Title
Road-crossing restoration on alluvial creeks in the Klamath National Forest, California

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Publication Date
2008-12-16

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Term Project for Restoration of Rivers and Streams – LD ARCH 227

FINAL DRAFT

December 16, 2008

Prepared By

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Abstract

In mountainous terrain, road-crossings may impair creeks by impeding fish passage, increasing sediment delivery to stream channels, and altering surface and subsurface flow paths. The objectives of this study were to quantify the short-term impacts of 6 road-crossing re-construction projects on alluvial creeks in the Klamath National Forest of California. I used a Before-After-Control-Impact study design with 1 set of data pre-construction, 1 set of data immediately following construction, and 2 sets of data over the following 2 yr. The data included measures of fine-sediment deposition, grain-size, longitudinal-profiles, cross-sections, and benthic macroinvertebrates. This study found little impact on fine-sediment deposition or grain-size. The majority of longitudinal-profiles and cross-sections tended to incise upstream in response to culvert replacement, but the responses were largely site-specific. Furthermore, most morphological changes in slope and bed elevation were minimal. Most of the commonly used biological metrics did not show significant changes, but I observed significant changes ($P = 0.005$) in the populations of 3 orders of insects (Ephemeroptera, Plecoptera and Trichoptera) that are often used as indicators of disturbance and are a primary salmonid food source. This study upholds Best Management Practices as an effective technique for salmonid habitat restoration.

Introduction

In California, restoration funds are often earmarked for salmonid habitat improvement, including measures to reduce fine sediment, enhance salmonid food sources, and remove structures that block the upstream migration of salmonids. For example, the federal government has spent billions of dollars on salmonid restoration projects in California (CALFED, 2000). Furthermore, much of this money has been spent on road-crossing improvement projects.

Road-crossings may impair fish passage (e.g., Furniss et al. 1991), intensify sediment delivery to creeks (e.g., Reid and Dunne 1984), and reroute surface and subsurface flow paths (e.g., Wemple et al. 1996). For example, Warren and Pardew (1998) observed fish passage to be an order of magnitude lower through culverts than through other crossings or natural reaches. Fortunately, state and federal agencies are taking steps, such as replacing undersized culverts, to minimize the effects of road-crossings on creeks and the aquatic organisms that live therein.

The Best Management Practices (BMPs) of the U.S. National Forest Service have provisions to improve native salmonid habitat by replacing undersized culverts (Luce et al. 2001, Madej, 2001) and to reduce the risk of catastrophic failures by reducing the volume of fill-material. In the BMP process, forest service personnel must obtain quotes from multiple contractors and select the most cost-effective contract that meets the ecological objectives. Although the intentions of the BMPs are notable, their effectiveness has not been sufficiently evaluated (Ice et al., 2004), and possible short-term impacts of the BMPs remain unclear.

Short-term impacts of road-crossing reconstruction that appear in the construction phase or in the first years after construction may include changes in sediment delivery, grain-size of bed material, bed-grade, channel-shape, and biota (Ice et al., 2004). For example, in the construction phase, fill-material excavation and bank re-contouring may release sediment directly into the stream and thereby induce fine-sediment deposition. In the first years after construction, surface erosion and mass wasting of the remaining or newly placed fill-material may deliver sediment and thereby harm fish and their primary food source, aquatic invertebrates. In addition, channel adjustments over time may release sediment from the channel bed and banks upstream or downstream of road-crossings in response to alterations in gradient and confinement.

In the Klamath National Forest, salmonids are a primary driver of restoration because they have cultural value to the Native Americans and because their populations are threatened. For example, Chinook salmon (*O. tshawytscha*) are absent from more than 70% of their potential range (Thurow et al., 1998). When sediment supply increases in this region, the fine-sediment in riffles and pools increases and sub-surface spawning gravel permeability decreases (Cover et al. 2008). These increases in fine-sediment may degrade salmonid habitat in creeks because egg survivorship is related to the permeability of the sediments in which the salmonids build redds.

The objectives of this study were to (1) monitor potential short-term impacts of road-crossing re-construction under Best Management Practices in the Klamath National Forest and to (2) evaluate the significance of these impacts. For example, we evaluated if road crossing re-constructions significantly impacted fine-sediment deposition over 2 yr following construction. We also evaluated changes in channel-morphology and benthic macroinvertebrate communities.

Methods

Study site

The study site was the Klamath National Forest, which is located in Siskiyou County in northern California. This site covers an area of 1.7 million acres and includes 388 miles of waterways. The study focused on 6 creeks (Figure 1) – Cecil Creek (CEC), upper Boulder Creek (UBO), upper Elk Creek (ULK), Bishop Creek (BIS), lower Boulder Creek (LBO), and Stanza Creek (STA) – with culverts replaced in either 2004 or 2005 (Figure 3). The largest annual flood during the study occurred in 2006 with an 11 yr recurrence interval, followed by a 2 yr flood in 2004, and 1 yr floods in 2005 and 2007. Thus, 2006 was the only year with relatively high flows.

The first 4 creeks listed above were reconstructed by contractors in summer 2004, and the last two in summer 2005 (Figure 2). At each site, consultants established 5 cross-sections downstream of the road-crossings and 7 upstream of the crossings to monitor short-term changes in fine-sediment, grain-size distributions, channel-shape, and aquatic invertebrate communities. The consultants delivered the raw data to UC Berkeley researchers to prepare the final report.

Study design

I used a Before-After-Control-Impact study design (e.g., Smith et al. 2003). The data included 1 set of monitoring in the weeks or months just before construction, 1 set in the summer just after construction, and 1 set in each of the following 2 summers. The control was the reach directly upstream of the road crossings and the impact was the reach directly downstream. In addition, in-stream traps were installed in the stream-bed to monitor invertebrate colonization upstream and downstream of the road-crossings over the first yr after construction (Figure 4).

I. Analysis of fine-sediment

I defined fine-sediment for this study as particles with diameters less than 4mm. Because construction began at different times, the labels Y0, Y1 and Y2 refer to different water years. The consultants recorded the presence or absence of fine-sediment at each of the 210 grid-crossing points of a 9ft x 4ft net with a 5in grid. I consulted facies maps to determine if the cross-sections were significantly stratified geomorphically (e.g., Figure 5), and finding they were not, I aggregated the fine-sediment data from the 4 uppermost cross-sections upstream of the road crossings (labeled XU4-XU7), and the 4 lower-most downstream of the crossings (XD2-XD5). I then calculated the percent of intersections at which the consultants observed fine-sediment. To test for significant differences in fine-sediment before construction (Y0), 1 yr after construction

(Y1), and 2 yr (Y2) after construction, I ran an analysis of variance (ANOVA) on the differences in percent fine-sediment between the control and impact reaches among the 6 creek sites.

II. Analysis of grain size

The consultants measured grain-size distributions using Wolman pebble counts (Wolman 1954), counting about 100 pebbles at each of 4 cross-sections upstream, and 4 downstream, of the road-crossings. I aggregated this data into upstream and downstream bins to estimate the median grain-size (D_{50}), the grain-size class for which 16% of the particles are smaller (D_{16}), and the grain-size class for which 84% of the particles are smaller (D_{84}). The D_{50} is useful in bedload transport calculations, and the D_{16} and D_{84} are useful in salmonid habitat evaluations (Kondolf 2000). Lastly, I ran a t-test to compare the median grain-sizes measured in the 6 creeks before culvert replacement with the median grain-sizes measured in the creeks after culvert replacement.

III. Analysis of channel-form

I used longitudinal-profiles and cross-sections to examine patterns in channel aggradation and incision. For example, I used linear-regression as a tool to analyze the longitudinal-profiles. An increase in the y-intercept of the trend-line through the longitudinal-profile would indicate aggradation and a decrease would indicate incision (Figure 6). Further, change from a lower to a higher magnitude slope in the trend-line would indicate that the channel is steepening (Figure 7).

I standardized the longitudinal-profiles by setting the elevation at the point where each longitudinal-profile crossed the second upstream cross-section (XU2) in each yr to be equal to the measured elevation of the thalwag[1] at XU2. Because distances along the longitudinal-profiles varied from yr to yr with the lengths of the thalwags, I used linear-interpolation to line up the distances with the cross-sections each year, which were marked with permanent monuments.

[1] The thalwag refers to the deepest point in the channel.

Lastly, I plotted a series of cross-sections to explore channel shape. For example, the cross-sections can show changes in thalwag elevations, and widening or narrowing of the channel. For all of the channel-form analyses, I did not perform any statistical analyses.

IV. Benthic Macroinvertebrate Sampling

Insects were identified from the macroinvertebrate colonization traps to the taxonomic level of family. Other macroinvertebrates were identified to either family (gastropods, crayfish, amphipods), class (segmented worms), or order (ostracods, water mites). The identifications were made using taxonomic keys in Merritt et al. (2007) and Thorp & Covich (2001).

To evaluate the condition of benthic assemblages, I calculated 3 metrics of diversity and 3 metrics of pollution-tolerance that are commonly used in stream bioassessment (e.g., Jackson & Resh, 1993). The diversity metrics included taxa richness, Shannon diversity index, and % dominant taxon. The pollution tolerance metrics included % EPT taxa and % EPT individuals, which tracks disturbance-sensitive families of mayflies, stoneflies and caddisflies. The pollution-tolerance metrics also included the Hilsenhoff Biotic Index, which is a score based on the pollution-tolerance of each taxon. I used a paired t-test to check for significant differences between the metrics of samples taken from traps upstream and downstream of the roads.

Results

The culvert replacements achieved the long-term goals of removing barriers to upstream salmonid migration and reducing the risk of catastrophic failures. For example, the median drop at the end of culverts before the replacements was 1.5 m (Table 1) and a drop of this size is impassible for most juvenile salmonid species (Table 2). This drop was smoothed-out in all the creeks as a result of the re-constructions. In addition, the fill volume was reduced by more than half in the majority of the creeks (Figure 8), thereby reducing the risk of catastrophic failure.

I. Deposition of fine sediment

Although fine-sediment levels in several creeks (e.g., Upper Elk and Lower Boulder) were much higher in the 1 yr after construction (Figure 9), I found no significant difference between control and impact (with $\alpha = 0.05$) in the percent of the creek beds covered by fine-sediment when accounting for all 6 creeks before and after construction (Prob>F = 0.30). The difference between the yr before construction and the yr after construction was not significant ($p = 0.13$), nor were the differences between the yr prior to construction and the 2 yr after construction ($p = 0.54$), and the 1 yr after construction and the 2 yr after construction ($p = 0.35$).

