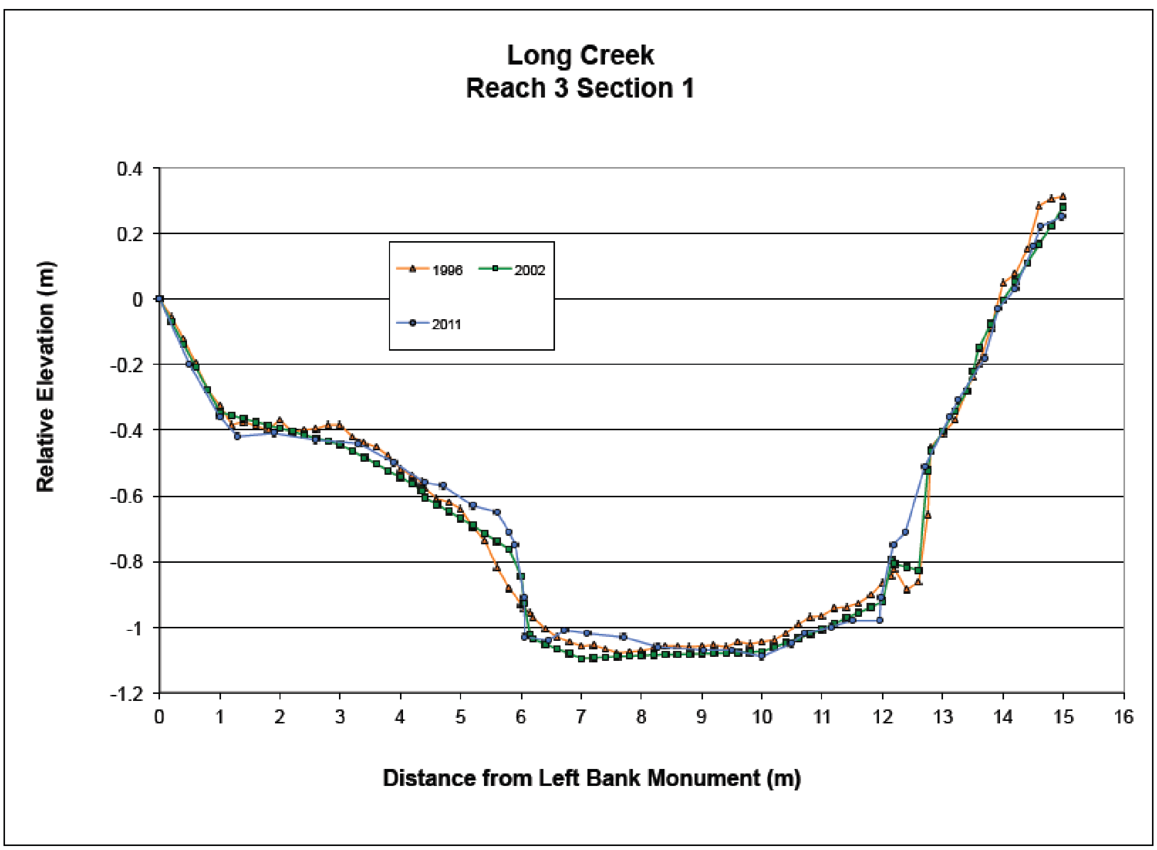


Figure 7. The low-flow channel of Reach 3 Section 1 narrowed slightly from 7.6m to 7.1m (10% change) from 1996 to 2011. There was no change in bed elevation or channel depth during the monitoring period.

