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Abstract:

This project provided for an improved version of the Fire and Fuels Extension to the Forest Vegetation Simulator (FFE-FVS), a program whose original development was largely financed by the JFSP. The program is widely used by JFSP member agencies and several JFSP-sponsored research projects to support analysis at the stand to large landscape spatial scales. New research results rendered version 1 obsolete and experience with the model demonstrated that some parts of it needed to be improved.

Equally important are issues regarding support, training, and system usability. We conducted 42 on-site training sessions over the last 4 years and also held 13 on-site/in-person model assistance visits. This work always utilized the latest revisions of FFE-FVS as improvements were made. In addition to technology transfer, this work acted as beta-testing of the latest revisions and helped guide development. To address system usability, the graphical user interface (Suppose) was modified to improve ease of use.

Background:

FFE-FVS is a model linking stand development, fuel dynamics, fire behavior, and fire effects. It allows comparison of mid- to long- term effects of management alternatives including harvest, mechanical fuel treatment, prescribed fire, salvage, and no action. Geographical variants use locally calibrated growth algorithms, decay parameters, fire effects relationships, and fuel modeling logic. A full description of FFE-FVS including chapters on applications, use, and model content, is available (Reinhardt and Crookston 2003) in hard copy and online at http://www.fs.fed.us/rm/pubs/rmrs_gtr116.html.

FVS simulates the growth of a forest stand on an individual tree level. It is a stand level model, although many stands can be simulated simultaneously. FFE links the stand dynamics with a model of surface fuel accumulation and decay. Fire behavior is predicted using surface and canopy fuels. Fires alter stand structure and fuel loadings. FFE-FVS allows users to design and simulate management alternatives at any point in the simulation. A wide range of treatments can be modeled, including pre-commercial and commercial thinning, salvage logging, pile and broadcast burning, and mechanical fuel treatments.

FFE-FVS predicts fuel loads, stand structure, measures of fire hazard including torching and crowning index, potential flame length, canopy fuel characteristics, canopy cover, and snags over time. It produces output that can be used with the Stand Visualization System (SVS) to visualize stands.

Uses of FFE-FVS include:

- Prescription development – design integrated fire and silvicultural prescriptions. Design prescriptions to reduce the risk of stand replacement wildfire.
- Environmental assessment – compare alternatives for NEPA documentation.
- Forest Planning – Site specific and strategic.
- Hazard assessment – assess fire hazard, and effectiveness of treatments on hazard mitigation

FFE-FVS has been calibrated for all geographic variants of FVS.

Approximately 150 people are trained in FFE-FVS annually. FFE-FVS has been used as part of a wide variety of projects. FFE-FVS has been used throughout the country by the USDA Forest Service. It has been used for projects on at least 40 national forests, by Forest Service research stations, and for regional assessments. FFE-FVS has also been used by other agencies, such as the Bureau of Indian Affairs, the Bureau of Land Management, Washington Department of Natural Resources, and Colorado State Forest Service, as well as universities. The model has been used as part of other research projects, some funded by the JFSP and others from a variety of sources including the National Fire Plan.

With such a large user base, any known model shortcomings must be addressed and the model updated to include new, relevant scientific findings. As an example, let's consider the FFE-FVS fuel model selection logic. In FFE-FVS, fuel loads are modeled dynamically. Historically, these fuel loads were only used indirectly in predicting fire behavior - the modeled fuel loads, together with potential vegetation type, canopy cover, and other stand attributes, were used to select one or more fire behavior fuel models. These fuel models were then used to predict fire behavior. At the time FFE-FVS was developed, only 13 fuel models were available to capture the whole range of fuel conditions. In order to simulate gradual changes in potential fire behavior over time, a complex method of interpolating between fuel models was implemented. Since then, a new suite of 40 fire behavior fuel models was developed (Scott and Burgan 2005) that allow a better representation of incremental changes in fuels. This project facilitated the incorporation of these models in the fuel model selection logic. In addition, we implemented a method of predicting fire behavior directly from modeled fuel quantities, bypassing the use of fuel models altogether.

