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Cover photo: Cutline crossing, Silvester Creek, Alberta, 30 May 2013. D. W. Mayhood photo.

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This report is an update with corrections and additional data based on Heidi Erdle's 2010-2011 major undergraduate project and prepared in partial fulfillment of her Bachelor of Science degree in the University of Calgary BSc Environmental Science Program. It incorporates observations made in 2013 by the second author. It was accepted for publication in the Wild Trout XI Proceedings, a symposium to be held in Yellowstone National Park in October 2013. The symposium was cancelled at the last minute due to a shutdown of the park by the US Government. Wild Trout XI was rescheduled to September 2014, but Ms Erdle was unable to attend and present the paper then, so it was withdrawn by the authors in favour of other presenters. It is presented here to make the work available without further delay.

Abstract

Silvester Creek is a small headwater stream in the Rocky Mountain foothills of Alberta holding one of the province's few remaining genetically pure Westslope Cutthroat Trout (*Oncorhynchus clarkii lewisi*) populations, identified as at risk (Threatened) under the Alberta *Wildlife Act* and the Canada *Species At Risk Act*. The drainage basin is in a highly developed multiple-use zone with extensive cutblocks, petroleum development, livestock grazing and heavy all-terrain vehicle use. We used a three-pronged approach to identify actual and potential effects of development on the creek and on the native fish population using simple, inexpensive techniques. 1) A cumulative effects assessment was conducted on the entire watershed; 2) field measurements of channel parameters were made at identified point source sediment sites, and total suspended sediment (TSS) measurements were made at these sites as well as throughout the creek; and 3) field data were compared to prior published and unpublished data to make inferences about the state of Silvester Creek's Westslope Cutthroat Trout population and its habitat. Results indicate that the basin is at high risk of channel damage from the combined effects of increased peak flows and increased surface erosion from developments (mostly roads). Human activities are negatively affecting Silvester Creek by changing channel structure, substrate composition and suspended sediment concentration through the stream network. In particular, TSS levels observed could be seriously harmful to the resident cutthroat population, and are likely causing population-level effects. Current land-uses impacting Silvester Creek need to be mitigated to ensure the long-term survival of its unique and valuable trout stock.

Introduction

Westslope Cutthroat Trout (*Oncorhynchus clarkii lewisi*) is designated as Threatened under Alberta's *Wildlife Act* and under the federal *Species At Risk Act*. Recovery and conservation programs are being developed to ensure the continued existence of the subspecies. Recovery will need to include restoring natural habitats of streams containing remnant populations, and protecting entire watersheds of those streams still holding genetically pure cutthroats (Mayhood 2001).

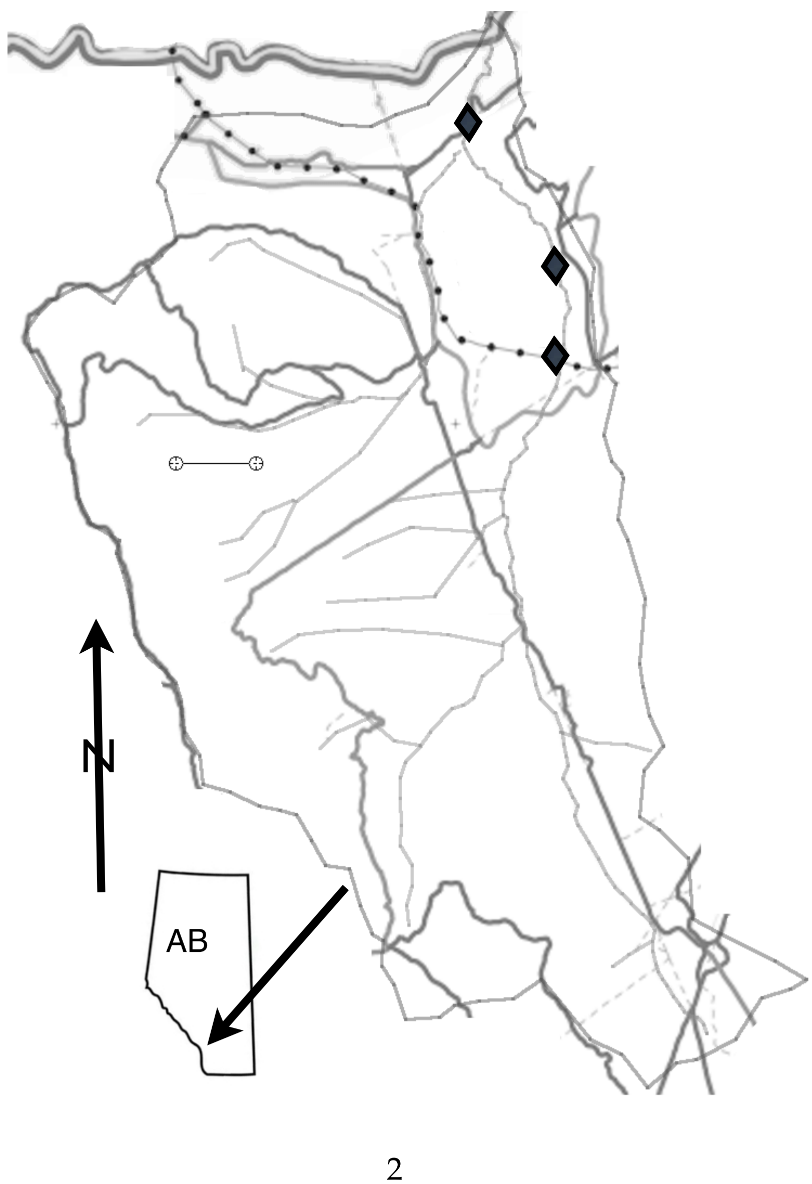
Silvester Creek is one of the few streams left in Alberta to host a genetically pure population of Westslope Cutthroat Trout (Cleator et al. 2009). The watershed has been extensively developed. All-terrain vehicle (ATV) trails, logging, livestock grazing, and petroleum development have increased fine sediment loading, extended the drainage network, and damaged stream banks. Fine sediments affect the structure and function of streams, fish distribution, population dynamics, and population health, reducing carrying capacity (Vondracek et al. 2003). Fine sediment deposited in Westslope Cutthroat Trout spawning areas decreases egg and larval survival (Weaver and Fraley 1993).

