OptFuels: Assessing fire risk and scheduling fuel treatments spatially over time to minimize expected loss from future fire in the Lake Tahoe Basin

User Guide

May 3, 2014

Greg Jones, RMRS

Woodam Chung, University of Montana

Jody Bramel, Axiom IT Solutions, Inc.

Edward Butler, University of Montana

Robert Lankston, RTL Networks, Inc.

Kurt Krueger, RMRS

Introduction

OptFuels is a modeling system for assessing fire risk and scheduling fuel treatments spatially and temporally across a landscape to minimize expected loss from future wildland fire. A Lake Tahoe Basin-specific OptFuels system has been developed by the SNPLMA-funded project "Integrated decision support for cost effective fuel treatments under multiple resource goals." OptFuels combines the vegetation simulation capabilities of the Forest Vegetation Simulator (FVS), the landscape fire behavior modeling functionality of FlamMap, and a heuristic algorithm for scheduling fuel treatments.

This integrated system provides land managers with a streamlined ability to develop spatiotemporal fuel treatment alternatives and assess trade-offs among various alternatives and no action. Trade-offs can be assessed in terms of effects on fire behavior including flame length and fire arrival time across the landscape, expected loss to values at risk, and sediment loading in stream channels if wildfire were to occur. Forest vegetation is modeled through time and can also be compared across treatment alternatives and no action. In addition to fuel treatment optimization by the heuristic algorithm, users also have the option of entering their own treatment alternatives for analyzing effects on fire behavior and conducting trade-off analyses. Four default models covering the Basin have been developed, making application of the system quick and easy. This guide documents the default OptFuels models and their use in the Lake Tahoe Basin.

OptFuels has several dependencies. The alternative builder uses FoxPro runtimes which are included in the installer. The OptFuels ArcMap toolbar is built for ArcMap 10.1. According to ESRI, 10.1 toolbars should also work with 10.2 but this will not be tested.

This Guide is organized as follows. First, it provides instructions for installing OptFuels. This is followed by an overview of the OptFuels system that provides basic system concepts and processes. The next section describes the data and processes that were used to build the default OptFuels Models for use in the Lake Tahoe Basin. That is followed by a section that describes how to run the OptFuels model that has been developed specifically for the Lake Tahoe Basin. That section includes instructions of how to select the model for one of four analysis areas in the Basin, how to enter the specifications for developing a fuel treatment alternative, description of the tabular and GIS outputs produced by the system, instructions for exporting results to Google Earth, and instructions for estimating loading of fine sediment into stream channels following potential wildland fire for both treated and untreated landscapes. Finally, the manual includes Appendices A-D that provide more detailed information about various aspects of the OptFuels system.

Installing OptFuels

The name "OptFuels" is a general term that encompasses both the fuels optimization utility and the prototype Lake Tahoe dataset. For convenience, these components have been posted separately on the website. The OptFuels installer will set up folder paths on the system and includes the OptFuels executable, ArcMap toolbar, and basemap layers. The prototype Lake Tahoe dataset hosted on the website is further broken into 4 analysis areas (North, West, South, East).

Getting started with OptFuels only requires the installer, found here: http://www.fs.fed.us/rm/human-dimensions/optfuels/downloads.php. This download includes a .zip with a MS Installer and Setup file. To install, just double-click the installer and let it run. When the installer finishes, there will be a new folder on your computer at C:\magfire which contains everything you need to start running custom project area alternatives. The ArcMap toolbar will be located in C:\magfire\toolbar and requires separate installation. Locate the file and double-click to run ESRI's addin installer.

If you want to use the 4 pre-defined analysis areas, download them from the website and extract into the magfire folder. The paths should look like C:\magfire\DBF_LT_NORTH (and under that, C:\magfire\DBF_LT_NORTH\Input).

Overview of OptFuels

This section describes the flow of information through OptFuels (Figure 1) and covers key concepts for using OptFuels to develop and compare fuel treatment alternatives.

Stand polygons are the basic landscape unit used in OptFuels for vegetation and treatment modeling. Fuel treatment options are defined for use in the model along with the stand, topographical, and ownership conditions where those treatments are appropriate. The Forest Vegetation Simulator (FVS; http://www.fs.fed.us/fmsc/fvs/) is then used to model these treatments to the stands that meet the treatment criteria, and is also used to project the stands into the future both with and without treatments. The Fire and Fuels Extension to FVS (FFE) is used to predict the resulting fuel parameters for modeling fire spread for each time period, with the exception of the surface fuel model which was assigned through a pathway approach described later in this document.

The OptFuels solver schedules fuel treatments over time and space to minimize the expected loss from future wildland fire. The information for this calculation includes the categories for the values at risk and the expected loss for each risk category for each of five flame length categories. It also includes a table that predicts probabilities for a range of fire durations. In the model solving process, this information is combined with fire arrival times and flame length predicted by FlamMap Minimum Travel Time (MTT) fire spread modeling to compute an expected loss from future fire.

After the information described above has been entered, the OptFuels model is ready for analyzing fuel treatment scenarios. There are two analysis modes in OptFuels: 1) optimization, where the heuristic solver schedules fuel treatments spatially over one or more time periods to minimize expected loss from future fire, and 2) simulation, where users assign fuel treatments to polygons and use the OptFuels solver to compute the expected loss from future fire to measure treatment effectiveness.

One or more fire scenarios are specified for both the optimization and simulation modes. When two or more fire scenarios are specified, weights are entered that reflect the likelihood of each fire scenario. A fire scenario consists of ignition locations (typically one or more ignition lines), and fire parameters that include fuel moisture, wind speed and direction.

