THE EFFECTIVENESS OF AERIAL HYDROMULCH AS A POST-FIRE EROSION CONTROL TREATMENT IN SOUTHERN CALIFORNIA

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Abstract Following a wildfire in the Santa Ana Mountains of northeast Orange County, California, a monitoring project was established to test whether aerial hydromulch reduced post-fire hillslope and small watershed erosion, and to document its impact on re-growing vegetation. The study site received below normal rainfall both the first and second winters after the fire. A high-intensity thunderstorm at the end of May 2008 produced very high peak rainfall intensities, providing an extreme test for the hydromulch. It appears that the mulch reduced hillslope erosion during low and moderate rainstorms, but not during heavy downpours. Once the hydromulch is removed, the sites are susceptible to erosion during subsequent higher intensity storms. Because the spatial differences in the rainfall were confounded with the treatment and control locations, the effect of the hydromulch on stream channel erosion is unknown. Cover assessments showed that the hydromulch did significantly reduce bare ground on the hillsides, and that this cover persisted until the time of the intense thunderstorm. Differences in pre-fire shrub composition and post-fire herbaceous species composition makes it impossible to separate the hydromulch effects from inherent site differences on plant response, suggesting that there was no treatment effect on vegetation recovery.

INTRODUCTION

In southern California the unrelenting urban expansion into neighboring uplands has created a wildland/urban interface that is increasingly difficult to manage. One of the biggest problem areas is wildfire. Fire increases flooding and accelerated erosion that can adversely affect natural resources and downstream human communities. Burned watersheds coupled with heavy winter rains can threaten life, property, and infrastructure (roads, bridges, utility lines, communication sites), placing an extra burden on land managers who must be able to predict post-fire hydrologic response and mitigate against any negative consequences to values at risk.

The physical landscape in southern California reflects the balance between active tectonic uplift and the erosional stripping of rock and soil material off the upland areas, with the transport and deposition of this sediment to the lowlands. Fire is a major disturbance event in southern California environments that drives much of the surface erosion. The post-fire landscape, with the removal of the protective vegetation cover, is susceptible both to dry season erosion – ravel – and to raindrop splash (Rice 1974). Moreover, fire alters the physical and chemical properties of the soil – bulk density and water repellency – promoting surface runoff at the expense of infiltration (DeBano 1981). The enhanced post-fire runoff removes more soil material from the denuded hillsides and can mobilize sediment deposits in the stream channels to produce debris flows with tremendous erosive power (Wells 1987). Post-fire accelerated erosion eventually abates as the re-growing vegetation canopy and root system stabilizes the hillslopes and provides protection against the agents of erosion (Barro and Conard 1991).

On October 21, 2007 an arson incident during a period of Santa Ana winds triggered a wildfire in Santiago Canyon, in northeastern Orange County, California. By the time the Santiago Fire was controlled it had consumed over 28,000 acres. The burn area consists of a deeply dissected mountain block underlain by sedimentary and metamorphic rocks that produces an erosive soil with both considerable fines and coarse, rocky fragments (Wachtell 1975). The area was covered with heavy chaparral vegetation, some of which had no recorded fire history (Moore 2007). A Forest Service Burned Area Emergency Response (BAER) team determined that there were significant threats to life, property, and infrastructure in the downstream human communities. After considering various treatment options, the BAER team recommended that some 1240 acres be treated with aerial hydromulch to control hillslope erosion and reduce the potential for devastating debris flows in the canyon bottoms (Moore 2007). Treatment application commenced in mid-December 2007 and was completed in mid-January 2008, excluding a Christmas hiatus and a period of heavy rain that precluded air traffic during early January. Total cost of the aerial hydromulch treatment was just under $5 million.

The aerial hydromulch used on the Santiago Fire was a wood and/or paper mulch matrix with a non water-soluble binder, often referred to as a bonded fiber matrix (BFM) (Hubbert 2007). The BFM's are a continuous layer of elongated fiber strands held together by a water-resistant, cross linked, hydrocolloid tackifier (bonding agent), a copolymer gel, and polyacrylamide that flocculates and anchors the fiber mulch matrix to the soil surface (Hubbert 2007). BFM's provide a thicker cover than ordinary hydromulch, and are recommended for steeper ground and areas frequented by high intensity storms. They eliminate direct rain drop impact onto the soil, have high water holding capacity, are porous enough not to inhibit plant growth, and will biodegrade completely. Breakdown of the product does not occur for up to six to twelve months through multiple weather cycles including rain. Typical application rates range from 3000 to 4000 lb/acre depending on slope (Hubbert 2007).