Here we investigate the effects of anthropogenic sediment sources in the Silvester Creek watershed on water quality and channel characteristics as they may impact trout habitat. We test the prediction (Tripp *et al*. 1979a) that land-use in Silvester Creek basin would damage channel structure and increase sediment delivery to an extent that is detrimental to the stream and its fish population. We identify risk of channel damage through a cumulative effects assessment of land use; quantify the effects of selected crossing points on water quality, channel dimensions and substrate as examples of what may be happening throughout the watershed; and evaluate potential effects on the native trout population.

Study Area

Silvester Creek is a 7-km long Rocky Mountain Foothills tributary of the Elbow River draining a catchment of 16.2 km^2. A 3-m high waterfall near the mouth is a barrier to fish movement into the stream, isolating a small Westslope Cutthroat Trout population above it. The creek lies entirely within the McLean Creek Public Land Use Zone (PLUZ), which allows logging, livestock grazing, petroleum exploration and development, and motorized off-highway recreation. The basin has a dense linear disturbance network as a result (Figure 1). In addition there are many eroded, unmapped, heavily-used but undesignated trails. Some large partially-regrown cutblocks occupy the uplands on the west and south sides of the basin.

Figure 1. Silvester Creek (light gray) basin with road network (dark gray), pipeline (beaded line) and cutlines (dashed). Diamonds, channel dimension study sites and pipeline crossing (N-S): ATV crossing, cattle crossing, pipeline crossing. Scale bar = 500 m. Base map adapted from Government of Alberta (2012).



Methods

We used a watershed analysis, the Interior Watershed Assessment Procedure (IWAP) Level 1 (BC Forest Service 1995), to assess risk to the creek from the cumulative effects of land disturbance. Data for the IWAP were obtained from current Alberta Government Access Series maps, Vegetation Inventory maps, digital elevation models and aerial photographs, all from the University of Calgary digital archives, supplemented with detailed publicly-available trail information (Government of Alberta 2012) and field observations. Soil erodibility was assessed from Reimchen and Bayrock (1977) and Bayrock and Reimchen (1980).

Channel dimensions and substrates were measured at two sites here called the ATV crossing and the cattle crossing (Figure 1) in October 2010. The ATV crossing is a heavily-used narrow ATV bridge 625 m (straight-line distance) upstream from the creek mouth. The western approach is a deeply-eroded, steeply-descending dirt road; the eastern approach closely parallels the stream for 350 m and has several large, deep mudholes. The cattle crossing is 1600 m upstream from the creek mouth in a damp meadow. Livestock have trampled the east bank; ATV tracks are prominent on both banks.

Discharge was calculated by the area-velocity method (Gordon et al. 1992). Flow velocity was measured using an averaging flow meter (Global Water Model FP101, Gold River, CA). Bank-full width was identified from indicators (Leopold 1994), measured to the nearest 0.1 m with a fiberglass tape, and bank-full depth was measured to the nearest 1 cm with a stadia rod against the tape stretched between bank-full marks, all at 10 transects 1-2 channel widths apart above and below each site. A pebble size-distribution analysis was conducted immediately upstream and downstream of each sample site (Bain 1999).