Because construction did not start in the same year on all 6 creeks (Figure 2) the hydrologic regime was potentially a significant confounding factor, but it probably was not significant because the largest flood in 2005 was very small. If most fine-sediment movement during the study occurred during the same floods in all 6 creeks, I would expect the hydrologic regime to be a significant factor. The largest changes in fine sediment between upstream and downstream occurred from 2004-2005 in Bishop Creek (9.8%) and Upper Elk Creek (25.3%), 2005-2006 in Cecil Creek (8.2%), Lower Boulder Creek (0.96%) and Upper Boulder Creek (8.7%), and 2006-2007 in Stanza Creek (13.7%). These changes coincided with different floods.

II. Grain size distribution

By the 2 yr after construction the D_{50} had increased upstream in 67% of the creeks and downstream in 84% of the creeks (Table 3). The D_{16} remained nearly constant over time in all 6 creeks. The D_{84} increased upstream of the culverts in all 6 creeks and downstream in 2 of the creeks. However, none of these changes in grain-size were statistically significant ($P>0.05$).

III. Channel-form

The y-intercepts on the trend-lines of the longitudinal-profiles tended to be lower after construction, indicating that the channels incised slightly. In addition, the slopes of the trend-lines tended to be more-negative, indicating that the channels steepened slightly (Table 4). For example, the regression-lines fit through the longitudinal-profile of Bishop Creek show a 0.7 m drop in the y-intercept from Y0 to Y2, and a 0.01 change in slope (Figure 10). Furthermore, the largest changes in bed-grade and channel-shape coincided with the 2006 flood.

Upstream of the road-crossings, by the 1 yr after construction the channel cross-sections had aggraded in 2 of the creeks, had incised in 3 of the creeks and had not changed in 1 of the creeks. By the 2 yr after construction fewer cross-sections had incised. Downstream of the road crossings by the 1 yr after construction, the cross-sections had incised in 2 of the creeks, and by the 2 yr after construction the cross-sections had incised in only 1 of the creeks (Table 5).

The thalwags tended to incise more downstream than upstream, which is evident in the longitudinal-profiles and cross-sections that are included in the appendix. For example, the cross-sections in Lower Boulder Creek incised upstream more than 0.25 m in the 1 yr (Figure 11). Out of 4 creeks that incised a lot upstream in the 1 yr, only 2 of them remained incised after the 2 yr, indicating that channel adjustments may smooth out the impacts of culvert replacement over time.

IV. Macroinvertebrate colonization

The colonization-traps captured a large number of organisms, indicating that these creeks are potentially high-quality habitat for salmonids. For example, 59 samples were found to contain 17,851 organisms in 54 distinct taxa. The most common organisms were chironomid midges (10,078 individuals), *Lepidostoma* caddisflies (1,477 individuals), and chloroperlid stoneflies (1,013 individuals). Other common organisms were ostracods (871 individual), biting midges (691 individuals), and *Paraleptophlebia* mayflies (571 individuals).

Most biological measures were not significantly different ($P>0.05$) between upstream and downstream samples, with the exception of the EPT-proportion indices (Figure 12). The proportion was significantly higher in the upstream samples of the EPT taxa (48.6% vs. 42.1%; t

= -3.19, 5 df, P = 0.02) and the EPT individuals (27.3% vs. 19.5%; t = -4.76, 5 df, P = 0.005)[2], indicating that the construction may have exerted some negative influence on these disturbance-sensitive orders of mayflies, stoneflies, and caddisflies. However, the impacts were small.

Discussion

This study found that the culvert-replacements did not significantly impact the amount of fine-sediment deposited along the reaches of the 6 creeks above and below the roads. For example, the amount of fine-sediment in the creeks 2 yr after construction was no different than the amount in the creeks before construction. These creeks are steep for their respective drainage areas and have a naturally high sediment-transport capacity. Thus, it is not surprising that fine -sediment, given its high mobility, did not increase after construction. Lastly, the changes observed in the median grain size in the 6 creek beds over time were negligible, providing further circumstantial evidence that the short-term impacts related to sediment-transport were minimal.

The channels responded site-specifically to the road crossing reconstructions by smoothing out the grade. For example, the 2.8 m vertical-drop in the longitudinal-profile of Lower Boulder Creek caused by the culvert was smoothed-out by the 1 yr after construction. The maximum jumping ability for adult coho is on the order of 2.5 m (Whyte et al. 1997). Thus, this smoothing-out of the grade should have some benefits for the threatened salmonid populations.

Many of the largest changes in the channel morphology occurred during the flood in 2006. For example, this flood caused about 1 m of incision in the second-upstream cross-section at Bishop Creek. Furthermore, the changes in morphology that occurred with the 1 yr recurrence-interval flood in 2005 were negligible compared to the changes that occurred in 2006.

[2] A t-test is any statistical hypothesis test in which the test statistic (t) has a Student's t distribution if the null hypothesis is true. The degrees of freedom (df) is the number of values in the final calculation of a statistic that are free to vary. The null hypothesis is rejected, i.e., there is a significant difference, if $P<0.05$.

Although the 2006 flood triggered adjustments in the longitudinal-profiles and cross-sections, it did not significantly impact the amount of fine-sediment deposited in the creek beds. The storm may have dislodged fine-sediment from the construction-zone, but this sediment would have been transported rapidly downstream because of the channel steepness. Thus, the culvert replacements probably did not exacerbate any impacts of sedimentation on salmonid redds.

The significant changes observed in benthic macroinvertebrate populations during this study were very small. For example, the difference between the % EPT taxa upstream and downstream of the road was only 6.5%, and the difference in % EPT individuals was only 7.8%. The EPT taxa include the mayflies, stoneflies, and caddisflies, which are a primary food source for salmonids (McCafferty, 1998). Thus, a large decline in EPT populations may have raised a red-flag for park-management, but the observed level of changes should not be cause for alarm.

In conclusion, the long-term benefits of improved fish passage and reduced risk of catastrophic failures as a result of the culvert replacements in the Klamath National Forest outweigh the short-term impacts. The culverts that blocked fish passage, for example, were removed and replaced with vastly improved structures (Figure 3). In addition, the total fill volume was reduced by more than half in the majority of the creeks (Figure 8). Lastly, potential improvements to salmonid populations have not been monitored with direct measurements of the salmonids. This type of monitoring would be a useful future direction for research in this region.

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Figure 1. Site map of sampling sites in Klamath National Forest of northern California.

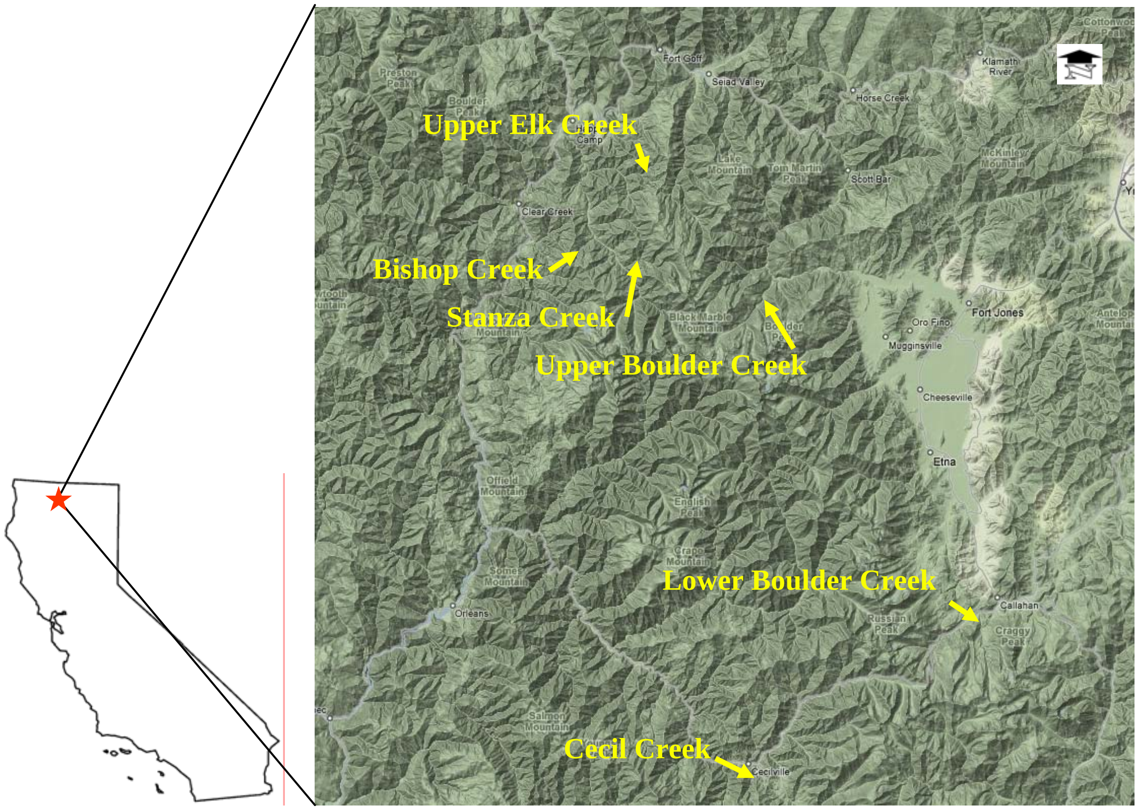


Figure 2. Hydrograph from the Scott River, a nearby site in the Klamath River Basin, showing the magnitude of the floods during the study, and a timeline of when the 6 culverts were replaced.

