FuelCalc: A Method for Estimating Fuel Characteristics

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***Abstract**—This paper describes the FuelCalc computer program. FuelCalc is a tool to compute surface and canopy fuel loads and characteristics from inventory data, to support fuel treatment decisions by simulating effects of a wide range of silvicultural treatments on surface fuels and canopy fuels, and to provide linkages to stand visualization, fire behavior and fire effects programs that rely on estimates of fuel loads and qualities.*

Canopy fuel characteristics, including available fuel, canopy bulk density, canopy base height and canopy cover are estimated from a list of trees.

***Key words**: canopy bulk density, canopy base height, wildland fuel, crown fire, fire behavior, biomass, stand table*

Introduction

Fuel treatment is mandated by the need to protect communities and municipal watersheds and manage ecosystems. Analysis to support fuel treatment decisions is required by the National Environmental Policy Act of 1969. In order to use the best available fire science in comparing fuel treatment alternatives, managers need access to high-quality fuel information, as well as the impact of fuel treatment alternatives on wildland fuels, fire behavior, fire effects, and fuel hazard. The most fundamental fuels information is, however, surprisingly hard to come by. We receive frequent requests for help from fuels managers who want to know simply: how can inventory data be converted to fuel quantities and qualities? Surface fuel loads, fire behavior fuel models, and canopy fuel characteristics are needed to model fire behavior, fire effects, smoke production, and to analyze fuel treatment alternatives. Managers need the ability to determine how these fuel quantities and qualities will change when treatments are applied to stands.

Site-specific, inventory-based data greatly strengthens the scientific foundation of fuel treatment decisions. Currently, although a variety of fuel analysis tools exist, it is quite daunting to perform these analyses with raw inventory data. There is a need for a simple, user-friendly, nationally applicable fuel analysis tool that accepts inventory data, allows users to simulate effects of silvicultural treatments on surface and canopy fuels, and provides linkages to other software for further analysis of fire behavior and fire effects in these fuels.

The FuelCalc computer program is a tool to meet these information needs. This tool, currently under development with support from the Joint Fire

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Science Program and the USDA Forest Service Rocky Mountain Research Station, will support fuel management decision-making directly and also provide input to a number of other analysis tools. This paper describes the sampling methods supported by FuelCalc, and the calculation procedures it uses to convert inventory data to estimates of fuel characteristics. It describes linkages and prescription development support provided by FuelCalc. Parts of FuelCalc, for example the canopy fuel calculations, are currently available in draft form, others are still in the design phase.

Fuel Strata in FuelCalc

Ground Fuels

Duff load information is critical in smoke management, soil heating, carbon balance, and site productivity applications. FuelCalc will include a method for estimating duff load based on a measurement of duff depth. Duff depth is multiplied by duff bulk density to estimate duff load. Duff bulk density can be entered or default values used based on cover type.

Surface Fuels

Surface fuel inventory may take a number of forms. FuelCalc will provide estimates from data collected using Brown's (1974) planar intercept method, Burgan and Rothermel's (1984) fuel sampling procedures, and Hardy's (1996) slash pile inventory method, as well as direct entry of fuel loads as estimated from photo-guides or other data sources. Crosswalks will be provided to standard fire behavior fuel models, and a first-cut custom fire behavior fuel model developed.

Planar intercept — Brown (1974) developed procedures for sampling down woody fuels by counting intercepts across a sampling plane by particles of different size classes. This is a well established method of inventorying woody fuels; FuelCalc contains procedures to convert this data to estimates of fuel loading.

Burgan and Rothermel — Burgan and Rothermel (1984) published a simple, effective method of inventorying surface fuel. The method relies on the relationship between fuel depth, load and bulk density. Field inventory requires estimates of depth and cover by life form, and the assignment of bulk density by comparison with photos. These inventory methods are supported in FuelCalc.

Hardy slash pile inventory — Hardy (1996) published guidelines for estimating biomass contained in slash piles. FuelCalc allows entry of pile shape and dimension, packing ratio and wood density, and uses these guidelines to estimate slash biomass.

Linkages to fire behavior fuel models — FuelCalc will provide a "best guess" standard fire behavior model (Scott and Burgan 2005) that seems to represent the sampled fuels.

