Hayman Fire Rehabilitation Treatment Monitoring
Progress Report

Sediment yields, runoff, and ground cover in the first two years after the Hayman Fire

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The Hayman Fire burned 138,000 ac with more than 60 percent burned at high or moderate severity. The watersheds and reservoir system within the fire area provide about 90 percent of the drinking water for nearly one million residents of the Denver metropolitan area. Many elements combined to make the Hayman Fire a high profile event, which demonstrated current wildland fire issues (high fuel loads, drought conditions, urban/wildland interface) and created public demand for land treatments to curb postfire flooding and erosion as well as rapid rehabilitation of the area.

In 2002, postfire rehabilitation treatments were applied to 45,500 ac (39 percent of the burned area) of National Forest land to mitigate the expected increase in runoff and erosion due to the fire. Another 4,500 ac were treated in 2003. Several activities are currently underway to monitor treatment effectiveness at a range of scales, from hillslope to watershed. This report contains first and second year postfire runoff and erosion results from six small watersheds and 32 hillslope plots.

Methods

Six (two sets of three) sediment traps with V-notch weirs were installed at the outlets of adjacent watersheds, 7 to 13 ac in size, in summer 2002. All of the watersheds were burned at high severity. In each set, two watersheds were treated with postfire rehabilitation treatments and the third watershed was left untreated as a control (watersheds B and E). These sites were designed to monitor and compare the effectiveness of contour-felled log erosion barriers (watershed A), aerial wheat-straw mulch (watershed D), and aerial hydromulch (watershed F) in reducing runoff and erosion. In addition, one watershed (C) is being used to assess the effects of postfire salvage logging on runoff and erosion. The salvage logging operation occurred in fall 2003, so the designated salvage logging watershed functioned as a third, untreated control during the first postfire year.

A simulated rill study is being conducted at two sites with high burn severity near the watersheds. Three treatments applied by hand --contour raking, wheat straw, and engineered wood straw-- as well as untreated controls are being used to measure rill erodibility for model development. Each treatment was applied to 8 plots with slopes of 20 percent and 8 plots with slopes of 40%. The plots had contributing areas of approximately 300 ft^2. For this experiment, water is pumped from a truck-mounted tank to a calibrated flow nozzle located at the top of the plot. Flow rates and rill geometry are measured periodically throughout the 60-minute test, and runoff samples are collected throughout the test. First year rill experiments were conducted in summer 2002.

To measure the hillslope sediment yields from natural rainfall, silt fences were installed at the outlets of half of the initial 64 rill plots in September 2002. Hillslope sediment yield is being measured on four replicates of each treatment on both the 20% hillslopes and 40% hillslopes. Subsequent rill experiments have been conducted on adjacent untreated plots in 2003 and 2004, and another set of measurements is planned for 2005.

Rainfall and other climatic variables, as well as ground cover, soil water repellency, and infiltration are measured on-site for the watersheds and hillslope plots. Sediment is removed from the sediment traps and silt fences after each storm. This report summarizes the results from the watersheds and hillslope plots for the first 27 months after the fire. Results from the rill experiments will be reported separately.

Watershed Results

Since the treatments were installed, 18 rain storms produced measurable runoff at one or both sites (Table 1). Of these 18 storms, only one was spatially extensive enough to produce large sediment responses (requiring mechanized equipment to remove sediment) at both the ABC and DEF sites (30 August 2003). In 2003 there was also a large sediment response from one other storm at each site (29 July 2003 at DEF and 9 August 2003 at ABC). In 2004, none of the storms produced large sediment responses at ABC while three storms produced large responses at the DEF site (28 July, 19 August, and 27 September). The mean 10-min intensity across sites of the storms that produced large sediment responses was 1.4 in hr^{-1} ($n = 7$). The mean 10-min intensity of the other storms was only 0.8 in hr^{-1} ($n = 20$ since several storms affected both sites). The storms on 29 July 2003 at the DEF site and 9 August 2003 at the ABC site were 2-yr, 10-min events, while the storm on 19 August 2004 at the DEF site was a 5-yr, 10-min event.

The maximum observed peak flow of 652 $ft^3\ s^{-1}\ mi^{-2}$ occurred on 28 July 2004 at untreated watershed E (Figure 1). The contour-felled watershed and the wheat straw watershed had consistently lower peak flows than their respective controls (Figure 1). The peak flows from watershed C after salvage logging were lower than the control for all but one storm in 2004. The peak flows from the hydromulch watershed were nearly the same as the flows from the untreated watershed except on 9 August 2003 and 28 July 2004. From observations immediately after the storm on 9 August 2003, we believe less rain fell on the hydromulch watershed than on the other watersheds at DEF. In all watersheds, the peak flows increased with increasing 10-min intensity (Figure 2) but the effect was greater for the untreated watersheds than the treated watersheds.

The maximum total runoff from an untreated watershed was 0.48 in or 67 percent of the rainfall on 9 August 2003 (Figure 3). The runoff from the contour-felled and wheat straw watersheds were consistently lower than from their respective untreated watersheds. The runoff from the C watershed after salvage logging and from the hydromulch watershed were nearly the same as the runoff from their respective control watersheds (Figure 3). Runoff also increased with increasing I_{10} (Figure 4).