After specifications for a treatment alternative have been entered the solver is launched in either the optimization or simulation mode. As depicted in Figure 2, in each iteration of optimization mode the Simulated Annealing Heuristic solver selects a unique alternative of fuel treatment assignments for the stand polygons across the time periods, updates the landscape fuel parameters for those treatments, then launches FLAMMAP – MTT to model fire behavior for each fire scenario in each period. FLAMMAP predicts flame length and fire arrival time by grid cell, which is combined with the loss values and fire duration probabilities to compute the resulting expected loss. Numerous iterations are run in optimization mode to determine the best fuel treatment schedule across the time periods for the specified fire scenarios. In simulation mode the process described in Figure 2 is used to compute expected loss for the fuel treatment assignments entered for the stand polygons by the user.

Results from both modes can be displayed in GIS or as tabular reports. In addition to the computed expected loss given the specified fire scenario(s), results from both the fuel treatment alternative and no action are displayed in GIS. These results show placement and scheduling and include displays of the fire arrival time, flame length, and expected loss by fire scenario and planning period. In addition the system includes the ability to compute the amount of sediment loading that would be expected to follow a wildfire, if it were to occur. These WEPP-based sediment predictions are computed for both the treated and untreated landscape.

Default Models for Lake Tahoe Basin

Default OptFuels models have been developed for each of the four analysis areas displayed in Figure 3.   The area/model is selected when the OptFuels program is launched from the ArcGIS OptFuels tool bar. This section provides an overview of the data and process used to develop these four default models.

Figure 4 presents a flowchart of the model-building process, which begins with a GIS shapefile of stand polygons. The Region 5 Vegetation Stratification System (http://www.fs.usda.gov/detail/r5/landmanagement/resourcemanagement/?cid=stelprdb5365220) was used to define the stands used in the default models developed for the Lake Tahoe Basin. These stand polygon data included the plot code identifiers for the FIA inventory plots that had been imputed to the stand polygons by the R-5 Remote Sensing staff.

Projecting Stands with and without Fuel Treatments

FVS ready data for the FIA inventory plots that were imputed to the stand polygons was down-loaded from the FIA website (http://www.fia.fs.fed.us/tools-data/). The stands affected by the Angora Fire, which occurred in June 2007, and the corresponding FVS ready data were updated with plot data from the Angora Fire Vegetation Monitoring Annual Progress Report October 2010, available at http://www.cfc.umt.edu/forestlandscapeecologylab/Publications/AngoraVegMon_2010_report_sm.pdf. In this process, photo interpretation was used to assign plot data from the Monitoring Report to the stands within the boundary of the Angora Fire. Typically, an inventory plot was assigned to more than one stand polygons, both in the R-5 imputed stand data as well as the Angora Fire updates. A file of FVS-ready plot data was developed that contained only the unique plots across all stands. A stand attribute identifies the plot assigned to each stand.

Three treatments, 1) hand thin followed by a prescribed burn, 2) mechanical thin followed by a prescribed burn, and 3) mechanical thin followed by mastication, were selected as the candidate treatments after discussing potential treatment options with basin managers. Table 1 provides details about these three treatments. The Western Sierra variant of FVS (http://www.fs.fed.us/fmsc/fvs/software/variantinstaller.php) was used to simulate applying these treatments to the plots. Using Suppose (http://www.fs.fed.us/fmsc/fvs/software/suppose.php) separate FVS runs were made for applying each treatment to each plot in each of five planning periods. In these runs, a fuel treatment option was applied in those cases where the projected plot data met the criteria for applying that treatment (Table 1). FVS runs were also made for No Action (no treatment applied) to project the untreated plot data through the five planning periods. FVS-FFE was used in these simulations to predict the following fuel parameters for fire behavior modeling: crown base height, stand height, crown bulk density, and percent crown closure. FLAMMAP's crown fire model is sensitive to crown base height. The default base height values from FFE-FVS consistently resulted in modeled crown fire behavior that was less severe than would be expected under the specified weather conditions. Because of this observed limitation in the FFE-FVS data, the predicted increases in crown base height values were adjusted downward by 50%. This adjustment resulted in more realistic modeled crown fire behavior.

FVS-FFE also assigns surface fuel models to projected forest stands, but we found that these fuel model assignments did not result in modeled fire behavior that matched observed fire behavior of past fires in the Basin. Other users have documented this limitation with FVS-FFE (Collins et al. 2011, Seli et al. 2008). We chose instead to assign surface fuels by a process in which the Fuel Characteristics Classification System (FCCS, Prichard and others 2011) was used with FIA (Forest Inventory and Analysis) data from the Basin to develop a set of "fuelbeds" that describe vegetation from the surface to the overstory canopy. Because there were more stands in the Basin than we could reasonably simulate with FCCS, we aggregated stands into "strata" as defined by the R5 Remote Sensing Lab using forest type, canopy cover, and average tree diameter. A fuelbed was built for each of these strata based on the FIA plots falling within each stratum, and then we assigned one of the standard fuel models (Scott and Burgan 2005, Anderson 1982) to the strata that most closely matched the FCCS-based fuels data. FVS was used to project stand growth for each strata, and the projected stands were placed into the resulting strata based on percent crown closure and average diameter criteria for the strata. The post-treatment fuel model assignment varied according to whether the thinning was followed by a prescribed burn or mastication. For prescribed burns, the original FCCS fuelbeds were modified to reflect post-prescribed fire fuel loads based on the literature (van Wagtendonk 1996; Knapp *et al*. 2005; Stephens and Moghaddas 2005). For mastication we simulated the effects of masticating surface fuels by calculating the relative percent change for several classes of surface fuels using the post-thin and post-mastication tables in Stephens and Moghaddas (2005) (pers. comm. Moghaddas 2011). The fuel model assignment process is described in more detail in Appendix A.

