EFFECTS OF CATASTROPHIC BLOWDOWN ON HEADWATER STREAMS OF THE ROUTT NATIONAL FOREST, COLORADO

A Thesis Presented to the Faculty of the

Department of Earth and Atmospheric Sciences

University of Houston

In Partial Fulfillment

of the Requirement for the Degree

Master of Science

By

Rose Aimée Feinstein

August 2012

Effects of Catastrophic Blowdown on Headwater Streams in the Routt National Forest, Colorado.

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Abstract

My study focuses on the effects of a severe storm event on headwater mountain stream morphology. In 1997 the Routt Divide Blowdown felled 13,000 acres of trees in the Routt National Forest, Colorado, causing massive amounts of large wood (LW) loading in streams. A previous study (Massey, 2000) established a 1998 baseline in three streams: Sanchez Creek (control stream with 0% blowdown, no human activity, no fire), Agnes Creek (88% blowdown, no human activity, fire-affected) and South Fork Lost Dog (SFLD) Creek (92% blowdown – past logging and road construction, fire-affected). I resurveyed the streams during the summers of 2010 and 2011. I mapped channel morphology, classified and quantified the number, location, and function of LW pieces within the stream channel, and measured pebble counts.

SFLD Creek had a reach-averaged increase in cross-sectional area (1998-2010) of ~1 m^2 (~90%). Agnes Creek had a reach-averaged increase of ~0.1 m^2 (~25%). Sanchez Creek had a reach-averaged increase of ~0.5 m^2 (~45%). SFLD Creek became deeper by ~0.25 m (~65%), Agnes Creek became shallower by ~0.01 m (~3%), and Sanchez Creek became deeper by ~0.1 m (~35%). SFLD Creek was the only stream to have a coarsening trend in particle size. Comparisons of the channel margins surveyed in planview indicated changes in channel width. Agnes Creek widened by 1.5 m (~30%) whereas SFLD Creek narrowed by ~0.4 m (~20%). The map view of the control stream (Sanchez) was not surveyed in 2011 because of high snow pack.

My initial hypothesis was that blowdown-related LW was a primary control on channel morphology over the 12-13 years study period. However, statistically significant differences in changes in area, width, and depth exist between SFLD and Agnes Creeks. In contrast, changes between Agnes and Sanchez Creeks were not statistically significant. This suggests other factors such as logging and road construction (as seen only in the SFLD Creek watershed) may play a larger role in channel morphology. To assess the importance of these factors on channel morphology, further studies are needed, including discharge and bank stability data, as well as recent mapping of the control stream (Sanchez).

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1. INTRODUCTION

The objective of this project is to study the role of blowdown-related large wood on Rocky Mountain headwater stream channel morphology. The project is unusual in that it focuses on a large-magnitude, low-frequency event that caused massive loading of LW into streams. This study compares geomorphologic data collected in 1998 (Massey, 2000) to the present channel conditions of three headwater streams in the Routt National Forest. A substantial number of trees were brought down in that single event; however a subsequent beetle outbreak (mountain pine beetle, *Dendroctonus ponderosae*) and a high intensity wildfire in 2002 helped fell remaining trees in the area. A partial re-survey was conducted by the US Forest Service in 2004. The original study in 2000 focused on determining the quantity and type of new blowdown-related LW. This study addresses subsequent changes in wood loads and their effect on channel morphology.

My initial hypothesis was that blowdown-related LW was been the primary driver of detectable changes in channel morphology occurring over the past 13 years (1998-2010/2011). This should have been evident in the differences between a study reach unaffected by the blowdown and study reaches with blowdown-related LW. It was expected that reaches affected by the blowdown would contain a greater total number of LW pieces, which were hypothesized to cause a greater overall change in channel morphology to those reaches. As will be shown, this appeared not to be the case.

A control stream, Sanchez Creek, not affected by the blowdown was compared to two other stream reaches, Agnes Creek and South Fork Lost Dog Creek. It was studied to see what lasting effects these disturbances had on headwater streams in the Routt National Forest. Furthermore, the control stream has not undergone any recent major disturbances, while the other two streams experienced additional disturbances such as salvage logging, fires, and dirt road construction.

Several authors (i.e. Dahlstrom et al., 2005; Harrison & Keller, 2007; Manners & Doyle, 2008) have stated that instream LW was smallest in size in the most disturbed watersheds. However, these studies focused on streams with naturally occurring levels of LW loading into streams. The disturbances affecting watersheds in this study are of a much greater magnitude; entire drainage basins were cleared of trees some of which subsequently fell into riparian and active channel areas. Therefore, it was predicted that pieces of LW found in the undisturbed reach would be larger on average than LW found in either of the disturbed reaches.

The formation of log jams impacts the channel form both up- and downstream from the obstruction. Channel widening, lateral migration, and avulsion are expected upstream of logjams and sediment-trapping log steps (Abbe & Montgomery, 2003; Brummer et al., 2006). Pool formation is expected downstream from logjams as wood concentrates flow causing scour. These features were expected to be much more pronounced in the reaches affected by the blowdown. This should be apparent by examining the channel planform and wood orientation in ArcMap, as well as relevant cross-section data and field observations. An assessment of the height and spacing of

steps, pools, and cascades should also reveal an increase in step frequency from the control reach to the two impacted reaches (Gurnell et al., 2002).

Although bank vegetation, material and stream discharge may all present confounding influences on channel morphology, their effects are expected to be rather limited. For example, Abernathy and Rutherford (1998) claim that large wood within the channel dominates the channel morphology of headwater reaches. Still, a comparison of these variables between the three stream reaches is necessary.

2. PREVIOUS WORK

Controls on the morphology of stream channels vary and reflect local geology, climate, and anthropogenic activity. A substantial change in these variables may result in channel modification, the scale of which depends upon many factors. Channel type largely determines the magnitude of morphologic change that occurs due to external stimuli (e.g. Montgomery & Buffington, 1997; Buffington et al., 2002; Gomi et al., 2002)

At the top of the stream morphology hierarchy is channel type. The channel types of the study reaches are locally similar to lowland gravel bed streams, but reflect higher slope and an increased channel roughness due instream large boulders and other obstructions. They are better described as step-pool to cascade channels, in some areas forming a staircase profile (Grant et al., 1990; Montgomery & Buffington, 1997). Step-pool streams commonly develop a vertically stepped longitudinal structure controlled by infrequent high-magnitude discharges and low sediment supply (Montgomery & Buffington, 1997). Cascade channels are characterized by steep slopes

and the presence of large (relative to flow depth) particles that induce tumbling flow and energy dissipation (Montgomery & Buffington, 1997). The largest roughness elements in step-pool streams are organized into steps perpendicular to flow, and are randomly distributed in cascade channels. Both channel types are interspersed locally in the study reaches.

The next level of stream morphology hierarchy is the channel unit. The spacing of channel units such as pools, steps, and riffles within stream channels has been extensively studied in recent years. A channel unit is defined as a "morphologically distinct portion of a channel, one to a few channel widths in length" (Trainor & Church, 2003). One of the most common approaches is the study of hydraulic flow parameters (Harrison & Keller, 2007). One theory for spacing in pool-riffle channels proposes a velocity reversal, in which riffle velocity exceeds pool velocity during low flow, but pool velocity exceeds riffle velocity during high flow. This results in smaller particles being removed from riffles and deposited in pools during low flow, and the scouring of pools during high flow (Harrison & Keller, 2007). Although this hypothesis has been the focus of several studies (as cited in Harrison & Keller, 2007 p. 233) it has not been universally accepted.

Although step-pool patterns form naturally as a state of equilibrium within channels, large (relative to flow depth) obstructions such as boulders may force pools and riffles to occur at greater spatial frequencies (Gurnell et al., 2002). This is especially common in high-gradient streams, which are characterized by "large roughness patterns and irregular flow patterns" (Harrison & Keller, 2007, p. 233) and generally

contain a greater number of obstructions (Tecle et al., 2001). Obstructions in mountain streams create roughness elements that significantly alter the hydraulics of water and sediment movement, and are considered to be the primary control on pool frequency and geometry (Buffington et al., 2002). The effects of an increased number of roughness elements within the channel cause flow convergence and an increase in sediment transporting capability (Harrison & Keller, 2007). However, the volume and availability of sediment also plays a large role in the formation of steps and pools (Buffington et al., 2002).

Finally, the last level of hierarchy is the distribution of grain sizes within a fluvial channel. This distribution reflects initial supply conditions and major transport processes (Knighton, 1998). Grainsize distribution is especially important in low-order streams, which are commonly characterized by alternating channel units such as pools, riffles and cascades. These channel units are defined partially by differing grain sizes (Montgomery & Buffington, 1997).

Grainsize distribution, which divides fine-grained pools from coarse-grained riffles and steps, is a product of "erosion, transport, and deposition … and provides a framework for examining channel processes in mountain drainage basins" (Montgomery & Buffington, 1997, p. 596). Extremely high discharges are able to move nearly every size clast in the channel, and it is only within the falling limb of the hydrograph that channel units and their frequencies are established or re-established (Montgomery & Buffington, 1997).

Disturbances in low-order mountain streams are especially important because headwater stream conditions influence many downstream changes (Wohl & Merritt, 2007). For example, sediment supplied from steep headwater channels can affect downstream stability, and a change in upstream sediment supply can decrease downstream stability (Wohl, 2006).

2.1. LARGE WOOD IN MOUNTAIN STREAMS

One of the most common obstructions that force geomorphic changes within high-gradient stream channels is instream large wood (Buffington et al., 2002; Gurnell et al., 2002). Specifically, instream large wood is defined, here and elsewhere, as trunks and large branches fallen from nearby riparian areas and hillslopes. Studies focusing on the effects of wood on channel morphology and flow hydraulics have increased in number within the last 30 years. Three key themes driving recent research have been the impact of wood on flow hydraulics, the transfer of sediment, and the geomorphological results of these two variables in river channels (Gurnell et al., 2002).

Wood as a geomorphic control is important in streams of any size, but the ratio of wood length to channel width is the major variable driving morphological change for small streams (Gurnell et al., 2002). In small streams, the wood length is relatively large in comparison to the channel width. This results in an overall low wood mobility, which in turn causes wood to control rather than respond to hydrological and sediment relationships (Gurnell et al., 2002). Other important factors controlling the effects of

wood on channel morphology include the spacing, size, and longevity of obstructions (Cadol & Wohl, 2011).

Wood has been found to increase the overall stability of small channels by creating channel units such as bars and jams, and by initiating the abandonment of smaller channels (Adenlof & Wohl, 1994; Gurnell et al., 2002). Large wood (LW) appears to have the greatest influence in forested, headwater streams, where it provides a major control on both channel roughness (Faustini & Jones, 2003) and energy dissipation (Gurnell et al., 2002). Wood in headwater streams also causes localized scour of beds and banks while creating aquatic habitats (Nowakowski & Wohl, 2008).

Photo 1. Large log jam in Agnes Creek, 2010.

Wood in small streams is found to be primarily oriented perpendicular to flow, while wood in larger streams becomes primarily oriented parallel to flow direction (Gurnell et al., 2002). This is probably a reflection of the ratio of wood piece length to channel width, which is higher in smaller channels. Mobility also increases in larger streams, which also controls the orientation of LW.

When incorporated into the channel bed, large wood forces a stepped longitudinal profile that stores sediment and reduces the overall transport efficiency of streams (Faustini & Jones, 2003). Furthermore, the concentration and orientation with respect to flow direction of LW in streams also modifies channel morphology. The orientation of LW can either intensify or limit the development of helical motion, which largely shape channel geometry. (Daniels & Rhoads, 2007). Smith et al., (1993) showed that LW could control the spacing interval of channel units such as pools. Logjams may also force localized scour, flow divergence, and sediment storage, which can control channel morphology (Montgomery & Buffington, 1997).

Large wood is known to affect sediment loading and transport in streams, but the relationships are complex (Smith et al., 1993). These relationships reflect the interaction between LW in the channel, flow hydraulics, and sediment transportation and storage (Gurnell et al., 2002). For example, LW in streams commonly creates steps that trap sediment, and the experimental removal of LW was shown to decrease such sediment storage sites (Smith et al., 1993). In one study, 49% of total sediment storage within 7 streams was attributed to wood (Gurnell et al., 2002).

Sediment in low-gradient rivers is commonly stored in bars downstream of wood, but sediment in high-gradient streams is stored upstream of wood obstructions (Gurnell et al., 2002). This is not only a major source of the step-pool longitudinal profile discussed above, but also provides for the rapid release and transportation of sediment once the obstruction is removed (Gurnell et al., 2002). Large wood in streams initially reduces downstream sediment transportation by storing it, but pulses of downstream sediment movement occur once these sediment storage sites are full (Adenlof & Wohl, 1994; Tecle et al., 2001).

The removal of hillslope trees, either by natural causes or harvest, has been shown to affect water yield. Living trees take up large amounts of water, and their absence may not only increase available water in a system but also affect runoff patterns during peak snowmelt (Wei & Lin, 2008). Forest harvesting has also been shown to increase peak discharge in small (less than 600 m^2) watersheds (Jones & Grant, 1996).

Controls on the amount of large wood within streams include land use such as logging and development, and natural processes e.g. fire, wind and insects. For example, studies have shown that streams within logged or managed watersheds contain fewer pieces of LW (Nowakowski & Wohl, 2008), and that LW in un-logged streams tends to be larger (Dahlström, et al., 2005). Fires provide a natural feedback loop by not only providing LW to streams, but also concentrating it and thus affecting the severity of later fires (Bendix & Cowell, 2010).

Climate may affect the amount of large wood in streams in several ways. One of the most distressing effects is the spread of native bark beetles. It is thought that bark beetles have proliferated in recent years due to temperature variations that allow more breeding cycles per year (Bentz, et al., 2010). Bark beetles have killed billions of hectares of coniferous trees in North America in recent decades, which may have serious consequences on forest ecosystems as new species fill in the void (Bentz, et al., 2010). This massive "beetle kill" may likely result in larger than average wood loading into forested streams as killed trees begin to decay, break, and fall into adjacent channels.

One of the most severe wood-loading events of the central Rocky Mountains occurred on October 25, 1997, when an unusual weather event caused high winds and gusts up to 50 m/s to topple close to 13,000 acres of old growth forest (Meyers et al., 2003). Known as the Routt Divide Blowdown, this storm was unusual in that the high winds were from the east, rather than the west, and the standing trees were unable to withstand the new direction of stress (Meyers et al., 2003). During the storm, local streams were loaded with massive amounts of LW, both in the form of living trees and trees that had previously been killed by beetles.

In 2002, the Hinman Fire burned large parts of the blowdown area, including the watersheds of Agnes and SFLD Creeks. This added another substantial amount of LW to many streams in the Routt National Forest and burned the already downed trees with high severity. Past studies suggest a difference in the sediment routing between disturbed and undisturbed watersheds, based on the amount of sediment-trapping

debris added to or removed from the system (Tecle et al., 2001). In particular, watersheds that have experienced fires may see a decrease in bank stability and an increase in sediment supply, which can both affect channel geometry by causing channels to become wider (Eaton et al, 2010) and more aggraded with fire-related sediment.

Large wood in streams is a vital part of channel morphology and habitat, but more studies are needed to focus on the various sources and management tactics of large wood. Specifically, the massive loading of large wood by severe disturbances (fire or blowdown) into streams been little studied. This study may provide insight into how changing climate and land use may affect headwater streams subject to high levels of large wood loading.

3. STUDY LOCATION AND DESCRIPTION

The study site is located within the Routt National Forest in northern Colorado, just west of the continental divide and the Mt. Zirkel Wilderness (figs. 1 & 2). The field location includes three tributaries of the North Fork Elk River: Sanchez Creek, Agnes Creek, and South Fork Lost Dog Creek. Each stream reach is at a relatively high elevation (between 2865 and 3505 meters) and is between 300 and 700 m long. The sites were first chosen and surveyed in 1998 and the management characteristics are summarized in Table 1 (after Massey, 2000). The streams in this study are characterized by steep slope (14-18%), small drainage areas (average of 3.4 km^2), and a gravel to boulder glacial debris substrate. Bedrock was only encountered in one roughly

5-m stretch of Agnes Creek. The three study reaches are considered to be “small” streams, which are defined as having a channel width smaller than the mean wood length (Gurnell et al. 2002). According to Massey (2000), Agnes Creek and South Fork Lost Dog Creek are first order streams, and Sanchez Creek is a second order stream.

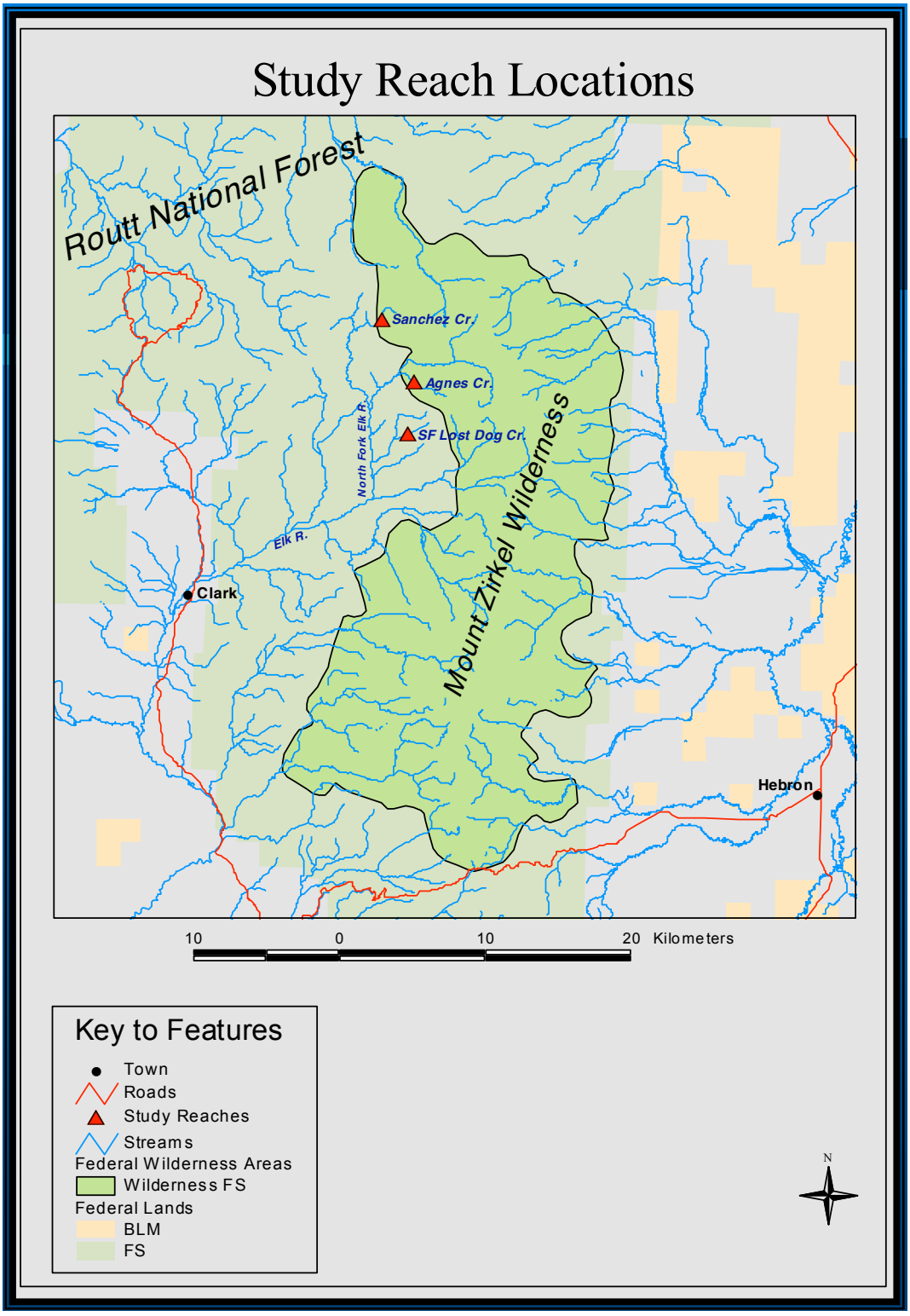


Figure 1. Study location (Massey, 2000).

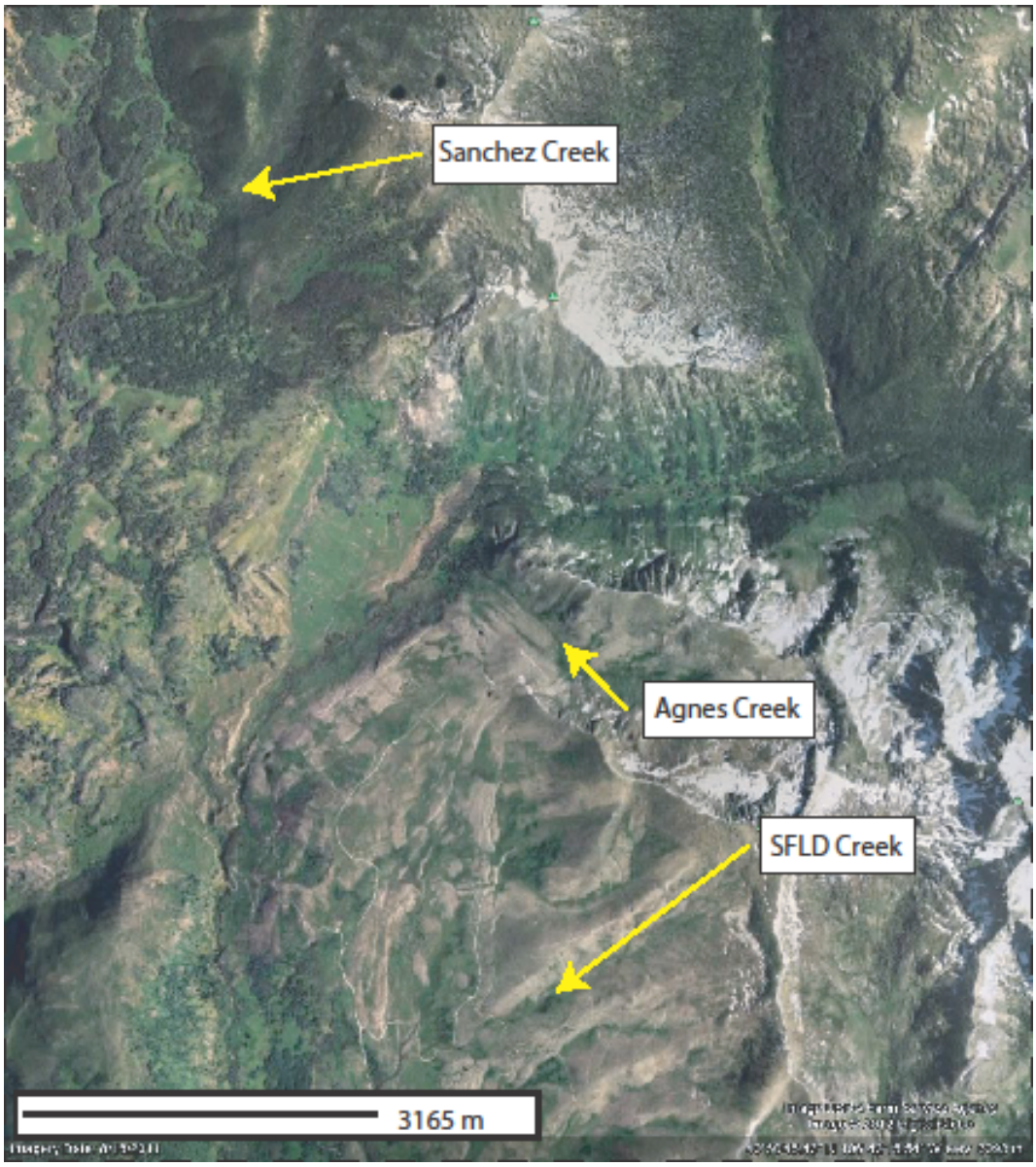


Figure 2. Study locations (GoogleEarth) Note Agnes and SFLD Creeks are in barren blowdown area.

