Development of custom fire behavior fuel models from FCCS fuelbeds for the Savannah River fuel assessment project

Submitted by:

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Electronic files:

filename	description
Savannah River FCCS fuel models.pdf	This document. Documentation of the process used to develop fire behavior fuel models for 23 candidate fuelbeds at the Savannah River NWR.
Savannah River FCCS fuel models.xls	Excel workbook that implements Rothermel's surface fire spread model, displays the FCCS-generated calibration data, and allows calibration and adjustment of the Savannah River NWR custom fuel models.
Savannah River ROS calibrated.fmd	FARSITE format fuel model file containing the 23 candidate fuel models calibrated for ROS accuracy. This file can be used in FARSITE, FlamMap and NEXUS.
Savannah River FLI calibrated.fmd	FARSITE format fuel model file containing the 23 candidate fuel models calibrated for FLI and FL accuracy. This file can be used in FARSITE, FlamMap and NEXUS.
Savannah River (ROS)	Folder containing 23 BehavePlus fuel model files calibrated to accurately replicate ROS.
Savannah River (FLI)	Folder containing 23 BehavePlus fuel model files calibrated to accurately replicate FLI.
Savannah River NEXUS files	Folder containing 23 NEXUS scenario files. These scenarios are set up—using two standard NEXUS multiplication factors—to simultaneously predict both ROS and FLI accurately. The scenarios use the “high” fire danger fuel moisture set, and a 3 mi/h midflame wind speed.
Savannah River CompareModels.xls	Custom spreadsheet allowing comparison of any of the 23 custom fuel models with each other and with any of the 53 standard fuel models. Results are adjusted so that both ROS and FLI are simultaneously predicted according to the calculated ROS adjustment factor.

Introduction

The purpose of this project is to create fire behavior fuel models that replicate the fire behavior characteristics (spread rate and fireline intensity) produced by 23 candidate FCCS fuelbeds developed for the Savannah River National Wildlife Refuge. These 23 fuelbeds were created by FERA staff in consultation with local fuel managers. The FCCS produces simulations of surface fire spread rate and flame length (and therefore fireline intensity) for each of these fuelbeds, but it does not produce maps of those fire behavior characteristics or simulate fire growth—those tasks currently require the use of the FARSITE and/or FlamMap software systems. FARSITE and FlamMap do not directly use FCCS fuelbeds, but instead use standard or custom fire behavior fuel models to describe surface fuel characteristics for fire modeling. Therefore, replicating fire growth and fire behavior potential calculations using FCCS-simulated fire characteristics requires the development of custom fuel models that mimic, as closely as possible, the fire behavior characteristics produced by the FCCS for each fuelbed, over a range of fuel moisture and wind speeds.

Method

The overall method for development of these special-purpose custom fuel models is as follows:

- Obtain fire behavior calibration data
- Obtain baseline fuel model parameters
- Adjust baseline fuel model parameters so that fuel-model predicted fire behavior matches FCCS-predicted fire behavior

Each of these steps is described in more detail below.

Fire behavior calibration data

Custom fuel models are typically calibrated to fire behavior observations. In this project the custom fuel models are calibrated to model-generated data. Here's what we did.

Laurie Kurth (Fire Modeling Institute) examined weather and live fuel moisture records for the Savannah River NWR and then developed three sets of dead and live fuel moisture scenarios for the project, representing moderate, high and extreme fire danger (fuel moisture conditions). The fuel moisture content values (percent) for each of these scenarios are listed in the table below.

	1-h timelag class	10-h timelag class	100-h timelag class	Live herbaceous (non- woody)	Live woody
Moderate	7	10	15	80	140
High	6	9	14	70	130
extreme	5	7	12	60	110

Next, Laurie examined the wind speed records for the area and, in conjunction with the likely wind adjustment factors, settled on three mid-flame wind speeds to use for calibration of the fuel models: 1, 3, and 6 mi/h at midflame height. (This option was used because moving the three wind speed points for each fuelbed according to the likely wind adjustment factor would be very cumbersome to simulate in FCCS. The approach used required 9 batch runs rather than up to 207 individual FCCS runs.)