Aerial hydromulch is a relatively new erosion control treatment that has not been extensively tested under field conditions in burned upland areas. Uncertainty remains about its ability to reduce erosion, while its impacts on re-growing vegetation are virtually unknown (Robichaud et al. 2000). These concerns, along with the costs, prompted this study to evaluate the performance of the aerial hydromulch treatment in a wildland setting.

METHODS

Rainfall Precipitation across the study area was measured at a number of different raingages. The U.S. Geological Survey installed several gages along the Harding Truck Trail in January 2008 for a debris flow initiation project, and they shared these data with us. One gage was located in lower Modjeska Canyon, one was located in an upper section of Modjeska Canyon, and the third was located at the very top of Harding Canyon (Figure 1). We installed our own raingage in February 2008 in a middle section of Modjeska Canyon. These raingages recorded amounts, storm durations, and peak rainfall intensities. Long-term rainfall patterns as well as specific rainfall amounts prior to January 2008 were measured at the Orange County Santiago Peak Alert station, located about two miles from the monitoring area (see Figure 1).

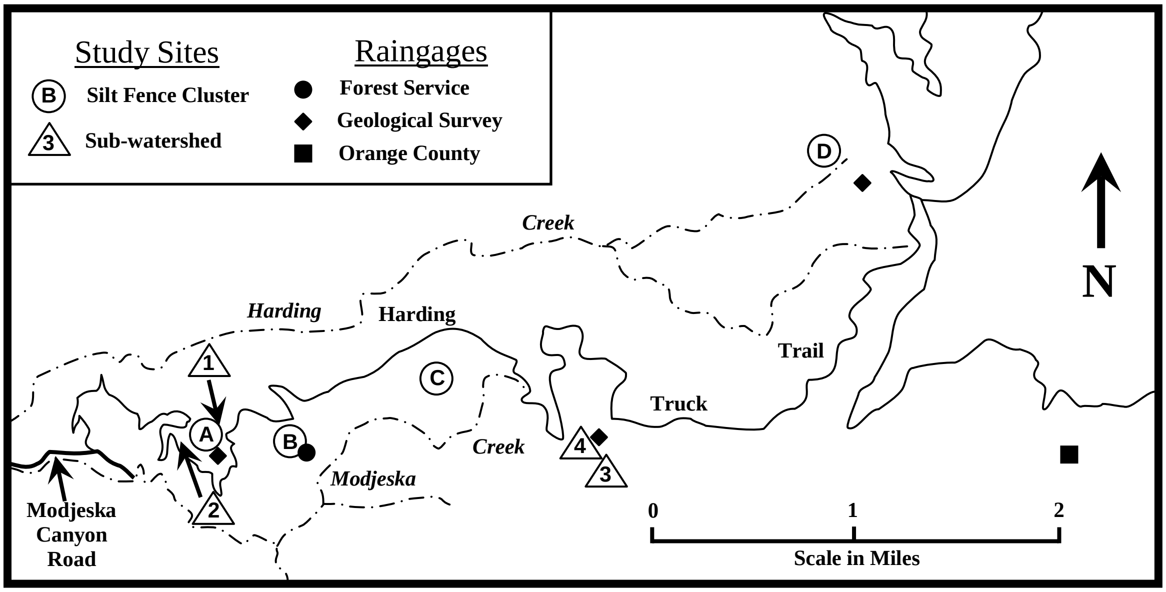

Figure 1 Location map of the study area.

Hillslope Erosion Hillslope erosion was measured in silt fences constructed of high tensile strength nylon landscape fabric wired to t-posts (Robichaud and Brown 2002). The landscape fabric also formed a floor or bench that facilitated silt fence cleanouts. The fences built for this project were approximately 15 feet wide and 2-3 feet high, with the capacity of the fence determined by its height and the slope gradient of the hillside. Sediment captured by the silt fences was cleaned out after each rainstorm or series of storms. Cleanouts were performed by hand using shovels and buckets along with a portable balance to get field weights. Subsamples were taken from each fence, moisture determinations were made in the laboratory for the subsamples, and the field weights were corrected to account for the weight of the water. The silt fences were arranged in four clusters (labeled A-D) of five replicates each, from west to east across the project area (see Figure 1). Topographic characteristics of the different cluster sites are arrayed in Table 1.

