Fuels Treatments and Fire Models: Errors and Corrections

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Fire behavior and fire effects models are arguably among the most important tools in fire and fuels management. Given the power, accessibility, and utility of these models, fuels planners and scientists commonly use them to compare potential fire intensity and severity on planned and unplanned wildland fires.

How well the models are run is another matter. Modeling errors in fuels treatment proposals and scientific papers can exaggerate or mischaracterize the effectiveness of potential fuels treatments designed to abate hazardous fire behavior. Unrealistic outputs can typically be traced to unrealistic inputs, so close analysis of common input errors can suggest best practices to minimize modeling problems and maximize treatment effectiveness. Beyond this, the revision of old models and the design of new models can promote ease of use and more realistic outputs in complex and extreme input conditions.

Modeling Fuels Treatments

Fire and fuels managers and planners use modeling software to predict changes in fire behavior resulting from surface and canopy fuels treatments according to the "activity fuels" that these treatments leave behind. In the Western United States, fuels treatments are typically designed to reduce surface fireline intensity, prevent crown ignition, and interrupt canopy fire spread; several models have the ability to predict changes in these behaviors, many based on equations developed by Rothermel (1972) and Van Wagner (1977) for surface and crown initiation and spread. Fire effects models, on the other hand, predict the consequences of fires, generating estimates of tree mortality, soil heating, erosion, fuels consumption, and emissions.

> Errors in modeling fuels treatment, fire behavior, and fire effects can often be tied to unsupported assumptions about actual conditions and over-reliance on default values.

In a recent survey of fire and fuels managers by Miller and Landres (2004), among the most used fire behavior models were BehavePlus, FARSITE, and NEXUS. Among fire effects models, several of the most used were First Order Fire Effects Model (FOFEM), Consume, the Fire Emission Production Simulator (FEPS), Fuels Management Analyst Plus, and the Forest Vegetation Simulator (FVS)-Fire and Fuels Extension (FFE) (Reinhardt and Crookston 2003). Development of both fire behavior and effects models (e.g., Crown Fire Initiation and Spread [CFIS]; Alexander 2007) continues.

McHugh (2006) reviewed the use of fire behavior and effects models by resource managers and fire scientists. Fuels managers use these behavior and effects models in fuels treatment planning to compare the results of proposed treatments. Fire and fuels scientists also use these models to compare outcomes on modeled fire behavior and to understand long-term changes in living and dead fuels. Between 1996 and 2009 alone, at least 19 papers were published in fire science and forestry journals and conference proceedings that used these models to predict fire behavior and/or effects following fuels treatment.

Many proposed fuels treatments and some of the recent scientific literature contain examples of the inexact application of these decision support tools—or more simply stated: "user errors." For example, a recent study by Jolly (2007) analyzed the sensitivity of BehavePlus to changes in live fuel moisture content, finding that users may commit errors if faulty assumptions are made. Other errors that may occur can be attributed to faulty assumptions regarding fuel moisture, wind adjustment, fuel model selection, fuel decomposition rates, fuel load estimates, foliar moisture content, and the patchiness of fuels. By examining these factors, future errors by fire and fuels managers and scientists may be avoided.

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Best Practices for Modeling Fuels Treatment Effects

1. **Fully disclose all inputs and assumptions.** Users should list all value assignments that were used in modeling (fuel moisture, loading, depths, and data sources). The greater the disclosure, the greater the result's repeatability and level of trust.
2. **Use field data as much as possible; use published estimates when necessary.** Field-derived values for fuel loading, depth, and moisture are always preferred. When these are not available and data collection is not possible, published values can be used but must be identified.
3. **Project results over time.** Treatment comparisons made immediately following fuels treatments may poorly characterize mid- or long-term fire behaviors. Comparing fire responses over longer timespans will help characterize treatment effects and guide the timing of retreatment or maintenance return intervals.
4. **Press the science community for decision support.** Activity fuels dynamics, for instance, are poorly understood; model users should support research that helps guide the management of these increasingly common fuels. Development of decision support tools that incorporate the dynamics of activity fuels and the effects of canopy and surface fuel patchiness should be encouraged.

Common Errors in Modeling

By being conscious of input factor complexity, managers may recognize and avoid modeling errors and increase the credibility of fuels treatment model output, while model developers can improve decision support tools to assist fuels planners and scientists. The following are common errors in assigning parameter values, their consequences in modeled outcomes, and best practices to avoid such errors in developing realistic and effective fuels treatments.

Fuel Moisture Estimation

Fuel moisture is a fundamental factor in the ignition and spread of wildland fires, and errors in moisture estimation are common in fire behavior modeling. These errors occur when investigators assign identical fuel moistures to different fuels treatment scenarios despite the differences in live and dead fuel moistures among stands with differing amounts of canopy closure.