In 2003 the total sediment yield from the untreated watershed B was 10.9 t ac^{-1}, while the untreated watershed C produced 8.5 t ac^{-1} (Table 1). For this year, the total from the contour felled log watershed was 5.1 t ac^{-1}, or a 53% reduction compared to the control. In 2004, the total sediment yield for the ABC watersheds decreased by 71-88 % as compared to 2003. In 2004, the untreated watershed B produced 3.2 t ac^{-1}. The contour felled log watershed produced 0.6 t ac^{-1} in 2004, and this was 81% less than the sediment yield from the control. After salvage logging, the C watershed produced only 1.5 t ac^{-1}, or about half of the sediment produced by the control watershed in 2004 (Table 1).

In 2003 at the DEF site, the untreated watershed produced 9.9 t ac^{-1}, while the wheat straw watershed produced only 3.6 t ac^{-1} (63% less than the control) and the hydromulch produced 8.1 t ac^{-1} (19% less than the control) (Table 1). In 2004 there was an overall increase in sediment yield at the DEF site since it received more rainfall and had greater 10-min intensities than in 2003. The total sediment yield from untreated watershed E increased by over 70% to 17.3 t ac^{-1} (Table 1). In 2004 the sediment yields from both the wheat straw mulch and the hydromulch watersheds increased by about 50% as compared to 2003. The total sediment yield from the wheat straw watershed was 5.5 t ac^{-1} (68% less than the control in 2004) while the hydromulch watershed produced 12.6 t ac^{-1} (27% less than the control).

On a storm by storm basis, the contour-felled and the wheat straw watersheds consistently produced less sediment than their respective controls (Table 1). The sediment yields from watershed C after salvage logging were less than the sediment yields from the untreated watershed for 6 of the 7 events in 2004. Similarly, the sediment yields from the hydromulch watershed were less than the sediment yields from the control for 3 of the 13 events in 2002 - 2004 (Table 1).

The amount of ground cover ranged from 6 to 41 percent for the untreated watersheds throughout the study (Figure 5). Although untreated watershed B had slightly more ground cover than watershed E over the three years, these differences were not significant. The ground cover in the untreated watersheds increased significantly from 2003 to 2004 ($p < 0.05$). The wheat straw watershed had significantly more ground cover than untreated watersheds in 2002 and 2003 ($p < 0.05$) (Figure 5), but there was no significant difference in 2004. The hydromulch watershed had more ground cover than the untreated watersheds in 2002 ($p < 0.05$) but not in 2003 or 2004 (Figure 5). For both types of mulch, the amount of ground cover decreased over time as the mulch was moved offsite or decomposed. The contour-felling and the salvage log treatments did not change the ground cover as compared to the untreated watersheds (Figure 5). Although there was a visible increase in the amount of woody debris, litter, and straw in watershed C after the salvage logging and skid trail rehabilitation was completed, there was no significant difference between pre- and post- logging measurements for any of these values. This is probably due to the limited areal extent of the logging operation (away from channels and on slopes of less than about 30-40%).

Hillslope results

At the silt fence sites, one storm produced sediment in the silt fences in 2002 (1 Oct), three storms produced sediment in 2003 (29 Jul, 9 Aug, and 30 Aug), and six storms produced sediment in 2004 (17 Jun, 29 Jun, 17 Aug, 23 Aug, 1 Sep, and 4 Oct). The total sediment yields from the four events in 2002-2003 in the untreated silt fences averaged 8.7 t ac^{-1} (Figure 6). The mean sediment yields from the treated plots were lower than this value, but only the wood straw had significantly lower sediment yields ($p < 0.05$). The sediment yields decreased significantly in 2004, when the untreated plots averaged 1.6 t ac^{-1} (Figure 6), but again only the wood straw had a significantly lower sediment yield than the untreated plots ($p < 0.05$). The sediment yields from the plots on the 20% slopes were not significantly different from those on the 40% slopes.

The ground cover in the untreated plots averaged 23 percent in summer 2002, while the raked plots had nearly this much (20 percent), and both the wheat straw and the wood straw had nearly three times this much (Figure 7). In 2003 the vegetative cover increased in all plots, but the control and raked plots had less litter, resulting in no significant change in cover for these two treatments. The amount of straw cover decreased in the wheat straw plots, resulting in a net decrease in cover in 2003 (Figure 7), but this value (40%) was still significantly greater than the amount of cover in the control plots ($p < 0.05$). There was no decrease in wood cover in the wood straw plots, and the total cover increased significantly to 75% ($p < 0.05$). In 2004, the untreated, raked, and wheat straw plots all had significantly greater cover than in 2003 ($p<0.05$) (Figure 7) but there was no significant change in cover in the wood straw plots.

We observed that some straw was moved by wind at one of the sites soon after it was applied in 2002. On average, the straw cover decreased due to degradation or removal of the straw, while the vegetation and litter increased. Although there was a reduction in wood cover in the wood straw plots in 2004, there average wood cover was still 35%, seven times the amount of wheat straw in the straw plots, suggesting that the wood straw is more durable than the wheat straw.

Summary

The ABC watersheds received less rainfall, and it fell at a lower rainfall intensity, in 2004 compared to 2003. This resulted in lower overall peak flows, runoff, and sediment yields in the watersheds at the ABC site. The less erosive rainfall in 2004 resulted in a greater observed reduction in sediment yields from the contour-felled log watershed compared to the control.

