JFSP Final Report: Postfire Erosion and the Effectiveness of Emergency Rehabilitation Treatments over Time

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EXECUTIVE SUMMARY

The primary goals of this project were to: (1) assess the effectiveness of four commonly used rehabilitation treatments to reduce post-fire erosion; (2) determine the relative importance of different controlling factors on post-fire erosion rates and treatment effectiveness over time; and (3) use our field data to help test and validate models for predicting post-fire erosion at the hillslope scale. Intensive field studies were conducted over a four-year period in the Colorado Front Range, and these were complemented by field- and lab-based rainfall simulation experiments to better understand the underlying processes. The results provide critical information on treatment effectiveness, the key processes that control post-fire runoff and erosion rates, and the use of models for predicting post-fire erosion rates. The major findings of this study are:

1. Straw mulch and hydromulch were effective in reducing post-fire erosion rates in the first two years after high-severity wildfires, as they immediately increased the amount of ground cover. Seeding and scarification and the application of a polyacrylamide had little or no effect on post-fire erosion rates as these did not directly increase the amount of ground cover or increase the rate of vegetative regrowth relative to the adjacent control sites.

2. Post-fire erosion rates in the Colorado Front Range typically decline to near-background levels in two years or the third summer after burning. In sites with particularly coarse-textured soils post-fire erosion rates can remain elevated for at least four years.

3. Percent ground cover is the predominant control on post-fire erosion rates. Removing the litter from unburned hillslopes resulted in sediment yields and erosion thresholds that were indistinguishable from sites that had been recently burned by high-severity wildfires. Soil water repellency decays too rapidly to be a primary cause of the sustained high sediment yields after high-severity wildfires. Rainfall simulation experiments indicate that ground cover is important because it can largely prevent soil sealing. The presence of ash also appears to provide a temporary protective cover against soil sealing, but this is rapidly removed by overland flow. Field studies show that most of the sediment generated from burned areas is derived from rill and channel erosion along concentrated flow paths, but post-fire rehabilitation treatments must include the hillslopes because these are the primary source of surface runoff.

4. The high variability observed in the field and the difficulty of accurately characterizing individual sites means that predictive models such as the Revised Universal Soil Loss Equation (RUSLE) and Disturbed WEPP generally are much better at estimating mean sediment yields than the sediment yields from individual hillslopes. Our validation efforts also show that RUSLE, Disturbed WEPP, and ERMiT all tend to overpredict low sediment yields and underpredict high sediment yields. We are working with the developers of Disturbed WEPP and ERMiT to improve their performance, as these two models have a stronger physical basis and generally show more promise for accurately predicting post-fire erosion rates than RUSLE.

5. Unit area sediment yields from areas burned at high severity are initially scale-independent, but decline sharply with increasing area as areas recover. This implies that hillslope-scale measurements can be used to characterize the initial sediment yields from burned areas.

Sediment yields per unit area decline at scales of more than a few square kilometers because the primary cause of post-fire runoff and erosion in the Colorado Front Range is localized convective thunderstorms. Snowmelt generates little or no post-fire erosion. Downstream areas are subject to large accumulations of post-fire sediment. The reductions in runoff due to the relatively rapid revegetation of the hillslopes reduce the ability of downstream channels to transport the accumulated sediment after burning, and decades or even centuries may be necessary before some of the aggraded channels can recover to pre-fire conditions.

6. The results of this project have been disseminated through more than 40 technical presentations at scientific conferences and workshops. The papers, book chapters, and theses resulting from this project are available online at: http://www.warnercnr.colostate.edu/frws/people/faculty/macdonald/macdonald.html, and future products as well as the data also will be disseminated through presentations, articles, and online.

1. INTRODUCTION

This project was initiated after a series of major fires in Colorado in summer 2002. Our work focused on the Colorado Front Range where we were already making measurements on four wildfires and three prescribed fires (Benavides-Solorio, 2003). The primary focus of the research conducted under this project was on the Hayman and Schoonover wildfires southwest of Denver, where we had fortuitously established a series of hillslope- and watershed-scale sites in summer 2001 to evaluate the effects of forest thinning on runoff and erosion (Libohova, 2004). The JSPF project allowed us to expand and intensively monitor sites on those two fires, and to continue our work on several other fires until post-fire sediment production rates had returned to near-background conditions.

The specific objectives of this project were to: (1) Test the effectiveness of four different BAER treatments (mulching, hydromulching, scarification and seeding, and application of a polyacrylamide) over time relative to untreated control sites; (2) Quantify post-fire erosion rates over time; (3) Test the importance of different site characteristics on runoff and erosion rates from untreated burned areas and burned areas subjected to four different BAER treatments; (4) Use the information and understanding developed in this project to better predict post-fire runoff and erosion risks for the four BAER treatments being evaluated in this study as well as the no treatment alternative; and (5) Determine the extent to which erosion rate measurements can be transferred between the small plot, hillslope, and small watershed scales. This report summarizes the key results and products produced to date and underway.

