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Observed Geomorphic Channel Response to Wildfire of Moose Creek, A Spring-Dominated Stream

Abstract

The headwaters of Moose Creek, a spring-dominated stream in eastern Idaho, burned during the Yellowstone fires of 1988. This study was conducted to determine if post-fire changes in channel form and behavior could be detected. The watershed's geology is predominantly rhyolite ash-flow tuffs, riparian areas are in excellent condition, and past land use includes logging and roads. Areas burned at high fire intensities have been difficult to revegetate, with persistent hydrophobic soils, high surface runoff, and high sediment production. Multiple measurement techniques used to detect channel change and assess response included discharge measurements, pebble counts, channel cross-section surveys and longitudinal profiles. These measurements were made at upper and lower sites within the watershed between 1985 and 1997. Limited bedload sampling also was conducted at the lower site. The greatest increase in fine bed surface materials (sand and finer) occurred at the lower site shortly after the fires (in 1991), with slightly lower but fluctuating amounts of surface fines since then; post-1991 levels of fines were highest in 1997. At the upper site, results were similar but less distinct because of coarser substrate. Cross-sectional and longitudinal channel surveys provided the greatest information on changes in channel morphology since the fires. At the lower site, flows were confined within the channel, and after initial degradation between 1986 and 1991, the site exhibited net aggradation. At the upper site, continued sediment input and increased frequency of overbank flows in recent years resulted in vertical floodplain accretion. In spite of data deficiencies, evidence suggested that fires have increased the amount of fine sediment in the stream system and that Moose Creek transports excess sediment delivered to it and is constructing a new floodplain where flows exceeding bankfull discharge access the floodplain.

Key Words: wildfire response, stream channel, channel morphology, spring-fed stream, Yellowstone.

Introduction

Yellowstone National Park and areas adjacent to it contain numerous springs, both hot and cold, associated with the area's recent volcanic history. Spring-fed streams are characterized by relatively low variation in annual discharge, peak flows that occur in late summer, and floodplains that are wet for much of the growing season (Stamm and Whiting 1994). Banks are stable and well-vegetated, and in-channel bars are commonly mobile. Moose Creek, located in the northeastern portion of the Targhee National Forest in eastern Idaho, fits this characterization. The headwaters of Moose Creek burned in 1988 in one of the Yellowstone fires (the North Fork Burn). Other investigators have included Moose Creek in their studies, analyzing various aspects of the stream and its watershed (Whitehead 1978, Benjamin this issue, Bressler and Gregory this issue). This study's

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objective was to analyze stream channel changes in Moose Creek since the 1988 fires. Because of the hydrology of Moose Creek, such a study may provide new insight into spring-dominated stream systems and their response to disturbance. This paper includes information and analysis not previously reported by Simon (1999).

Study Area

Watershed Description

Moose Creek is a tributary to the Henry's Fork of the Snake River in eastern Idaho (Van Kirk and Benjamin this volume, Fig. 1). Elevations along the stream vary from about 2378 m where defined channels can first be identified to about 1948 m at the confluence with the Henry's Fork (Fig. 2). The apparent drainage area is 41.6 km^2. Springs, which are the primary source of perennial water for the stream, emanate from steep volcanic headwalls; secondary spring sources further downstream originate at the base of the volcanic flows. The watershed extends above these springs, with the upper reaches characterized by intermittent drainages containing infrequent perennial springs. Surficial geology includes Quaternary rhyolite ash-flow tuffs, with Quaternary alluvium in the lower reaches of the stream. Obsidian sand and gravel are commonly found with the tuff in alluvial deposits. Soils are generally young, developed in volcanic ash and related volcanic materials, and have loess caps in some areas. Textures are mostly silt loams and gravelly sands, and soils are well-drained and acidic (pH about 4.5-5.0).

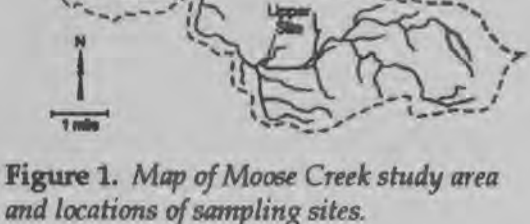

Figure 1. *Map of Moose Creek study area and locations of sampling sites.*

The entire watershed is on federally

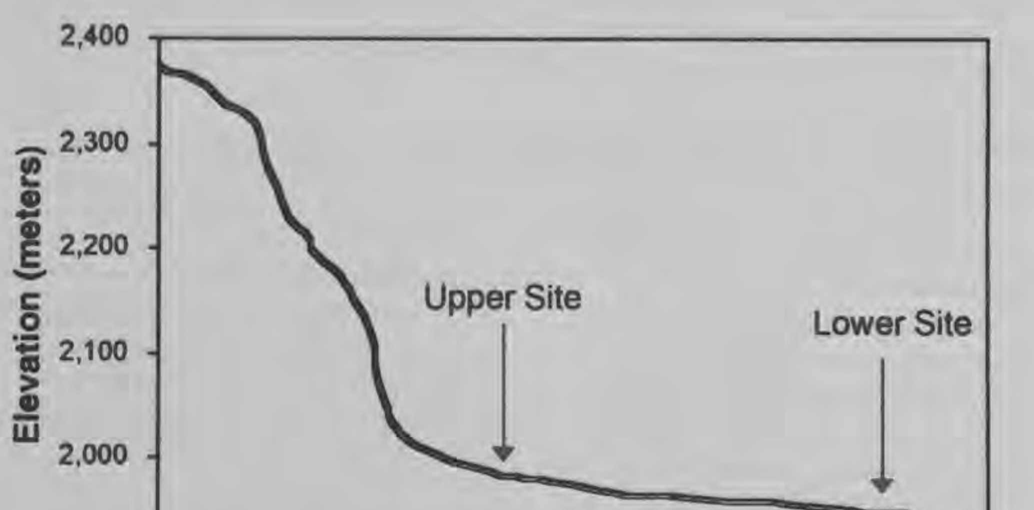

Figure 2. *Longitudinal valley profile with site locations.*

managed land. Most of the watershed is managed by the Targhee National Forest, but some of the upper watershed lies in Yellowstone National Park. No domestic livestock grazing has occurred in the watershed for many years. Logging and associated road construction in the 1980s, in response to an infestation of mountain pine beetles, affected about 26 percent of the Moose Creek drainage. Total area affected by clearcut logging in the drainage basin amounted to about 10.4 km^2 (25%), with about 80.4 km of road construction. No logging has taken place since the late 1980s. Recent rehabilitation efforts in the area have been directed at obliterating roads. Most of the headwater area is closed to motorized vehicle access except for snowmobiles, although a main access road through the headwater area was reopened in 1999. A number of summer homes are located near the lower reaches of Moose Creek.