The peak flows, runoff, and sediment yield generally were lower in the salvage logged watershed than in the control in 2004. However, since there was no large rain event at the ABC site after logging was completed, we feel the salvage logging treatment remains relatively untested, and the results may not represent what would be observed during a typical year. Although there was a visible increase in ground cover as a result of the logging treatment, there was no measured increase. Trees were de-limbed and the slash scattered on the skid trails before logs were skidded on the south ridge of the watershed and trees were de-limbed at the landing and slash was then scattered on the skid trails on the north ridge. There was only one skid trail crossing of the channel, and the skid trails had waterbars and straw mulch installed as post-logging rehabilitation measures. Approximately 65% of the watershed was logged.

Three highly erosive storms occurred at the DEF site in 2004, resulting in greater peak flows and sediment yields from all three watersheds in 2004 as compared to 2003. Even with the greater overall sediment yields, the straw mulch reduced the sediment yields by about 70% as compared to the controls. The peak flows and runoff from the straw mulch watershed were also consistently lower than from the control watershed. In 2004, the hydromulch reduced the sediment yield by about 30% as compared to the controls, and this was a slightly greater reduction than in 2003. Also, unlike the results from 2003, the peak flows and runoff from the hydromulch watershed were consistently lower than the values from the control in 2004.

The increase in vegetative cover in the watersheds probably caused a reduction in the peak flows, runoff, and sediment yields, but this effect was masked at the DEF site by the higher intensity rainfall in 2004.

Based on the effects on the first year runoff and peak flows, reduction in sediment yields, and establishment and persistence of ground cover relative to the controls, the aerially-applied wheat straw was the most effective of the watershed treatments during the first two postfire years. The contour-felled log treatment followed, and although some benefits were observed from the aerial hydromulch, it was the least effective of the three watershed treatments.

In the hillslope plots, the engineered wood straw has been the most effective at increasing cover and thereby reducing sediment yields. The manually applied wheat straw has also been effective at increasing ground cover, but no significant reduction in sediment yields has been observed. This suggests that only the wood straw plots have enough cover to protect the soil surface and reduce sediment yields. Contour raking has not significantly affected the ground cover or the sediment yields as compared to the controls.

Monitoring will continue on all sites at least through the summer of 2006. Current weather and sediment yield data from the paired catchment sites are updated daily and available online at http://forest.moscowfsl.wsu.edu/engr/weather/Hayman.html.

Table 1. Data from rainfall events and resulting watershed sediment yields in 2002-2004. Rainfall and resulting sediment yields from three storms at ABC and one storm at DEF that occurred prior to the installation of the treatments in September 2002 are not included.

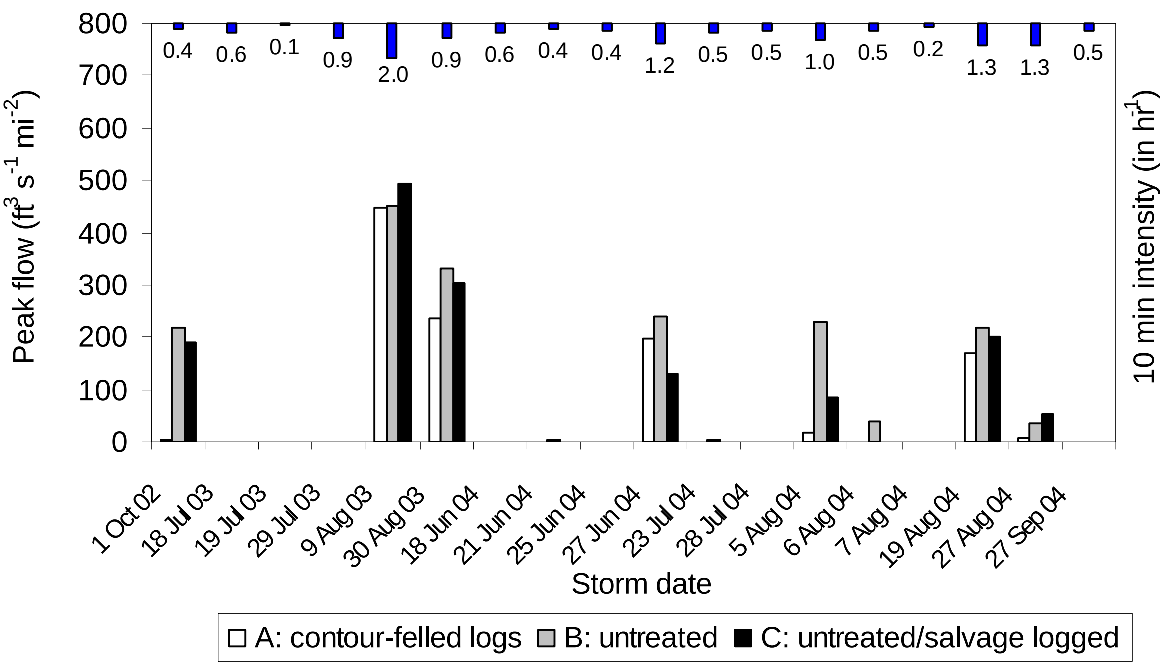
Watersheds A, B, C	01 Oct 02	18 Jul 03	19 Jul 03	29 Jul 03	9 Aug 03	30 Aug 03+	2003 Total	18-27 Jun 04+	23 Jul 04	28 Jul 04	5-6 Aug 04+	19 Aug 04	27 Aug 04	27 Sep 04	2004 Total
Rainfall (in)	0.7	0.3	0.01	0.2	0.7	1.1		1.8	0.5	0.2	0.7	0.6	0.4	0.5	
Max. I_{10} (in hr^{-1})	0.4	0.6	0.1	0.9	2.0	0.9		1.2	0.5	0.5	1.0	1.3	1.3	0.5	
Sediment yield (t ac^{-1})															
Contour-felled logs (A)	0.03	0.0	0.0	0.01	4.2	0.9	5.1	0.4	0.0	0.0	0.02	0.2	0.04	0.0	0.6
Control (B)	0.3	0.002	0.0	0.0	8.8	2.0	10.9	1.4	0.001	0.0	0.6	1.0	0.2	0.01	3.2
Control/Salvage (C)*	0.3	0.002	0.0	0.0	7.5	1.0	8.5	0.6	0.0	0.0	0.2	0.5	0.3	0.001	1.5