Stream	Blowdown (1997)	Hinman Fire (2002)	Salvage Logging (1960 and post-blowdown)	Wilder-ness Area	Beetle Kill
Sanchez Creek	No	No	No	Yes	Yes
Agnes Creek	Yes	Yes	No	Yes	Yes
SFLD Creek	Yes	Yes	Yes	No	Yes

Table 1. Study area descriptions.

Agnes Creek is within both the blowdown impacted area and a wilderness area (photo 6). No past logging has occurred along the study reach. South Fork Lost Dog (SFLD) Creek is within the blowdown area but is not in a protected wilderness area (photos 3, 4 &5). Past logging and post-blowdown salvage logging have both occurred in this watershed. Logging roads have been constructed in the watershed of SFLD. Although their exact age is unknown, they are estimated to be at least 40 years old, and have been decommissioned since the burn by pulling culverts. A buffer was established around the wetland area, but few records exist of the effects of past logging. Most of the buffer was the predominant fuel remaining in the watershed and was burned severely in subsequent fire. Sanchez Creek was established as the control, as it is within a wilderness area and was not affected by the blowdown, the fire, or past logging and road construction (photo 2).

Photo 2. Sanchez Creek watershed, 2011. Note presence of riparian trees; many are dead due to beetle kill.

Photo 3. SFLD Creek, 2011. Note logs creating log step.

Photo 4. SFLD Creek post blowdown and pre-fire, 1998 (Massey, 2000).

Photo 5. SFLD Creek post fire, 2003 (USFS).

Photo 6. Agnes Creek, 2011. Note lack of riparian trees, and the presence of burnt and toppled trees in the creek.

The study area is underlain by glacial debris surrounded (outside of the study location) by outcrops of pre-Cambrian granite and gneiss (Stoeser et al., 2005). The three study reaches are within the Park Range, which forms part of the Continental Divide. Topography of the area includes glacial features such as lateral and terminal moraines and U-shaped valleys below the study reaches. Perched water tables within glacial drift cause seasonal wetlands to form, which are sometimes adjacent to the study reaches (Massey, 2000). The substrate within the study reaches is mainly gravel to boulder-sized sediment.

Vegetation is mainly low grasses, shrubs, and clumping wildflowers in the study reaches of Agnes Creek and South Fork Lost Dog Creek. A few small stands of dead

(beetle kill) pine trees are adjacent to these stream reaches. The Sanchez Creek study reach is entirely within an old-growth forest, with both living and dead (beetle kill since the last re-survey) trees in abundance in the adjacent hill slopes and riparian zones. Some trees remain living immediately adjacent to or within the stream, a feature not seen in the other two study reaches.

4. METHODS

4.1. FIELD METHODS

4.1.1. Survey methods

To assess changes in channel planform, a total station was used to survey the location of the right bank, left bank, and centerline of each stream reach. Survey points in the planform study were selected to best record vertical and horizontal breaks in slope and stream bank characteristics. Points ranged in distance from a few centimeters to nearly a meter in some areas with little change in slope.

Control points from the previous survey were the cross sections. The cross sections were marked with rebar driven into the ground. There are 2 rebar stakes on either side of the channel. They were located at distances roughly 2 and 10 m away from the channel edge. The 2 m rebar were established the first year post-blowdown while the 10 m rebar were established in 2004 (after the 2002 fire) by the US Forest Service to provide additional data on channel migration and avulsion, should it occur. Agnes Creek and Sanchez Creek each had 10 cross sections, while South Fork Lost Dog

had 16. All cross sections were re-located for Agnes and SFLD. However, only 8 cross sections were re-located in Sanchez Creek. These cross sections were surveyed using the same method described above, except in the case of Sanchez Creek, where cross sections were surveyed using a rod and level.

Channel depth and bankful width were determined from the cross section surveys of each reach. During each cross section survey, the points signifying bankfull height on each bank were recorded. These values were used to calculate the amount of change in cross sectional area between survey periods. The trapezoid rule was used to calculate cross-sectional area.

$$\int_a^b f(x)\,dx \approx (b-a)\frac{f(a)+f(b)}{2}.$$

4.1.2. Wood methods

All large pieces of wood (greater than 1 m in length and 10 cm in diameter at one end) were tagged using numbered aluminum tags and nails for future relocation and to monitor movement. The original (2000) study tagged a random sampling of logs, and it was noted when an original tag from this survey was found in 2010 or 2011. All logs were categorized based on their location, and function within the stream using criteria recommended by Wohl et al. (2010). Each end of the large wood (LW) was surveyed with a total station to map location and orientation, and to determine the length of each log. The diameter of each end of each piece of wood was measured using tree calipers.

The volume of LW was calculated following the methods of the original (2000) study, using the following equation modified from Gomi et al. (2003):

Volume = length * π * (average diameter/2)^2

The wood data were then used to address questions such as a comparison of pre-blowdown wood (as defined in Massey, 2000), wood immediately post blowdown, and current wood. The amount of breakage and movement of large wood was observed, especially for pieces that could be re-located from the original (2000) study. A visual survey was completed in 2011 of any movement of wood tagged in the 2010 survey. Observations regarding the size, frequency, and locations of logjams were also made.

The following tables indicate how each piece of wood was categorized. These categories are based upon the work of Wohl et al. (2010), which called for the standardization of metrics used in studies of large wood in streams. The categories are as follows.

(A -Age) Wood characterized using this category is relatively ranked from oldest to youngest using visual indications such as attached bark and needles, rot, or decay. (B - Stability) Stability of wood in the channel was assessed to estimate relative mobility. Stable pieces of wood have both ends anchored to the bank or channel while unstable pieces of wood are either floating or resting in the channel and could be moved by high discharges. The amount of (C) burn (unburned, partly burned, and completely burned) was assessed for each log as another measure of age. This category was used to determine which logs might have been thoroughly incorporated into the stream prior to the Hinman fire of 2002. (D - Function) The function of each piece of large wood was

determined in order to better understand its potential to alter channel geometry. (E – Channel type) was determined for each piece of large wood. This was simply an observation of channel type where the wood was located within the stream. (F) Structural association of each log was recorded. This category was used to determine how often LW was associated with a particular structure within the stream, such as a debris jam, the bank, a bar, or a log step.

Other factors included the orientation of the wood with respect to overall flow direction, whether or not a root wad was attached to the log, and the source of the wood. Due to the amount of decay of most of the logs, source was mainly narrowed to "riparian" or "unknown".

Age
0 – Rotten
1 – Decayed
2 – Bare
3 – Limbs
4 – Bark
5 – Needles

Stability
0 – No ends stabilized
1 – One end
2 – Two ends

Burn
0 – Unburned
1 – Partly burned
2 – Completely burned

Function
0 – Drift
1 – Bridge
2 – Collapsed bridge
3 – Ramp
4 – Incorporated

Channel Type
1 – Pool
2 – Riffle
3 – Glide
4 – Rapid
5 – Step/pool
6 – Cascade
7 – Other

Structural Association
1 – Debris jam
2 – Tree/rootwad
3 – Boulder
4 – Meander
5 – Bar
6 – Bedrock
7 – Beaver dam
8 – Bank
9 – Log step
10 – Buried in bed
0 – None/other

4.1.3. Particle-size methods

Sediment particle counts were conducted at each of the ten cross sections in the three streams, including the channel bottom from 1 m above the cross section to 1 m below the cross section. The method used to conduct particle counts was a modified Wolman method, following the procedure of the previous (Massey, 2000) study (Wolman, 1954 and Harrelson, 1994). 100 particles were selected and measured at each cross section. Particle-size distributions were compared to both the 2000 study and to post-fire data collected in 2004. Changes in the distribution of particle sizes in the vicinity of each reach, along with changes in cross section, were used to detect patterns of aggradation and degradation associated with large-scale disturbances.

The particle-count method differed slightly from previous (Massey, 2000) methods. In 2011, particle diameter was only measured up to 128 mm, so all particle size distributions were truncated at 256 mm (indicating anything larger than 128 mm).

Agnes Creek and South Fork Lost Dog were completely surveyed in 2010. A complete survey consists of using a total station to survey cross sections, banks, all tagged wood, and major tributaries. A complete survey of Sanchez Creek (the control stream) was attempted in 2011, but due to a very late season high flow limiting access to the sites and reducing the length of the field season, only a rod and level survey of the cross sections could be completed. No additional data on the planform of Sanchez were collected. Other field data collected on all sites in 2011 were the pebble count, vegetation survey, and a wood assessment, in which all wood within the reach was tagged and manually recorded. While a total station survey of cross sections, bank

morphology, and wood locations would have been helpful for better understanding of the background levels of morphologic dynamics in Sanchez Creek, there are still enough cross section morphology data to complete an initial comparison between the other two streams. Data available for each site and years are indicated in Table 2.

	Plan-view survey	Cross-section survey	Wood survey	Wood metrics	Particle count
Sanchez	1998 - -	1998 2004 2011	1998 - -	1998 - 2011	1998 2004 2011
Agnes	1998 2010	1998 2004 2010	1998 - 2010	1998 - 2010	1998 2004 2011
SFLD	1998 - 2010	1998 2004 2010	1998 - 2010	1998 - 2010	1998 2004 2011

Table 2. Summary of field data collected across entire survey.

4.2. DATA ANALYSIS

The results from the channel survey were compiled primarily in ArcMap. Results from the cross-sectional surveys were manipulated in Excel.

Information recorded during the planview (total station) surveys also includes the spacing and height of steps and pools. These results were used to assess changes in step/pool spacing between surveys and reaches. Cross sections were constructed from the survey data using Excel to compare channel bottom changes between reaches and

surveys. Changes in channel bottom elevation were attributed to local aggradation or erosion. Pebble counts were processed using appropriate statistical analyses in order to compare particle sizes between reaches.

To determine whether a particle size distribution became coarser or finer overall, the plots were examined visually. A plot was determined to become coarser if the size distribution shifted to the right at any location along the line, and did not have any shift to the left (see Results). The opposite was true for a fining trend.

5. RESULTS

5.1. PLANVIEW

A comparison of planview between 1998 and 2010 was only available for Agnes Creek (Plate 2) and South Fork Lost Dog Creek (Plate 3). A planview survey of Sanchez Creek was done in 1998 (Plate 1), but not in 2010 due to the very limited field season following the recession of historical levels of snowmelt runoff.

The planview maps indicate where the channel banks and LW have changed position between the 1998 and 2010 survey periods. The maps can also indicate where LW has possibly had an impact on channel morphology, as seen in the examples below (figs. 3 & 4).

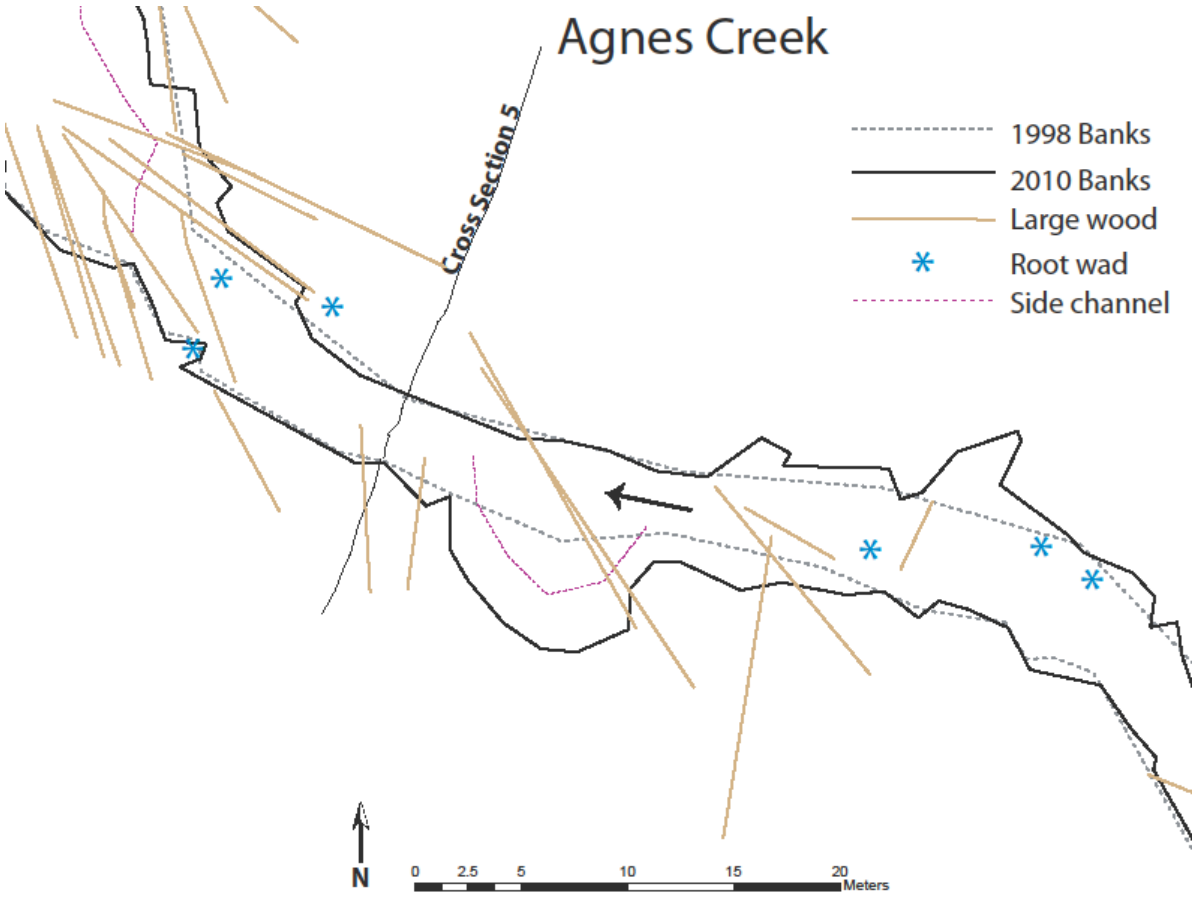


Figure 3. A portion of Agnes Creek showing bank position in 1998 and 2010, and associated LW. Note logs parallel to flow to the left of the cross section appear to be stabilizing banks in present location, while banks appear to be scouring around logs more perpendicular to flow to the right of the cross section.

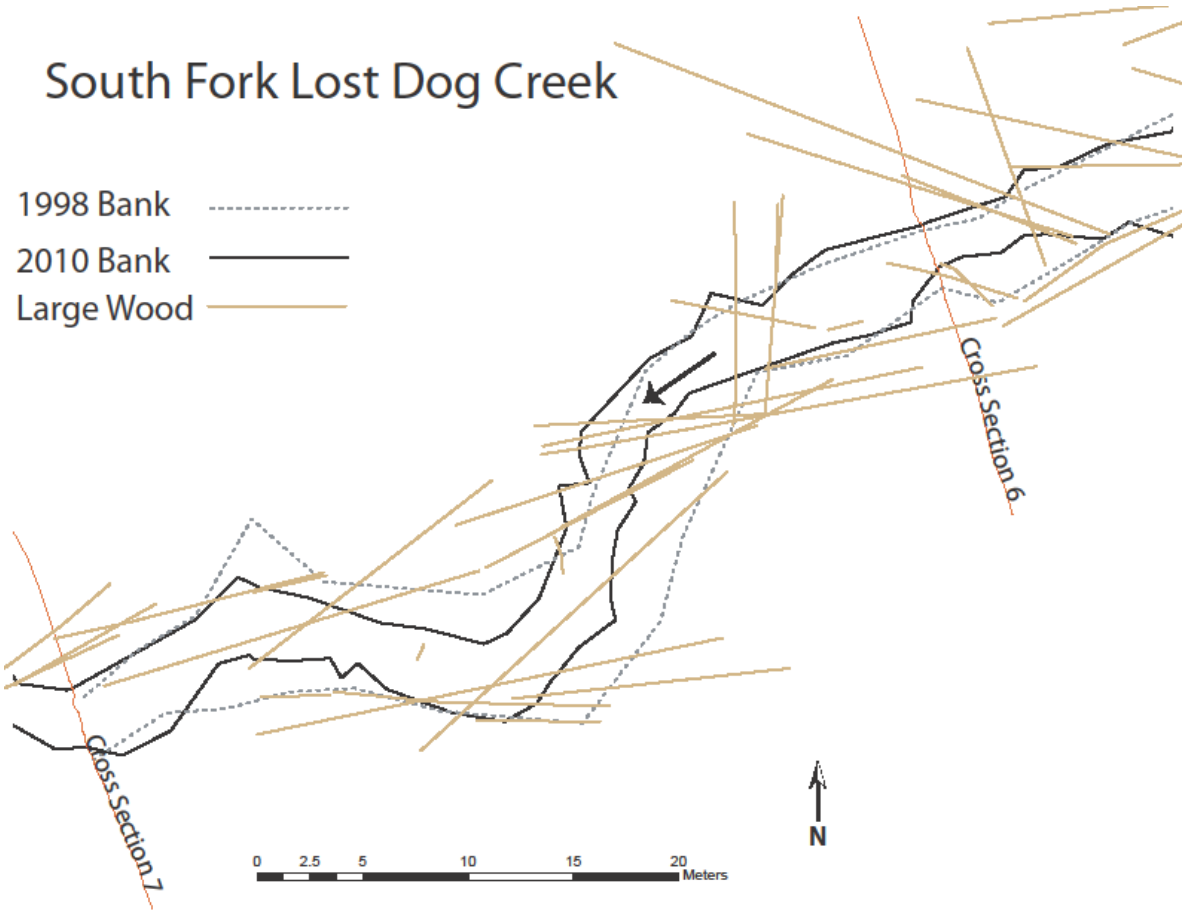


Figure 4. A portion of SFLD Creek showing bank position in 1998 and 2010, and associated LW. Note that logs downstream of cross section 6 appear to have caused channel narrowing and a shift to the west.

5.2. CROSS SECTIONS PARTICLE SIZE

5.2.1. South Fork Lost Dog Creek

Overall, SFLD Creek coarsened over both survey periods, and in both upstream and downstream reaches. SFLD Creek also appeared to scour or degrade, especially post-fire, between 2004 and 2011. This stream had an 89% increase in cross-sectional area from 1998 to 2010 (fig. 6).

SFLD Creek had the highest number of cross sections with changing particle -size distributions of the three streams. Figure 5 shows the changes in particle-size distribution for each cross section. A positive number indicates coarsening, and a negative number indicates fining; however no scale is implied. No value indicates that the distributions were equal for that study period, or that there was no overall fining or coarsening trend.

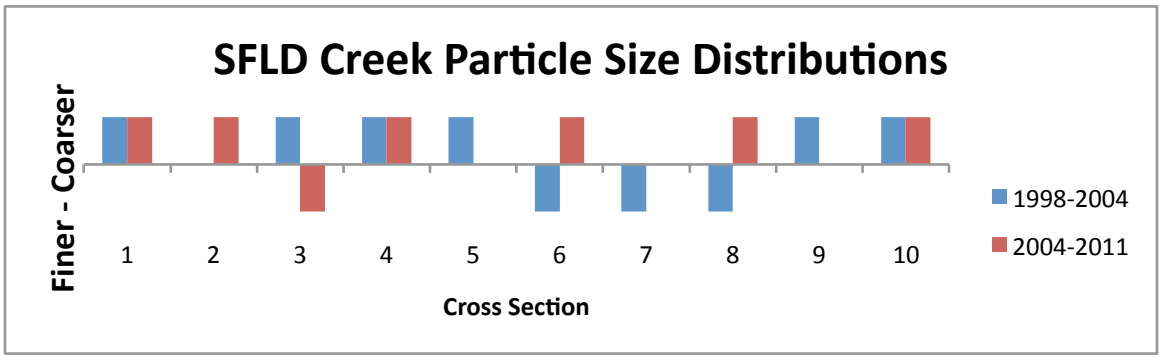


Figure 5. Particle-size distributions for SFLD Creek. The absence of a bar indicates "no change".