The results from the FVS runs and the surface fuel model assignments were stored in the Treatment Databases (Figure 4). These results include the fuel parameters computed for each plot for each period for the No Action alternative, and for each of the three treatment options. Treatment options were included for each period for each plot where the treatment criteria were met by the projected stand.

The next step was to build a stand polygon GIS layer (Treat.shp) which stores the attributes needed by the OptFuels interface. This file contains the following attributes for each stand polygon:

1) Attributes from the GIS stand data, including size in acres, aspect, slope, ID for imputed plot data, jurisdiction, etc.
2) An attribute field for each treatment option to identify whether a specific treatment option should be available for each individual stand polygon ('Y' means the option is included, 'N' means it is not). The determination of whether treatment option is available for a stand polygon was based on: a) whether the stand conditions for the treatment were met (as determined in the FVS runs of the plot data) and b) whether the spatial criteria for applying the treatment listed in Table 1 were met by the stand.
3) An attribute field to identify the most important value at risk category (VALCAT) that is present in each stand polygon.

The vegetation data and modeling are related to stand polygons, and the fuel treatments options are related to these stand polygons as well. FlamMap, however, uses raster data (not polygon vector data) to model fire behavior and spread. This is handled by developing a raster file called 'treatgrid.asc' from the Treat shape file using the 'feature to raster' process in ArcMap. 'Treatgrid.asc' is a raster version of the stand polygons, where each grid cell stores the ID for the stand polygon having the most area falling within that cell. OptFuels assigns treatments to this raster version of the stand polygons in the fuel treatment scheduling process.

Expected Loss Calculation and Associated Data

The heuristic solver used in OptFuels to schedule fuel treatments has an objective of minimizing the expected loss summed across the planning area. This approach is patterned after the approach for large-scale wildfire risk assessment proposed by Thompson and others (2010).

The expected loss that is computed for a planning area is essentially an index of loss that is computed by summing expected loss across the grid cells in a planning area.   Expected loss for fire scenario ***s*** is calculated as follows:

$$\textbf{\textit{Expected loss}}_s = \sum_{t} \sum_{c} \sum_{r} P_{c,s,t} \times W_r \times Loss_{c,r,f,t} \qquad \text{(Equation 1)}$$

where:

c is an index of grid cells (pixels),

t is a time period,

r is an index for risk category,

f is an index for flame length category,

s is an index for fire scenario, which has specified fire ignition locations, wind direction and speed, fuel conditions.

$P_{c,t}$ is the probability of cell ***c*** being burned by fire scenario ***s*** in time period ***t***,

W_r is the weight factor for risk category ***r***,

$Loss_{c,r,f,t}$ is the expected loss for value at risk category ***r*** for grid cell ***c*** given a predicted flame length category ***f*** in time period ***t***.

When a fuel treatment alternative is optimized for two or more fire scenarios, the solver seeks to minimize the weighted average expected loss across fire scenarios:

$$\textbf{\textit{Weighted average expected loss}} = \sum_{s} \mathbf{Scenario}_s \times \textbf{\textit{Expected loss}}_s \qquad \text{(Equation 2)}$$

where $\mathbf{Scenario}_s$ is the user-entered weight for fire scenario ***s.*** The weights, which must sum to 1.0, quantify the relative importance of each fire scenario in scheduling fuel treatments.

Table 2 lists the Value at Risk Categories that are included in the four OptFuels default models. This table also stores the estimated loss for the Flame Length Categories for each of the Values at Risk, as well as the Weight Factors that provide the relative importance of loss for the various Value at Risk Categories. The OptFuels interface provides users the ability to edit both the loss by Flame Length Categories and the Weight Factors.

The loss values represent the percent of the original value that is lost by Flame Length Category. This estimates the percent loss if fire of that flame length were to occur in close proximity to the value at risk. Expressing loss as a percentage follows a framework for risk assessment proposed for wildland fire management in several recent papers (Calkin and others 2011; Thompson and others 2011a; Thompson and others 2011b). Furthermore, our conversations with managers indicated that they were more comfortable with loss expressed as a percentage, than the alternative of expressing loss in dollar terms.   It would be easy, however, to enter loss in terms of dollar values via the OptFuels user interface if that measure of loss were preferred.

The other component of expected loss is the probability, $P_{c,s,t}$, of grid cell ***c*** being burned in fire scenario ***s*** in time period ***t***. This is based on the fire duration probabilities shown in Table 3 and the fire arrival times computed for each grid cell for each fire scenario and each period being analyzed by MTT fire spread modeling.   For example grid cells with fire arrival times under 240 spread minutes have a fire probability of 0.99, cells with fire arrival times between 240 and 480 spread minutes have probability of 0.88 and so on.

Table 3 was based on past fires that occurred in the Lake Tahoe Basin. FireFamilyPlus (http://www.firemodels.org/index.php/) was used to identify the fires over five acres in size that occurred from 1995 to the current year.   Managers preferred excluding fires prior to 1995 because of differences in forest fuels and fire policy prior to that year. Duration for these fires was computed as the number of days between the fire *Discovery* Date and the *Strategy Met* date. The Strategy Met date was not recorded for a few of the fires, and for those cases the Fire-*Out* date was used in place the Strategy Met date. The MTT fire spread model measures fire arrival time for the grid cells, in spread minutes. We assumed that on the average fire day active spread occurs for 240 minutes, to convert fire duration from days to active spread minutes.

