Creating Visual Simulations of Fuel Conditions Predicted by the Fire and Fuels Extension to the Forest Vegetation Simulator

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Abstract—The Fire and Fuels Extension (FFE) to the Forest Vegetation Simulator (FVS) can help managers assess the risk, behavior, and impact of fire in forest ecosystems. The FFE reports surface fuel characteristics including the weight of woody material in various size classes. Visualization software currently linked to FVS can help managers better understand and communicate stand structure and changes in stand structure resulting from growth, mortality, and management activities. However, such visual simulations do not currently include surface fuels. This paper describes the development of calibrated log models: models of individual pieces of coarse woody debris that represent specific weights of fuels in various sizes. Such models are used to represent surface fuels in visual simulations. The paper presents motivations for the study along with a description of the procedures used to measure and photograph logs and an overview of the process for creating the calibrated log models. An example log model is presented along with visual simulations that depict fuel conditions.

Users of the Forest Vegetation Simulator (FVS) (Wykoff and others 1982, Teck and others 1996) have been using visual simulations produced by the Stand Visualization System (SVS) (McGaughey 1997; http://www.fs.fed.us/pnw/svs) to better understand and communicate the results of their FVS projections. The Fire and Fuels Extension (FFE) to FVS links changes in forest vegetation due to growth, natural or fire-caused mortality, and management activities to changes in expected fire severity and behavior (Beukema and others 2000). Given the recognition of fire as an important component of forested ecosystems and the realization that decades of fire suppression activities have resulted in an increase in the amount of forest lands at risk of catastrophic fires, it makes sense to incorporate the results from FFE into visual simulations designed to portray stand conditions.

This paper describes the development of calibrated log models: models of individual pieces of coarse woody debris that represent specific weights of fuels in various sizes. The paper discusses motivations for the study along with a description of the procedures used to measure and photograph logs and an overview of the process use to create calibrated log models. An example log model is presented along with visual simulations of fuel conditions produced using EnVision (McGaughey, in press; http://www.fs.fed.us/pnw/envision), a program that has several of the capabilities of SVS.

The primary objective of this study is to build a set of models that represent individual pieces of coarse woody debris. These models, called calibrated log models in this paper, represent the physical dimensions of a log and use photographs to characterize the log ends, surface (bark), and branches. Models provide sufficient detail to represent specific fuel weights in various size classes. EnVision uses the models to produce visual simulations that depict standing live and dead trees reported by FVS along with downed fuels reported by FFE.

Motivations for this Study

This study was motivated by a desire to represent fuel conditions and fire effects predicted by FFE in visual simulations commonly produced by FVS users. Previous efforts to represent fuel conditions have focused on two methods: photo series and visual modeling of individual fuel components.

The most common method used to illustrate fuel conditions relies on a library of images, called a photo series, to depict conditions within various stand and grassland ecotypes. For a specific ecotype, a photo series includes images that illustrate a range of fuel conditions along with quantitative data describing fuels. Photo series have great appeal because users can directly compare their site conditions to photographs included in the series and select the image that best matches the conditions they observe. They can then use the quantitative information associated with the image to estimate fuel loads for their site. The Fire and Environmental Research Applications (FERA) Team within the USDA Forest Service, Pacific Northwest Research Station, has produced a comprehensive photo series that includes single photos and stereo pairs for the United States. For an example from this series, see Ottmar and others 1998.

Fuel specialists successfully apply the photo series approach to a variety of forest and grassland ecotypes. Users typically relate well to photographs that depict actual sites. However, their ability to correctly match conditions illustrated in a photograph to their specific site and fuel conditions remains untested. In addition, because a photo series

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includes a limited number of images, users may not find images that adequately represent the conditions they observe. An approach that produces images based on the quantitative descriptions of fuel and stand conditions produced by FVS-FFE may be more appropriate for model users.

Previous work by this author created visual models of fuel conditions for stands in eastern Oregon being treated as part of the Limber Jim Fuels Reduction Project using SVS (McGaughey 1997). For that project, fuels were inventoried using standard line transect methods. Computer programs used the fuel data to create a population of plant and log models to represent fuel conditions. Figure 1 shows example images that depict pretreatment and posttreatment stand conditions. This effort, while it produced images that were useful for public orientation prior to site visits, did not produce images that compared well with the typical photo series. Limitations of the rendering system (SVS) made it difficult to accurately represent fuels smaller than 3 inches in diameter. The inability to represent fine fuels did not greatly affect the visual simulations because most of the downed logs were actually full-length tree stems with few intact branches. In addition, the standard SVS viewpoint (viewer located some distance from the stand and the image contains most, if not all, of the 1 acre stand representation) used for most images made it impossible to discern individual branches on downed trees.

