2012

Evaluating the Effectiveness of Wood Shreds on Post-fire Erosion

Peter R. Robichaud
USDA Forest Service

Randy B. Foltz
USDA Forest Service

Charles G. Showers
USDA Forest Service

James S. Groenier
USDA Forest Service

Rory Sternke
USDA Forest Service

See next page for additional authors

Robichaud, Peter R.; Foltz, Randy B.; Showers, Charles G.; Groenier, James S.; Sternke, Rory; Ashmun, Louise E.; Brown, Robert E.; and Jordan, Peter, "Evaluating the Effectiveness of Wood Shreds on Post-fire Erosion" (2012). *JFSP Research Project Reports*. 68.
http://digitalcommons.unl.edu/jfspresearch/68

Authors

Peter R. Robichaud, Randy B. Foltz, Charles G. Showers, James S. Groenier, Rory Sternke, Louise E. Ashmun, Robert E. Brown, and Peter Jordan

Evaluating the Effectiveness of Wood Shreds on Post-fire Erosion

(Project ID: 07-1-1-01) Final Report

31 May 2012

Principal Investigator: Peter R. Robichaud[a]

Co-Principal Investigators: Randy B. Foltz[a], Charles G. Showers[b]

Federal Cooperator: Peter R. Robichaud[a]

Additional Federal Collaborators: James S. Groenier[b], Rory Sternke[c]

Additional Co-Authors: Louise E. Ashmun[a], Robert E. Brown[a], Peter Jordan[d]

Affiliations: [a]USDA Forest Service, Rocky Mountain Research Station, Moscow, ID; [b]USDA Forest Service, Missoula Technology and Development Center, Missoula, MT; [c]USDA Forest Service, Coconino National Forest, Flagstaff, AZ; [d]British Columbia Ministry of Forests, Research Branch, Nelson, BC, Canada.

I. **Abstract**

Agricultural straw mulching is a commonly used post-fire hillslope erosion control treatment that is aerially applied by helicopter. While widely used and reasonably effective at reducing erosion, agricultural straw is not native to the forest environment. There is a growing consensus among Burned Area Emergency Response (BAER) teams that mulch made from native forest material would be preferable to agricultural straw. Wood shred mulch made from post-fire road hazard trees is an alternative to agricultural straw. An optimized blend of sizes of wood shreds was effective in reducing sediment yields in both indoor rainfall simulation and outdoor field experiments. Several post-wildfire field experiments showed that wood shreds and agricultural straw were effective in reducing sediment yields as compared to the controls but neither treatment had an effect on runoff. Erosion reductions from wood shred treatments ranged from 50-96% in these experiments, and the presence and effectiveness of wood shreds appears to outlast both agricultural straw and hydromulch.

Wood shreds are denser than agricultural straw and, as a consequence, about 4 times more wood shreds (by weight) than straw are needed to provide the same ground cover in a designated area. As a result, a helicopter with cargo nets required about four to five times as many round trips to treat an acre with wood shreds as with agricultural straw. This made wood shred application take longer and cost more than agricultural straw ($1,500 to $2,000 per acre [$3,750 to $5,000 per ha] and $500 per acre [$1,250 per ha], respectively). Field tests using a Heli-Claw, an alternative to a cargo net for heli-mulching, suggest that the Heli-Claw is a viable option for the aerial application of wood shreds.

Results from these studies were disseminated through publications and a wide range of presentations, such as webinars, national meetings, and regional specialists meetings; thus, research findings have been directly conveyed to BAER teams and land managers.

[Note: Throughout this report customary (English) units are stated first and metric equivalents are parenthetical where appropriate. The use of the symbol “t” is for ton (2000 lbs) in the customary system and the symbol “t” is for tonne (1000 kg [~2200 lbs]) in the metric system.]

II. Background and Purpose

Since 2000, Burned Area Emergency Response (BAER) teams have increasingly recommended post-fire mulch treatments to stabilize burned hillslopes and protect values at risk. In 2007, when this project began, it was known that application of agricultural straw mulch on a burned hillslope provided immediate ground cover, protect the soil from raindrop impact, and thereby reduce post-fire runoff and erosion (Bautista et al., 1996; Napper, 2006; Robichaud et al., 2000; Wagenbrenner et al., 2006). The aerial application of straw mulch made it possible to treat remote hillslopes that lacked road access, which increased the use of straw mulch as post-fire hillslope treatment. In the 5 years during which this study has been in progress, new studies have confirmed that agricultural straw mulch is highly effective in reducing post-fire hillslope erosion and sometimes effective in reducing runoff (Bautista et al., 2009; Robichaud et al., 2010; Robichaud et al. in review). These studies also provided insights as to the longevity of straw mulch and the conditions that can compromise its effectiveness.

After straw mulch had been used on a few large fires, issues related to its use in the forest environment became apparent. Agricultural straw mulches may contain non-native seed species that can persist and compete with the re-establishment of native vegetation (Beyers, 2004; Kruse et al., 2004). In addition, straw mulch was easily dislocated by wind making it unsuitable for ridge lines and other exposed areas (Copeland et al., 2009). Because of these concerns, other mulch materials, such as hydromulch, forest floor debris, and a variety of woody materials, continue to be developed and used experimentally.

Wood strands were developed as one such bioengineered material. Yanosek et al. (2006) measured erosion on plots covered with wood strands at various slopes, soil textures and cover amounts using indoor rainfall simulations, and found that wood strands were more effective than agricultural straw, particularly for finer grained sandy loam soil. However, wood strands must be purchased and shipped from their point of manufacture, which makes them an expensive alternative to agricultural straw (Foltz and Dooley, 2003).

Managers were interested in using on-site trees (e.g., logging slash, and in the case of post-fire, burned hazard trees) to produce mulch for hillslope erosion control. To meet this need, the USDA-Forest Service, Missoula Technology & Development Center (MTDC) developed wood shred mulch that could be produced from small diameter trees that were ground on-site. The wood shred mulch had the potential to reduce erosion from road construction, road removal, and site restoration (Groenier and Shower, 2004). Small adjustments in the grinder allowed for larger burned trees to be shredded into a similar wood shred product for use as a post-fire hillslope erosion mitigation treatment.