In 1988, fires burned much of Yellowstone National Park and some areas outside the Park. One of the fires, the North Fork Burn, began in July in the vicinity of the Moose Creek headwaters, burned into Yellowstone, and then burned back onto the National Forest. About 24 km^2 (60%) of the Moose Creek drainage burned. Burn intensities varied; about 12 km^2 burned at high intensity, and the rest burned at low intensity. Rehabilitation efforts included aerial grass seeding, contour felling of logs on hillsides and in drainage bottoms to reduce soil loss, construction of sediment dams, and other measures. In areas having hydrophobic soil conditions, heavy equipment was used to break up water-repellent surface layers before seeding. In spite of these efforts, high-intensity burn areas have been difficult to revegetate because of persisting high surface soil temperatures (which likely dessicate grass seed) and hydrophobic soil conditions. As recently as 1995, a small amount of water applied to high-intensity burn areas would not infiltrate soils after as much as 30 minutes. This hydrophobic layer extended as much as several inches into the top soil layers. In contrast, areas that burned at lower intensities revegetated readily. In 1999 hydrophobic soil conditions appeared less prevalent than they did immediately after the fires, and vegetation was establishing in some areas not previously revegetating. A large amount of soil remains exposed in these high-intensity burn areas, however.

Hydrophobic soil conditions and lack of vegetation that resulted from the fire have led to conditions favoring accelerated headwater surface runoff in response to precipitation events. This runoff is quickly delivered to ephemeral draws and intermittent channels, and then downstream. Given the erodible nature of the parent material, this has led to extensive surface erosion (both gullying and sheet erosion), erosion of road-related features, e.g., ditches, and delivery of sediment to ephemeral and intermittent headwater channels and then to perennial streams below. Turbid flows in lower Moose Creek are often reported in association with spring and summer rain storms. Snowmelt is probably the primary source of recharge for local springs, along with rain that falls in areas lacking hydrophobic soil conditions. Benjamin (this issue) further describes groundwater recharge mechanisms in the area.

Descriptions of Stream and Survey Sites

General stream types, as described using the Rosgen (1996) classification system, vary along the length of Moose Creek. Headwater reaches are steep, deeply entrenched, and well-confined "A" type channels where they cut across the front of ash flows. Moving downstream, confinement decreases, the stream becomes less entrenched, and it consists of "B" and "C" channel types. The lowermost reaches flow through broad alluvial flats and are characterized by unconfined "E" channel types.

The stream's steepest reach is in the upper 5.6 km of the drainage (Fig. 2). This reach has an average gradient of 6.3 percent, punctuated by locally steeper segments where the stream cuts through the front lobes of volcanic deposits. In the lower 12.6 km, the profile flattens and is smooth, with an average gradient of about 0.4 percent.

Channel surveys and discharge measurements were conducted at two sites (Table 1 and Fig. 1). The lower site is about 1.1 km upstream of the confluence with the Henry's Fork and 9.0 km downstream of the upper site, at an elevation of 1949 m. About 55 percent of the watershed above this site burned in 1988. The stream at this location is characterized as an E4 type channel (Rosgen 1996, Fig. 3). The channel has low gradient (0.1 percent), high sinuosity, and low width/depth ratio (8.0) and flows through extensive meadows, with sedges and grasses providing excellent bank stability. Mobile sand/gravel bars are common. Remnants of log fish-habitat improvement structures are present in the channel. A number of summer homes are located upstream of the site.

Table 1. *Moose Creek study site characteristics.*

	Upper site	Lower site
Drainage area	19.8 km²	41.6 km²
Valley gradient	1.0 %	0.4 %
Rosgen channel type	C4	E4
Percent of watershed burned upstream of site	90%	55%

The upper site is located about 7.6 km below the beginning of the first defined channels, at an elevation of 1989 m (Fig. 1). The channel has the general characteristics of a C4 channel. Typical C4 channels have entrenchment ratios greater than 2.2, gradients between 0.1 percent and 2 percent, high sinuosity, moderate to high width/depth ratios (>12), and substrates comprised predominantly of gravel. The reach is in a confined valley, which results in lower

Figure 3. *Photo of lower study site.*

sinuosity and width/depth ratio than would normally be expected for a C channel (Fig. 4). The entrenchment ratio for the site is about 3.7, width/depth ratio is 8.7, and bankfull slope is 0.7 percent. The substrate is mainly comprised of gravel. Adjacent reaches, both above and below, are more typical C channels (Fig. 5). The upper study site also has mobile instream gravel bars.