Total and organic suspended sediment (TSS and OSS) were measured twice in fall 2010, once using upstream (control)/downstream (impact) design and the other using a longitudinal sampling design. Grab samples were collected in 1-L wide-mouth polyethylene bottles, filtered (Whatman 934-AH-equivalent glass fibre, pore size 1.5 μm) in the field with a portable hand pump and filter holder, and stored refrigerated in the dark until laboratory analysis within 3 days of sampling (Bain and Hynd 1999).

Numerical analyses were performed with spreadsheets (Excel, Microsoft, Inc.; Numbers, Apple Corp.) and Minitab Solutions 15 on pebble count and channel parameter data. Kolmogorov-Smirnov 2-sample tests (Kirkman 1996) were performed on the non-transformed pebble count data, non-transformed lower ATV crossing, and non-transformed cattle-crossing channel data to detect differences between upstream and downstream measurements.

Results

Data developed for the watershed analysis (Table 1), in some cases minimum estimates, gave the following IWAP results. Peak-flow score, reflecting the risk of increases in the highest flows, was 0.7, rated as moderate. The rating results from high road density, especially above the H_{60} line, plus limited hydrological recovery in extensive clear-cuts as measured by the Equivalent Clear-Cut Area (ECA). The surface erosion score assesses the risk of increased surface erosion. That score, 1.0, the highest possible, was influenced by overall high road density, and especially by high road density within 100 m of watercourses. The riparian buffer score assesses risk to the sensitive zone of direct interaction between stream and land. Its score of 0.7 ranks as moderate, reflecting high levels of logging and road development along channels. The mass wasting score was low, based on incomplete data: no landslides were included in the calculations, although some exist, and no roads were situated on slopes greater than 60%. The combined effects of increased peak flows and surface erosion from cumulative surface disturbance in the watershed, measured by the peak-flow vs. surface-erosion interaction matrix score of 4, ranks high. The high-density road network in the basin (2.5 km/km^2), and its many connections with watercourses (stream crossings and extent of road in 100 m buffer), had the most effect on the peak flow vs. surface erosion score.

Table 1. Parameters used in the IWAP. The H_{60} line is the elevation above which 60% of the basin area lies. The buffer extends 100 m on each side of stream. Fish-related measures are based on the distribution found by Paul & Dormer (2005).

Parameter	
Total area of basin, km^2	16.2
H_{60} elevation, m	1585
Total ECA, km^2	2.5
ECA above H_{60}, km^2	1.2
Road length, km	40.0
Road length above H_{60}, km	19.7
Road length on erodible soils, km, min.	3.2
Road length in 100-m stream buffer, km	11.1
Road length in buffer on erodible soils, km, min.	1.2
Stream crossings (not including close approaches)	25
Total watercourse length, km	29.8
Length of watercourse logged, km	7.6
Length of watercourse logged above H_{60}, km	3.2
Total fish-bearing stream length, km	5.72
Length of fish bearing stream logged, km	2.10

The creek was at low flow at the time of the October 2010 channel parameter assessment. Stream discharge was 0.07 m^3/s at the lower ATV crossing and 0.02 m^3/s at the cattle crossing. The channel was wider at the ATV crossing than at the cattle-crossing but had a similar depth.

At the cattle crossing, bank-full width (Figure 2A; $D = 0.7235$, $n = 27$, $p = 0.001$) and wetted width (Figure 2B; $D = 0.6471$, $n = 27$, $p = 0.005$) were significantly different between upstream and impact locations: both were wider within and downstream of the crossing. No significant difference was found in bank-full maximum depth (Figure 2C; $D = 0.3294$, $n = 27$, $p = 0.420$) above versus within and below the crossing. No significant difference was found in pebble sizes above and below the cattle crossing (Figure 2D; $D = 0.1703$, $n = 203$, $p = 0.094$). Most pebbles at the cattle crossing were in the 0-10 mm class along the β axis.

At the ATV crossing, bank-full width was significantly greater upstream than downstream (Figure 3A; $D = 0.700$, $n = 20$, $p = 0.007$). No significant differences were found in wetted width (Figure 3B; $D = 0.300$, $n = 20$, $p = 0.675$) and bank-full maximum depth (Figure 3C; $D = 0.300$, $n = 20$, $p = 0.675$) above and below the crossing. Pebble sizes below the ATV crossing were clustered around small size classes (0-30 mm along the β axis), while pebble sizes above the crossing were more evenly distributed. Pebbles were significantly smaller below the ATV crossing than above (Figure 3D; $D = 0.2074$, $n = 206$, $p = 0.020$).