Watersheds D, E, F	1 Oct 02	18 Jul 03	19 Jul 03	29 Jul 03	9 Aug 03	30 Aug 03+	2003 Total	21-27 Jun 04+	23 Jul 04	28 Jul 04	7 Aug 04	19 Aug 04	27 Aug 04	27 Sep 04	2004 Total
Rainfall (in)	0.6	0.5	0.3	0.5	0.2	1.4		2.2	0.3	0.5	0.3	0.9	0.2	0.8	
Max. I_{10} (in hr^{-1})	0.4	0.6	0.7	2.0	0.5	0.9		1.1	0.5	1.7	1.4	2.8	0.5	0.6	
Sediment yield (t ac^{-1})															
Wheat straw (D)	0.02	0.001	0.002	3.2	0.2	0.3	3.6	0.02	0.0	0.4	0.1	4.6	0.0	0.5	5.5
Control (E)	0.1	0.002	0.01	8.3	0.4	1.2	9.9	0.9	0.0	2.4	1.5	11	0.0	1.5	17.3
Hydromulch (F)	0.07	0.001	0.001	4.5	0.0	3.6	8.1	0.9	0.0	1.4	1.3	7.7	0.0	1.5	12.6

*Salvage logging was completed in September 2004. Prior to this, watershed C was an untreated control.

+ 2 storms occurred on 30 August 2003, 4 storms occurred between 18-27 Jun 2004, and 2 storms occurred 5-6 August 2004.

a)



b)

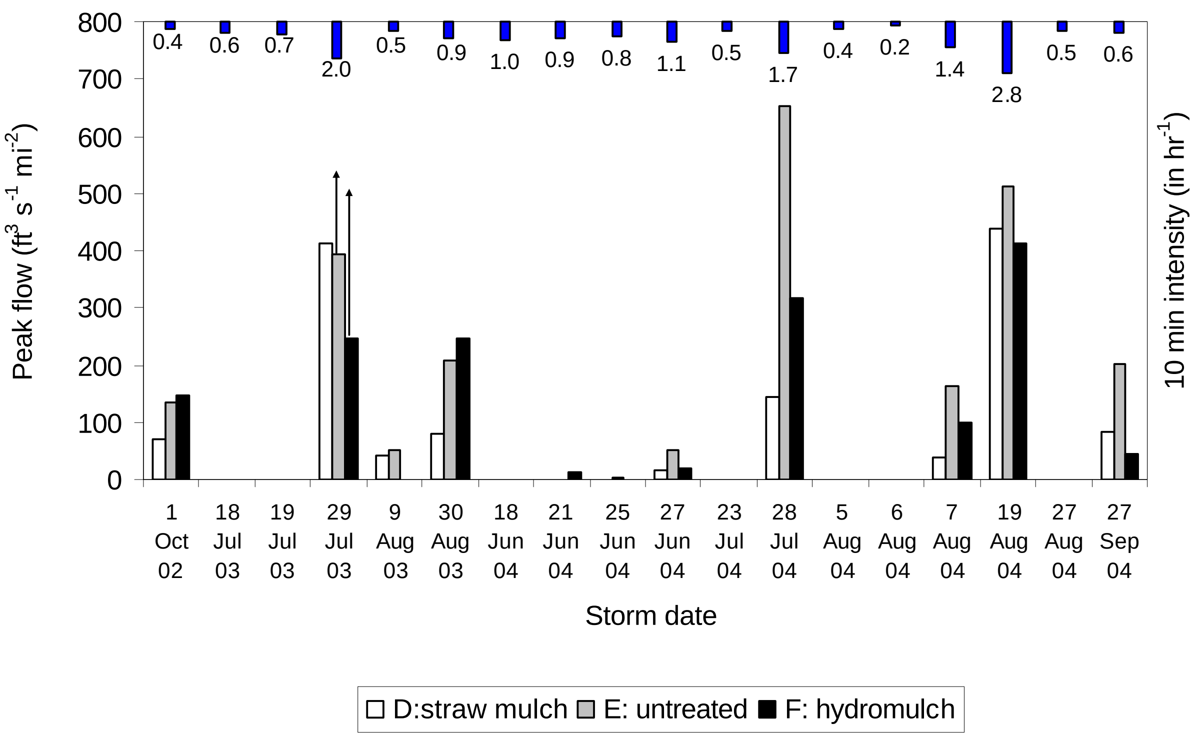


Figure 1. Peak flows and rainfall intensity for a) the ABC watersheds and b) the DEF watersheds. The weirs overtopped with flow on 29 Jul 03 (D, E, and F), 30 Aug 03 (F), 28 Jul 04 (E), and 19 Aug 04 (D, E, and F), so the peak flow values are probably underestimated. As a result of lightning, the data logger was not operating at DEF on 29 Jul 2003 and the instruments at F were not operating on 27 Sep 2004, so the peak flows for these watersheds and storms were estimated.

