United States
Department
of Agriculture

Forest Service

Rocky Mountain
Research Station

General Technical Report
RMRS-GTR-307

July 2013

Production and Aerial Application of Wood Shreds as a Post-Fire Hillslope Erosion Mitigation Treatment

Peter R. Robichaud, Louise E. Ashmun, Randy B. Foltz,
Charles G. Showers, J. Scott Groenier

Robichaud, Peter R.; Ashmun, Louise E.; Foltz, Randy B.; Showers, Charles G.; Groenier, J. Scott; Kesler, Jennifer; DeLeo, Claire; Moore, Mary. 2013. **Production and aerial application of wood shreds as a post-fire hillslope erosion mitigation treatment.** Gen. Tech. Rep. RMRS-GTR-307. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 31 p.

Abstract

Guidelines for the production and aerial application of wood shred mulch as a post-fire hillslope treatment were developed from laboratory and field studies, several field operations, and the evaluations of professionals involved in those operations. At two early trial sites, the wood shred mulch was produced off-site and transported to the area of use. At the 2010 Schultz Fire in Arizona, the wood mulches were produced on-site from burned hazard trees that were felled and skidded to a processing area where the logs were shredded by a horizontal grinder and piled. The subsequent aerial applications of the wood shreds were staged from the same landings where they were produced. At the 2010 Fourmile Canyon, 2012 High Park, and 2012 Waldo Canyon Fires in Colorado, wood shreds were produced from various combinations of on- and off-site burned and green trees that were generally shredded near the harvest or storage site. The wood shreds were transported by chip trucks to aerial application staging areas. The most challenging aspect of wood shred production was adjusting the grinder screens and through-put speed to maximize the proportion of shreds that were 2 to 8 inches (50 to 200 mm) in length. The same equipment and techniques used for aerial mulching with agricultural straw worked, with some adjustments in flight altitude and speed, for wood shreds. The Heli-Claw, an experimental device designed to replace the cargo net in aerial mulching, was tested and used to apply 80 percent of the wood shred mulch at the Beal Mountain mine reclamation site. Because wood shreds are four to six times heavier than agricultural straw, wood shred mulch took longer to apply than agricultural straw for the same area (25 to 35 ac [10 to 14 ha] per day for wood shreds; approximately 200 ac [81 ha] per day for straw). The additional flight time makes mulching with wood shreds cost three to four times more than with agricultural straw ($1700 to $2200 per ac [$4200 to $5500 per ha] for wood shreds; $500 to $700 per acre [$1200 to 1700 per ha] for straw). However, the advantages of wood shreds—on- or near-site availability, greater stability in high winds and on steep slopes, and lack of unwanted plant seeds from off-site—make wood shred mulch useful in areas where agricultural straw mulch may not be desirable.

Keywords: heli-mulching, aerial mulching, wood mulch, post-fire, Burned Area Emergency Response (BAER), erosion mitigation

Authors

Peter R. Robichaud and **Randy B. Foltz** are Research Engineers and **Louise E. Ashmun** is a Civil Engineer with the Air, Water and Aquatic Environments Science Program of the USDA Forest Service, Rocky Mountain Research Station located at the Forestry Science Laboratory, Moscow, Idaho.

Charles G. Showers is the Engineering Program Leader and **J. Scott Groenier** is a Project Leader for the National Technology and Development Program, National Forest Systems, Missoula, Montana.

Jennifer Kesler is a Plant Ecologist and **Claire DeLeo** is a Senior Plant Ecologist with the Colorado's Boulder County Parks and Open Space Department.

Mary Moore is a Hydrologist in the Urban Forest Management Program of the Lake Tahoe Basin Management Unit, USDA Forest Service. She was the lead hydrologist on the 2012 Waldo Canyon Fire BAER team and the team leader of the BAER implementation team.

CONTENTS

Introduction..........1

Study Sites..........4
- 2007 Cascade Complex Fire..........4
- 2010 Schultz Fire..........4
- 2010 Fourmile Canyon Fire..........4
- 2011 Beal Mountain Abandoned Mine Site..........5
- 2012 Waldo Canyon Fire..........5
- 2012 High Park Fire..........5

Production of Wood Shreds..........5
- Controlling and monitoring the quality of the wood shreds being produced..........7
- Off-site production and transportation..........8

Aerial Application of Wood Shreds..........9

Comparison of Wood Shred and Straw Mulches..........11

Conclusions and Management Implications..........12

Acknowledgments..........14

References..........14

Appendix A: 2010 Fourmile Canyon Fire Case Study..........17

Appendix B: 2012 Waldo Canyon Fire Case Study..........22

Introduction

Aerial application of agricultural straw mulches, developed and refined in the past 12 years, has allowed mulch to be used as a post-fire hillslope treatment in remote burned areas that lacked road access. Because mulching provides effective ground cover immediately after application, it can effectively mitigate potential post-wildfire increases in runoff, flooding, and erosion (Robichaud and others 2013a, b). Although aerial mulching is logistically demanding and expensive, the effectiveness of dry mulches as compared to other post-fire hillslope treatments has increased its use in areas where downstream values are at high risk for damage, such as the hillslopes above municipal water intakes, heavily used roads, and stream reaches that are critical habitat for protected species (Robichaud and others 2010).

Problems associated with using agricultural straw mulch in burned forest environments emerged as the use of post-fire mulch treatments increased. These problems include 1) lack of available straw in the locations and quantities needed (Beyers 2004); 2) introduction of non-native seed species that can persist and compete with the re-establishment of native vegetation (Beyers 2004; Robichaud and others 2000, 2003); 3) susceptibility to displacement by wind (Copeland and others 2009) that may result in exposed hillslopes and deep piles of straw in gullies and channels; and 4) straw mulch physically blocking or shading emerging vegetation (Beyers 2004). As issues with straw mulch became apparent, alternatives were tried. Although many erosion-mitigating mulch products (e.g., geotextiles, compost, wood bark, hydromulches, etc.) were available, few of them were easily adapted to aerial application and had the potential to effectively reduce erosion on steep hillslopes with long flow paths.

Wood-based mulches, such as wood chips, wood shreds, and manufactured wood strands, have been tested and used along with various hydromulch products. Small rounded wood chips have not successfully reduced post-fire erosion and were easily displaced by overland flow when tested in Arizona and northern Spain (Fernández and others 2011; Riechers and others 2008). In contrast, limited testing has shown that wood mulches composed of coarse shredded pieces, flat slats, or strands (>2 inches [50 mm] and at least 4 times longer than they are wide) are less susceptible to wind displacement, degrade slowly, and reduce erosion as well or better than agricultural straw mulches (Copeland and others 2009; Foltz and Copeland 2007; Foltz and Dooley 2003; Robichaud and others 2013a, c). In addition, these wood mulches can be aerially applied using the same equipment and similar application protocols as agricultural straw mulch (Lynch 2008; Skeen and Becker 2007).

Wood-based mulch products often are produced from small diameter trees and slash removed during thinning operations, roadside clearing, and logging operations, and the production of wood mulch from local forest materials for post-wildfire application was a logical extension for these products (Groenier and Showers 2004)[1]. Burned Area Emergency Response (BAER) teams discussed the possibility of using local burned trees, such as hazard trees that were designated to be felled for safety reasons, to produce wood shreds for immediate application as a

[1] Logging companies and forest product manufactures that create wood mulching products may own and operate grinding equipment that can be adjusted to produce wood shreds for post-fire mulching. Groenier and Showers (2004) produced an *Engineering Tech Tip* that described tree shredding equipment, gave details, had photographs of three specific machines and the product they produced, and listed nine manufacturers of shredding/grinding equipment. This Tech Tip is available online at http://fsweb.mtdc.wo.fs.us/pubs/pdfpubs/pdf12282311/pdf12282311dpi100.pdf.

hillslope treatment. It seemed possible that burned trees could supply a significant quantity of wood mulch without the purchase and transportation costs associated with using agricultural straw or manufactured wood strands. In addition, local wood product manufacturers might also produce and transport wood shreds for post-fire mulching. Locally produced material is less likely to introduce unwanted plants or seeds from outside the burned area and may fit into a broader ecological restoration plan for the area (Bautista and others 2009; Groenier and Showers 2004).

Wood shreds have been produced and their erosion reducing capacity evaluated by the USDA Forest Service, Rocky Mountain Research Station (RMRS) and the Missoula Technology Development Center (MTDC) for nearly a decade (Foltz 2012; Foltz and Copeland 2007; Foltz and Wagenbrenner 2010; Groenier and Showers 2004; Robichaud and others 2013c). Horizontal shredding machines that can handle larger burned trees were identified and tested, which resulted in several commercially available machines being recommended (Groenier and Showers 2004). Laboratory rainfall and overland flow simulations were used to determine the optimum wood shreds specifications (dimensions and coverage) for reducing post-fire hillslope erosion. Blends containing 24, 18, or 2 percent or less of the shortest wood shreds (≤ 1 inch [25 mm]) at three coverage rates (0, 50 and 70 percent) were tested (Foltz and Wagenbrenner 2010) (fig. 1). With rainfall only (no overland flow), all blends were equally effective in reducing sediment loss by 90 to 98 percent compared to bare soil; but in the simulations of rainfall plus a high concentrated flow rate, the 2 percent blend was the most effective in reducing sediment loss (approximately 70 percent less than the bare soil control). Although the 70 percent coverage provided greater erosion reduction than the 50 percent coverage, Foltz and Wagenbrenner (2010) recommended 50 to 60 percent coverage of the 2 percent blend for the post-fire environment. The authors reasoned that the small increase in erosion reduction provided by the 70 percent coverage was not worth the added expense of obtaining that greater coverage (Foltz and Wagenbrenner 2010).

Figure 1. A portion of the rainfall and overland flow simulation laboratory plot with a 70 percent cover of wood shred mulch.

Following the 2009 Terrace Mountain Fire in Kelowna, British Columbia, Robichaud and others (2013c) conducted three experiments (rainfall simulation, rill simulations, and sediment yield from natural rainfall) to compare the runoff and erosion mitigation attained by agricultural straw and wood shreds. They found that wood shreds and agricultural straw were similar in their ability to reduce erosion in comparison to untreated controls and that the wood shreds remained on the soil longer than the straw during the 3 years of the study.