The following sections of this report summarize the key results under each objective and show how the data collected under this project already are providing important guidance to resource managers, modelers, and scientists. However, the unique extent and quality of the data collected under this project (>600 plot years of data from both treated and control sites) means that the results will continue to provide the source material for peer-reviewed journal articles, presentations, and other studies for the foreseeable future. Perhaps more importantly, once we have submitted the papers outlined in this report, we will post the entire dataset on our respective web sites. This open access means that the data collected under this and related projects will have maximum utility by as wide an audience as possible. This means that the data will be as widely disseminated as possible, and be used for purposes that extend well beyond the objectives outlined in this proposal.

2. RESULTS

OBJECTIVE 1: *Test the effectiveness of four different BAER treatments (mulching, hydromulching, scarification and seeding, and application of a polyacrylamide [PAM]) over time relative to untreated control sites.*

Under this objective we established 18 pairs of treated and control hillslopes and four nearby hillslopes that had been treated with aerial hydromulching. We also conducted rainfall simulations on 1 m^2 plots in treated and control sites, and conducted a laboratory experiment to determine the extent to which the polyacrylamide preferentially binds with mineral soil and ash in aqueous solutions. The initial treatments were established in August and September 2002 and are still being monitored in summer 2007 as sediment production rates in summer 2006 substantially exceeded the mean values prior to burning and the values from nearby unburned sites.

The results show that the straw mulch and aerial hydromulch each reduced sediment production rates by more than 90% from the time of initial application in summer 2002 through summer 2003, and by 50-77% in summer 2004. By summer 2005 the two types of mulch cover had deteriorated to the extent that there were no further significant differences in either ground cover or sediment yields between the treated and control sites. This means that the sediment production rates from 2004 to 2006 was being controlled primarily by the rate of vegetative regrowth and the magnitude of summer storm events rather than the post-fire treatments. There was no evidence that the mulching treatments had any significant effect on vegetative regrowth over time or the degree of soil water repellency, so their effectiveness was due to the fact that they immediately provided a protective ground cover (see results under objective 3).

The scarification and seeding treatment was not effective in reducing sediment yields. The observed lack of effectiveness is attributed primarily to the fact that the scarification and seeding treatment had no significant effect on vegetative regrowth. Field measurements also showed that the mean depth of scarification using McLeod hand tools was only about 2-3 cm, whereas the post-fire soil water repellency initially extended to a depth of 9 cm. Hence the scarification treatment did not break up the water repellent layer (note that our results under objective 3 indicate that soil water repellency is not a primary control on post-fire runoff and erosion rates). Qualitative field observations suggest that the scarification using harrows behind ATVs also was ineffective, as surface rilling was observed after rainstorms and there was no visual evidence of improved revegetation rates relative to adjacent untreated areas.

The results from the ground hydromulch treatment were mixed, as one treated hillslope was only partially hydromulched. Compared to the aerial hydromulch, the ground-based hydromulch mixture had a higher water content, did not include a polyacrylamide binding agent, and had a lower seed density. Visual observations indicated that the aerial hydromulch resulted in a much stronger and more cohesive surface cover. The four pairs of treated and control plots showed that the ground-based hydromulch treatment did not significantly reduce sediment yields or revegetation rates relative to the adjacent control plots. Nevertheless, we believe that ground-based hydromulching--if correctly formulated and properly applied--could be effective in reducing post-fire erosion rates.

The polyacrylamide (PAM) was applied in August 2002 to three hillslopes as a dry powder, and to three hillslopes in a wet solution that included ammonium sulfate. There was no evidence that the dry PAM treatment reduced sediment production rates. The wet PAM treatment appeared to reduce sediment yields for two rainstorms in summer 2002 and one larger storm in summer 2003, but this reduction was only statistically significant in summer 2002. In order to confirm these results, we applied the same wet PAM treatment in June 2003 and June 2004 to the same three hillslopes that had been initially treated with the dry PAM, but this second wet PAM treatment had no significant effect on sediment yields. A lab experiment showed that the PAM preferentially binds with ash, and we attribute some of the variability in our results to the tendency for the PAM to preferentially bind with the more readily erodible surface ash layer and the varying amounts of ash present on the hillslopes prior to treatment. We conclude that under certain conditions a heavier and carefully formulated application of PAM **might** provide some initial benefit in terms of reducing post-fire erosion rates, but at this point we cannot support the use of PAM as an effective post-fire erosion control treatment for the coarse-textured soils and climatic regime characteristic of our study sites. Additional research is needed to determine under what conditions and whether the application of PAM could contribute to a short-term reduction in post-fire erosion rates.