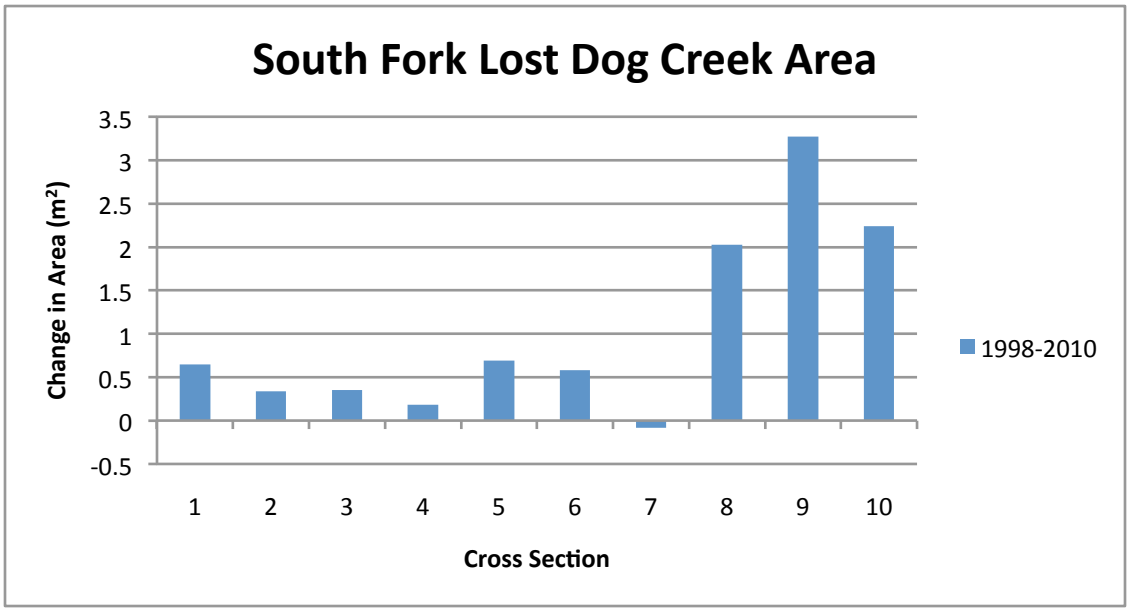


Figure 6. Changes in cross sectional area of SFLD Creek from 1998 to 2010. Positive values indicate scour; negative values indicate aggradation.

		Channel Response (No. of Cross Sections)		
		No Change	Fining	Coarsening
Channel Response (No. of Cross Sections)	No Change	0	1	2
	Aggradation	1	1	3
	Scour	0	1	1

Table 3. Summary of SFLD Creek cross sectional changes, 1998-2004.

		Channel Response (No. of Cross Sections)		
		No Change	Fining	Coarsening
Channel Response (No. of Cross Sections)	No Change	0	0	3
	Aggradation	0	0	1
	Scour	1	2	3

Table 4. Summary of SFLD Creek cross sectional changes, 2004-2011.

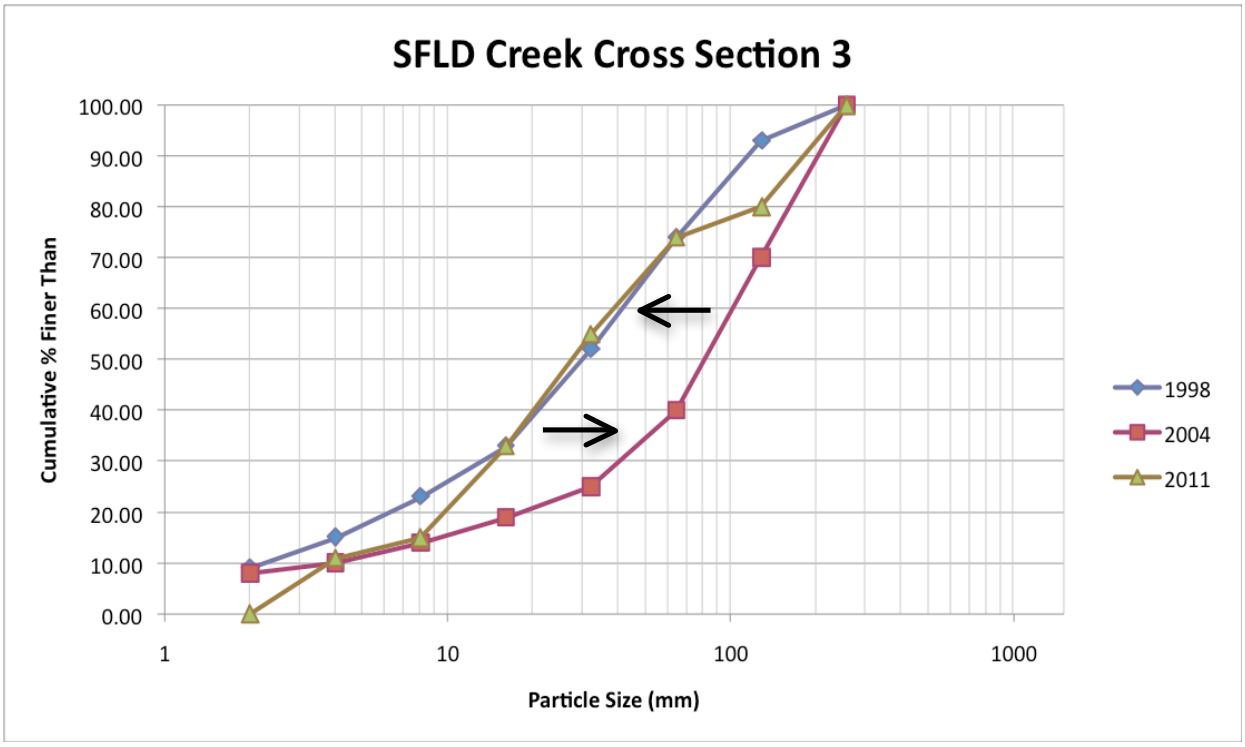


Figure 7. Particle-size distribution for SFLD Creek, cross section 3.

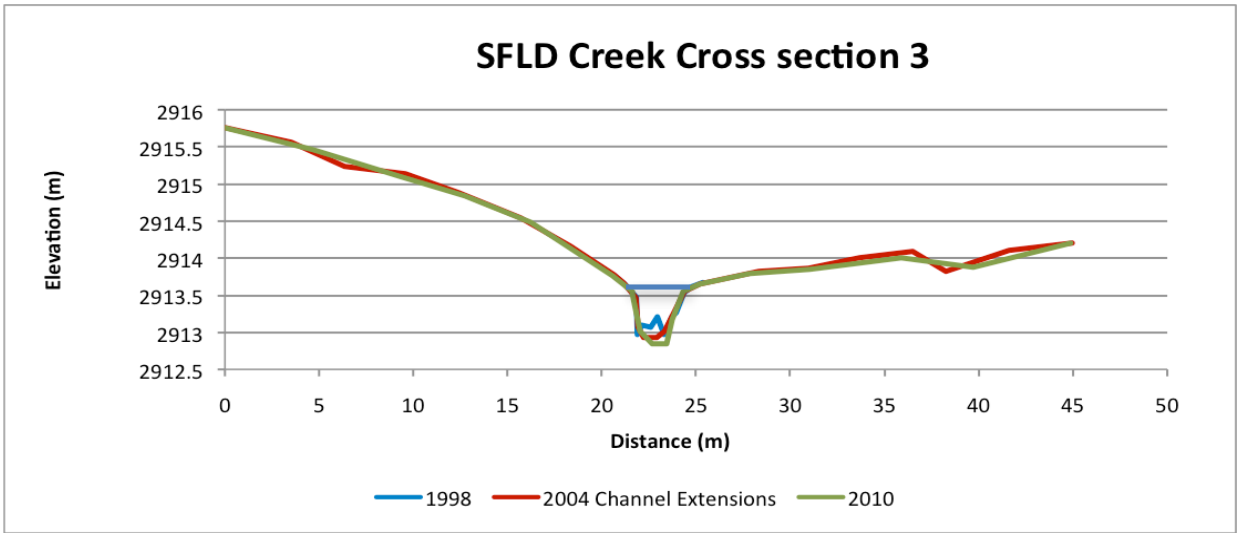


Figure 8. Cross sectional profile for SFLD Creek, cross section 3. Bankfull locations indicated by horizontal line.

Cross section 3, used here as an example of cross-sectional changes, coarsened between 1998 and 2004 as indicated by a substantial shift to the right on the graph in the middle portion of the distribution, but then became finer between 2004 and 2011, nearly returning to the 1998 distribution. This cross section also became deeper between 1998 and 2010, as can be seen by the cross section profile (fig. 8).

5.2.2. Agnes Creek

Overall, Agnes creek had the most change in particle-size distributions between 1998 and 2004. Between 2004 and 2011, the particle-size distributions remained relatively equal, did not have a major trend, or became finer. Between 1998 and 2010 Agnes Creek had an overall decrease in cross sectional area of 24% (fig. 10).

Contrary to SFLD Creek, Agnes creek appeared to have no overall trend in particle-size (fig. 9). The following graphs show the downstream changes in particle-size distribution and cross-sectional area.

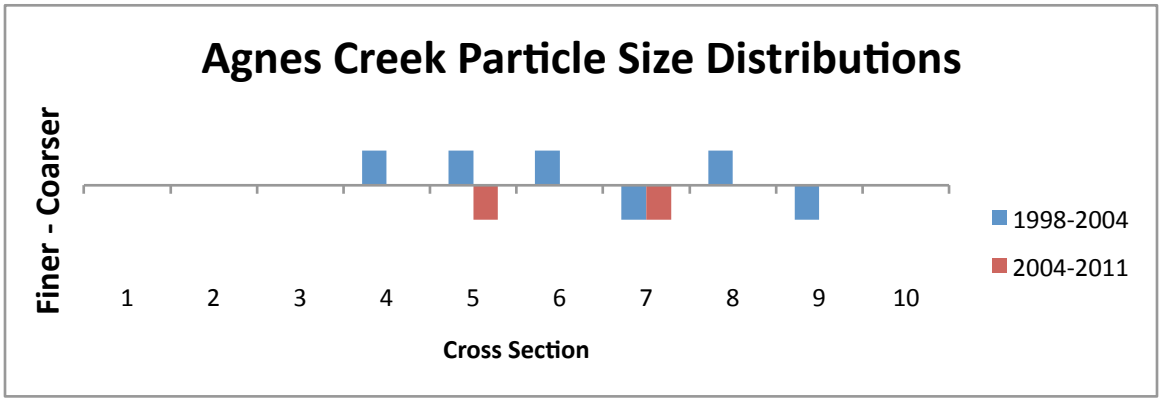


Figure 9. Particle size distributions for Agnes Creek.

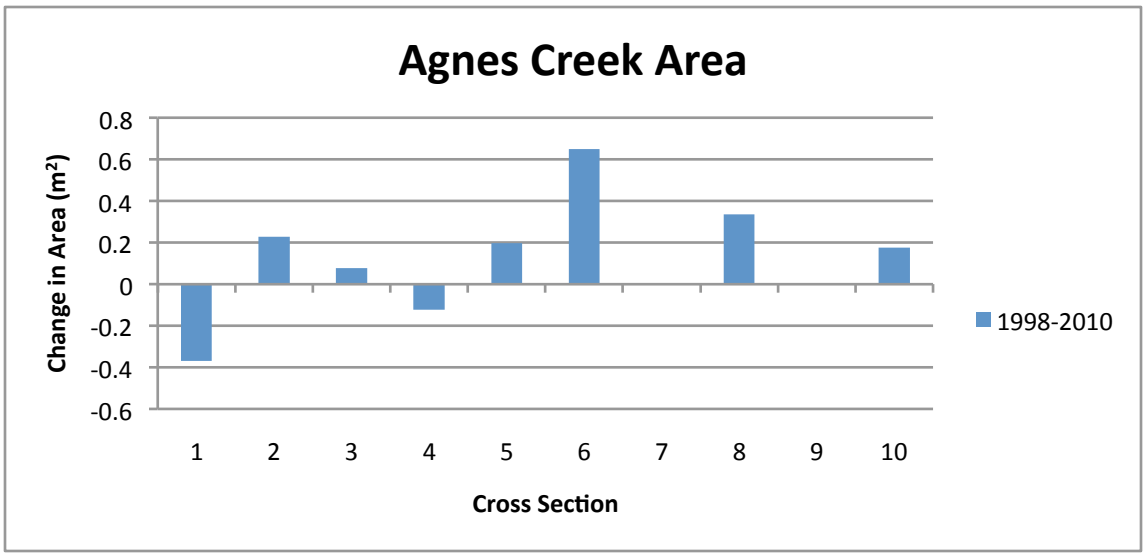


Figure 10. Changes in cross-sectional area of Agnes Creek from 1998 to 2010. Positive values indicate scour; negative values indicate aggradation.

		Channel Response (No. of Cross Sections)		
		No Change	Fining	Coarsening
Channel Response (No. of Cross Sections)	No Change	2	0	1
	Aggradation	3	1	1
	Scour	1	1	0

Table 5. Agnes Creek cross-sectional changes from 1998 to 2004.

		Channel Response (No. of Cross Sections)		
		No Change	Fining	Coarsening
Channel Response (No. of Cross Sections)	No Change	0	0	2
	Aggradation	1	0	0
	Scour	4	0	3

Table 6. Agnes Creek cross-sectional changes from 2004 to 2011.

The following charts are examples of particle-size distribution and cross-sectional area for Agnes Creek cross sections.

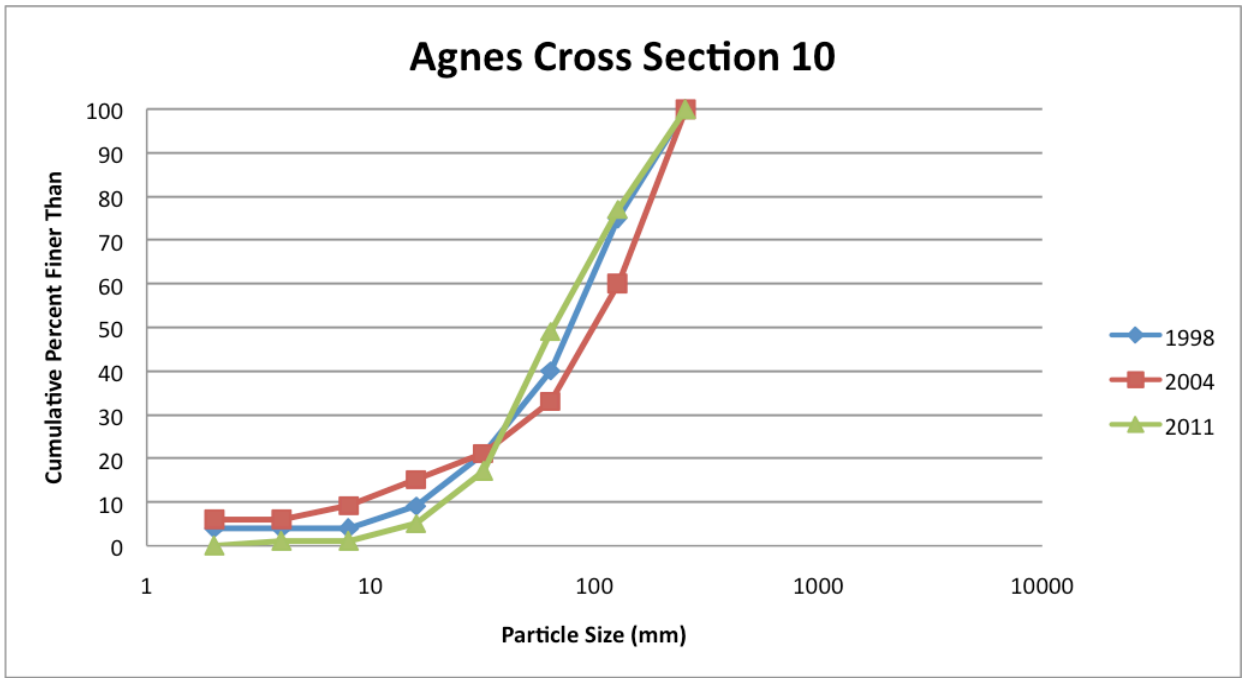


Figure 11. Particle-size distribution for Agnes Creek, cross section 10. Used as an example of "no change" in particle size distribution.

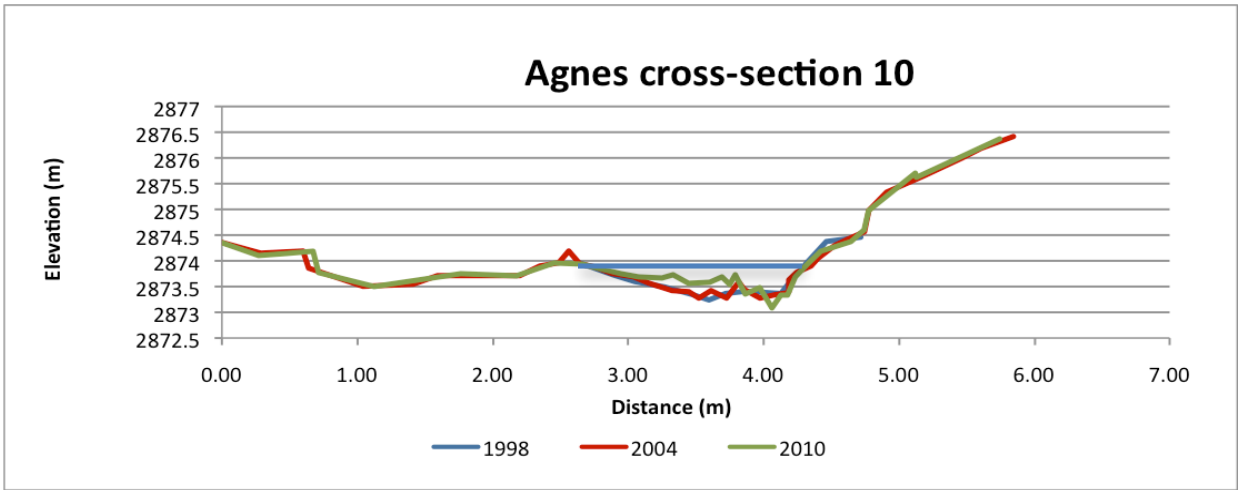


Figure 12. Cross-sectional profile for Agnes Creek, cross section 10. Bankfull locations indicated by horizontal line.

This cross section (fig. 12) shows no particle-size change during the surveys. The cross section with the largest change in distribution was cross section 4, below. This cross section had slight (0.02 m^2) scour between 1998 and 2004. It scoured again between 2004 and 2010, gaining 0.16 m^2 in cross-sectional area.

This cross section became coarser between 1998 and 2004. Between 2004 and 2011 the finest sizes appear to be selectively removed, while middle grain sizes increase in abundance.

5.2.3. Sanchez Creek

Similar to Agnes Creek, Sanchez Creek did not have as much variation in grain size distribution as SFLD Creek. Overall, the particle size distribution of Sanchez Creek remained relatively stable. Sanchez Creek had a 44% increase in cross sectional area between 1998 and 2010.

Due to the difficulty of re-locating cross section rebar pins, several cross sections were not resurveyed, and a particle count was not taken at cross section 5. Flagging in tree branches was located at several cross sections at which rebar could not be location. For these cross sections (3 and 4) there is particle count data but no rod and level cross sectional survey.

The following graphs show the downstream change in particle size distribution and cross sectional area for Sanchez Creek.

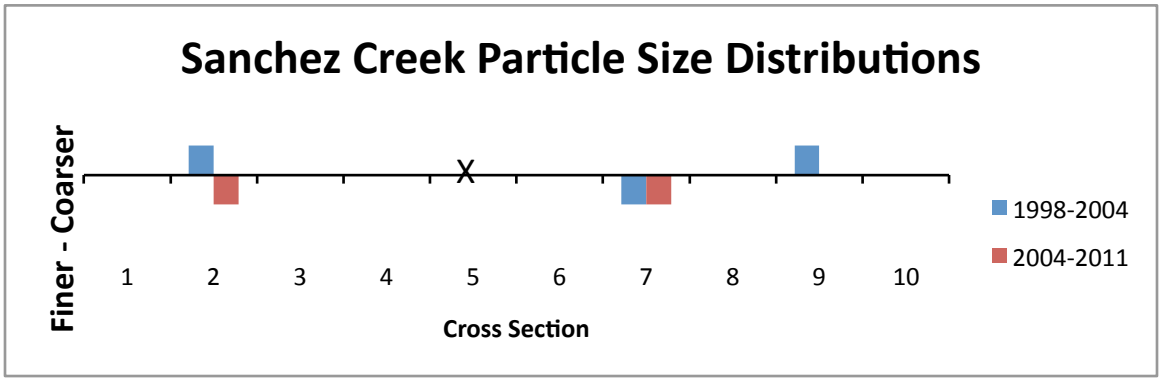


Figure 13. Particle size distributions for Sanchez Creek. "X" indicates no data.

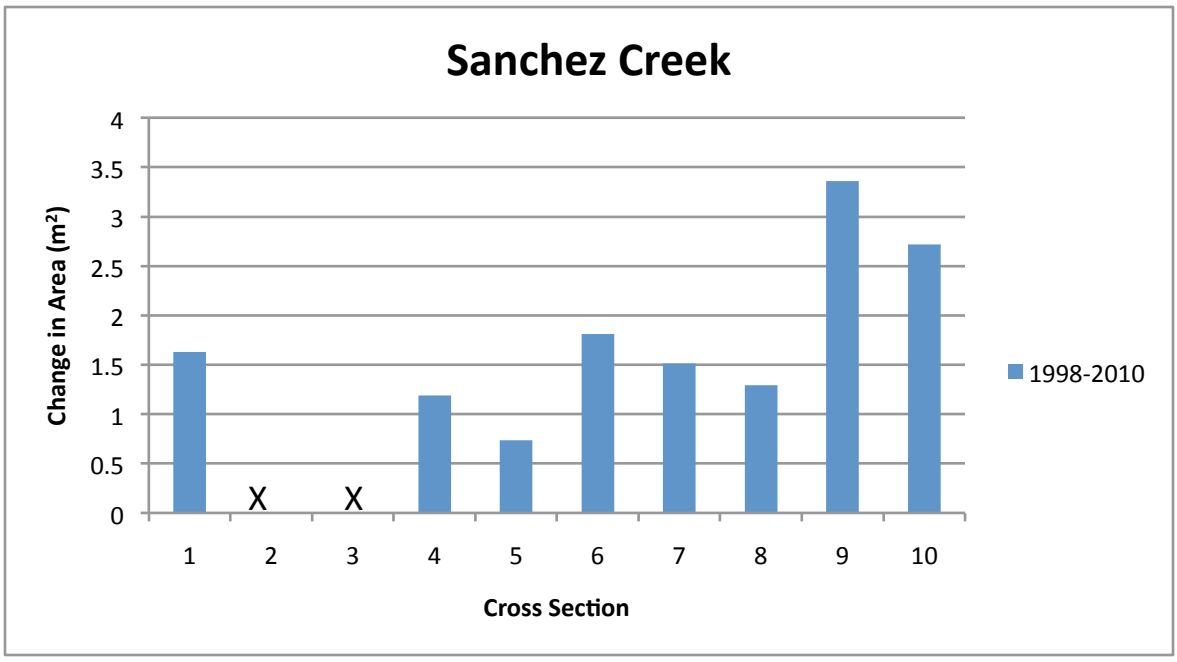


Figure 14. Changes in cross-sectional area for Sanchez Creek. Positive values indicate scour; negative values indicate aggradation.