The limited wood shred mulch tests (rainfall simulations on unburned soil and road obliteration plots [Groenier et al., 2005; Foltz and Copeland, 2007]) were completed before this project began and indicated that wood shreds were an effective erosion control material. However, these preliminary tests of wood shred mulch had raised the questions that evolved into this proposal. The test batches of wood shreds were composed of 20% by weight of small pieces (less than 1in [25 mm]), and we speculated that these fine pieces would likely be washed or blown away if applied in a post-fire environment. The first objective, prior to any field experiment, was to determine the specifications of the “best” size range of wood shred pieces. Second, limited testing had indicated that wood shreds could be effective in post-fire erosion control, but this needed to be tested as BAER treated hillslopes are typically steeper and have longer flow paths than those in the road obliteration project plots (Foltz, personal communication 2006). Third, in the tests, wood shred mulch had been spread by hand. We knew if wood shreds were to be used as a post-fire hillslope treatment, a viable procedure for the aerial application of the wood shred mulch needed to be developed and tested.

Project objectives:

The overall goal was to evaluate the effects, effectiveness, production protocols, and costs of using wood shred mulch as a post-fire hillslope treatment. Specifically,

1. Determine the optimum wood shreds specifications (dimensions and coverage) for reducing erosion and runoff;
2. Compare the effects of wood shreds on post-fire rill erosion and runoff to those of agricultural straw and the no-treatment alternative;
3. Compare the effects of wood shreds to agricultural straw and no treatment on post-fire hillslope erosion measured at the hillslope scale under natural rainfall;
4. Develop a technical guide for the on-site manufacture and post-fire aerial application of wood shreds.

A combination of indoor rainfall simulations and *in-situ* field experiments were used to determine the optimum specifications for wood shred mulch (piece sizes and cover amounts) and to determine wood shred effectiveness in reducing post-fire hillslope erosion. We worked with MTDC to develop wood shred production and application protocols and with the British Columbia (BC) Ministry of Forests in determining treatment effectiveness.

We received two 1-yr no-cost extensions (May 2010 and May 2011). The additional deliverables were: 1) collect additional field data from the Terrace Mountain Fire, BC in 2010 and 2011; 2) add results from rainfall simulation plots conducted by the BC Ministry of Forests in 2009 and 2010; 3) determine the logistics and economics involved in the on-site production and application woods shreds doing a pilot application project in the summer of 2011 on the Schultz Fire and Beale Mountain mine reclamation sites; and 4) present findings at additional BAER team trainings and workshops.

III. Study Description and Locations

Study sites

Indoor rainfall simulation — All indoor rainfall simulations were conducted at the Rocky Mountain Research Station in Moscow, ID using a Purdue-type rainfall simulator, plot frames, and a flow distributor. Burned fine grained soil was collected from the 2006 Tripod Fire, Okanogan-Wenatchee National Forest, WA from areas of high soil burn severity to represent a typical post-fire soil found in western forests. Laboratory rainfall simulations were conducted in summer/fall 2007 prior to conducting field experiments.

Field Sites

Field experiments were conducted at wildfire sites that would be typical of where postfire erosion control treatments would be applied. The selection and installation of all experimental plots was done in cooperation with BAER; and at the Canadian site, a Risk Analysis team (Canadian counterpart to a BAER team), as well as local land managers. Additionally, an informal cooperative agreement was established between the BC Forest Service and this project for the work at the Terrace Mountain Fire field site.

Other specific site selection criteria included: adequate access for the personnel and equipment needed to install, monitor, and maintain the sites; and relatively uniform hillslopes (i.e., generally matched in steepness aspect, soils, etc.) in close proximity to one another. The matched sets of hillslopes were identified with the help of local land managers, and the areas selected for each treatment were assigned as randomly as possible. Treatments (wood shred and agricultural straw mulches) were applied to study plots at each site in the same manner (either by hand or by helicopter) except at the Gap Fire where hydromulch was aerially-applied and the wood shreds hand-applied. Whenever possible, treatments on research plots were representative of “typical” BAER mulching operations.

Cascade Fire — The 2007 Cascade Fire, Payette National Forest in central Idaho was selected because this fire had large areas of high soil severity and site characteristics that indicated a high potential for runoff and erosion. The Cascade Fire burned 302,400 ac (120,960 ha) with 77% burned at high or moderate soil burn severity. The fire occurred on the upper South Fork of the Salmon River in a mixed conifer forest that has a history of catastrophic erosion events from past fires and management activities. For example, the 1961 Poverty Flat Fire was followed by intense storm events that resulted in 100,000 yd^3 (76,500 m^3) of sediment being delivered to stream channels. This resulted in significant damage to many important fish spawning and rearing areas. With this history in mind, we installed three matched watersheds (approx. 4 ac [2 ha] each) at this site to compare the effectiveness of wood shreds, agricultural straw and control-no treatment.

Gap Fire — In July 2008 an accidental fire start during a period of high winds triggered a wildfire in the Santa Ynez Mountains, in Santa Barbara County, California. The Gap Fire burned 9,500 acres (3800 ha) on the Los Padres National Forest in Southern California. The burned area was underlain by sedimentary rocks that produce an erosive fine-grained soil. The area was covered with heavy mixed chaparral vegetation with some oaks prior to the fire. This site was used to compare erosion rates from hillslope plots treated with wood shreds and hydromulch.

Terrace Mountain Fire — The 2009 Terrace Mountain Fire located approximately 14 mi (24 km) NW of Kelowna, BC burned 23,200 ac (9280 ha) on Provincial Forest Land in the Okanagan-Shuswap Forest District. There were no wildfires (outside of CA) that provided suitable research potential in the Western US in 2009. The large California fires were largely in areas dominated by chaparral and oaks. We felt these sites would not be good candidates for the additional testing of wood shreds since wood shred mulch could not be produced locally and would have to be transported from a timber forest. Therefore, we selected a site in BC that would meet our objectives in a mature Douglas fir, lodgepine mixed forest. This research, in cooperation with the BC Forest Service, compared the effectiveness agricultural straw, wood shreds, and control-no treatment using three experiments—rainfall simulation on small plot (3 ft^2 [$1m^2$]), rill (concentrated flow) experiments on (30 ft [9 m]) runs, and nine hillslope plots (15 ft by 50 ft [5 m by 15 m]) with sediment fences to measure erosion from natural rainfall and snow melt.