Other improvements, such as how the initial fuel loading is set, were also investigated and added to FFE-FVS. The numerous model additions and improvements will be discussed in detail in later sections of this report.

Study Description and Location:
The initial project objectives are described below.

1. Model development

a) Rebuild the fire behavior model to add the new fire behavior fuel models (Scott and Burgan 2005). Revise the current scheme of interpolating between fire behavior fuel models to improve model behavior.
b) Add a method to use the modeled fuel loads directly when modeling fire behavior so that this approach can be evaluated in place of using interpolation between standardized fuel models.
c) Revise the canopy fuel calculations to take advantage of recent JFSP-funded research results.
d) Add a way to represent season of burn in the fire behavior and effects calculations.
e) Add the Canadian fire behavior prediction system and fuel models for the Lake States variant.

f) Improve the representation of shrubs and other non-tree plants. Incorporate shrub and herbaceous fuels dynamically in fire behavior calculations.
g) Add a soil heating output, as implemented in FOFEM, a First Order Fire Effects Model, previously funded by the JFSP (Reinhardt 2003).
h) Improve the fuel loading initialization. Compile existing data to strengthen the fuel initialization logic used when users have not inventoried fuels (which is often the case).
i) Review model architecture with respect to FVS cycle boundary discontinuities, with an objective of redesigning the portion of the model that causes these.
j) Improve decay dynamics, making use of recent work (Dumroese, RMRS-Moscow) that would give more realistic decay rates as a function of habitat type and canopy cover.

2. Interface and Usability

a) Add thinning options that will allow users to specify a residual canopy base height or residual canopy bulk density.
b) Add an output option that will provide users with the output they need to create canopy profile graphs.
c) Improve the graphical user interface (Suppose) by reworking features that are not used or are confusing, and adding others that will make the program easier to learn and use. Additions will include ways for users to easily specify management actions that include combinations of thinning and fuel management activities. The current technique requires that these activities be specified separately from different parts of the program.

3. Delivery and Training

a) Six training sessions per year will be provided. These training sessions will be part of the normal FVS training. Current training materials will be updated to reflect the most recent model changes and these training materials will be made available online. We will also provide six onsite project assistance visits to FFE-FVS users per year.
b) JFSP-member agencies from the USDI are blocked from using software unless it has been certified by the Information Management staff of the member agency. Currently, there is at least a one-month delay for BLM users to obtain the latest FFE-FVS software releases; the requirements and protocols of each member agency are likely different. We will attempt to get and maintain the necessary certification for the FVS-FFE suite of software that would allow users in USDI member agencies immediate access to the latest software releases. Failing this, we will document what these requirements and protocols are for future use and consideration by the JFSP board.
c) Write and publish revised model documentation.

Key Findings:

The project objectives listed above were initially tagged as possible model improvements. Most of them were completed. However, after addition interaction with model users, some were found to be less important than we initially thought or were handled differently than initially planned. The status of each of these items is described in the "Status of Deliverables" section below. In summary, major model additions that were accomplished include the incorporation of the 40 new fuel models into a new version of the fuel model selection logic, the ability to predict fire behavior from fuel loading directly (without the use of fuel models), a new fuel load initialization option where users can select an appropriate fuels photo series photo, new output related to soil heating and the canopy fuels profile, and new, easier-to-use options in the Suppose interface. In addition, 42 FVS training session were held in the last four years. (These sessions cover FFE in depth.) 13 on-site/in-person model assistance visits were also completed. Many model updates and additions not listed above, such as the FFE carbon reporting features, two new FFE variants, and improved visualizations, rose to the top of the model update list and were also accomplished. Revised model documentation is almost finished. This document will be maintained by the FVS staff and posted to the FVS website. This allows for documentation updates to be made along with every code change, whereas a published document cannot be updated over time. This approach also provides users with searchable text thereby providing faster access to desired information.