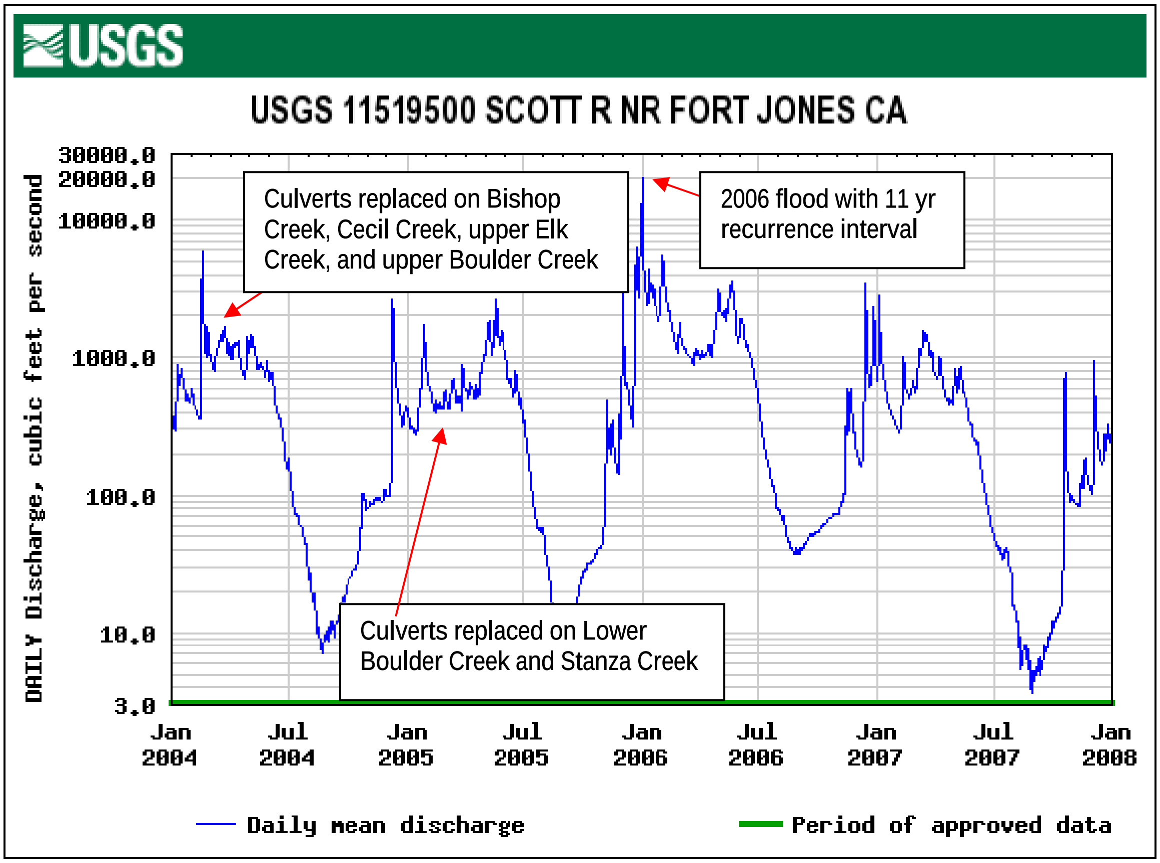


Figure 3. Example of fish-passage improvement and reduction in risk of catastrophic failure at Stanza Creek (a) before and (b) after culvert replacement.

(a)

(b)

Figure 4. The dogbowl traps collected colonizing invertebrates in the months after construction. This example is from Stanza Creek in 2005 before (left) and after construction (right).

Figure 5. The facies map for upper Boulder Creek in 2004 shows that the channel was not significantly stratified geomorphically, therefore the grain-size information could be aggregated.

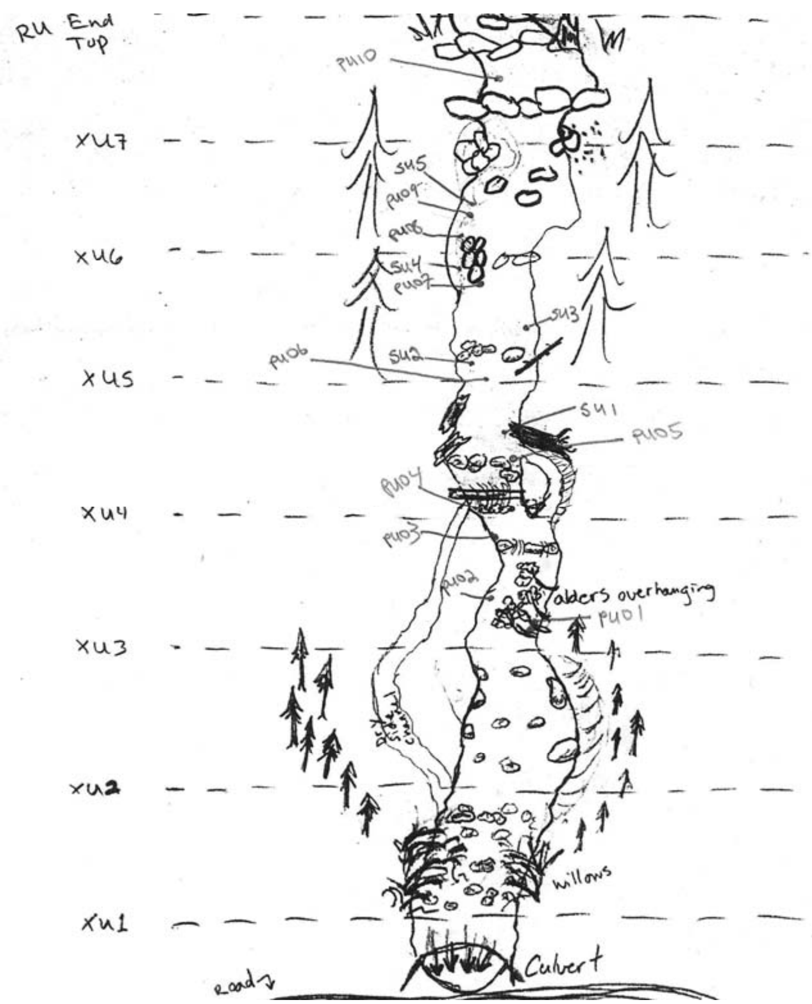


Figure 6. This cartoon shows how the drop between y-intercepts is related to incision.

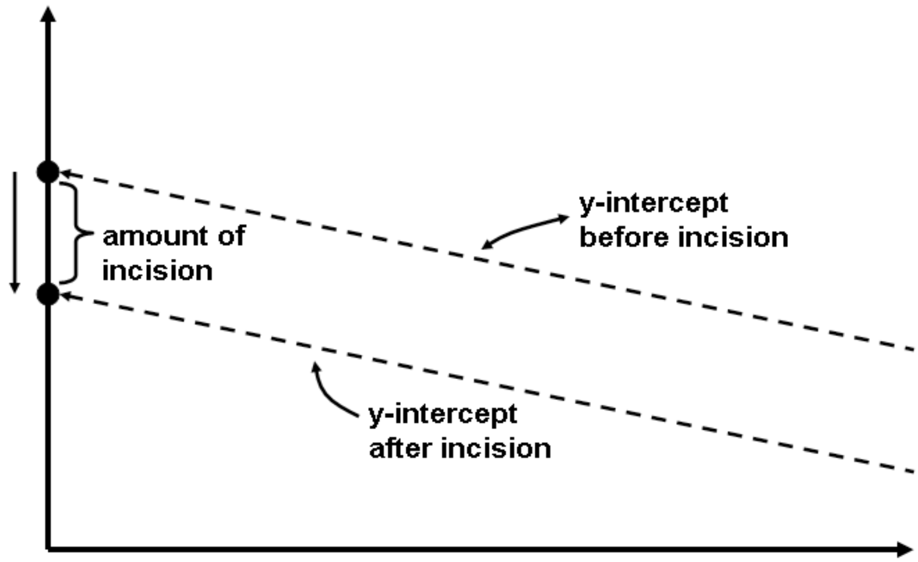


Figure 7. This cartoon shows what a more negative slope looks like on the longitudinal-profile.

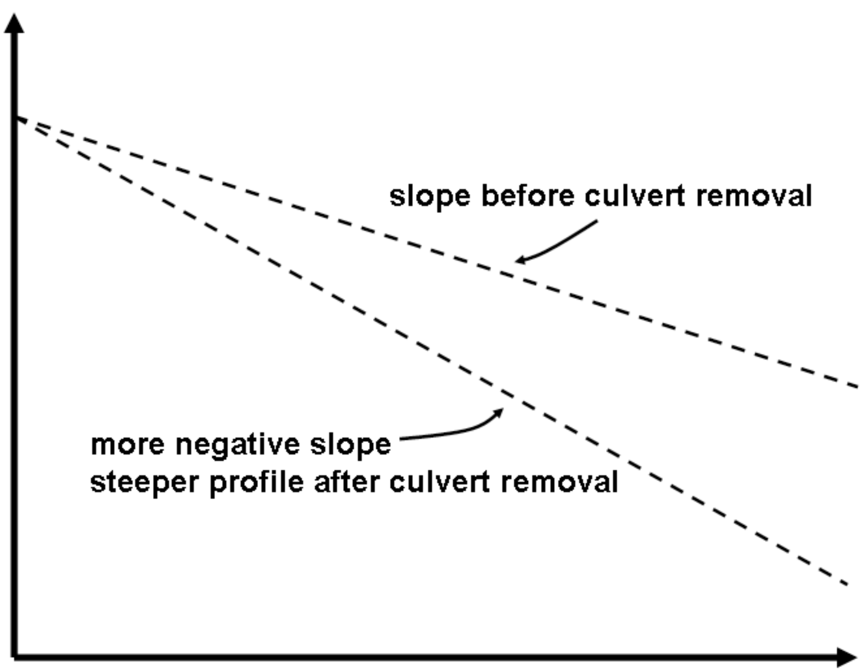


Figure 8. The fill-volume was reduced by more than half in the majority of the creeks.