Treatments designed to reduce stand density, canopy bulk density, or crown base height result in decreased woody fuel moisture content due to greater incoming solar radiation, greater wind penetration, and reduced relative humidity—factors requiring adjustment of input moisture levels. Assigned fuel moisture values should be derived from on-site measurements, and future research should examine fuel moisture variation in beneath-canopy fuels.

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Wind Adjustment Factor

Windspeed is another fundamental factor in fire spread and intensity, and the effects of fuels treatment on those winds is not generally appreciated: as stand density and vertical structure are reduced, so is the impediment to wind (Albini and Baughman 1979). A common goal of silvicultural fuels treatments is to increase the spacing between crowns and increase canopy base height (Agee and Skinner 2005), both of which increase in-stand windspeeds, a factor not always taken into account in fuels treatment comparisons.

Future research efforts should clarify the effects of different fuels treatments on the wind adjustment factor. In the meantime, most modeling software allows users to project wind speeds with the aid of look-up tables based on published approximations (e.g., Albini and Baughman 1979) or personal experience.

Fuelbed Characterization

Fuel Loading Estimates

Fuel mass is a major driver of fire behavior and severity, and errors in estimating fuel loading are common in published fuels treatment studies. Specific errors include use of unexamined default values and crude estimates of activity fuels.

Both underestimating and overestimating fuel loads result in poor prediction of fire intensity and severity, particularly where large amounts of woody activity fuels remain following a treatment. Rather than basing their estimates of loading on small sample sizes or on unsupported default values, researchers and managers should refer to photo series data (e.g., Ottmar and Vihnanek 2000), conduct on-site sampling using line intersect sampling (e.g., Brown 1974) or biomass equations (Means et al. 1996), or estimate fuel loading values with much deliberation.

Fuel Model Assignment

Fuel models are based on values of fuelbed loading, bulk density, surface area-to-volume ratio, moisture of extinction, depth, and heat content (Anderson 1982). Every fuel model carries its own assumptions about the interactions of these parameters, making fuel model selection (or "assignment") an integral part of meaningful analysis. Managers and scientists make fuel model assignment errors when they violate model assumptions. These fuel model assignment errors are most apparent when modeled fuelbeds contain activity fuel loadings that exceed the loads used to build the models; a recent example of this is the difficulty many managers and scientists have faced in modeling masticated fuelbeds. Users also commit assignment errors in applying the same models to both untreated and treated stands.

Fuel model selection is an important disclosure in any fuels analysis report. The Scott and Burgan (2005) models and models created in Fuels Management Analysts Plus (Carlton 2006) offer more input options for fuelbeds with substantial activity fuels. Users should also examine the methods of investigators that base their fuel modeling on collected field values.

Foliar Moisture Content

Many investigators fail to disclose modeled values of foliar moisture or use default values that may be poor estimates of actual field conditions. Some reports include assigned foliar moisture content values without justification or use values that lie on the extremes of published data.

In addition to surface fireline intensity and canopy base height, foliar moisture content is a determinant of torching and crown fire initiation. Its importance is minor at lower surface fire intensities, but its proportional importance increases and becomes operationally significant as predicted surface fire intensities increase (Keyes 2006) or when dead, dry foliage is attached to standing trees. In a review of published foliar moisture content values of western conifers, Keyes (2006) found that foliar moisture content in conifers of North America varied between 73 and 480 percent, depending upon species, foliage age, and season. The range and importance of such values require careful consideration when modeling fire behavior after fuels treatment.

Time Since Treatment

Model users often maintain constant fuel values when projecting fuel conditions into the future. Yet fuel load and the availability of activity fuels changes tremendously following treatment: both values are affected by the amount and arrangement of residual overstory (Carlton and Pickford 1982). In addition, the time elapsed since treatment is critical to fuelbed decay, recruitment, and recovery. This error is most obvious when a treated area is subjected to modeled wildfire soon after treatment and before fuelbed recovery.

As time elapses, downed fuels cure, decompose, and flatten. Particularly after fire and herbicide use—but also with mechanical treatments—tree and shrub mortality leads to substantial increases in post-treatment surface fuels. Depending on the time elapsed, fuel levels may be higher, lower, or the same as pretreatment fuels. Brose and Wade (2002) examined contrasting treatments across time, illustrating how treatment effects may be short-lived and long-term effects may be unexpected. Furthermore, post-treatment changes in vertical and horizontal canopy closure may change future windspeeds, affecting surface woody fuel moisture.

With time, fuels generated by treatment begin to decay, affecting subsequent potential fire behavior. Comparison of fuels treatment effects should thus address an extended period of time following the initial treatment—a factor typically modeled within the FVS-FFE.