The methods used in SVS do not adequately represent fuel properties. First, SVS uses simple tree models that are not detailed enough to represent individual branches or branch patterns. The tree models used in SVS are abstract representations of trees that are recognizable as trees but do not realistically model tree characteristics and do not generally compare well to images of actual trees. The lack of adequate branch representations makes it impossible to model a known quantity of fine fuels because most of the fine fuels are contained in tree branches. A second problem with tree models used in SVS is that they all look "perfect." That is, all trees have straight stems and well-shaped crowns. These models produce stand visualizations that communicate overall stand characteristics but do not represent the variety of tree forms and condition classes needed to produce images that compare favorably with on-site impressions. The third problem with the process used for the Limber Jim project was the algorithm used to place downed material. The current algorithm included with SVS (TBL2SVS utility) does not accurately model the interaction of downed pieces. The result is that many of the downed logs appear to be floating above the ground surface with no visible means of support. This anomaly did not necessarily create problems for the Limber Jim project because viewpoints were located to provide overviews of the 1 acre stand; therefore, viewers simply could not see the problem. When rendering the same data in EnVision using a viewpoint that approximates the view from the ground within the stand (fig. 2), the problem is more apparent.

Existing methods used to represent fuel conditions are adequate only in select situations. Photo series do not include images that represent all conditions present within an ecotype. In addition, users match images to site conditions and then use the corresponding fuel descriptions for analysis and planning. A more desirable approach is to have the FFE results directly influence the image because it is unlikely that a photo series image will represent fuel quantities that exactly match the FFE results. Previous work with SVS indicates that its rendering methods cannot sufficiently represent fuel properties for pieces less than 3 inches in diameter.

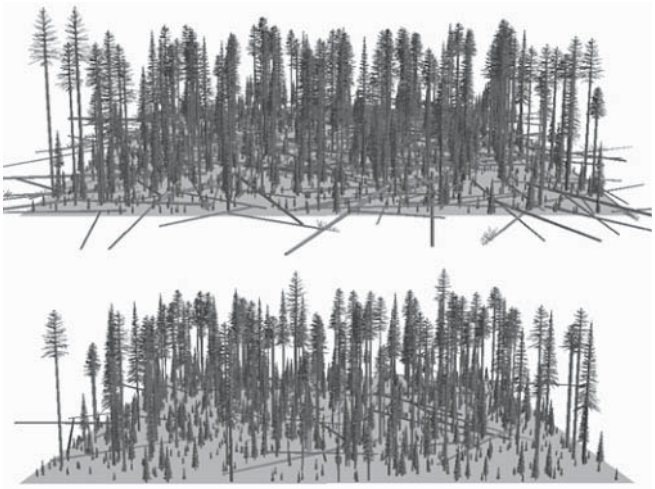

Figure 1—Visual simulations of pretreatment (top) and posttreatment (bottom) conditions in a mixed conifer stand in eastern Oregon. Pretreatment fuel load for material 3 inches in diameter and greater is 54 tons per acre, and posttreatment fuel load is 10 tons per acre.

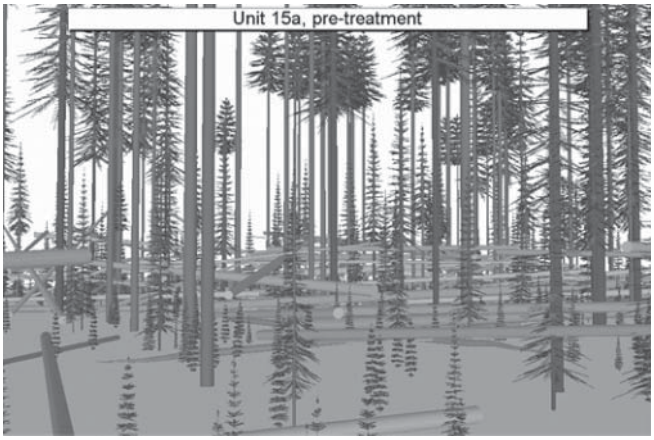

Figure 2—Data from the Limber Jim project rendered in EnVision using a near-ground viewpoint.