Foltz (2012) applied wood shred and agricultural straw mulch on bare soil after forest road obliteration. He found that agricultural straw and wood shreds were similar in reducing erosion as compared to the controls, but in contrast to Robichaud and others (2013c), he measured no difference in the longevity (based on the half-life of original cover proportion) of the agricultural straw and wood shred mulches.

Helicopters with cargo nets have been used for years to distribute agricultural straw over disturbed landscapes to help stabilize hillslopes and protect bare soil (Napper 2006) this was an obvious starting place for aerial application of wood shreds. In 2007, the first attempt to aerially apply wood shreds using a helicopter with a cargo net occurred at a research site established immediately after the Cascade Complex Fire in central Idaho and it continues to be the most common method for aerial application of dry mulches. Several trial productions and applications of wood shreds were completed as hillslope stabilization treatments on fires that occurred in 2010 to 2012 in the western United States. However, as wood shreds were being developed and tested for use, the MTDC developed and built a prototype Heli-Claw[2] (fig. 2) as a potential alternative to cargo nets for the aerial application of mulches (Lynch 2008). The Heli-Claw was designed as a pilot-controlled device that could pick up and hold loose mulch material and, by controlling the flight speed and the width of the claw opening, allow the mulch to spill out more slowly and over a greater distance than can be done using a tethered cargo net (Groenier 2012; Lynch 2008). A trial use of the Heli-Claw for the aerial application of wood shred mulch is included in this report.

Based on the experience garnered from these trial productions and aerial applications of wood shreds, our goal was to develop a guide for the production and use of wood shreds as a post-fire hillslope treatment. Specifically, we described the 1) equipment and procedures that were used, 2) labor and time requirements, and 3) costs involved in producing, staging, and aerially applying wood shreds in the post-wildfire environment. In addition, if both wood shred mulch and straw mulch were aerially applied at the same location, the time, labor, and costs were compared. Since details of wood shreds production, transport, characteristics, and application

Figure 2. The prototype Heli-Claw being used for wood shred mulching at the Beal Mountain mine site: (a) picking up a load, (b) taking off with the claws closed on a load, (c) applying mulch by opening the claws while flying over the target area.

[2] MTDC hopes to continue the development of the Heli-Claw for aerial dry mulching. The current prototype is available for use in National Forests. If you are interested in using the Heli-Claw, please contact J. Scott Groenier at 406 329 4719, jgroenier@fs.fed.us.

differed among the sites where it has been used, we have presented the information as individual case studies. Important issues, key decisions, contract specifications, and other aspects of using wood shred mulch as a post-fire hillslope treatment have been generalized in the conclusions and manager implications sections.

Study Sites

Reports from several sites were examined to determine the salient features of successful operations to produce and use wood shreds as a post-fire hillslope mulch treatment.

2007 Cascade Complex Fire

Following the 2007 Cascade Complex Fire on the Payette and Boise National Forests near McCall, Idaho, a set of three small catchments were installed to compare the treatment effectiveness of aerially applied wood shreds, agricultural straw, and no treatment. The wood shreds, produced off-site and transported to the staging area, were applied at a rate of 4.6 tons ac^{-1} (10.3 metric tons ha^{-1}) by a helicopter equipped with cargo nets. This was the first aerial application of wood shreds as a post-fire treatment.

2010 Schultz Fire

The 2010 Schultz Fire occurred on the Coconino National Forest adjacent to the Kachina Peaks Wilderness near Flagstaff, Arizona. In the year after the fire occurred, a contractor produced and distributed nearly 2000 tons (1800 metric tons) of wood shred mulch on 330 ac (130 ha) of steep mountainous landscape burned at high severity. The contractor used burned hazard trees harvested from the sides of a forest road that were skidded on the road to a landing and subsequently ground to produce the required wood shreds. The wood shreds were then aerially applied to hillslopes by helicopters equipped with cargo nets.

2010 Fourmile Canyon Fire

In the fall of 2010, the Fourmile Canyon Fire burned 5 miles (8 km) west of Boulder, Colorado in a densely populated urban-wildland interface. In the spring of 2011, post-fire hillslope treatments included aerial application of agricultural straw mulch (1,620 ac [656 ha]; 1.3 tons ac^{-1} [2.9 metric tons ha^{-1}]) and a commercially produced wood strand material (350 ac [140 ha]; 4.7 tons ac^{-1} [10.5 metric tons ha^{-1}]). In the fall of 2011, 364 ac (147 ha) that had been treated previously were identified for retreatment based on the loss of treatment ground cover, limited recovery, high burn severity, and downstream values at continued risk. In April 2012, a mix of agricultural straw and wood shreds was aerially applied (0.5 tons ac^{-1} [1.1 metric tons ha^{-1}] of agricultural straw and 4 tons ac^{-1} [9.0 metric tons ha^{-1}] of wood shreds) on 20 to 60 percent slopes to attain 1 to 3 inches (25 to 76 mm) mulch depths and 60 percent mulch cover. (See Appendix A for a case study of the wood shred mulching project on the Fourmile Canyon Fire.)

2011 Beal Mountain Abandoned Mine Site

Beal Mountain on the Beaverhead-Deerlodge National Forest was an abandoned mine land reclamation site in the Pintler Mountains outside of Fairmont, Montana. The Heli-Claw and cargo nets were used with a helicopter to aerially apply wood shred mulch to the gentle hillslopes (0 to 20 percent) designated for rehabilitation.

2012 Waldo Canyon Fire

The Waldo Canyon Fire occurred on the Pike and San Isabel National Forest and Comanche and Cimarron National Grasslands near Colorado Springs, Colorado. A contractor produced and distributed nearly 11,750 tons (10,660 metric tons) of wood shred mulch on 1,960 ac (793 ha) of steep mountainous landscape (20 to 60 percent slopes) burned at moderate and high burn severity. The contractor obtained wood shreds from four sources (burned roadside hazard trees and green trees from a fuel break construction, a stewardship area project, and a local timber products stock yard) and applied the mulch using up to five helicopters equipped with cargo nets. (See Appendix B for a case study of the wood shred mulching project on the Waldo Canyon Fire.)

2012 High Park Fire

The High Park Fire occurred 15 miles (24 km) west of Fort Collins, Colorado and burned 87,284 ac (35,323 ha) across multiple jurisdictions—49 percent on the Roosevelt National Forest, 44 percent on private holdings, and 6 percent on state lands. Wood shred mulch was aerially applied by helicopter with cargo nets on 881 ac (357 ha) burned at high severity. The wood shreds were produced from mostly green trees (there were some beetled-killed trees in the mix) from a timber sale. The same contractor that had worked the wood shred mulching project at the 2012 Waldo Canyon Fire was hired for the High Park Fire and the same methods for wood shreds production, aerial application, and contract monitoring were used in both places.

Production of Wood Shreds

The MTDC produced the wood shreds that were applied at the 2007 Cascade Complex Fire in Idaho. After grinding, the wood shreds were blown out onto the ground. To optimize the mix of wood shred sizes by reducing the largest and smallest pieces (Foltz and Wagenbrenner 2010), only the wood shreds from the middle two-thirds of the pile were used. The wood shreds used at the Beal Mountain mine site were produced off-site by a contractor and a post-grinding process was used to reduce the proportion of smaller shreds (<2 inches [50 mm]; “fines”) in the shreds mix. In both cases, the wood shreds were hauled unconsolidated in a bulk container (chip) truck to the project site.

The first time wood shreds were produced, staged, and aerially applied as a post-fire hillslope treatment was at the 2010 Schultz Fire. A week before the shredding was scheduled to begin, burned hazard trees along a forest road were felled and skidded (using a grapple skidder) on the forest road to a staging area. A forest material handler with a 12-ft (3.7-m) rotating grapple was used to stack the trees and then to load them into a radio-controlled horizontal grinder. The operator of the forest material handler also operated the grinder using the radio controls. The wood shreds were produced and piled at the staging areas (1,200 tons and 800 tons [1090 and 730 metric tons], respectively). (See video at the Arizona State Geologist blog site—http://arizonageology.blogspot.com/2011/06/schultz-fire-burn-area-mulching-to.html.)

Material for the wood shreds was harvested within or near the burned area of the Fourmile Canyon, Waldo Canyon, and High Park Fires. Burned hazard trees provided some of the wood shreds on the Waldo Canyon and High Park Fires but not on the Fourmile Canyon Fire. Stewardship projects (fuel management projects) provided green trees for wood shreds on all three fires, and in the case of the Waldo Canyon Fire, green trees also were obtained from a log deck that was a byproduct of fire break construction. Whatever the source of the trees, harvested trees were skidded to road-accessible landings where horizontal grinders and excavators or forest material handlers could be safely operated (fig. 3). Using front-end loaders, the wood shreds were loaded into chip trucks (fig. 4) and moved by road to a treatment staging area where they were piled and covered (fig. 5).

Figure 3. Wood being fed into a horizontal grinder to produce wood shreds at the 2012 Waldo Canyon Fire.

Figure 4. Wood shreds being loaded into a chip truck for transport to a treatment staging area at the 2012 Waldo Canyon Fire.

Figure 5. A helicopter with an empty cargo net is approaching a treatment staging area with a chip truck on the road at the 2012 Waldo Canyon Fire.

Controlling and monitoring the quality of the wood shreds being produced

Based on research results (Foltz and Wagenbrenner 2010), it was assumed that the most effective wood shred mulch would have a minimal amount of small material (generally referred to as "fines"). However, research has not yet determined the specific wood shred length that should be designated a fine or what the maximum proportion (by weight or by volume) of fines should exist in the wood shred mulch applied to burned hillslopes. Among the post-fire treatment sites described here, the description of fines ranged from 0.5 to <2 inches (13 to <50 mm). No matter how fines were defined, the production of wood shreds at each site involved a trial period in which various grinder screen sizes and orientations were tried with a range of throughput speeds to minimize the amount of small shredded material in the product. At the Schultz Fire, a series of screens with openings ranging from 2 to 4 inches (50 to 100 mm) were used to create wood shreds that were observed and reported to be "mostly" ≥2 inches (50 mm) and ≤6 inches (150 mm); however, no direct measurements of wood shreds samples were done. At the High Park and Fourmile Canyon Fires, the grinders were tested with 2-, 4-, and 6-inch

Figure 1. (a) Wood shreds produced and piled for use at the 2012 High Park Fire. (b) Wood shred mulch applied by hand on a research plot at the 2012 High Park Fire.