Creation of custom fire behavior fuel models — FuelCalc will also provide a first cut custom fire behavior fuel model suitable for testing with BehavePlus (Andrews and Bevins 2003) or Nexus (Scott 1999).

Canopy Fuels

Van Wagner (1977) proposed a theoretical model suggesting that crown fire initiation is dependent on surface fire intensity and canopy base height, while sustained crown fire spread is dependent on crown fire rate of spread and canopy bulk density. His work has been further developed by Alexander (1988), Agee (1996), Scott and Reinhardt (2001), and Van Wagner (1993) and is incorporated in the Canadian Fire Behavior Prediction System (Forestry Canada 1992), FARSITE (Finney 1998), and NEXUS (Scott 1999).

Fire managers need estimates of canopy base height and canopy bulk density to use these fire models. The LANDFIRE program (Rollins, in prep.) has committed to mapping these variables at a 30 meter resolution for the continental U.S. In addition, land managers have a growing concern that crown fire activity may be increasing in some forest types due, in part, to fire suppression and resultant changes in stand structure. Assessing these changes in stand structure requires defining and consistently evaluating canopy fuel characteristics.

A rich body of literature exists quantifying tree crown and forest canopy characteristics for purposes other than fuel characterization. A number of studies exist that predict foliar and branch biomass from tree dimensions, typically diameter, sometimes in combination with height, crown ratio or sapwood thickness. Brown (1978) provides predictive equations for the common conifer tree species of the Inland West; Snell and Brown (1980), provide similar methods for Pacific Northwest conifers. A large number of allometric equations of this type from many research studies are summarized in the computer software BIOPAK (Means and others 1994). These equations, together with a list of trees representing a stand, may be used to estimate total foliar biomass, as well as biomass of branchwood of various sizes.

Canopy bulk density is the weight of available canopy fuel per unit volume of canopy space. It is a bulk property of the stand, not an individual tree. Estimates of total canopy biomass can be divided by canopy volume to estimate canopy bulk density. This method carries the implicit assumption that canopy biomass is distributed uniformly within the stand canopy. This assumption is unlikely to be true even in stands with very simple structures; multi-storied stands are likely even more poorly represented by this procedure.

Even canopy base height, a simple characteristic to measure on a single tree, is not well defined or easy to estimate for a stand. Neither the lowest crown base height in a stand nor the average crown base height is likely to be representative of the stand as a whole. In terms of its consequences to crown fire initiation, canopy base height can be defined as the lowest height above the ground at which there is sufficient canopy fuel to propagate fire vertically through the canopy. Using this definition, ladder fuels such as lichen, moss and dead branches can be incorporated. Sando and Wick (1972) suggested describing the canopy fuels by plotting the vertical distribution of available canopy fuel in thin (1-foot) vertical layers (figure 1). Canopy base height can then be computed as the height above the ground at which some critical bulk density is reached. Their method could also be used to define effective canopy bulk density. Scott and Reinhardt (2001) used the Sando and Wick approach in combination with Brown's (1978) equations to estimate canopy base height and canopy bulk density. Canopy base height was defined as the lowest height above which at least 100 lbs/acre/vertical foot of available canopy fuels was present. Canopy bulk density was defined as the maximum of a 15-foot deep running mean of canopy bulk density for one-foot deep vertical layers. This method has been incorporated into the Fire and Fuels