Figure 4. *Photo of upper study site.*

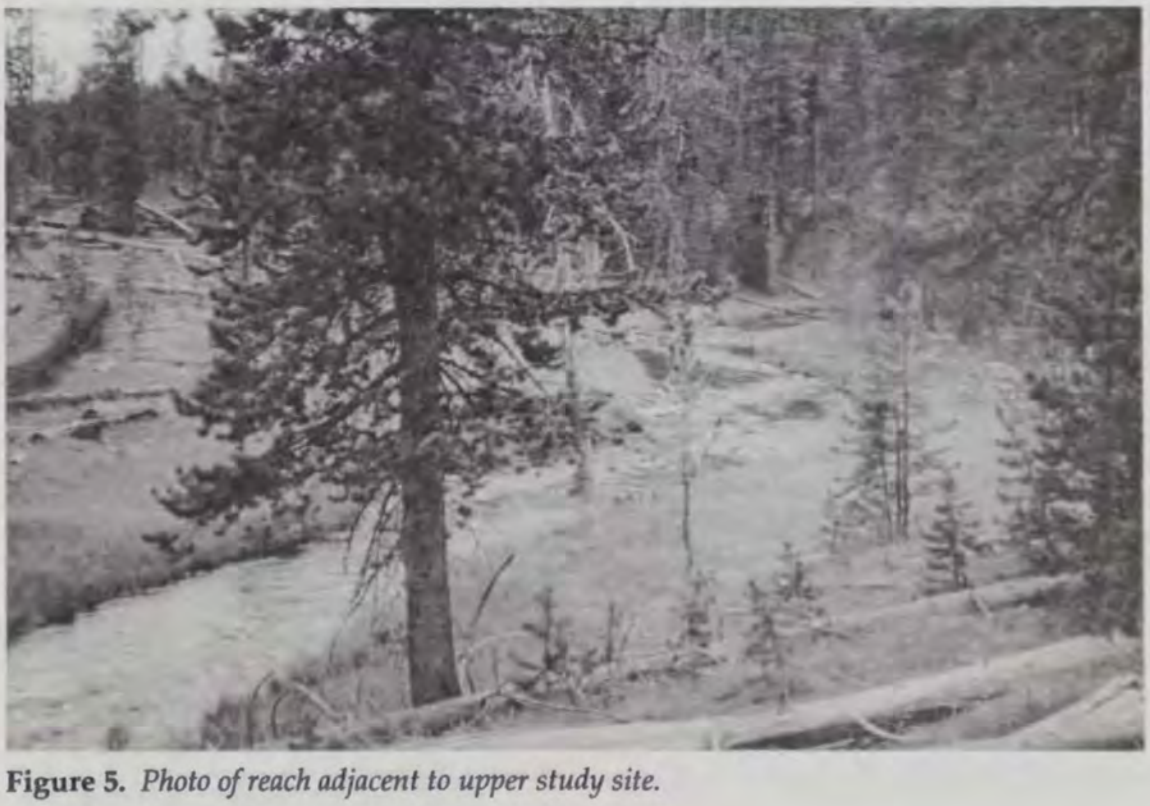

Figure 5. *Photo of reach adjacent to upper study site.*

About 90 percent of the watershed above this site burned in 1988, roughly 50 percent at high intensity. Logging was conducted on both sides of the stream at this site in the 1980s, and an old (closed) road is located about 12 m from the channel's right bank. No timber was harvested between the road and the stream, however. Selective harvest of lodgepole pine occurred within the riparian area on the left side of the stream. Large wood in and suspended across the channel is common, and healthy grass/beaked sedge (*Carex rostrata*) communities occupy the riparian area along both streambanks, providing excellent bank stability.

Methods

Both sites were established and monumented in 1985, as part of a monitoring effort conducted by the Forest Service to determine channel changes that could be attributed to roads and logging in the watershed (Moulton 1985). After the 1988 fires, monitoring objectives were expanded to include determination of channel change caused by the fires. Data were collected sporadically between 1985 and 1997; lack of systematic data collection limits the interpretive value of this study. Only data from 1986 (where available), 1991, 1994, and 1997 are discussed in this paper.

Measurements were made of discharge, bedload transport, particle size distribution of bed material, channel cross section, and longitudinal channel profile. Discharge was measured with pygmy and Price AA current meters, using standard USGS techniques (Rantz *et al.* 1982). Measurements were made as time allowed and more frequently at the lower site because of greater accessibility. Measurements were made throughout the year, with emphasis placed on visiting sites around the time of peak flow (especially at the lower site) so that rising and falling limbs of the hydrograph, as well as the peak, were captured.

Bedload transport was measured from 1994 to 1997 at the lower site using a Helley-Smith type bedload sampler with a 7.6 cm (3 in) orifice. Sampling was generally conducted around the time of peak flows in conjunction with discharge measurements. Samples were taken at 30 verticals across the channel (two traverses, 15 verticals/traverse) for 30 seconds at each point. The number of sampling points was limited because the stream is relatively narrow. These composite samples were later dried, sieved, and weighed. Bedload transport rate was calculated with the formula

$$\text{total bedload (English tons per day)} = 0.381 \times \frac{\text{mass of sample (g)} \times \text{channel width (ft)}}{\text{\# verticals} \times \text{sampling time per vertical (s)}}$$

(Emmett 1981 and W. W. Emmett, U.S. Geological Survey retired, personal communication and field training, 1993 and 1994.)

Wolman pebble counts (Wolman 1954) were used to characterize the particle size distribution of surficial bed material. A minimum of 100 particles were measured (B-axis) as the channel was traversed, where the first particle encountered by the finger tip at the toe of the sampler's boot was selected for measurement. The channel was sampled up to the bankfull level, and if the total of 100 particles was reached in mid-channel, sampling continued until the traverse was completed. Pebble counts were made annually (generally in fall) in riffle/runs on straight channel reaches at the same site where discharge measurements and cross section surveys were made. A contingency table and chi-square test (King and Potyondy 1993, Bevenger and King 1995) were used to statistically compare pre- and post-fire differences in percent fines (particles < 2 mm in diameter).

Channel cross sections were surveyed with level and rod, and elevations were recorded to the nearest 0.0033 m (0.01 ft). Cross-section endpoints were located at the base of the same stakes used in pre-1988 surveys. Net changes in channel cross-sectional area between years were computed by evaluating net differences in depths across the channel (Olson-Rutz and Marlow 1992) according to the formula

$$\text{net change in area (percent)} = 100 \times \frac{\sum(y_{after} - y_{before})}{\sum y_{before}}$$

where y is the depth at a given point along the channel cross section, and the sums are taken over all depths measured along the cross section. For the purposes of this investigation, the numerator was reversed from the formula of Olson-Rutz and Marlow (1992) so that a positive net change indicates degradation (channel incision) and a negative net change indicates aggradation.

Longitudinal channel profiles were surveyed annually between 1994 and 1997 (except 1995 at the upper site) by stretching a tape 33 m (100 ft) upstream and downstream of the sites used for discharge measurements. Elevation was measured to the nearest 0.0033 m (0.01 ft) using a level and rod. Unless there was a noteworthy change in channel form that needed to be measured at some intermediate distance, elevations of the bankfull level on both banks, water surface elevation, and the centerline of the channel bed were surveyed at 3.3 m (10 ft) intervals.