Wood shreds can be highly variable. Based on our research and trial studies, wood shreds that are 2 to 8 inches (50 to 200 mm) long and less than 1 inch (25 mm) in diameter are best suited to be aerially applied for hillslope stabilization (fig. 1).

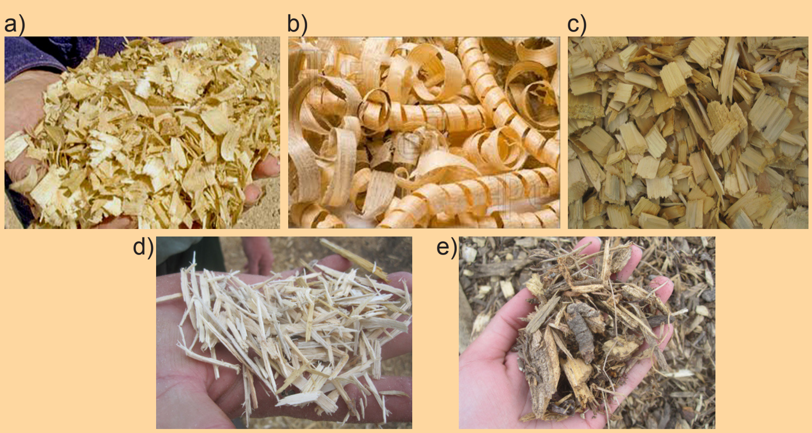

Figure 2. Wood products that are not recommended for use as post-fire hillslope mulch: a) animal bedding, b) shavings, c) chips, d) shreds that are predominantly less than 2 inches (50 mm), and e) shreds that are mostly lightweight bark and less than 2 inches (50 mm).

A wide range of wood mulch products are manufactured for a variety of purposes. Many of these products are not well-suited for post-fire hillslope stabilization treatments as they are too light and/or do not interlock on the slope (fig. 2). In addition to the products pictured, pole peelings and extra-large excelsior (aspen shavings) have been suggested but are not desirable for use as post-fire hillslope treatments (C. DeLeo, personal communication).

(50-, 100-, and 150-mm) screens, but the best wood shreds, based on visual inspection, were obtained with 4-inch (100 mm) screens only. At Waldo Canyon and High Park Fires, 2- to 4-inch (50- to 100-mm) grinder screens were delineated in the contract specifications along with a restriction of ≤30 percent fines in the wood shred product. The resulting wood shreds were sampled and the volume of fines (<0.5 in [13 mm]) within the samples were compared to the volume of the wood shreds in the desired size range (≥0.5 to 8 inches [50 to 200 mm]) to ensure contract compliance (for more details about this sampling procedure, see Appendix B).

Off-site production and transportation

Producing and transporting wood shreds to an area where trees for shredding are not readily available may be a viable option for some post-fire mulch treatment projects. For example, burned chaparral areas in southern California often are exposed to high winds, and wood shred mulch may be a desired hillslope treatment because of its resistance to wind displacement; however, there may not be adequate wood resources to support local production of wood shreds in the areas that are recommended for treatment. In this case, the added costs of transporting wood shreds produced off-site may be worth the potential erosion mitigation that the wood shreds can provide. Other situations may preclude the harvest of trees within or near a fire. For example, logging equipment may not be advised or safe on soils burned at high severity or on steep hillslopes. Fuel treatments in unburned areas near a wildfire may provide woody material needed for shredding, and short-distance transportation costs to move the wood shreds to a staging area may be economically competitive with other hillslope mulches such as agricultural straw and on-site production of wood shreds.

A cost comparison of on-site production of wood shreds to off-site production and shipping of wood shreds was developed using production costs of wood shreds at the 2010 Schultz Fire and wood shred transportation costs calculated by the contractor for the 2011 Beal Mountain mine reclamation project (table 1). The estimated cost for the on-site production of the 2,000 tons (1,800 metric tons) of wood shreds used at the Schultz Fire, based on the contractor's costs for equipment and manpower, was approximately $37,800 or $18.90 per ton ($21 per metric ton) (table 1). Given that the first on-site production of wood shreds from burned trees occurred at the Schultz Fire, these costs may not be representative of the costs that would be incurred in different areas or from a more practiced and efficient process. The contracted cost to produce 31.7 tons (28.8 metric tons) of wood shreds off-site and deliver them to

Table 1 Costs to obtain wood shreds at the 2010 Shultz Fire site and the Beal Mountain mine reclamation site are compared in the sub-tables a) and b) using $US and conventional units only. Both sites were mulched in 2011.

a) Evaluation of the cost of wood shreds produced on-site at the Schultz Fire.

Process	Cost per hour ($ h^{-1})	Time (h)	Total cost ($)	Amount of shreds (t)	Cost per ton ($ t^{-1})
Tree felling	280	80	22,400	2,000	$11.20
Shredding	385	40	15,400	2,000	$7.70
				Total cost per ton	**$18.90**

b) Evaluation of cost of wood shreds produced off-site and shipped 100 miles to the Beal Mountain mine reclamation site.

	----------Hauling----------			
Process	**Cost per ton ($ t^{-1})**	**Cost per ton-mile ($ t-mi^{-1})**	**Distance (mi)**	**Cost per ton ($ t^{-1})**
Wood shreds	19.84	0.50	100	69.84
			Total cost per ton	**$69.84**

the Beal Mountain reclamation site (a distance of 100 miles [161 km]) was $2,214, or approximately $69.80 per ton ($76.90 per metric ton), with hauling expenses accounting for 72 percent of the cost (table 1). The cost for shredding the trees was not much different at the two locations—$18.90 per ton ($20.84 per metric ton) at the Schultz Fire and $19.84 per ton ($21.87 per metric ton) for the Beal Mountain site—but the cost of transporting the wood shreds substantially impacted the total cost of the wood shreds. There is likely to be a significant economic advantage to producing wood shreds on or near the treatment site.

Aerial Application of Wood Shreds

Figure 6. Wood shred mulch falling from a cargo net that had been released by the pilot at the 2012 Waldo Canyon Fire.

Generally, wood shred mulch was aerially applied using the same equipment and processes as the aerial application of agricultural straw. A 4-point cargo net (50 ft^2 [4.6 m^2] or larger) was spread out on the ground in the staging area and a small front end loader piled the wood shreds onto the center of the net. As the helicopter hovered above a loaded net, ground personnel attached the corners of the cargo net to a long line cable (50 to 150 ft [15 to 46 m]) equipped with a remote hook and tether. The pilot then flew to the treatment area with the loaded net hanging below the helicopter. When over the target treatment area, the pilot remotely unhooked three corners of the cargo net and let the mulch drop and spread over the area (fig. 6). The pilot returned to the staging area, the single tethered corner of the empty cargo net was released to drop the empty cargo net, and the process was repeated (fig. 6). To keep the aerial application running smoothly and minimize helicopter hover-time, three to four cargo nets may be used, which allows the ground crew to have at least one loaded net ready to go during most of the operation. At the Beal Mountain mine reclamation site, the aerial application of wood shreds with a Heli-Claw was used in addition to the standard process described above.

The first aerial application of wood shred mulch was on a 4.7 ac (1.9 ha) research catchment at the Cascade Complex site. The helicopter pilot found that the wood shreds dropped more quickly and with less spread than agricultural straw and made adjustments to flight height and speed to compensate for the greater density of the wood shreds. Pilots generally fly at 100 to 200 ft. (30 to 60 m) above mean tree height at 30 to 50 mph (26 to 44 knots) for aerial straw mulching. This was increased to 200 to 300 ft. (60 to 90 m) elevation and 70 to 90 mph (60 to 80 knots) for wood shreds. The wood shreds were applied at a rate of 4.6 tons ac^{-1} (10.3 metric tons ha^{-1}). Immediately after application, ground cover was assessed using 25 ground cover plots (five 160-ft [50-m] transects with five evenly spaced ground cover plots along each transect) within the research catchment. The adapted flight speed and altitude resulted in a relatively even spread of mulch in the research watershed (fig. 7). Immediately after application, the total average ground cover was 57 percent with wood shreds providing 37 percent of the cover and rock, charred woody debris, litter, etc. making up the remaining 20 percent.

At the Schultz Fire, the contract specified 6 tons ac^{-1} (13 metric tons ha^{-1}) of wood shred mulch to provide 50 percent cover on steep slopes (30 to 65 percent). The burned area had 15 to 50 percent rock fragment cover; thus, the combination of rock fragments and wood shred mulch was to provide

Figure 7. Wood shred mulch cover on a research catchment at the 2007 Cascade Complex Fire.

at least 60 percent coverage of the bare soil. The average cargo net load was about 1.25 tons (1.13 metric tons) and at 6 tons ac^{-1} (13 metric tons ha^{-1}) it took nearly five loads to treat each acre (0.4 ha). The single helicopter treated 25 to 35 ac (10 to 14 ha) per day. Cover plots and photos from the wood shred mulched areas measured 49 to 68 percent cover (fig. 8).

At the Beal Mountain mining site, a contract for site rehabilitation included the off-site production and delivery of 30 tons (27 metric tons) of wood shreds that were aerially applied by helicopter using both cargo nets and the Heli-Claw. After some trial and error, the pilot discerned that the Heli-Claw could pick up the largest loads when the wood shred pile was flat-topped rather than peaked, "fluffed up" (un-compacted), and the claw was set down partially closed on the pile, opened up to its maximum width, then closed as the helicopter slowly lifted. When the wood shred piles were too small for the claw to efficiently pick up the material, the helicopter was reconfigured for cargo nets and the remaining wood shreds (about 20 percent of the total) were applied. (A video of a flight test can be viewed at: http://fsweb.mtdc.wo.fs.fed.us/pubs/htmlpubs/htm12282311/.) The application rate was 4.2 tons ac^{-1} (9.4 metric tons ha^{-1}) for 50 percent coverage. The average wood shred load with the Heli-Claw was 0.34 tons (0.31 metric tons) and the pilot was able to distribute approximately 6 tons (5.4 metric tons) of wood shreds per hour. Although the Heli-Claw operation was efficiently supported by a smaller ground crew than generally needed for aerial mulch applications with cargo nets, the smaller loads resulted in more helicopter trips from the staging area to the treatment area. Given the high cost of helicopter time ($1000 to $1800 per hour), the greater helicopter expense of the Heli-Claw operation would potentially offset any cost advantage of a smaller ground crew.

