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Deliverable #2: Draft manuscript describing the study area project. Manuscript will be submitted to a journal by early summer after some additional work is completed. Preliminary results from this study were presented at the 2nd Fire Behavior and Fuels Conference, Destin, FL on March 28, 2007.

# The costs and benefits of large scale treatment programs under conditions approximating real-world fire, climate, vegetation and economic conditions

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## Introduction

Mechanical fuel treatments have been identified as one method for reducing fuel loads, and thus reducing fire the probabilities of high-intensity, damaging wildfires in fire-prone areas in the Western U.S (Graham et al. 1999, Graham et al. 2004). Alternatives to mechanical fuel treatments include wildland fire use (natural prescribed fire) and (unnatural) management-ignited prescribed fire. Continuing concerns with the risks of escaped fire and air quality impacts will make these alternatives more difficult to implement. In addition, continuing seasons of extreme weather and subsequent fire render reliance on suppression as the principal means of limiting catastrophic losses unappealing. Thus, interest in and promotion of mechanical fuel treatments will likely persist well into the future.

Previous research has suggested that mechanical fuel treatments can reduce the extent and intensity of fires (Rothermal 1991, van Wagtendonk 1996, Stephens 1998, Scott 1998, Finney 1998, Graham et al. 1999, Carey and Schumann 2003, Graham et al. 2004, Pollett and Omi 2004). Other research has shown that the costs and losses from wildfire can be substantial (Butry et al. 2001, Kent et al. 2003). However, conducting an accurate economic assessment of the long run costs and benefits deriving from fuel treatment programs requires that the uncertainties of fire location, extent, and climate and weather conditions be accounted for. We contend that simulation approaches can account for many of these uncertainties and permit such an assessment. Simulation approaches may be particularly appropriate where there is limited experience and data on fuel treatments and their impacts, which would allow for a statistical analysis of treatment effects (e.g., Mercer et al. 2007). A useful simulation would include actual landscape data, stand growth, alternative treatment scenarios, and stochastic fire activity. From this, potential landscape outcomes emerge under each treatment scenario.  Applying statistical estimates of economic benefits, costs and damages to these simulation outcomes results in a probability distribution of total treatment program benefits.  We evaluated a single landscape fuel treatment project under a single fire weather scenario to determine if the data produced by the fire simulation models could be used to develop estimates of the effects of treatments on such economic impacts as suppression costs.

This study focused on two main tasks: (1) generating data from the landscape analysis by integrating existing data and tools to be used in the economic analysis, and (2) generating expressions of treatment and suppression costs that can adequately summarize the variability in these costs. We used a 400 thousand acre landscape from the Lincoln National Forest to evaluate the methodology.

The general consensus from the literature is that, although fuel treatments can reduce fire severity, there is still a need for landscape level analyses of the effectiveness of fuel treatments to accomplish stated fire risk and behavior goals (Agee and Skinner 2005). Without statistical evidence of treatment effects, research is focused on the simulation approach to evaluating treatment effects. There have been, however, some initial attempts at accounting for the broad scale, long-run influences of mechanical fuel treatments to partially address this need. In a study focusing on BLM land, Stratton (2004) uses FARSITE and FlamMap to evaluate changes in key pre- and post-treatment variables, including burned area, fire perimeter, and crown fire area. Finney (2001, 2005) quantify the impact of alternative fuel treatment patterns on fire spread across a landscape. Finney et al. (2006) employ a model called RandIg/FlamMap to account for the stochastic nature of wildfire and the growth of fuels following fuel treatments when quantifying their long-run net impacts.

The principal objective of this study is to quantify the economic net benefits of fuel treatments. To do this, similar to previous analysis, we use simulation approaches to quantify the net impact of fuel treatments on wildfire activity. Simulation results are translated into net benefits by applying information about treatment costs and suppression cost changes resulting from the changes in wildfire activity that they produce. Below, we describe our study area, results of completed simulations, estimates of suppression cost relationships to wildfire activity, and a prototype economic analysis framework for quantifying net benefits.