Results

Discharge

Moose Creek has a narrow range of discharge when compared to surface-runoff-dominated streams. At the lower site, where most data were collected, discharges varied about 10 percent between peak flows and base flows (Table 2). Peak flows occur in late summer, generally late July to early August. Unlike most low-order mountain streams in which discharge increases in a downstream direction with increasing watershed area, discharge decreases in the downstream direction. This is probably caused by lack of surface water inputs in the middle and lower reaches of Moose Creek, with losses to groundwater exceeding gains in discharge to the stream. On average, discharge at lower

Table 2. *Discharge at lower Moose Creek study site.*

Date	Discharge (m^3/s)	(cfs)
26 Jun 1985	0.742	26.2
18 Jul 1985	0.875	30.9
8 Aug 1985	0.813	28.7
15 Aug 1985	0.683	24.1
26 Aug 1985	0.674	23.8
19 Sep 1985	0.668	23.6
26 Jun 1991	0.518	18.3
25 Jun 1993	0.606	21.4
6 May 1994	0.450	15.9
8 Jun 1994	0.447	15.8
11 Aug 1994	0.428	15.1
17 Oct 1994	0.382	13.5
2 Mar 1995	0.123	4.4
26 May 1995	0.399	14.1
14 Jun 1995	0.459	16.2
27 Jun 1995	0.609	21.5
5 Jul 1995	0.589	20.8
24 Jul 1995	0.615	21.7
7 Aug 1995	0.663	23.4
25 Sep 1995	0.663	23.4
19 Oct 1995	0.598	21.1
3 Jun 1996	0.660	23.3
21 Jun 1996	0.677	23.9
8 Jul 1996	0.688	24.3
30 Jul 1996	0.722	25.5
19 Aug 1996	0.711	25.1
30 May 1997	0.683	24.1
19 Jun 1997	0.677	23.9
9 Jul 1997	0.711	25.1
8 Aug 1997	0.716	25.3
19 Aug 1997	0.725	25.6
28 Aug 1997	0.719	25.4
9 Sep 1997	0.708	25.0
12 Jun 1998	0.708	25.0
6 Jul 1998	0.711	25.1
7 Aug 1998	0.654	23.1
14 Jun 1999	0.671	23.7
21 Jul 1999	0.756	26.7

Moose Creek was about 75 percent of that at the upper site. Bankfull discharge at the upper site was estimated at about 1.2 m^3/s (43 cfs), whereas at the lower site it was about 0.71 m^3/s (25 cfs). Bankfull discharge determination was based on field observations of the measured flows that reached the floodplain at the upper site, and of flows that appeared to reach the top of the adjacent flat at the lower site.

Flows measured at lower Moose Creek in 1985 were consistently higher than those measured from 1991 to early 1995 (Table 2). Flows began to increase in July 1995, and summer discharge was relatively constant over the next four years, ranging from about 0.57 m^3/s (20 cfs) to 0.74 m^3/s (26 cfs) at the lower site (Table 2). Although fewer measurements were made at the upper site, the trend in discharge there is consistent with that at the lower site. At the time of this study, there were no gaging stations on non-regulated streams in the area; however, the U.S. Geological Survey and U.S. Forest Service collected miscellaneous streamflow measurements at Big Springs (Table 3), a large spring near Moose Creek (see Van Kirk and Benjamin this issue). Compared to flows measured in the years prior to 1987, records at this site also show reduced flows from September 1987 through October 1994 and possibly into June 1995 (Table 3).

Bedload

A scatterplot of bedload transport versus discharge (Fig. 6) may indicate that bedload transport is initiated at a discharge of about 0.40 m^3/s (14 cfs) at the lower site. Streamflows less than 0.40 m^3/s (14 cfs) were not observed during the summer when bedload sampling was conducted, however, and the correlation between bedload transport and discharge is weak (r^2= 0.017, Fig. 6). The low coefficient of determination may be caused in part by a lack of data collected during storm events, when the relationship between bedload transport and discharge may be stronger. In 1995 and 1996, bedload transport increased on the rising limb of the hydrograph, peaked before streamflow did, and declined quickly as discharge peaked.

Table 3. *Selected discharge measurements at Big Springs (U.S. Geological Survey and U. S. Forest Service).*

Date	Discharge (m^3/s)	(cfs)
20 Oct 1983	6.15	217
14 Nov 1983	5.66	200
03 Oct 1984	6.29	222
26 Aug 1985	4.73	167*
16 Sep 1985	5.61	198
29 Oct 1985	5.98	211
8 Oct 1986	6.32	223
23 Sep 1987	5.15	182
20 Oct 1987	4.67	165
12 Sep 1988	4.42	156
17 Oct 1988	4.47	158
15 Sep 1992	4.50	159*
15 May 1993	5.35	189*
13 Oct 1993	5.10	180*
14 Jun 1994	5.55	196*
17 Oct 1994	4.81	171
27 Jun 1995	5.49	194*
6 Sep 1995	5.55	196*
21 Jun 1996	5.24	185*
23 Jun 1997	5.83	206*
9 Sep 1997	6.34	224
12 Jun 1998	5.86	207*
14 Jun 1999	5.13	181*

*U. S. Forest Service measurements

Bed Material Composition

The pebble count data were collected by different investigators over the years, which may have biased results. Nonetheless, findings reported here are assumed to be a reasonable representation of changes in particle size distributions of bed material at the Moose Creek sites. In general, bed materials were finer at the lower site than at the upper site (Figs. 7 and 8). The median particle size (d_{50}) at the lower site remained relatively constant following the fires, averaging 4 mm and ranging from 2.6 to 4.7 mm (Fig. 7). The