It was initially planned to use just three calibration data points—the extreme fuel moisture scenario with the highest wind speed, the high moisture scenario with the middle wind speed, and the moderate moisture scenario with the lowest wind speed. It was eventually decided that simultaneously varying both wind speed and fuel moisture in the calibration data would not permit development of a robust fuel model. There would be no way of knowing if the fuel model worked well for either fuel moisture or wind speed separately. To resolve this issue we decided to use nine calibration points—three fuel moisture scenarios crossed with three wind speeds. This would allow us to verify that the wind speed and fuel moisture responses were each working reasonably.

The nine calibration data points were sent to FERA, who ran FCCS in batch mode to produce the desired data—rate of spread and flame length. From the flame length data we worked backward to fireline intensity using Byram's equation. Therefore, there are nine observations of three fire behavior characteristics (FL, ROS, FLI) for each of the 23 candidate fuelbeds. The FCCS calibration data points are compiled and reformatted in the "FCCS runs" tab of the "Savannah River FCCS fuel models.xls" spreadsheet.

Baseline fuel model parameters

Twenty-three candidate fuelbeds were created earlier by FERA staff. Each of these fuelbeds consists of a wide variety of fuelbed characteristics, only a few of which are directly pertinent to surface fire behavior modeling using Rothermel's original spread equation. Of the 12 required fuel model parameters, only five fuel model parameters—fuel load by dead fuel timelag class (1-h, 10-h and 100-h) and live fuel type (woody and non-woody)—were taken from the FCCS fuelbeds in setting the baseline fuel model parameters. Component and overall fuelbed depth values for each fuelbed were initially considered, but eventually discarded because they did not aid in developing the fuel models.

FCCS fuelbed characteristics that were used as initial fuel model parameters are found in the "FCCS data" sheet of the "Savannah River FCCS fuel models.xls" spreadsheet mentioned earlier.

The following sub-sections describe how each of the 12 fuel model parameters was initialized.

Load of 1-h timelag class fuel particles

This fuel model parameter was set as the sum of Shrubs_needledrape, MLL_litter, and Woody_sound_zero_to_quarter FCCS fuelbed characteristics. MLL_litter load always dominated this sum for the candidate fuelbeds.

Load of 10-h timelag class fuel particles

This fuel model parameter was set to the Woody_sound_quarter-to-one FCCS characteristic.

Load of 100-h timelag class fuel particles

This fuel model parameter was set to the Woody_sound_one_to_three FCCS characteristic.

Load of live herbaceous fuel particles

This fuel model parameter was set to the sum of the Nonwoody_primary and Nonwoody_secondary FCCS characteristics. However, nonwoody_secondary was 0 in all 23 candidate fuelbeds.

Load of live woody fuel particles

This fuel model parameter was set to the sum of the LadderFuels, Shrubs_primary, and Shrubs_secondary FCCS characteristics. Shrubs_secondary was always 0 t/ac for these fuelbeds. Also, LadderFuels was 0.3 t/ac for all fuelbeds except 7 and 15, both of which had LadderFuel values of 3.0 t/ac.

Fuel model type

We decided to make any fuel models with a live herbaceous component “static”—as is FM2 in the original 13 standard fuel models—rather than “dynamic”—as are all such fuel models in the 2005 set of 40 standard fuel models. This would not only make calibration simpler, but was expected to produce a better match with FCCS-simulated fire behavior characteristics.

Surface-area-to-volume (SAV) ratios

We elected to keep the 1-h, live herbaceous and live woody SAV ratios as stylized parameters not associated with any particular fuelbed. At the start of calibration, all three SAV ratios were set to values of 1500 ft⁻¹.

Fuelbed depth

As mentioned earlier in this section, we first seeded this fuel model parameter with the Depth SurfaceFuels FCCS characteristic. However, it quickly became apparent that the approach would not work well—the loads and depths resulted in a huge range of bulk densities that were not reflected in the FCCS simulations of fire behavior. Instead, we set an initial fuelbed bulk density value of 20 ton/ac-ft for each potential fuel model, then computed the fuelbed depth needed to produce that bulk density. 20 ton/ac-ft represents a fairly compact fuelbed, something like a timber litter fuel model. When setting the final calibrations, we directly adjusted bulk density, which indirectly adjusted the fuelbed depth parameter. We saw this as a reasonable approach because the Rothermel is directly affected by bulk density (and packing ratio), not by fuelbed depth.