Table 4 illustrates the steps used to compute the fire duration probabilities from the observed durations of past fires.   Column (3) lists the number of fires that were recorded for each time step, 16 fires in total.   Column (4) is the fraction of the total number of fires that occurred in each time step.   We use this fraction to estimate the probability of fire duration for each time step. Column (5) is the cumulative totals of the Column (4) probabilities. These cumulative totals represent the probability that fire duration will not exceed each time step. For example, a cumulative probability of 0.31 for time step 2 means that there is a 31% chance that the fire strategy will be met prior to the end of time step 2.   Column (6), which is calculated as 1.00 minus the cumulative probability in Column (5), estimates the probability that fire duration will exceed each time step. For example, 0.69 (1 – 0.31 = 0.69) is the estimated probability that the fire will burn beyond the end of time step 2. Column (6) is the empirical estimate for fire duration by period.   We note that a number of time steps have the same probability of fire duration in Column (6). This happened because there are a limited number of fires that occurred in the Basin from 1995 and no past fires were observed for a number of time steps. We chose to statistically smooth those empirical numbers by statistically fitting a curve to the fire duration probabilities in Column (6) using a technique called nonparametric kernel density estimation (Scott 1992).   The smoothed probabilities are compared to the empirical probabilities in Figure 5. Column (7) in Table 4 lists the durations by time step that were estimated by this statistical technique. These are the probabilities for fire duration shown in Table 3 that are in the default OptFuels models for the Tahoe Basin.

<u>Importing Data into the OptFuels Interface</u>

The next step in the modeling building process (Figure 4) was to run the import process (MAGfire/main/magfire_import.exe). This program, which was run separately for each of the four OptFuels default models, imports the information stored in the Treatment Databases and in the Treat Shape file into the OptFuels interface files. After the import has been accomplished the model is ready for developing and analyzing fuel treatment alternatives for the planning area. The files needed to run OptFuels are stored in the following directories:

C:\MAGfire\dbf_lt_XXXX

where 'XXXX' represents a Lake Tahoe Area (South, North, East, or West). See Appendix D for a listing of the files used in the OptFuels system.

WEPP-Based Post-Fire Sediment Loading Predictions

The OptFuels system developed for the Tahoe Basin includes the capability of using WEPP (Flanagan and Livingston 1995; Elliot and Hall 1997) predictions of sediment to estimate annual loading of fine sediment into stream channels from weather events that follow potential future wildland fire. This application of WEPP utilizes information that was developed for the online application of WEPP designed specifically for the Lake Tahoe Basin (http://forest.moscowfsl.wsu.edu/fswepp/). Sediment loading following wildland fire is estimated for both treated and untreated landscapes to provide a measure of treatment effects in reducing sediment in the event of future fire followed by several possible precipitation events. Sediment loading estimation is designed to be run after an OptFuels alternative has been developed and is based on the MTT fire behavior simulations for no action and the final treatment alternative that is made in the OptFuels' treatment scheduling process.

WEPP models splash, sheet, inter-rill, and rill scale erosion. WEPP does not model for mass-scale erosion processes such as incision, gullying, and mass failure. Though roads may be a significant source of sediment, and WEPP provides the capability of predicting sediment from roads, OptFuels has no road component. Thus, sediment from road prisms is not included in the OptFuels application at this time.

The WEPP sediment predictions in this effort were restricted to fine sediment less than 20 microns. This fine sediment remains suspended for long periods of time affecting Lake clarity, whereas coarse sediment settles-out (Smith and Kuchnicki 2010). Through our work it was noted that yield of fine sediment varied in direct proportion to total sediment, averaging around 30% of total sediment loading. Estimates of total sediment could be made by using this percentage.

Literature review and WEPP sensitivity have shown that hillslope sediment does not get into a stream channel from distances greater than 70-meters, even from intense events (Burroughs 1990; Belt et al. 1992). Based on this information, a decision was made to estimate sediment loading for only the portion of stands that were within 70 meters of a stream channel or a shoreline, based on the stream network downloaded from the National Hydrological Dataset

(NHD) perennial streams (http://nhd.usgs.gov/data.html). We refer to this this 70-meter radius as the "riparian contribution zone" (RCZ). It is important to note that the RCZ is in no way related to the streamside management zone (SMZ) or any other administrative rule.

The annual sediment predictions were made in a series of batch runs of WEPP for: a) two severe weather scenarios (10-year and 50-year precipitation events), b) surface cover conditions for undisturbed sites, thinning treatments, and high severity fire, and c) a variety of slopes, aspects, soils, and vegetation conditions representative of the range of these variables across the portions of stands within the RCZ. The unique combinations of these WEPP input variables resulted in 17,920 WEPP simulations made to predict fine sediment rates for each combination of input variables.

The strategy for utilizing WEPP was to make separate sediment predictions for the each portion of each stand in the RCZ, then sum those individual predictions to estimate sediment loading at the analysis unit level. This was accomplished by using the feature to raster process in ArcMap to develop a 5-meter raster coverage. The WEPP-based sediment loading rates computed for stand polygons were used to calculate the sediment loading amounts for the 5-meter raster cells within the RCZ. This produced the six 5-meter raster data layers shown in Table 5. For computational efficiency, these 5-meter layers were then aggregated to the 90-meter grid cells used in fire behavior modeling. This operation simply summed the sediment amount across all 5-meter cells within a 90-meter cell to compute the total sediment amounts for the 90-meter raster cells, so no precision in sediment prediction is lost.

Sediment movement is mostly of concern if a significant precipitation event were to occur within a year following a wildland fire. Sediment loading predictions were made for two levels of precipitation events occurring 9 -12 months following a future wildland fire, a 10-year event, and a 50-year event. These events and the associated precipitation amounts were identified using CLIGEN weather data via the Rock:Clime application (Elliot et al. 1999).
Slope and aspect classes for sediment yield estimation were derived for the 5m grid cells from a National Elevation Dataset using Spatial Analyst in ArcMap. Seven slope classes were used for the range of values found in RCZ buffers. Only four aspect classes were used, (northwest, northeast, southeast, and southwest) because sensitivity tests showed that WEPP is not very sensitive to aspect.