Since the PAM treatments had no significant effect on sediment yields or revegetation rates in summer 2004, we installed a new experiment in summer 2005 using the same six pairs of hillslopes. The general objective was to better understand the relative effectiveness of the straw mulch in reducing sediment yields from the hillslopes and the convergent channels. The basic design was to spread straw mulch on the hillslopes in three of the study plots but use bird netting to exclude it from the central rills that generate much of the post-fire sediment (see results under objective 3). On three other hillslopes the mulch was only placed in the central rills. The results showed that placing mulch on the hillslopes was much more effective in reducing erosion rates than only placing mulch in the convergent rills. The implication is that the hillslopes are the critical source area for surface runoff, and post-fire rehabilitation treatments must include the hillslopes if they are to reduce the magnitude of post-fire runoff and erosion rates.

The rainfall simulation experiments confirmed that the mulched and hydromulched treatments can reduce post-fire erosion, while seeding and scarification is not effective. The effectiveness of these five different BAER treatments from 2002-2004 is summarized in a recently-completed M.S. thesis (Rough, 2007) on Dr. MacDonald's web site (http://www.warnercnr.colostate.edu/frws/people/faculty/macdonald/macdonald.html). The data from 2005 and 2006 are being incorporated in a second M.S. thesis by Keelin Schaffrath that is now in preparation. The combined data will be written up into one article on the effectiveness of the seeding and mulching treatments, and one article on field- and lab-based PAM treatments. The rainfall simulation data are in a third draft thesis by Darren Hughes that should be completed in late 2007. All of the additional theses will be placed on Dr. MacDonald's web site as soon as they are completed and the journal articles will be posted as soon as they are submitted.

OBJECTIVE 2: *Quantify post-fire erosion rates over time.*

Under this objective we established and/or continued monitoring 63 untreated control sites on four wildfires and one prescribed fire (16 hillslopes in the 2000 Bobcat wildfire, 12 convergent hillslopes and 11 planar hillslopes in the 2002 Hayman wildfire, six hillslopes in the 2002 Schoonover fire, six hillslopes in the 2003 Big Elk fire, three hillslopes burned in the 2002 Hewlett Gulch wildfire, and four hillslopes adjacent to the Schoonover fire that were burned by a prescribed fire in 2005). These data were combined with our pre-existing data from seven wild and three prescribed fires to yield a total dataset of 422 plot-years of data from 110 untreated hillslopes. We also conducted rainfall simulation experiments in the third year after burning on plots in the Bobcat wildfire, and in the second and third years after burning in the Hayman wildfire. Most of the study sites were in areas that burned at high severity, as previous work had shown that these areas generate nearly an order of magnitude more sediment than sites burned at moderate and low severity (Benavides-Solorio, 2003).

Sediment production rates from sites burned at high-severity generally approach background rates by the third summer or roughly 24 months after burning. However, in drier areas with particularly coarse-textured soils, revegetation rates are substantially slower. In these sites 50-60% ground cover may not be achieved until four or even five years after burning. In the June 2000 Bobcat fire, sites in the granitic Green Ridge area had lower ground cover and elevated erosion rates through summer 2004, while sediment production rates in the sites with finer-textured micaceous soils dropped to near-zero values by summer 2003. In the Hayman and Schoonover fires, erosion rates were still elevated in summer 2006, which is four full years after burning. We attribute the slower revegetation and post-fire recovery rates in areas with coarse-textured soils to the limited ability of these soils to store and retain soil moisture. The implication is that in dry areas like the Colorado Front Range, soil texture is a critical control on post-fire revegetation rates, and elevated post-fire erosion rates will persist longer in areas with particularly coarse-textured soils. When compared to other regions, it appears that the Colorado Front Range has exceptionally high post-fire erosion rates given the limited amount of precipitation, and is among the slowest to recover.

Most of these data are presented in a M.S. thesis available on Dr. MacDonald's web site (Pietraszek, 2006), and this confirms the general trends published in an earlier paper on our work (Benavides-Solorio and MacDonald, 2005). A draft paper summarizing the results of our current, much larger dataset is being prepared for submittal to a peer-reviewed journal.