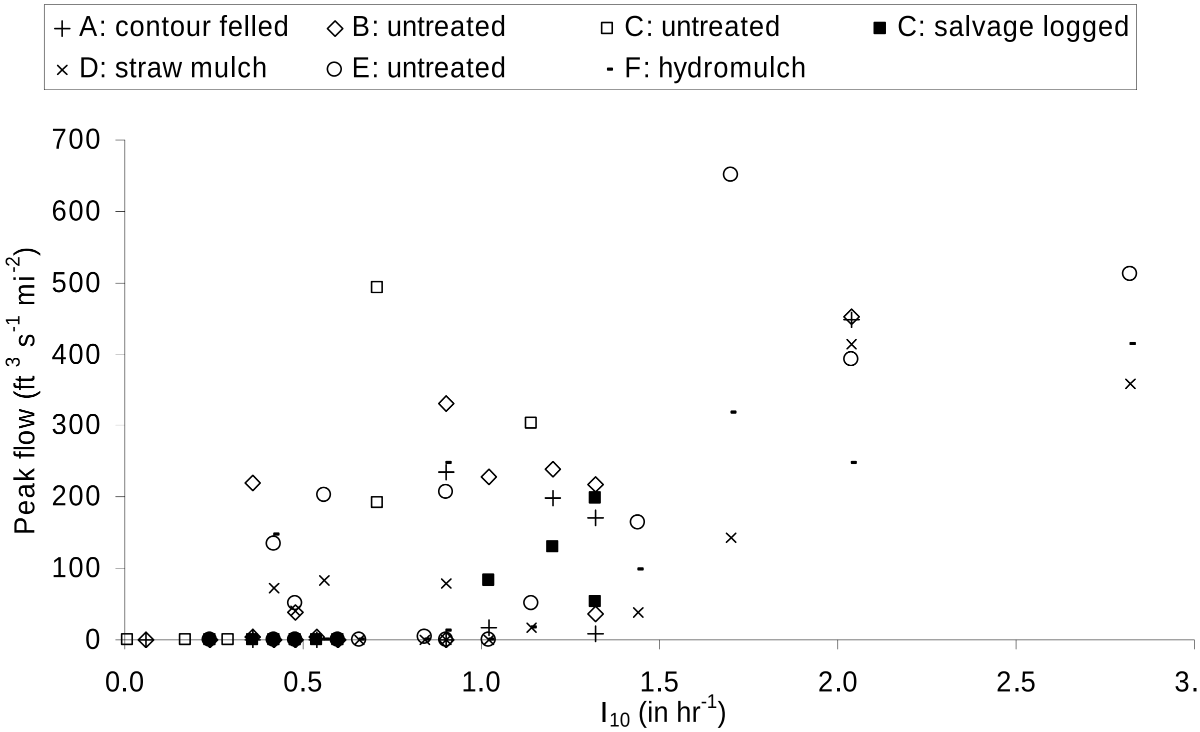
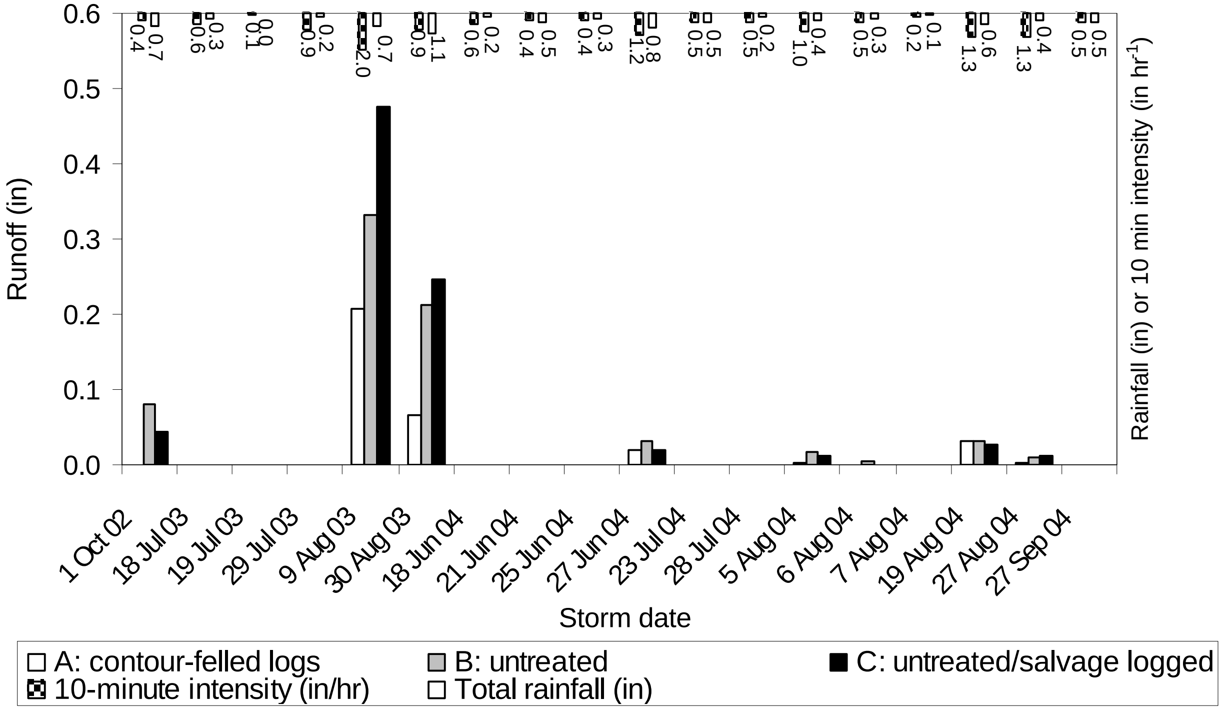