Creating Calibrated Log Models

Calibrated log models are created using field measurements and photographs of actual pieces of woody debris. The

intent of the log models is to provide accurate, visually realistic representations of downed fuels in various size classes. The models do not represent highly detailed log form or individual branch locations or orientations.

Collecting Field Measurements and Photos

Field measurements and photographs capture an adequate description of individual logs without collecting more information than needed to produce visually realistic models. Field measurements characterized the size and general shape of the bole, branching patterns, and bole and branch weights. Field measurements were divided into three procedures: log characterization, branch inventory, and photography.

Log characterization—Log characterization procedures capture the log size and geometry. The overall procedure for log measurement involved suspending the log from two tripods rigged with a block-and-tackle for lifting the log and a spring scale for weighing the log. After the log was suspended, field personnel recorded the weight from each scale and visually divided the log into sections for measurement and photography. Section breaks were located at major bends in the log or were placed to keep sections shorter than 5 feet. Section markers (string and nails) were left in place for photography. Orientation guides (2-foot diameter tempered hardboard discs with attachment points for reference lines) were attached to each end of the log. Reference lines (strings), used to measure the shape of the log, were attached to the orientation guides.

The length, large and small end diameters (outside bark), and the weight were measured for each log. Weight was recorded with and without branches. For each log section the following attributes were measured: length of section, large and small end diameters (outside bark), and the distance from the reference line to the actual log center at the small end of the section. (Note: large end diameter was measured for only the first section; for subsequent sections, the large end diameter was the same as the previous section's small end diameter.) Section attributes were measured twice. The second set of measurements was taken after the log had been rotated 90 degrees clockwise. This produced two diameter measurements that were averaged to compute the small end diameter of the section and two deviations from centerline that were used to calculate the rotations needed to properly orient the log section in the final log model.

Branch inventory—The branch inventory was designed to quantify the weight of small fuels present on the log. The inventory was done for each log section to facilitate the construction of new logs (different from those measured) by stacking several sections and adding the fuel weights. The branch inventory was a 100 percent sample. All branches were removed from the logs and clipped at size break points using a go/no-go gauge with openings for 0.25-, 1-, and 3-inch sizes. As branches were clipped, they were placed in separate buckets to be weighed at the completion of each section. A sample was collected from all branches on the log in each size class to determine moisture content.

Photography—Three types of photographs were taken: log section photos, branch photos, and log end photos. Log section photos captured the surface (bark) of the bole and some branches that were cropped from the final image. The log section photos were digitally merged to create a texture map for the conic frustum used to represent a particular log section. Branch photos were taken with the entire log section positioned at the bottom of the frame. Images were framed to include all branches that originated on the log section. Extensive overlap between branch images on adjacent sections was expected. The goal of branch images was to capture all branches on the upper surface of the log and the portion of the log section above its centerline. Four sets of images were taken for each log section. Each set captured the view of the log as it was rotated in 90-degree increments. Log end photographs were taken to be used as texture maps for the disk that closes the large and small end of the log.

Photographs were taken with a digital camera using a resolution of 2048 by 1536 and 24-bit color. Images were stored on the camera's 64Mb storage cards (about 83 images per card). Section markers were visible in both log and branch images to assist when editing the images. A total of two to four overview images, two log end images, and eight images per log section (four log section images and four branch images) were captured for each log.

Branch photographs were taken using a blue backdrop held on a rigid frame (to minimize wrinkles) and positioned behind the section being photographed. The consistent background color facilitated image editing.

Building the Log Models

Logs models are created using the solid modeling capabilities in EnVision. Logs models consist of a series of tapered cylinders stacked end-to-end with spherical joints to hide gaps between sections. A disc closes the ends of the first and last sections. Branch planes are added using "wings" that project from the log center. Figure 3 shows the EnVision model file for a single log section (the large end section of the log model shown in fig. 4). Figure 4 shows the geometric primitives used to model a simple log containing three sections.

Figure 5 shows an example log model with all texture images applied.