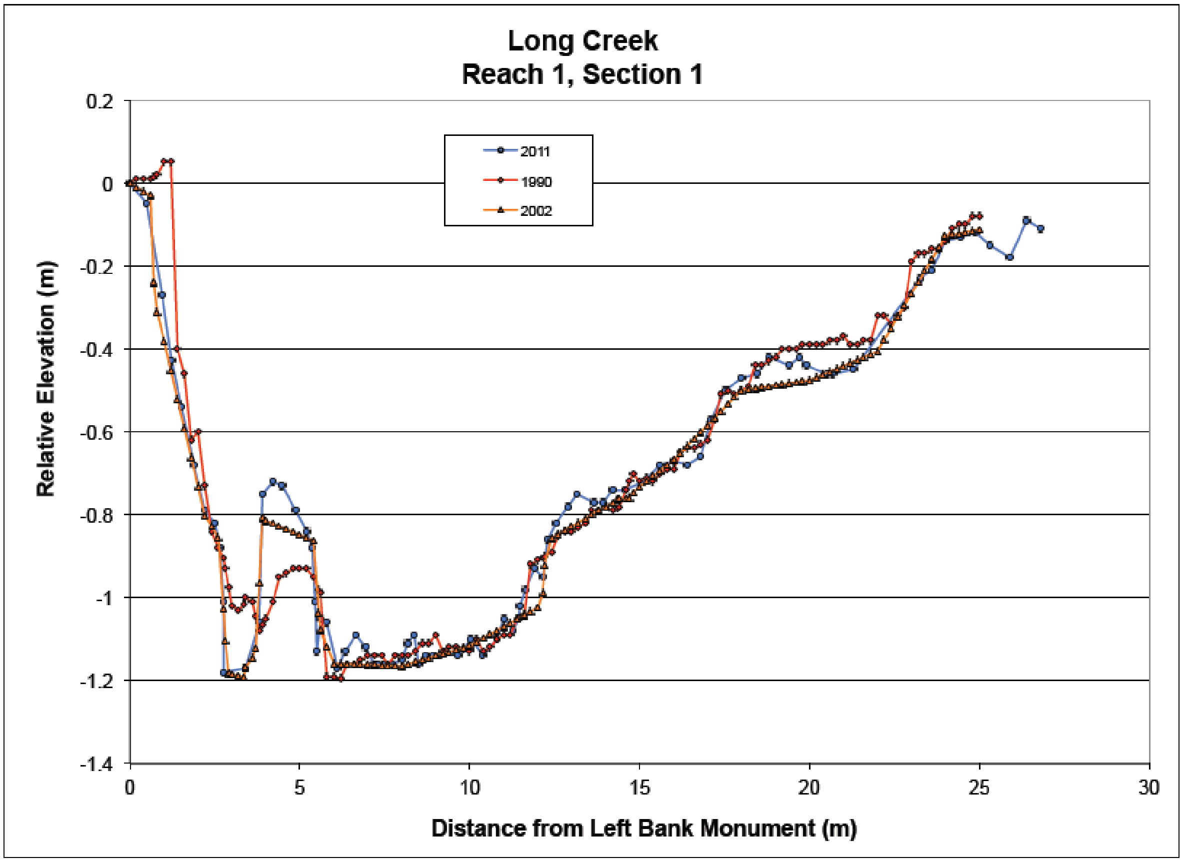


Figure 8. Reach 1 Section1 had no channel change between surveys in 1990 and 2011.

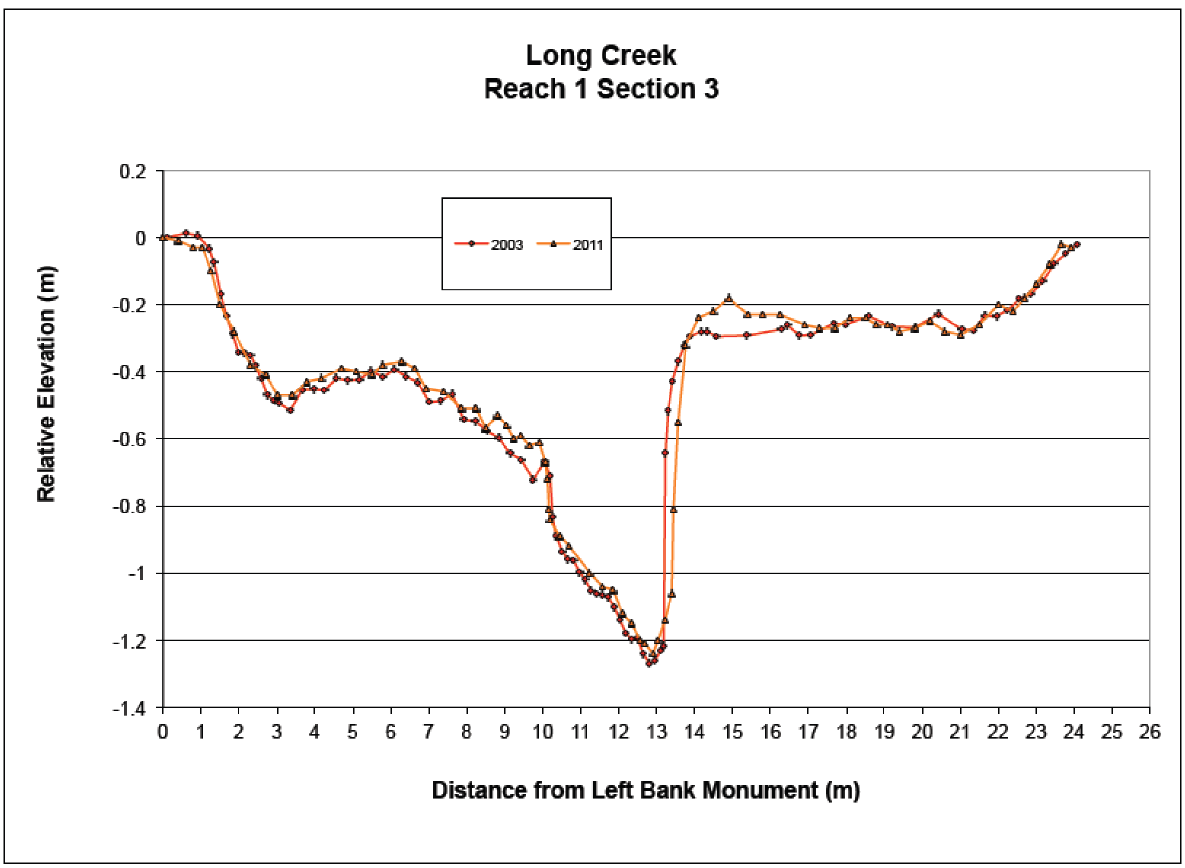


Figure 9.Reach 1 Section 3 had no channel change between surveys in 2003 and 2011.

a) Facing West, Downstream

b) Facing East, Upstream

Figure 11. Photopoints at cross-section R1S1 in 1990 and 2011, respectively.

a) Facing South, Right Bank

Figure 12. Photopoints at cross-section R1S2 in 1990 and 2011, respectively.

a) Facing West, Downstream

Figure 13. Photopoints at cross-section R1S3 in 1990 and 2011, respectively.

a) Facing West, Downstream

b) Facing East, Upstream

Figure 14. Photopoints at cross-section R3S1 in 1990 and 2011, respectively.

a) Facing South, Right Bank

Figure 15. Photopoints at cross-section R4S3 in 1900 and 2011, respectively.

a) Facing South, Right Bank

Figure 16. Historical photopoints at cross-section R1S3 in 1991 and 2003, respectively.

a) 

b) 

Figure 17. a) Beaver dam just downstream of R4S3. b) The resulting pond that extends upstream of cross section R4S3.