Figure 2. Peak flow versus 10-min maximum intensity for all 6 watersheds.

a)



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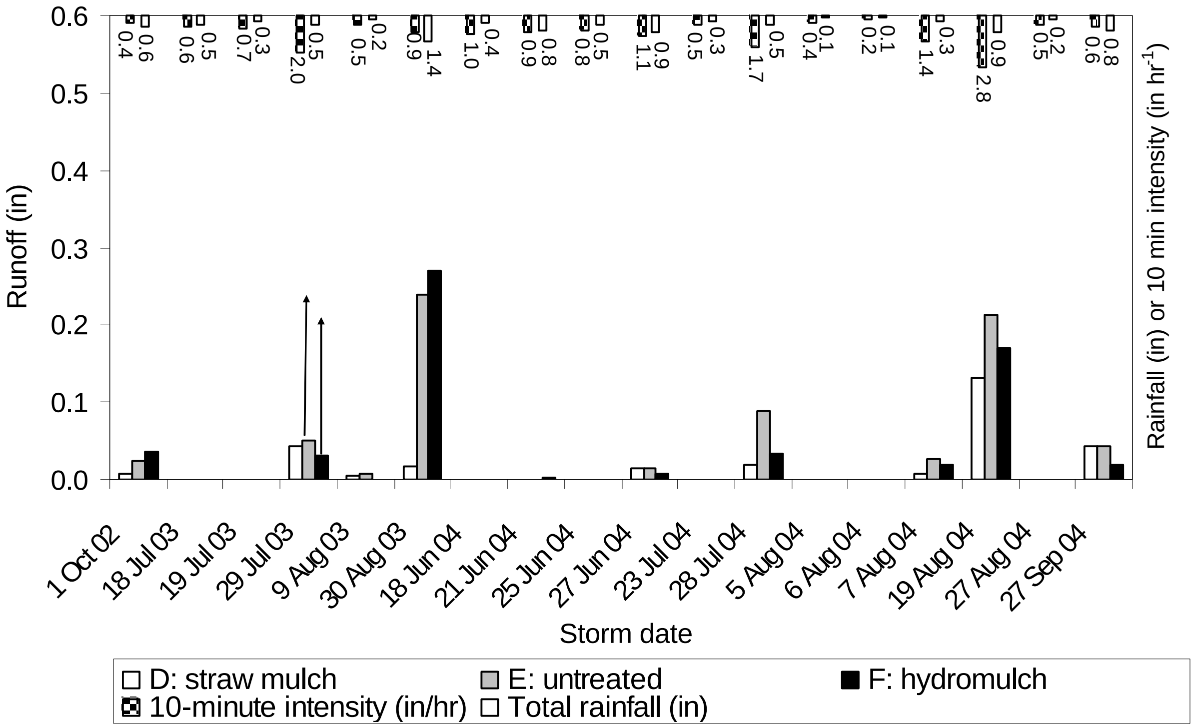

Figure 3. Runoff, rainfall, and rainfall intensity for a) the ABC watersheds and b) the DEF watersheds. The weirs overtopped with flow on 29 Jul 03 (D, E, and F), 30 Aug 03 (F), 28 Jul 04 (E), and 19 Aug 04 (D, E, and F), so these runoff values are probably underestimated. As a result of lightning, the data logger was not operating at DEF on 29 Jul 2003 and the instruments at F were not operating on 27 Sep 2004, so the runoff for these watersheds and storms were estimated.