Schultz Fire — The 2010 Schultz Fire burned 15,050 ac (6020 ha) on the Coconino National Forest in northern Arizona. This fire was located in a ponderosa pine-mixed conifer forest on steep hillslopes above the city of Flagstaff. About one third of the burn area had high soil burn severity according to the post-fire assessment report. This site was used to test the procedures of on-site production of wood shreds from burnt trees and the subsequent aerial application of the mulch.

Beal Mountain Mine Reclamation Site — Beal Mountain located on the Beaverhead-Deerlodge National Forest was an abandoned mine land reclamation site in the Pintler Mountains outside of Fairmont, Montana. The site is dominated by gently rolling hills (0 to 20% slope). The Heli-Claw and cargo nets were used with a helicopter to aerially apply wood shreds to hillslopes designated for rehabilitation.

Data collection and sampling

Indoor Rainfall Simulations — Indoor rainfall simulations were conducted on six replications of three mixes and three levels of ground cover—42 separate rainfall simulations. Three wood shreds mixes were: 1) shreds blend with 80% of the "fine" particles (< 1 in [25 mm]) from present manufacture method; 2) shreds blend with 40% of the fine particles remaining created by half of fine fraction by hand, and (3) shreds blend with 2% of fine fraction remaining. The three ground cover levels were accomplished by hand-spreading the wood shreds on the plot to achieve 0, 50, and 70% ground cover as determined using a point-intercept grid. The rainfall simulation plot was 12 ft (4 m) long, 3.5 ft (1.25 m) wide, and 0.8 ft (0.2 m) deep with a 40% slope. A fine-grained soil from the 2006 Tripod Fire was selected to represent a typical burned forest soil in the western U.S. A Purdue type rainfall simulator was used to deliver a raindrop size distribution and velocity approximating those of natural rainfall. The high-intensity design rainfall rate was 2 in hr^{-1} (50 mm hr^{-1}), which is comparable to a 15-minute storm intensity with a 50-year return period in the Intermountain West (NOAA, 1973). Simulated rainfall was applied for a total of 35 minutes to each plot. After the first 15 minutes of rainfall, concentrated overland flow was added to the top of the plot at a rate of 2 L min^{-1} for 10 minutes, and then increased to 8 L min^{-1} for the last 10 minutes. Timed grab samples were taken each minute and were processed in the laboratory to determine runoff rates, sediment concentrations, and total sediment yields.

Field Experiments — Three field experiments were conducted in this study: rill simulations, hillslope erosion measurements from hillslope plots (sediment fences) and small watersheds. Each experiment compared three treatments: wood shreds, agricultural straw, control (no treatment). However at the Gap Fire site, hydromluch was also evaluated.

Rill Simulation — After the 2009 Terrace Mountain Fire, rill simulations were conducted on 21 plots—7 of each treatment (wood shreds, agricultural straw, untreated) and were repeated in 2010 and 2011. In each simulation, water was released at the top of the plot (30-ft [9-m] long) at flow rates of 7, 22, 30, 15, and 48 L min^{-1} for 12 min; flow velocity, flow width, and flow depths were measured during each flow rate. Samples of runoff and suspended sediment were collected at 2 min intervals at the base of the plot throughout the run and processed in the laboratory to determine runoff rates, sediment concentrations, and total sediment yields. The site characteristics measured included pre-simulation soil water repellency, soil bulk density, surface soil particle-size distribution, and post-treatment ground cover.

Rainfall simulation — Two sets of 1 m^2 rainfall simulation plots (18 in 2009 and 15 in 2010) were established within the burn area and the three treatments (agricultural straw, wood mulch, and control) were randomly applied to 5 plots. Straw was applied at a rate of 0.2 kg m^{-2} (equivalent to 1 t ac^{-1} [2 t ha^{-1}]) and wood shreds were applied at 1.3 kg m^{-2} (equivalent to 6 t ac^{-1} [13 t ha^{-1}]). In 2009 only, an additional 3 plots were installed in an area of thick ash deposits, to test the effect of ash on runoff and sheet erosion. A 1-m^2 steel plot border was pounded into the soil such that the down slope edge of the border was level with the ground surface so the runoff and sediment flowed over it and into a trough which funneled into a single point for collection into 1-L sample bottles. Before and after each simulation, ground cover, soil moisture and water repellency were measured adjacent to the plot. Upon completion of the rain simulation, the metal frames were removed. In August 2010, 15 new plots were installed in a different location within the study area and 5 replicates of the three treatments were randomly applied.

Hillslope Plots (Fences) — Subject to natural rainfall, sediment fence plots (installed as described in Robichaud and Brown 2002) collected eroded sediment to calculate hillslope unit-area sediment yields. To the extent possible, the fences were emptied and the sediment yield calculated after each storm. Sediment in each fence was weighed in the field and sub-sampled for soil moisture analysis to determine the dry sediment mass. The site characteristics measured included contributing area, slope, aspect, soil water repellency, ground cover, and surface soil texture.

Gap Fire had 28 hillslope plots (fences) that were 13 ft wide by 65 ft (4 m wide by 20 m) length with 6 hand-applied wood shreds plots, 6 wood shred control plots, 10 aerially-applied hydromulch plots and 6 hydromulch control plots (as part of another study). Whereas the Terrace Mountain Fire had 9 hillslope plots that were 16 ft wide by 50 ft length (5 m wide by 15 m length) with 3 hand-applied wood shred plots, 3 hand-applied agricultural wheat straw plots and 3 control plots. Because the hydromulch sites and the wood shred sites were separated by about 2 mi (3 km) and had some different site characteristics, comparisons between treatments are not directly possible. Rather, each treatment is compared to its own control plots.