## Study Area

The study area is a 400 thousand acre southern New Mexico landscape that was being studied for treatment to protect human and Mexican Spotted Owl habitats. The treatments were designed and their effects predicted by a local interdisciplinary team. In our analysis, the treatments and effects are accepted as given. The study area encompasses parts of the Sacramento and Smokey Bear Ranger Districts of the Lincoln National Forest, New Mexico.  The treated portion of the study area comprises 87,000 acres, or about 23 percent of the total landscape, which is above the amount recommended by

Finney et al. (2006) to achieve long-term treatment effectiveness. The treatments, including their design and effectiveness, are further discussed in Ortega et al. (2006).

## Methods

There are two distinct components to the analysis of costs and benefits from landscape level fuel treatment programs: the landscape analysis and the economic analysis. The economic analysis will only be as good as the outputs from the landscape analysis, including: the determination of treatment type, extent and arrangement and predicted effects under specified fire weather conditions; the applicable fire weather scenario; vegetation condition and subsequent growth; ignition probabilities; fire length (duration time) estimates; and the fire simulation itself. Without a reasonable simulation of a succession of fire years, including the location, length, extent and intensity of fire on a landscape, the benefits of the fuel treatment program cannot be calculated. The economic methods are well developed, and the only analytical uncertainty of our study is whether the data are available at the level of detail needed to develop reasonable treatment and suppression cost estimates. These two analytical components are discussed below.

## Landscape Analysis

The landscape analysis for this study will include a single mechanical fuel treatment scenario on the Lincoln National Forest. The scenario consists of five dimensions or scenario “variables”: (a) specified fire weather conditions; (b) a starting spatial matrix of current stand conditions, including a wildfire risk measure (e.g., condition class, torching index, crowning index); (c) a specified treatment approach (e.g., thin from below, flexible stand density index-based); (d) a specified treatment extent (i.e., number of acres of treated); and (e) a specified treatment arrangement (e.g., random location, “fire break” for WUI areas, highest-risk-first, herringbone, etc.). Decisions on these scenario variables were made by the local land managers. (In a more dynamic analytical framework, it might be possible to address the trade-offs between the treatment arrangement and type and suppression cost effects, but we will leave that to a later analysis.)

FSVeg common stand exam data from the National Resource Information System (NRIS) provide the detailed vegetative conditions. The Integrated Forest Management System (INFORMS) are used to spatially reference the vegetative data and update FARSITE layers. Treatments are developed and applied with the Fire and Fuels Extension to the Forest Vegetation Simulator (FFE-FVS: Reinhardt and Crookston 2003). Note that all of these tools and data are currently available and used by federal land management agencies. The vegetation after the application of the treatments is developed in a similar manner. Therefore, we have two alternative landscapes to compare in the landscape analysis: treated and untreated.

The simulations are conducted with RandIg/FlamMap. These are done for both treated and untreated landscapes and for each fire weather condition and involve igniting 1,000 fires in random locations on the study area landscape, allowing each of the fires to burn until self-extinction or five days, whichever is first. From the 1,000 fires simulated for each fire weather and treatment scenario, the model generates a probability of burning for each cell of the landscape, including the probability of burning at flame lengths in 0.5m increments. The simulations also retain the size of each fire burned, resulting in a fire size distribution for each scenario, and a total acreage burned under each scenario. Multiplying the probability of each intensity by 1,000 for each cell gives the number of times a cell burns at each intensity. This allows construction of a probability distribution of simulated intensity levels for the treatment and no treatment alternatives.

## Economic Analysis

To develop reasonable and reliable estimates of the costs and benefits of landscape scale fuel treatment programs, we use information about the costs of fuel treatments, which we obtain from existing studies, and about the costs of suppressing fires, which we estimate from historical fire data using statistical approaches. While these two categories of costs represent only a portion of the overall costs and benefits of a fire program, they comprise the majority of the monetized and quantifiable costs accruing to the land management agency and adjacent landowners (e.g., Kent et al. 2003). We note here that our economic assessment ignores the losses generated by wildfires, including damages to timber and private property, impacts of fire and smoke on human morbidity and mortality, and effects on other non-timber, non-market goods and services (e.g., Butry et al. 2001). Likewise, we are ignoring the additional positive and negative impacts associated with mechanical fuel treatments themselves, including how treatments affect soils, water quality, ecosystem functions, and the values placed on forests by humans.