Fuelbed Patchiness

Fire behavior and effects models suffer from a fundamental weakness that hinders their ability to match field observations: models assume fuelbed uniformity, while canopy and surface fuels are typically distributed in patches. While model developers are the first to point out this limitation, users may fail to recognize it.

Canopy fuel is a collection of individual crowns that may be patchy, regularly spaced, or distributed at random, and this distribution influences the spread of canopy fire whether or not the canopy bulk density among patches or stands are equal. Surface and ground fuels, too, are rarely arranged uniformly, even in fuelbeds without activity fuels. In stands with recent fuels treatments, activity fuels are typically patchy, whether aggregated in piles, on skid trails, or on bare soil generated by mechanical equipment.

In activity fuelbeds, available fuel loading and packing may be poor predictors of surface fire spread and intensity across these patchy fuels. In lieu of models that incorporate patchiness typical of managed fuelbeds, managers and scientists should acknowledge the irregularity inherent in activity fuelbeds and the resulting unpredictability in fire spread and intensity.

Conclusions

Errors in modeling fuels treatment, fire behavior, and fire effects can often be tied to unsupported assumptions about actual conditions and over-reliance on default values. In some cases, the basis for assigning fire modeling values are available but have not been adequately implemented. In other cases, model limitations are known but no compensation is made in assigning values or interpreting results.

Ultimately, the complex relationships between wildland fire and stand structure must be captured in useful rules and readily accessible forms so that the individuals responsible for prescribing fuels management operations can base their plans on a foundation of best available scientific knowledge. In general, guidance to assist fuels managers in model assumptions and parameter assignments needs revision to better support fuels treatment decisionmaking.

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References

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

Albini, F.A; Baughman, R.G. 1979. Estimating windspeeds for predicting wildland fire behavior. Res. Pap. INT-221. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 12 p.

Alexander, M.E. 2007. Software can assess fuels treatment effectiveness on crown fire behavior. Fire Management Today. 67(3): 30.

Anderson, H.A. 1982. Aids in determining fuel models for estimating fire behavior. Gen. Tech. Rep. INT-122. Ogden UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 22 p.

Brose, P.: Wade, D. 2002. Potential fire behavior in pine flatwood forests following three different fuels reduction techniques. Forest Ecology and Management. 163: 71–84.

Brown, J.K. 1974. Handbook for inventorying downed woody material. Gen. Tech. Rep . INT-16. Ogden UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 24 p.

Carlton, D.W. 2006. Fuels management analyst plus software. Estacada, OR: Fire Program Solutions, LLC.

Carlton, D.W.; Pickford, S.G. 1982. Fuelbed changes with aging of slash from ponderosa pine thinnings. Journal of Forestry. 86: 91–93, 107.

Jolly, W.M. 2007. Sensitivity of a surface fire spread model and associated fire behaviour fuel models to changes in live fuel moisture. International Journal of Wildland Fire. 16: 503–509.

Keyes, C.R. 2006. Role of foliar moisture content in the silvicultural management of forest fuels. Western Journal of Applied Forestry. 21(4): 228–231.

McHugh, C.W. 2006. Considerations in the use of models available for fuel treatment analysis. In: Andrews, P.L.; Butler, B.W., comps. Proceeding of the conference: Fuels Management–How to Measure Success; 28–30 March 2006; Portland, OR. Proc. RMRS-P-41. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 81–105.

Means, J.E.; Krankina, O.N.; Jiang, H.; Li, H. 1996. Estimating live fuels for shrubs and herbs with BIOPAK. Gen. Tech. Rep. PNW-GTR-372. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 28 p.

Miller, C.; Landres, P. 2004. Exploring information needs for wildland fire and fuels management. Gen. Tech. Rep. RMRS-GTR-127. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 36 p.

Ottmar, R.D.; Vihnanek, R.E. 2000. Stereo photo series for quantifying natural fuels. Volume VI: longleaf pine, pocosin, and marshgrass types in the Southeast United States. PMS 835. Boise, ID: National Wildfire Coordinating Group, National Interagency Fire Center. 56 p.

Reinhardt, E.D.; Crookston, N.L. 2003. The fire and fuels extension to the forest vegetation simulator. Gen. Tech. Rep. RMRS-GTR-116. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 218 p.

Rothermel, R.C. 1972. A mathematical model for predicting fire spread in wildland fuels. Res. Pap. INT-RP-115. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 40 p.

Scott, J.H.; Burgan, R.E. 2005. Standard fire behavior fuel models: A comprehensive set for use with Rothermel's surface fire spread model. Gen. Tech. Rep. RMRS-GTR-153. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 72 p.

Van Wagner, C.E. 1977. Conditions for the start and spread of crown fire. Canadian Journal of Forest Research. 7: 23–34.