Small Watersheds — Three small 4 ac (2 ha) adjacent watersheds burned at high soil burn severity were equipped with sediment traps and V-notch weirs after the 2007 Cascade Fire. Two watersheds were treated with aerially-applied mulch treatments—agricultural straw in one and wood shreds in another—with the center watershed was left untreated as a control. Agricultural wheat straw was applied at the nominal rate of 1 t ac^{-1} (2.2 t ha^{-1}) for a targeted 60% cover. Wood shreds were applied at 3.7 t ac^{-1} (8 t ha^{-1}) for a targeted 60% cover. The lengths and widths of the wood shreds were variable but were filtered through a 0.25 in (6 mm) expanded metal sieve with 0.25 by 0.9 in (6 by 22 mm) diamond shaped openings to extract fines.

Other Field Measured Data

Ground Cover — Ground cover at all sites was categorized as rock, treatment (wood shreds, agricultural straw, hydromulch) herbs and shrubs, litter, moss, ash, and mineral soil. The total cover was calculated as the sum of all categories except ash and mineral soil.

At Terrace Mountain, measurements of ground cover were taken immediately after the plots were installed, and again at the peak of the growing season in August of 2010 and 2011. The ground cover was measured by taking visual observations at 100 points on a 10 cm grid, covering a total of 1 m^2, at two sites within each sediment fence plot. The sites were marked with pins, so that each subsequent measurement was taken at the same location. However in 2011, ground cover was estimated from photographs of each plot, rather than direct measurement.

At the Gap Fire, two quadrats (1 m^2, 100 point grid plots) were sampled just upslope of each sediment fence in November 2008 and again in March 2009. An additional five quadrats were established for each fence in June 2009.

The ground cover on watersheds at the Cascade Fire were measured with five repetitions on four transects using 1 m^2, 100 point grid plots. A total of 2500 points were used to measure ground cover per watershed.

The ground cover at the Schultz Fire was ocularly estimated using 0.2 m by 0.5 m Daubenmire frame on various slope classes in the treatment area. Five plots were established and monitored in agricultural straw mulched areas and two plots on wood shred mulched areas on slopes less than 35% and greater than 35%slope. One plot adjacent to agricultural straw mulched areas was established as a control.

Rainfall — Rainfall on these fires was measured with a series of tipping bucket rain gages located near hillslope plots and watersheds across the study areas. These rain gages recorded the amounts and timing of falling rain, from which storm durations and peak rainfall intensities were calculated. Long-term rainfall patterns were determined from nearby long-term weather stations operated by various government entities.

Pilot Study of Wood Shred Aerial Application

Wood shreds were aerially-applied for the first time at the Cascade Fire over a 4 ac (2 ha) study watershed. At the Beal Mountain mine reclamation site, one contract was let for the off-site production and delivery of 30 tons (27 metric tons) of wood shreds, and a second contract was let for distribution of the wood shreds by a helicopter using the Heli-Claw for most of the work and cargo nets for the remainder. The wood shred mulch treatment applied at the Shultz fire was noteworthy in that it was the first time wood shreds were produced, staged, and aerially-applied within a burned area. Nearly 2000 tons (1800 metric tons) of wood shred mulch was produced on site and applied to 330 ac (134 ha) with cargo nets.

Statistical Analysis

Indoor rainfall simulation — The primary interest was to determine differences among the wood shred blends and coverage amounts for each of the three flow schemes. Two-way mixed model ANOVAs were performed within each flow period to determine differences among runoff and sediment response variables. Mixed model ANOVAs were performed to test for differences among treatments for runoff depth, and sediment concentration for a given simulation scheme. Model treatment effects included run plus inflows, shred types (80, 40, and 2% fine particles) and cover (0, 50, 70 %).

Field experiments — For the rainfall simulation experiment, non-parametric correlations and scatterplots were used to evaluate the relative strength of controlling factors (ground cover, water repellency and infiltration, and soil moisture) for the dependent response variables. The runoff and sediment yields showed some heteroscedasticity, so log (runoff) or fourth-root (sediment flux rate) transformations were used to make the model residuals more homoscedastic. Linear mixed statistical models were developed using post-fire year and treatment as fixed effects and the plot-treatment replicate as a random effect. Response variables were runoff depth (mm), sediment yield (kg m^{-2}), and time to runoff start (calculated from simulation start) and runoff peak (calculated from the time runoff started). A repeated measures structure was applied to each plot, and the year of the measurement was used as the period of repetition. Least-squares means with a Tukey-Kramer adjustment were used to test the significance of multiple comparisons among treatments and years. The significance level was 0.05 for all statistical tests.

For the rill experiment, linear mixed models were developed using the treatment as a fixed effect, while the plot-treatment replicate was a random effect. Dependent variables were runoff rate, runoff velocity, sediment flux rate, and flow width and depth. In the year of the fire, the runoff and sediment flux rates approached a steady state condition by the fourth sample in each experimental flow rate, so only samples 4-6 were used to compare treatments. Samples with runoff were very limited in the first and second post-fire years (no-runoff samples resulted in no-data for the other variables), therefore the model was developed using only the data from the year of the fire. The runoff rates, sediment flux rates, and runoff velocities showed some heteroscedasticity, so square-root (runoff rate and runoff velocity) or fourth-root (sediment flux rate) transformations were used to make the model residuals more homoscedastic. Least-squares means with a Tukey-Kramer adjustment were used to test the significance of multiple comparisons among treatments.

For the hillslope plots, a linear mixed model was also developed using the post-fire year and treatment as fixed effects, while the plot-treatment replicate was a random effect. The dependent variable was sediment yield, which was log-transformed for heteroscedascity. The covariance structure of the repeated measures on each plot was modeled using a spatial power function and the number of days between burning and the cleanout event. Differences in the log-transformed sediment yields were compared using the least squares mean estimates for each treatment and post-fire year. A Tukey-Kramer adjustment was used for comparisons of multiple least-squares means.