Channel Erosion and Deposition Channel erosion and deposition was measured at permanent cross sections, spaced 100 feet apart, marked by rebar monuments. Repeated surveys, using a laser level and a stadia rod, documented changes in channel bed and bank positions, representing local scour and fill. A computer program calculated the area of air space at each cross section for each successive survey using the tops of the rebar monuments as reference points. Four small watersheds (6-25 acres) were selected for the channel erosion and deposition work, two in areas treated with aerial hydromulch – containing 25 cross sections – and two in untreated control areas – containing an additional 25 cross sections (see Figure 1). Topographic characteristics of the different watersheds are arrayed in Table 2.

Table 1 Topographic characteristics of the Santiago Fire silt fence clusters.

Cluster	Fences	Type	Slope Aspect	Slope Length	Slope Gradient	Elevation
A	1-5	Untreated	007 ^{o}	175’	26 ^{o}	2100’
B	6-10	Treated	326 ^{o}	229’	27 ^{o}	2600’
C	11-15	Treated	126 ^{o}	195’	25 ^{o}	3100’
D	16-20	Untreated	144 ^{o}	131’	23 ^{o}	4400’

Table 2 Topographic characteristics of the Santiago Fire study watersheds.

Watershed	Type	Area	Channel Length	Channel Gradient	Relative Relief*	Relative Steepness**
1	Untreated	17 ac	2328’	17.7 ^{o}	691’	0.37
2	Untreated	6 ac	1621’	19.2 ^{o}	303’	0.37
3	Treated	25 ac	2298’	19.8 ^{o}	698’	0.44
4	Treated	8 ac	1158’	23.6 ^{o}	651’	0.48

* Relative relief is the highest point in the watershed minus the lowest point.
** Relative steepness is the relative relief divided by the horizontal basin length.

Cover/Plant Re-growth Cover on the Santiago Fire was measured in 40 inch by 40 inch plots using a grid frame and a pointer. The pointer was lowered at 100 points in a 4 in by 4 in grid within each plot. Aerial cover from the re-growing vegetation was tallied separately from ground cover provided by plant bases. Hits were recorded for the various classes of cover and were converted to a percentage. Ground cover categories included bare soil, gravel (mineral pieces ranging in size from 0.5 to 3 inches), rock (fragments greater than 3 inches in size), stumps, wood, live plant bases, litter, and hydromulch. If the aerial hydromulch covered pieces of rock or wood, it was counted as mulch. Two plots were sampled just upslope of each silt fence in March 2008. An additional five plots were established for each fence in May 2008. These latter plots were placed along vertical transects at the edges of each silt fence: 15 feet, 45 feet, and 75 feet from the fence on one edge; and 30 feet and 60 feet on the other edge. Aerial plant cover was recorded by species. Measurements were repeated in June 2009.

RESULTS AND DISCUSSION

Rainfall According to the 58-year record from the Orange County Santiago Peak Alert station, the average annual rainfall in the upper part of the Santiago Fire area is 34.52 inches (Orange County, http://www.ocwatersheds.com/envres/Rainfall). However, comparisons with newly installed gages in Modjeska and Harding Canyons indicate that rainfall on the study area was actually greater than on Santiago Peak during the both the 2008 and 2009 hydrologic years. Therefore the long-term records may underestimate the annual precipitation on the project site.

A synthesis of records from the Forest Service gage, the USGS gages, and the Orange County gage shows that the project site received 26.84 inches of rainfall for the first post-fire year, from September 2007 through May 2008; about 78 percent of the long-term annual average for the Santiago Peak station. Over a quarter of this rainfall occurred before the aerial hydromulch was applied, and over half the precipitation fell before the monitoring project was established. For the most part, rainfall intensities during the study were low to moderate. However, a thunderstorm associated with local tornados – rare in southern California – crossed the study area on May 22, 2008. While rainfall amounts were not spectacular in the thunderstorm, peak intensities were over twice as high as any other recorded storm over the study period. Moreover, rainfall amounts and intensities during this event were variable across the project site. The lower elevation western section of the project area (fence Clusters A and B along with Watersheds 1 and 2) experienced greater rainfall and almost twice the peak intensity as the higher elevation eastern section of the study (fence Clusters C and D along with Watersheds 3 and 4). This was reflected in observations of deep rilling on the hillsides, substantial erosion in the stream channels, and extensive road damage in the western area after the May thunderstorm, but little rilling, moderate channel erosion, and little road damage in the eastern section.