Figure 8. Ground cover of wood shred mulch being measured on a steep slope at the 2010 Schultz Fire.

Helicopters with cargo nets were used to aerially apply both agricultural straw and wood shred mulches at the 2010 Fourmile Canyon, 2012 Waldo Canyon, and 2012 High Park Fires. At Fourmile Canyon, wood shreds and agricultural straw were mixed at the treatment staging area and the mixed mulch (4 t ac^{-1} [6 metric tons ha^{-1}] of wood shreds plus 0.5 t ac^{-1} [1.1 metric tons ha^{-1}] of agricultural straw) was applied in the spring of 2012 as a retreatment on areas previously mulched. Details of wood shred production and the mixed mulch application are provided in Appendix A. At Waldo Canyon, the wood shreds were applied at 6 tons ac^{-1} (13 metric tons ha^{-1}) and the agricultural straw at 1.5 t ac^{-1} (3.4 metric tons ha^{-1}); the contracted production and application of wood shreds are covered in detail in Appendix B. The same contractor and processes that were used at the 2012 Waldo Canyon Fire were subsequently used at the 2012 High Park Fire.

All of the aerial applications of wood shreds used "weight per acre" as a criterion for the operation or a contract specification. However, researchers (Foltz and Copeland 2007) and managers of the treatment installations have commented about the inadequacy of that approach. Since the weight of wood shreds is dependent on moisture content (and may also vary by type of tree, location, etc.), a designation of 6 tons ac^{-1} (13 metric tons ha^{-1}) may provide various amount of ground cover. There was general agreement that the contract specifications should delineate the amount of ground cover provided by the wood shreds as applied, but such contract specifications would require field personnel doing cover measurements to ensure contract compliance. It is more costly and time consuming to monitor ground cover than the weight of mulch applied per unit area—a specification that can be estimated from truck load weights or helicopter flight logs.

Comparison of Wood Shred and Straw Mulches

Both agricultural straw and wood shred mulch were aerially applied using helicopters and cargo nets at the Schultz, Waldo Canyon, and High Park Fires. This allowed for some comparisons of application processes, performance characteristics, and costs between the two mulch types. Given that the wood shreds were about four times denser than agricultural straw, it required three to five times as many round trips to treat a unit area with wood shreds as with straw. This factor made wood shred application take longer and cost more than straw application—\$1700 to \$2200 ac^{-1} (\$4200 to \$5500 ha^{-1}) for wood shreds compared to \$500 to \$700 ac^{-1} (\$1200 to 1700 ha^{-1}) for agricultural straw (table 2).

On the Schultz Fire, the decrease in ground cover provided by the straw mulch compared to wood shred mulch during the first year after treatment differed by slope steepness. On steep slopes (>35 percent), the straw mulch ground cover decreased from 60 to 20 percent (a 67 percent decrease). The greatest loss of agricultural straw was on south-facing slopes where wind was most intense due to the orographic position and the weather patterns associated with the mountain range. During the same period, the wood shred ground cover, which had been applied to very steep slopes (about 65 percent) only decreased 25 percent—it went from 68 to 52 percent. However, on moderately steep slopes (about 25 percent) the straw mulch decreased less than the wood shred mulch. One year after treatment, the average straw mulch ground cover on moderate slopes had decreased 19 percent (going from 70 to 57 percent) while the average wood shred mulch ground cover

Table 2. Cost comparisons for wood shred and agricultural straw mulching treatment. The application rates—6 tons ac^{-1} for wood shreds and 1 ton ac^{-1} for agricultural straw—were the same for the three fires, with the exception noted in the Shultz Fire comment section using US\$ and conventional units only.

Fire	Straw mulch (\$ ac^{-1})	Wood shreds mulch (\$ ac^{-1})	Comments
2010 Schultz	395-750	1700	The differences in cost for agricultural straw mulching were mostly dependent on the distance the straw had to be shipped; however, the highest cost (\$750 ac^{-1}) was for the mulching done with straw shipped the longest distance and applied at a higher rate (1.5 tons ac^{-1}).
2012 Waldo Canyon	548	2141	Direct contract costs
	679	2272	These amounts include the direct costs as well as the costs of contract preparation and administration.
2012 High Park	na	2136	The agricultural straw mulching has not been completed (work scheduled for Spring 2013) and final costs are not available.

decreased 31 percent (going from 49 to 34 percent) (USDA 2011). Field observers reported that in areas where the wood shred ground cover was <50 percent, overland flow displaced the thinly scattered wood shreds more easily than in areas with greater wood shred coverage (R. Steinke, personal communication, email to P. Robichaud 18 Sep 2012). Observations during research studies have described the tendency of mulches made up of wood strands or pine needles to interlock and pile up into "mini-dams" that slow overland flow rates and increase the lengths of flow paths (Foltz and Copeland 2008; Foltz and Dooley 2003; Pannkuk and Robichaud 2003). This may happen with wood shreds as well, and if so, there may be a threshold cover amount below which the wood shreds formed fewer interlocking "mini-dams" and were more easily displaced.

Conclusions and Management Implications

Laboratory and field studies have shown that wood shred mulch can be an effective post-fire hillslope treatment. Experience and information from six wood shred mulching operations were combined to develop this guide for the production, transport, and application of wood shred mulch as a hillslope stabilization treatment. Wood shreds have been successfully produced from burned and green trees and the same equipment and techniques that are used for aerial mulching of agricultural straw have worked, with some adjustments in flight altitude and speed, for wood shreds. At the Beal Mountain mine reclamation site, the Heli-Claw (an experimental replacement for the cargo net in aerial mulching) was successfully used to apply 80 percent of the aerial application of wood shred mulch.

The general function of any post-fire mulch treatment is to provide immediate ground cover on hillslopes where erosion mitigation is needed. A mulching rate of about 6 tons ac^{-1} (13 metric tons ha^{-1}) of wood shreds can provide the 60 percent ground cover needed to protect the soil; yet that application rate does not always ensure adequate cover for bare soil if the wood shreds are heavier than average (due to wood type, higher moisture content, etc.) or unevenly spread.

Starting points for wood shred production based on field trials

- Maximize the proportion of wood shreds in the 2- to 8-inch (50- to 200-mm) range.
- Green trees generally produce less fines than dry or burned trees.
- Including branches and needles will increase fines.
- Take time to "calibrate" tree/grinder system to minimize fines (particles <1 inch [25 mm]) prior to moving into operational mode.
- Use 4-inch (100-mm) screens in a horizontal grinder as a starting point for production of wood shreds.
- Increase the through-put rate of the grinder to decrease fines.
- Align the 4 to 5 ft (1.2 to1.5 m) tree trunk sections perpendicular to the direction of the feed; i.e., set the logs on the conveyor belt so that the logs approach the screens sideways (bark side), not endwise.
- Monitor wood shred production for compliance to standards/contract specifications.

Post-fire mulch applications, including wood shred mulch, should be monitored by uniformity of ground cover spread and the percent ground cover achieved as opposed to a weight-based application rate. Getting a relatively even spread of the mulch is mostly dependent on pilot skill and experience and somewhat on the characteristics of the mulch. Ground cover assessments need to be made at the start of the application process so that adjustments in flight altitude and speed can be made to attain the needed ground cover (fig. 9). In addition, if the contractor is going to be required to re-work areas where the ground cover does not meet the contract specifications, ground cover monitoring needs to occur throughout the application operation so deficient areas can be reworked before the contractor is finished and equipment has been moved off-site. In the future, monitoring ground cover amounts and uniformity may be done using remote sensing techniques that could provide more comprehensive examinations of mulched areas (Lewis and Robichaud 2011).

Figure 9. Ground cover assessment of aerially applied wood shred mulch at the 2012 Waldo Canyon Fire.

Starting points for wood shred application based on field trials

- Contract for an average ground cover amount (60 to 70 percent), rather than a weight per unit area.
- In steep areas, compute the treatment area using calculation applications that factor in slope angle to more accurately determine the amount of wood shreds needed for the desired coverage.
- Buy or produce 6 to 8 tons ac^{-1} (13 to 18 metric tons ha^{-1}) of wood shreds to get 60 to 70 percent ground cover.
- Wood shreds produced from green trees weigh more than wood shreds from dry and/or burned trees.
- Cover wood shreds piled at staging areas to keep dry.
- Make ground cover assessments early in the application operation process so that pilots can adjust speed and altitude to get the desired coverage. Recognize that this may need to be repeated when there are changes in the qualities of the wood shreds, wind, terrain, pilots, or equipment.
- Monitor ground cover throughout the application operation to identify low coverage areas that need to be reworked prior to the contractor leaving.

The development of post-fire wood shred mulching was motivated largely by its potential on-site availability, stability in windy conditions, and lack of unwanted seeds from off-site. Since wood shreds weigh about four times more than agricultural straw, application requires more round trips between the staging and treatment areas and takes longer when compared to straw. This generally makes the economics more favorable to agricultural straw mulch when choosing between the two types of mulch. At the Schultz Fire, wood shreds were significantly more stable than straw on the steeper slopes (above 35 percent) but the difference in mulch stability was not so obvious on moderate and low slopes. Consequently, there may be advantages to applying both mulches to optimize the time and expense of treating the burned area. Wood shreds may be prescribed for treatment areas where straw is unlikely to work well, such as steep slopes and open areas with high wind exposure. Straw may be preferred for other areas because it provides adequate protection at less cost.