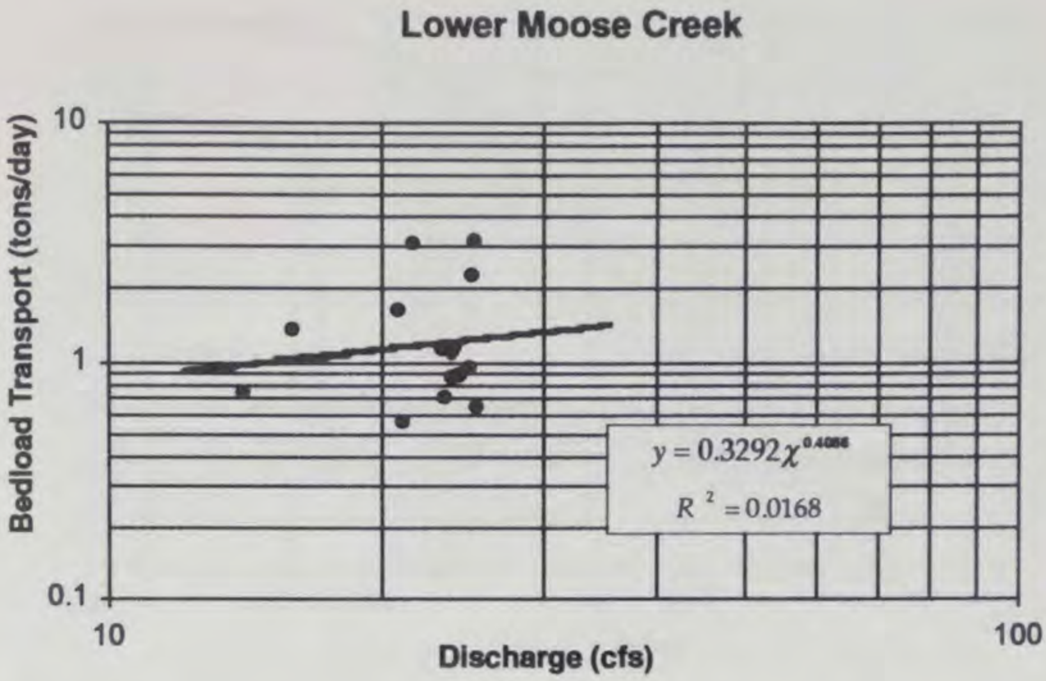

Figure 6. *Scatterplot of bedload transport (English tons/day) versus discharge, lower Moose Creek site (1 English ton = 0.907 metric tons, 1 cfs = 0.2832 m³/s).*