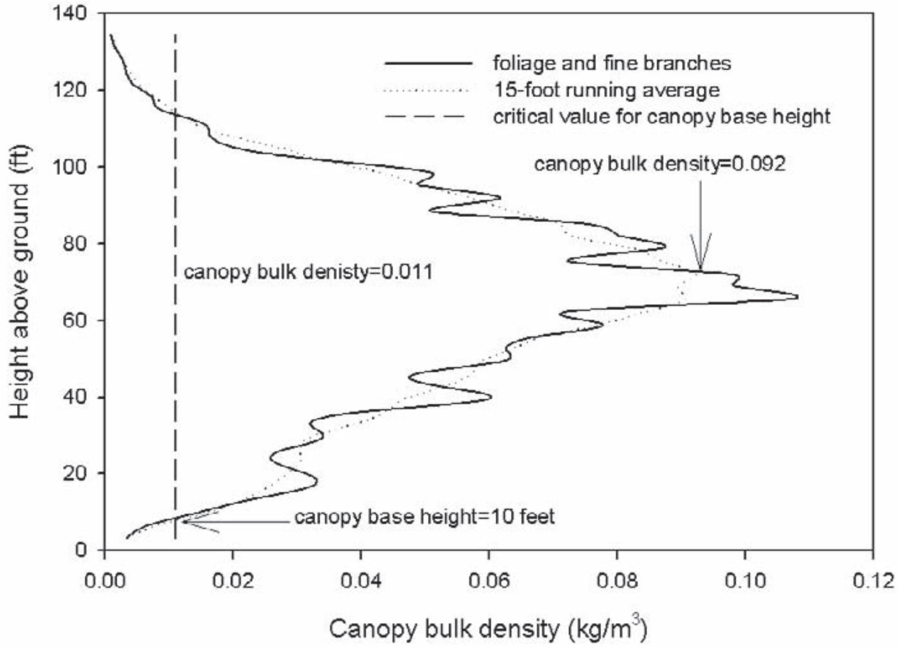

Figure 1—Vertical distribution of available canopy fuel as computed from a tree list using FuelCalc methods. Canopy bulk density is the maximum of the running mean. Canopy base height is the lowest point at which the running mean exceeds 0.012 kg/m^3, while stand height is the highest such point.

Extension to the Forest Vegetation Simulator (FFE-FVS, Reinhardt and Crookston 2003) and was validated by destructive sampling of forest canopies in five interior west conifer stands (Reinhardt and others, in prep.).

In FuelCalc we use this approach for computing canopy base height and canopy bulk density from a stand table or tree list. These methods have several advantages: 1. They do not require visual judgment calls or extensive interpretation that might result in inconsistent or subjective estimation, 2. They were developed with the underlying fire behavior models in mind, so the computed values are relevant in the context in which they will be used, 3. Because they are computed directly from a stand table or tree list they are derived using detailed information on stand structure, unlike methods based on image interpretation, 4. They can be performed quickly, using data sources that are widely available, so that values can easily be generated for thousands of stands.

Available canopy fuel load —Available canopy fuel load is assumed to be all the foliage and one-half of the 0-.25” branch material in the stand. We use Brown’s (1978) equations for estimating the weight of foliage and small (0-1/4”) branchwood for each tree from species and diameter. For some species no estimates of these components are available. In that case we use other published equations for total foliage biomass or crown biomass, if available, and crosswalk the proportions to Brown’s equations. If no foliage or crown biomass equations of any kind are available, we crosswalk the species to a similar species that has published biomass relationships. These estimates are further adjusted to account for crown class (dominant, co-dominant, intermediate, suppressed) using adjustment factors developed in our canopy fuels field study (Gray and Reinhardt 2003). Trees less than 6 feet tall are excluded from the analysis, however, trees over 6 feet tall can contribute crown weight from branches less than 6 feet off the ground.

Canopy bulk density — Canopy base height is calculated by distributing the available crown fuel from each tree between its crown base and its top. The fuel is distributed vertically using regression equations developed from our destructively sampled data from 600 trees. These equations vary by species, but more biomass occurs higher in the crown. Fuel is summed in 1 foot height increments for all the trees in the stand. We smooth this profile with a 15-foot deep running mean, and define canopy bulk density as the maximum of this running mean.

Canopy base height — Canopy base height is computed in FuelCalc as the lowest point at which the running mean exceeds .012 kg/m^3 (33 lbs/acre/foot). This value, like Sando and Wick's 100 lbs/acre/foot, is arbitrary and not based on any kind of combustion physics, but it seems to perform well.

Stand height — Stand height is calculated in a way analogous to canopy base height, using the maximum height within the canopy at which canopy bulk density exceeds 0.012 kg/m^3.

Canopy cover — Canopy cover is estimated from the sum of the areas of individual tree crowns. Individual crown widths are computed from tree diameter (Moeur 1981). Following Crookston and Stage (1999), and assuming the crowns are randomly distributed within a stand, percent cover = $100(1-e^{-\text{totalcrownarea}/43560})$.

FuelCalc Linkages

FuelCalc is intended to make data management and analysis easy for managers by automating linkages to other software (figure 3).