Soil texture, which relates to factors of hydraulic conductivity and surface erosion, is a sensitive WEPP input. William Elliot, Project Leader for the WEPP modeling group, provided soil files based on soil types found in the Lake Tahoe Basin RCZ buffers. Though there are minor exceptions, these soils are predominantly coarse, porous soils interspersed with rock outcrops that rarely allow runoff or the resulting erosion due to their porous nature. The texture of these soils are described in the WEPP inputs files in terms of "coarse sandy loam, sandy loam, loam and rock" and are further attributed with surface conditions (regarding shear factors) of shrub, grass, bare, rocked barren, rocked vegetated (limited vegetation in cracks and shallow pockets), untreated forest, forest treated by thinning, and post-high severity fire. The midpoint for soil depth was used for all soil classes (except rock which had a depth of zero) because sensitivity analyses on these soil files found that soil depth had a negligible effect on erosion for the soil types present.

Percent groundcover is the final input needed for simulating sediment loading using WEPP. Groundcover is any object on the ground surface larger than 2mm, and includes pebbles, exposed roots, twigs, downed woody debris, grass, duff, boulders, etc. Groundcover provides an armoring effect that attenuates splash, retards flow, reduces soil detachment, and reduces runoff. The percent groundcover values used in the WEPP simulations are summarized in Table 6. These percentages are based on the cover amounts listed in FS WEPP, On-line Tahoe Basin Sediment Model (http://forest.moscowfsl.wsu.edu/cgi-bin/fswepp/tahoe/tahoe.pl). The cover amounts for Treated Forest and High Severity Fire were adjusted to reflect ground cover vegetation expected to regenerate over 9-12 months following disturbance. While these cover percentages are estimates, we note that for most weather, WEPP predicts little or no fine sediment loading until groundcover is reduced to less than ~65% coverage (Miller et al. 2011) and empirical studies support that dynamic (Larsen et al. 2009).

The OptFuels Interface for Scheduling and Evaluating Fuel Treatment Alternatives

The OptFuels Interface is implemented as a toolbar in ArcMap 10.x, which is displayed after OptFuels has been installed (Figure 6). The toolbar contains icons for 5 items: 1) Selecting Analysis Area, 2) Launching OptFuels for entering specifications for a fuel treatment alternative and launching the solver, 3) Adding OptFuels outputs to GIS, 4) Exporting layers to Google Earth, and 5) Predicting sediment by fire duration.

Select Analysis Area Icon (OptFuels Toolbar)

The first step in running OptFuels for the Lake Tahoe Basin is to select one of the four analysis areas. This is come by clicking the ‘Select Analysis Area’ icon in the OptFuels tool bar. Then the window displayed in Figure 3 appears. Select one of the four areas by clicking within the boundary of the desired area. A dialog box will then display identifying which area has been selected. Click ‘ok’ to complete the selection process.

Launch OptFuels Icon (OptFuels Toolbar)

Clicking the Launch OptFuels Icon displays the OptFuels menu screen, which is shown in Figure 7. This screen is used for defining and entering the specification for a fuel treatment alternative. It is contains a button for launching the OptFuels solver for scheduling fuel treatments for an alternative.

Screen Basics

The analysis area that was selected prior to accessing this screen is displayed at the top of the menu. The field labeled '***Alternative Name***' displays the names of the alternatives that have been defined for current area. The field labeled '***Description of Selected Alternative***' is available to enter and display a description for the current (highlighted) alternative.

The '***New***' button at the top of the menu is used to define a new alternative. Pressing '***New***' brings up dialog box for entering the name for the new alternative and a description (optional). After the 'Save' button in the dialog box is clicked, the new alternative is added to the list in the '***Alternative Name***' field.

The '***Copy***' button at the top of the menu is used to copy the specifications for the alternative that is selected in the '***Alternative Name***' field to a new alternative. After pressing '***Copy***' enter the name for the new alternative and a description (optional) in the dialog box. Then press 'Save' to the new alternative to the list displayed in the '***Alternative Name***' field.

The '***Done***' button at the top of the menu is used to exit the OptFuels menu.

All of the remaining fields on this menu either display or record information related to the current (highlighted) alternative displayed in the '***Alternative Name***' field. The field '***Objective Function Value***' displays the expected loss computed for the current alternative providing the solver has been run for that alternative; if not, the field is blank.

The four buttons under the heading '***Alternative Specs***' access screens for entering specifications for the current alternative: 1) Specify the FLAMMAP parameters for one or more fire scenarios, 2) Edit the inputs for computing Expected Loss, 3) Specify constraints for use by the solver in scheduling fuel treatments, and 4) Entering user-specified fuel treatment assignments (specific fuel treatment prescriptions assigned to specific stand polygons).

Build Alternatives: 'Fire Scenarios for FLAMMAP' Button

This button accesses the screen for entering the FLAMMAP input parameters for the fire scenario (or scenarios) to be used in scheduling treatments for the current alternative (Figure 8). FLAMMAP will be run for each combination of fire scenario and planning period in each iteration processed by the OptFuels solver. Exit this screen by pressing the '***Done***' button in the upper right corner of the screen.

The '***Fire Scenario Number***' field lists the fire scenarios that have been specified for the current alternative (identified in the upper left corner of the screen). Fire scenarios are identified in this field by number. New (additional) fire scenarios are added via the '***Add new Fire Number***' button. The '***Scenario Description***' field is available to enter and display a description for the current (highlighted) fire scenario number.

The '***Copy from Another Alternative***' button at the top of the screen provides the ability to copy to this fuel treatment alternative the fire scenarios that were previously entered for another fuel treatment alternative.