OBJECTIVE 3: *Test the importance of different site characteristics on runoff and erosion rates from untreated burned areas and burned areas subjected to four different BAER treatments.*

Our work under this objective has focused on understanding the relative importance of the different factors that contribute to the observed large increases in post-fire runoff and erosion, and gaining a more detailed understanding of the underlying processes. Our initial focus was to empirically test the measured sediment production rates against a wide range of site variables. This work emphasized the untreated sites because multivariate analyses were only possible with this much larger data set. The resulting relationships then led to a series of laboratory experiments and more detailed field studies designed to better understand the processes that drive the observed, order of magnitude increases in post-fire runoff and erosion rates.

The most significant finding is that post-fire sediment yields at the hillslope scale are most closely related to percent surface cover (R^2=0.61, $p<0.001$). If the amount of ground cover is held constant, rainfall intensity is the next most important control on sediment yields, as summer thunderstorms generate nearly all of the post-fire erosion in the Colorado Front Range. For most of our work we have been using either the maximum 30-minute rainfall intensity (I_{30}) or the rainfall erosivity (Brown and Foster, 1987), but more recent analysis confirms Dr. Robichaud's observation that the 10-minute maximum intensity (I_{10}) is a slightly stronger predictor of sediment yields than the I_{30}. We cannot directly test the importance of soil water repellency for our entire dataset as we don't have soil water repellency for each site for each year. However, published soil water repellency data from the Bobcat and other fires indicate that much of the soil water repellency is lost within the first year after burning (Huffman et al., 2001; MacDonald and Huffman, 2004), but post-fire erosion rates showed little decline until the third year after burning (Benavides-Solorio and MacDonald, 2005; Pietraszek, 2006). On the Hayman fire the soil water repellency persisted into the second year at a depth of 3 cm, but high post-fire erosion rates continued for much longer (MacDonald et al., 2005; Pietraszek, 2006; Rough, 2007). These temporal discrepancies indicate that soil water repellency probably makes a much smaller contribution to the observed increases in post-fire erosion than is commonly assumed.

Our data consistently confirm the importance of percent surface cover in controlling post-fire sediment yields, but these empirical observations do not explain the underlying mechanism. We therefore conducted a series of rainfall simulation experiments as well as a field experiment where we raked all of the litter from three unburned hillslopes. The rainfall simulation experiments used two soils and four treatments: bare soil, a thin ash cover, a thick ash cover comparable to what was present after a high-severity wildfire, and a bare soil with a screen to reduce raindrop energy. The results showed that rainfall at 40 mm hr^{-1} quickly caused a thin structural surface seal to develop on the bare soil plots, and these plots had the highest runoff and erosion rates. The presence of ash on the soil surface reduced surface runoff and erosion rates, and larger reductions were observed for the thicker ash layer. The repeated simulations showed that this ash cover was rapidly removed, and by the second or third simulation the runoff and erosion rates were very comparable to the values being measured from the plots with no ash cover.

In the field experiment the raked plots produced just as much sediment for a given rainfall intensity as nearby plots that had been recently burned at high severity. Taken together, these results show that the high post-fire runoff and erosion rates observed in the Colorado Front Range are primarily due to the loss of surface cover and resultant soil sealing, and that soil water repellency is probably not a primary control. This view also explains why those BAER treatments that immediately provide ground cover are most effective in reducing post-fire runoff and erosion rates, while treatments such as seeding and PAM, are largely ineffective. This process-based explanation of post-fire erosion rates has been presented at recent conferences (Larsen and MacDonald, 2007), and is being finalized in a paper that will shortly be submitted to a peer-reviewed journal. The empirical analyses of our hillslope-scale data from burned areas are summarized in the M.S. thesis by Pietraszek (2006), and a paper that follows up on our earlier field observations (Benavides-Solorio and MacDonald, 2005) is being prepared for submission to a journal.

A separate component of our work has been to determine the relative importance of sheetwash versus rill erosion as sources of post-fire sediment. For this component of the study we established numerous cross-sections on the major rills in most of our study sites in the Hayman and Schoonover wildfires, and monitored the changes in cross-sectional area over time. The calculated changes in rill volume were then compared to the sediment yields measured from the sediment fences. The results show that the rills were consistently incising during each major rainstorm, and the mass of material removed from the rills typically accounted for about 60-80% of the sediment yields measured from the sediment fences at the bottom of each hillslope (Pietraszek, 2006). We conclude that the hillslopes are generating most of the surface runoff, but the rills generated by concentrated flow are generating most of the sediment. This conceptual model helps confirm why mulching in the rills is a relatively ineffective treatment as compared to applying mulch on the hillslopes.