Like all forest operations, we expect that these guidelines for producing and applying wood shreds will be refined and improved by experience. Safety practices that are in place for machine operation, hazard tree felling, heli-mulching, general aviation, etc., may need to be adjusted to accommodate new situations that arise from processing and handling burned tees. The information in this report reflects what we have learned from research and the initial treatment projects—it is a starting place for BAER treatment implementation teams, forest managers, and contractors. Input from practitioners will improve these guidelines to make the operations of producing and applying wood shreds more efficient and cost effective.

Acknowledgments

The portions of this project related to the production and application of wood shreds as a post-fire hillslope treatment were funded by the U.S. Department of the Interior and USDA Forest Service, Joint Fire Science Program, Project 07-1-1-01. Development of the Heli-Claw was jointly funded by the U.S. Department of Agriculture, Forest Service, Fire & Aviation Program and Engineering Program of the National Technology and Development Center. We are grateful for the generous sharing of information, observations, photographs, and lessons learned as well as manuscript review by:

Schultz Fire: Rory Steinke, Soil Scientist; Sean Untalan, Civil Engineer
Fourmile Canyon Fire: Claire DeLeo, Plant Ecologist
Waldo Canyon Fire: Mary Moore, Hydrologist
High Park Fire: Eric Schroder, Soil Scientist; Deborah Entwistle, Hydrologist

References

Arizona State Geologist Blog Site. 2011—June 19 post. Schultz Fire burn area mulching to reduce flooding, debris flows. Video. Online: http://arizonageology.blogspot.com/2011/06/schultz-fire-burn-area-mulching-to.html [Accessed on 29 May 2012].

Bautista, S.; Robichaud, P.R.; Bladé, C. 2009. Post-fire mulching. Chapter 13. In: Cerdà, A.; Robichaud, P.R., eds. Fire effects on soils and restoration strategies. Enfield, NH: Science Publishers: 353-372.

Beyers, J. 2004. Postfire seeding for erosion control: effectiveness and impacts on native plant communities. Conservation Biology. 18(4): 947-956.

Copeland, N.S.; Sharratt, B.S.; Wu, J.Q.; Foltz, R.B.; Dooley, J.H. 2009. A wood-strand material for wind erosion control: Effects on total sediment loss, PM_{10} vertical flux, and PM_{10} loss. Journal of Environmental Quality. 38: 139-148.

Fernández, C.; Vega, J.A.; Jiménez, E.; Fonturbel, T. 2011. Effectiveness of three post-fire treatments at reducing soil erosion in Galicia (NW Spain). International Journal of Wildland Fire. 20(1): 104-114.

Foltz, R.B. 2012. A comparison of three erosion control materials on decommissioned forest road corridors in the northern Rocky Mountains, USA. Journal of Soil and Water Conservation. 67(6): 536-544.

Foltz, R.B.; Dooley, J.H. 2003. Comparison of erosion reduction between wood strands and agricultural straw. Transactions of the ASAE. 46(5): 1389-1396.

Foltz, R.B.; Copeland, N.S. 2007. Field testing of wood-based biomass erosion control materials on obliterated roads. Paper No: 078046. Presented at: Annual International Meeting; 2007 June 17-20; Minneapolis, MN. St. Joseph, MI: American Society of Agricultural and Biological Engineers (ASABE).

Foltz, R.B.; Wagenbrenner, N.S. 2010. An evaluation of three wood shred blends for post-fire erosion control using indoor rain events on small plots. Catena. 80: 86-94. doi:10.1016/j.catena.2009.09.003.

Groenier, J.S.; Showers, C. 2004. Shredding small trees to create mulch for erosion control. Tech Tip 0471–2335–MTDC. Missoula, MT: U.S. Department of Agriculture, Forest Service, Missoula Technology and Development Center. 6 p. Online: http://www.fs.fed.us/t-d/pubs/pdfpubs/pdf04712335/pdf04712335dpi72.pdf [accessed on 22 May 2012].

Groenier, J.S. 2013. Field testing the heli-claw at Beal Mountain abandoned mine site. Tech Tip 1228-2311P-MTDC. Missoula, MT: U.S. Department of Agriculture, Forest Service, Missoula Technology and Development Center. 6 p. Online: http://fsweb.mtdc.wo.fs.fed.us/pubs/pdfpubs/pdf12282311/pdf12282311dpi100.pdf [accessed 10 May 2013].

Lewis, Sarah A.; Robichaud, Peter R. 2011. Using QuickBird imagery to detect cover and spread of post-fire straw mulch after the 2006 Tripod Fire, Washington, USA. Res. Note RMRS-RN-43. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 9 p.

Lynch, T. 2008. The heli-claw: a new way to transport mulch for erosion control. Tech Tip 0851–2323–MTDC. Missoula, MT: U.S. Department of Agriculture, Forest Service, Missoula Technology and Development Center. 6 p. Online: http://www.fs.fed.us/t-d/pubs/pdfpubs/pdf08512323/pdf08512323dpi72.pdf [accessed on 22 May 2012].

Napper, C. 2006. Burned area emergency response treatment catalog (BAERCAT). Tech. Rep. 0625 1801P-SDTDC. Washington, DC: U.S. Department of Agriculture, Forest Service, National Technology & Development Program, Watershed, Soil, Air Management. 204 p. Online://www.fs.fed.us/eng/pubs/pdf/BAERCAT/lo_res/06251801L.pdf [10 May 2013].

Pannkuk, C. D.; Robichaud, P. R. 2003. Effectiveness of needle cast at reducing erosion after forest fires. Water Resources Research. 39(12): 1333-1344.

Riechers, G.H.; Beyers, J.L.; Robichaud, P.R.; Jennings, K.; Kreutz, E.; Moll, J. 2008. Effects of three mulch treatments on initial postfire erosion in north-central Arizona. In: Narog, M., tech. coord. Proceedings of the 2002 fire conference: managing fire and fuels in the remaining wildlands and open spaces of the southwestern United States; 2002 December 2–5; San Diego, CA. Gen. Tech. Rep. PSW-GTR-189. Albany, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station: 107-113.

Robichaud, P.R., J.L. Beyers, and D.G. Neary. 2000. Evaluating the effectiveness of postfire rehabilitation treatments. Gen. Tech. Rep. RMRS-GTR-63. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 85 p.

Robichaud, P.R.; MacDonald, L.; Freeouf, J.; Neary, D.; Martin, D.; Ashmun, L. 2003. Postfire rehabilitation of the Hayman Fire. In: Graham, Russell T., tech. ed. 2003. Hayman Fire Case Study. Gen. Tech. Rep. RMRS-GTR-114. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 293-313.

Robichaud, Peter R.; Ashmun, Louise E.; Sims, Bruce D. 2010. Post-fire treatment effectiveness for hillslope stabilization. Gen. Tech. Rep. RMRS-GTR-240. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 62 p.

Robichaud, P.R.; Lewis, S.A.; Wagenbrenner, J.W.; Ashmun, L.E.; Brown, R.E. 2013a. Post-fire mulching for runoff and erosion mitigation: Part I: Effectiveness at reducing hillslope erosion rates. Catena. 105: 75-92.

Robichaud, P.R.; Wagenbrenner, J.W.; Lewis, S.A.; Ashmun, L.E.; Brown, R.E.; Wohlgemuth, P.M. 2013b. Post-fire mulching for runoff and erosion mitigation Part II: Effectiveness in reducing runoff and sediment yields from small catchments. Catena. 105: 93-111.

Robichaud, P.R.; Jordan, P.; Lewis, S.A.; Ashmun, L.E.; Covert, S.A.; Brown, R.E. 2013c. Evaluating the effectiveness of wood shred and agricultural straw mulches as a treatment to reduce post-wildfire hillslope erosion in southern British Columbia, Canada. Geomorphology http://dx.doi.org/10.1016/j.geomorph.2013.04.024.

Skeen, R.; Becker, R. 2007. Helimulching—equipment and techniques. Tech Tip 0757–1305–SDTDC. San Dimas, CA: U.S. Department of Agriculture, Forest Service, San Dimas Technology and Development Center. 6 p. Online:http://www.fs.fed.us/eng/pubs/pdf/07571305.pdf. [22 May 2012].

Steinke, R.; Haessig, P. 2012. BAER from a practitioner's viewpoint, treatment effectiveness and lessons learned (abstract). Presented at: Southwest Wildfire Hydrology and Hazard Workshop; 2012 April 3-5; Tucson, AZ. Tucson, AZ: University of Arizona.

U.S. Department of Agriculture (USDA). 2011. Schultz Fire Treatment Effectiveness Monitoring Report, 8 Sept 2011. Unpublished report on file at: U.S. Department of Agriculture, Forest Service, Coconino National Forest, Flagstaff, AZ. 12 p.

Appendix A: 2010 Fourmile Canyon Fire Case Study

Post-fire Hillslope Retreatment with Wood Shred Mulch on the Fourmile Canyon Fire

Jennifer Kesler, Plant Ecologist and Claire DeLeo, Senior Plant Ecologist
Boulder County Parks and Open Space

Only English standard units are used in the following case study.
The following conversions apply:

- 1 inch = 25.4 millimeters
- 1 acre = 0.405 hectare
- 1 ton ac^{-1} = 2.24 metric tons ha^{-1}

Introduction

The Fourmile Canyon Fire started on 6 September 2010 and burned approximately 6,200 acres just west of Boulder, Colorado, in one of the most densely populated urban interfaces in Boulder County. The burned area was aerial mulched in 2011 with certified weed-free straw on 1,620 acres at a rate of 1.3 tons ac^{-1} and WoodStraw® (manufactured wood mulch produced by Forest Concepts, LLC, Auburn, WA) on 350 acres at a rate of approximately 4.7 tons ac^{-1}.

In the fall of 2011, 364 acres were identified for retreatment based on limited recovery, high burn severity, and downstream values at-risk primarily to the Town of Salina. Problems with the mulch from the 2011 treatments included agricultural straw blowing off of treated areas and WoodStraw® moving in high intensity thunderstorm events. Of the 364 acres that were retreated in 2012, 145 acres had been treated with agricultural straw and 219 acres had been treated with WoodStraw® the previous year.