*Treatment Costs*

Treatment cost estimates are based on Skog et al. (2006). In the absence of a cut-list describing the numbers and sizes of trees removed as well as specific site information, we are unable to apply a treatment cost model to the simulations. In this analysis treatment cost per acre is $1,100 which is the mean identified by Skog et al. (2006). The treatment scenario assumes that 23 percent of the landscape is treated, but treating the landscape requires several years of work, due to limited budgets. To accommodate the budget constraint, we assume that 10 percent of the identified treated area is treated each year. It follows, then, that it takes 10 years to treat all of the planned treated area and therefore ten years to achieve the full impact of the treatment program on wildfire activity (and hence suppression costs).

*Suppression Costs*

Calculation of wildfire suppression costs requires accounting for the timing of fuel treatments and the effects of treatments on wildfire sizes, frequencies, and intensities under differing weather conditions. We use data from the Forest Service financial records (the Foundation Financial Information System) and from the National Interagency Fire Center database to estimate statistical models relating the cost of fire suppression to fire characteristics and other site variables. The FFIS and NIFMID data are matched, and weather data applicable to each fire in the data set are obtained from Fire Family Plus. Data on 120 fires in the USFS Southwestern Region (Region 3) for FY2000-2003 and their suppression costs are expressed in real (year 2000) dollars.

Specifically, suppression costs are expressed as a function of time of year (i.e., "season"), fire length (in time), fire intensity, fire size class, fire location, and site elevation and slope. Fire intensity in this model was derived from flame lengths reported in NIFMID, and intensity 1 represents flame lengths of 0-4 feet, intensity 2 is 4-8 feet and intensity 3 is 8+ feet. Although preliminary models included several weather variables hypothesized as potentially important (wind speed, temperature, humidity, energy release component, and KBDI), these variables had little statistical effect directly on suppression costs. We contend that, in the final versions of these statistical models, reported below, most of the effects of weather are captured in the size and intensity variables.

In the final statistical estimate of the suppression cost function, fire size and intensity both enter as a set of class variables (dummies), and the intensity variables are interacted with total burned acre for the fire (Table 1). Initial models also included small fires (size class C and smaller, less than 100 acres), but their inclusion added considerable dispersion to the data and thereby reduced model significance. We determined that because most area burned is in the larger size classes (D and higher), estimation of a D and higher statistical model would capture the majority of suppression costs observed on a landscape. The estimated model shown in Table 1 therefore applies only to fires in size class D and higher (with the size class D fire variable omitted and therefore having its effect captured by the intercept).

Table 1. Ordinary least squares regression results: FY2000-2003 suppression costs for USFS Southwestern Region ($n$ = 120, $R^2$ = 0.76).

| Variable | Parameter Estimate | Std. Error | *t* value |
|---|---|---|---|
| Intercept | 178,815 | 188,349 | 0.95 |
| Size Class E | 361,040 | 281,248 | 1.28 |
| Size Class F | 652,665 | 342,696 | 1.90 |
| Size Class G | 2,785,317 | 493,103 | 5.65 |
| Intensity 1 x Burned Acres | -162.30 | 81.40 | -1.99 |
| Intensity 2 x Burned Acres | -2.51 | 65.48 | -0.04 |
| Intensity 3 x Burned Acres | 143.15 | 15.27 | 9.38 |

Applying the regression model shown in Table 1 to the mean fire size by size class and intensity level for observed D and larger fires occurring, 1985-2004, in the USFS Southwestern Region, we calculate the estimated suppression cost for the average fire in each size class and intensity level. Dividing these by the mean fire size for each size class and intensity level gives the average cost per acre by size class and intensity level, presented in Table 2. The per acre costs of fires less than 100 acres in size (classes A, B, and C) are calculated by summing over intensity level the acres burned and suppression costs then dividing total cost by total acres burned in each intensity level. These costs are also reported in Table 2. In general, the cost per acre decreases with fire size and increases with fire intensity.