IV. Key Findings

1) Objective: *Determine the optimum wood shreds specifications (dimensions and coverage) for reducing erosion*

Under simulated rainfall only, all mixes were equally effective in reducing sediment loss by 90 to 98% compared to a bare soil. However, when concentrated flow was added to the rainfall, the mix with the least amount of fine particles (2% blend) was the most effective in reducing sediment loss (by about 70%). Under all rainfall and concentrated flow conditions, more greater the cover the maximum cover rate (70%) had the largest erosion reduction. Given that 1) the erosion reduction with 50% cover was only slightly less than with 70% cover; 2) wood shreds cost more and take longer to apply than agricultural straw (because shreds can weigh up to 4 times more than straw); and 3) there is a high likelihood of concentrated flow on burned hillslopes, we recommend a 50 to 60% cover of the wood shreds with fine particles removed for post-fire conditions.

2) Objective: *Compare the effects of wood shreds to agricultural straw and no treatment on post-fire runoff and rill erosion*

Rainfall Simulation — In the year of the fire, runoff started earliest on the control plots (2.1 min), followed by wood shreds and agricultural straw (2.5 and 3.0 min, respectively), yet the amount of runoff did not differ by. However, the control plots had significantly higher sediment yields (0.60 kg m^{-2}) than the agricultural straw (0.23 kg m^{-2}) and wood shreds (0.18 kg m^{-2}) plots. In the first post-fire year, although sediment yields were almost an order of magnitude smaller on the straw and wood plots (0.03 kg m^{-2}) compared to the control plots (0.10 kg m^{-2}), the difference was not significant. Because the straw and wood treatments had similar sediment yields and runoff amounts, they were combined into a “treated” class and compared to the control plots. Similar to the individual results, the difference in runoff on the control and treated plots was not different in the year of the fire, while the sediment yields on the treated plots (0.20 kg m^{-2}) were significantly smaller than on the controls (0.60 kg m^{-2}). In the first post-fire year, there still were no differences between the control and treated plots for either runoff or sediment yields.

In the year of the fire, ground cover on the rainfall simulation averaged 10% on the control plots, 85% (80% was treatment) on the agricultural straw plots, and 62% cover (54% was treatment) on the wood shreds plots. In the first post-fire year, ground cover was 37%, and 75% and 73% on the control, agricultural straw, and wood shreds plots, respectively and remaining treatment cover was 53% on the agricultural straw plots 49% on the wood shreds plots. In both years, the treated plots had double or more ground cover than the control plots.

<u>Rill Simulation</u> — In the year of the fire, 87% of the samples from the control plots had runoff compared to about 70% from the treated plots. In the first post-fire year, the control plots produced runoff in about 70% of the samples, while runoff from the treated plots was reduced to 15% of samples on the agricultural straw plots and 6% of the samples on the wood shreds plots. By the second post-fire year, 17% of samples on the control plots had runoff and only 1 and 3% of the agricultural straw and wood shreds samples produced runoff. The mean runoff rates from all three treatments were not the control plots was 12 L min^{-1}, and on the agricultural straw and wood shreds plots 9.0 and 9.2 L min^{-1}, respectively, none of which were statistically different. In the first post-fire year, the runoff value on the control plots decreased to 8.5 L min^{-1}, but the decrease on the treated plots was more substantial. The mean runoff on agricultural straw was 0.66 L min^{-1} and the wood shred plots was 0.25 L min^{-1}. By the second post-fire year, the runoff value on the control plots decreased to 1.0 L min^{-1}, the agricultural straw plots to 0.2 L min^{-1}, and the wood shred plots 0.13 L min^{-1}.

Sediment flux rates responded similarly to runoff rates over time, and values from the treated plots decreased by about an order of magnitude each year. The highest mean sediment flux rate was measured on the control plots: 0.88 g s^{-1} in the year of the fire, 0.41 g s^{-1} in the first post-fire year, and 0.09 g s^{-1} in the second. Sediment flux rates on the agricultural straw and wood shred plots (respectively) were 0.43 and 0.50 g s^{-1} in the year of the fire, 0.05 and 0.01 g s^{-1} in the first post-fire year, and 0.03 and 0.03 g s^{-1} in the second post-fire year. Given that the runoff and sediment flux rates values on the control plots are similar to the previous year’s values on the treated plots, the additional ground cover provided by the straw and wood shreds approximated an additional year of recovery at this site. Since the treatment effects of the agricultural straw and wood shreds are similar, combining the data shows the runoff rate and the sediment flux rates on the treated plots were approximately half of rates measured on the control plots in the year of the fire.

Total ground cover on the control rill simulation plots was low in the year of the fire (15%); the agricultural straw plots had 86% total ground cover, similarly, the wood shreds plots had 74% total cover. In the first post-fire year, total cover on the control plots increased to 46%, the agricultural straw plots changed to 65% and the wood shreds plots increased to 84%. Live vegetation cover on all plots ranged from 22 to 27%. By the second post-fire year, total cover on the control plots increased to 62%; 51% of which was live vegetation. The agricultural straw plots had 75% cover; 18% of which was the treatment and 48% was vegetation. The wood shreds plots had 90% total cover; 33% treatment and 51% vegetation. Two trends were apparent: 1) vegetation increased similarly on all plots, regardless of treatment; and 2) the wood shreds remained on site longer than the straw mulch. The straw mulch treatment cover decreased by nearly 80% during the study period whereas the wood shreds only decreased by about 50%.