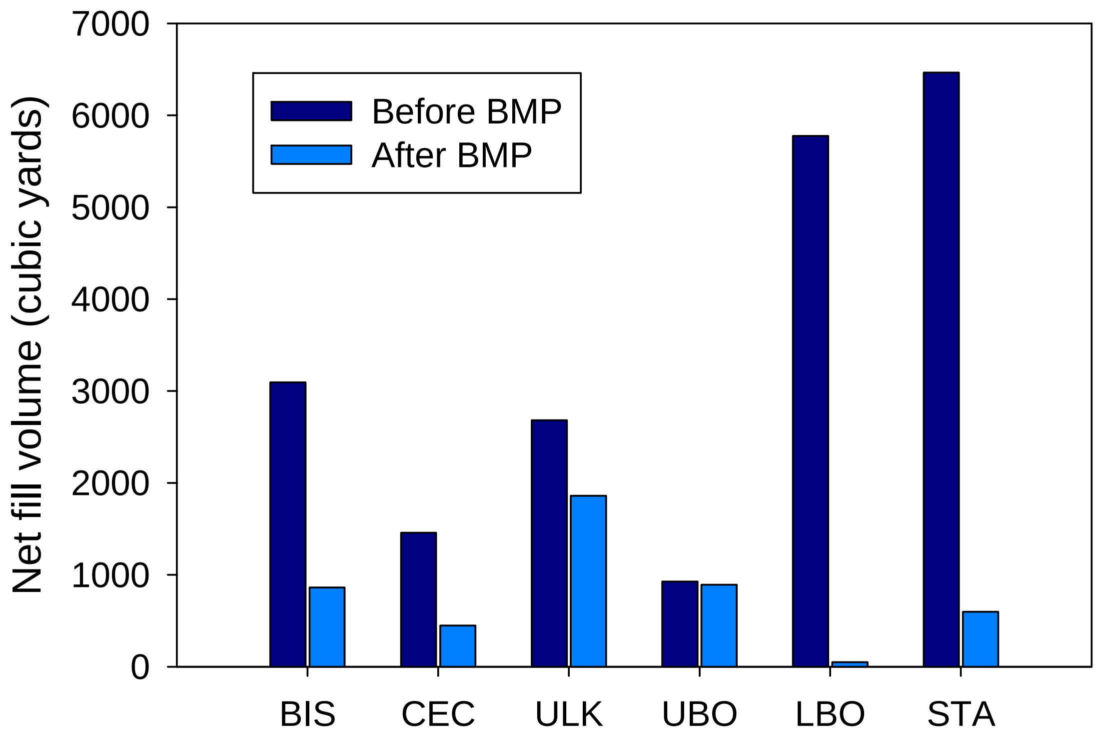
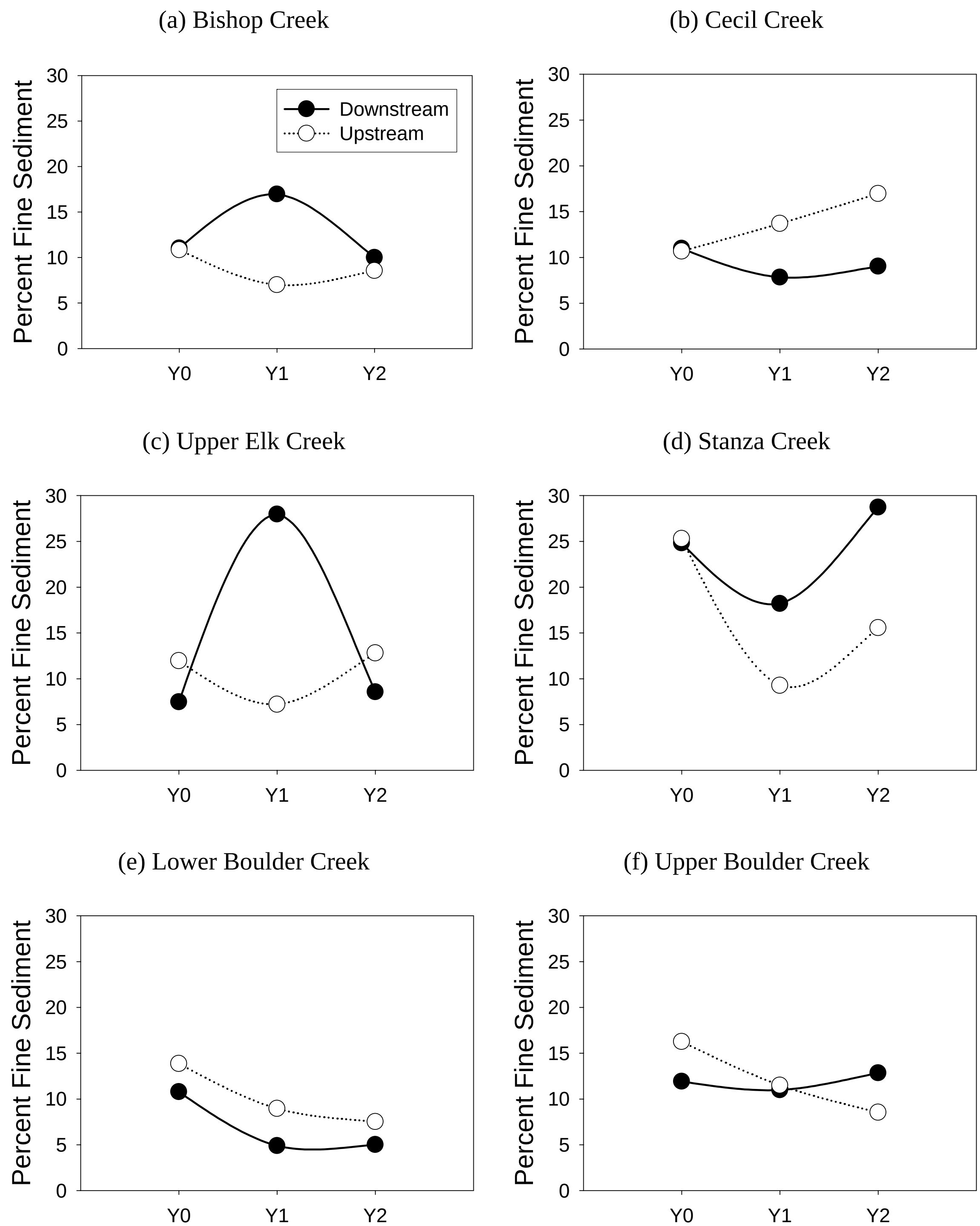
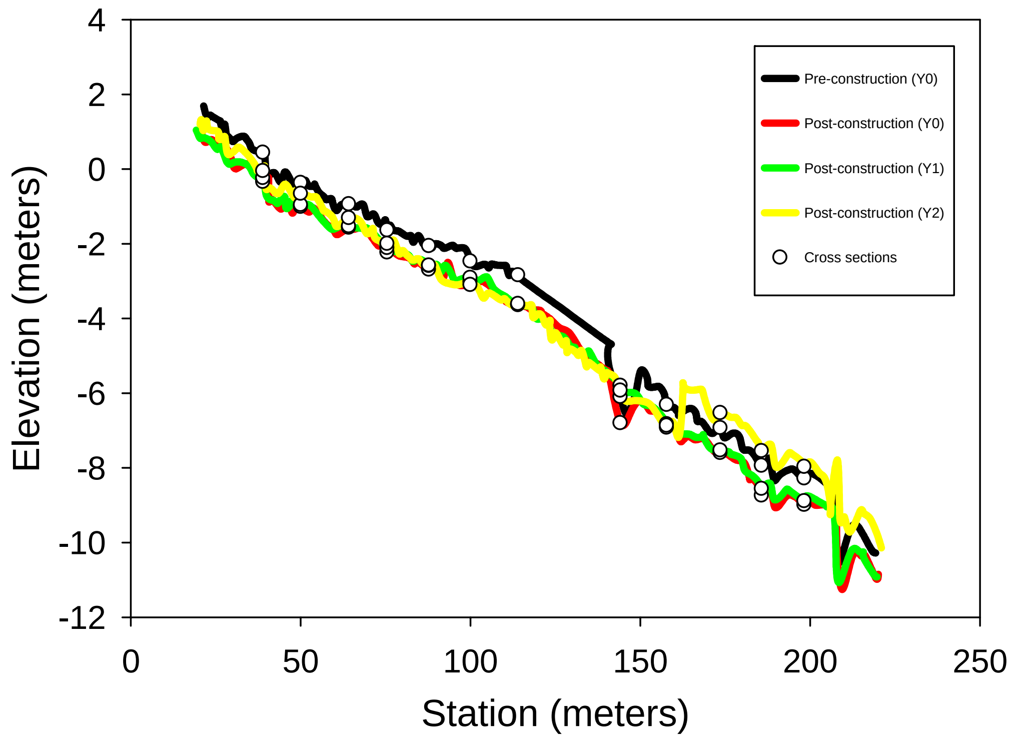


Figure 9. The BMPs had no significant short-term impacts on fine-sediment deposition (Prob>F = 0.30) in the 6 creeks before (Y0) and after (Y1 & Y2) construction.

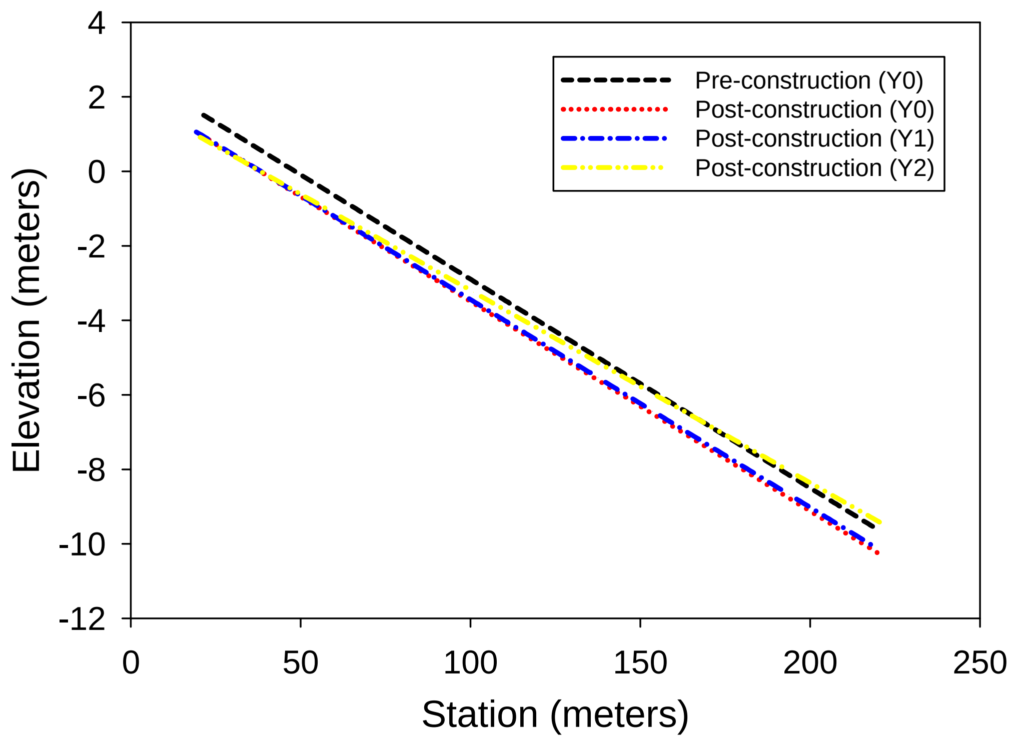


* Percent Fine Sediment is the composite sum of all the fine particles, defined as particles with diameters less than 2mm, measured in cross-sections upstream or downstream of the road crossings divided by the total number of particles, times 100. The cross-sections were not treated as replicates, hence no error bars.