Moisture of extinction

Because of the general climate and region where the Savannah River NWR is located, we set a baseline extinction moisture content value of 35 percent for all 23 potential fuel models. This relative high value reflects the fact that fuelbeds in that region and climate tend to burn well even at moderate to high fuel moisture values.

Heat content

An initial heat content of 8000 BTU/lb was set for both live and dead fuel components for all 23 fuel models.

Calibration procedure

The requisite data—FCCS calibration runs and initial fuel model parameters—are now in place. All that is needed is a tool to put it all together. We developed a custom spreadsheet application based on a long-ago developed spreadsheet that implements Rothermel’s surface fire spread model. The spreadsheet

was modified to include calibration and adjustment factors for tuning the initial fuel model parameter values in order to get the simulations to match the FCCS data. The backbone of this tool is a set of three charts—one each for ROS, FLI, and FL—and a table of calibration/adjustment factors. Below is one of those three charts.

On this one chart you can see the simulated behavior of the custom fuel model for a range of midflame wind speeds and all three fuel moisture scenarios (colored lines). Superimposed on these lines are the nine calibration data points, with points for the same fuel moisture set connected by a black line. The goal of the calibration exercise was to adjust fuel model parameters to get the simulations to be as close as possible to the FCCS calibration runs. Each fuelbed would be adjusted in turn, one at a time, manually. Goodness of fit was determined visually, not by any sort of least-squares measure¹.

Building this custom tool required a significant investment of time, but it was felt that calibrating the custom fuel models would go fast enough to pay off the up-front investment. That certainly turned out to be true.

During calibration, one thing became clear right away—no custom fuel model could be produced to match both ROS and FLI/FL at the same time while still matching the shape of the fire behavior response to wind speed. When ROS was good across a range of wind speeds and fuel moistures, FLI was too high by a factor of about two, and vice versa. In Rothermel's model, getting less FLI for the same ROS requires a shorter burning duration. Duration is a function solely of characteristic SAV ratio. Making the fuel particles finer (higher SAV ratio) results in shorter duration and consequently lower fireline intensity for the same ROS. Unfortunately, the large SAV ratio required to get ROS and FLI in the same ballpark (circa 2500 ft⁻¹, representing a grass fuel model) drastically, and undesirably, changes the shape of the wind speed response of the fuel model.

¹ A shotgun-approach—wherein parameters were adjusted blindly and the best combination picked from a list of tens of thousands of choices— was tried from within the spreadsheet. It should have worked, in theory. But it did not. That was just too much to expect of Excel.

We could do either FLI or ROS well, or both very poorly. We chose the former option, and abandoned the idea of creating a single fuel model to replicate FCCS-simulated FLI and ROS at the same time. All calibrations were initially made to make FLI match as closely as possible. When that was completed for all 23 fuel models, we computed the ratio of FCCS-simulated ROS to fuel-model simulated ROS (for high fire danger, 6 mi/h midflame wind speed) and used this as a separate adjustment factor by which to get ROS calibrated. In Rothermel's model this can be simulated by multiplying all fuel loads and fuelbed depth by this same adjustment factor. This blind second calibration to ROS worked very well. All ROS-calibrated fuel models were created in this fashion.

The result of this procedure is two sets of 23 fuel models—one for accurately replicating FCCS FLI and FL, the other for accuracy in replicating FCCS ROS—and a set of adjustment factors that can be used in FARSITE and NEXUS for getting both ROS and FLI/FL right in a single simulation.

Results

The calibration results are contained in the "Calibration" sheet of the Savannah River FCCS fuel models.xls spreadsheet. Columns B – F are multiplication factors on the five initial fuel load values. Column G is the fuelbed bulk density for the fuel model. The actual fuel model parameter—depth—is calculated as the sum of columns B – F divided by this bulk density. Column H is the heat content parameters (both live and dead were given the same value). Column I is the dead fuel extinction moisture content. Columns J – L contain SAV ratios. For simplicity, all calibrations varied all three SAV ratios together. Those columns comprise the adjustments that could be made to the fuel model parameters. Goodness of fit was judged by making a change and noting the fit visually on the three graphs.