OBJECTIVE 4: *Use the information and understanding developed in this project to better predict post-fire runoff and erosion risks for the four BAER treatments being evaluated in this study as well as the no treatment alternative.*

The unique dataset collected under this project is allowing us to develop, test, and validate different models for predicting post-fire erosion. Pietraszek (2006) used half of the hillslope-scale data to develop an empirical model to predict post-fire erosion from untreated sites, and then validated this model against the other half of the data. He also developed a series of progressively simpler models, and the simpler empirical models performed nearly as well as the more complex empirical models that required more input data. A more realistic and rigorous test was to use the data from all but one fire to develop an empirical model, and then test the resulting empirical model against the data from the fire that had been excluded in model development. These tests yielded much less positive results for the different empirical models, and this indicates that locally-developed empirical models may still be relatively poor predictors of post-fire erosion from another fire in the same geographic region.

More recently we have been using our data from untreated sites to test the Revised Universal Soil Loss Equation (RUSLE) and Disturbed WEPP (Water Erosion Prediction Project). The basic results are that neither model is able to accurately predict post-fire sediment yields on a site-by-site basis because of the high variability between sites and the inability to accurately represent all of the site characteristics. Both models are much more successful at predicting average values for a given fire and fire severity, and Distrubed WEPP generally performed better than RUSLE. Both models also tend to overpredict low erosion rates and underpredict high erosion rates. Our paper on the validation of Disturbed WEPP and RUSLE has been through two rounds of reviews and is now awaiting acceptance for *Water Resources Research*. In this paper we also make a series of recommendations for using and modifying Disturbed WEPP and RUSLE to more accurately predict post-fire erosion.

Similarly, we have been using our data from untreated, seeded, and mulched hillslopes to validate ERMiT (Erosion Risk Management Tool), which is a probabilistic, web-based model that uses the underlying WEPP technology. The results are consistent with our work on Disturbed WEPP, as ERMiT also tends to underpredict erosion rates for both untreated and mulched sites in the Colorado Front Range. Again we make specific recommendations as to how ERMiT might be improved, and these include a longer recovery period and an increased likelihood for an entire hillslope to burn at high severity. We are currently finalizing a paper on the validation of ERMiT for submission to a peer-reiewed journal. We have not developed or tested erosion prediction models for the hydromulch and PAM treatments because our data set is too limited and there aren't any models designed to predict post-fire erosion rates for these two treatments.

OBJECTIVE 5: *Determine the extent to which erosion rates and predictive models can be transferred between the small plot, hillslope, and small watershed scales.*

A key issue for managers and researchers is whether erosion rates measured at the plot or hillslope scale can be extrapolated to larger scales. This is an important issue because it becomes much more expensive to make measurements and replicate studies at larger scales. Under this project we have collected runoff and sediment yields from rainfall simulations on 1 m^2 plots, hillslope sediment yields from plots varying in size from 0.003 to 0.7 ha, and Dr. Robichaud has been collecting data from 6 small watersheds that are approximately 3-5 ha. All of these sites are on the Hayman and Schoonover fires, and they all have relatively similar slopes, soils, and precipitation regimes. The results indicate that the sediment yields from the rainfall simulations cannot be readily compared to the hillslope- and watershed-scale data because the rainfall simulations use a single simulated storm with a very high intensity (approximately 80 mm in one hour). Efforts to normalize the data by precipitation, rainfall intensity, and rainfall erosivity have not yielded much success because the relationship between precipitation and sediment yields is non-linear and poorly defined for larger and relatively rare storm events. Hence rainfall simulation studies appear to be a useful technique for studying the role of specific factors and for model parameterization, but the data cannot be readily extrapolated to larger scales.

Comparisons of the hillslope and watershed-scale data are hindered by the lack of replication for the watershed-scale data, as only two watersheds have been left as untreated controls while the other four have been subjected to different BAER treatments. Hence the effects of spatial scale are best evaluated by using the data from the hillslope-scale plots, as these vary by a factor of nearly 100 in their contributing areas. For recently-burned high-severity sites, unit area sediment production rates do not appear to change significantly with increasing spatial scale, and the comparisons with the more limited watershed-scale data support this conclusion. As sites recover, the sediment production rates per unit area tend to sharply decrease with increasing spatial scale, so the hillslope and watershed-scale sediment yields become less comparable, but this is less important because the absolute values are so much lower. In the Colorado Front Range it is particularly difficult to extrapolate from hillslopes or small watersheds to much larger watersheds because there are few data on the spatial extent of the summer convective storms that generate most of the post-fire flooding and erosion. The data from our relatively dense network of rain gages show that storm rainfall can vary greatly over distances of one or two kilometers, but there is not a consistent pattern in the amount or intensity of rainfall. The large and largely unmeasured variation in rainfall probably helps explain some of the observed variability in sediment production rates at the hillslope and watershed scales. The important role of rainfall in controlling post-fire erosion rates, when combined with the spatial variability in the amount and type of precipitation, means that the accuracy of any predictive model will be limited by the accuracy of the precipitation data. A draft paper on the effects of spatial scale has been prepared, and we hope to submit this to a peer-reviewed journal later this year.