A similar synthesis of the various gages shows that the project site received 15.65 inches of rain during the second post-fire year, from September 2008 to June 2009; only 45 percent of the long term average and only 60 percent of the first year's totals. Not only were the rainfall totals less during the second year of the study, but rainfall intensities were much lower.

Hillslope Erosion Because the rain in late January 2008 restricted road access, the silt fences were built in two phases. Clusters A and B were constructed in late January, while Clusters C and D were installed in early February. Fence Clusters A and B were cleaned out in early February, and then all fences were cleaned out in late February, following the next series of moderate storms. Sporadic light rains in March and April 2008 generated negligible sediment, so the fences were not cleaned out again until after the thunderstorm at the end of May 2008. All fences were cleaned out in early December 2008 after the initial storms of the new rainfall season, then again in late December following the relatively heavy storm in the middle of that month. Fences were cleared again in late February 2009 after the largest storm of the second season, and finally in August 2009 following the many light spring storms.

Hillslope erosion was spatially variable over the project site. For this reason, erosion values were averaged by fence cluster rather than by treatment (Table 3). Erosion did not correlate well with rainfall amount, but there appears to be a positive linear association with peak intensity (see Figure 2), corroborating previous work (Moody and Martin 2001). However, this relationship needs to include more of the larger erosion events before it can be verified.

The majority of post-fire hillslope erosion was generated by the thunderstorm in May 2008 at the western fence clusters. The heavy rainfall produced massive rilling on the hillsides, scouring the surface soil and completely filling the silt fences. All five fences filled and overtopped on Cluster A (untreated), while three of five overtopped on Cluster B (hydromulched). The disparity in erosion between Clusters A and B in the June 2008 cleanout (Table 3) simply reflects the differences in fence capacity – the fences at Cluster B had less storage volume than those at Cluster A. The same storm generated only low to moderate erosion in the eastern clusters.

The response to the thunderstorm also demonstrates the effectiveness of the aerial hydromulch at reducing erosion during an extreme event. The hydromulch substantially reduced hillslope erosion at the Santiago Fire sites during low and moderate rainfall events (see Table 3). However, the full force of the thunderstorm-generated runoff tore through the hydromulch as easily as through the soil on the untreated controls.

The lower intensities of the storms in the second post-fire year produced, for the most part, only moderate erosion (Table 3). However, the most intense storm of the second season, mid-December 2008, generated the largest response throughout the study period from Cluster D, while treated Cluster B exhibited the largest response from that storm (Table 3). The hydromulch treatment on Cluster C persisted into the second post-fire year, producing a consistently low erosion response. In contrast, the hydromulch treatment was effectively removed from Cluster B during the May 2008 thunderstorm, rendering the site susceptible to erosion from subsequent storms.

Channel Erosion and Deposition The same disruptive rainfall at the end of January 2008 that affected the silt fence construction also impacted the establishment of the monumented channel cross sections. Some were constructed in late January, while others were not built until late February. The cross sections were re-surveyed in March or April 2008, then again in June 2008 after the late-May thunderstorm. The sections were measured again in May 2009. It is unclear how much scour or fill was experienced in these watersheds prior to cross section establishment.

The initial re-surveys showed little or no changes in the position of the bed and banks, indicating virtually no scour or fill. However, evidence between the cross sections (fresh deposits, new high water marks, etc.) suggested that both water and sediment were moving through the channel networks during the small and moderate storms in February and March 2008. In contrast, there were obvious large changes to the channel bed and banks following the May 2008 thunderstorm event (see Table 4). In the larger watersheds (1 and 3), nearly every cross section was affected. Newly exposed bedrock was apparent in the channel bed and banks, often limiting any subsequent scour. Moreover, large chunks of the banks had been removed, exposing plant roots and in one case undermining one of the rebar pieces. Some cross sections exhibited scour of

Table 3 Timing, rainfall, and average hillslope erosion by fence cluster.