Wood shreds were chosen for this 2012 retreatment because, while the WoodStraw® treatment performed well overall, the cost was prohibitive. With many fuels reduction and forest restoration projects in Boulder County and along the Front Range, shredded wood is an abundant locally available resource. After speaking with R. Steinke about the first large contracted wood shred aerial mulching project done as a post-fire rehabilitation treatment (the wood shred mulching on the 2010 Schultz Fire) and with other contractors, we determined that wood shreds would be a viable wood mulch treatment at about half the cost of a comparable re-treatment with WoodStraw®. In addition, we decided to mix agricultural straw with the wood shreds because it reduced the amount of "heavy" wood material in the mulch (making it less costly to apply) and retained some of the advantages of agricultural straw. These advantages included the residual crop seed in the straw which, if it sprouted and grew, provides additional vegetative cover and the better soil moisture conservation with the straw mulch as compared to wood-based mulches. Thus, we decided to aerially mulch with a combination of agricultural straw and wood shreds for retreating burned areas in 2012.

Production of Wood Shreds

The wood shred specifications required the material be from pine, spruce, or fir trees. Urban tree removal was restricted because of possible contamination of seed from undesirable non-native tree species, particularly Russian olive trees (*Elaeagnus angustifolia*). The wood shred size specifications were for two dominant sizes with an even mix of small strands (2 to 3 inches in length) and large strands (up to 8 inches in length). The diameter of the strands could range from ⅛ to ¼ inch for shorter shreds and up to 1 inch for longer shreds. Finer materials (less than about 1 inch) were allowed, but at a much lower percentage compared to the two dominant sizes. Our wood shred contract specifications, unfortunately, did not give a specific percentage of fines allowed. The specifications required wood shreds that were free from dirt and rocks.

The wood shreds were produced from unmarketable trees from a U.S. Forest Service Stewardship Project in Allenspark, Colorado, (fig. A1) using a new Peterson horizontal grinder (fig. A2). Boulder County Parks and Open Space staff only inspected the wood shreds during the initial calibration of the horizontal grinder. Several combinations of screens from 2-inch combined with 4- and 6-inch screens were tested (fig. A3). We determined through trial and error that using 4-inch screens only produces the best wood shreds (fig. A4). The raw tree material did include some limbs with pine needles still attached.

Figure A1. Raw material for wood shred production from USFS Forest Stewardship Project.

Figure A2. Peterson horizontal grinder.

Figure A3. Wood shred product test.

Figure A4. Final approved wood shreds (C. DeLeo in photo).

Mixed agricultural straw and wood shred mulch

Our specifications for the aerial mulching required 60 percent cover on 20 to 60 percent slopes with a minimum of 0.5 tons of agricultural straw and 4 tons of wood shreds per acre, equating to 1 to 3 inch mulch depth on the ground. These proportions for the straw-wood shred mix were determined by using one-third the typical application rate of agricultural straw (0.5 ton ac^{-1} given the typical application of 1.5 ton ac^{-1}) and two-thirds the typical application rate of wood shreds (4 ton ac^{-1} given the typical application of 6 ton ac^{-1}). The resulting mix was calculated to be 4.5 ton ac^{-1}. The wood shreds and agricultural straw were mixed at the staging area before the mulch was loaded into the cargo nets (fig. A5).

Aerial Application of the Mixed Mulch

Two County inspectors were on the ground inside the treatment polygons during the mulching aerial operations. They examined the proportion of ground cover provided the mulch components (straw versus wood shreds), the depth of mulch, the evenness of the mulch spread, and any clumping of the mulch. There was minimal clumping of either mulch product. Despite consistent mixing of the agricultural straw and the wood shreds on the ground prior to loading the nets, we found that in most areas, the two mulch types separated while falling to the ground, with the straw always landing on the top (fig. A6).

The mulch application inspections included measuring the mulch component of the ground cover. The measurements were taken at 10 sampling points along 10 transects that were randomly located within the treatment polygons. The observer took samples 10 paces (approximating 30 feet) apart along the transect line. At each sampling point, the grid was placed on the surface of the ground and the grid intersections that overlaid mulch were counted (fig. A7). The counted intersection number was converted to a percentage and recorded. The percentages for the 10 samples were averaged for each transect and the 10 transects were then averaged for the treatment polygon. The Ingram Gulch treatment polygon had 69 percent mulch cover rate and the Melvina Gulch treatment polygon had 70 percent mulch cover. These mulch measurements did not include mulch that was applied in 2011. The proportion of cover that was agricultural straw versus wood shreds was not determined.

Figure A5. Wood shreds and agricultural straw mixed in staging area prior to loading into cargo net.

Figure A6. Applied mixed mulch.

Figure A7. Ground cover monitoring grid (Forest Concepts, LLC, Auburn, WA).

Table A1. The 2010 Fourmile Canyon Fire treatment costs for mulching with a combination of wood shreds (4 tons ac^{-1}) and agricultural straw (0.5 tons ac^{-1}).

Item	Cost per unit area (\$ ac^{-1})	Total cost (\$)
Certified weed-free straw, delivered	170	61,880
Wood shreds only, delivered	408	148,519
Mixed mulch application	996	362,459
Total for mixed wood shreds and agricultural straw mulch treatment	1,574	572,858

Project Costs

The cost per acre of the mixed mulch we applied will likely be less than the costs of mulching with wood shreds only because the agricultural straw portion of the mulch is less costly than wood shreds (table A1).

Lessons Learned

- The weight of wood shreds varied because of moisture content. Green trees had a higher wood shred weight than burned and/or dead trees. Also, the wood shreds dried out between the time they were shredded and when they were flown. Therefore, an application rate based on tons per acre needs to take into account moisture content if this is used as a contract specification.
- If you must base the wood shreds on tons per acre, each truck-load should be weighed and percent moisture content estimated. Moisture content must be part of the contract specifications if an application rate of tons per acre is used. However, it may not be practical or cost-effective to weigh each truck delivering wood shreds.
- The treatment should not be based on the weight of the mulch; rather it should be based on the percent cover desired. While our contract had specifications for both percent cover and weight per acre, we concentrated too much on weight or tons per acre. As a result, some areas did not get treated near the bottoms of the watersheds.
- Use 3-D slope calculations in GIS to estimate hillslope acreage to get an accurate estimation of surface area, especially in areas with steep slopes.
- Do not mix straw and wood shreds as a mulch treatment. No matter how well they are mixed, the lighter weight straw will drop more slowly than the wood shreds and will always end up on the top. If using the two mulches together, lay down agricultural straw first, then overlay with wood shreds to hold the straw down and prevent it from blowing away. However, the flying costs for two separate mulch applications would likely be cost prohibitive, in which case, only wood shreds should be used.
- The quality of the wood shreds was not consistent because of the inclusion of a high percentage of smaller-than-desired shreds and pine needles. We did not specify a percent of fines as part of our contract specifications, nor did we have a way to measure the percent fines. However, the Waldo Canyon Fire BAER Implementation Team devised a good way to measure fines in the field for contract enforcement (see Appendix B).
- If using a percent cover as a contract specification for wood shred application (recommended), an adequate number of inspectors are needed on the ground to make ground cover assessments during the aerial application.
- The even spread of wood shreds varied by helicopter operator.

Appendix B: 2012 Waldo Canyon Fire Case Study

Post-fire Wood Shred Mulching After the 2012 Waldo Canyon Fire in Colorado

Mary Moore, Hydrologist, Lake Tahoe Basin Management Unit, South Lake Tahoe, California; BAER Implementation Team Leader on the 2012 Waldo Canyon Fire

Only English standard units are used in the following case study.

The following conversions apply:

- 1 inch = 25.4 millimeters
- 1 square foot (ft^2) = 0.0929 square meter (m^2)
- 1 acre = 0.405 hectare
- 1 ton ac^{-1} = 2.24 metric tons (Mg) ha^{-1}

Introduction

The 2012 Waldo Canyon Fire occurred on the Pike and San Isabel National Forest and Comanche and Cimarron National Grasslands near Colorado Springs and Manitou Springs, Colorado. A contractor produced and distributed nearly 11,750 tons of wood shred mulch on 1,958 acres in 49 units of steep mountainous landscape (20 to 60 percent slopes) burned at moderate and high burn severity.

The BAER Implementation Team designed a program to provide quality control and ensure that contract specifications were met in all aspects of the project. We developed methods to measure the quality of the wood shreds being produced and to measure the cover provided by the aerial application. We had up to 12 Inspectors and two Level III Contracting Officer Representatives on site for most of the project. We had foresters and forestry technicians as inspectors for the production of wood shreds (at the felling operations, site sources, and landings) and we had inspectors for the aerial mulch application. Additionally, we had an agricultural inspector examine and certify the agricultural straw that arrived onsite each day. We also had several other support staff, such as an archeologist and botanist, clearing the hazard tree removal units, landings, staging areas, etc., to ensure that natural and cultural resources were recognized and protected before project implementation.

Production of Wood Shreds

Prior to contract preparation, we determined the amount of material available for shredding and if site conditions were conducive to roadside hazard tree removal. The Timber Management Officer (TMO) was brought into the project to determine the available wood material (estimated in tons per acre) as hazard trees within the burned area and in close proximity to the burned area. Additionally, the BAER Implementation Team contacted several local timber contractors to determine the amount of available material in their "stock yards." As a result, before advertising the contract, we knew there was enough material in local area to mulch the designated treatment area, but hazard trees from the burned area only would provide about a third of the needed trees for the project. We clearly indicated in the solicitation that the contractor would have to find off-site material (that met FS approval before it was brought into the project area) to complete the project. Additionally, we indicated in the contract language that a Stewardship Contract Area *may be* available to the contractor awarded the mulching contract, but the contract would be separately negotiated with the local forest. The Roadside Hazard Tree removal units and the Stewardship Contract Area were depicted on the contract maps submitted with the request for solicitation.