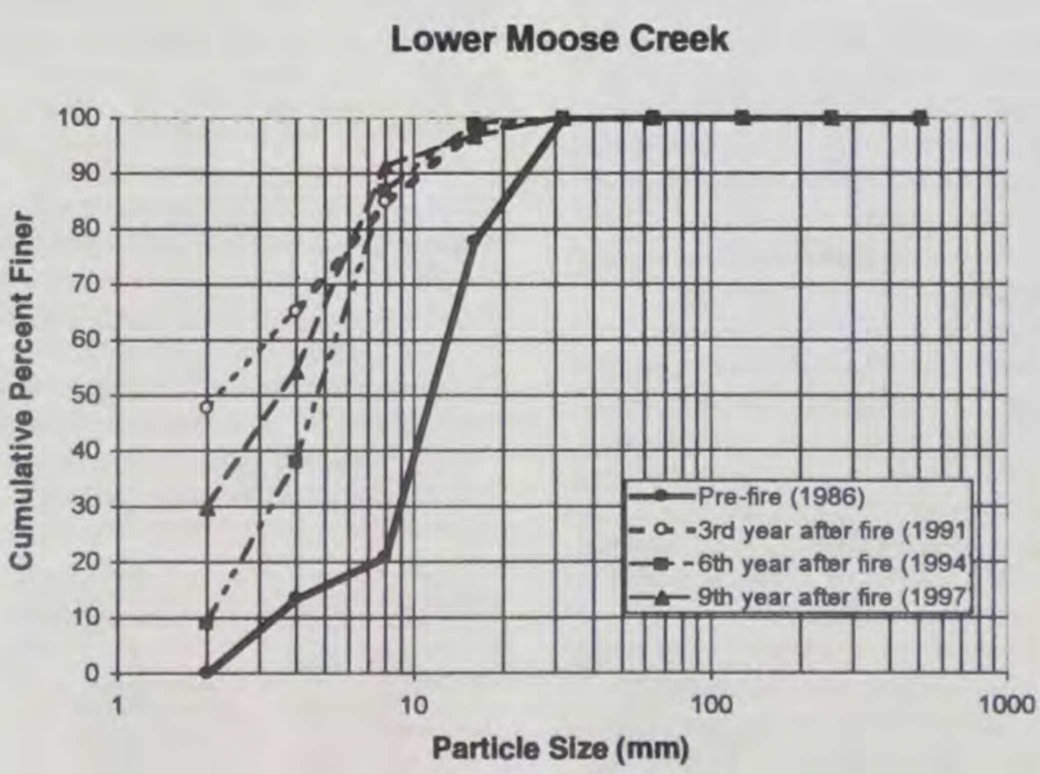

Figure 7. *Cumulative particle size distributions, lower Moose Creek site.*

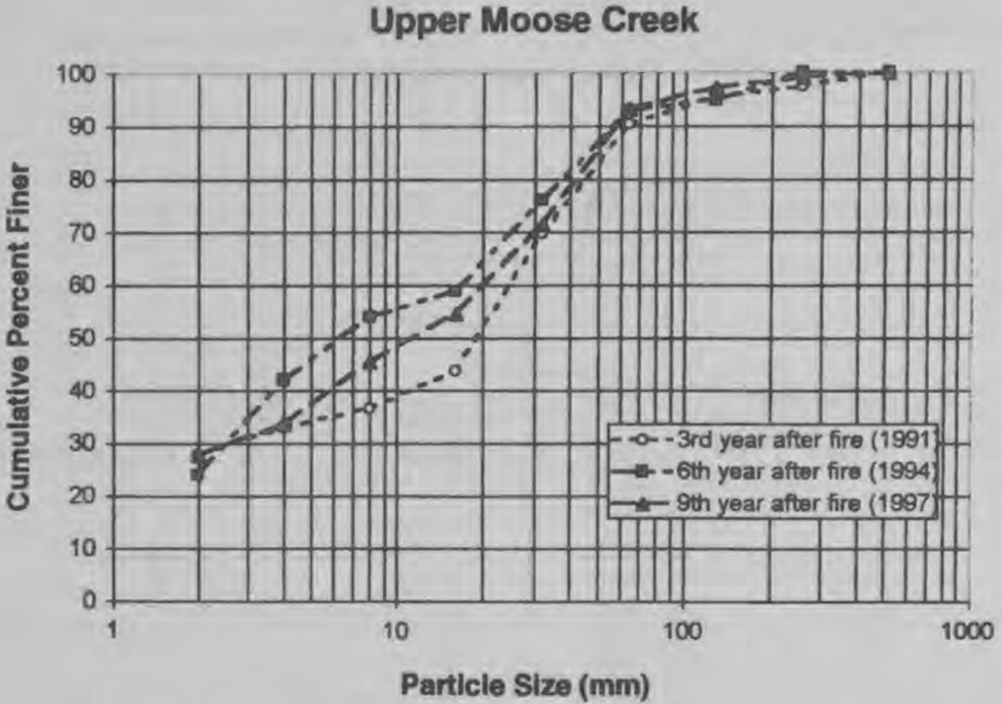

Figure 8. *Cumulative particle size distributions, upper Moose Creek site.*

pebble count data from the lower Moose Creek site show a statistically significant increase in fine material between 1986 (pre-fire) and 1991 (post-fire) (chi-square, $P<0.05$). Pre-fire cumulative frequency plots show that none of the sampled bed material was finer than 2 mm (Fig. 7). By contrast, the 1991 (post-fire) plot shows 47.8 percent of the bed material finer than 2 mm (Fig. 7). In all post-fire samples collected, the percentage of fine material was significantly higher than that observed in 1986 (chi-square, $P<0.05$). Materials finer than 2 mm comprised between 8.0 and 29.8 percent of particles in samples collected after 1991. There was no apparent trend in bed material composition after 1991, and the highest post-1991 percentage of fine material was observed in 1997.

No pre-fire particle size data were available for the upper site. After the fire, the d_{50} at this site ranged from 6.2 to 19 mm, with an average of 14 mm (Fig. 8). The percentage of material smaller than 2 mm observed in 1997 was not significantly different at $\alpha = 0.05$ than that observed in 1991. Smaller percentages of fine material were observed in intervening years, but there was no apparent trend over time (Fig. 8).

Channel Cross Section

At the lower site, post-fire cross-sectional area calculations show net degradation at the site when compared to 1986 (Table 4), but no major changes in cross-section are visually evident (Fig. 9). The greatest net change relative to 1986 was observed in 1991 (first post-fire data). After 1991, aggradation occurred,

Table 4. *Net changes in channel cross-sectional area at lower Moose Creek study site.*

Years compared	Net change
1986 – 1991	+15.7 %
1986 – 1994	+2.5 %
1986 – 1997	+7.0 %
1991 – 1994	-11.5 %
1991 – 1996	-5.5 %
1991 – 1997	-7.5 %

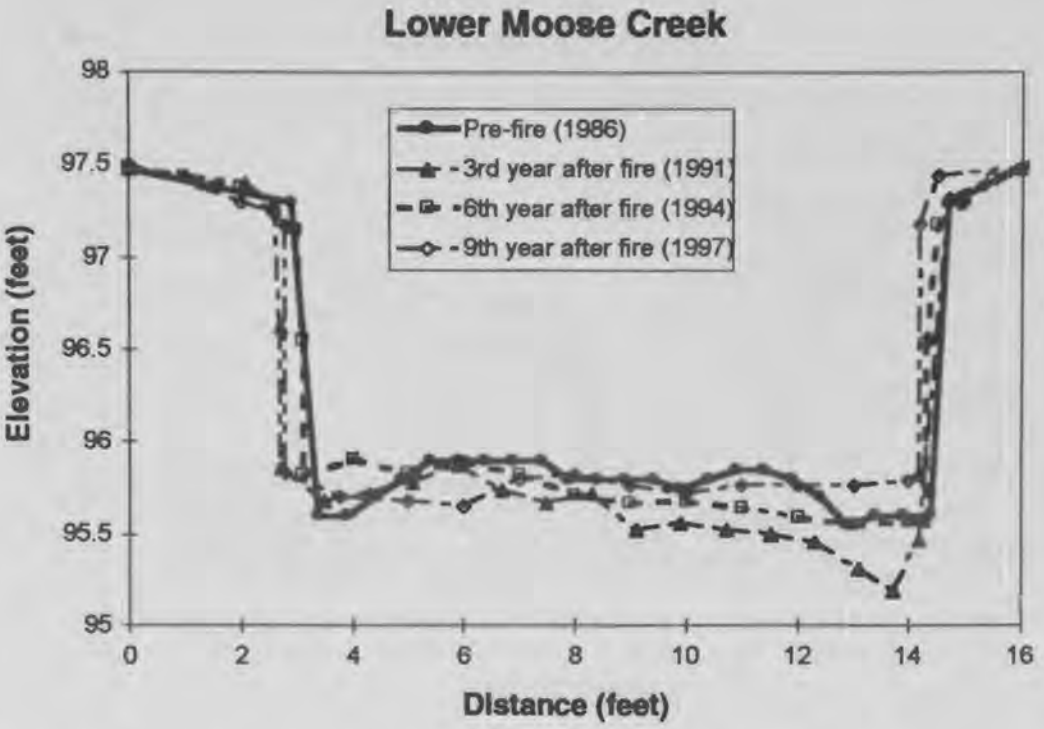

Figure 9. *Channel cross sections, lower Moose Creek site (1 ft = 0.3048 m).*

and the greatest net difference (-11.5%) relative to 1991 was observed in 1994 (Table 4). All changes occurred within the bankfull channel. The channel bed appeared to smooth out after 1991, but the cross-section was generally very stable (Fig. 9), with bank vegetation providing excellent lateral stability.

No cross-section surveys were conducted at the upper site before the fires. Net changes in cross-section area between 1991 and subsequent years had consistent, negative values (between -11.9% and -13.8%), indicating aggradation (Table 5). Because bank position is stabilized by riparian vegetation and valley confinement, all changes in cross-section appeared to be

Table 5. *Net changes in channel cross-sectional area at upper Moose Creek study site.*

Years Compared	Net Change
1991 – 1994	-13.8 %
1991 – 1996	-11.9 %
1991 – 1997	-13.7 %

taking place with respect to channel depth and floodplain elevation, not lateral movement. Visual inspection of cross-section plots shows the most interesting changes occurring not within the bankfull channel, but in the floodplain (Fig. 10). The right bank built steadily after the 1991 survey, indicating vertical floodplain development since the fire.

Longitudinal Profile

Pre-fire longitudinal profiles do not exist for either site. Regression of bankfull (floodplain) elevation versus distance downstream showed very little change in elevation at the lower site between 1994 and 1997 (Fig. 11). By contrast, bankfull elevation at the upper site increased during this period (Fig. 12).