Silt Fence Cleanout Dates	Rain Amount (Inches)	Peak 10-Minute Intensity (Inches per Hour)	Type		Average Hillslope Erosion by Cluster (Tons per Acre)
2/8/08	6.87	0.64	Untreated	A)	1.45
			Treated	B)	0.01
			Treated	C)	(not yet
			Untreated	D)	installed)
2/27/08	1.97	0.42	Untreated	A)	0.05
			Treated	B)	0.01
			Treated	C)	0.12
			Untreated	D)	0.18
6/6/08	3.21	3.18	Untreated	A)	21.21*
			Treated	B)	8.94*
	2.73**	1.80**	Treated	C)	0.04
			Untreated	D)	0.53
12/5/08	2.60	0.15	Untreated	A)	0.23
			Treated	B)	0.16
			Treated	C)	0.02
			Untreated	D)	0.07
12/31/08	4.71	0.32	Untreated	A)	2.66
			Treated	B)	5.25
			Treated	C)	0.03
			Untreated	D)	3.97
2/27/09	7.50	0.14	Untreated	A)	0.68
			Treated	B)	0.16
			Treated	C)	0.06
			Untreated	D)	0.42
8/7/09	0.84	0.11	Untreated	A)	0.03
			Treated	B)	0.02
			Treated	C)	0.01
			Untreated	D)	0.03

* Fences overtopped; minimum value is a function of fence capacity.
** Sites A and B had different rainfall than sites C and D for the big storm of 5/22/08.

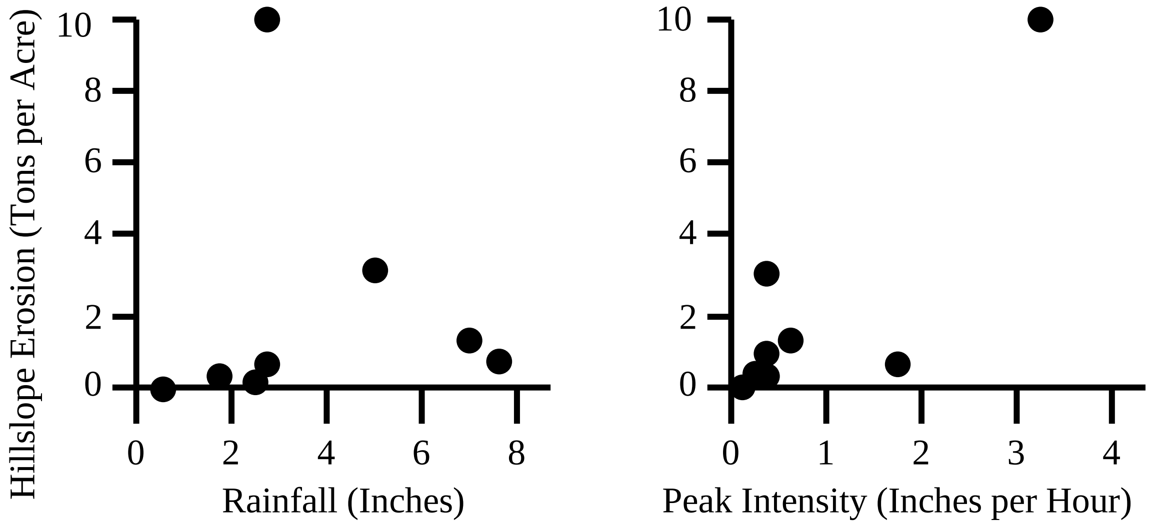

Figure 2 Rainfall-erosion relationships after the Santiago Fire.

Table 4 Patterns of channel erosion and deposition after the May 22, 2008 thunderstorm.

Watershed	Type	Total Cross Sections	Number of Cross Sections Affected: Bed Fill	Bed Scour	Bank Fill	Bank Scour
1	Untreated	17	4	13	1	10
2	Untreated	8		4		2
3	Treated	13		11		6
4	Treated	12		1		

both the bed and the banks. In a few cross sections, bed or bank deposition was documented. In two cases both scour and fill was measured at the same cross section location.