The contractor obtained the needed trees to produce the wood shreds from four sites:

1. Burnt roadside hazard trees on <30 percent slopes

Hazard trees were identified as burnt trees that were within one-and-half tree lengths of the road or any other target (such as dispersed camp sites, roads, etc.) or dead or dying (>30 percent of the canopy was burnt) such that they would create long term hazards for the forest. A Forester determined the designation of questionable trees. Individual trees were not marked; we cut in areas based on a designated prescription. Hazard trees were cut using hand fellers and mechanized equipment (table B1). A grapple skidder forwarded the trees to landings or large piles. A horizontal grinder was later moved to each landing to shred the trees. Some of the material was flown directly from designated landings. The remainder of the wood shreds were loaded into chip "trucks/vans" and hauled to treatment staging areas or other landings (table B2).

2. Green trees from a Stewardship Contract Area partially in the burn

The Stewardship Contract Area was laid out and marked, but not awarded, prior to the fire. Using the same harvesting procedure described above, the material was

Table B1. Harvest of trees for wood shreds production on the 2012 Waldo Canyon Fire. The mechanized harvest was done with two feller-bunchers.

Production type	Workers (#)	Time (days)	Area (ac)	Area per unit time (ac day^{-1})	Wood mass per unit area (t ac^{-1})	Wood shreds (t)
Hand felling	4	8	36	4.5	45	1620
Mechanized harvest	2	10	39	3.9	45	1755

Table B2. The contractor's equipment from the 2012 Waldo Canyon Fire included the following items for producing wood shreds.

Equipment type	Quantity
horizontal grinder	2
bobcat	2
8′ bucket for bobcat	2
excavator	5
dozer	3
fuel truck	1
skid steer	2
grapple skidder	3
road grader	1

processed at the cutting area and hauled in chip trucks to treatment staging areas and landings in the burn.

3. Green trees from a fuel break construction (Mount Herman deck)

Trees had been removed and piled during the construction of a fuel break during the fire. After the fire, the log deck was sold to the contractor. This was a win-win for the forest since the stacked timber was a fuel problem (liability) and the sale to the post-fire treatment contractor resulted in remuneration and removal of the fuel problem. A horizontal grinder was brought to the deck and processed the material into wood shreds, which were then loaded into chip trucks/vans and hauled to the various landings.

4. Off-forest green wood from a local vendor's stock yard

Due to haul-weight requirements (ratio of dead wood to green wood being hauled), the vendor (subcontractor) processed the green trees purchased from their stock yard. This material was processed using a horizontal grinder at the yard, dumped into chip trucks, and hauled to the treatment staging area. We inspected several pick-up bed loads of these off-forest wood shreds before we gave the contractor approval to use this source.

Contract specifications for wood shreds

Based on limited wood shred research data and trial studies, we knew that the wood shreds produced by the contractor should meet size specifications and that the amount of "fines" (small wood shreds—not specifically defined in the contract) should be restricted. The contract specifications for the wood shreds are listed below. Changes we would make in the next wood shred mulching project are listed in italic text.

a) Wood shreds shall meet the following specifications. Product may be rejected if these specifications are not upheld. At least 70 percent of the shreds shall meet these specifications with 30 percent or less being fines. *If I had to do it again I would quantify the 30 percent of fines to accept 15 percent as a size-equivalent to the local needle cast and 15 percent of "dusty" fines (≤0.5 inch).*

b) The wood shreds should be processed in a manner that promotes even distribution when aerially released from cargo nets or similar equipment to at least a 70 percent cover within the treatment unit and to a depth of at least 0.5 inches. *Would ask for 85 percent coverage next time rather than just 70 percent and depth up to 0.5 inch; in other words, emphasize the coverage and depth over the weight of wood shreds per acre.*

c) Wood shreds shall have a stubble length of 4 to 8 inches, less than 1 inch diameter, and minimal fines. *After seeing the product produced and applied to the hill slopes, we decided to accept material that measured 2 to 4 inches in length as this size was equivalent to the local needle cast.*

d) It is recommended that a horizontal grinder be used on trees and a tub grinder be used for the resulting slash. Grinder screens of 2 to 4 inches will be used to meet the desired specifications.

e) Wood shreds shall be covered during transportation and when staged to prevent material from blowing around on site.

To enforce these contract specifications, each source site, landing, and large collection area of wood shreds material was inspected using a random sampling method. To evaluate the quality of the wood shreds, we constructed a 2-ft^2 frame with a 1-inch edge and a solid bottom panel (white) divided into four 1-ft^2 quadrants. A 0.5-inch mesh screen fit over the frame and the wood shred sample was poured onto the screen. Through trial and error we determined the volume of wood shred material the sample frame and screen could support and marked 5-gal sample buckets with a fill line that indicated the sample volume needed—approximately $^1/_2$ to $^2/_3$ of a bucket. The screen allowed fine wood shreds to pass through while the remainder of the wood shred sample stayed on the screen. The fines and large pieces (>8 inches) were pushed into the upper right quadrant of the frame. All the remaining sample wood shreds were placed in the remaining frame space. Using a visual examination of the area occupied by the wood shreds in each size category, the percentage of fines in the sample was estimated. (A video that shows the sample frame, screen, and sampling process is available at: http://www.youtube.com/watch?v=n2pqAxBaCTc&list=UU7oCsexW1Y_ibLkzkc6QRDQ.)

A photo of each sample laid out in the frame was used to document the inspector's evaluation of the wood shred compliance with contract specifications (fig. B1). Depending on the distance between inspection sites, 40 to 50 samples per day were processed and documented by each inspector.

a)

b)

Figure B1. Two wood shred samples that passed inspection for BAER treatment implementation at the 2012 Waldo Canyon Fire. Both samples had been screened and are shown distributed in the quadrants of the sample frame. Note that sample b) contains green needles and is generally more finely shredded as compared to a).

Aerial Application of Wood Shreds

The contract specified:

a) Wood shreds were to be applied at 6 tons ac^{-1} to provide 70 percent coverage and a depth of 0.5 inch (table B3). *Next time we would ask for 85 percent coverage and up to 0.5 inches in depth. We easily got 100 percent coverage in the interior of the units and areas of lighter coverage only were observed at the edges of the units. This was likely due to edge effect or missed areas.*

b) Agricultural straw was to be applied to provide 85 percent coverage at 1 inch depth.

c) All designated treatment units will meet the coverage specifications delineated above.

Note that the contractor is paid in full for meeting 90 percent of the contract specification. Given that 90 percent of 70 percent coverage is 63 percent, under this contract full payment could be received for wood shred treatment units that averaged 63 percent coverage. This is why we would increase the contract specifications for percent coverage of wood shreds in the next contract—we are confident that we can ask and get greater than 63 percent wood shreds treatment coverage. The straw mulch coverage was similar. Ninety percent of 85 percent straw mulch coverage is 77 percent and, based on these contract specifications, distribution of straw mulch that averaged 77 percent coverage would receive full payment.

The wood shreds (and the agricultural straw) were distributed by up to five helicopters equipped with cargo nets over several mapped treatment areas (fig. B2). On-the-ground inspectors worked in two-person teams and assessed contract compliance for the aerial mulching. Treated units that were smaller than 40 acres were sampled at 10 points along a directional (as determined by a compass bearing) transect line and units that were larger than 40 acres were sampled at a minimum

Table B3. Final coverage (in percent) of the 49 units treated with wood shreds on the 2012 Waldo Canyon Fire. Some of these units may have been re-worked to achieve contract completion.

Unit (#)	Coverage (%)	Unit (#)	Coverage (%)	Unit (#)	Coverage (%)
W10	71	W38	80	W59	88
W11	92	W39	81	W60	73
W12	90	W40	87	W61	79
W14	63	W41	63	W62	68
W15	92	W43	73	W63	75
W22	71	W44	65	W64	78
W23	63	W46	77	W65	38
W24	67	W47	66	W66	75
W25	75	W50	84	W67	80
W26	69	W51	63	W68	90
W27	73	W52	77	W69	81
W28	72	W53	81	W72	83
W29	74	W54	79	W74	74
W30	67	W55	63	W75	63
W32	70	W57	82	W8	65
W36	81	W58	75	W9	73
W37	88				