		Channel Response (No. of Cross Sections)		
		No Change	Fining	Coarsening
Channel Response (No. of Cross Sections)	No Change	0	1	1
	Aggradation	2	1	3
	Scour	2	0	0

Table 7. Sanchez Creek cross-sectional changes from 1998-2004.

		Channel Response (No. of Cross Sections)		
		No Change	Fining	Coarsening
Channel Response (No. of Cross Sections)	No Change	0	1	1
	Aggradation	2	1	3
	Scour	2	0	0

Table 8. Sanchez Creek cross-sectional changes from 2004-2011.

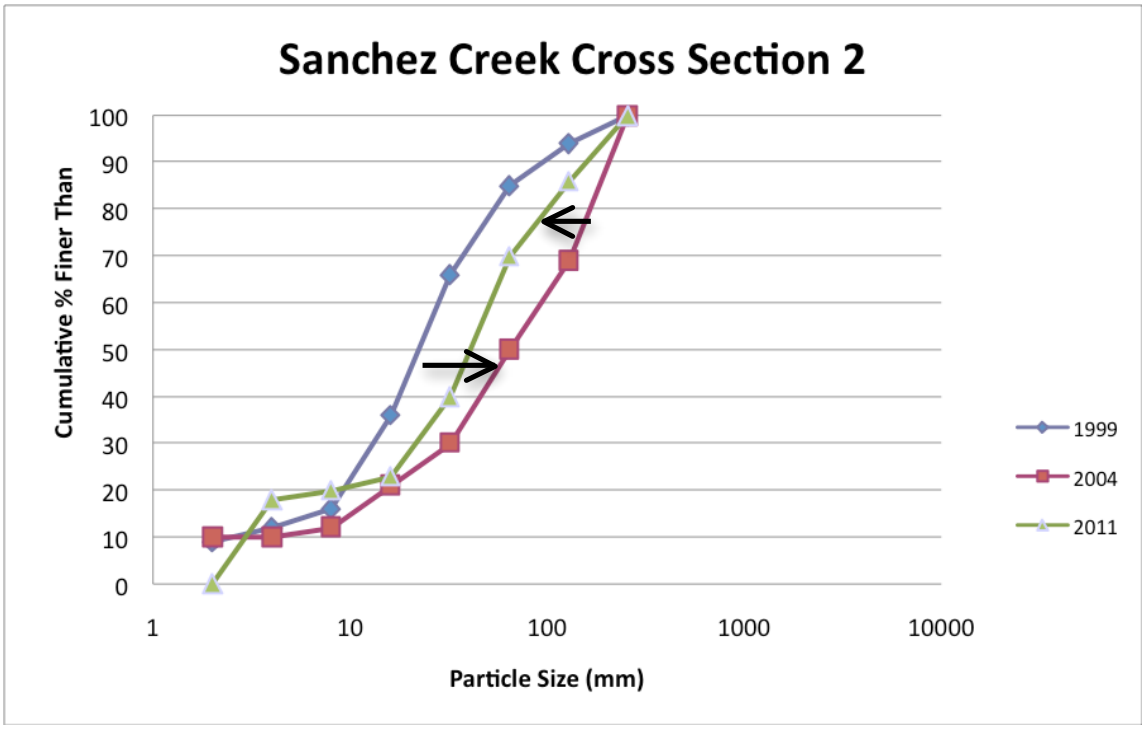


Figure 15. Particle-size distribution for Sanchez Creek, cross section 2.

Cross section 2 had the largest change in particle-size distribution of Sanchez Creek. From 1998 to 2004 the cross section became coarser, but then became finer between 2004 and 2011, although not reaching the original particle-size distribution of 1998. Flagging, but not rebar, was found at this cross section in 2011. The cross section was not re-surveyed in 2011, although the particle count was completed successfully due to the flagging indicating the approximate cross section location.

Paired t-test p-values (table 9) from Massey (2000) indicate that a significant difference in particle size distribution was only found between the 50th percentile of Agnes Creek and SFLD Creek, between the 84th percentile of Agnes Creek and Sanchez Creek, and between the 95th percentile of Agnes Creek and Sanchez Creek. A similar test was conducted on the particle count data from 2011, and only found a significant difference in the 50th percentile of particles in SFLD Creek and Agnes Creek. The 84th and 95th percentiles were not used in this comparison due to the difference in survey methods between 1998 and 2011.

Creek	16th percentile p-value	50th percentile p-value
Agnes and Sanchez	0.3303	0.0723
Agnes and SFLD	0.1686	**0.0128**
Sanchez and SFLD	0.8934	0.4418

Table 9. T-test results (p-values) for particle size distributions. **Bold** type indicates statistical significance.

5.3. CHANNEL WIDTH AND DEPTH

Bankfull area and mean depth were calculated from data taken in the field at each cross section (described in methods section). Bankfull width was taken from the planview survey data of SFLD and Agnes Creeks.

5.3.1. Bankfull width

SFLD Creek had the largest change in cross-sectional width over the entire study period of 1998 to 2010, with an overall reach-averaged decrease of 19%. Agnes Creek had an overall reach-averaged increase in width of 32%. There is no comparable data for Sanchez Creek, but Massey (2000) reported the width was 4.47 m in 1998.

The following figures (figs. 16 & 17) show the downstream changes in width of each channel as measured from the planview survey in ArcMap. Widths were measured in ArcMap in several-meter increments in the downstream direction, and were measured approximately perpendicular to the thalweg. Agnes Creek had an average width of 4.6 m in 1998 and an average width of 6.1 m in 2010. SFLD Creek had an average width of 4.0 m in 1998 and an average width of 3.6 m in 2010.

Bankfull width was also calculated from the cross section survey data. These results do not match the results given above from the planview survey. This is possibly a result of the small number of cross sectional widths measured (10 to 16) versus the large number of downstream planview widths measured (150-180). The discrepancy could also indicate that the "bankfull location" was not accurately recorded during the cross section survey of either stream. Since the planview map clearly shows narrowing of SFLD Creek in many locations, the results from the cross sectional survey are assumed to be inaccurate.

Overall, the widths measured from the planview survey are probably more accurate, but they were only measured in 1998 and 2010. Therefore, the cross-sectional widths are useful in that they give some idea of the changes that occurred in the early

(pre-fire) and late (post-fire) parts of the survey period. For the purposes of this report, the widths measured from the planview survey will be used when discussing channel width.

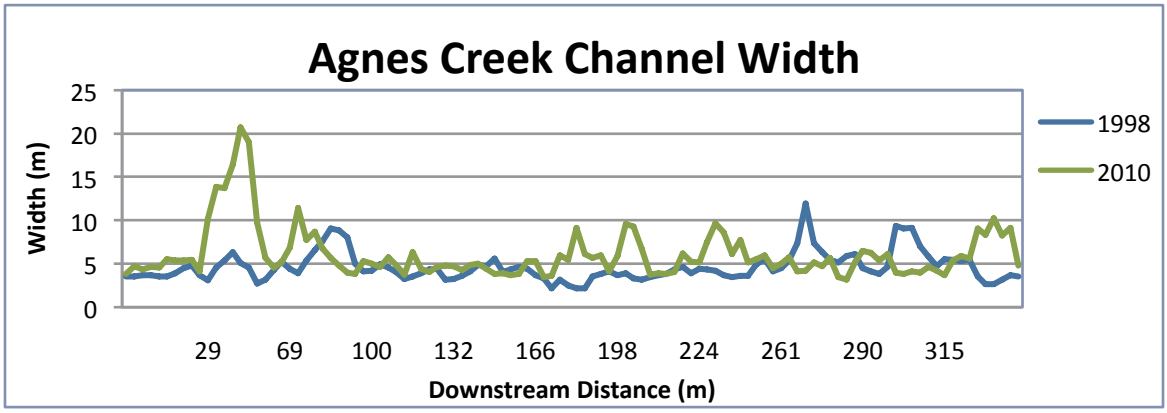


Figure 16. Downstream change in planview width between 1998 and 2010, Agnes Creek.

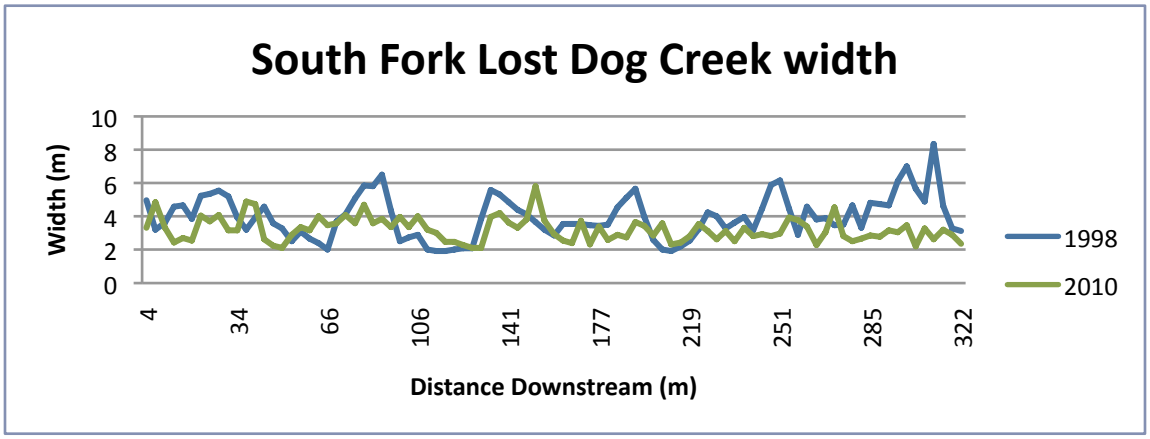


Figure 17. Downstream change in planview width between 1998 and 2010, SFLD Creek.

5.3.2. Mean depth

The change in depth, taken from the cross sectional survey, was also analyzed. Again, SFLD Creek had the largest total change, with an overall reach-averaged increase in depth of 64%. Sanchez Creek had the next largest change, with an overall reach-averaged increase of 37%. Agnes was the only creek to become shallower, with an overall reach-averaged decrease of 3%, which is probably not significant.

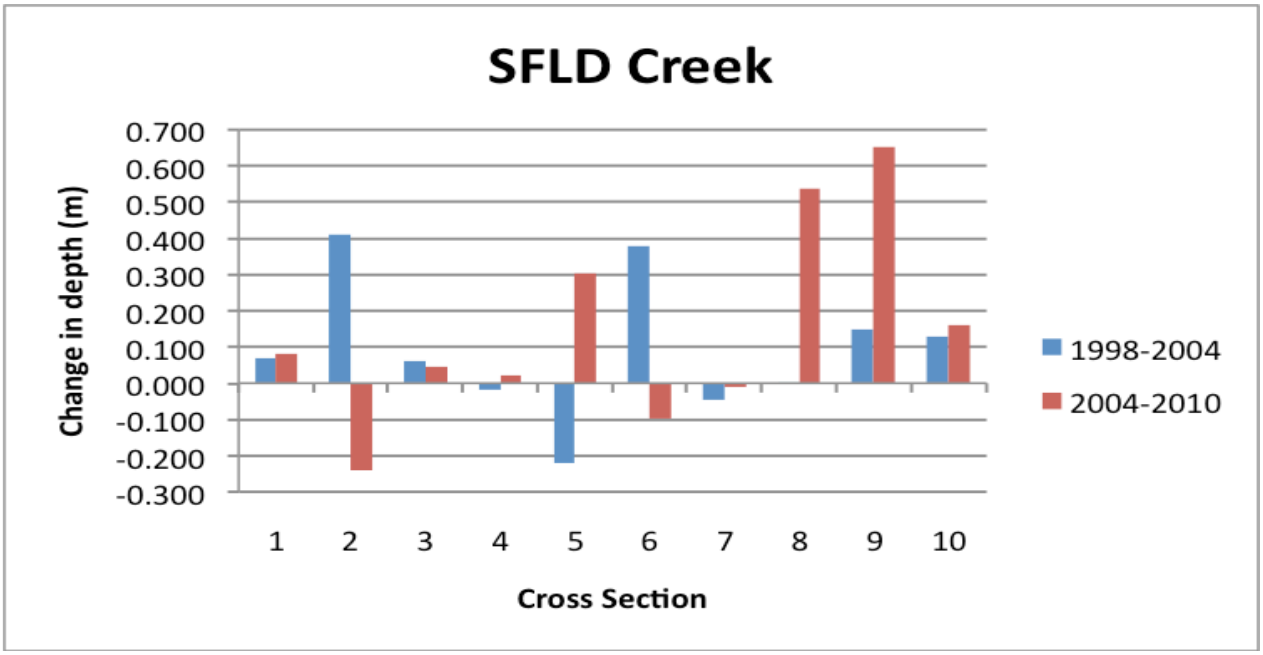


Figure 18. Change in depth of SFLD Creek across study period. Negative value indicates shallowing; positive value indicates deepening.

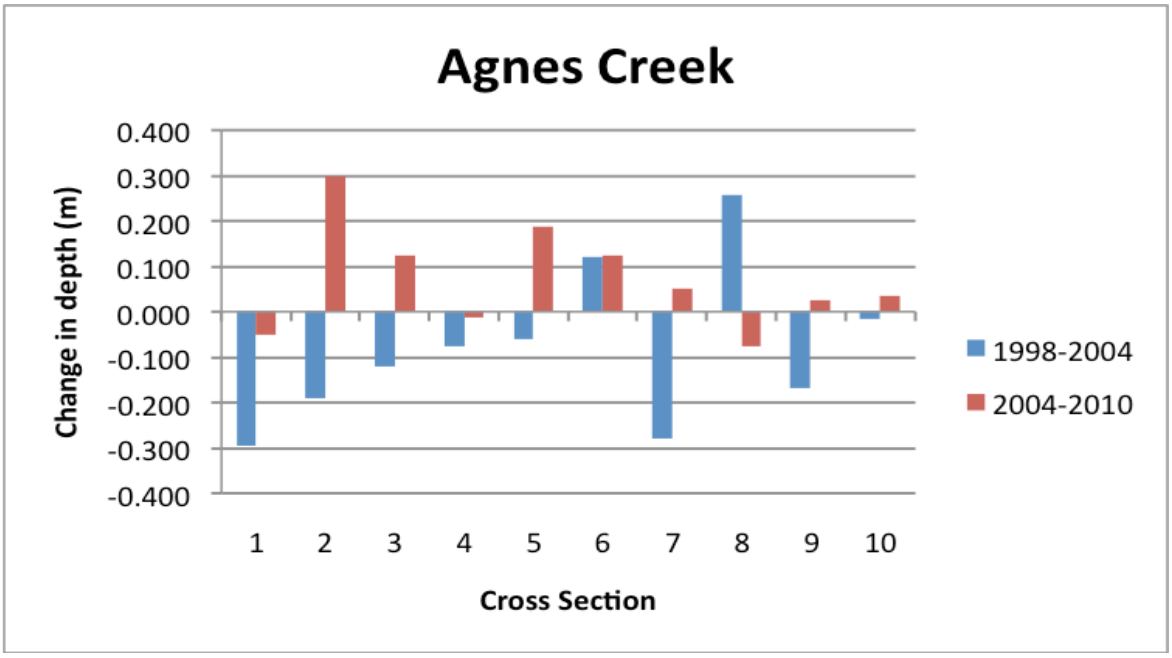


Figure 19. Change in depth of Agnes Creek over study period. Positive values indicate deepening; negative values indicate shallowing.

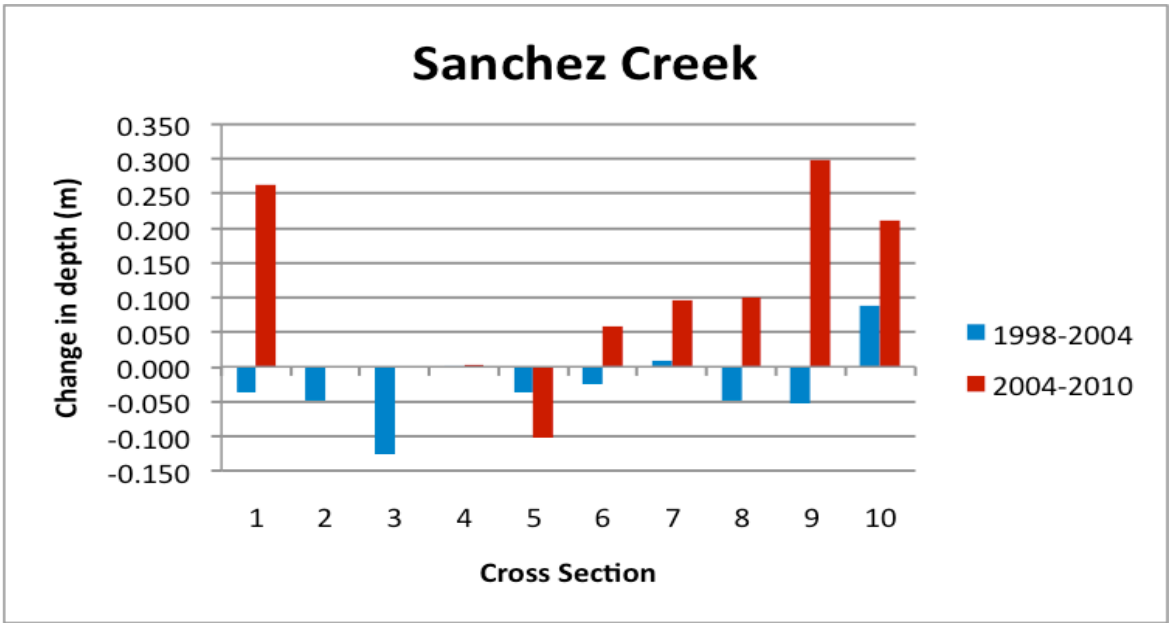


Figure 20. Change in depth of Sanchez Creek over study period. Positive values indicate deepening; negative values indicate shallowing.

A simple t-test analysis was performed on the changes in channel geometry seen between survey periods (tables 10 & 11). The only significant difference in the change in cross sectional area between surveys was between Agnes Creek and SFLD Creek, between 1998 and 2010. The only significant difference in the change in channel width (taken from cross section survey) was between Agnes Creek and SFLD Creek, for the period between 2004 and 2010, and between SFLD Creek and Sanchez Creek for the same survey period. Finally, the only significant differences in the change in channel depth were between Agnes Creek and SFLD Creek, from the period 1998 to 2004, and from 1998 to 2010.

Area	1998	2004	2010/2011
Agnes vs. SFLD	**~0**	**~0**	**~0**
Agnes vs. Sanchez	**~0**	**~0**	**0.0051**
SFLD vs. Sanchez	0.39	0.541	0.658
Width*			
Agnes vs. SFLD	**~0**	**~0**	**~0**
Agnes vs. Sanchez	**~0**	**~0**	**~0**
SFLD vs. Sanchez	**0.0021**	**~0**	**0.011**
Depth			
Agnes vs. SFLD	0.593	**0.013**	**0.014**
Agnes vs. Sanchez	**0.049**	**0.051**	0.773
SFLD vs. Sanchez	**0.005**	**0.0001**	**0.03**

Table 10. Results of T-test (p-values) between the three streams. **Bold** type indicates statistical significance. * Width calculated from cross-sectional survey in order to compare all 3 reaches.

Area	1998-2004	2004-2010/2011	1998-2010/2011
Δ Agnes vs. SFLD	0.266	0.083	**0.029**
Δ Agnes vs. Sanchez	0.862	0.182	0.14
Δ SFLD vs. Sanchez	0.199	0.795	0.303
Width*			
Δ Agnes vs. SFLD	0.266	**0.022**	0.913
Δ Agnes vs. Sanchez	0.605	0.559	0.911
Δ SFLD - Sanchez	0.208	**0.05**	0.869
Depth			
Δ Agnes vs. SFLD	**0.045**	0.206	**0.025**
Δ Agnes vs. Sanchez	0.354	0.458	0.161
Δ SFLD vs. Sanchez	0.086	0.971	0.187

Table 11. Results of T-test (p-values) conducted on changes between the three streams. **Bold** type indicates statistical significance. *Width calculated from cross-sectional survey in order to compare all 3 reaches.

5.4. CHARACTERISTICS OF LARGE WOOD LOADS

The following charts show the downstream changes in the total amount of LW within each study reach.

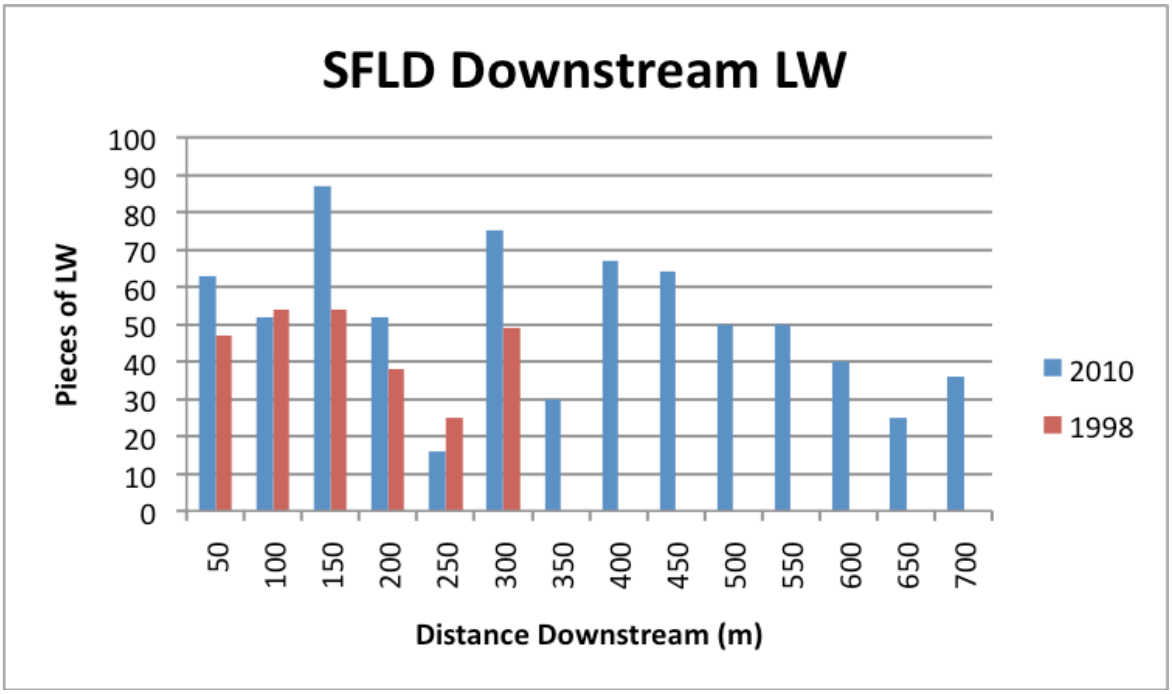


Figure 21. Comparison of total LW at each cross section between 1998 and 2010, SFLD Creek.