Unfortunately, the treatment effects of the aerial hydromulch on channel erosion were confounded by the spatial impacts of the thunderstorm. The western part of the study area (Watersheds 1 and 2) was hardest hit by the heavy rainfall, yet these were also the untreated watersheds. The eastern section of the study area (Watersheds 3 and 4) was spared the heaviest rain, but these were both treated with the hydromulch. Watershed 4 was virtually unchanged after the thunderstorm event, and hardly displayed any evidence of surface flow at all. However, rather than attributing this lack of change to the effectiveness of the hydromulch, it may be a simply a function of the small watershed size (Table 2) and a local lack of rain.

The massive scour associated with the May 2008 thunderstorm effectively re-set the channel landscape. This combined with the low rainfall totals and small rainfall intensities of the second post-fire year produced negligible channel scour or fill during 2009. There was little evidence of surface flow in the stream channels and the second year cross sectional profiles were virtually unchanged.

Cover/Plant Re-growth The amount of ground surface covered by material other than bare mineral soil is an indicator of the degree of protection from or resistance to hillslope erosion. A portion of this cover is the protection afforded by living plants. In chaparral-dominated areas, much of the above ground biomass and most or all of the litter layer are consumed in a wildfire. In the immediate post-fire environment, cover consists of standing dead stobs and stumps, residual wood and ash on the surface, and rocks or bedrock outcrops. Vegetation recovery begins with sprouting from basal root crowns and the emergence of new seedlings. Cover was first measured in late March 2008, after most of the rainfall had occurred on the study site. Bare ground was significantly greater in the untreated plots, while the cover of aerial hydromulch was consistent within the treated plots (see Table 5). The organic components (live plant bases, stumps, and wood) provided negligible cover on the study sites. Above-ground plant material ("Aerial plants" in Table 5) provided only minor cover, with a good deal of spatial variability between clusters but no differences between treatments.

Cover was measured again, including on additional plots, in May 2008, mostly prior to the thunderstorm event. Average percent bare ground was greater than it had been in March on nearly all clusters, undoubtedly a function of the increased sample size, and was still significantly greater on the untreated sites. The aerial hydromulch persisted on the treated plots and was still present when the thunderstorm occurred. Organic cover was still only a minor component, but aerial plant cover had greatly increased with the progression of the growing season. The lower values in gravel and rock cover seem puzzling, but may reflect the increase in area sampled.

Cover was re-measured in June 2009. A substantial amount of hydromulch (nearly 30 percent) remained on the ground at Cluster C, while most of the mulch was removed from Cluster B in the May 2008 thunderstorm. Bare ground was nearly twice as great in the untreated plots compared to those areas treated with hydromulch. However, compared to May 2008, the area of bare ground on the untreated plots has decreased with the addition of organic material (litter and plant bases), while the amount of bare ground on the treated plots has increased with the erosion of the hydromulch. Cover of rock and gravel increased on the plots compared to the May 2008 survey, especially on Cluster B with the removal of the hydromulch. The fact that the percent of rock and gravel on the untreated sites (Clusters A and D) returned to the March 2008 levels illustrates the vagaries of sampling (placement of the grid frame, different observers, etc.). Percent cover of rock actually decreased on Cluster C due to the substantially higher cover of plant bases, reflecting the explosion of a ground-hugging vine, which also afforded extra protection accounting for the low levels of erosion on that site. Litter, derived from the first year plant growth, begins to provide some cover, especially on Cluster A. Aerial plants form a nearly complete canopy in 2009, except on Cluster D. On two sites, cover actually exceeds 100 percent due to the overlapping strata of shrubs and herbaceous plants.

Table 5 Average percent cover by silt fence cluster in the Santiago Fire study area.

Cluster	Type	Bare Ground	Rock & Gravel	Live Plant Bases	Stump & Wood	Litter	Hydro-mulch	Aerial* Plants
Survey of March 2008 (200 points per silt fence)								
A	Untreated	72.1	26.3	0	1.6	0	0	5.5
B	Treated	4.2	30.9	0	0.5	0	64.4	0.6
C	Treated	15.3	16.2	0.6	0.4	0	67.5	7.7
D	Untreated	51.7	45.8	0.7	1.8	0	0	3.5
Survey of May 2008 (Cluster A - 500 points per silt fence; Others - 700 points per fence)								
A	Untreated	79.8	16.6	0.9	2.7	0	0	29.6
B	Treated	24.1	13.1	1.1	1.6	0	60.1	8.5
C	Treated	10.8	14.6	2.1	1.3	0	71.2	17.6
D	Untreated	59.1	39.0	0.6	1.3	0	0	12.1
Survey of June 2009 (500 points per silt fence)								
A	Untreated	44.5	25.5	11.7	4.0	14.3	0	153.1**
B	Treated	29.4	45.9	12.2	1.7	3.5	7.3	84.9
C	Treated	22.0	10.5	36.1	0.5	1.5	29.4	105.1**
D	Untreated	44.8	44.2	8.4	0.7	1.9	0	45.8

* Cover of aerial plants is considered separately from the ground cover percentages.
** Overlapping plant cover can produce percentages greater than 100.