Table 2. Estimated Suppression costs per acre by size class and fire intensity for USFS Southwestern Region.

| Size Class | Intensity 1 | Intensity 2 | Intensity 3 |
|---|---|---|---|
| A,B,C | 2,445.26 | 4,431.22 | 7,621.14 |
| D | 938.00 | 1,069.68 | 1,117.24 |
| E | 863.15 | 967.64 | 1,058.15 |
| F | 214.76 | 368.10 | 485.67 |
| G | 79.79 | 136.16 | 312.68 |

A complication in evaluating suppression costs using the fire simulation models is that these models are designed to simulate only escaped fires, those not controlled by initial attack. The determination of whether a fire ever achieves escaped status is reported in NIFMID, but there are few escaped fires for which suppression costs are recorded in NIFMID. Hence, our statistical models of suppression costs are based on all fires, not just escaped fires, and escaped and non-escaped fire suppression costs are deemed identical for fires of identical sizes and intensities. Acres in escaped fires represented 40 percent of the total acres burned in Region 3 from 1986 to 2004, although the fires represented only 3 percent of total number of fires.

To evaluate the effects of fuel treatments on fire suppression costs, the simulated distribution of fire sizes and intensities produced by the landscape simulation without treatments need to be translated to fire size and intensity distributions observed historically. To do this, we apply a proportional scaling procedure. The scaling involves comparing how the proportion of fires in each size and intensity class changed, in percentage terms, between the untreated and treated landscape simulation under each fire weather scenario. The results of these allocations for high fire weather are shown in tables 3 and 4.

Table 3. Conditional probability distribution of acres burned by size class and intensity for the treated landscape under high fire weather. Each cell is the probability of intensity given a final burned area. Rows sum to 1.

| Size Class | Intensity 1 | Intensity 2 | Intensity 3 |
|---|---|---|---|
| A,B,C | 0.602 | 0.349 | 0.050 |
| D | 0.381 | 0.457 | 0.162 |
| E | 0.357 | 0.516 | 0.127 |
| F | 0.297 | 0.428 | 0.275 |
| G | 0.145 | 0.450 | 0.405 |

Table 4. Conditional probability distribution of acres burned by size class and intensity for the untreated landscape under high fire weather. Each cell is the probability of intensity given a final burned area. Rows sum to 1.

| Size Class | Intensity 1 | Intensity 2 | Intensity 3 |
|---|---|---|---|
| A,B,C | 0.323 | 0.537 | 0.139 |
| D | 0.000 | 0.000 | 0.000 |
| E | 0.143 | 0.593 | 0.264 |
| F | 0.101 | 0.415 | 0.484 |
| G | 0.041 | 0.364 | 0.595 |

The differences in probabilities shown between tables 3 and 4 can be viewed as the net effects of fuel treatments on fire sizes and intensities. We apply these tables to the total acres burned in the treated and untreated landscape scenarios to determine the effect of fuel treatments on all size classes and intensities. To determine the effects on non-escaped fires, we assume that non-escaped fires would continue to be 60% of total burned acres both with and without treatment. Dividing the simulated escaped acres burned by 0.40 yields an estimate of the total area burned by escaped and non-escaped fires. The area burned by non-escaped fires is estimated by multiplying this total by 0.60. We assume that the treatments will have effects on non-escaped fires that are identical to escaped fires and use Tables 3 and 4 to estimate the shifts in intensity and size class for non-escaped fires.

At this time, our analysis includes only the high fire weather scenario. This analysis will be extended to include all fire weather in a fire season, with the contribution of each fire weather scenario to the total changes in fire acres and costs proportionate to the fire weather percentile from Fire Family Plus. In this case, high fire weather constitutes 16 percent of the total fire weather in the study area, and thus the contribution of the effects on acres and costs to the overall analysis of the effects of treatments on suppression costs will be for just 16 percent of the total time of a fire season.

## Assumptions and Sensitivity Analysis

Although not a part of the current analysis, it is possible to modify the assumptions used in this analysis to permit evaluation of the net benefits of treatments when confronted with other distributions of fire weather conditions. For example, we can shift the percentile fire weather to reflect global warming, perhaps increasing the high or extreme fire weather to represent more time observed in these weather states than observed historically in the study area. We can also modify our assumptions regarding the percentage contribution of escaped fires, the effects of treatments on non-escaped fires, and the size class by intensity effects of the treatments.