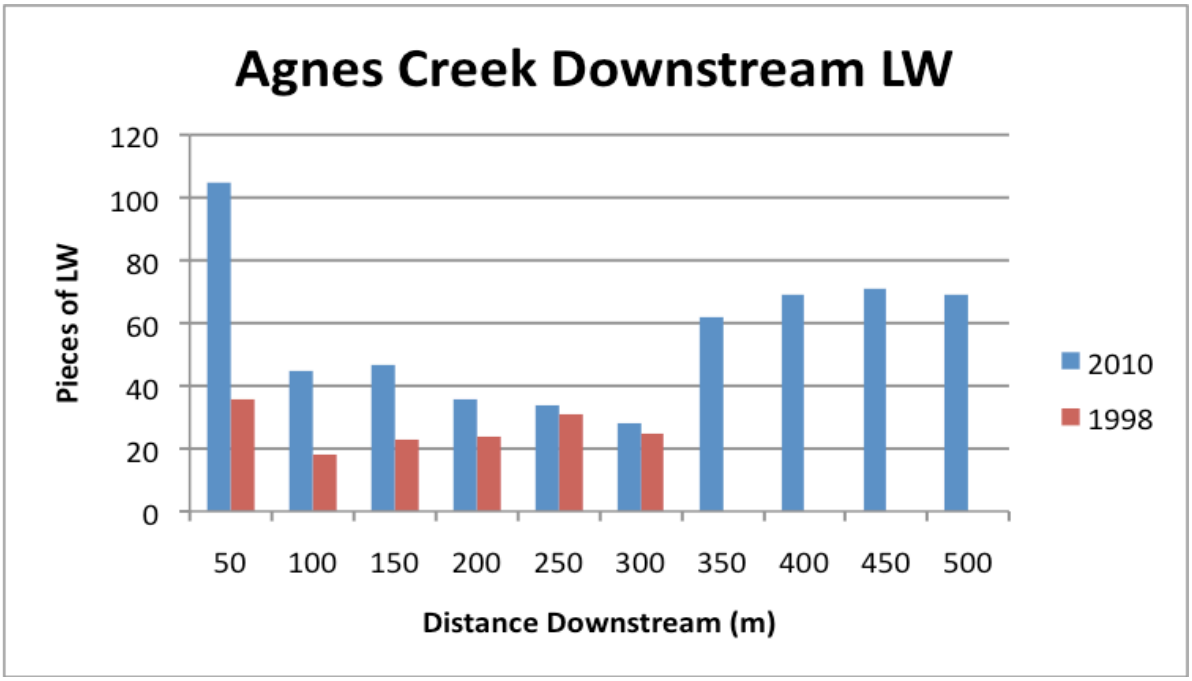


Figure 22. Comparison of total LW at each cross section between 1998 and 2010, Agnes Creek.

Note – that wood was not surveyed in all areas in 1998. These counts include both old (and wood in the channel prior to blowdown) and new (blowdown-related) wood in each stream. In 1998, SFLD Creek contained 79% new wood and Agnes Creek contained 60% new wood.

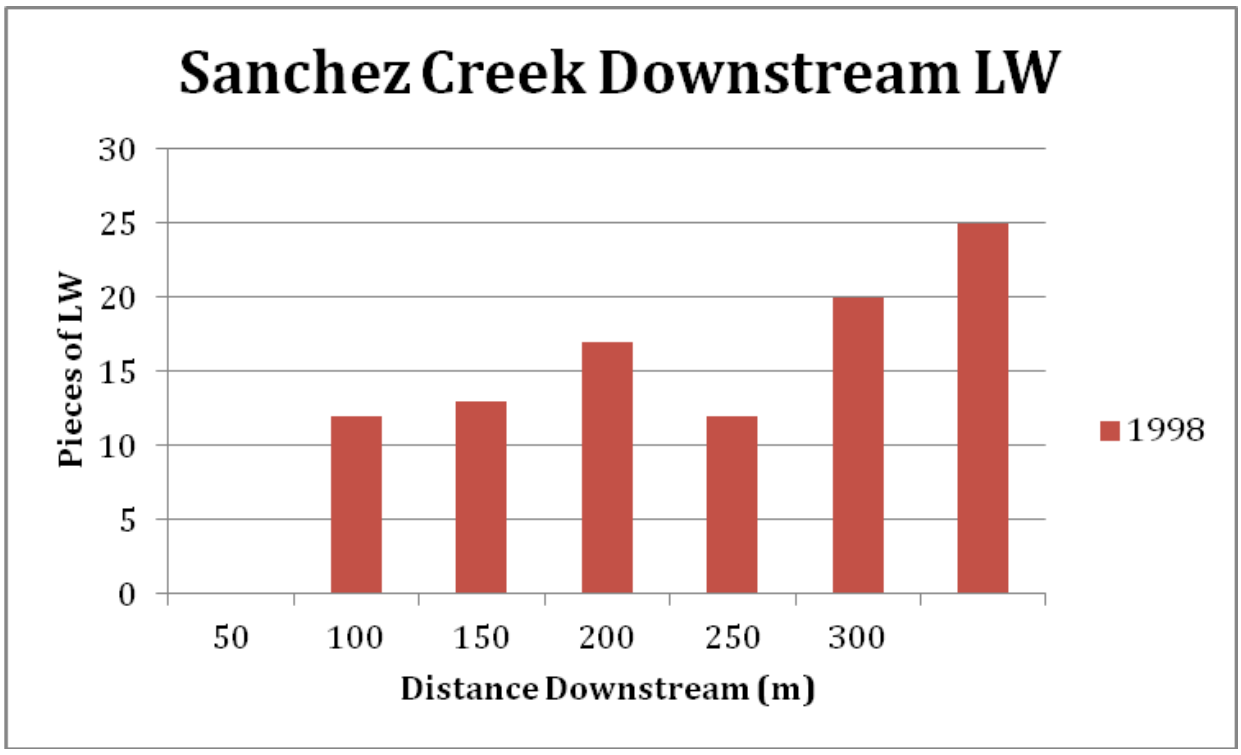


Figure 23. Total LW at each cross section in 1998, Sanchez Creek.

With the exception of the first 50 m of Agnes Creek, both Agnes and Sanchez Creeks generally have increasing LW with downstream distance. SFLD Creek has a slight trend of decreasing wood with downstream distance, especially during the 2010 survey.

In 2011, Sanchez Creek, the control stream, contained 184 pieces of wood in its 323m length (0.57 pieces per meter stream length). Of these, 9 pieces tagged by Massey from the original (2000) study were found, presumably close to their original location. In 2010, SFLD Creek contained 708 pieces in its 752m length (0.94 pieces per meter stream length), and 8 tagged logs were found from the original survey. In the same year,

Agnes Creek contained 554 pieces in its 504m length (1.1 pieces/m), and 8 tagged logs were found from the original survey.

In 2010, the average diameter of logs in Sanchez was 20.8 cm. The average diameter of logs in Agnes Creek was 17.1 cm. The average diameter of logs in SFLD was 18.2 cm. The average length of wood in Agnes was 4.2 m, and in SFLD Creek it was 4.6 m. The length of wood was not measured in Sanchez Creek in 2011, but had an average of 4.8 m in 1998.

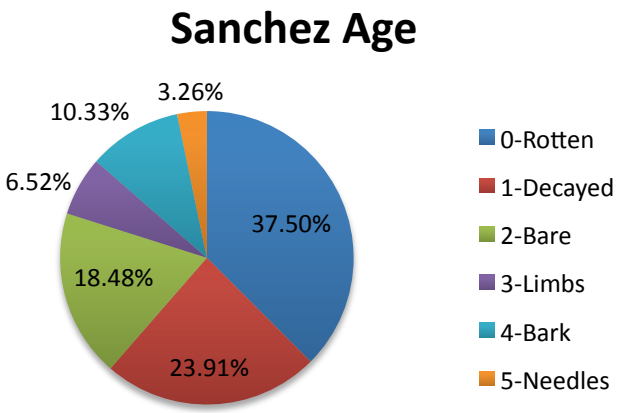
The total volume of wood surveyed in SFLD Creek in 2010 was 111.03 m^3. The volume of wood in Agnes Creek in 2010 was 64.95 m^3. These volumes are higher than the volumes surveyed by Massey (2000), primarily because there are more logs. In 1998, the volume of wood in SFLD Creek was 81.0 m^3 (0.12 m^3/m) the volume of wood in Agnes Creek was 58.0 m^3 (0.11 m^3/m) and the volume of wood in Sanchez Creek was 29.2 m^3 (0.1 m^3/m). The volume of wood for Sanchez Creek could not be calculated for 2011 because the length of logs was not recorded.

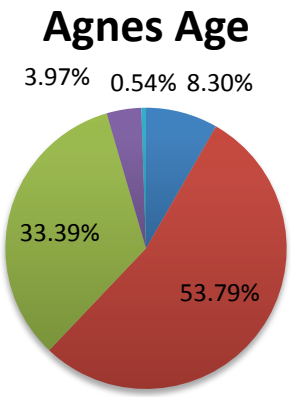
5.4.1. Age and presence of root wads

The age of LW is an indication of its residence time in the stream. Large wood that is soft and rotting indicates that it has been dead and in the channel for a relatively longer period of time than LW that still has bark and needles. The LW in Agnes Creek and SFLD Creek did not have any bark or needles due to the Hinman fire of 2002, although it was younger than the majority of wood found in Sanchez Creek.

While it was expected that Agnes Creek and SFLD Creek would have similar amounts of burnt wood and Sanchez Creek would have none, it was surprising that Agnes Creek had the lowest percentage (8.3%) of rotten wood (rated 0 out of 5 in age, with 0 being rotten and 5 having needles). Sanchez Creek had the highest percentage of rotten wood (37.5%). SFLD and Agnes Creek had similar amounts of decayed wood (about half of the LW load). Sanchez Creek had the highest combined percentage of wood in the more recent categories (20.11%) while SFLD had a combined percentage of 6.92% and Agnes had a combined percentage of 4.51%. This is probably because all indications of a piece being a new recruit from the blowdown, such as bark or needles, were destroyed by the 2002 fire.

Sanchez Creek had the lowest percentage of logs attached to root wads, at 10.33%. Agnes Creek had the highest percentage, with 27.12%, followed by SFLD Creek with 25.53%. Agnes and SFLD Creeks are probably significantly similar to each other in root wad concentration. This is likely due to the fact that many of the trees that were blowndown were live, healthy trees that fell as clumps, including whole root wads and root wad complexes rather than by snapping from the base. In general, root wads are more stable than floating pieces of LW. This is because they are either still partially rooted in the ground, or are too large to travel long distances downstream.





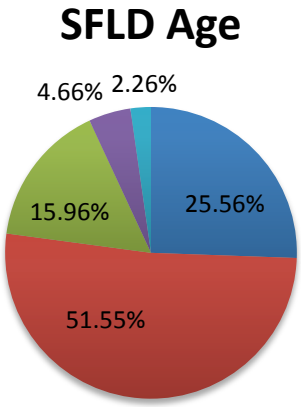


Figure 24. Age of LW found in each reach, 2010.

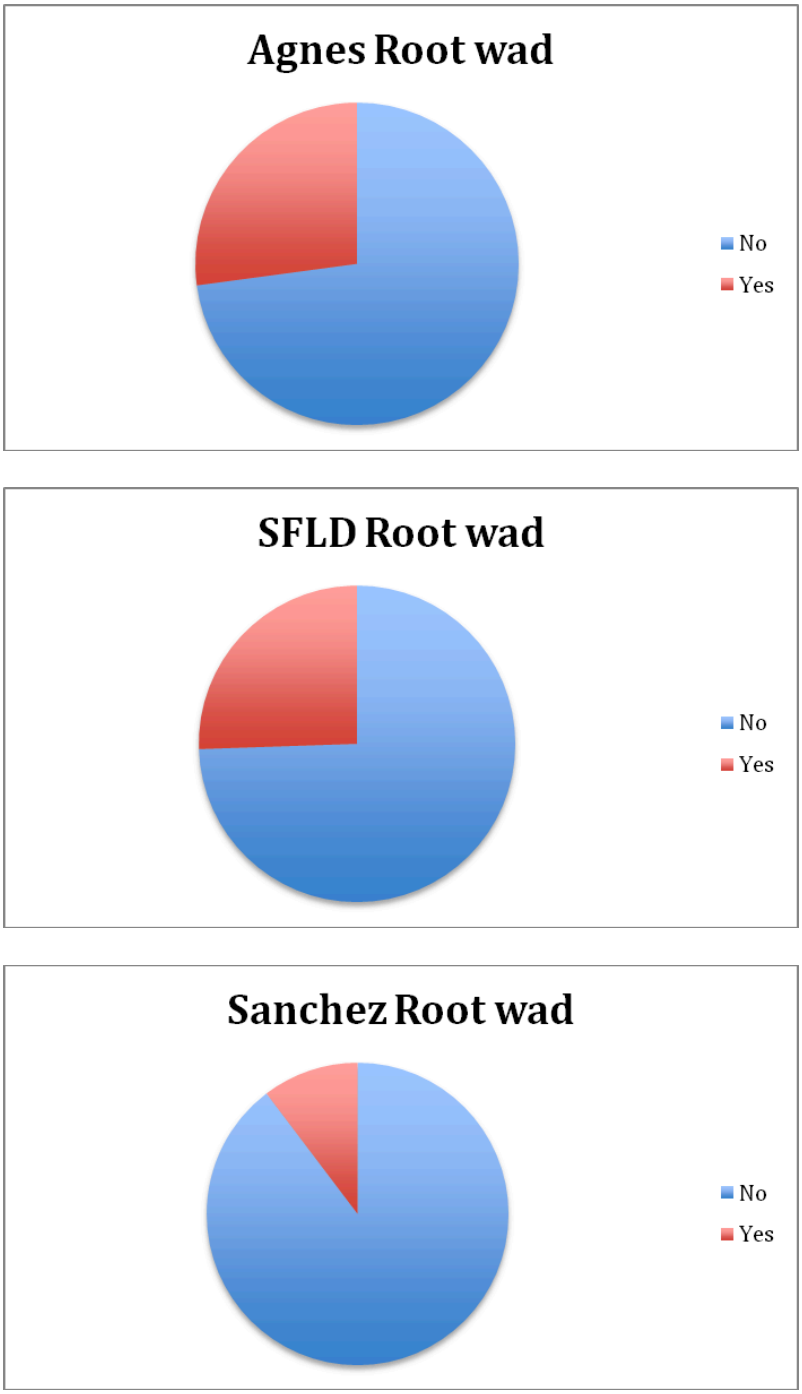


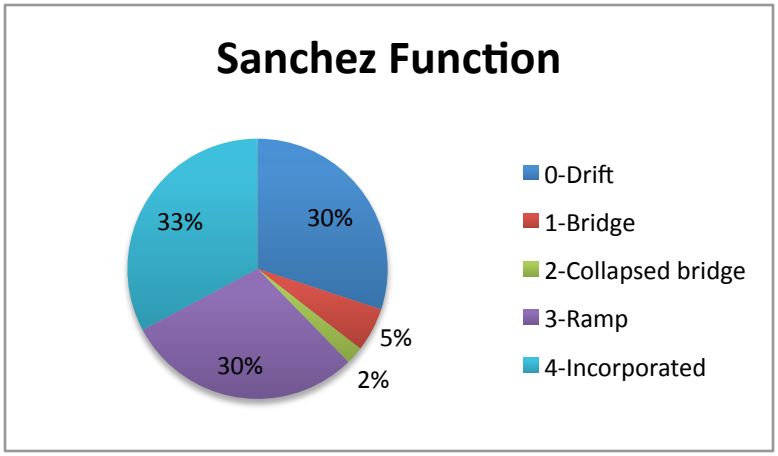
Figure 25. Percentages of root wads found in each reach, 2010.

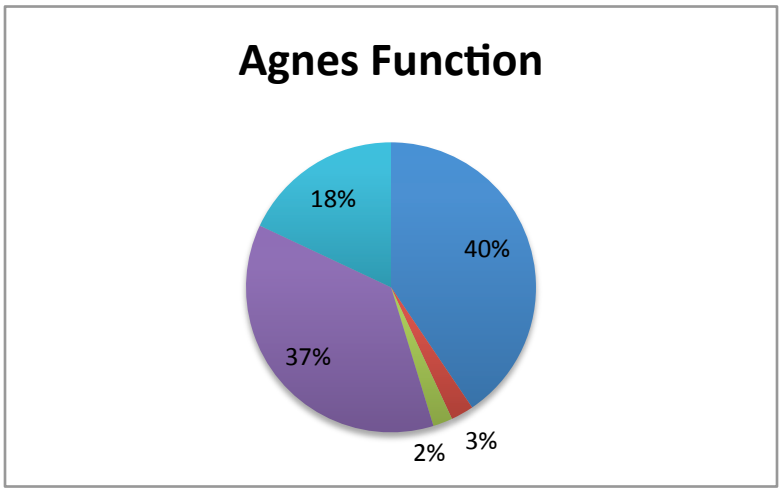
5.4.2. Function

The function of each log within the channel was recorded. Of the three streams, Sanchez had the highest percentage of wood that was incorporated into the stream. This could suggest that since Sanchez Creek didn't experience a sudden influx of new logs, more logs in Sanchez Creek have been in the channel for a longer period of time, and have had more time to break down and become incorporated.

South Fork Lost Dog Creek had the highest percentage of bridge-forming logs. This stream also had the highest percentage of ramped logs. Ramped logs were more prevalent in the blowdown affected reaches overall, which could suggested that blowdown trees entered the channel as bridges, and have since broken into collapsed bridges and ramps.

Agnes Creek had the highest percentage of drift logs. It had the lowest percentage of incorporated logs. Agnes Creek was wider than SFLD Creek, according to the planview channel survey, although the cross-section surveys indicate that Agnes is narrower. Because the logs in Agnes and SFLD Creeks had roughly similar lengths, these logs would have more freedom to drift downstream in the wider Agnes Creek. The ratio of length to channel width was 1.27 in SFLD Creek and 0.69 in Agnes Creek.





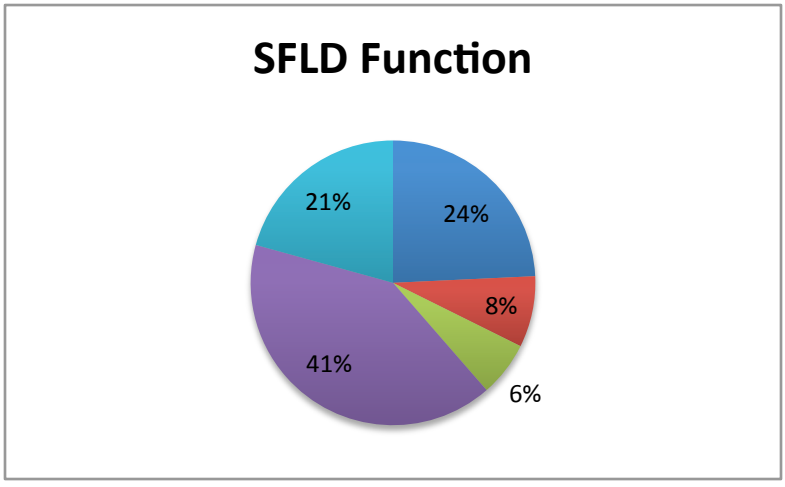
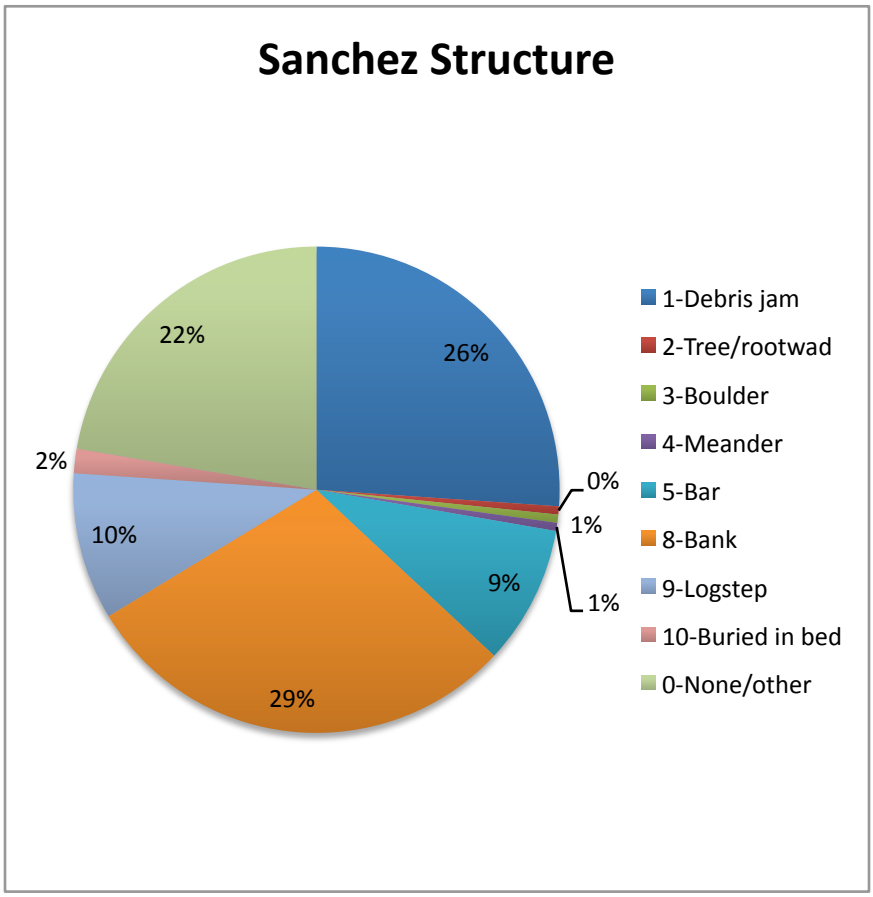


Figure 26. Percentages of LW function within each reach, 2010.