Aerial plant cover was recorded by species in May 2008 and again in June 2009. Cover by species was separated into two categories: shrubs – the eventual climax vegetation; and herbs – a transient fire-following community. A variety of undifferentiated oaks dominated the shrub re-growth, while wild morning glory, wild cucumber, and common eucrypta were the primary herbaceous species. Other shrubs and herbs had only a minor presence. Shrub species that only reproduce from seeds, such as hoaryleaf ceanothus, were present in great numbers, but did not provide substantial ground cover. The average cover of shrub species on the untreated plots was twice that of the areas treated with the aerial hydromulch, but the cover of herbs was nearly identical between the two treatments. Plant cover for both classes of vegetation was extremely spatially variable, no doubt reflecting the patterns of pre-fire shrub composition and the specific site characteristics.

SUMMARY

The Santiago Fire aerial hydromulch monitoring project was established to evaluate the performance of the mitigation treatment on reducing hillslope and stream channel erosion, as well as to document its impact on re-growing vegetation. The study site received only 78 percent of the estimated normal annual rainfall during the first post-fire winter and only 45 percent the following year. Unfortunately, much of the first-year rain occurred prior to the hydromulch treatment and over half fell before the monitoring commenced. A high-intensity thunderstorm at the end of May 2008 produced very high peak rainfall intensities, providing an extreme test for the hydromulch. While the aerial hydromulch appeared to be effective at reducing hillslope erosion during light and moderate rains early in the monitoring period, the mulch did not appear to have any effect on the major erosion resulting from the May 2008 thunderstorm. This downpour stripped the hydromulch from the lower treated site, but the upper treated site was left intact. Subsequent higher intensity storms in the second post-fire year produced substantial erosion on the formerly treated site, while the site with the residual hydromulch generated negligible sediment.

Although there was evidence of both water and sediment moving through the channel networks, there was little change in the position of the bed and banks during the periods of low and moderate rainfall. In contrast, large scour and fill were documented after the May thunderstorm. Unfortunately, spatial variability in rainfall across the study site during the thunderstorm caused the untreated watersheds to receive nearly twice the peak intensities as the catchments treated with the hydromulch. This confounding factor precludes an assessment of the ability of the hydromulch to reduce channel erosion. The massive changes in channel geometry caused by the May 2008 thunderstorm, combined with the low rainfall totals during the second post-fire year, produced negligible scour and fill along the measured stream reaches during 2009.

Cover assessments showed that the hydromulch did significantly reduce bare ground on the hillsides during the first post-fire year, and that this cover persisted until the time of the intense thunderstorm. The areas treated with the hydromulch had lower sprouting shrub cover than the untreated controls during the first year, but this may be explained by pre-fire vegetation composition, especially as the cover of the fire-following herbs was the same. In 2009, the treated sites still had about half the bare ground of the untreated controls, but the lower stripped site had a preponderance of rock and gravel, while the upper intact site was dominated by the plant bases of wild morning-glory. Although there was a great deal of spatial disparity, when all the plots for the two treatments are lumped together, very little difference in plant cover or seedling density is apparent between the two groups. The differences in pre-fire shrub composition and post-fire herbaceous species composition among the clusters make it impossible to separate any hydromulch effects from inherent site differences on plant response. Thus, based on the results of this study, the hydromulch had no effect on plant recovery.

In conclusion, the aerial hydromulch reduced hillslope erosion in small and medium rainstorms, but not during an extremely intense downpour; the treated areas became more susceptible to erosion once the hydromulch was removed; the mulch had an unknown effect on reducing stream channel erosion because the spatial patterns of rainfall confounded direct treatment comparison; and the hydromulch had no effect on re-growing vegetation composition.

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