Suspended sediment concentrations, high at the pipeline crossing 2 October 2010, decreased with distance downstream (Figure 4). A dirt bike stuck at the pipeline crossing caused the initial spike from 13 mg/L to 96 mg/L. The ATV crossing also increased TSS concentration from 4 mg/L to 15 mg/L. The tributary had a lower TSS concentration than the main stem; its input further diluted TSS concentration. TSS concentration was still slightly higher at the mouth of Silvester Creek (14 mg/L) than it was above the pipeline crossing.

Figure 2. Cattle crossing site: A - bank-full width; B - wetted width; C - bank-full maximum depth (27 transects); D - pebble size frequency distribution (n = 203). Black bars in A-C are transects within the crossing itself.

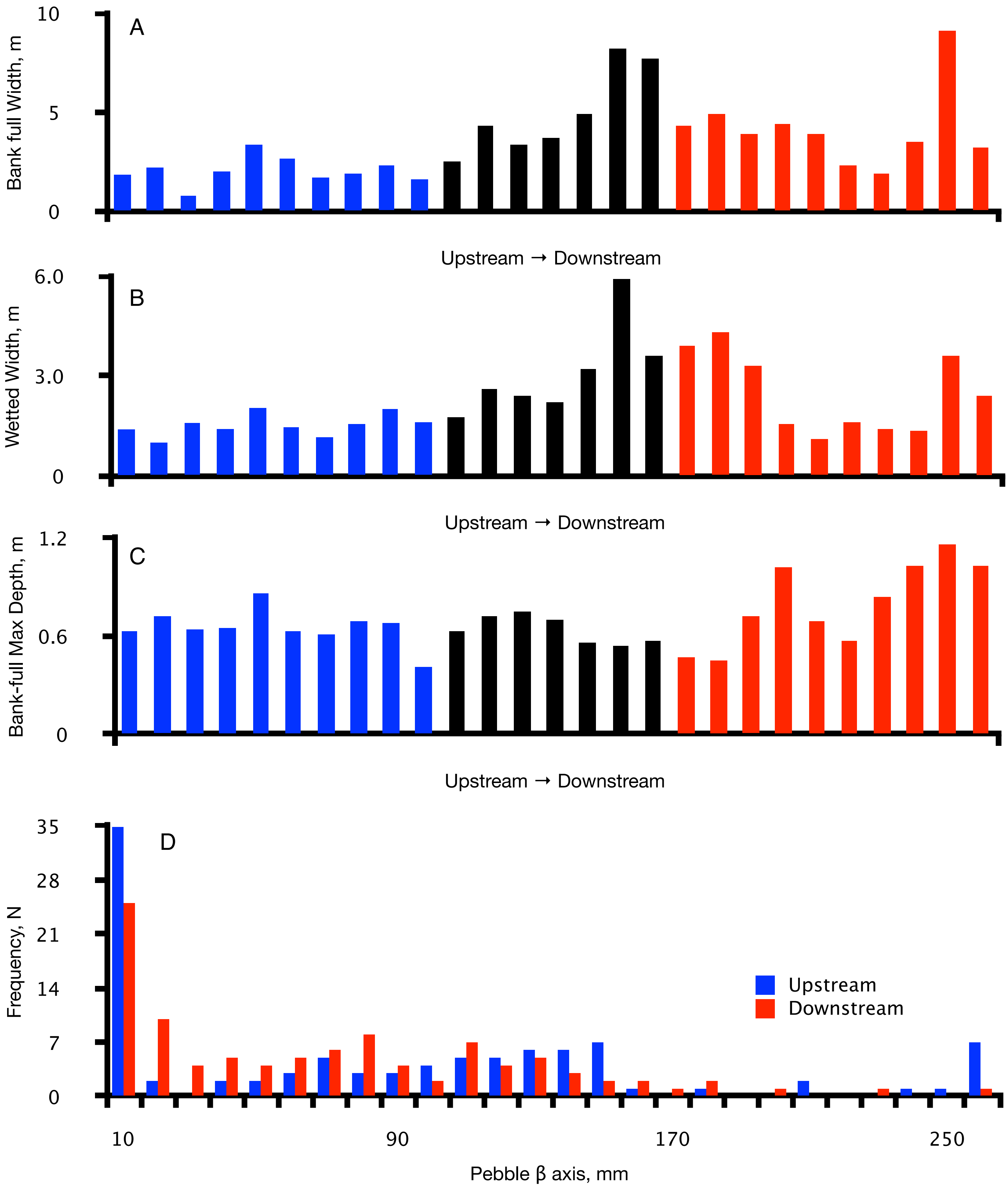


Figure 3. ATV crossing site: A - bank-full width; B - wetted width; C - bank-full maximum depth (20 transects); D - pebble size frequency distribution (n = 206).