5.4.3. Structural association

The structural association within the channel was recorded for each piece of wood found. Common structural associations included logs that were part of jams, logs that created log steps, and logs that were incorporated into the bank. Sanchez Creek had the lowest percentage of debris jam-forming logs, at 26.09%. SFLD and Agnes had similar amounts of jam-forming logs, with 44.20% and 40.87%, respectively. Sanchez Creek had the highest percentage of logs associated with channel banks, at 29.35%. SFLD Creek and Agnes Creek had 25.11% and 19.71% of bank-related wood, respectively.



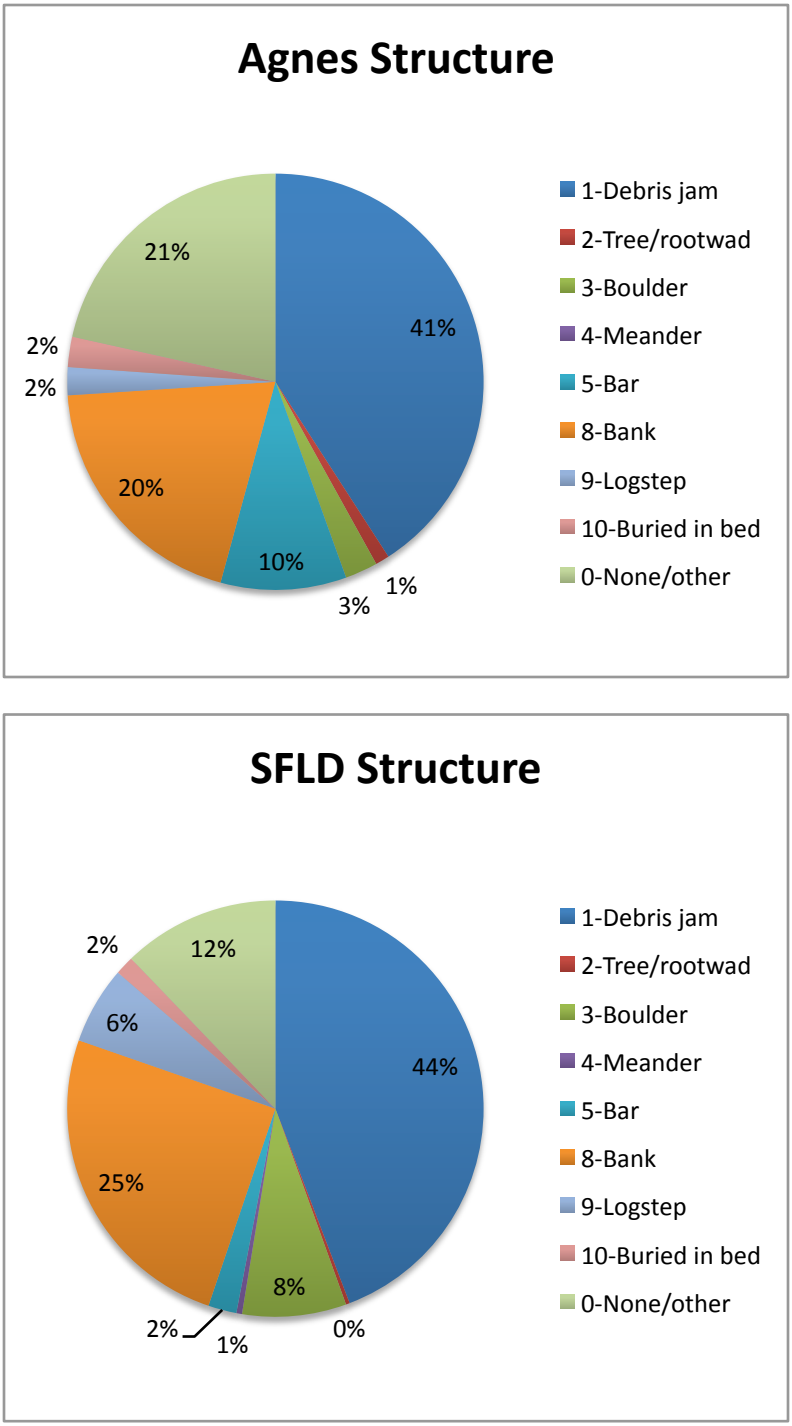


Figure 27. Percentages of LW structure within each reach, 2010.

5.4.4. Channel type

The dominant channel type where logs were found in Sanchez Creek was glide followed by step/pool and riffle. The dominant channel type where logs were found in SFLD Creek was rapid followed by step/pool and cascade. The dominant channel type where logs were found in Agnes Creek was cascade followed by step/pool and riffle.

SFLD Creek was the only stream with a significant amount of wood accumulation on rapid channel type. It was also the only stream to have less than 10% wood accumulation on glides. Both Agnes and Sanchez had similar percentages of wood found on riffles and in cascades. SFLD also had a higher percentage of pools.

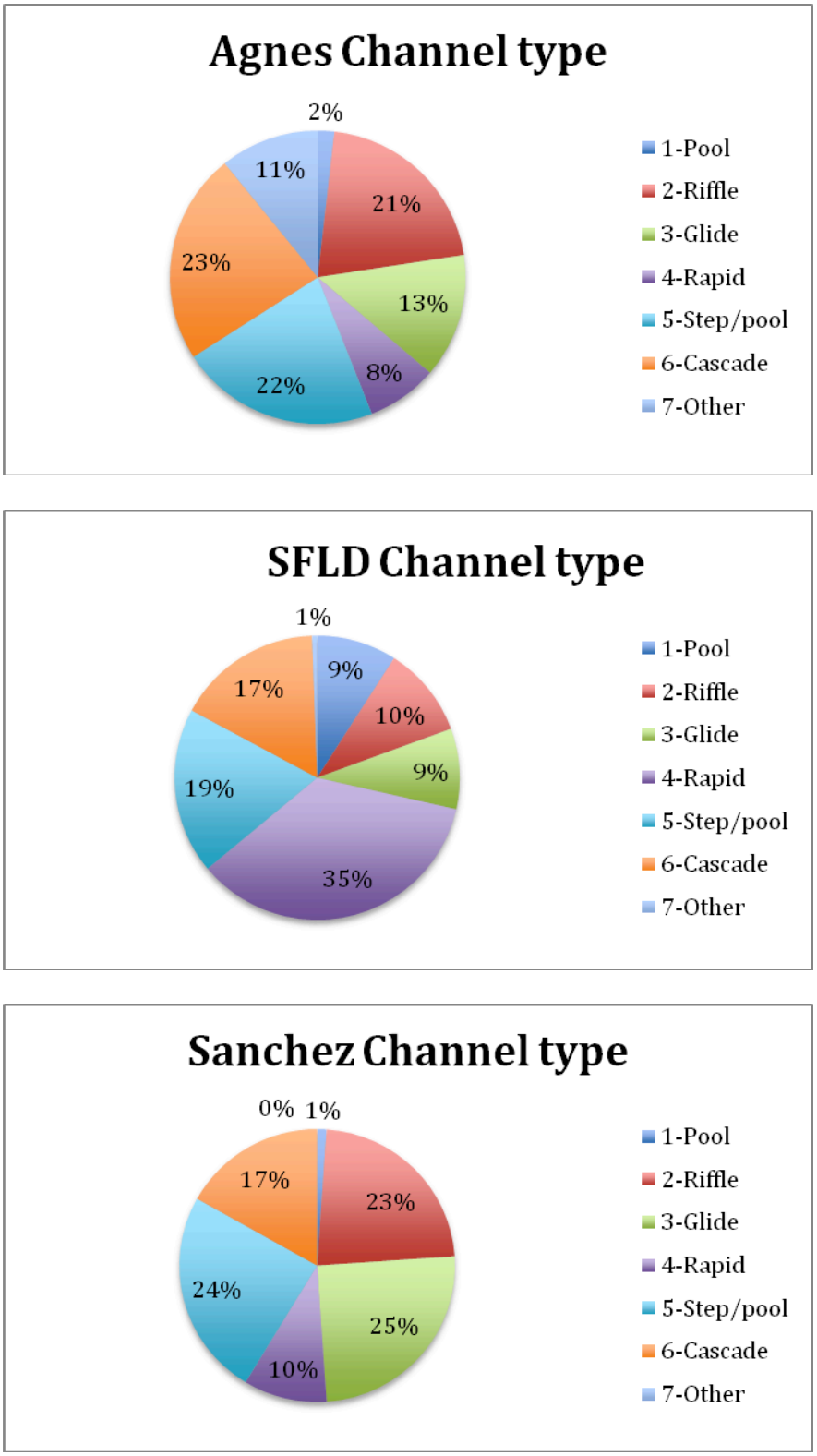


Figure 28. Percentages of each channel type within each reach, 2010.

5.4.5. Orientation

The following table summarizes the average orientation of the logs found in each channel. Orientations are recorded in degrees away from reach-averaged flow direction, with 0 degrees being parallel to flow and 90 degrees being perpendicular to flow.

	0-45°	**45-90°**
Sanchez*	52.68%	47.32%
Agnes	66.01%	33.99%
SFLD	65.87%	34.13%

Table 12. Orientation of LW in streams, 2010. *Logs surveyed are from original 1998 study.

LW in Sanchez is about evenly split between perpendicular and parallel, while the orientation at the disturbed sites is more perpendicular to the direction of the flow. This likely reflects the recency of LW recruitment following blowdown where as a more parallel orientation suggests the LW has been pushed in the predominant direction of the flow.

5.4.6. Channel units

Information regarding channel units was recorded during the 2010 re-survey of Agnes Creek and SFLD Creek. These channel units were labeled during the center-line survey in the stream, and were labeled as the top or bottom of a log step or rock step. Channel units such as cascades and riffles were not recorded.

	Agnes Creek (504 m)	**SFLD Creek (752 m)**
# Log steps	6	45
# Rock steps	11	26
Log steps per 100 m	1.19	5.98
Rock steps per 100 m	2.18	3.54

Table 13. Channel units in streams, 2010.

6. DISCUSSION

This study attempted to identify possible ways in which large wood affects channel geometry in three study reaches in the Routt National Forest, Colorado. In order to recognize changes in channel geomorphology over the study period of 13 years, a survey was completed of each channel. After trends in channel geometry were noted in both plan-view and cross sectional area, an attempt was made to attribute those trends to characteristics of wood within the streams where possible. Particle counts were also used to identify trends in sediment routing and storage around obstructions.

The major trends recognized in the three channels were based on cross sectional area of each cross section, the bankfull width as measured from the planview survey, and a mean depth measured at each cross section.

6.1. CROSS-SECTIONAL CHANGES

Trends in cross sectional area showed that SFLD had the largest change over the entire study period, with a reach-averaged increase of 1.02 m^2. This stream also had the highest overall rate of change, with the reach-averaged cross sectional area changing at a rate of 0.09 m^2/year. Agnes Creek showed a smaller change, with a reach-averaged increase of 0.11 m^2, and a reach averaged rate of 0.01 m^2/year. However, according to a t-test, the only significant difference in area (p value of 0.029) was found in the total amount of change between Agnes Creek and SFLD Creek, from the period of 1998 to 2010.

According to the planview bankfull widths measured from the survey, SFLD Creek was narrower than Agnes Creek in 1998, and continued to narrow throughout the study period while Agnes Creek became wider. According to the cross section width results, there is a significant difference in width only between SFLD Creek and Agnes Creek in the amount of change in width that occurred between 2004 and 2010.

SFLD Creek also had the largest change in mean cross section depth. This stream had an overall reach-averaged increase of 0.24 m, and a rate of 0.02 m/year. Agnes creek was the only creek with an overall negative change, with an overall reach averaged depth decrease of 0.01 m and a rate of -0.001 m/year, probably an insignificant amount. Again, the only significant difference in the total change was between Agnes Creek and SFLD Creek, from the periods 1998 to 2004 (p value of 0.045) and between 1998 and 2010 (p value of 0.025).

Overall, SFLD Creek had the largest amount of change in cross sectional shape over the 11-year study period. The stream became narrower and deeper overall, and at a greater rate than the other two streams. This high rate of change may be attributed to the fact that the SFLD Creek watershed has seen the highest number of disturbance of the three study streams. Over the last 50 years, SFLD Creek has been affected by logging, the construction of logging roads, beetle kill, the blowdown of 1997, the fire of 2002, and subsequent salvage logging. In comparison, there has been no logging or road construction in Agnes Creek , and Sanchez Creek has *only* been affected by recent and ongoing beetle-kill. This could possibly indicate that the effects of logging and road disturbance are greater than the effects of beetle kill, fire, and destructive storms. As

roads are constructed in clear-cut drainages, sediment loading into streams is increased drastically (Sidle et al., 1985). It is possible that SFLD is still recovering from these effects, which were exacerbated by the addition of massive amounts of blowdown-related LW.

Additionally, the original survey (Massey, 2000) reported that the only significance found in the channel widths was between SFLD Creek and the other two streams. This indicates that even in 1998, SFLD Creek was already significantly different than both Agnes Creek and Sanchez Creek, at least in channel width.

6.2. WOOD METRICS

The main difference between the wood characteristics of the two blowdown reaches and the control reach is the total amount of wood. Sanchez Creek, the control reach, had an average of 0.56 logs/m. SFLD Creek had 0.94 logs/m, and Agnes Creek had 1.11 logs/m. This indicates that total wood loading was higher in the two streams impacted by the fire and blowdown. Over time, the amount of wood in each reach has increased. This could be an indication that riparian trees continued to be weakened by fire and beetle kill and fell into the stream, or it could also reflect the fact that the original study did not tag all of the trees in each reach and some trees were not measured due to difficulties in measuring wood in blowdown areas. The recorded number of pieces in Sanchez Creek increased by 90% between 1998 and 2011, the number of pieces in Agnes Creek increased 260% between 1998 and 2010, and the number of pieces in SFLD Creek increased by 183% between 1998 and 2010. The

higher percentage of newly tagged wood in Sanchez Creek could reflect the higher amount of available riparian wood to become incorporated into the channel.

The average orientation of the wood in each stream was calculated. Because the total station was not used on Sanchez Creek after 1998, the only orientation data available is from that year. These data were compared to the 2010 data for both other streams, which is not a direct comparison of similar conditions and probably produces some amount of error. However, there were 97 pieces reported in 1998, and 184 pieces reported and tagged in 2011.

Gurnell et al. (2002) reported that in small streams, wood is aligned primarily perpendicular to flow reflecting the primary fall direction of the trees. As the width of the channel increases relative to the length of wood and there is increased mobility, the wood should become more oriented parallel to flow. The orientation of logs in Agnes Creek and SFLD Creek was very similar. This is likely a result of the blowdown, where vast amounts of wood were loaded into the streams at once, and have remained in the channel for the same amount of time.

The control stream, Sanchez Creek, had the greatest range of wood ages. Although Sanchez Creek had the highest percentage of rotten wood (37.5%), it also had the highest percentage of wood that still had bark and needles (13.5%, combined). This would be expected from an un-impacted watershed such as Sanchez, in which most of the tree-fall is due to smaller-scale or more evenly supplied sources? In SFLD and Agnes Creeks, however, the fire destroyed much of the bark and needles of the LW produced by the blowdown.

Sanchez Creek had the highest percentage of wood found within the channel types “glide” and “riffle”. This does not necessarily mean that Sanchez Creek had the largest percentage of glide-channel type overall, only that the most wood was found in these locations. However, this result combined with the fact Sanchez Creek had the lowest percentage of jam-forming logs may indicate that forced channel units associated with jams are less common in this un-impacted reach. SFLD Creek had the highest percentage of wood found in rapids. This could indicate that sediment routing in SFLD Creek differs from that of the other reaches.

One major difference in the wood loading between Sanchez Creek and the two impacted reaches is the amount of wood found in jams. Sanchez Creek only had 26% of jam-forming wood, while Agnes and SFLD Creeks had 41% and 44%, respectively. This may be a product of the higher concentration of wood in the affected reaches. Wood in jams causes more flow deflection than single pieces, so it was expected that the channels in the affected reaches would have undergone more change. However, because SFLD Creek had more overall change in cross sectional area than Agnes Creek while having a similar concentration of wood in jams, other factors may have greater effects on channel morphology. The percentage of wood classified as drift was highest in Agnes Creek, at 41%. It was lowest in SFLD Creek, at 25%. Because these two streams had similar jam frequency, this could indicate that jam formation was driven by different processes in those two streams. For example, the narrower width of SFLD Creek may have confined more drift logs to the same area, causing them to become jammed with more stable pieces.

A primary difference in the function of the wood between streams was the amount of incorporated wood. Sanchez had the largest number of incorporated logs, which means that logs were buried in the bank or channel to some extent. Since it takes time for wood to break down, enter the channel margin, and become buried by sediment, it reflects that fact that the wood in Sanchez Creek is older and more stable. Much of the instream LW in the blowdown areas is fairly new and is only beginning to break down and become part of the structure of the channel.

Both Sanchez and Agnes Creek had a very small percentage of wood found in rapids, while this type of channel dominated the wood placement of SFLD. Rapids are similar to riffles, in that they are finer grained and less steep than step-pools and cascades. However, average particle size is larger than riffles, which causes more tumbling flow and increased resistance. The fact that Agnes and Sanchez Creeks are similar while SFLD differs in dominant channel type also supports the argument that factors other than wood loading are responsible for the changes in channel cross section. It could also indicate that new rapids are being created around LW obstructions in the channel, but the frequency of LW in SFLD Creek (0.97 logs/m) is slightly less than that of Agnes (1.11 logs/m).

6.3. PLANVIEW AND CHANNEL CHANGES

The number of channel units is possibly a reflection of the land use history of each watershed. In particular, the highest concentration of log steps was found in SFLD (45 vs 6 found in Agnes Creek). This could possibly reflect the reach's history of wood

loading during logging and road construction, although a buffer of standing trees was left in the immediate riparian zone. In a study of channel units and reach morphology by Gomi et al. (2003), the authors found the highest concentration of steps in channels that had previously been clear-cut. The results of this study are similar to the results from Gomi et al., in that the logged reach has the highest concentration of steps. This could indicate greater total wood recruitment of logged reaches during its history of disturbances, resulting in greater total morphological change.

These channel units were recorded during the longitudinal stream survey of 2010. Although there is a chance that the presence channel units was mis-labeled or left out of the records, it is unlikely that the difference between the number of steps in Agnes and SFLD is insignificant. The longitudinal survey also indicates a difference in the frequency of steep elevation drops between the streams. However, without more conclusive information, watershed logging in SFLD Creek cannot be positively linked to the difference in channel units.

It appears as though SFLD Creek has had the highest amount of geomorphic change between 1998 and 2010, and that it has changed in ways that differ from the other two study reaches. SFLD Creek was the only stream to decrease in width over any survey period and was also the stream with the greatest increase in depth over the entire study period (from 1998 to 2010). SFLD Creek had the largest change in total cross sectional area over the entire study period. SFLD Creek had the largest number of rock and log steps per meter of the three streams. It had the lowest percentage of LW classified as drift. SFLD appeared to have the most change in particle size distributions.

Significant differences in channel geometry were found between all three streams over various survey periods. Significant differences in cross sectional area were found between SFLD Creek and Agnes Creek, and between Agnes Creek and Sanchez Creek from 1998 to 2004, from 2004 to 2010, and from 1998 to 2010. Significant differences in cross-sectional width were found between all three streams over all survey periods, and significant differences in channel depth were found between all streams and survey periods except for Agnes Creek and SFLD Creek from 1998 to 2004, and between Agnes Creek and Sanchez Creek from 1998 to 2010.

Significant differences in the *amount* of change were always found between SFLD Creek and either of the two other creeks, and were never found between Agnes Creek and Sanchez Creek. Significant change in area was found between SFLD Creek and Agnes Creek between 1998 and 2010; significant change in width was found between SFLD Creek and Sanchez Creek, and between SFLD Creek and Agnes Creek, both from 2004 and 2010; and significant change in depth was found between SFLD Creek and Agnes Creek, both in the periods of 1998 to 2004 and 1998 to 2010.

The two affected reaches (Agnes and SFLD Creeks) did have some similarities over the study period. The wood in these two streams had similar orientations, ages, and percentages found in debris jams and having root wads. They both had a greater concentration of wood than Sanchez Creek.

The similarities between the two affected reaches were mainly constrained to LW and its characteristics, which are considered to be triggers of geomorphic change in this study. The differences between these two channels were mainly geomorphic

changes, or potential responses to LW loading. For these reasons, it might be concluded that massive loading of LW did not in fact drive the majority of geomorphic change in the affected channels. Rather, it was the amount and type of previous disturbance that has occurred within SFLD Creek's drainage basin that caused the greatest change in that stream. However, there is not enough conclusive data to positively make this assumption, so this conclusion can only be tentatively suggested.

7. CONCLUSIONS

This study examined the effects of massive LW loading on channel morphology. The null hypothesis is that streams with large amounts of blowdown-related LW would not differ significantly from a control stream with natural amounts of LW. An alternate hypothesis of this study was that two streams affected by the 1997 Routt Divide Blowdown would have higher rates and levels of geomorphic change than a stream unaffected by blowdown. A third hypothesis is that South Fork Lost Dog Creek, which has historically had higher levels of logging and road construction than the other two streams, would have the highest rate and total amount of change during the study period.

The null hypothesis was not supported. At least one affected reach, SFLD Creek, had geomorphic change between 1998 and 2010/2011 that differed significantly from the control stream, Sanchez Creek. The characteristics, amount, and location of LW in both affected reaches differed from that in Sanchez Creek, although it is not known if this difference is significant.

The first alternate hypothesis, that both Agnes Creek and SFLD Creek would have higher amounts of geomorphic change than Sanchez Creek, was partially supported. SFLD Creek did indeed have a higher amount of geomorphic change than Sanchez Creek. The amount of change between Agnes Creek and Sanchez Creek was not statistically significant. The amount of change between SFLD Creek and Sanchez Creek was only significant in the change of width (calculated from cross sectional survey) between 2004 and 2010. However, other differences exist between the affected reaches and the control reach, such as the amount, type, and location of wood, which may be significant.