## Results

The results from the simulations for the high fire weather scenario are shown in Table 5, which includes the shifts in fire intensity probability, the shifts in size class distribution, and the shifts in total acres resulting from implementation of the full treatment program. This table also includes the effects on the simulated suppression costs.

Table 5. Simulated total acres burned and expected suppression costs over 1,000 randomly ignited fires under high fire weather conditions, with and without landscape treatments.

| Size Class | With Treatment | | Without Treatment | |
|---|---|---|---|---|
| | Acres (000) | Cost (000) | Acres (000) | Cost (000) |
| A, B, C | 4 | 16,465 | 0 | 229 |
| D | 6 | 6,055 | 0 | 0 |
| E | 33 | 31,892 | 8 | 8,181 |
| F | 586 | 209,227 | 50 | 20,832 |
| G | 46,058 | 9,217,693 | 130,347 | 30,958,899 |
| All sizes | 46,686 | 9,481,331 | 130,404 | 30,988,141 |

To apply these effects to the actual Lincoln National Forest study area, we use the percentage reductions in both acres and costs and apply these reductions to actual fire data. Because our fire records extend only from 1986 to 2004, and fire is highly variable on this landscape, there are inadequate data from this area alone to develop expected size and intensity acres. Thus, we use the USFS Southwestern Region averages and apply the simulation results depicted in Table 5 to the study area based on acres of wildfire observed historically in the study area. Expected changes in the study area acres burned and costs are shown in Table 6.

Table 6. Expected average annual acres burned and suppression costs for the Lincoln National Forest study area, without treatment and with treatment.

| | Without Treatment | With Treatment | % Change |
|---|---|---|---|
| Acres Burned | 3,864 | 1,384 | -64% |
| Suppression Cost (mm) | $3.2 | $1.0 | -69% |

The results shown in Table 6 assume that the simulated treatment, covering 23 percent (86,700 acres) of the study area, is fully in place. Assuming that high fire weather conditions are experienced 100 percent of the fire season, the expected savings in suppression costs per year, shown in Table 6, would be $2.2 million ($3.2 million – 1.0 million), once the treatment program has been fully phased in. Because we assume that treatments are implemented over 10 years, full suppression cost savings are not achieved until year 10. The cost of treating one tenth of the simulated treated area each year, 8,760 acres, is $9.5 million, but savings in suppression costs in the first ten years of the program are a fraction of the costs of treatment. Even after year 10, however, the suppression cost savings will only offset (100 x $2.2 million) ÷ $9.5 million = 24 percent of the expected annual treatment costs experienced under high fire weather conditions. Thus, other benefits must accrue from the treatments beyond suppression savings to make the proposed treatment program cost effective for the USFS.

## Summary and Further Research

We have developed a statistical model that can be used with landscape scale treatment projects to determine the potential savings in expected (average annual) suppression costs resulting from large-scale fuel treatment projects. Although still limited by various assumptions that were necessary, we believe this type of analysis and modeling will continue to improve and will result in valid and reliable measures of effects on economic variables of interest.

The next steps in this research include (1) developing simulations for the remaining three fire weather conditions comprising the fire weather profile for the study area (low, moderate, and extreme), (2) explicitly modeling a realistic phase-in and continuation of the treatment program (e.g., 10 percent per year), (3) including the effects of pre- and post-treatment and pre- and post-fire stand re-growth, and (4) improving the estimates of fuel treatment costs.

## Literature Cited

Agee, J.K. and C.N. Skinner. 2005. Basic principles of forest fuel reduction treatments. Forest Ecology and Management 211:83-96.

Butry, D.T., D.E. Mercer, J.P. Prestemon, J.M. Pye, and T.P. Holmes. 2001. What is the price of catastrophic wildfire? Journal of Forestry 99: 9-17.

Carey, H. and M. Schumann. 2003. Modifying wildfire behavior—the effectiveness of fuel treatments. National Community Forestry Center, Southwest Region Working Paper, April 2003. Accessed on December 12, 2005 at http://www.theforesttrust.org/images/swcenter/pdf/WorkingPaper2.pdf.