Figure 10. Example of (a) longitudinal-profiles and (b) linear regressions for Bishop Creek.



(a)



(b)

Figure 11. The thalwag elevation change from pre-construction to post-construction was highest in Lower Boulder Creek in the 1 yr after construction; error bars are SE among the cross-sections.

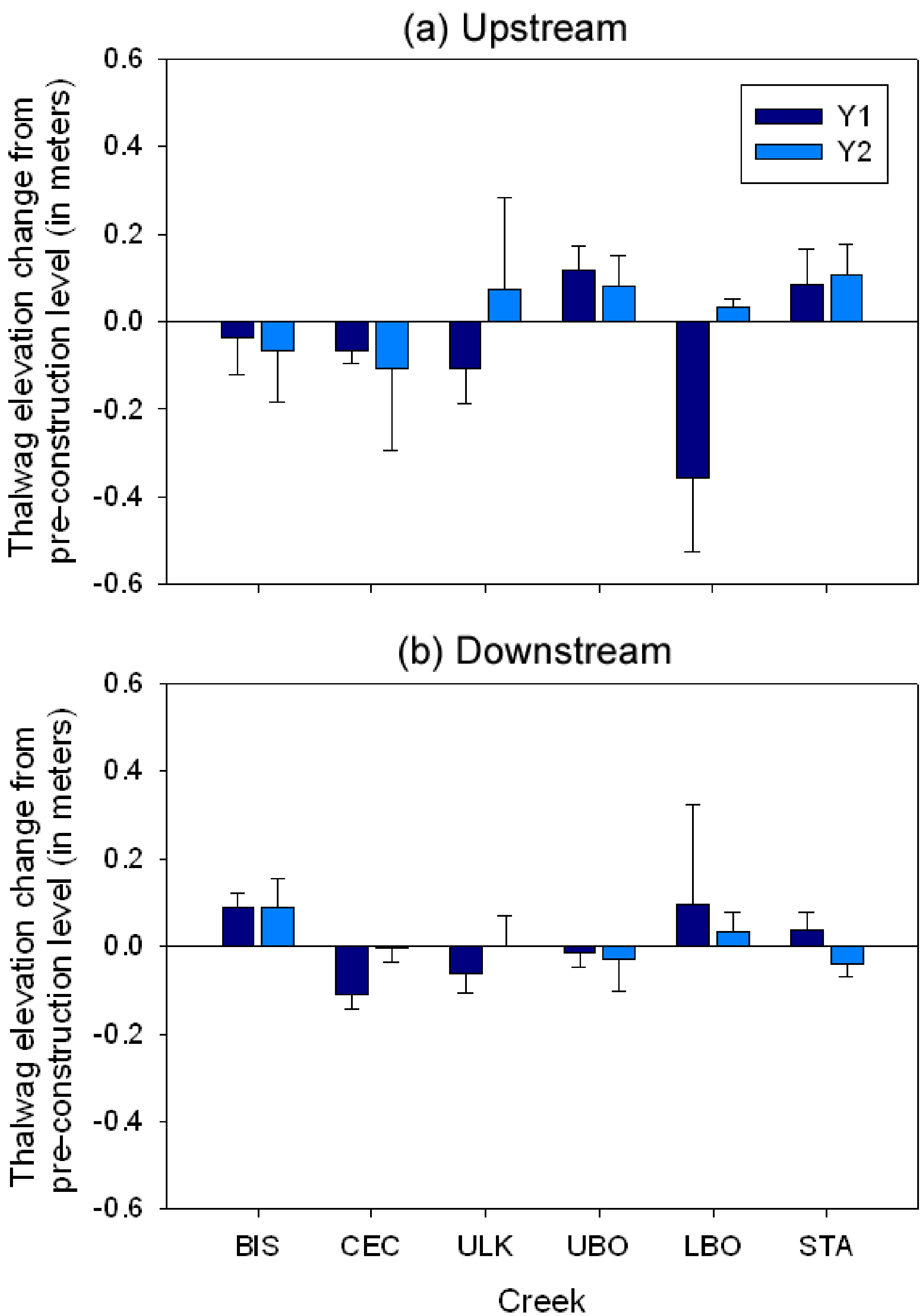
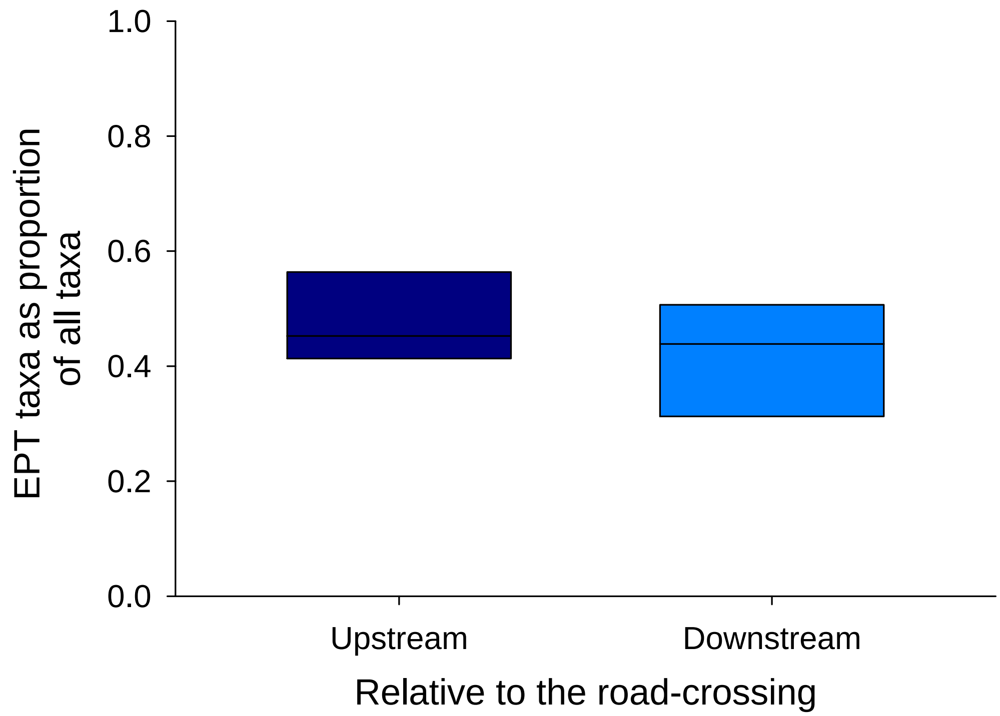


Figure 12. Proportion EPT taxa and Proportion EPT individuals with upper and lower quartiles.



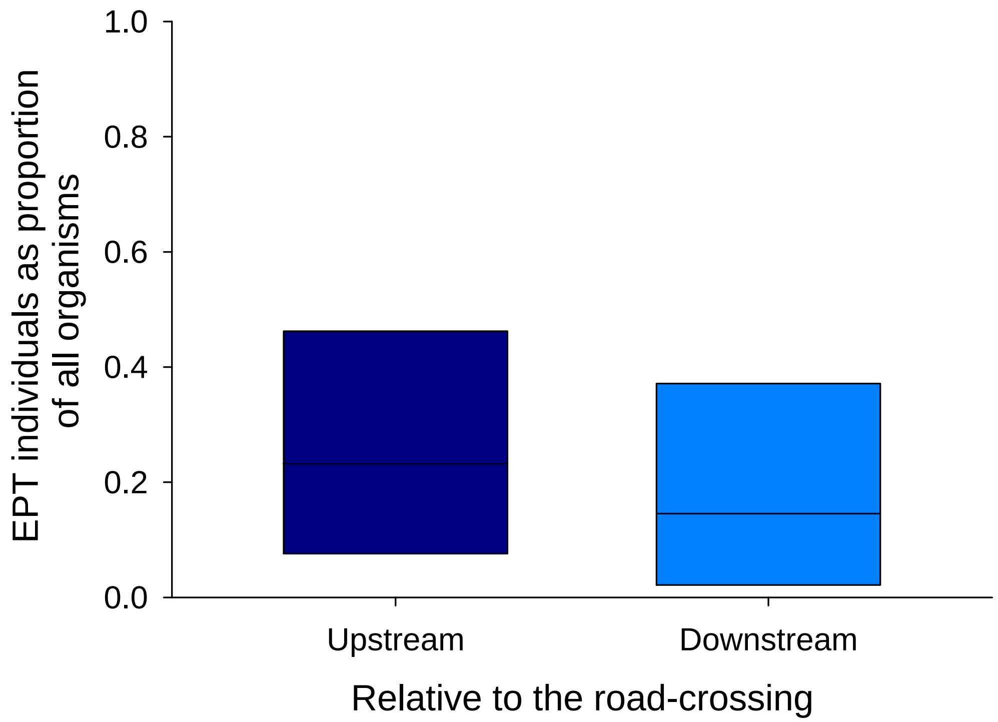


Table 1. These drops at the end of the culverts were smoothed-out by the restoration.

Creek Name	Drop (meters)
Bishop Creek	1.5
Cecil Creek	1.5
Upper Elk Creek	1.4
Upper Boulder Creek	1.5
Lower Boulder Creek	2.8
Stanza Creek	1.0

Table 2. Jumping abilities for selected salmonid species (Whyte et al. 1997).