FIREMON Database

For users who wish to store their data in a database, FuelCalc is linked to the FIREMON database (Lutes and others 2006). FIREMON provides a whole suite of statistical analysis tools. Similarly, FIREMON users will have the entire capability of FuelCalc available to them as an analysis tool, capable of reading data directly from the database.

SVS

The Stand Visualization System or SVS (McGaughey 1997) produces graphic representation of stands from tree list data (figure 2). These graphics are very helpful both for managers and even more importantly, for the public in assessing thinning treatments. FuelCalc will format data for use with SVS.

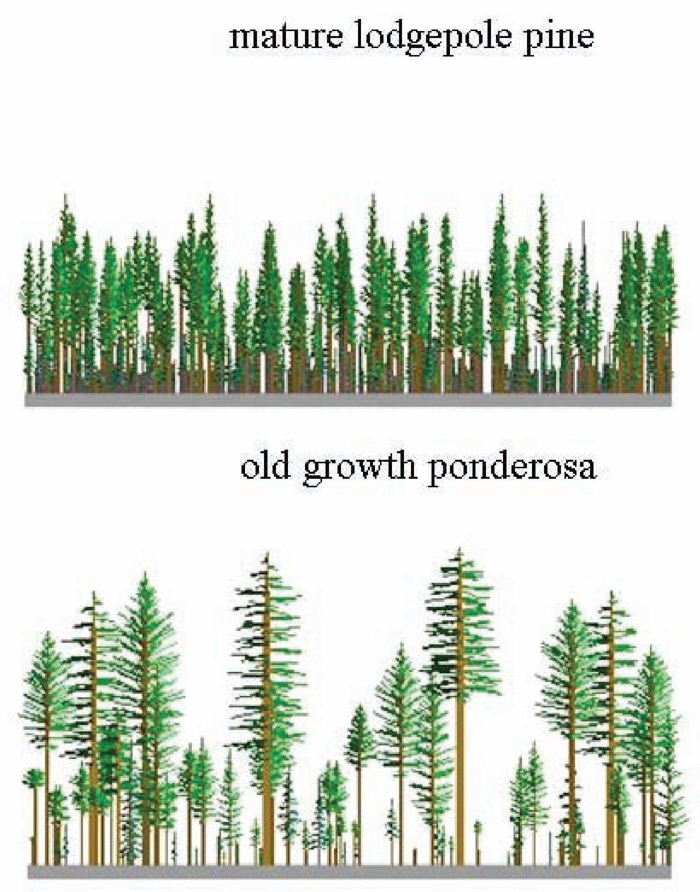

Figure 2—Examples of SVS (McGaughey, 1997) outputs.