All of the remaining fields on this screen record information related to the current (highlighted) fire number displayed in the '***Fire Scenario Number***'' field. The '**Scenario Weight (fraction of 1.0)**' field is used for entering a numerical weight between 0-1.0 that reflects the relative importance of each fire scenario in scheduling fuel treatments. These weights, which must sum to 1.0, are used by the solver to compute a weighted average expected loss across the fire scenarios that is used in scheduling fuel treatments. The weights should be based on the relative likelihood of the fire scenarios occurring in the future.

The '***MTT Run time in Spread Minutes***' field is used to specify the number of spread minutes that FLAMMAP MTT will be run each time it is launched by the OptFuels solver. Selecting a value of '***0***' causes FLAMMAP MTT to run until fire spread is modeled across the entire planning area. This is the option suggested for scheduling fuel treatments. A specific amount for spread minutes can be entered if modeling fire spread across less than the full extent of an analysis area is desired in the fuel treatment scheduling process. Be aware, however, that expected loss, which is based in part on flame length, will be zero for any grid cell in an analysis that is not reached by fire in the number of spread minutes specified.

The '***Fuel Moisture***' options include using a default fuel moisture file, '***Fuel Moisture File (.FMS)***' or using '***Use Custom Fuels***' that are recorded in a user-created file. The default fuel moisture files are found in the following directory location:

C:\MAGFIRE\DBF_LT_XXXX\INPUT

where 'XXXX' represents a Lake Tahoe Area (South, North, East, or West). There is also an option for '***Use Fuel Moisture Conditioning***'. If fuel moisture conditioning is selected, the user will be asked to provide a '***Weather File (*.wtr)***' and '***Wind File (*.wnd)***'. These files are not provided in the default models.

There are three options for '***Winds***': '***Wind Blowing Uphill***', '***Wind Direction***', or '***Wind Vectors – select speed and direction ascii grids***'. If '***Wind Direction***' is selected, then '***Wind Speed (mph)***' and '***Wind Direction***' (which is entered as an azimuth) must also be specified. If ***Wind Vectors – select speed and direction ascii grids*** is selected the user must supply '***Direction***' and '***Speed***' grid files.

The ignition line(s) or points for the fire scenario are stored in what is called an ignition shape file and is selected in the file labeled '***Select Ignition File***'. The default ignition files are found in the following directory location:

C:\MAGFIRE\DBF_LT_XXXX\INPUT

where 'XXXX' represents a Lake Tahoe Area (South, North, East, or West). See Appendix C for instructions of how to create a new ignition file.

Build Alternatives: 'Expected Loss Inputs' Button

This button accesses the screen for editing the data used to calculate expected loss from future wildland fire. Figure 9 shows the '***Value loss percentage***' tab, which is the user interface for editing the percentage value loss amounts and associated '***Weight***' for the value at risk categories that were listed earlier in Table 2. The numerical values in this table can be updated via the '***Update Loss Table for this Alternative***' button. As the button name suggests, the edits apply only to the current fuel treatment alternative.

The loss values displayed in Figure 9 represent the percent of the original value that is lost by flame length category. This estimates the percent loss if fire of that flame length were to occur in close proximity to the value at risk. Expressing loss as a percentage follows a framework for risk assessment proposed for wildland fire management in several recent papers (Calkin and others 2011; Thompson and others 2011a; Thompson and others 2011b). If there is a desire to compute expected loss in dollar terms, the values in Figure 9 can be replaced with dollar loss values.

The '***Weight***' column in Figure 9 shows the weight that is applied to the expected loss for each value category. These weights provide a means for ranking the relative importance of loss across the value categories. It is recommended that the value category with the lowest importance be assigned a weight of '1'. Then, assign multiples of 1 to reflect the higher importance of loss in the other value categories.

Figure 10 shows the '***Fire Duration Probabilities***' tab, which is the user interface for editing these probabilities. These probabilities were computed from analyzing the duration of past fires in the Lake Tahoe Basin, as described earlier in the section titled "Expected Loss Calculation and Associated Data." Use the '***Delete Row***' button to delete a row in the table and the '***Append Row***' button to append a row at the bottom on the table. Be sure to press the '***Apply***' button after making any changes. Changes made on this screen apply only to the current fuel treatment alternative.

Build Alternatives: 'Set Constraints' Button

Figure 11 shows the screen for specifying constraints for the solver to use in scheduling fuel treatments for an alternative. These constraints are used to limit the number treatment acres or limit the budget in scheduling treatments.

The '***Treatment Acre Constraints***' are used to specify lower limits and upper limits for the number of acres of treatment for the alternative. There is one acreage constraint per period. The '***Lower Limit***' in the table specifies that a constraint must have a solution value that exceeds the lower limit amount. The '***Upper Limit***' specifies that a constraint must have a solution value that does NOT exceed the upper limit amount. '***Period***' identifies the period to which the constraint applies.

Cost constraints may also be used to limit the treatment schedule developed by the solver. They are specified in the section titled '***Cost Constraints (Optional)***'. To add a new constraint press

‘***Add Cost Constraint***’ and new constraint will appear in the list. The constraint ‘***Name***’ can be edited as well as the other fields for cost constraints. The table at the bottom of the screen labeled ‘***Cost Amounts***’ is used to enter the cost per acre amounts for each fuel treatment option. After these costs have been entered, press ‘***Apply***’ to implement the specified cost constraint. Cost constraints can be removed by selecting (highlighting) the desired constraint, then clicking ‘***Delete Selected Cost Constraint***’.

In general the solver will tend to allocate treatments until the upper limit of one or more acreage or cost constraints is reached. This occurs because more treatment acres generally result in lower expected losses from future fire. Thus, the upper bound is the more useful bound for targeting number of treatment acres and/or the costs for an alternative. The lower bound can be used to ensure that treatment acres (or costs) exceed some minimum threshold, but it is important to leave a difference between the lower and upper bound of at least 3 times the cluster size in acres (cluster size is entered on the OptFuels main menu screen) to ensure the solver has sufficient room to work.