3) Objective: *Compare the effects of wood shreds to agricultural straw and no treatment on post-fire hillslope erosion measured at the hillslope scale*

Gap Fire — There was no difference in hillslope erosion between either the hydromulch or the wood shreds plots and their respective controls during the initial November 2008 storms. However, during the two periods of relatively heavy rains with storm peak 10-min rainfall intensity (I_{10}) of 0.9 to 2.3 in hr^{-1} (23 to 58 mm hr^{-1}) that followed, the hydromulch reduced erosion by 70% and the wood shreds by 60% compared to their respective controls. By the end of the first year, the mean sediment yield for the hydromulch control plots was 9.6 t ac^{-1} (21.1 t ha^{-1}) and the hydromulch treated plots was 3.5 t ac^{-1} (7.7 t ha^{-1}) whereas the wood shred control plot sediment yield was 6.1 t ac^{-1} (13.4 t ha^{-1}) and the wood shred treated plot sediment yield was 2.8 t ac^{-1} (6.2 t ha^{-1}) with a storm I_{10} of 1.1 to 2.0 in hr^{-1} (28 to 51 mm hr^{-1}). Thus, both treatments reduced sediment yield during the first post-fire year – by 65% for the hydromulch and 55% for the wood shreds. During the second post-fire year, both treatments again reduced sediment yields compared to their respective control plots, by 44% and 54% for the hydromulch and the wood shreds, respectively. Sediment yields were 1.3 t ac^{-1} (2.9 t ha^{-1}) for the hydromulch plots and 2.3 t ac^{-1} (5.1 t ha^{-1}) for its control plots. The wood shred sediment yield was 4.9 t ac^{-1} (10.8 t ha^{-1}) compared to10.8 t ac^{-1} (23.8 t ha^{-1}) for its control plots from a storm with an I_{10} of 1.1 to 1.9 in hr^{-1} (28 to 48 mm hr^{-1}). During the third year, the hydromulch material was undetectable on the hillslope, and there was no treatment effect. In contrast, some wood shreds persisted, so during the very wet third post-fire year the wood shred treatment reduced sediment yield by 28% compared its control plots. The degree of sediment yield reduction afforded by the wood shreds was identical for the first and second years after the fire (55% and 54% less sediment than controls), then a 28% reduction for the third year, indicating that the wood shred mulch treatment remains effective over a longer time period than the hydromulch. The wood shreds treatment reduced total erosion by an average of 53% over the three year study period, essentially the same as the hydromulch.

Total ground cover after the first rainy season on the wood shreds control plots was 24% compared to 55% cover on the wood shreds treated plots and the hydromulch treated plots. Total cover increased after the second rainy season to 80% on the control plots and 84% on the hydromulch plots and 81 % on the wood shred plots. Only 1% of the hydromulch remained after the second rainy season whereas the 16% of the wood shreds remained.

Terrace Mountain Fire — In the year of the fire, the mean sediment yield in the control plots was 0.3 t ac^{-1} (0.7 t ha^{-1}) with a storm I_{10} of 0.5 in hr^{-1} (14 mm hr^{-1}). On the agricultural straw and wood shreds plots, the first cleanout yielded 0.03 and 0.04 t ac^{-1} (0.06 t ha^{-1} and 0.08 t ha^{-1}). In the first post-fire year, sediment yields on the control plots averaged 0.09 t ac^{-1} (0.2 t ha^{-1}), and 0.02 t ac^{-1} and 0.02 t ac^{-1} (0.04 t ha^{-1} and 0.05 t ha^{-1}) on the agricultural straw and wood shreds fences respectively, with a storm I_{10} of 1.8 in hr^{-1} (47 mm hr^{-1}), which was also the highest I_{10} measured during the study period. In the second post-fire year, the greatest sediment yields were attributed to a storm with an I_{10} of 0.43 in hr^{-1} (11 mm hr^{-1}). Sediment yields were much lower compared to the previous two years, ranging from 0.0004 t ac^{-1} (0.009 t ha^{-1}) on the control plots to 0.001 and 0.002 t ac^{-1} (0.003 and 0.004 t ha^{-1}) on the agricultural straw and wood shreds plots. Sediment yields decreased significantly each post-fire year. When we combined agricultural straw and wood shreds into a single treated class and compared sediment yields to the control, the treatment effect resulted in significantly lower sediment yields.

Total ground cover on the control plots in the year of the fire was low (14%), cover on the agricultural straw plots was 74%, and cover on the wood shreds plots was 65%. In the first post-fire year, cover increased to 26% on the control plots, and remained about the same (74% and 69%) on the agricultural straw and wood shreds plots respectively. In the second post-fire year, total cover ranged from 67% to 70% on all plots regardless of treatment. Only 3% straw cover remained in the second post-fire year, while 19% of the wood shreds treatment remained. Vegetation increased considerably during the study period and wood shreds had a greater longevity than the agricultural straw.

Cascade Fire — A paired watershed was installed after the Cascade Fire in Idaho to compare wood shreds, straw and control. No significant rainfall events have occurred since installation in 2007, thus treatment effectiveness remains untested at this site.

4) Objective: *Develop a technical guide for the on-site manufacture and post-fire aerial application of wood shreds*

Production of Wood Shreds — The wood shreds applied to the Cascade Fire, Gap Fire, and Terrace Mountain Fire sites were produced by MTDC and shipped to the sites. The shreds were sieved to remove the small fine pieces (< 1 in [25 mm]). The wood shreds applied to the Beal Mountain reclamation project were produced off-site by a contractor and shipped to the site. These shreds were unscreened. At the Shultz Fire, wood shreds were produced on-site using a horizontal grinder to shred burned hazard trees that were removed from along forest roads. The

BAER team decided that the benefit of removing the fine particles from the shred mix was not worth the cost of the added step in the production. Therefore, the shreds that were applied were the same mix that the grinder produced. Production from the grinder was about 100 t hr^{-1} (90 t hr^{-1}) and about 2000 tons (1800 metric tons) were produced at an estimated cost of approximately $37,800, or $18.90 per ton ($20.79 per metric ton).

Cargo Net Wood Shreds Application — At the Shultz Fire, the contract specified 6 tons of wood shred mulch per acre (13 t ha^{-1}) within the treatment areas. Three to four cargo nets were used to apply wood shreds, which allowed the ground crew to have at least one loaded net ready to go. The staging area needed to be large enough to accommodate the loading of cargo nets while the helicopter pilot dropped empty nets and picked up the next full one—this can require up to 1 ac (0.4 ha) of staging area per cargo net being used. Using a single Bell 204 helicopter with the nominal application rate (6 t ac^{-1} [13 t ha^{-1}]), it took nearly 5 net loads to treat each acre (10 net loads ha^{-1}) and about 1600 net loads to complete the 330 ac (130 ha) designated for wood shred treatment. Average production rate of 25 to 35 ac (10 to 14 ha) per day was achieved. The average round trip flight time was estimated to be 4 minutes and require about 110 flight hours for the project. Ground cover plots indicated an average of 60% cover with the wood shreds.