The second alternate hypothesis, that SFLD Creek had the highest total amount of geomorphic change of the three study reaches, was also partially supported. Between 1998 and 2011, the only significant changes in either cross sectional area or depth were between SFLD and Agnes Creeks, which were both statistically similar to Sanchez Creek. However, SFLD Creek had the largest total change of these two streams. The only significant change in grain size was also found between Agnes and SFLD Creeks, and SFLD Creek appeared to have the largest total change in grain size distribution with an overall coarsening trend. SFLD was the initially narrowest of the three streams, and was the only stream to narrow additionally during the study period. It had the highest number of log steps. It was the only stream to become deeper on average between 1998 and 2004, and gained the most depth overall across the entire study period of 1998 to 2010.

Because neither of the alternate hypotheses can be fully disproved or supported, this report concludes that blowdown-produced LW does indeed have a larger effect on channel morphology than naturally produced LW, but this effect may not be as large as other watershed disturbances such as logging and road construction. Without other data to support either hypothesis above the other, neither can be conclusively supported.

Other parameters to be investigated include possible confounding variables such as discharge and localized bank vegetation. A comparison of these variables between study reaches could possibly highlight other factors causing geomorphic change.

The lack of complete survey data for Sanchez Creek in 2011 negatively impacts the number of conclusions that can be drawn from a comparison of the three stream reaches. However, enough data was collected in Sanchez Creek to find several significant results between the stream reaches. Other sources of error are differences in survey methods between the survey periods. Because wood loading was so severe in 1998, Massey (2000) was unable to reach sections of the channel and did not take as many survey points per bank as the present study. He also does not appear to have surveyed every piece of wood, for similar reasons.

The implications of this project are mainly centered on forest management. If future blowdowns occur that destroy thousands of acres of trees, forest managers should be prepared to either remove some LW if it poses a threat to channel stability, or leave LW if it does not negatively impact streams. After the Routt Divide Blowdown, trees were left in the active channels of SFLD and Agnes Creeks, but were harvested

from the hillslopes of SFLD Creek. This report concludes that blowdown-related LW does have a significant impact on stream channel morphology, beyond what geomorphic changes are produced by naturally occurring LW, but it cannot be determined from this study whether this change is overall positive or negative to watershed stability.

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Appendix A. Large Wood Metrics

Sanchez Creek

184 logs/323 m

0.57 logs/m

Age		Stability		Burn	
0-Rotten	**38%**	0 -No ends	**29.89%**	Yes	**0%**
1-Decayed	**24%**	1-1 end	**21.74%**	No	**100%**
2-Bare	**18%**	2-2ends	**48.37%**		
3-Limbs	**7%**				
4-Bark	**10%**				
5-Needles	**3%**				

Root wad		Source		Structural Association	
No	**89.67%**	0 unknown	**32.61%**	1-Debris jam	**26.09%**
Yes	**10.33%**	1 riparian	**64.67%**	2-Tree/rootwad	**0.54%**
		2 hillslope	**0.00%**	3-Boulder	**0.54%**
		3 floated	**0.00%**	4-Meander	**0.54%**
		4avalanche	**2.72%**	5-Bar	**9.24%**
		5 other	**0.00%**	8-Bank	**29.35%**
				9-Logstep	**9.78%**
				10-Buried in bed	**1.63%**
				0-None/other	**22.28%**

Function		Channel type	
0-Drift	**30%**	1-Pool	**1%**
1-Bridge	**5%**	2-Riffle	**23%**
2-Collapsed bridge	**2%**	3-Glide	**25%**
3-Ramp	**29%**	4-Rapid	**10%**
4-Incorporated	**33%**	5 Step/pool	**24%**
		6-Cascade	**17%**
		7-Other	**0%**

Agnes Creek

554 logs/504 m

1.11 logs/m

Age		Stability		Burn	
0-Rotten	**8%**	0 -No ends	**26.71%**	0-Unburned	**21%**
1-Decayed	**54%**	1-1 end	**34.84%**	1-Partly burned	**41%**
2-Bare	**33%**	2-2ends	**38.45%**	2-Burned	**38%**
3-Limbs	**4%**				
4-Bark	**1%**				
5-Needles	**0%**				

Root wad		Source		Structural Association	
No	**72.88%**	0unknown	**49.01%**	1-Debris jam	**40.87%**
Yes	**27.12%**	1riparian	**43.76%**	2-Tree/rootwad	**1.08%**
		2hillslope	**0.18%**	3-Boulder	**2.53%**
		3floated	**7.05%**	4-Meander	**0.00%**
		4avalanche	**0.00%**	5-Bar	**9.76%**
		5other	**0.00%**	8-Bank	**19.71%**
				9-Logstep	**2.17%**
				10-Buried in bed	**2.35%**
				0-None/other	**21.52%**

Function		Channel type	
0-Drift	**41%**	1Pool	**2%**
1-Bridge	**3%**	2Riffle	**21%**
2-Collapsed bridge	**2%**	3Glide	**14%**
3-Ramp	**37%**	4Rapid	**8%**
4-Incorporated	**18%**	5Step/pool	**22%**
		6Cascade	**23%**
		7Other	**11%**

South Fork Lost Dog Creek

708 logs/752 m

0.94 logs/m

Age		Stability		Burn	
0-Rotten	**26%**	0 -No ends	**25.04%**	0-Unburned	**34%**
1-Decayed	**52%**	1-1 end	**38.19%**	1-Partly burned	**34%**
2-Bare	**16%**	2-2ends	**36.78%**	2-Burned	**32%**
3-Limbs	**5%**				
4-Bark	**2%**				
5-Needles	**0%**				

Root wad		Source		Structural Association	
No	**74.47%**	0unknown	**42.65%**	1-Debris jam	**44.20%**
Yes	**25.53%**	1riparian	**45.26%**	2-Tree/rootwad	**0.29%**
		2hillslope	**0.33%**	3-Boulder	**8.08%**
		3floated	**11.76%**	4-Meander	**0.44%**
		4avalanche	**0.00%**	5-Bar	**2.20%**
		5-other	**0.00%**	8-Bank	**25.11%**
				9-Logstep	**6.02%**
				10-Buried in bed	**1.47%**
				0-None/other	**12.19%**

Function		Channel type	
0-Drift	**24%**	1Pool	**9%**
1-Bridge	**8%**	2Riffle	**10%**
2-Collapsed bridge	**6%**	3Glide	**9%**
3-Ramp	**41%**	4Rapid	**35%**
4-Incorporated	**21%**	5Step/pool	**19%**
		6Cascade	**17%**
		7Other	**1%**

Appendix B. Particle Counts

Sanchez Creek

	XS1	XS2	XS3	XS4	XS5	XS6	XS7	XS8	XS9	XS10
4	11	18	2	9		5	10	4	11	3
8	2	2	1	0		2	1	4	2	3
11.3	8	1	2	0		1	2	3	2	2
16	12	2	3	3		6	2	4	3	10
22.6	11	5	9	4		15	9	13	4	9
32	13	12	12	10		8	10	12	11	9
45.3	6	12	12	15		16	8	15	11	12
64	6	18	17	18		10	12	12	8	15
90.5	8	11	17	0		12	7	14	10	16
128	7	5	13	8		6	9	7	12	10
256	16	14	12	33		19	30	12	26	11
Total	100	100	100	100	0	100	100	100	100	100

Agnes Creek

	XS1	XS2	XS3	XS4	XS5	XS6	XS7	XS8	XS9	XS10
4	8	3	16	5	2	5	6	1	7	1
8	0	3	0	0	2	0	0	1	0	0
11.3	2	5	1	3	5	1	1	6	3	1
16	2	4	4	9	4	4	4	2	2	3
22.6	7	15	3	12	11	8	7	4	1	5
32	8	12	7	8	7	12	9	10	10	7
45.3	7	9	12	11	14	7	8	9	15	17
64	9	8	10	5	9	7	12	15	14	15
90.5	9	5	13	9	7	9	11	11	8	13
128	12	10	9	9	11	6	9	14	1	15
256	36	26	25	17	28	41	33	27	39	23
Bedrock				12						
Total	100	100	100	100	100	100	100	100	100	100

South Fork Lost Dog Creek

	XS1	XS2	XS3	XS4	XS5	XS6	XS7	XS8	XS9	XS10
4	7	7	11	6	1	9	3	7	0	3
8	3	0	4	1	4	0	0	1	1	3
11.3	11	0	5	1	2	1	2	1	5	6
16	14	5	13	5	4	3	12	4	4	3
22.6	6	3	10	10	5	6	9	13	21	12
32	7	10	12	13	13	16	9	10	17	12
45.3	3	10	11	6	12	11	11	17	12	11
64	8	16	8	12	12	11	7	17	10	15
90.5	9	13	5	14	8	12	9	16	7	15
128	7	9	1	9	9	7	10	7	7	12
256	25	27	20	23	30	24	28	7	16	8
Total	100	100	100	100	100	100	100	100	100	100

Appendix C. Cross Section Survey Data

Sanchez Creek

XS1	Corrected Distance (m)	Elevation (m)	Notes	XS4	Corrected Distance (m)	Elevation (m)	Notes
	52.02	2927.94	Bankfull		4.995	2920.375	Bankfull
	53.02	2927.76			5.885	2920.245	
	53.99	2927.75			6.67	2920.17	
	54.57	2927.96			7.37	2920.03	
	55.16	2928.11			7.95	2919.95	
	55.56	2928.36	Bankfull		8.72	2920.17	
					9.875	2920.23	
					10.49	2920.07	Bankfull

XS5	Corrected Distance (m)	Elevation (m)	Notes	XS6	Corrected Distance (m)	Elevation (m)	Notes
	8.83	2918.065	Bankfull		1.54	2914.585	Bankfull
	9.415	2918.041			2.435	2914.51	
	10.025	2917.935			3.32	2914.803	
	10.465	2917.865			4.19	2914.42	
	10.86	2917.765			4.99	2914.525	
	11.465	2917.72			5.74	2914.655	
	11.98	2917.795			7.49	2914.805	
	12.495	2917.95			7.69	2914.925	Bankfull
	13.355	2918.05	Bankfull				

XS7	Corrected Distance (m)	Elevation (m)	Notes	XS8	Corrected Distance (m)	Elevation (m)	Notes
	2.295	2911.72	Bankfull		2.845	2909.782	Bankfull
	3.215	2911.665			3.08	2909.263	
	4.545	2911.68			4.135	2909.362	
	5.605	2911.82			5.185	2909.482	
	5.7263	2911.914			6.035	2909.421	
	6.025	2912.14	Bankfull		6.365	2909.656	Bankfull

XS9	Corrected Distance (m)	Elevation (m)	Notes	XS10	Corrected Distance (m)	Elevation (m)	Notes
	0.73	2907.486	Bankfull		1.07	2905.391	Bankfull
	1.115	2907.181			2.44	2904.902	
	3.145	2907.061			3.37	2904.584	
	4.1	2906.616			4.2	2904.63	
	4.62	2906.571			4.69	2904.665	
	5.2	2906.696			5.72	2904.858	
	6.385	2906.786			5.95	2905.113	
	6.59	2907.196	Bankfull		6.08	2905.248	Bankfull

Agnes Creek

Notes:

tob=	Top of bank
bob=	Bottom of bank
tor=	Top of rebar
bor=	Bottom of rebar
trs=	Top rock step
brs=	Bottom rock step

XS1	Corrected Distance (m)	Elevation (m)	Notes	
	0	2913.238818	bor	
	0.43061741	2913.134409		
	0.872676299	2912.626076		
	1.239743058	2911.73812	bor	
	1.692030865	2911.665834		
	2.156164445	2911.613835	tob	Bankfull
	2.261550326	2911.250075	bob	
	2.469337636	2911.125749		
	2.542807384	2911.274505		
	2.603192818	2911.154879		
	2.722496887	2911.38746		
	2.880359913	2911.373802		
	3.067764064	2911.309813	bob	
	3.25	2911.613835		Bankfull
	3.354869367	2911.814861	tob	
	3.703374573	2911.98773	bor	
	4.096169901	2912.456246		
	4.428164247	2913.443025		
	4.823063179	2913.998875		
	5.115256945	2913.812544		
	5.437344583	2914.462843		
	5.801877433	2914.58563	bor	

XS2	Corrected Distance (m)	Elevation (m)	Notes	
	0	2907.373212	bor	
	0.771705892	2907.165111		
	1.319122651	2906.813606	side chan	
	1.676820963	2906.720752	side chan	
	2.096365837	2906.893649	bor, tob	Bankfull
	2.269458854	2906.344372	bob	
	2.498758258	2906.445346		
	2.717023826	2906.421346		
	2.932808302	2906.206095		
	3.113932228	2906.16781		
	3.403209611	2906.307692	bob	
	3.525923874	2906.84695	tob	Bankfull
	3.965887208	2906.957806		
	4.083279332	2907.157649	bor	
	4.727574204	2907.785734		
	5.163312159	2908.158686		
	5.658750991	2908.395551		
	6.383273918	2908.431225	bor	

XS3	Corrected Distance (m)	Elevation (m)	Notes	
	0	2903.934947	bor	
	0.656824355	2903.590215		
	1.217835765	2903.313779		
	2.076162472	2902.971282		
	2.341726099	2902.763559		
	2.388979087	2902.945166	on rock	
	2.693743145	2902.598745	bor	
	2.879036142	2902.468742		
	3.065804233	2902.576509		
	3.353573681	2902.410247	tob	
	3.38	2902.331696		Bankfull

	3.569927481	2901.792047	bob	
	3.711734733	2901.829164		
	3.770843102	2901.979923		
	3.791750577	2901.731376		
	4.033093213	2901.900539		
	4.202893681	2901.956613		
	4.396128957	2902.066682		
	4.559405178	2901.996338	bob	
	4.708641695	2902.331696	tob	Bankfull
	4.907952047	2902.481682	bor	
	5.425117355	2902.740169		
	5.883527079	2902.758043		
	6.374198464	2902.943817		
	6.859923094	2902.991051	bor	

XS4	Corrected Distance (m)	Elevation (m)	Notes	
	0	2899.101013	bor bedrock	
	0.389216668	2899.271871	bedrock	
	0.675339453	2899.699897	bedrock	
	0.861057145	2899.568311	bedrock	
	1.270222464	2899.439517	bedrock	
	1.422954504	2900.056198	bedrock	
	1.919580931	2899.958856	bedrock	
	1.966522781	2899.461297	bedrock	
	2.241652454	2899.429326	bedrock	
	2.587223766	2899.143652	bor bedrock tob	
	2.799802231	2898.993318	bedrock	Bankfull
	2.827170358	2898.672998	bob	
	3.02131912	2898.74494		
	3.244897356	2898.353441		
	3.396502886	2898.272084	brs	
	3.489455769	2898.814196	trs	
	3.648375592	2898.634342		
	3.838408922	2898.705225		
	3.945713957	2898.901839	bob	
	3.97	2898.993318		Bankfull
	4.000712587	2899.285467	tob	
	4.232585514	2899.427998	bor	
	4.867944369	2899.704481	rootwad	

	5.576189606	2900.018369	rootwad	
	6.159295867	2900.529189	rootwad	
	6.57507387	2901.17805	rootwad	
	6.791179646	2900.835722		
	7.246385456	2900.759489		
	7.31934094	2900.950187		
	7.599305561	2901.132024		
	7.874254573	2901.563922		
	8.487971241	2901.620506		
	8.675543148	2901.742941	bor	

XS5	Corrected Distance (m)	Elevation (m)	Notes	
	0	2897.804792	bor	
	0.377989484	2898.002005		
	0.723915029	2897.442383		
	0.931515779	2896.990591		
	1.137046251	2897.269991		
	1.449945214	2896.193204		
	1.961329801	2896.105198	bor	
	2.358795384	2895.947405	tob	Bankfull
	2.456568203	2895.601121	bob	
	2.603639708	2895.507216		
	2.735924734	2895.544893		
	2.767473711	2895.429915		
	3.00839115	2895.431433		
	3.197343648	2895.440896		
	3.260967046	2895.572258	bob	
	3.45	2895.947405		Bankfull
	3.477804655	2896.002316	tob	
	3.729788514	2896.205792	bor	
	4.553341801	2896.019673		
	4.74107966	2896.139697		
	5.372012706	2896.114505		
	5.939935608	2896.513629		
	6.129955897	2896.516551		
	6.348238765	2897.00422	rootwad	
	6.683318987	2896.238585		
	7.435266873	2896.099014		
	8.770799357	2896.020609	bor	

XS6	Corrected Distance (m)	Elevation (m)	Notes	
	0	2893.133254	bor	
	1.334331276	2892.811686		
	1.829386327	2892.617778	bor	
	2.602344327	2892.589436	tob, boulder	
	2.937893424	2892.384344		Bankfull
	3.097243952	2891.834543	bob	
	3.429613237	2891.542713		
	3.676387335	2891.897		
	3.724714881	2891.731563		
	3.754638688	2891.912914		
	3.943649314	2891.538105		
	4.128583354	2891.846401	bob	
	4.680612959	2892.247108	bor	
	4.8	2892.384344		Bankfull
	5.19555854	2892.894828	tob	
	5.863745166	2893.151292		
	6.373766403	2893.769483		
	6.926319319	2893.912105	bor	

XS7	Corrected Distance (m)	Elevation (m)	Notes	
	0	2890.600607	bor	
	0.240592446	2890.250855		
	0.331531009	2890.09771		
	0.660281515	2889.627124	bor	
	1.014113543	2889.137032		
	1.279982248	2888.499783	tob	
	1.357084105	2888.15804	bob	
	1.476233714	2888.087026		
	1.591610916	2887.895021		
	1.757374021	2888.117704		
	1.903410155	2888.119519		Bankfull 1
	2.072082146	2887.912434		
	2.262550575	2887.649282		
	2.349554154	2887.651906		
	2.366759521	2887.721555		
	2.449259003	2887.779067	bob	

2.469639782	2888.078513		
			Bankfull
2.49	2888.119519		2
2.574673344	2888.349923	boulder	
2.875625002	2888.299723		
3.002653786	2888.363824		
			Bankfull
3.168680393	2888.538815	tob	3
3.209010295	2888.3349	bob	
3.372105762	2888.189188		
3.476335111	2888.173614		
3.493285319	2888.042318		
3.719461595	2888.025983		
3.751734879	2888.164541	boulder	
3.779616626	2887.975323		
3.956890702	2888.039863		
4.001414798	2887.969777		
4.153136884	2887.932821		
4.16598213	2888.164849	boulder	
4.198906262	2888.041181		
4.306078691	2888.075891		
4.370617304	2888.322295	bob	
			Bankfull
4.4	2888.538815		4
4.413621431	2888.609056	tob	
4.614563624	2888.699744		
4.884875175	2889.205358	bor	
5.087416971	2889.411528		
5.126766982	2889.727074	boulder	
5.224557579	2889.85802	boulder	
5.420610596	2889.671607		
5.832862274	2889.88171		
5.980302503	2890.114589	boulder	
6.037870574	2889.967182		
6.606712192	2890.02512		
6.679574686	2890.211625	boulder	
6.802070792	2890.088774		
6.865731525	2890.098662	bor	

XS8	Corrected Distance (m)	Elevation (m)	Notes	
	0	2885.983908	bor	
	0.651617441	2885.384918		
	0.821957389	2885.203159		
	1.026352583	2885.054819	bor	
	1.348383716	2884.866701		
	1.70904336	2884.744306	tob	Bankfull
	1.947004318	2884.426273	bob	
	2.029914552	2884.367131		
	2.077781982	2884.452088	boulder	
	2.120233399	2884.385075		
	2.222984028	2884.498535	boulder	
	2.261899149	2884.388124		
	2.403727312	2884.358148		
	2.440204	2884.205905		
	2.61802515	2884.150635		
	2.698998244	2884.164817		
	2.736145827	2884.410545	boulder	
	2.771647963	2884.640756	boulder	
	2.831925557	2884.367267		
	2.907096878	2884.229859		
	2.952402493	2884.55598	boulder	
	2.978471069	2884.199147		
	3.044074731	2884.244472		
	3.057332921	2884.359593		
	3.13325246	2884.589108	boulder	
	3.162003783	2884.396775		
	3.273980972	2884.390476		
	3.345936926	2884.559983	bob	
	3.365	2884.744306		Bankfull
	3.393102356	2884.935801		
	3.623725541	2885.29941	bor	
	3.737287006	2885.473635	tob	
	4.287432488	2885.843674		
	4.89516549	2886.261093		
	5.262122939	2886.760589		
	5.550326504	2886.755568	bor	

XS9	Corrected Distance (m)	Elevation (m)	Notes	
	0	2881.019412	bor	
	0.690706821	2880.3842		
	1.279338769	2879.902306		
	1.584169804	2879.637769		
	1.720533549	2879.425132	bor	
	1.849320033	2879.212722	tob	
	1.865	2879.115613		Bankfull
	1.899804665	2878.833946	bob	
	2.144369624	2878.740709		
	2.243697857	2878.892055	boulder	
	2.266525131	2878.720649		
	2.385779255	2878.764468	boulder	
	2.426148232	2878.58396		
	2.480658018	2878.571033		
	2.504947777	2878.682712	boulder	
	2.577862649	2878.532641		
	2.602827534	2878.683514	boulder	
	2.63562204	2878.502358		
	2.771403557	2878.530633		
	2.859309599	2878.596598		
	2.897861033	2878.759277	boulder	
	3.039309683	2878.559099		
	3.127887542	2878.59587		
	3.22523524	2878.554871		
	3.245699769	2878.604425		
	3.276344536	2878.716702	boulder	
	3.42673997	2878.740281	boulder	
	3.45405047	2878.584615		
	3.521260727	2878.603459		
	3.718079268	2878.704584	bob	
	3.787635563	2879.115613	tob	Bankfull
	3.94185779	2879.220343		
	4.034411313	2879.319363	bor	
	5.034777574	2879.850068		
	5.187665089	2879.965324	rootwad	
	5.314004519	2879.962123		
	5.570962284	2880.075347		
	5.916492536	2880.335987		
	6.22902232	2880.46279	bor	