Species	Life stage	Max. jump height (m)
Coho and chinook	Adults	2.4
	Juveniles (120mm)	0.5
	Juveniles (50mm)	0.3
Sockeye	Adults	2.1
	Juveniles (130mm)	N/A
	Juveniles (50mm)	N/A
Cutthroat and rainbow	Adults	1.5
	Juveniles (125mm)	0.6
	Juveniles (50mm)	0.3
Steelhead	Adults	3.4
Chum/Pink	Adults	1.5

Table 3. Summary of grain-size distributions upstream and downstream of the road-crossings.

Control/ Impact	Creek Name	D_{16} (mm)			D_{50} (mm)			D_{84} (mm)		
		Y0	Y1	Y2	Y0	Y1	Y2	Y0	Y1	Y2
Upstream	Bishop	8	6	5	67	82	64	313	442	365
	Cecil	6	4	4	128	113	134	460	385	476
	Upper Elk	4	4	5	91	66	90	457	371	464
	Upper Boulder	5	<4	5	186	145	237	516	445	623
	Lower Boulder	<4	5	4	123	252	157	498	585	520
	Stanza	<4	<4	<4	50	69	61	354	299	407
Downstream	Bishop	8	<4	4	58	53	59	273	428	257
	Cecil	6	5	7	257	445	264	550	607	607
	Upper Elk	5	4	6	118	112	84	439	425	386
	Upper Boulder	<4	4	4	164	117	166	554	408	542
	Lower Boulder	<4	5	<4	104	178	114	370	459	478
	Stanza	<4	<4	<4	70	23	91	397	421	439

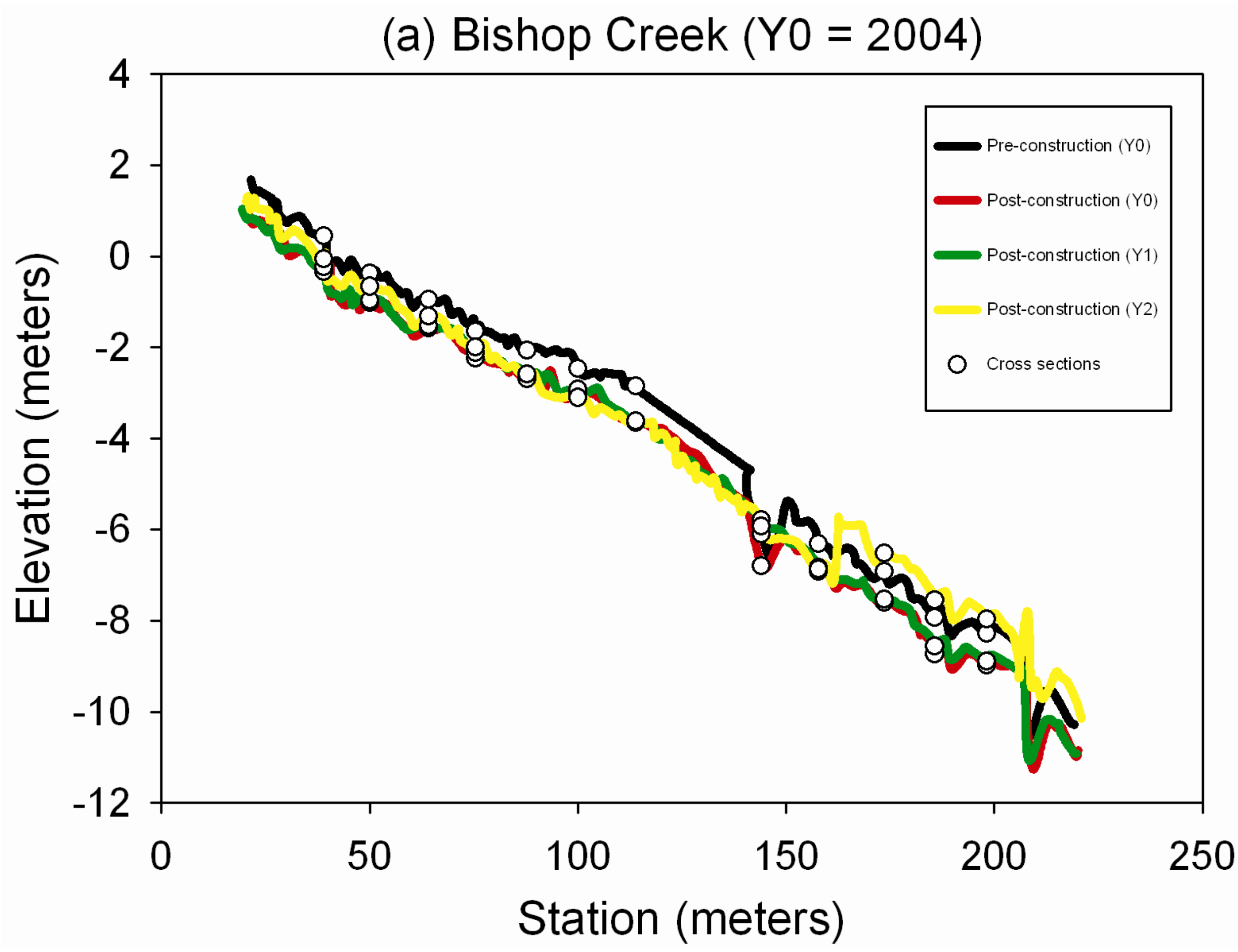
Table 4. Linear-regression analysis of the longitudinal-profiles of the 6 study creeks.

Creek	Year	Regression parameters	
Bishop Creek	Y0	y-intercept	2.7
		slope	-0.06
	Y1	y-intercept	2.1
		slope	-0.06
	Y2	y-intercept	2.0
		slope	-0.05
Cecil Creek	Y0	y-intercept	4.5
		slope	-0.06
	Y1	y-intercept	4.4
		slope	-0.06
	Y2	y-intercept	4.3
		slope	-0.06
Upper Elk Creek	Y0	y-intercept	2.5
		slope	-0.05
	Y1	y-intercept	2.3
		slope	-0.05
	Y2	y-intercept	2.4
		slope	-0.05
Upper Boulder Creek	Y0	y-intercept	7.2
		slope	-0.11
	Y1	y-intercept	7.4
		slope	-0.11
	Y2	y-intercept	7.2
		slope	-0.11
Lower Boulder Creek	Y0	y-intercept	8.9
		slope	-0.12
	Y1	y-intercept	8.2
		slope	-0.12
	Y2	y-intercept	8.2
		slope	-0.12
Stanza Creek	Y0	y-intercept	5.3
		slope	-0.08
	Y1	y-intercept	5.5
		slope	-0.08
	Y2	y-intercept	6.0
		slope	-0.08

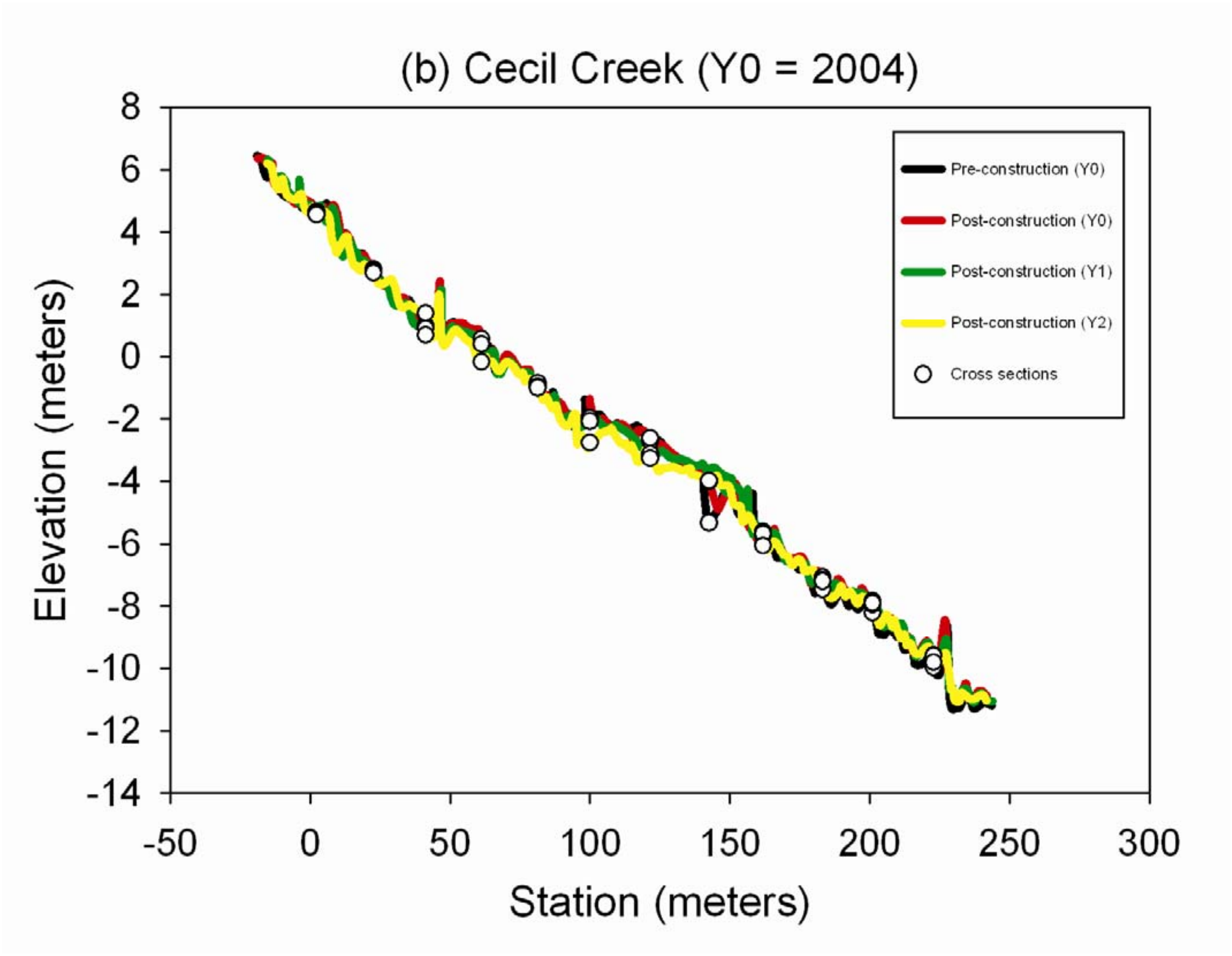
Table 5. Aggradation (⇧) and incision (⇩) of cross-sections in the first (Y1) and second (Y2) yr after construction at each creek.