Column M is not a calibration factor but the resulting discrepancy between predicted and FCCS-generated ROS when FLI was accurately predicted. These values were calculated as described above.

Finally, the "fuel models" sheet of the project workbook contains the resulting fuel model parameters. The parameters are listed in the correct order and units for exporting as a FARSITE-format fuel model file. Two fuel model sets were produced. Use the drop-down box in cell P1 to switch between them.

After calibration of a dozen or so fuel models some general patterns emerged:

- Live herbaceous (non-woody) load was very small in all fuelbeds. Removing that entire load from the fuel models produced good results.
- In nearly all cases, the best fit to the fuel moisture calibration data was achieved by removing all live fuel from the fuel model. Apparently, Rothermel's model was more sensitive to the relative small change in live woody fuel moisture content among the three fire danger scenarios than is the FCCS model. Without removing this component, the fuel models were simulating too much fire behavior difference between the three fire danger scenarios.
- Despite the fact that FCCS sets the exponent on the wind coefficient calculation to that when characteristics SAV ratio is 1500 ft^{-1} , we found the best results—in most cases—when using a universal value of 1100 ft^{-1} . This is particularly true when looking at the windspeed range between 3 and 6 mi/h².

² Having more FCCS wind speed data points would likely prove this to be untrue in general, but we don't have the luxury of those data points or the time to use them. My suspicion is that FCCS actually produces a more curvilinear response to wind than the three data points suggest.

- We found no reason to vary from the initial 35% extinction moisture content.
- The bulk density values that eventually replicated the calibration data are representative of compact surface fuel, much like FM8 of the original 13.
- The average ROS adjustment factor among the 23 fuel models is 1.9. One fuel model actually over-predicted ROS when FLI was correct (adjustment = 0.620).

Fuel model parameters

The draft fuel model parameters are provided in a variety of formats so they can be tested in fire modeling systems that use Rothermel's model, including BehavePlus, FARSITE, FlamMap, FSPRO, and NEXUS. See the files and folders listed in the cover table. Some general instructions and considerations for using these files in fire modeling systems are discussed below. A working knowledge of each system is assumed.

Considerations for use in fire modeling systems

To facilitate review of the fuel models, input files have been provided for use in BehavePlus, FARSITE, FlamMap, and NEXUS. In addition, another custom spreadsheet is provided to simplify comparison of these 23 draft fuel models with each other and with any of the 53 standard fuel models. Each tool is discussed below.

BehavePlus

The two draft sets of BehavePlus fuel model files are included in two separate folders—one for ROS-calibrated fuel models and another for FLI-calibrated fuel models. Certain steps must be followed in order to use these custom fuel models in BehavePlus.

1. Install BehavePlus4 or later on your machine, if not already installed. Note the location where it is installed, because you'll have to find this location for the next step.
2. Copy the two BehavePlus fuel model file folders.
3. Paste those two fuel model file folders to the FuelModelFolder of the DefaultDataFolder of the installation directory. The result should be something like this:

Address: C:\Program Files\SEM\BehavePlus4\DefaultDataFolder\FuelModelFolder			
Name	Size	Type	Date Modified
MyFuelModels		File Folder	7/14/2009 2:59 PM
Savannah River (FLI)		File Folder	7/21/2009 1:16 PM
Savannah River (ROS)		File Folder	7/21/2009 1:13 PM
SoCalifornia		File Folder	6/9/2008 12:23 PM

BehavePlus4 is the installation directory. Mine is installed in ProgramFiles/SEM/; yours may be anywhere. There are at least two other folders already in the FuelModelFolder. Don't worry about them.

4. Launch BehavePlus. Attach one or both fuel model sets (Configure > Fuel model set selection) by single-clicking on the two folders you just copied, as shown here.

Click OK. These fuel models are now available for selection in BehavePlus. They'll be listed after the 53 standard fuel models.

Remember that there are two sets of fuel models. To replicate FLI and FL, use that fuel model set. ROS will be under-predicted by a factor of about 2. The exact adjustment factor can be found in the "Calibration" sheet of the workbook.

FARSITE

Using these fuel models in FARSITE is complicated, so I assume you know or can learn the procedure for using custom fuel models in FARSITE.