The final M.S. student supported by this project has been examining the post-fire changes in downstream channel cross-sections and estimating the time needed to return to pre-fire conditions. We do have a limited amount of pre-fire channel morphologic data, and these show that there has been nearly 1.5 m of aggradation in the lower Saloon Gulch watershed since the Hayman fire. Most of the runoff in this watershed now flows through the aggraded material as subsurface flow. In a second watershed there also has been extensive aggradation, but the presence of perennial surface flow is allowing the stream to incise through the aggraded sediment and slowly transport this material into the South Platte River. These two case studies indicate that streams with perennial surface flow may be able to slowly remove the accumulated post-fire sediment, but several decades may be required before the stream channel approaches pre-fire conditions. In streams without perennial flow the runoff rates decline rapidly as the hillslopes recover, and in these channels the accumulated sediment may remain for hundreds of years (as suggested by Moody and Martin [2001] after the 1996 Buffalo Creek fire). Our overall conceptual model is that after burning there is a very rapid headward extension of the channel network and extensive rilling at the hillslope scale. This extension of the channel network is the predominant source of post-fire sediment, and the downstream transport of this sediment can cause extreme aggradation in lower gradient, downstream areas. There is a large discrepancy between the relatively rapid hydrologic and geomorphic recovery at the hillslope scale where surface erosion and incision are the dominant processes, and the much slower recovery of downstream channels where aggradation is the dominant post-fire response. The resulting draft thesis is now under revision and should be completed later this year, and this will be posted on Dr. MacDonald's web site and form the basis for a peer-reviewed journal article.

3. LITERATURE CITED

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4. DELIVERABLES

The original proposal indicated that the deliverables from this project will include: (1) a minimum of five M.S. theses, with each of these expected to lead to one or more peer-reviewed journal articles; (2) presentations at scientific conferences; (3) data to populate and validate current erosion prediction efforts, and (4) annual reports as specified by the grant agreement. The proposal also stated that the results will be presented to users through various meetings and workshops, and disseminated through Dr. MacDonald's web site.

To date, the project has resulted in two M.S. theses with three others nearing completion. The results have contributed to five publications (one published journal article, one monograph, and three book chapters), with four more book chapters in press. We also have one journal article that should be accepted within the next few days, three others in draft form, and four thesis chapters that are being prepared for submission. All of the publications, including those in press and those that have been submitted for review, are available along with the completed theses from Dr. MacDonald's web site (www.cnr.colostate.edu/frws/people/faculty/macdonald/macdonald.html). Over 40 scientific presentations have resulted from this work, including at least 12 presentations at various workshops and training courses aimed at land managers. We also have been interviewed by various newspapers and magazines, particularly with respect to the effectiveness of post-fire rehabilitation treatments and the erosion risks over time. Each of the annual reports was submitted as specified in the proposal. The following section lists the journal articles, invited book chapters, and completed theses in alphabetical order, and this is followed by a listing of the presentations at scientific meetings and workshops in reverse chronological order.

4.1. Journal articles, book chapters, and completed M.S. theses (in alphabetical order)

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Troendle, C., L.H. MacDonald, I.J. Larsen, and C. Luce, in press. Fuels management and water yield. In *Cumulative Watershed Effects of Fuels Management: A Western Synthesis*. Gen. Tech. Rep., U.S. Department of Agriculture, Rocky Mountain Research Station, Fort Collins, CO. (Some of the information in this report was derived from this project.)

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

2. Training courses, scientific presentations, and published abstracts (in reverse chronological order)

<u>2007</u>

Larsen, I.J., and L.H. MacDonald, 2007. Does ash contribute to post-fire soil sealing and increased runoff rates? Presentation and abstract, *AGU Hydrology Days*, Colorado State University, Fort Collins, CO.

MacDonald, L.H. 2007. Post-fire erosion in the Colorado Front Range: Processes and Rehabilitation. *Invited lecture, University of Guadalajara*, Mexico.

MacDonald, L.H., M. Welsh, Z. Libohova, I.J. Larsen, E. Brown, J. Pietraszek, and D. Eccleston, 2007. Long-term sediment production from forest thinning, roads, and wildfires. *Invited seminar, Dept. of Forest, Rangeland, and Watershed Stewardship*, Colorado State University, Fort Collins, CO.

MacDonald, L.H., and I.J. Larsen, 2007. Sediment from wildfires: production, delivery, and recovery at different spatial scales. Invited lecture, *Afforestation and Sustainable Forests to Combat Desertification*, 16-19 April, Jerusalem, Israel.