Branch Representation

The method illustrated in figure 4 uses branch images mapped onto flat plates. This approach produces a model that appears correct when viewed from the side. However, when viewed from the end, branches are not visible because the "wings" have no thickness. The net result when rendering sets of log models to depict fuel conditions is that viewers will not be able to see all of the branch material. One solution to this problem is to twist the branch plates. Figure 6 shows end views of the log shown in figure 5 with flat branch plates and twisted branch plates. The viewpoint used in figure 6 is raised slightly above the log end so branches mapped onto the flat plates are visible. When viewed from the same elevation as the log end, you cannot see the branch plates.

```
EPO
1.0
Log 001-section 1
; do rotation for section
rotate -1.4 y
rotate -.24 x
pushmatrix
      ; draw log end
      settextureimage "001_large_end.bmp" 0 0 0
      disk 0 2.3 18 1 1
      ; draw log
      rotate 90 z
      settextureimage "001_stem_sect1.bmp" 0 1 1
      cylinder 2.3 2.29 47.0541 18 1 1
      ; draw joint
      translate 0 0 47.0541
      sphere 2.29 9 9 1
popmatrix
; branches
pushmatrix
      settextureimage "001_branches_sect1alt.bmp" 1 0 0
      spiral 33 33 47.0541 0 12 1 .75 0 .25 1
      rotate 90 z
      spiral 36 36 47.0541 0 12 1 .5 0 .25 1
      rotate 90 z
      spiral 12 12 47.0541 0 12 1 .25 0 .25 1
      rotate 90 z
      spiral 12 12 47.0541 0 12 1 0 0 .25 1
popmatrix
```

Figure 3—Sample EnVision model file for a single log section.

Using the twisted plates also affects the appearance of the log when viewed from the side. The branches appear slightly shorter but the appearance is still satisfactory.

When placing the log models and subsequently rendering them, only half of the branches will be visible because most logs will lay on the ground surface and half of the branches will project below ground. In reality, when a tree falls down, the branches on the portion of the stem closest to the ground either break or bend. Few branches are driven into the ground. Modeling the bending or breakage of branches would be difficult given that the log models do not represent individual branches, only collections of branches. However, there needs to be some adjustment to account for the broken or bent branches in a rendered image. One solution is to simply double the number of branch plates on each log model. For logs resting on the ground, this should result in a viewer "seeing" the correct amount of branches. For logs that are partially elevated, too many branches would be visible. It is unclear just how many of the additional branches would be visible since other logs would either partially or completely screen these branches from view. Further experimentation will be needed to assess various branch representation options.

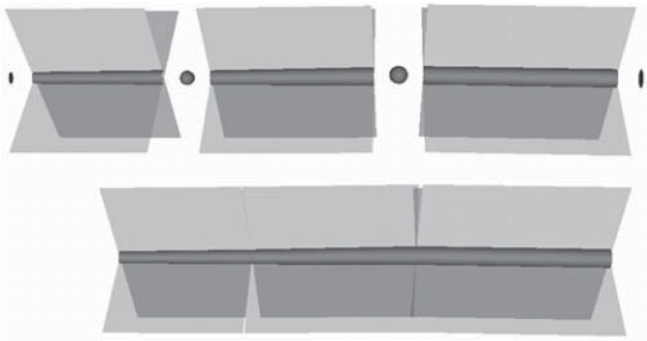

Figure 4—Log models consist of a series of geometric primitives. The upper image shows the individual components and the lower image shows primitives combined to form a log model.

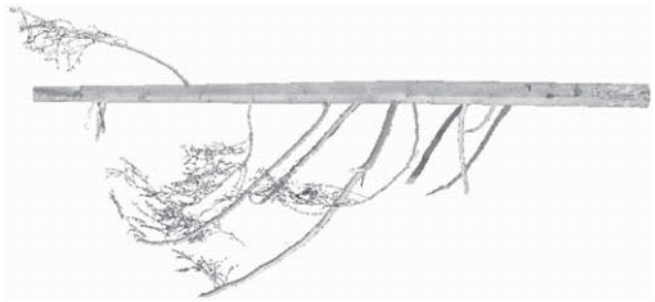

Figure 5—Log model rendered in EnVision.

Figure 6—End views of the log model shown in figure 5 with flat branch plates (left) and twisted branch plates (right).

Simulating Fuel Conditions

The final step in producing visual simulations to represent fuel properties is the creation of a population of log models that represents the specific fuel conditions reported by FFE. This part of the project was not complete at the time of this writing so the discussion that follows is subject to change.