Management Implications:
Because FFE-FVS is used so widely by natural resource personnel, any model updates and improvements benefit these users and their analyses. As the model is improved, it leads to better, more realistic, or more user-friendly simulations and makes all project analyses done with FFE-FVS more defensible. Improved model runs help ensure that when users simulate real-life fuel treatments, the model results more closely match real-life ones.

Relationship to other recent findings and ongoing work on this topic:
Some projects are doing research that may be incorporated into FFE-FVS, such as project ID 06-3-3-13, Estimating Canopy Fuels and Their Impacts on Potential Fire Behavior for Ponderosa Pine in the Black Hills, South Dakota. Future changes to FOFEM and FuelCalc will continue to be evaluated for inclusion in FFE.

Future Work Needed:
Although this project provided for a number of improvements to the FFE-FVS modeling system, there is still much to be done. The following is a list of tasks that will ideally be done in the future.

- General maintenance of the FFE source code
- Continued training and user support
- Work with FS research and universities to validate/update model components, such as snag fall rates, mortality predictions, crown biomass/canopy fuels equations, and prescribed fire behavior
- Updates and improvements to the FFE carbon reports and underlying biomass algorithms

- Additions to the reporting of woody debris for wildlife applications
- Addition of new fuels photo series references to the model
- Improvements to the methodology used to simulate mastication treatments and how mastication affects fire behavior
- Development of FFE for the new Alaska Northern variant of FVS

Status of Deliverables:

The following table lists every original deliverable and several additional items that were added to this work as the project was accomplished. Many of the original objectives were accomplished as foreseen, others were not. Those that where not done were replaced by items that we determined were generally better uses of our time and resources.

Deliverable	Original ID	Current Status
Rebuild the fire behavior model to add the new fire behavior fuel models (Scott and Burgan 2005). Revise the current scheme of interpolating between fire behavior fuel models to improve model behavior.	1a	This was done. Users now have the choice between the original fuel model logic and the new fuel model logic that incorporates the 40 new fuel models and works for all variants. The torching index calculation was adjusted to improve model behavior when interpolating between fuel models
Add a method to use the modeled fuel loads directly when modeling fire behavior so that this approach can be evaluated in place of using interpolation between standardized fuel models.	1b	This was done.
Revise the canopy fuel calculations to take advantage of recent JFSP-funded research results.	1c	This has not been done yet. Although recent JFSP research examined alternate canopy shape assumptions and made some adjustments to Brown's crown biomass equations (Brown 1978, Brown and Johnston 1976) based on crown class, these changes have not been incorporated into FFE. The crown biomass equations in FFE have been expanded and improved over the years (for example, separate equations are implemented for small trees and interpolation is done to smooth the model behavior for trees near the small / large tree size break.) Also, FFE uses the most complex of Brown's equations that have DBH, HT, and/or CR as predictors, while other software programs such as FuelCalc use the simplest, DBH-driven equations. The FFE developers do not want to change the crown biomass equations without good reason and no good reasons were identified. Yet, this issue should be monitored as justification for changing may become evident in the future. One possibility is to first do a comprehensive comparison of the