	Y1 BIS	Y2 BIS	Y1 CEC	Y2 CEC	Y1 UEL	Y2 UEL	Y1 UBO	Y2 UBO	Y1 LBO	Y2 LBO	Y1 STA	Y2 STA
Upstream	no trend	50% ⇩	83% ⇩	no trend	67% ⇩	67% ⇧	83% ⇧	67% ⇧	83% ⇩	83% ⇩	67% ⇧	83% ⇧
Downstream	100% ⇧	75% ⇧	100% ⇩	no trend	75% ⇩	no trend	50% ⇧	no trend	75% ⇧	50% ⇧	75% ⇧	75% ⇩

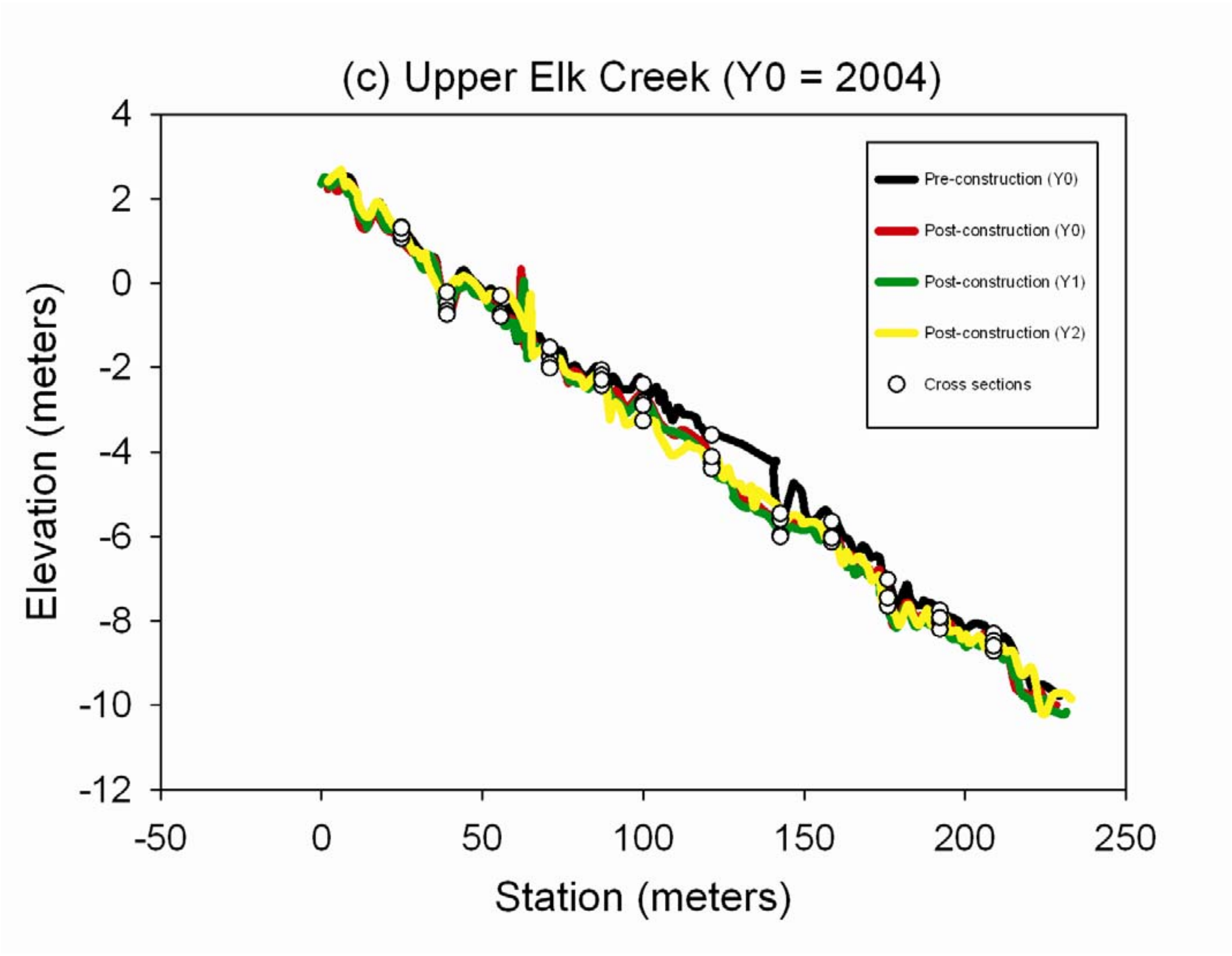
A1. Bishop Creek was most active in flood year 2006 and predominately incised during the study.



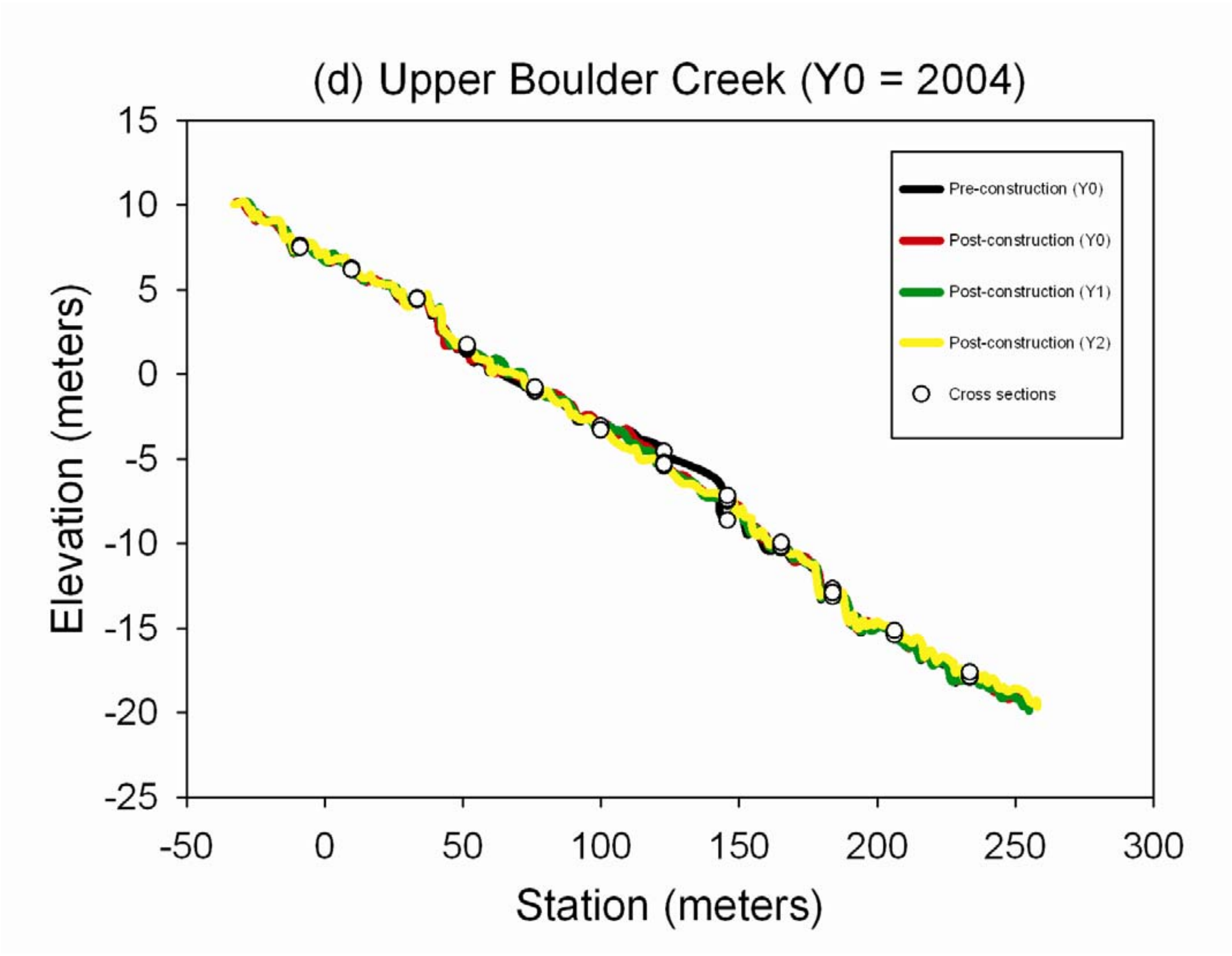
A2. The plunge pool after the culvert in Cecil Creek disappeared in the years after construction.