The fuel bed simulation program will accomplish two tasks. First, it will sample from the collection of log models to build a population of models that represents specific fuel conditions. Second, it will distribute the models throughout the stand and calculate an appropriate orientation for each model.

The first step of the sampling algorithm is to select an appropriate subset of log models based on characteristics of standing trees such as the species mix and size distribution. After selecting a subset, the algorithm assembles a collection of models that matches the fuel characteristics reported by FFE. The initial prototype of the fuel bed simulation program will attempt to match the fuel weights in larger size classes only. Experimentation with the program will likely indicate the need for more complex logic. Most likely, the algorithm will use a heuristic approach that looks at the weight of material already added to the fuel bed and selects a model with an appropriate mix of material weights in each of the fuel size classes. It may be possible to fine-tune the fuel weights by adding or subtracting branches from individual log models or by assembling new log models using sections from measured logs.

After creating an acceptable collection of log models, the spatial positioning algorithm needs to distribute models over the stand plot. There are two major issues to be resolved when calculating the spatial distribution and orientation of individual log models: log models should be placed so they do not collide with standing trees, and models should be oriented so all logs appear to be stacked correctly. Solving the first issue is relatively straightforward. The algorithm can evaluate the position and size of the standing trees and place log models so logs do not pass through standing trees. In dense stands, placement could be difficult especially if the log models are long. The stacking problem is more difficult to solve. The new algorithm will need to look at how all logs interact to determine a realistic stacking orientation.

A simple example illustrates the potential for representing fuel conditions using the log models. Figure 7 shows a sample fuel bed created using a single log model. This fuel bed represents 3 tons per acre of material less than 3 inches in diameter and 20 tons per acre of material 3 inches and larger. Figure 8 shows the simulated fuel bed along with standing trees.

Conclusions

The ability to produce visual simulations that depict fuel properties as well as stand conditions will help FVS-FFE users communicate changes in stand structure and fire risk that result from natural processes, management activities, and fire. Preliminary experiments with the use of the calibrated log models described in this paper look promising. The resulting visual simulations depict fuels in small size classes represented by fine branches and larger fuels represented by large branches and boles. Remaining work in this project includes measurement of many more logs and branches, both burned and unburned, and subsequent construction of log models for use in the fuel bed simulation program. Field crews will collect measurements during spring 2002 and model building should be complete by late

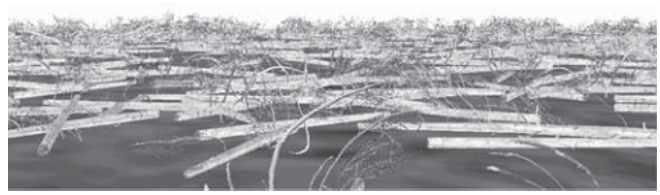

Figure 7—Visual simulation of surface fuel layer representing 3 tons per acre of material less than 3 inches in diameter and 20 tons per acre of material 3 inches and larger.

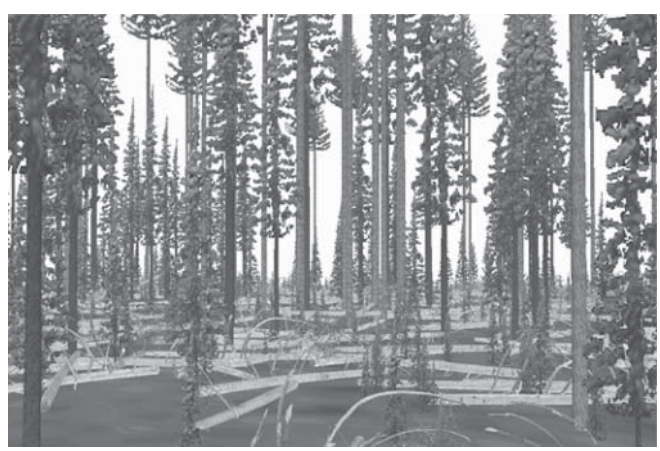

Figure 8—Visual simulation that combines the surface fuel layer shown in figure 7 with standing tree information.

2002. Work on the fuel bed simulation program is progressing and a prototype should be ready by mid-2002. Visual simulations will be compared to photographs of areas where fuel conditions have been measured. This will include comparison with images from the photo series produced by the Fire and Environmental Research Applications Team of the PNW Research Station. The results of these comparisons will dictate further work on the fuel bed simulation program.

Acknowledgments

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