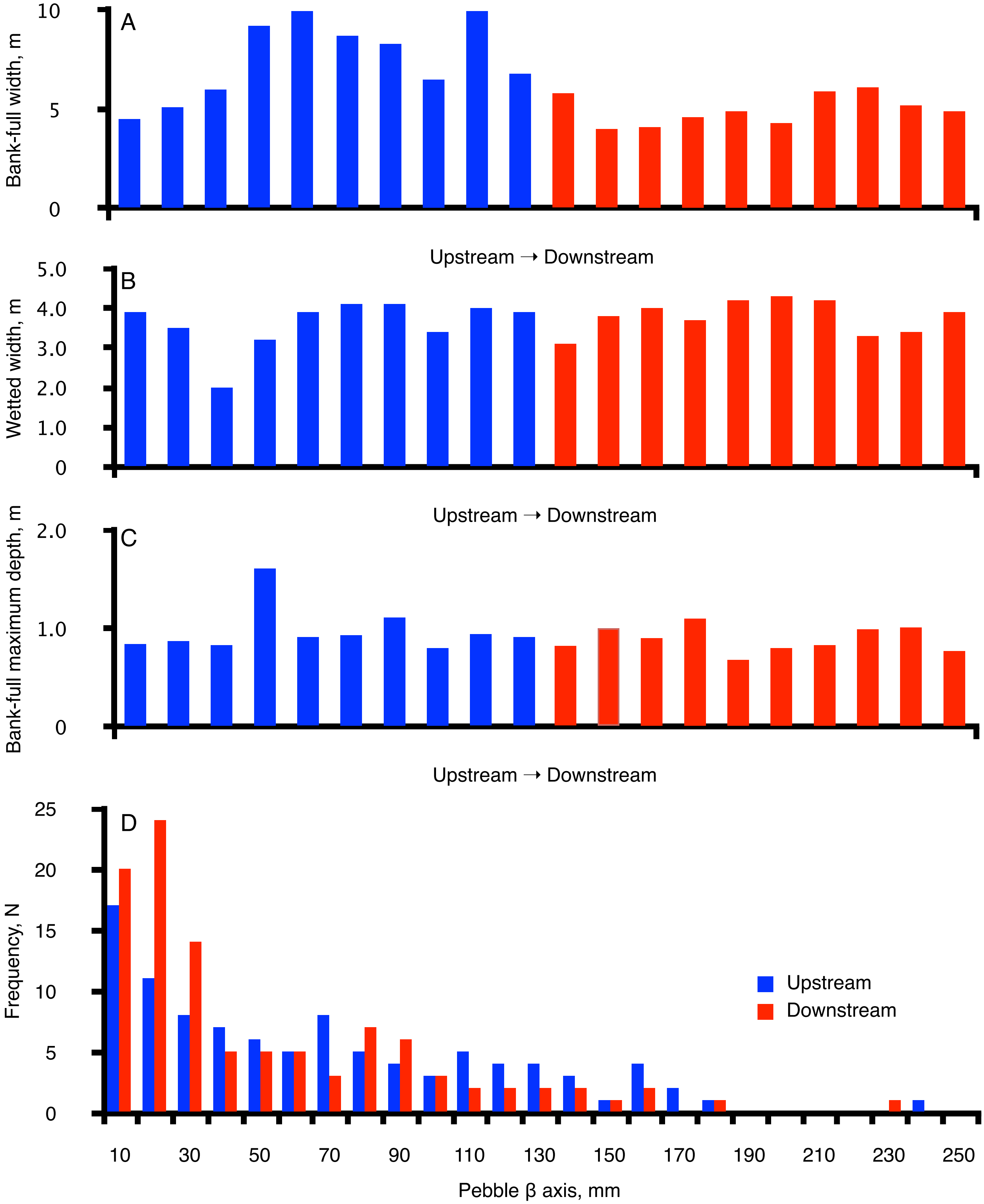
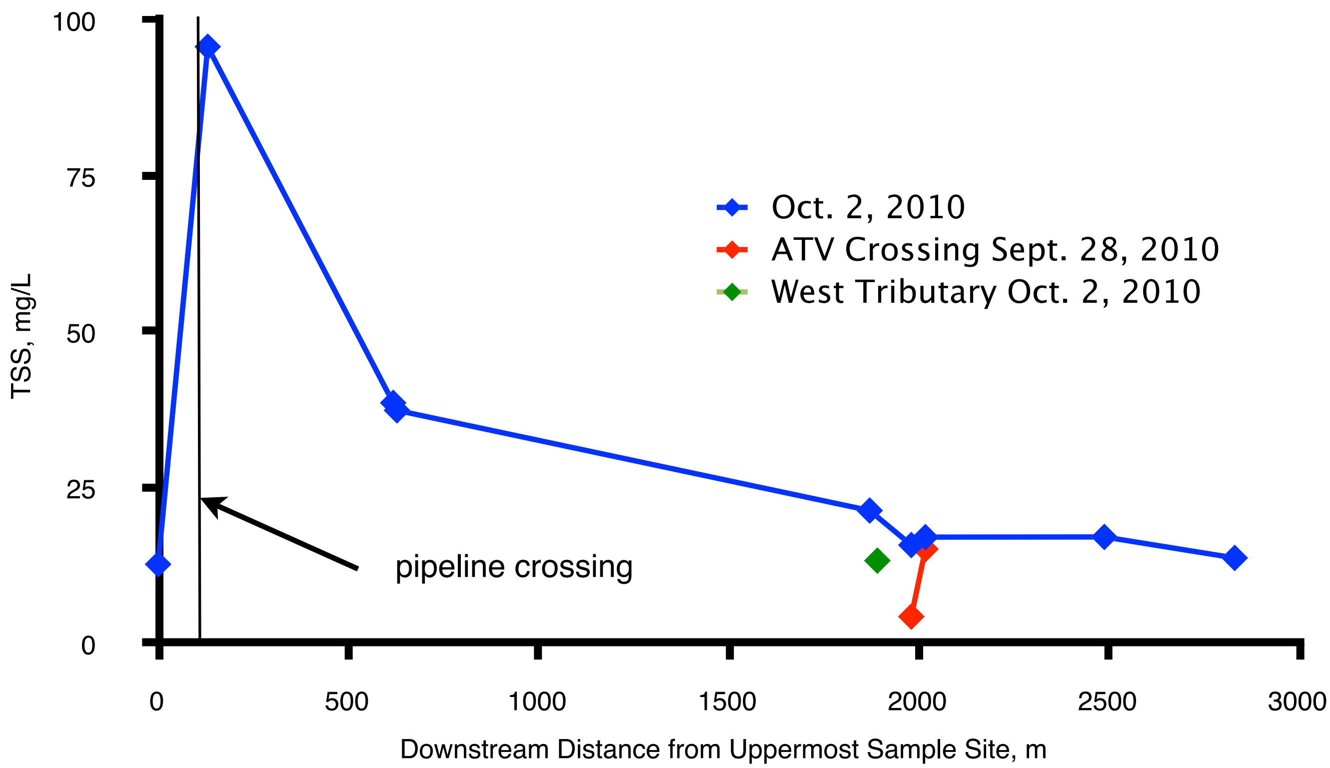