Discussion

Flows in Moose Creek appeared to be lower during the post-fire period of 1991 to early 1995 than in prior and subsequent years, possibly in response

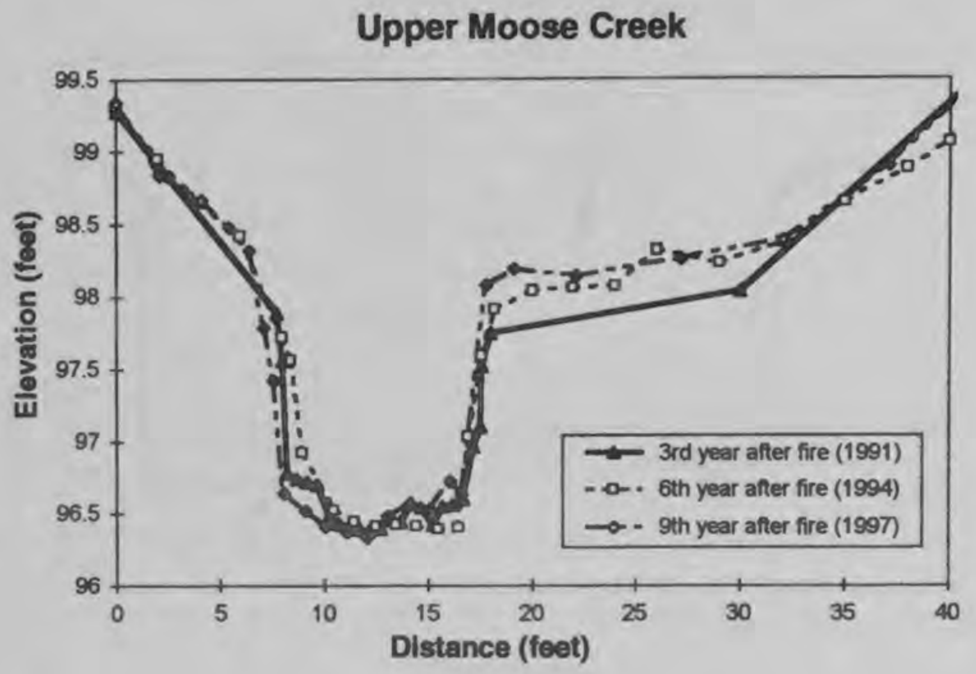

Figure 10. *Channel cross sections, upper Moose Creek site (1 ft = 0.3048 m).*

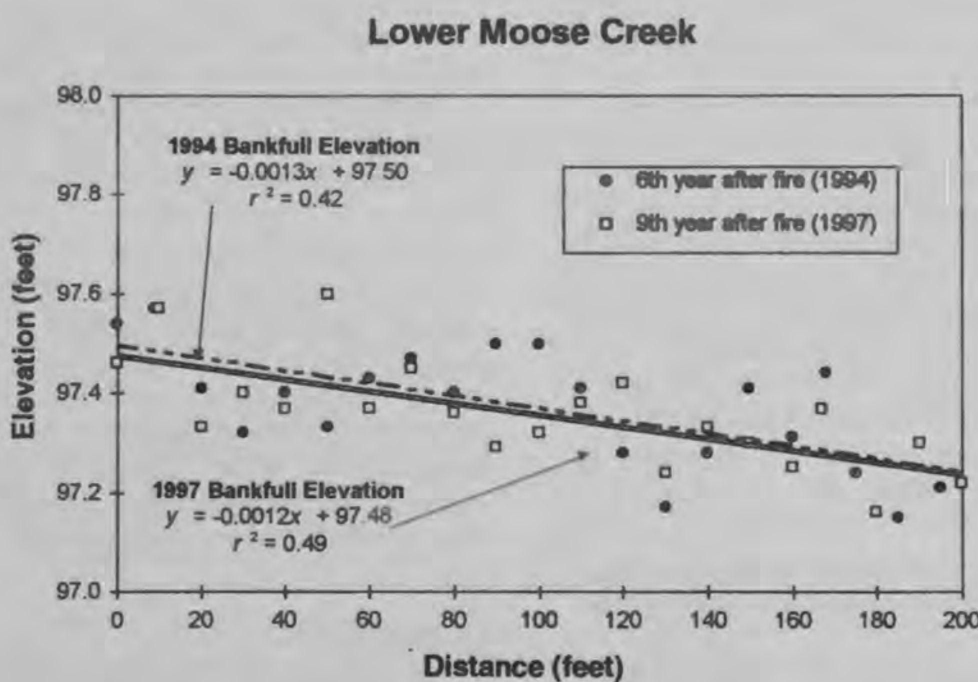

Figure 11. *Longitudinal profile of bankfull (floodplain) elevation, lower Moose Creek site (1 ft = 0.3048 m).*

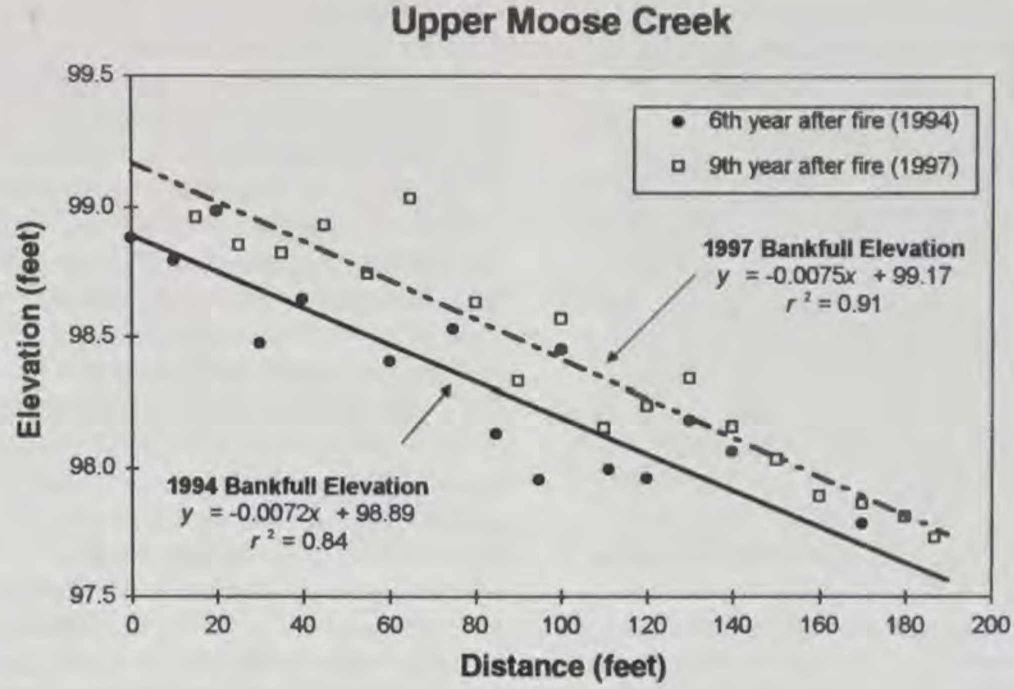

Figure 12. *Longitudinal profile of bankfull (floodplain) elevation, upper Moose Creek site (1 ft = 0.3048 m).*