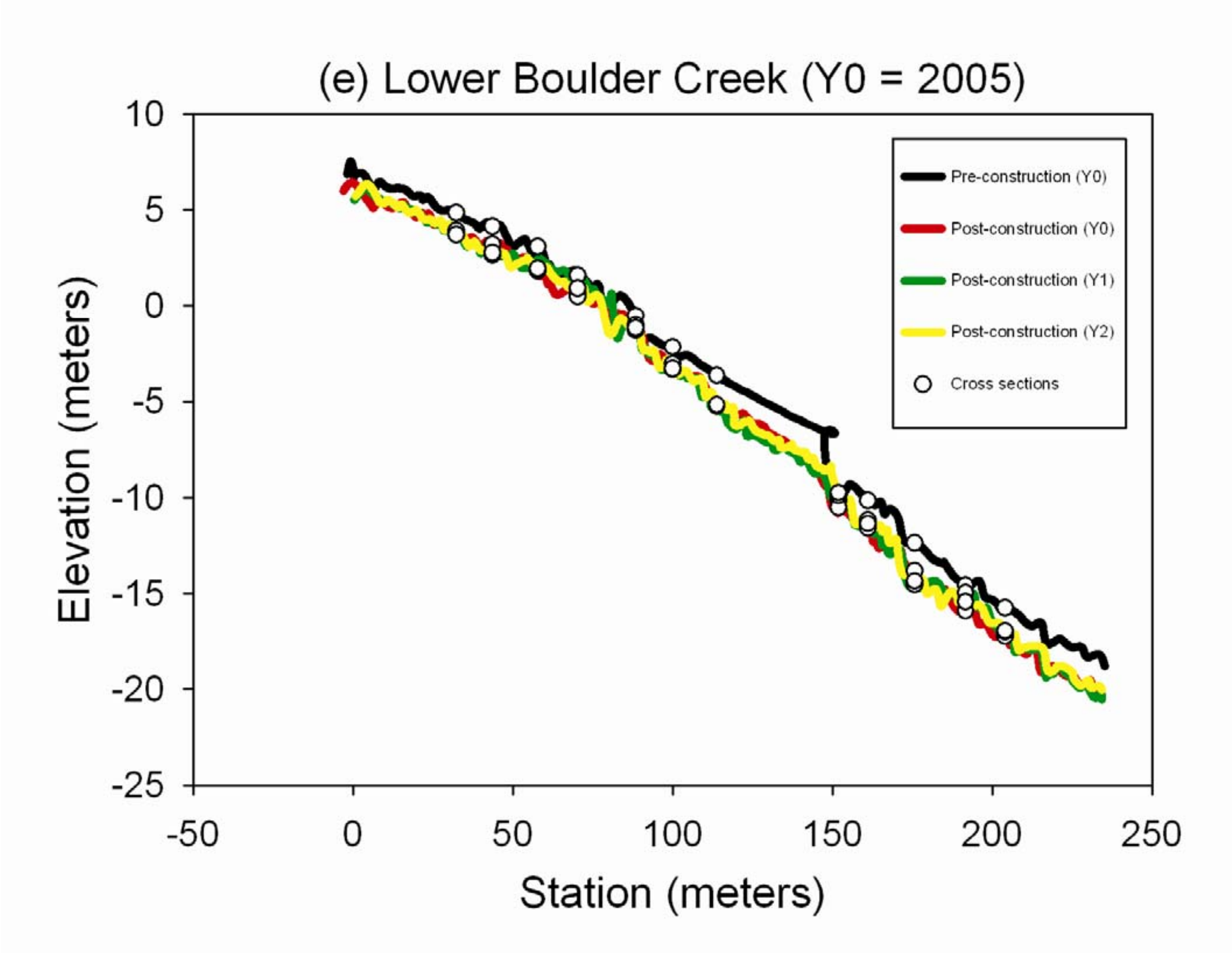
A3. Upper Elk Creek assumed a more even grade after the culvert was replaced.



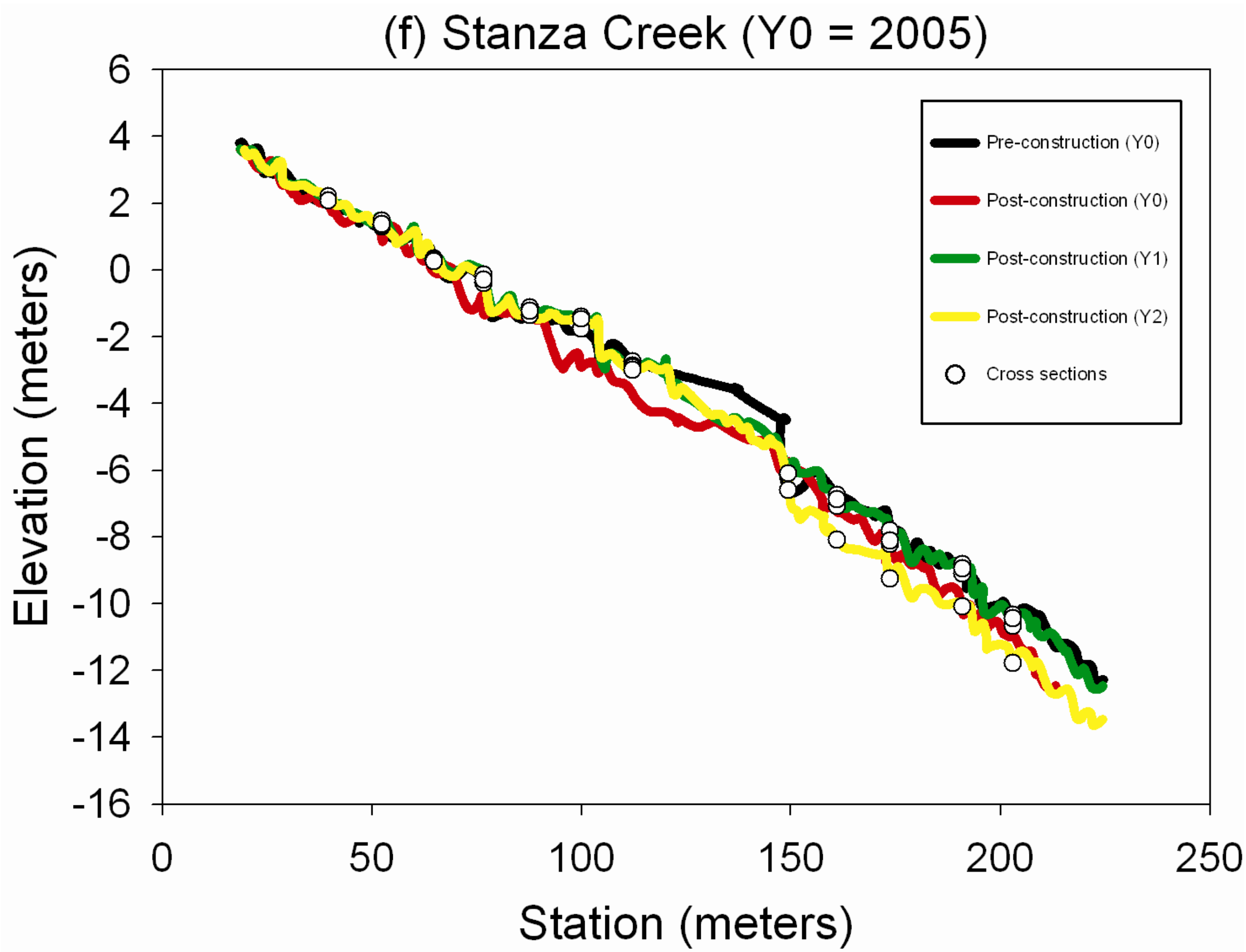
A4. Changes in the longitudinal profile in Upper Boulder Creek were minimal over the course of the study.



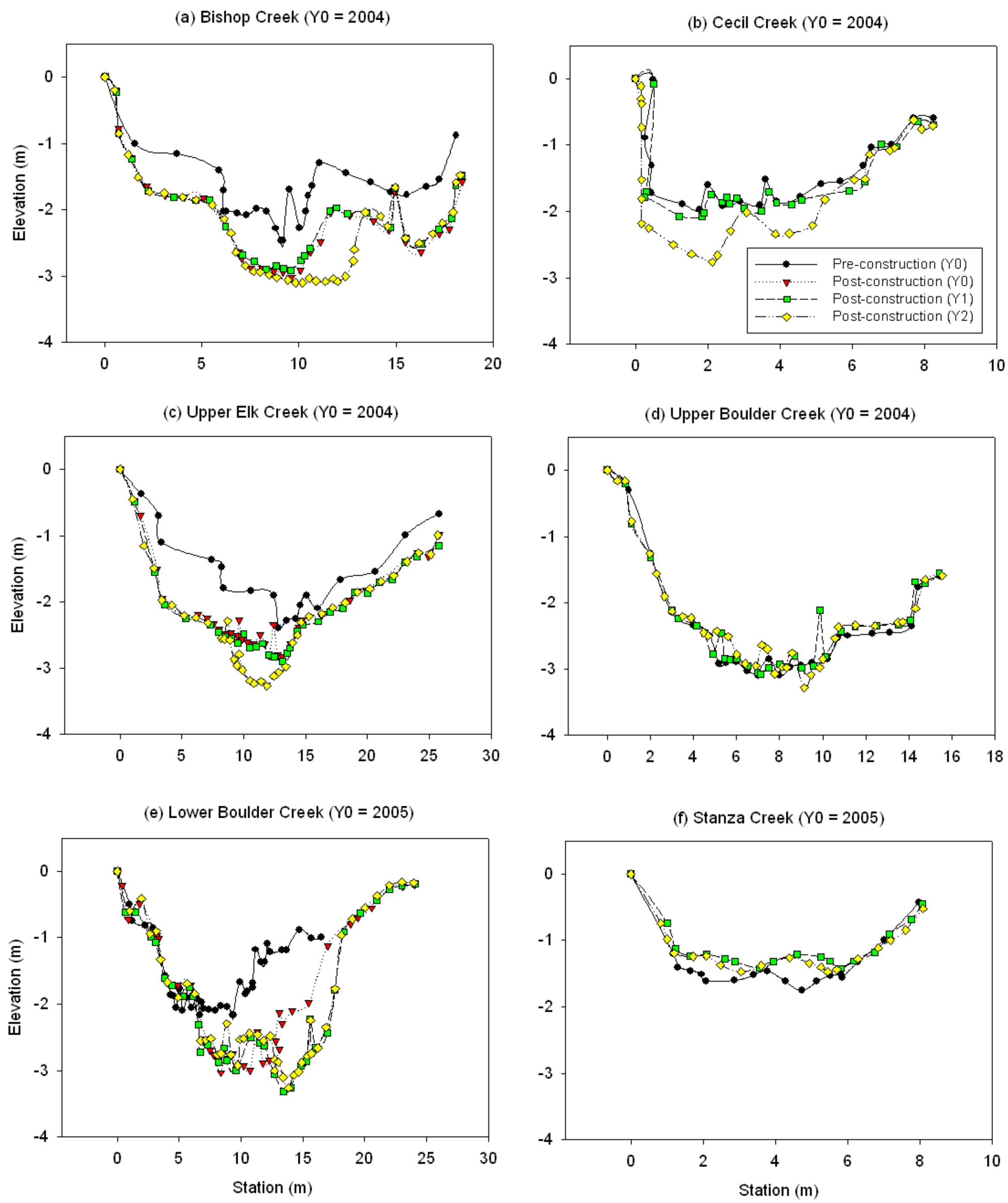
A5. Lower Boulder Creek incised and the 2.7 m drop after the culvert was smoothed-out.



A6. Stanza Creek was most active in flood year 2006 and the channel incised in the years after construction.



7. Channel adjustments at upstream cross-section (XU2) throughout the study.



A3. Channel adjustments at downstream cross-section (XD2) throughout the study.