Average coverage = 75%

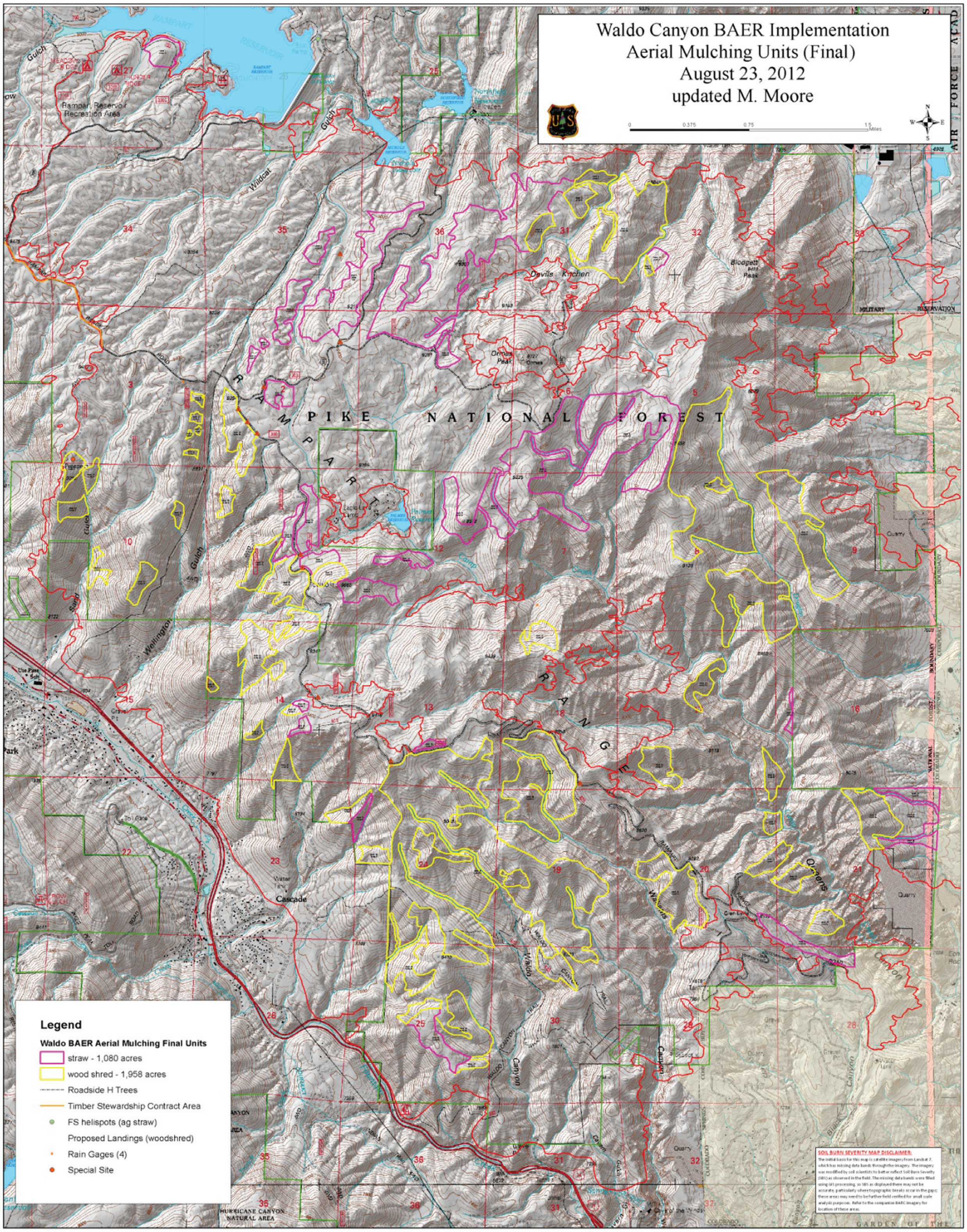

Figure B2. The 2012 Waldo Canyon Fire BAER aerial treatment map. Wood shreds and agricultural straw treatment units are designated by color-coded perimeters.

of 10 random points. Some of the bigger units were sampled at 20 or 30 points depending on access and entry points available.

A WoodStraw® grid (Forest Concepts, LLC, Auburn, WA) (fig. B3) was used to measure the ground coverage at each sampling point. Each intersection of the grid was counted if a ground cover component (mulch treatment, live vegetation, or needle cast) was visible beneath the plastic sheet at that point. The total count of covered intersections was converted to a percentage using the table printed on the grid. All sample points were photo-documented and labeled by GPS-determined coordinates (fig. B4). Units that did not pass were re-worked by the contractor (table B4). Experienced inspectors occasionally used a visual inspection from vantage point when circumstances precluded direct measurement. Inspectors designated ten "random points" across the unit and predicted the percent coverage from the vantage point. Photo documentation of the selected random points occurred to the best of the inspectors' abilities. Some re-worked areas were visually inspected.

Figure B3. The WoodStraw® grid (Forest Concepts, LLC) being used to sample ground cover for contract compliance during treatment implementation at 2012 Waldo Canyon Fire.

Figure B4. Photo documentation of wood shred cover at a sampling point in the field at the 2012 Waldo Canyon Fire.

Table B4. A sample Application Summary Report from the contractor for the 2012 Waldo Canyon BAER implementation project. The contractor provided this information daily as part of the required contract documentation.

SUMMARY REPORT OF WOOD SHRED APPLICATION[a]

Unit no.	Unit area (ac)	Treated area (ac)	Exempt area (ac)	Touch-up USDA (ac)	Flight time (h)	Wood shreds applied (@ 6 t ac^{-1})
8	13.4	13.4			3.0	80.4
9	10.2	10.2			3.2	61.2
10	16.4	16.4			2.8	98.4
11	246.8	246.8			33.0	1481.1
12	3.4	3.4			0.9	20.4
14	200.3	186.3	14.0		60.5	1201.9
15	96.6	84.8	11.8		20.3	579.7
22	18.0	14.5	3.5		3.8	108.0
23	69.5	69.5			19.6	417.0
24	19.5	17.0	2.5		5.5	117.2
25	26.6	26.6			8.1	159.7
26	15.0	14.6	0.4		4.0	89.7
27	10.0	10.0			3.5	60.0
28	17.1	17.1			6.1	102.6
29	16.5	16.5			5.8	99.0
30	17.8	17.8			5.0	106.6
32	45.5	45.5			10.9	273.0
36	65.5	58.5	7.0		20.7	393.3
37	60.6	60.6			15.3	363.5
38	64.9	62.9	2.0		14.1	389.4
39	492.9	492.9			105.8	2957.1
40	40.8	40.8			10.3	244.8
41	13.2	13.2			3.3	79.2
43	6.2	6.2			1.8	37.2
44	48.7	48.7			13.7	291.9
46	13.1	13.1			3.0	78.5
47	16.7	16.7			3.7	100.2
50	4.5	4.5			1.0	27.0
51	4.3	4.3			0.9	25.9
52	4.4	3.6		0.8	1.0	26.2
53	44.4	44.4			8.8	266.3
54	20.5	15.5	5.0		1.9	122.9
55	46.4	44.5		1.9	5.2	278.2
57	25.5	24.5	1.0		2.7	153.0
58	9.9	9.5		0.4	1.9	59.2
59	45.2	45.2			6.6	271.2
60	3.1	3.1			0.7	18.7
61	2.5	1.9		0.6	0.2	14.8
62	2.1	2.1			0.3	12.4
63	1.1	1.1			0.3	6.8
64	4.4	3.3		1.1	0.7	26.3
65	5.4	5.4			2.3	32.5
66	14.5	14.5			2.6	87.0
67	12.8	12.8			4.2	76.6
68	12.9	8.7	4.0	0.2	2.4	77.3
69	13.3	5.2	7.4	0.8	1.9	79.9
72	17.9	14.9	3.0		3.1	107.3
74	8.4	4.2	4.2		1.0	50.6
75	37.7	37.7			5.9	226.4
Total	**2006.2**	**1934.7**	**65.7**	**5.8**	**442.9**	**12037.4**

[a] This table has been adapted from the original submitted by the contractor. Some repetitive columns have been removed and column headings were revised to be more self-explanatory.

Documentation and document tracking

Each evening, inspectors filed reports that delineated the units that passed inspection and the units that needed to be reworked because of a failed inspection (table B3). All GPS units were downloaded to a master shapefile (map component files in GIS) and electronic copies of all photo-documentation were filed by unit number. Hard copies of photographs, maps, and the attribute tables for the shapefiles were filed by date in the Unit Inspection Log folder. All original data sheets were organized by date and kept in a separate log folder.

Reporting required from the contractor

The contractor was required to file written reports of the work done each day. These reports included general information about the day and the progress on the contract from their perspective (table B4). Project maps indicating the locations and extent of work done were also required at the end of each day. A full written report was required upon completion of the contract.

Monitoring

Ten percent of the mulched acres may be monitored for treatment effectiveness for the next 3 years. To facilitate future monitoring, the BAER Implementation Team identified several contract inspection plots that are easily accessed from existing roads or unit access points as potential monitoring points.

Costs

Post-fire mulching with wood shreds is not inexpensive. Based on the data in the Waldo Canyon 2500-8 Interim #1, we estimate the following cost factors for the aerial mulching project: 3,038 acres were treated—1,958 acres of wood shred treatment and 1,080 acres of agricultural straw treatment. The contract cost was $4,783,918 ($2,141 per acre for wood shred mulching and $548 per acre for agricultural straw mulching). A field team (post-assessment team) that inspected the treatment areas and confirmed the area estimates and determined the size and scope of the treatment implementation was used as part of the contract preparation and cost approximately $50,000. The contract administration team cost was $348,000 for a total of $398,000. Thus the total cost (contract plus overhead) for wood shred treatment was $2272 per acre and for agricultural straw treatment was $679, which brought the total project cost to $5,181,896.

Acknowledgments

This case study used the comments, charts, images, etc. from the combined effort of the entire Waldo Canyon BAER Implementation Team. The success of the entire operation, and of the wood shred mulching in particular, reflects their knowledge, skill, and hard work.

Waldo Canyon BAER Implementation Team

R2/ Pikes Peak Ranger District: Adam LaSalle, Alex Doud, Dan Kleist, Leah Lessard, Lisa Gowe, Rachael Blair, Rob Hoey, Ryan Kolling

R5/Lake Tahoe Management Unit: Mary Moore, George Gusses, Jen Bridgewater, Travis Buckalew, Nadia Aslami, Brian Hansen, Matt Panks

R5/Modoc National Forest: Cathy Carlock

R5/San Bernardino National Forest: Angelica Mendoza

Inquiries related to this Waldo Canyon Case Study should be directed to Mary Moore (marymoore@fs.fed.us)

You may order additional copies of this publication by sending your mailing information in label form through one of the following media. Please specify the publication title and series number.

Publishing Services

Telephone	(970) 498-1392
FAX	(970) 498-1122
E-mail	rschneider@fs.fed.us
Website	http://www.fs.fed.us/rm/publications
Mailing address	Publications Distribution Rocky Mountain Research Station 240 West Prospect Road Fort Collins, CO 80526

Rocky Mountain Research Station

The Rocky Mountain Research Station develops scientific information and technology to improve management, protection, and use of the forests and rangelands. Research is designed to meet the needs of the National Forest managers, Federal and State agencies, public and private organizations, academic institutions, industry, and individuals. Studies accelerate solutions to problems involving ecosystems, range, forests, water, recreation, fire, resource inventory, land reclamation, community sustainability, forest engineering technology, multiple use economics, wildlife and fish habitat, and forest insects and diseases. Studies are conducted cooperatively, and applications may be found worldwide. For more information, please visit the RMRS web site at: www.fs.fed.us/rmrs.

Station Headquarters

Rocky Mountain Research Station
240 W Prospect Road
Fort Collins, CO 80526
(970) 498-1100

Research Locations

Flagstaff, Arizona
Fort Collins, Colorado
Boise, Idaho
Moscow, Idaho
Bozeman, Montana
Missoula, Montana
Reno, Nevada
Albuquerque, New Mexico
Rapid City, South Dakota
Logan, Utah
Ogden, Utah
Provo, Utah

To learn more about RMRS publications or search our online titles:

www.fs.fed.us/rm/publications

www.treesearch.fs.fed.us