XS10	Corrected Elevation (m)	Elevation	Notes	
	0	2874.346156	bor	
	0.276114591	2874.097058		
	0.492150895	2874.14297	rootwad	
	0.678659871	2874.181039	rootwad	
	0.721351598	2873.751603		
	1.131994681	2873.483155		
	1.773154913	2873.742844		
	2.180592818	2873.697644		
	2.462862991	2873.936783	tob	
	2.666184186	2873.935259	bor	Bankfull
	2.816789622	2873.819874	bob	
	2.953738592	2873.74191		
	3.080542751	2873.668521		
	3.255069116	2873.646861		
	3.34081476	2873.72182		
	3.452929166	2873.546193		
	3.611186619	2873.579741		
	3.69851029	2873.680914		
	3.756616847	2873.526246		
	3.799869635	2873.70785	top log step	
	3.820587931	2873.588185		
	3.869981417	2873.352263	bot log step	
	3.981271205	2873.462487	top log step	
	4.068833016	2873.084963	bot log step	
	4.133762405	2873.330857		
	4.181088966	2873.329398		
	4.244279655	2873.675123	bob	
	4.33	2873.935259		Bankfull
	4.431802775	2874.173416	tob	
	4.65482802	2874.353379	bor	
	4.752762667	2874.599292		
	4.779178199	2874.962856	boulder	
	5.126838354	2875.69274	boulder	
	5.133729292	2875.619516		
	5.745258931	2876.369841	bor	

South Fork Lost Dog Creek

Notes:

tob=	Top of bank
bob=	Bottom of bank
tor=	Top of rebar
bor=	Bottom of rebar
trs=	Top rock step
brs=	Bottom rock step

XS1	Corrected Distance (m)	Elevation (m)	Notes	
	0	2922.924348	bor	
	4.80750257	2922.674838		
	7.75556944	2922.890303		
	14.7646869	2923.096912		
	17.405356	2922.941916		
	18.4778363	2922.614775		
	20.9502458	2922.867411	tob, bor	Bankfull
	21.6974906	2922.400279	bob	
	22.1507995	2922.483756	on boulder	
	22.6268495	2922.163688		
	22.9969734	2922.197099		
	23.3103156	2922.573523	bob, boulder	
	23.7	2922.867411		Bankfull
	23.9498577	2922.967622	bor, tob	
	25.7874944	2923.250778		
	29.4836577	2923.050869		
	35.2463316	2923.378619		
	40.686029	2923.935415		
	46.7874586	2924.319576	bor	

XS2	Corrected Distance (m)	Elevation (m)	Notes	
	0	2919.55	bor	
	4.06163658	2919.281698	in a sm side channel	
	11.3849633	2919.435108		
	16.8880007	2919.496295		
	22.220048	2919.171911	bor	
	25.0382796	2918.903437	tob	Bankfull
	25.4510974	2918.593069	bob	
	26.033692	2918.509788		
	26.856662	2918.382878		
	27.6967544	2918.612893	bob	
	27.75	2918.903437		Bankfull
	27.7787643	2919.002351	tob	
	28.9797641	2919.134947	bor	
	32.8861532	2919.46616		
	35.419065	2919.208323	side channel	
	37.9053536	2919.032369	side channel	
	43.4099861	2919.634486	bor	

XS3	Corrected Distance (m)	Elevation (m)	Notes	
	0	2915.756905	bor	
	4.70655255	2915.445857		
	9.252504	2915.095029		
	12.7545323	2914.835088		
	16.272928	2914.481352		
	20.5819501	2913.75548	bor	
	21.65	2913.542953		Bankfull
	21.6580249	2913.521139	tob, on boulder	
	22.0851624	2913.008552	bob	
	22.7096739	2912.846699		
	23.451383	2912.844948		
	23.7609025	2913.15596	bob, boulder	
	24.3771953	2913.542953	tob	Bankfull
	25.2318558	2913.644391		
	27.8860142	2913.77709	bor	
	31.064228	2913.840398		
	35.9662593	2913.994038		

	39.7772758	2913.874445		
	44.8761231	2914.190019	bor	

XS4	Corrected Distance (m)	Elevation (m)	Notes	
	0	2911.658586	bor	
	3.50954793	2911.002754		
	6.73292513	2911.02935		
	11.5176296	2910.739535		
	17.3609667	2910.751399		
	21.0473322	2910.390955		
	25.7424635	2909.662378		
	28.4121205	2909.369653	bor	
	28.823275	2909.29868	tob	Bankfull
	29.1223878	2908.824974	bob	
	30.4055222	2908.8498		
	31.2417027	2908.928636	bob	
	31.7821446	2909.211894	tob	
	32.3	2909.29868		Bankfull
	33.0331849	2909.433938	bor	
	33.8357881	2909.898841		
	35.5205837	2910.571625		
	39.1761268	2910.936792		
	45.5039099	2911.378094	bor	

XS5	Corrected Distance (m)	Elevation (m)	Notes	
	3.55984267	2907.354733		
	5.97863713	2907.191402		
	7.50685795	2905.99169	tob, bor	
	7.63	2905.838388		Bankfull
	7.99593778	2905.451427	bob	
	8.70264479	2905.164744		
	9.3580554	2905.129348		
	10.181434	2905.387898	bob	
	11.1138127	2905.838388	tob	Bankfull
	11.7194515	2905.939823	bor	
	15.1877578	2906.230331		
	18.6324581	2907.51502		
	21.792307	2908.116757	bor	

XS6	Corrected Distance (m)	Elevation (m)	Notes	
	0	2903.287257	bor	
	1.13772849	2903.184879		
	2.83707382	2902.917232		
	6.70365666	2901.300078		
	8.12360977	2901.017934		
	10.6540799	2900.797164	bor	
	11.8131885	2900.734282		
	12.2164636	2900.638276	top	Bankfull
	12.4389775	2900.398365	bob	
	12.81554	2900.219119		
	13.1753351	2900.094159		
	13.3249546	2900.183668	boulder	
	13.5607463	2900.100411		
	13.9094911	2900.210744		
	14.4200148	2900.302012		
	14.593708	2900.581267	bob, boulder	
	14.64	2900.638276		Bankfull
	14.8457667	2901.023336	tob	
	15.2204438	2901.220405		
	15.7602478	2901.451765		
	16.7640741	2901.594083	bor	
	18.9998911	2901.821576		
	21.5589098	2902.022321		
	25.3194205	2902.274906		
	27.7008552	2902.598126		
	29.3962816	2903.180632		
	31.0775665	2903.247593		
	33.4608287	2903.761766	bor	

XS7	Corrected Distance (m)	Elevation (m)	Notes
	0	2900.442685	bor
	2.56117882	2900.092647	
	4.30287529	2900.031078	
	6.87880722	2899.730278	
	11.3187994	2899.256811	

	14.7360857	2898.856002		
	15.7321448	2898.637436		
	16.8180227	2898.774012		
	17.8395115	2898.821277		
	18.4169247	2898.443171		
	20.0542219	2898.002986		
	20.8387681	2897.752818		
	21.4417847	2897.401134	bor	
	21.9380896	2897.051355	tob	Bankfull
	22.2791868	2896.852144	bob	
	22.4222611	2896.670058	boulder	
	22.5343	2896.471153		
	22.7403669	2896.45599		
	23.0657836	2896.478771		
	23.6289235	2896.563595		
	24.1973113	2896.592866		
	24.4630759	2896.739791	bob	
	24.9024095	2896.850959		
	25.15	2897.051355		Bankfull
	25.2616464	2897.110435	tob	
	25.824828	2897.061585	bor	
	26.6118886	2897.105622		
	29.8909649	2897.034869		
	31.6818348	2897.369185		
	34.7073795	2897.636333		
	41.2114522	2898.019944		
	43.3468494	2898.383275	bor	

XS8	Corrected Distance (m)	Elevation (m)	Notes	
	0	2897.595844	bor	
	3.52455579	2897.642958		
	9.70260295	2897.380477		
	12.2377866	2897.18824		
	15.8775242	2897.222644		
	17.9551065	2897.441943	bor	
	20.2687855	2897.070184	tob	Bankfull
	20.4980517	2896.752024	bob	
	21.0133207	2896.628451		
	21.5133894	2896.355402		

	21.9277249	2896.506142		
	22.5924183	2896.60299		
	22.82	2897.070184		Bankfull
	22.8650511	2897.185053	bob	
	24.0173995	2897.703508	tob, bor	
	26.9937033	2898.266198		
	29.5952347	2898.625986		
	31.7366726	2899.120502		
	33.5200738	2899.439953		
	36.3460356	2899.757211		
	38.777528	2900.293059		
	42.161792	2901.02733		
	45.0136868	2901.461636	bor	

XS9	Corrected Distance (m)	Elevation (m)	Notes	
	0	2900.936791	downstream from avulsion?	
	0.61938634	2900.862947		
	7.21392216	2899.902008		
	8.85128942	2899.335694		
	10.5411776	2898.869095		
	15.3396686	2898.483267		
	21.1043805	2897.901055	bor	
	21.7201552	2897.757332		
	22.414571	2897.735669		
	23.2629585	2897.242494		
	24.3786258	2897.29221	tor?	
	25.38	2896.362748		Bankfull
	25.5791927	2896.161051	bob	
	26.3044233	2895.97436		
	26.8523639	2895.93926		
	27.2945304	2895.824887		
	27.8085784	2895.710421	bob	
	28.4614803	2895.742281	tob	
	29.0654553	2895.917483		
	29.1567741	2896.362748		Bankfull
	30.0564358	2896.678836	bor?	
	31.6904441	2897.464459		
	33.8689057	2898.829511		

	34.5367845	2898.526071		
	35.7182201	2898.558188		
	38.153028	2899.653173		
	39.1414952	2899.754443	bor	

XS10	Corrected Distance (m)	Elevation (m)	Notes	
	0	2892.003257	bor	
	1.19040043	2891.994283		
	2.97355609	2892.273637		
	4.21444946	2891.836704		
	5.08570659	2892.178431		
	6.64174295	2892.34916		
	7.69773792	2891.846299	hole from rootball	
	8.32079398	2892.219441		
	9.63512377	2892.29029		
	11.760939	2891.80597	bor	
	11.9977089	2891.730398	tob	Bankfull
	13.10056	2891.369192	bob	
	13.6167306	2891.156774		
	14.2149014	2891.174443		
	15.3097355	2891.110778		
	15.7613426	2891.336109	bob	
	16.7131237	2891.584038	tob	
	16.9	2891.730398		Bankfull
	17.3842145	2892.015037	bor	
	18.7571986	2892.699821		
	22.9522879	2893.992103		
	25.4896506	2894.699653	bor	

Appendix D. Cross Section Calculations

Sanchez Creek

Total change in area - 44%

	XS Area 1999 (m^2)	XS Area 2004 (m^2)	XS area 2010 (m^2)	Change 2004-1999 (m^2)	Change 2010-2004 (m^2)	Change 2010-1999 (m^2)
XS1	0.96	0.77	1.63	-0.18	0.86	0.67
XS2	1.49	1.29	-	-0.20	-	-
XS3	1.46	0.84	-	-0.62	-	-
XS4	0.83	0.99	1.19	0.16	0.20	0.36
XS5	1.18	1.22	0.73	0.04	-0.48	-0.44
XS6	1.76	1.48	1.81	-0.28	0.33	0.06
XS7	1.33	1.34	1.51	0.01	0.17	0.18
XS8	0.90	0.77	1.30	-0.13	0.52	0.40
XS9	1.80	1.51	3.36	-0.29	1.85	1.56
XS10	1.01	1.39	2.72	0.39	1.33	1.72
Average	1.27	1.16	1.78	-0.11	0.60	0.56
Rate (m^2/year)				-0.02	0.10	0.05

Sanchez Creek Mean Depth

Total change in mean depth – 37%

	Mean depth (1999) (m)	Mean depth (2004) (m)	Mean depth (2010) (m)	Change 2004-1999 (m)	Change 2010-2004 (m)	Change 2010-1999 (m)
XS1	0.23	0.20	0.46	-0.04	0.26	0.23
XS2	0.36	0.31	-	-0.05	-	-
XS3	0.30	0.18	-	-0.13	-	-
XS4	0.21	0.21	0.22	0.00	0.00	0.01
XS5	0.30	0.26	0.16	-0.04	-0.10	-0.14
XS6	0.26	0.24	0.30	-0.03	0.06	0.03
XS7	0.30	0.31	0.41	0.01	0.10	0.11
XS8	0.29	0.24	0.34	-0.05	0.10	0.05
XS9	0.33	0.28	0.57	-0.05	0.30	0.25
XS10	0.24	0.33	0.54	0.09	0.21	0.30
Average	0.28	0.26	0.37	-0.03	0.12	0.10
Rate (m/year)				-0.01	0.02	0.01

Agnes Creek

Total change in area – 24%

	XS Area 1999 (m^2)	XS Area 2004 (m^2)	XS area 2010 (m^2)	Change 2004-1999 (m^2)	Change 2010-2004 (m^2)	Change 2010-1999 (m^2)
XS1	0.69	0.34	0.32	-0.35	-0.02	-0.37
XS2	0.52	0.25	0.74	-0.27	0.50	0.23
XS3	0.41	0.26	0.49	-0.15	0.23	0.08
XS4	0.55	0.45	0.43	-0.10	-0.02	-0.12
XS5	0.23	0.22	0.43	-0.02	0.21	0.20
XS6	0.28	0.43	0.93	0.15	0.50	0.65
XS7	0.70	0.36	0.70	-0.34	0.34	0.00
XS8	0.25	0.63	0.58	0.39	-0.05	0.34
XS9	0.83	0.60	0.84	-0.23	0.23	0.00
XS10	0.37	0.38	0.54	0.02	0.16	0.18
Average	0.48	0.39	0.60	-0.09	0.21	0.12
Rate (m^2/year)				-0.02	0.03	0.01

Agnes Creek Mean Depth

Total change in depth - -3%

	Mean depth (1999) (m)	Mean depth (2004) (m)	Mean depth (2010) (m)	Change 2004-1999 (m)	Change 2010-2004 (m)	Change 2010-1999 (m)
XS1	0.64	0.34	0.29	-0.29	-0.05	-0.34
XS2	0.41	0.22	0.52	-0.19	0.30	0.11
XS3	0.36	0.24	0.37	-0.12	0.12	0.01
XS4	0.45	0.38	0.37	-0.08	-0.01	-0.09
XS5	0.24	0.18	0.37	-0.06	0.19	0.13
XS6	0.25	0.38	0.50	0.12	0.12	0.25
XS7	0.61	0.34	0.39	-0.28	0.05	-0.23
XS8	0.17	0.43	0.35	0.26	-0.08	0.18
XS9	0.58	0.41	0.44	-0.17	0.03	-0.14
XS10	0.31	0.29	0.33	-0.02	0.03	0.02
Average	0.40	0.32	0.39	-0.08	0.07	-0.01

South Fork Lost Dog

Total change in area – 89%

	XS Area 1999 (m^2)	XS Area 2004 (m^2)	XS area 2010 (m^2)	Change 2004-1999 (m^2)	Change 2010-2004 (m^2)	Change 2010-1999 (m^2)
XS1	0.73	0.96	1.38	0.23	0.41	0.65
XS2	0.93	2.10	1.26	1.17	-0.83	0.34
XS3	0.96	1.14	1.31	0.18	0.17	0.35
XS4	0.97	0.89	1.15	-0.09	0.26	0.18
XS5	1.44	0.70	2.13	-0.73	1.43	0.69
XS6	1.31	2.40	1.89	1.10	-0.52	0.58
XS7	1.43	0.92	1.35	-0.52	0.44	-0.08
XS8	1.09	0.78	3.12	-0.32	2.34	2.03
XS9	1.44	1.47	4.72	0.02	3.25	3.27
XS10	1.21	2.20	3.45	0.99	1.26	2.24
Average	1.15	1.36	2.18	0.20	0.82	1.03
Rate (m^2/year)				0.04	0.14	0.09

South Fork Lost Dog Mean Depth

Total change in depth – 64%

	% change	0.64				
	Mean depth (1999) (m)	**Mean depth (2004) (m)**	**Mean depth (2010) (m)**	**Change 2004-1999 (m)**	**Change 2010-2004 (m)**	**Change 2010-1999 (m)**
XS1	0.35	0.42	0.50	0.07	0.08	0.15
XS2	0.29	0.70	0.46	0.41	-0.24	0.17
XS3	0.37	0.44	0.48	0.06	0.04	0.11
XS4	0.33	0.31	0.33	-0.02	0.02	0.00
XS5	0.51	0.29	0.59	-0.22	0.31	0.09
XS6	0.44	0.81	0.72	0.38	-0.10	0.28
XS7	0.46	0.42	0.41	-0.05	-0.01	-0.06
XS8	0.30	0.30	0.83	0.00	0.54	0.54
XS9	0.36	0.50	1.16	0.15	0.65	0.80
XS10	0.32	0.45	0.61	0.13	0.16	0.29
Average	0.37	0.46	0.61	0.09	0.15	0.24
Rate (m/year)				0.02	0.02	0.02

Appendix E. Channel widths from Planview Survey

South Fork Lost Dog Creek

1998 Width (m)	2010 Width (m)	Distance Downstream (m)
4.99	3.34	3.46
3.21	4.85	7.37
3.64	3.34	10.71
4.60	2.43	14.70
4.67	2.72	18.45
3.85	2.57	22.30
5.24	4.06	26.07
5.37	3.70	30.31
5.56	4.07	34.03
5.20	3.16	37.86
3.95	3.18	41.52
3.22	4.90	45.23
3.95	4.75	48.24
4.59	2.64	52.21
3.61	2.24	56.03
3.28	2.11	60.41
2.53	2.89	63.00
3.10	3.37	65.23
2.66	3.17	69.15
2.41	4.01	72.29
2.02	3.48	75.27
3.70	3.58	78.15
4.15	4.09	80.73
5.10	3.59	83.28
5.88	4.69	86.25
5.81	3.59	90.20
6.51	3.86	94.49
4.38	3.38	98.43

2.52	3.99	102.59
2.74	3.37	105.62
2.89	4.03	108.79
2.01	3.21	111.97
1.93	3.01	115.83
1.92	2.47	118.88
2.01	2.48	121.61
2.11	2.29	124.45
2.08	2.13	126.92
3.86	2.15	130.83
5.60	3.99	134.94
5.32	4.21	138.97
4.87	3.64	142.71
4.41	3.33	146.35
4.11	3.82	148.98
3.66	5.82	152.05
3.20	3.74	155.79
2.84	2.93	159.07
3.56	2.54	162.02
3.57	2.41	164.85
3.54	3.74	167.70
3.46	2.32	170.62
3.43	3.40	173.75
3.51	2.59	175.81
4.54	2.89	178.13
5.14	2.73	181.81
5.65	3.68	185.44
3.97	3.45	188.54
2.60	2.87	191.02
2.03	3.58	193.54
1.99	2.32	196.32
2.20	2.45	197.77
2.54	2.80	201.55
3.26	3.56	205.12
4.23	3.12	208.58
4.00	2.63	211.99
3.28	3.14	215.35
3.63	2.53	219.00
3.97	3.34	222.21
3.18	2.83	225.11
4.47	2.94	228.09

5.89	2.82	231.36
6.16	3.00	235.27
4.46	3.93	238.78
2.89	3.79	241.92
4.59	3.39	244.32
3.83	2.27	249.74
3.91	3.04	254.20
3.48	4.57	256.22
3.51	2.82	259.49
4.68	2.51	263.78
3.31	2.67	267.60
4.83	2.85	271.56
4.75	2.80	275.79
4.65	3.16	279.33
6.12	3.05	282.25
7.01	3.46	286.08
5.68	2.20	290.08
4.92	3.27	294.08
8.38	2.63	297.75
4.63	3.22	301.13
3.29	2.89	304.03
3.12	2.36	305.90

Agnes Creek

1998 Width (m)	2010 Width (m)	Distance Downstream (m)
3.54	3.82	3.40
3.57	4.70	6.62
3.67	4.32	8.84
3.70	4.65	11.34
3.52	4.58	13.62
3.56	5.55	17.93
3.90	5.39	20.67
4.49	5.39	23.64
4.77	5.42	26.83
3.67	4.12	29.64
3.08	10.18	33.21
4.58	13.84	36.09
5.38	13.73	40.68
6.31	16.42	43.78
5.05	20.71	46.35
4.59	19.03	49.97
2.75	9.73	52.24
3.17	5.66	54.18
4.28	4.57	56.23
5.20	5.19	60.59
4.42	6.83	63.58
3.93	11.40	65.49
5.39	7.73	67.70
6.58	8.71	70.38
7.62	6.81	73.24
9.04	5.69	74.58
8.84	4.78	75.98
8.00	4.01	78.38
5.02	3.87	82.10
4.09	5.31	83.81
4.23	4.98	86.20
4.91	4.66	88.35
4.59	5.77	93.61
4.09	4.85	96.41

3.25	3.77	100.01
3.51	6.33	101.72
3.94	4.45	104.57
4.37	4.04	107.60
4.43	4.64	110.88
3.14	4.80	112.69
3.26	4.69	115.50
3.58	4.27	118.20
4.15	4.86	121.61
4.89	5.03	124.29
4.71	4.39	127.11
5.60	3.81	129.36
4.08	3.90	132.65
4.37	3.67	136.33
4.65	3.87	138.49
4.42	5.31	140.06
3.70	5.29	142.29
3.28	3.48	144.26
2.26	3.60	145.52
3.14	5.98	147.32
2.52	5.47	148.87
2.17	9.10	150.82
2.30	6.10	152.67
3.52	5.66	155.34
3.83	6.00	157.80
4.09	4.12	160.34
3.67	5.86	163.37
3.90	9.61	165.74
3.34	9.30	169.22
3.18	6.69	172.97
3.50	3.75	175.68
3.69	3.93	179.02
3.80	3.86	183.04
4.34	4.07	186.36
4.68	6.18	188.64
3.88	5.21	191.18
4.42	5.16	194.95
4.37	7.55	197.22
4.17	9.67	200.09
3.67	8.65	202.59
3.45	6.10	204.58

3.59	7.75	207.00
3.63	5.17	210.54
4.90	5.54	212.83
5.50	5.99	215.11
4.11	4.49	217.12
4.49	4.98	218.89
5.35	5.77	222.27
7.34	4.12	224.86
11.94	4.18	227.81
7.34	5.14	231.04
6.37	4.69	233.39
5.46	5.67	237.14
5.16	3.50	240.08
5.88	3.18	242.80
6.14	5.16	246.78
4.49	6.50	249.87
4.11	6.26	253.13
3.85	5.39	256.09
4.66	6.08	259.22
9.35	3.94	262.60
9.03	3.87	266.28
9.11	4.14	268.24
7.03	4.00	270.74
5.84	4.63	274.20
4.75	4.17	276.00
5.56	3.68	280.45
5.43	5.39	284.64
5.33	5.88	287.41
5.44	5.63	290.25
3.55	9.03	294.44
2.66	8.35	298.11
2.68	10.28	301.40
3.16	8.29	303.17
3.71	9.11	305.29
3.52	4.81	305.29