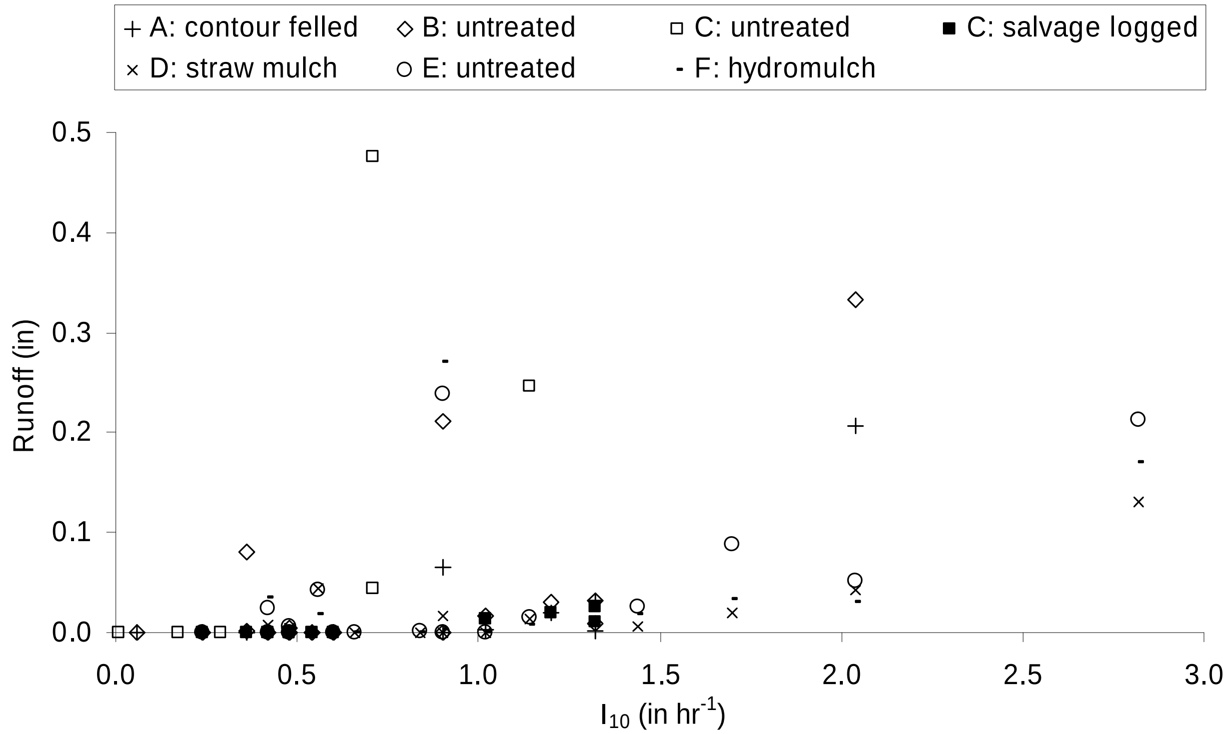

Figure 4. Runoff versus 10-min maximum intensity all 6 watersheds.

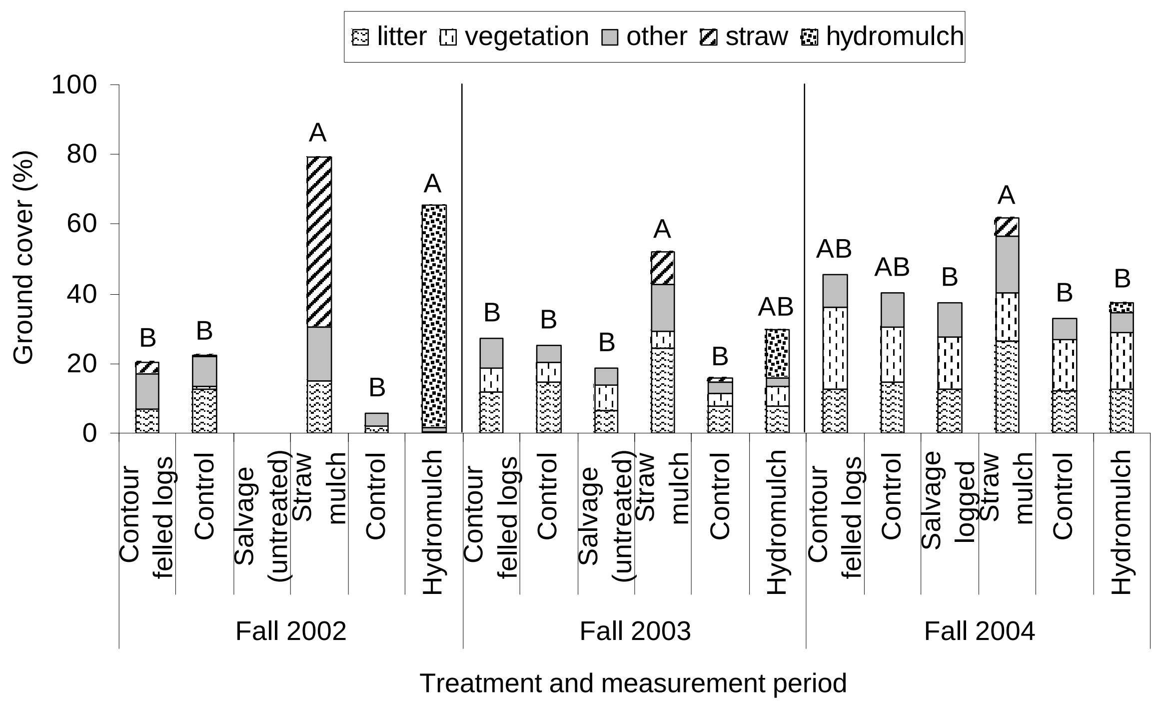

Figure 5. Ground cover by watershed treatment and year. Different letters represent significant differences between treatments within a measurement period at α=0.05.