Use the FLI-calibrated fuel model set, and then also use the provided adjustment factors within FARSITE. FARSITE will then produce accuracy in both FLI and ROS simultaneously.

FlamMap basic

For use in FlamMap basic, which displays potential fire behavior but does not simulate fire growth, I suggest using the FLI-calibrated fuel model set, knowing that FLI, FL, type of fire, etc. will be about right. Spread rate for surface and passive crown fire will be under-predicted, however, but ROS is not the most important fire behavior characteristic when looking at fire potential. Type of fire and fireline intensity are more important in such cases.

FlamMap MTT

This is a difficult application when using two sets of fuel models. You need simultaneous accuracy in both ROS and FLI because both affect fire growth—ROS directly, and FLI by affecting crown fire initiation and spread rate. I suggest starting with the FLI-adjusted set. If there is little or no influence of crown fire behavior on fire growth, then you can safely switch to the ROS-adjusted fuel model set. If crown fire is significant, then I'd stay with the FLI-adjusted models because switching to the ROS-calibrated models could greatly overpredict fire growth by over-predicting the prevalence of crown fire.

NEXUS

NEXUS uses the FARSITE fuel model file format, so the .fmd file can be used in NEXUS directly. Like FARSITE, NEXUS uses adjustment factors for fine-tuning simulations. They work a little differently, though. Use the FLI-calibrated fuel model set. For the ROS multiplier, use the standard adjustment factors listed earlier in the spreadsheet. In NEXUS, unlike FARSITE, this adjustment also affects FLI, which we don't want. Therefore, we need to use a FLI adjustment in NEXUS that equals the inverse of the ROS multiplier. This will have the desired effect—both ROS and FLI will be correctly predicted in a single simulation. Now you can use NEXUS to compare with other fuel models or judge how the fuel model interacts with crown fire initiation and spread models.

A few example NEXUS files are included in the Savannah River NEXUS files folder. This file includes a copy of the FLI-calibrated fuel model file, as well as four example scenario files—for SR1 through SR4—that use the multiplication factors as indicated above.

To use the NEXUS files:

1. Install NEXUS 2.0 if you have not already done so. NEXUS 2.0 is available from fire.org.
2. Launch NEXUS.
3. Load the custom fuel models: Tools > Custom fuel models. Select the FLI-calibrated fuel model file provided in the Savannah River NEXUS files folder.

The fuel models are now available for use in NEXUS.

4. Load the SR1 scenario file into the first column of inputs by clicking on the Scenario button labeled "A". Note that the ROS multiplier is 1.871 and the FLI multiplier is 0.534. Load the other three scenarios in the next three columns. Click on the output chart tab to see a graph of potential fire behavior for these four fuel models. Change to any fire behavior characteristic, FL, FLI, and ROS should all be simulated correctly.

Savannah River CompareModels.xls

This is a basic spreadsheet based on the “CompareModels” spreadsheet developed to facilitate comparison of the 40 fuel models with each other and with the original 13. It has been extended to address the 23 draft Savannah River fuel models. All but one sheet—an interactive graph—is hidden in this workbook.

In the upper left corner of the chart, select one of the three fuel moisture scenarios. At the top, select the fire behavior characteristic to compare. Above the legend, select the wind adjustment factor to use in the simulations. Finally, on the legend itself select up to eight standard or custom fuel models to compare on the chart.

This spreadsheet is pre-adjusted so that FLI and ROS are predicted as indicated by the FLI-calibrated fuel models and ROS is adjusted by the calculated factors. This is the simplest way to see how these fuel models simulate fire behavior over a range of wind speeds and fuel moistures.

Discussion

It is likely that three wind speed calibration points are insufficient to describe the shape of the FCCS-simulated response of fire behavior to wind speed. These fuel models appear to match fire spread and intensity in the range of wind speeds between 3 and 6 mi/h, but that may be entirely due to the few calibration data points. If the shape of the curve in that range is less linear, then drastically different fuel model parameters would be needed. Perhaps we could generate a dozen or so wind speed data points (0 – 6 mi/h in 0.5 mi/h increments) for one or two fuelbeds, then use that data to test how well these models really work.