Finney, M.A. 1998. FARSITE: Fire Area Simulator-model development and evaluation. Res. Pap. RMRS-RP-4, Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 47 p.

Finney, M.A. 2001. Design of regular landscape fuel treatment patterns for modifying fire growth and behavior. Forest Science 47(2):219-228.

Finney, M.A. 2005. Calculating fire spread rates across random landscapes. International Journal of Wildland Fire 12(2):167-174.

Finney, M.A., R.C. Seli, C.W. McHugh, A.A. Ager, B. Bahro, J.K. Agee. 2006. Simulation of long-term landscape-level fuel treatment effects on large wildfires. USDA Forest Service Proceedings RMRS-P-41.

Graham, R.T., A.E. Harvey, T.B. Jain, and J.R. Tonn. 1999. The effects of thinning and similar stand treatments on fire behavior in Western forests. General Technical Report PNW-GTR-463. Portland, OR: USDA Forest Service, Pacific Northwest Research Station. 27 p.

Graham, R.T., S. McCaffrey, and T.B Jain. 2004. Science basis for changing forest structure to modify wildfire behavior and severity. General Technical Report RMRS-GTR-120. Fort Collins, CO: USDA Forest Service, Rocky Mountain Research Station. 43 p.

INFORMS. http://www.fs.fed.us/informs/index.php.

Kent, B., K Gebert, S. McCaffrey, W. Martin, D. Calkin, E. Schuster, I. Martin, H.W. Bender, G. Alward, Y. Kumagai, P.J. Cohn, M. Carroll, D. Williams, and C. Ekarius. 2003. Social and Economic Issues of the Hayman Fire. Hayman Fire Case Study, USDA Forest Service General Technical Report RMRS-GTR-114 (Revision), R.T. Graham, ed., p. 315-395. Fort Collins, CO: USDA Forest Service.

Mercer, D.E., J.P. Prestemon, D.T. Butry, and J.M. Pye. 2007. Evaluating Alternative Prescribed Burning Policies to Reduce Net Economic Damages from Wildfire. American Journal of Agricultural Economics 89(1):63-77.

NRIS. http://www.fs.fed.us/emc/nris/index.shtml.

Ortega, A.M., D.S. Martinez, R.A. Hall. 2006. Evaluating risks associated with forest management scenarios in areas dominated by mixed severity fire regimes in southeastern New Mexico. Proceedings of the 1st Fire Behavior and Fuels Conference; How to Measure Success. International Association of Wildland Fire, March 28-30, 2006, Portland, OR.

Pollett, J. and P.N. Omi. 2004. The effect of thinning and prescribed burning on crown fire severity in ponderosa pine forests. International Journal of Wildland Fire 11(1):1-10.

Reinhardt, E., and N.L. Crookston. (Technical Editors). 2003. The fire and fuels extension to the forest vegetation simulator. Gen. Tech. Rep. RMRS-GTR-116. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 209 p.

Rothermal, R.C. 1991. Predicting behavior and size of crown fires in the northern Rocky Mountains. Res. Pap. IN T-438. Ogden, UT: USDA Forest Service, Intermountain Forest and Range Experiment Station. 46 p.

Skog, K.E., R.J. Barbour, R.J., K.L. Abt, E.M. Bilek, F. Burch, R.D. Fight, R.J. Huggett, Jr., P.D. Miles, E.D. Reinhardt, W.D. Shepperd. 2006. Evaluation of silvicultural treatments and biomass use for reducing fire hazard in western states. Research Paper FPL-RP-634. Madison, WI. USDA Forest Service, Forest Products Laboratory. 29p.

Stephens, S.L. 1998. Evaluation of the effects of silvicultural and fuels treatments on potential fire behavior in Sierra Nevada mixed-conifer forests. Forest Ecology and Management 105(1-3):21-35.

Stratton, R.D. 2004. Assessing the effectiveness of landscape fuel treatments on fire growth and behavior. Journal of Forestry 102(7):32-40.

van Wagtendonk, J.W. 1996. Use of a deterministic fire growth model to test fuel treatments. Vol. II Assessments and Scientific Basis for Management Options. Wildland Resources Center Report No. 37. Davis: Centers for Water and Wildland Resources, University of California; 1155-1165.

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