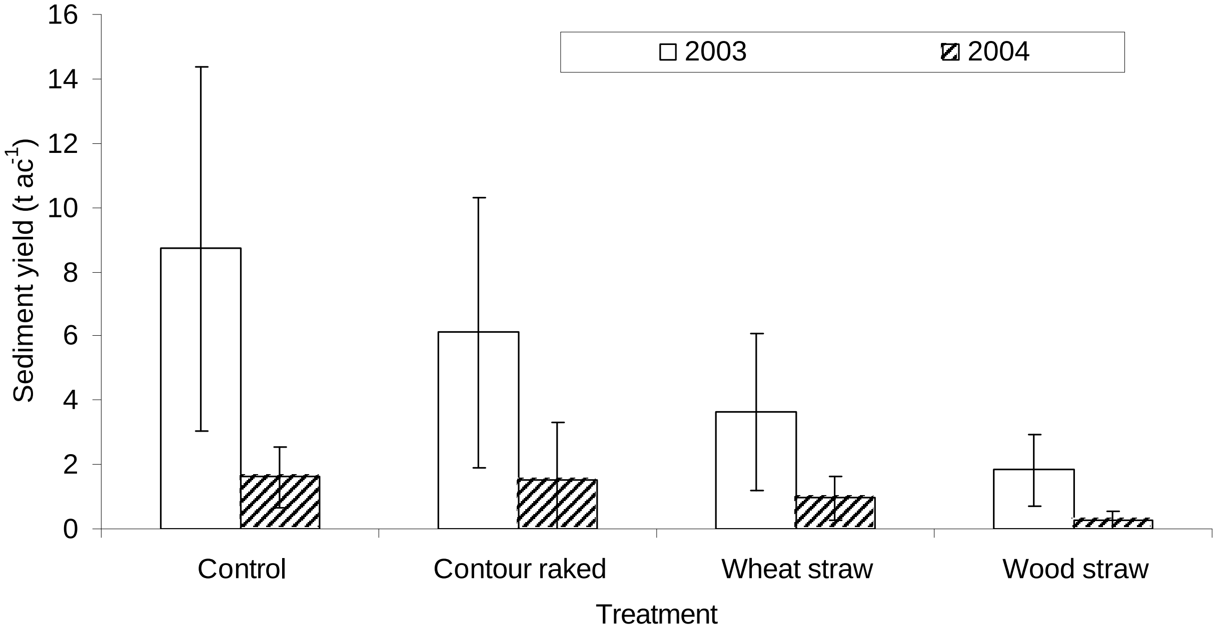

Figure 6. Mean silt fence sediment yields by treatment and year. Error bars represent one standard deviation.

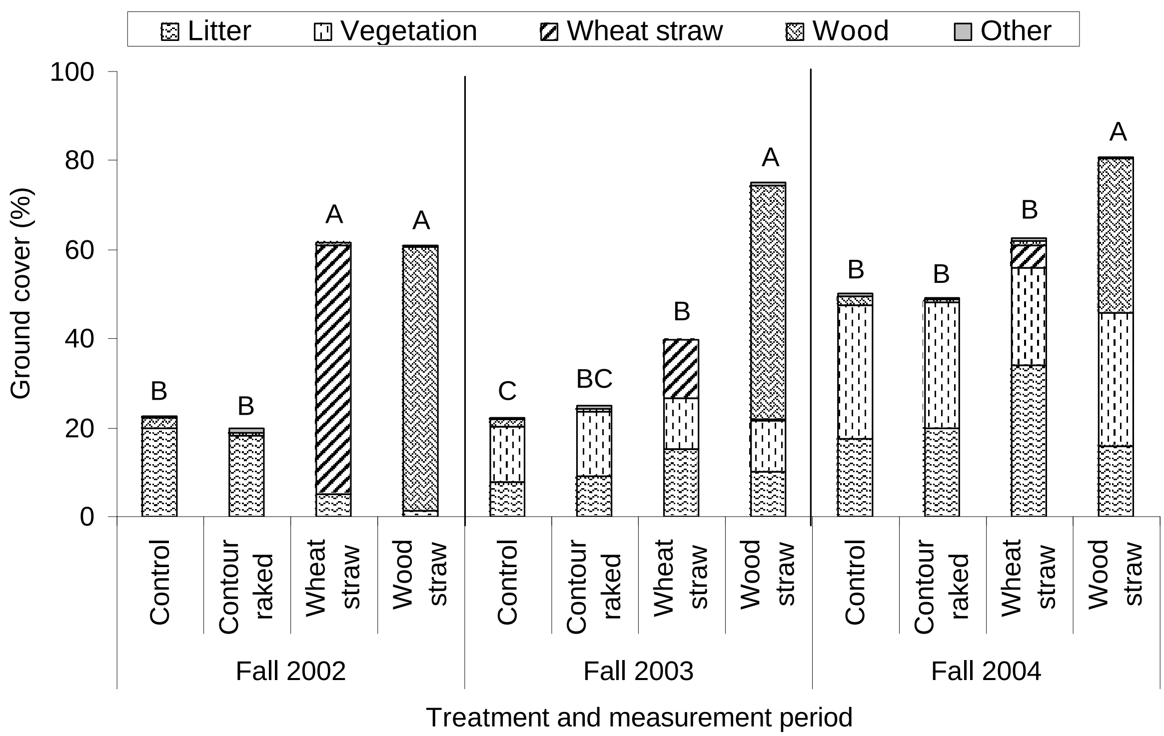

Figure 7. Mean ground cover in the silt fence plots by treatment and measurement period. Different letters represent significant differences between treatments within a year at α=0.05.