Figure 4. Total suspended sediments (TSS) distribution in Silvester Creek, autumn 2010.



Discussion

The IWAP results show that Silvester Creek is at high risk from the combined effects of increased peak flows and high surface erosion. Peak flow risk is elevated due to incomplete hydrological recovery of large cutblocks and the extension of the drainage network by road ditches. This especially true for the basin above the H_{60} elevation, the upper 60% of the basin where changes in forest cover have the greatest capacity to increase peak runoff (Gluns 2001). Linear disturbances are major sources of fine sediment, form a dense network in this basin, and are well-connected to watercourses at crossings and within the riparian zone. These factors strongly dispose Silvester Creek to high sediment loading. Increases in peak flows themselves are also likely to change channel morphology (Leopold 1994), but the channel changes we observed at crossing points had more local causes.

Both crossings showed effects on channel dimensions. The cattle crossing was widened at, and downstream from, the crossing. The channel was also widened above the ATV crossing. The widening at the cattle crossing was primarily a result of bank trampling by livestock. At the ATV crossing, the widening above the bridge we interpret as an impoundment effect. The bridge constricts the channel at high flows, which itself will partially impound the creek, but it also serves to capture large woody debris, potentially causing debris jams that would impound the flow even more.

After a large flood in the entire Bow River basin 20-22 June 2013, we observed during post-flood inspection that the bridge had impounded flows, as evidenced by watermarks high on upstream trees and banks. It also directed the flow at the downstream left bank, causing severe erosion that toppled trees into the channel, redirecting the flow toward the right bank, which the stream then unravelled, connecting itself with the ATV trail paralleling the original channel. The result was to erode at least two new channels by taking over the ATV trail and its bypass track on the right below the bridge, and initiate two others through the left bank floodplain, all ultimately caused by the bridge and its connected road.