Heli-Claw Wood Shreds Application — The Heli-Claw has a design capacity of 2000 lbs (910 kg) with working capacity about 70-80% of design capacity. The pilot at the Beal Mountain mine site found that about 1200 lbs (540 kg) was the maximum wood shred load. Flying at about 30 knots at an elevation of 200 to 300 ft (60 to 90 m) above the ground, the pilot was able to accurately place and distribute approximately 6 tons (5.4 metric ton) of wood shreds per hour or about 1.75 ac hr^{-1} (0.53 ha hr^{-1}). After becoming familiar with the Heli-Claw operation, the average turn-around time was 2 min. The Heli-Claw was able to pick up larger loads when the wood shred pile was “fluffed up” (un-compacted), and the claw was set down partially closed on the pile, then opened up to its maximum width, and closed as the helicopter slowly lifted. While dispersing the wood shreds, the pilot described the use of the Heli-Claw “like painting the hillside,” because the pilot could see the ground, open the claw slowly, and have more control of the delivery. Stockpiling wood shreds and using the Heli-Claw uses less area than multiple cargo nets in the staging area.

Cost Comparisons — At the Beal Mountain site, the contractors cost to produce 31.7 tons (28.7 metric ton) of wood shreds off-site and deliver them to the Beal Mountain mine site was $2,214, or approximately $69.80 per ton ($76.94 per metric ton), with hauling expenses accounting for 72 percent of the cost. The total cost of producing the wood shreds was not much different at the two locations—$18.90 per ton at the Schultz Fire and $19.84 per ton at Beal Mountain ($20.79 per metric ton at the Schultz Fire and $21.82 per metric ton at Beal Mountain). These data demonstrate that transportation of any mulch material is costly and that there are significant economic advantages to producing mulch on or near the treatment site.

The wood shreds produced at the Shultz Fire site were about four times denser than agricultural straw, which resulted in different application rates for agricultural straw (1.5 t ac^{-1}, 3.3 t ha^{-1}) and wood shreds (6 t ac^{-1}, 13.2 t ha^{-1}). Given that the helicopter payload was a fixed parameter, it required about 5 times as many round trips and to treat an acre with wood shreds as with agricultural straw. This factor made wood shred application take longer and cost more than straw application ($1,500 to $2,000 per acre and $500 per acre, respectively, ($3,750 to $5,000 per ha and $1,250 per ha, respectively). The cost per acre for application of wood shreds using cargo nets was similar at the Shultz Fire ($1500-2000 ac^{-1} [$3,750-5,000 ha^{-1}]) and Beal Mountain ($1426 ac^{-1} [$3565 ha^{-1}]).

V. Management Implications

Indoor rainfall studies and small-scale field experiments have shown that wood shred mulch can be an effective and useful post-fire hillslope treatment. Erosion reduction capability of wood shreds is comparable to agricultural straw, and wood shreds persist longer than agricultural straw or hydromulch.

Burned trees that are slated to be felled and/or removed (hazard trees) provide a significant quantity of wood that when processed through a grinder provides a useful wood mulch material. Since wood shreds weigh about four times more than agricultural straw, application costs more and takes longer as compared with straw. However, mulches made onsite do not have to be purchased or transported which provides a cost savings.

Although aerial mulching is logistically demanding and expensive, the effectiveness of mulch as compared to other post-fire hillslope treatments has increased its use in areas where downstream values are at high risk for damage. At the Schultz Fire, aerially-applied wood shreds were more stable on slopes greater than 35% than agricultural straw. Consequently, there may be advantages to applying both mulches differentially to optimize the time and expense of treating the burned area. Wood shreds might be prescribed for areas with high values at risk and where straw is unlikely to work well such as steep slopes and open areas with high wind exposure. Straw may be preferred for in other areas because it provides adequate protection at less cost.

VI. Relationship to other findings and ongoing work on this topic

We recently completed a post-fire hillslope treatment effectiveness synthesis, JFSP project #08-2-1-10 (Robichaud et al. 2010) on current treatments in use. This project now adds another treatment, wood shreds, to the various mulches that post-fire assessment teams can consider after wildfires when downstream values at risk are high. The synthesis focused on post-fire hillslope emergency stabilization treatments, including erosion barriers, mulching, chemical soil treatments, and combinations of these treatments. However, these hillslope treatments are usually the most expensive post-fire treatments used, which makes cost effectiveness an important factor in their selection. These results, which include costs of making and applying wood shreds, will be useful to BAER teams when they are making treatment decisions. Technology transfer of these results will continue at future BAER trainings and webinars.

VII. Future work needed

Mulch application is now common place after large wildfires; yet there are limited long term studies, only up to 8 years in Robichaud et al. (in review), on mulch effectiveness on hillslope erosion. Mulch effects on below ground processes such as the C/N ratio or its ability to affect carbon storage is not well understood. Long term effects on native species establishment and natural regeneration has limited evaluation.

Since the Erosion Risk Assessment Tool was developed (Robichaud et al. 2007), additional research results have become available to improve treatment performance predictions. Therefore, a revision of the ERMiT model would provide more accurate estimates of erosion reduction benefits of various mulches being used, including hydromulches and wood mulches.

VIII. Deliverables Crosswalk Table

This project determined the effectiveness of a new post-fire erosion control method. The authors have disseminated the research findings through publication of peer-reviewed articles and a practical application guide in the form of a Research Note. Finally, results and recommendations have been disseminated directly to specialists and managers via conferences, workshop presentations, national and regional meetings and webinars.

Table 1. Description and delivery dates of project deliverables. Note proposed deliverables and proposed deliverable dates in *italics*.