Build Alternatives: ‘Set Decision Variables’ Button

The screen accessed by this button is displayed in Figure 12. This screen is used to develop a query to select a set of treatments from the database containing all the potential treatment options (treatment prescriptions x polygon x time period). When this screen has been completed, the selected set of treatment options is fixed into solution for the current treatment alternative.

Treatment option is selected from the ‘***Treatment***’ pick list at the top of the screen, and the period for implementing the treatment is selected from the list under ‘***Period***’. If all possible combinations of selected treatment and period are desired, press the ‘***Search on Just Period and Treatment***’ button.

The query can be further restricted by GIS attributes in Treat shape file. The attributes that are characters are listed under ‘***Treat Fields with Character Values***’. To restrict the query by one of these attributes, click on the desired attribute (e.g. ‘***JURIS***’ – for jurisdiction) and the dialogue box shown in Figure 13 appears. This dialogue box is used to select the categories of JURIS to which the previously selected treatment is to be restricted (eg. ‘***FS_MNG***’ – for Forest Service managed acres that are not restricted by other designations). To select a category, highlight the desired category in the list under ‘***Excluded Outputs***’, then press ‘>’, which moves the selected category to the list under ‘***Included Outputs***’. After all the desired categories are listed under ‘***Included Outputs***’ press ‘***Apply***’ to implement that portion of the query, which is written in the field labeled ‘***SQL Search String***’ at the bottom of the Set Decision Variable Screen (Figure 12). The treatment will only be applied to the stand polygons having the selected attribute categories (for the example displayed, that includes only those polygons having the category ‘***FS_MNG***’ for ‘***JURIS***’)

The query can be further restricted by the numerical attributes that are listed under '***Treat Fields with Number Ranges***' the Set Decision Variable Screen. This is accomplished by selecting (highlighting) the desired attribute (e.g. SLOPE), then entering the acceptable numerical range for that attribute under '***Range of Number Values***' (e.g. 35 and 100). Then press '***Add Number Values***' to add that selection to the query displayed at the bottom of the Set Decision Variable Screen. The selected treatment will only be applied to the stand polygons having numerical values within the selected range (for the example displayed, that includes only the polygons with SLOPES between 35 and 100 percent).

Press the '***Apply Search***' button at the bottom of the screen to activate the query. This process sets the selected decision variables into solution prior to the launching the OptFuels Solver. If the solver is run in '***Single Iteration Simulation***' Mode, the fuel alterative includes only the treatment options selected on this screen (ie., the solver will not select any additional treatments). If the solver is run in Optimization Mode ('***High***', '***Medium***', or '***Low Intensity Solution***' buttons) it will add additional treatments to the selected treatment options as permitted by the constraints that have also been specified for the alternative.

Solver-Related Buttons and Fields

These include the '***Cluster Size***' field, the '***Solver Options***', and the '***Run Heuristic Solver***' button for launching the solver. The field '***Cluster Size***' is the target size for the individual fuel treatment units to be developed by the solver in scheduling treatments for the current alternative. Treatments are assigned to adjacent stands until the cluster size target is met. See Appendix C for more details.

Four '***Solver Options***' are available. The first three ('***High***', '***Medium***', and '***Low Intensity Solution***') specify alternative stopping rules for the heuristic solver in scheduling treatments to minimize expected loss. '***Low Intensity***', as the name suggests runs the fewest iterations and is most useful for preliminary investigation of fuel treatment alternatives. The '***Medium Intensity***' option can be expected to develop fuel treatment schedules that provide a lower expected loss than the '***Low Intensity***' option, but at the cost of a longer run time. The '***High Intensity***' option will result in the most iterations processed by the solver and treatment schedules developed by this option would generally be expected to produce a lower expected loss than the other two options. However, tests of the solver have shown that there are diminishing marginal returns associated with additional solver iterations past the '***Medium Intensity***' option. Thus, although the '***High Intensity***' option could be expected to produce a treatment schedule with lower expected loss, the improvement relative to the '***Medium Intensity***' option may prove to be small. See Appendix C for more information about the heuristic process used in OptFuels to schedule fuel treatments.

The '***Single Iteration Simulation***' option is used to analyze a treatment option that is comprised only of treatment options selected on the '***Set Decision Variables***' screen. It can also be used to analyze untreated landscapes. This is accomplished by developing an alternative in which no treatment options are selected on the '***Set Decision Variables***' screen.

At this point it may be useful to reiterate that OptFuels assigns and analyzes treatments using a raster version of the stand polygons in the fuel treatment scheduling process. This is necessary because FlamMap MTT (as well as all applications of FlamMap) models fire behavior and spread using raster fuels and topographical data. As a result, the fire behavior results as well as the expected loss computations are based on this raster representation of the stand polygons. Also, all GIS results are displayed in this raster representation of an analysis area.

Add OptFuels output to GIS Icon (OptFuels Toolbar)

Clicking the Add OptFuels output to GIS Icon on the ArcGIS OptFuels Toolbar displays the dialog screen (Figure 14) for selecting the results to be displayed in GIS. Select the alternative to display from pick list labeled '***Select OptFuels Alternative***', select the fire by typing the appropriate fire number in the field labeled '***Fire to Display***', and select the planning period by typing the number in the field labeled '***Period to Display***'. The output layers available for display in GIS are shown in the section titled '**Select Output Layers**'. Select or un-Select an output layer by clicking in the box adjacent to it.