MacDonald, L.H., and I.J. Larsen, 2007. Sediment from wildfires: production, delivery, and recovery at different spatial scales. *Eos Trans. AGU*: 88(23) Joint Assembly Supplement, Abstract H43A-05.

Robichaud, P. Latest on postfire treatment effectiveness, *U.S.D.A. Forest Service National BAER Coordinator's Meeting*, Spokane WA.

Robichaud, P. Postfire treatment effectiveness. *U.S.D.A. Forest Service Region 1 and 4 Introduction to BAER and Refresher Course*, Missoula, MT.

Schaffrath, K. and L.H. MacDonald, 2007. Surface armoring and post-fire recovery in the Colorado Front Range. Presentation and abstract, *AGU Hydrology Days,* Colorado State University, Fort Collins, CO.

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Eccleston, D., and L. H. MacDonald, 2006. Post-fire channel change in small mountainous catchments. Presentation and abstract, *AGU Hydrology Days,* Colorado State University, Fort Collins, CO.

Larsen, I.J., and L.H. MacDonald, 2006. Predicting post-fire sediment yields with RUSLE, WEPP, and ERMiT: accuracy and limitations. *EOS Trans. AGU* 87(52), Fall Meet. Suppl. Abstract H31C-1437.

Larsen, I.J., L.H. MacDonald, P.R. Robichaud, and W.J. Elliot, 2006. Predicting variability in post-fire sediment yields: Efforts to validate ERMiT in the Colorado Front Range. Presentation and abstract, *AGU Hydrology Days,* Colorado State University, Fort Collins, CO.

Libohova, Z., L. MacDonald, and J. Pietraszek, 2006. Erosion rates of different particle sizes from roads and a wildfire, Colorado Front Range. *18th World Congress of Soil Science*, 9-15 July, Philadelphia, PA.

MacDonald, L.H., 2006. Post-fire Erosion in the Colorado Front Range: Processes, Rehabilitation, and Recovery. *Invited seminar, University of Georgia*, Athens, GA.

MacDonald, L.H., 2006. Effects of fires on soils, runoff and erosion: processes and rehabilitation. *Six hours of invited lectures, training course on forest restoration*, Lisbon, Portugal.

MacDonald, L.H., 2006. Post-fire erosion in the Colorado Front Range: processes, rehabilitation, and recovery. *Invited seminar, Oregon State University*, Corvallis, OR.

MacDonald, L.H., Welsh, M., Brown, E., and Z. Libohova, 2006. Effects of forest thinning and roads vs. fires in the Colorado ponderosa pine zone. Invited presentation at the *Long-Term Ecological Research All Scientists Meeting*, 20-23 September, Estes Park, CO.

MacDonald, L.H., E. Brown, J.H. Pietraszek, M. Welsh, D. Eccleston, and I.J. Larsen, 2006. Long-term sediment production and recovery rates from forest thinning, roads, and wildfires. *EOS Trans. AGU* 87(52). Fall Meet. Suppl., Abstract B22E-08.

Miller, M.E., and L.H. MacDonald, 2006. Modeling post-fire erosion in the Western US. Presentation and abstract, *AGU Hydrology Days*, Colorado State University, Fort Collins, CO. (Some of the information in this paper was derived from this project.)

Robichaud, P.R. Latest findings of effectiveness of various postfire rehabilitation treatments. *Joint U.S.D.I.-U.S.D.A. Forest Service Burned Area Emergency Response Meeting*, San Diego, CA.

Robichaud, P.R. Latest findings on effectiveness of various postfire rehabilitation treatments, *U.S.D.I. Burned Area Emergency Response Pre-season Meeting*, Reno, NV.

Robichaud, P. Latest findings on effectiveness of various postfire rehabilitation treatments. *U.S.D.A. Forest Service Region 4 and 6 BAER Refresher Workshop*, LaGrande, OR.

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Brown, E., L.H. MacDonald, Z. Libohova, D. Rough, and K. Schaffrath, 2005. Sediment production rates from forest thinning, wildfires, and roads: what is important? *Eos Trans. AGU* 86(52): H51E-0418, AGU Fall Meeting, San Francisco, CA.

Hughes, D.J., and L.H. MacDonald, 2005. Assessing the role of ground cover in post-fire runoff and erosion using simulated rainfall, Colorado Front Range. Presentation and abstract, *AGU Hydrology Days*, Colorado State University, Fort Collins, CO.

Larsen, I.J., and L.H. MacDonald, 2005. Predicting post-fire sediment production at the hillslope scale: efforts to validate RUSLE and Disturbed WEPP in the Colorado Front Range. Presentation and abstract, *AGU Hydrology Days*, Colorado State University, Fort Collins, CO.