		equations used in FuelCalc vs FFE. Also, new crown biomass equations have been developed for Ponderosa pine in the Black Hills and these equations should be added to FFE for the Central Rockies variant whenever published.
Add a way to represent season of burn in the fire behavior and effects calculations.	1d	This was done – season of burn was incorporated in the fire behavior and effects in the Lake States and Northeast variants.
Add the Canadian fire behavior prediction system and fuel models for the Lake States variant.	1e	This was not done. Although initially it was thought this was needed for the Lake States variant, when a development workshop was held there, it was determined that including the 40 new Scott and Burgan fuel models would suffice.
Improve the representation of shrubs and other non-tree plants. Incorporate shrub and herbaceous fuels dynamically in fire behavior calculations.	1f	This was not done. An analysis was done with an eye towards developing a method of predicting shrub biomass from stand measurements. The analysis showed that disturbance history is needed to predict shrubs (a confirmation of other findings). In general, however, the findings did not support inclusion into FFE-FVS.
Add a soil heating output, as implemented in FOFEM, a First Order Fire Effects Model	1g	This was done.
Improve the fuel loading initialization. Compile existing data to strengthen the fuel initialization logic used when users have not inventoried fuels.	1h	An option was added so that users can initialize their fuel loadings by selecting a photo series photo. Currently 32 photo series books are available to select from.
Review model architecture with respect to FVS cycle boundary discontinuities, with an objective of redesigning the portion of the model that causes these.	1i	This was not done. Based on user feedback, it seems that what users would like is to have an easy way to output FFE reports on FVS cycle boundary years only, rather than annually, so this will be completed this summer.
Improve decay dynamics, making use of recent work that would give more realistic decay rates as a function of habitat type and canopy cover.	1j	This was not done. The current decay rates in FFE have proven adequate.
Add thinning options that will allow users to specify a residual canopy base height or residual canopy bulk density.	2a	This was not done. Although initially it was something a user requested, no recent requests for it have come in.
Add an output option that will provide users with the output they need to create canopy profile graphs.	2b	This was done.
Improve the graphical user interface (Suppose) by reworking features that are not used or are	2c	This was done.

confusing, and adding others that will make the program easier to learn and use.		
Six training sessions per year will be provided. Current training materials will be updated to reflect the most recent model changes and these training materials will be made available online. We will also provide six onsite project assistance visits to FFE-FVS users per year.	3a	This was done. We planned to accomplish 12 trainings (6 a year for 2 years) and 12 on-site assistance visits (6 a year for 2 years). Because this JFSP award was extended, we were able to hold 42 training sessions over 4 years and 13 on-site project assistance visits. Training materials have been updated and improved every year.
JFSP-member agencies from the USDI are blocked from using software unless it has been certified by the Information Management staff of the member agency. Currently, there is at least a one-month delay for BLM users to obtain the latest FFE-FVS software releases; the requirements and protocols of each member agency are likely different. We will attempt to get and maintain the necessary certification for the FVS-FFE suite of software that would allow users in USDI member agencies immediate access to the latest software releases. Failing this, we will document what these requirements and protocols are for future use and consideration by the JFSP board.	3b	Currently BLM employees must download software from a BLM website and cannot download software from FS websites. As a result, the BLM posts a version of FVS to their website which is updated every 6 months or so. (Our BLM rep, Tim Bottomley, gets notices when there are code changes and deals with the BLM Configuration Management Team to handle this.) He is also investigating whether or not this can be improved so that BLM users can get updates immediately. The BIA has some sort of blanket FVS authorization and does not have this problem.
Write and publish revised model documentation.	3c	The FFE Addendum is a document that contains all updates to the model since 2003, when the FFE GTR was published. This addendum is being folded into the FFE GTR and this new document is being reformatted. This should be completed shortly, at which point it will be reviewed and posted to the FVS website. This document will also be updated based on all future model changes. The decision to keep this document as web-based and updateable was made after carefully considering the long-term costs and usability of the documentation.
Create new FFE carbon reports that report carbon stored in	added	This was done. The carbon reports estimate stored carbon in various pool, as well as the carbon removed from the stand

various stand-level pools		through management activites and emitted from simulated fires. Carbon removed through management is also tracked through time to estimate how much of it is still being stored (for instance, in forest products).
Create FFE for the Central States variant	added	This was done.
Create FFE for the Southeast Alaska variant	added	This was done.
Add new output as requested by users	added	This was done. Variables such as spread rate and reaction intensity are now available for output.
Improve the SVS images that FVS creates so that stand components such as snags and fuels more closely match FVS simulation results	added	This was done.

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