The west approach to the bridge is responsible for the decreased particle size below the ATV bridge. The steep road is deeply eroded. Piles of small stones accumulate on the left of the channel during low flow, deposited there from the road ditch. Cutthroats were observed spawning over and near this deposit 17 June 2013. Eggs deposited at that location are probably lost, as muddy ditch water pours into this location with every runoff-generating rainfall.

Silvester Creek was muddy on every visit, and muddy water was commonly seen draining into the stream at several crossings, including the ATV bridge and pipeline right-of-way. Most of the TSS was inorganic, typical of road runoff. The TSS concentrations we found were much higher than the 0.6 mg/L reported by (Tripp *et al*. 1979a) for the mouth of the creek in fall 1978; most were higher than 16 of the 17 foothills streams Tripp *et al*. (1979a) sampled that fall (mean 2.2 mg/L, range < 0.2 - 14.8 mg/L). Elevated TSS concentrations now are visually obvious and chronic through the open-water season from snowmelt- and rainfall-generated runoff, and from repeated vehicle fording.

TSS effects on trout are tabulated and predictable: they depend on concentration and duration of exposure (Newcombe and Jensen 1996). Except for the spike of TSS below the pipeline crossing, concentrations were between 10 mg/L and 40 mg/L. TSS concentrations in this range, if they persisted for a day, would cause minor to moderate physiological distress to juveniles and adults, but major physiological distress to eggs and larvae. If they persisted for weeks they would impair homing, reduce feeding rate and success, producing poor condition in juveniles and adults. In eggs and larvae they could cause 20-60% mortality.

To better estimate duration, a follow-up study was completed during the Cutthroat Trout spawning period in spring 2013 (Mayhood 2013). TSS concentrations at headwater control sites uninfluenced by linear disturbances never exceeded 1.2 mg/L. During prolonged rainfall, road-related TSS concentrations commonly averaged 20-40 mg/L over at least 1 km of creek, and averaged 20-30 mg/L at some stations even during prolonged dry weather. Thunderstorms and vehicle crossings produced spikes of 154 mg/L and 179 mg/L, respectively, at two different stations. A conservative estimate using the lowest observed dry-weather TSS concentrations (5-7 mg/L) persisting through the 6.5-week period of egg incubation and larval in-gravel residence suggested that eggs and larvae sustained paralethal to lethal effects, including 20-60% mortality from TSS exposure in Silvester Creek, in spring 2013. Considering all of the survey results as a reasonable sample of a typical year, it was estimated that eggs and larvae suffer at least 40 - 60% mortality, and adults experience moderate physiological stress due to TSS exposure in most years. Juveniles would sustain major physiological stress, reduced feeding rate and success, and show poor condition.