Larsen, I.J., and L.H. MacDonald, 2005. Predicting post-fire erosion at the hillslope scale: Efforts to validate RUSLE and Disturbed WEPP. *Eos Trans. AGU* 86(52):H41C-0421, AGU Fall Meeting, San Francisco, CA.

MacDonald, L.H., 2005. Post-fire erosion and rehabilitation: a process-based understanding. Invited 4-hour lecture, *European Unition Advanced Course on Land Restoration*, Zaragoza, Spain.

MacDonald, L.H., 2005. Post-fire soil erosion in the USA. *Invited presentation, Jornada sobre Incendios Forestales (Forest Fires Workshop)*, Universidad Miguel Hernandez de Elche, Alicante, Spain.

MacDonald, L.H., 2005. Post-fire erosion in the Colorado Front Range: processes, controls, and rehabilitation. *Invited seminar, Dept. of Ecology, Universidad de Alicante*, Spain.

MacDonald, L.H., D. Rough, and Z. Libohova, 2005. Effects of forest fires on the strength and persistence of soil water repellency in the Colorado Front Range. *EGU Geophysical Research Abstracts* 7:08613.

MacDonald, L.H., and J. Pietraszak, 2005. Post-fire erosion at the hillslope scale in the Colorado Front Range: rates and controls. Presentation and abstract, *AGU Hydrology Days,* Colorado State University, Fort Collins, CO.

Miller, M.E., and L.H. MacDonald, 2005. Large scale predictions of potential post-fire erosion. *Eos Trans. AGU* 86(52):H34C-05, AGU Fall Meeting, San Francisco, CA.

Robichaud, P. BAER: new information, latest methods, what is effective? where? *USDA Forest Service Region 4 Soils Meeting*, Grangeville, ID.

Rough, D., and L.H. MacDonald, 2005. Effectiveness of BAER treatments in reducing post-fire erosion after the Hayman Fire, Colorado Front Range. Presentation and abstract, *AGU Hydrology Days*, Colorado State University, Fort Collins, CO.

<u>2004</u>

Hughes, D.J., L.H. MacDonald, J. de D. Benavides-Solorio, 2004. Comparisons of post-fire runoff and erosion rates using a rainfall simulator, Colorado Front Range. Prresentation and abstract, *AGU Hydrology Days*, Colorado State University, Fort Collins, CO.

MacDonald, L.H., J. Benavides-Solorio, J. Stednick, J. Pietraszek, and D. Hughes, 2004. Controls on post-fire erosion rates from wild and prescribed fires in the Colorado Front Range. *Geophysical Research Abstracts*, Vol. 6, 06003, SRef-ID: 1607-7962/gra/EGU04-A-06003.

Pietraszek, J.H., and L.H. MacDonald, 2004. Hillslope erosion processes after high severity wildfires, Colorado Front Range. Presenation and abstract, *AGU Hydrology Days*, Colorado State University, Fort Collins, CO.

Robichaud, P., and J. Wagenbrenner. BAER effectiveness research: field tour. *Implementing Emergency Stabilization Techniques*, *Regional Burned Area Emergency Response (BAER) Training,* Denver, CO.

Rough, D., L.H. MacDonald, and J. Wagenbrenner, 2004. Effectiveness of post-fire rehabilitation treatments in reducing post-fire sediment yields. *Geophysical Research Abstracts*, Vol. 6, 06016, SRef-ID: 1607-7962/gra/EGU04-A-06016.

Rough, D., and L. H. MacDonald, 2004. Effectiveness of PAM treatments in reducing post-fire erosion on the Schoonover Fire, Colorado Front Range. Presentation and abstract, *AGU Hydrology Days*, Colorado State University, Fort Collins, CO.

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Pietraszek, J. H., and L.H. MacDonald, 2003. Hillslope erosion processes after high severity wildfires, Colorado Front Range. *Eos Trans. AGU, 84*(46), Fall Meet. Suppl., Abstract H51D-1106.

Robichaud, P.R. BAER effectiveness monitoring. *USDA Forest Service Region 1 Soils Workshop*, Butte, MT.

Robichaud, P.R. When the rains come . . . postfire rehabilitation effectiveness. *Fire Science for Managers and Policy Makers Seminar Series*, USDA Forest Service, Washington, D.C.

Rough, D. T., and L. H. MacDonald, 2003. Effectiveness of emergency rehabilitation treatments in reducing post-fire erosion, Colorado Front Range. *Eos Trans. AGU, 84*(46), Fall Meet. Suppl., Abstract H51D-1107.