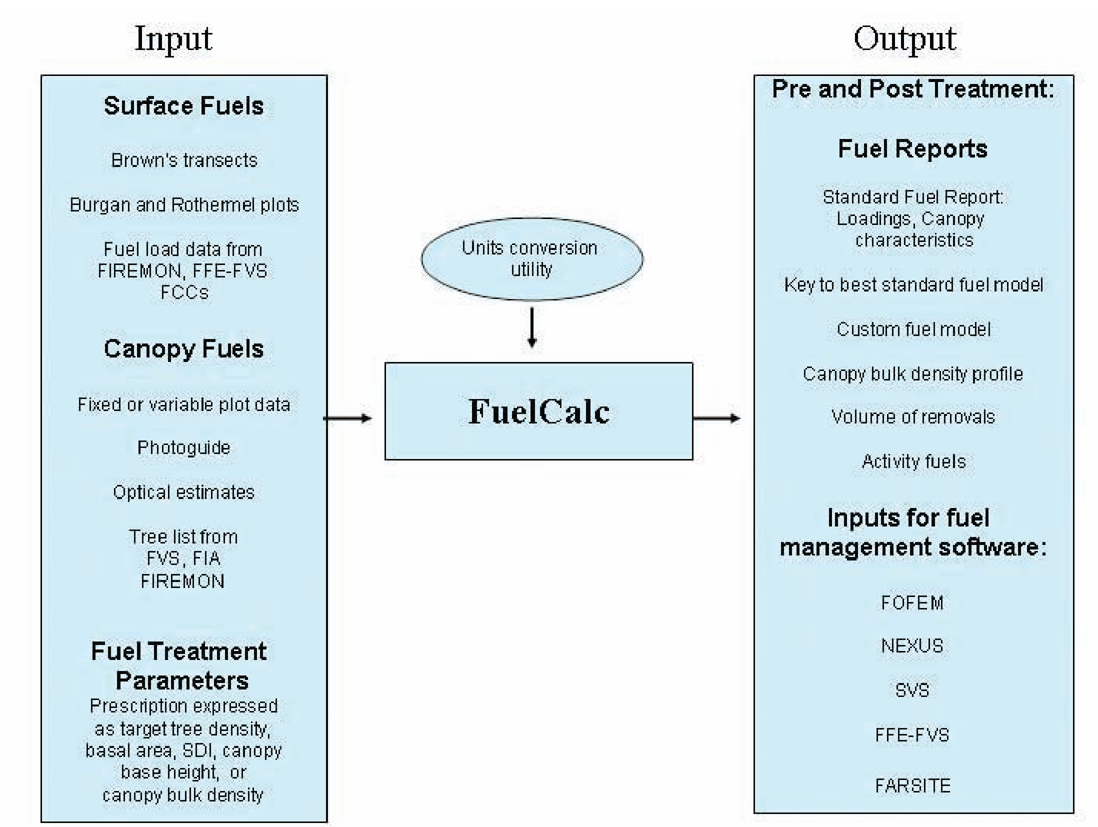

Figure 3—FuelCalc linkages.

FOFEM

FOFEM: a First Order Fire Effects Model (Reinhardt and others 1997, Reinhardt 2003) predicts tree mortality, fuel consumption, soil heating and smoke production from prescribed fire and wildfire. FOFEM requires as input exactly the kind of data that FuelCalc manages. FOFEM is widely used for NEPA documentation as well as smoke regulation. FOFEM will be fully integrated with FuelCalc so that as fuel treatment alternatives are developed within FuelCalc, FOFEM is invoked to assess impacts of those treatments on expected fire effects.

Nexus

Nexus (Scott 1999) is a fire behavior prediction system as well as a crown fire hazard assessment tool. It computes torching and crowning indices (Scott and Reinhardt 2001), as well as the full suite of fire behavior outputs including rate of spread, fireline intensity, and reaction intensity. Torching and crowning indices are windspeeds at which torching and active crowning can be expected to occur in a given fuel complex. Lower values indicate fuels that are more prone to crown fire behavior, i.e., crown fire can be expected at lower windspeeds. Torching and crowning indices vary as canopy and surface fuels are altered, thus they are useful indicators of crown fire hazard and of fuel treatment success. Nexus, like FOFEM, will be fully integrated with FuelCalc, so that as fuel treatment alternatives are developed in FuelCalc, expected changes in fire behavior and crown fire hazard can be assessed.

FFE-FVS

FuelCalc will convert data into files suitable for use with the Fire and Fuels Extension to the Forest Vegetation Simulator: FFE-FVS (Reinhardt and Crookston 2003). FFE-FVS can then be used to simulate treatment effects on fuels, potential fire behavior and stand structure over time.

National Volume Estimator Library

When thinning treatments are simulated, FuelCalc will use the National Volume Estimator Library of equations maintained by the USDA Forest Service Forest Management Service Center (USDA Forest Service 1993) in order to estimate the amount of potentially merchantable material that may be generated by thinning treatments.

FuelCalc Features

Prescription Design and Assessment

FuelCalc will provide analytical tools for prescription development. A user will be allowed to specify criteria such as: thin from below to a residual canopy bulk density of 0.05 kg/m^3, or thin from below to a residual basal area of 100 sq ft/acre, and FuelCalc will identify the number, volume, and characteristics of trees to be removed, as well as compute the activity fuels that would be generated by such a thinning. This analysis will combine the work of the JFSP-funded Canopy Fuels Study (Reinhardt and others 1999) with earlier work by Brown and Johnston (1976), and the National Volume Estimator Library (U.S. Forest Service 1993).

Batch Mode for Linking with GIS

FuelCalc is designed as a stand level tool, however, a batch mode will be provided to link with GIS and landscape level applications. We have successfully used this approach in developing FOFEM and Nexus. The LANDFIRE program has been using the batch FuelCalc program to process data from 1000s of plots.

Library of Code for Incorporation in Other Software

FuelCalc code will be provided on request to other software developers, hopefully resulting in more consistent use of inventory data across agencies and for a variety of applications.

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