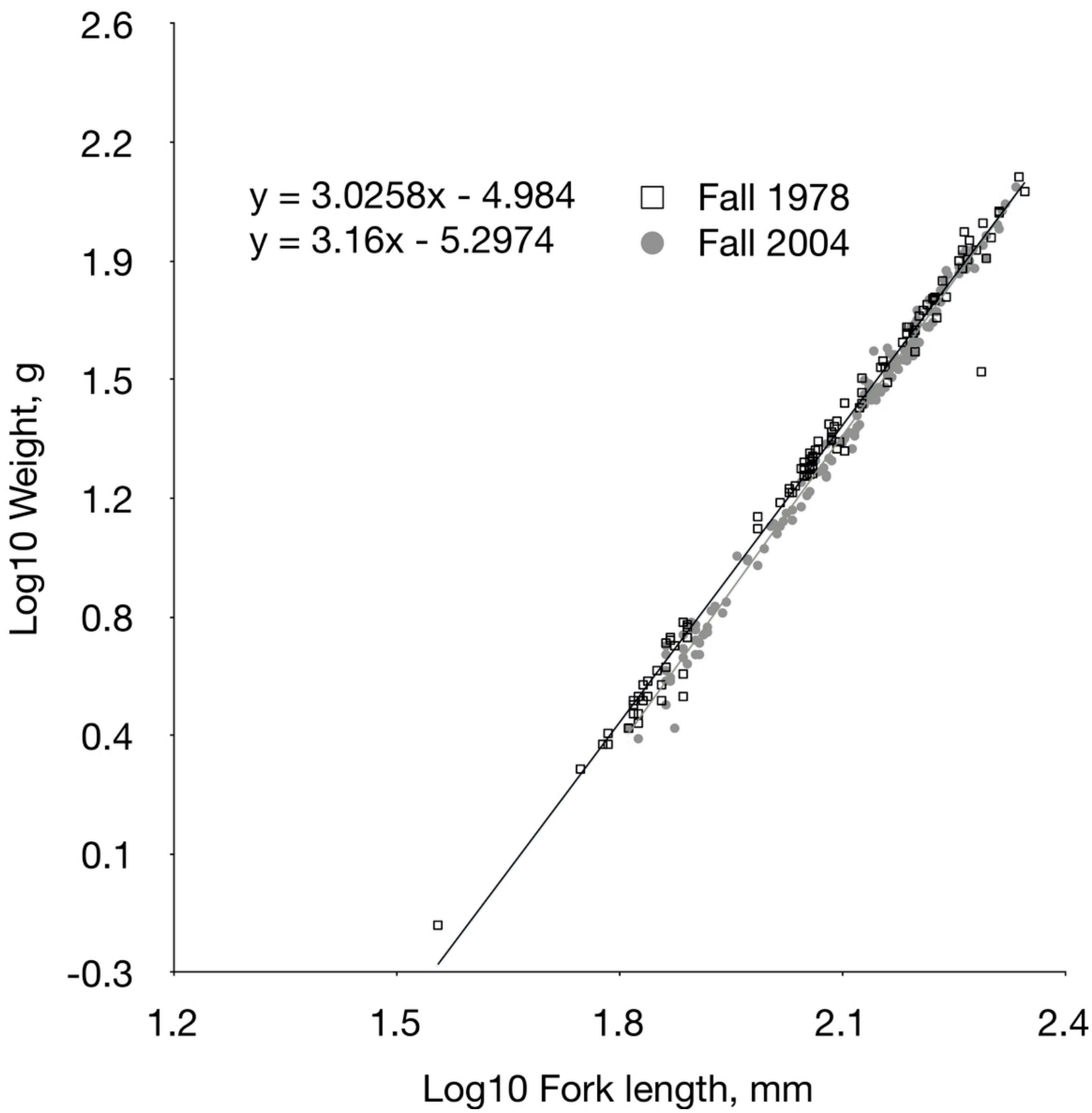
The TSS concentrations we observed in fall 2010 are similar to those found in spring 2013, probably persisted for similar time periods for similar weather and vehicle activity, and would have had similar effects on juveniles and adults. Eggs and larvae would not have been present in fall 2010.

There is evidence of reduced condition in this population from the difference in the weight-length relationship between trout caught in fall 1978 (Tripp *et al*. 1979b) and fall 2004 (Paul and Dormer 2005). The slopes of the weight-on-length regression of the Silvester Creek cutthroats sampled in the fall of 1978 and 2004 differed ($t = 3.25$, $p < 0.01$, d. f. = 252; Zar 1974), trout being lower in weight for a given length in 2004 than 1978. The difference was greatest in the smaller (i.e., juvenile) fish, which in 2004 were 10-15% lower in weight than their 1978 counterparts (Figure 5).

The IWAP peak flow vs. surface erosion score is a good predictor of channel and sediment problems actually observed in stream networks on the southern East Slopes, even though those problems may not be directly caused by increased peak flows or surface erosion (Sawyer and Mayhood 1998). This is probably owing to the prominence of road-related measures in the IWAP: linear disturbances of all kinds are often the cause of other issues besides changes in surface erosion or extension of the drainage network. The channel damage and substrate changes at the ATV crossing are of this type in part, and consistent with the high IWAP risk assessment. The channel damage at the cattle crossing is attributable mostly to livestock bank trampling not considered in the IWAP, therefore not related to it, although ATV tracks contributed erosion channels. The latter is also consistent with the IWAP assessment. The high TSS concentrations are a direct result of erosion from the road network at road crossings, are a basin-wide phenomenon, so are consistent with the IWAP risk evaluation.

The TSS concentrations are high enough and persistent enough to be seriously harmful to trout, and may be causing population-level effects. The linear disturbance network is the principle cause of high TSS throughout the creek, and of local channel damage and substrate changes at crossing points. To reduce the level of risk to the valuable Silvester Creek Westslope Cutthroat Trout population, especially from high TSS concentrations, the road network needs to be reduced and disconnected from the stream and its tributaries.

Figure 5. Weight - fork length relationship of Westslope Cutthroat Trout population above the falls in Silvester Creek, fall 1978 (Tripp *et al*. 1979b; N = 109) and fall 2004 (Paul and Dormer 2005; N = 147).



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