Deliverable	Description	Delivery Dates
Peer-reviewed article	*Technical article on the effectiveness of wood shreds on erosion in post-fire soils using indoor rainfall simulations* 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(2010) 86-94, doi:10.1016/j.catena.2009.09.003	*May 2008* Feb 2010
Peer-reviewed article	*Technical article on the effects of wood shreds on in-situ post-fire erosion* Robichaud, P.R., Lewis, S.L., Jordan, P. Ashmun, L., Brown, R.E., Covert, A., Curran, M. 2012. Evaluating woods shreds as a post-fire erosion control treatment using three different experiments in Southern British Columbia. **Geomorphology** in submission.	*May 2010* May 2012

General Tech. Report	*Guide to Wood Shreds in Post-Fire Rehabilitation Applications* Robichaud, P.R., Showers, C., Groenier, J.S., Foltz, R.B. 2012. Production and aerial application of wood shreds as a post-fire hillslope erosion control treatment. **Research Note.** Ft. Collins, CO: U.S. Department of Agriculture Forest Service, Rocky Mountain Research Station, 14 p. in submission	*May 2010* May 2012
3 or more workshops	*Presentation at annual FS BAER Team Leader meeting* *Presentation at annual USDI BAER Team Leader meeting* *Presentation at a regional Forest Service/BLM workshops*	*2008, 2009, 2010* *2008, 2009, 2010* *2008, 2009, 2010*
	Robichaud is active in disseminating research results; below are additional presentation and workshops presenting some of these findings.	
	Department of Interior BAER Team Refresher Course	Feb 2008, Feb 2009, Mar 2011
	Forest Service National BAER Coordinators Meeting	Jan 2009, Jan 2010. Jan 2011, Jan 2012
	Forest Service Regions 1, 2, 3, 4 and 6 BAER Trainings	Feb 2008, May 2009, Sep 2009, Oct 2010
	Forest Service Region 5 Soils Training Workshop	Mar 2010
	Forest Service Region 4 Watershed Program Training	Sep 2010, Nov 2011
	Forest Service Region 6 Watershed and Soil Programs Meeting	Mar 2011, Apr 2012
	Schultz Fire Field Trip	June 2011
	International Webinar on Post-fire Treatment Effectiveness	Apr 2012
	SW Post-fire Hydrology Conference, Tucson, AZ	Apr 2012
	IAHS-ICCE International Conference Wildfire and Water Quality: Process, Impacts and Challenges. Banff Alberta, Canada	Jun 2012
	Wagenbrenner presented at: Dept. of Interior National Interagency Preseason Meeting; and Forest Service Region 3 Air, Watershed and Soil Workshop	Apr 2012

References

Bautista, S., J. Bellot, V. R. Vallejo. 1996. Mulching treatment for post-fire soil conservation in a semiarid ecosystem. *Arid Soil Research and Rehabilitation* 10:235-242.

Bautista, S., P.R. Robichaud, C. Bladé. 2009. *Post-fire Mulching*. Chapter 13 in: Cerdà, A.; Robichaud, P.R., eds. Fire Effects on Soils and Restoration Strategies. 2009. 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., B.S. Sharratt, J.Q. Wu. R.B. Foltz, J.H. Dooley. 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.

Foltz, R.B., N.S. Copeland. 2007. Field testing of wood-based biomass erosion control materials on obliterated roads. 2007 ASABE Annual International Meeting. Paper No: 078046. Minneapolis, MN, 17-20 June 2007. July 2007.

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

Groenier, J.S., C. Showers. 2004. Shredding small trees to create mulch for erosion control. Tech Tip 0471-2335-MTDC. September 2004. Missoula, MT: USDA Forest Service, Missoula Technology and Development Center. 6 p.

Groenier, J.S., R.B. Foltz, C. Showers. 2005. Using rainfall simulators to test wood shreddings for erosion control. Tech Tip 0571-2329-MTDC. August 2005. Missoula, MT: USDA Forest Service, Missoula Technology and Development Center. 6 p.

Kruse, R., E. Bend, P. Bierzynchudek. 2004. Native plant regeneration and introduction of non-natives following post-fire rehabilitation with straw mulch and barley seeding. *Forest Ecology and Management* 196(2-3):299-310.

Napper, C. 2006. The burned area emergency response treatment catalog (BAERCAT). Tech. Rep. 0625 1801-SDTDC. Washington DC: U.S. Department of Agriculture, Forest Service, National Technology & Development Program, Watershed, Soil, Air Management. 253 p. [Online] Available: http://www.fs.fed.us/eng/pubs/pdf/BAERCAT/lo_res/06251801L.pdf [19 June 2009].

National Oceanic and Atmospheric Administration (NOAA). 1973. Western U.S. precipitation frequency map, NOAA Atlas 2. Available at http://www.wrcc.dri.edu/pcpnfreq.html. Accessed on 1 December 2009.

Robichaud, P.R., R.E. Brown. 2002. Silt fences: an economical technique for measuring hillslope soil erosion. Gen. Tech. Rep. RMRS-GTR-94. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 24 p.

Robichaud, P.R., J.L. Beyers, 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, 63 p.

Robichaud, P.R., W.J. Elliot, F.B. Pierson, D.E. Hall, C.A. Moffet 2007. Predicting postfire erosion and mitigation effectiveness with a web-based probabilistic erosion model. *Catena* 71(2):229-241.

Robichaud, P.R., L.E. Ashmun, B.D. Sims. 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., J.W. Wagenbrenner, S.A. Lewis, L.E. Ashmun, R.E. Brown, P.M. Wohlgemuth. In review. Post-fire mulching for runoff and erosion mitigation Part II: Effectiveness in reducing runoff and sediment yields from small catchments. *Catena*

Wagenbrenner, J.W., L.H. Mac Donald, D. Rough. 2006. Effectiveness of three post-fire rehabilitation treatments in the Colorado Front Range. *Hydrological Processes* 20:2989-3006.

Yanosek, K.A., R.B. Foltz, J.H. Dooley. 2006. Performance assessment of wood strand erosion control materials among varying slopes, soil textures, and cover amounts. *Journal of Soil and Water Conservation* 61(2):45-50.