to drought conditions that prevailed in the region from 1987 to 1994. This trend was consistent with measurements at nearby Big Springs. Discharge data from Moose Creek are inadequate to draw conclusions about the effects of fire on the flow regime, however.

Overbank flows were not observed at the lower site even during years of higher precipitation following the drought; peak flows did not overtop the channel banks although associated meadows, which have high-organic soils, contained standing water for long periods of time. Overbank flows were observed at the upper site, as were riparian meadows that remained saturated for extended periods of time.

A threshold discharge may exist below which bedload is not transported, but this could not be confirmed with the limited amount of data collected. There also is no clear evidence that lower flows from 1991 to 1995 affected the stream's ability to transport sediment. In fact, Moose Creek apparently transports large amounts of bedload for a stream of its size despite the lack of a distinct peak discharge. HabiTech, Inc. (1997) reported that "Moose Creek appears to transport a relatively greater amount of bedload than does either the [Henry's Lake] Outlet or the Henry's Fork."

Increased sediment supplied following the 1988 fires probably comprised the majority of the stream's sediment load. This inference is based on increased sediment availability caused by decreased vegetative cover in the watershed compared to pre-fire conditions. Lack of vegetation allowed increased surface erosion and facilitated sediment delivery to channels. The inferred increase in sediment availability was also based on observed erosion in the burn area and storage of this material in the upper watershed. Moose Creek, however, apparently is capable of transporting sediment delivered from the burn area.

The lower Moose Creek site exhibited an increase in fine materials (<

2 mm) 3 years after the 1988 fires. Measurements made in subsequent years contained smaller percentages of fine material than those made in 1991 but higher percentages than observed in 1986. Levels of fines in 1997 were the highest since 1991. Although there were no pre-fire data at the upper site, levels of fine materials there were higher in 1991 and 1997 than in intervening years, as was the case at the lower site. With a change in transport capacity of the stream ruled out at this time, a change in the amount of fine sediment delivered to the stream is the probable reason for this occurrence. A logical cause for the 1991 increase in fines was the fire, which resulted in loss of vegetation, creation of hydrophobic soil conditions, and accelerated delivery of fine sediment to the stream. The 1997 increase in fines may have been caused by continued sediment production in the burn area, where revegetation was still not complete, and where high amounts of fine sediment were still being delivered downstream. Fresh deposits were evident along the upper reaches of the stream in 1997. Logging units and associated roads in the watershed also were contributing fine materials to the fluvial system and exacerbating effects of the fire. The contribution from these features could not be separated from fire effects using data from this study. Road obliteration, when effective, eventually would reduce sediment delivery to channels, and levels of fines also can be expected to decline if upland revegetation is successful.

The post-fire increase in fine particles at the lower site is consistent with that observed in other studies in Idaho and Wyoming (Potyondy and Hardy 1994, Minshall *et al.* 1998). Post-fire increases in levels of fine materials have persisted longer at Moose Creek than in central Idaho streams (Potyondy and Hardy 1994), but these authors did not report high amounts of post-fire erosion. The Moose Creek response also is consistent with findings of Minshall *et al.* (1998), who attributed increased fine material to continued upstream input. Field observations from 1999 confirmed that large amounts of sediment are still produced by the burn area. Some road features were actively eroding, surface erosion was evident in upland areas, and intermittent headwater channels were filled with fresh sediment. In addition, extensive areas of fresh overbank and lateral accretion deposits in 1997 along perennial reaches of upper Moose Creek provide evidence that sediments produced by the burn area were deposited along the channel.

A comparison of pre-and post-fire cross-sections at the lower site indicates net degradation between pre- and post-fire periods, i.e., a net increase in cross-section area. Since 1991, however, net aggradation appears to be taking place at the lower site. No floodplain building is taking place, and although the floodplain is frequently wet, overbank flows have not been observed to access the floodplain, and all changes are restricted to the sides and bottom of the channel. Net changes in cross-sectional area at the upper site since 1991 indicated that although the bed of the stream has not been aggrading, the floodplain on the right side of the stream has been rising in elevation, accounting for the calculated net change in cross-section area. Overbank flows have had extensive access to the floodplain, and increased flows and continued high sediment input in recent years would explain this development. The fresh overbank and lateral accretion deposits seen in other reaches of the stream in 1997 further supported the floodplain development shown in cross-section plots.

Changes in floodplain elevations were not evident in longitudinal profiles at the lower site, where lack of overbank flows precludes any major change. This is consistent with the channel trend changes observed at the cross-section and the observed lack of overbank flows. Longitudinal profiles of the upper site, however, show a trend of rising bankfull (floodplain) elevations from 1994 to 1997, which confirmed the cross-section evidence that the floodplain is building vertically. The buildup of the bankfull elevation is consistent with the floodplain accretion exhibited at the cross-section.

A series of different geomorphic measurements provided a valuable tool to understand channel response in this study. Rather than interpreting one piece of evidence, such as changes in percent fines, multiple indicators allowed for an integrated interpretation of channel function. The various techniques reinforced each other to allow inference of stream system function, assuring greater certainty in having correctly interpreted channel change.

These findings support current understanding of watershed response to disturbance by fire. Recovery in the Moose Creek stream system was not complete because of continued delivery of fine sediment from the burn. Nevertheless, when soils in the burn area do become stabilized, the stream apparently should transport the sediment delivered to it and return to near pre-fire conditions.

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