The selected output layers are computed and displayed in ArcGIS after the '***Add Data***' button on the bottom of the screen is pressed. Select '***Clear Current Layers***' if you want the GIS display to include only the newly specified layers. If '***Clear Current Layers***' is unchecked, the specified layers are added to any layers already being displayed. This can be used, for example, to include output layers from multiple alternatives, fires, or period in the same display. Select '***Rebuild GIS Layers***' if you want all selected layers to be rebuilt even if one or more has been previous developed for the selected Alternative, Fire, and Period. Otherwise leave '***Rebuild GIS Layers***' unchecked.

The base map and ignition layers are automatically generated and turned-on in the ArcGIS display (Figure 15). Figure 16 shows the four layers available for No Action: Arrival Time, Burn Probability, Flame Length, and Expected Loss. The same four output layers are available for the treatment schedule developed by the OptFuels solver. In addition, there is a treatment layer showing the fuel treatments that were selected for the alternative and period (Figure 17) and another layer showing the locations of treatments by period (Figure 18).

Figure (19) shows the comparison layers for Arrival Time, Flame Length, and Expected Loss. These layers show the difference between the treatment alternative and no action (No Action value minus the treatment alternative value) for each raster cell.

This interface provides the ability to easily create basic GIS displays of the OptFuels outputs. Once the output layers are in GIS, then all the ArcGIS functionality can be used to make comparisons across alternatives, fires, or periods.

Export Layers to Google Earth Icon (OptFuels Toolbar)

Clicking the Export Layers to Google Earth Icon on the ArcGIS OptFuels Toolbar displays the dialog screen (Figure 20) for selecting the output layers to export to Google Earth KML format. This screen lists only the output layers that were in the GIS display that was active when the Export Layers to Google Earth Icon was clicked (if no GIS display is active when this icon is clicked, then no layers will be listed on this screen). The layers are categorized by '***No Action***', '***Treatment Alternative***', and '***Comparison layers***' to make them easy to identify.

Select or un-Select an output layer for export by clicking in the box adjacent to it. There is no restriction on how many layers are selected for export on this screen. Specify the location where the exported KML file is to be written in the field labeled '***Save KML to***;'. This is most easily done by clicking '***Browse***' which displays a standard Windows dialogue screen for entering the desired directory path and file name.

After the output layers have been selected and path and file name specified for the KML file, press 'Export Now'. The selected layers will be written to the specified KML file name at specified location. You can now open this KML file with Google Earth to display the exported layers.

Predict Sediment by Fire Duration Icon (OptFuels Toolbar)

Clicking the Predict Sediment by Fire Duration Icon on the ArcGIS OptFuels Toolbar displays the dialog screen (Figure 21) for selecting the '***Project Area***' and '***Alternative***' for which to compute the predicted sediment. This screen executes the WEPP-based post-fire sediment loading computations described earlier in this manual (see section titled 'WEPP-Based Post-Fire Sediment Loading Predictions). Sediment loading following wildland fire is estimated for both treated and untreated landscapes to provide a measure of treatment effects in reducing sediment in the event of future fire following within 9-12 months by a severe precipitation event. Sediment loading estimation is designed to be run after an OptFuels alternative has been developed and is based on the MTT fire behavior simulations for no action and the final treatment alternative that is made in the OptFuels' treatment scheduling process. This process estimates only fine sediment (< 20 microns) loading from hillslopes.

For the field labeled '***Riparian Contribution Zone (RCA) Polygon***' (Figure 21), select the shape file named '***RCZ70_stands5d.shp***', which is found in sub-directory 'C:\MAGfire\rcz'. This shape file contains the WEPP-based sediment loading predictions that were made for Lake Tahoe Basin. This shape file contains predicts for each of the four project areas.

For section labeled '***Identify Sediment Fields***' select the field names present in the '***RCZ70_stands5d.shp***' shape file. The field names should match the field labels, for example, select field '***NA10***' under the label with name, and so on for all of the six fields in that section.

The field '***Flame Length (meters)***' identifies the lowest flame length considered to be high-severity field for purposes of sediment loading calculations. Three meters is the suggested length, but other minimum values can be entered here. This can be useful for analyzing the sensitivity predicted sediment loading to flame length.

At the bottom of the screen, enter the '***Project Area***' and '***Alternative***' for which to compute the predicted sediment. Sediment amount is computed for both the alternative selected as well as No Action.

Press the Execute button at the bottom screen to launch the sediment calculations for the selected alternative. The results are written to an Excel file named 'SedimentByArivalTime.csv' which is written to the following directory location:

C:\MAGfire\dbf_lt_XXXX\input\YYYY\RESULTS\graph

Where 'XXXX' represents a Lake Tahoe Area (South, North, East, or West) and 'YYYY' represents the alternative name. Figure 22 shows an example graph of the predicted fine sediment loading for 10-year and 50-year precipitation events occurring 9-12 months following a wildland fire. Sediment loading is graphed across fire duration for both the treated and untreated landscape.

References Cited

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

Belt, George H.; O'Laughlin, Jay; Merrill, Troy 1992. Design of Forest Riparian Buffer Strips for the Protection of Water Quality: Analysis of Scientific Literature. Report Number 8, University of Idaho. June: 7 p.

Burroughs, E. R. 1990. Predicting Onsite Sediment Yield from Forest Roads. XXI, International Erosion Control Association, Erosion Control: Technology in Transition, Washington, D.C. 223-232.

Calkin, David E.; Ager, Alan A.; Thompson, Matthew P., eds. 2011. A comparative risk assessment framework for wildland fire management: the 2010 cohesive strategy science report. Gen. Tech. Rep. RMRS-GTR-262. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 63 p.

Collins, Brandon M.; Stephens, Scott L.; Roller, Gary B.; Battles, John 2011. Simulating fire and forest dynamics for a coordinated landscape fuel treatment project in the Sierra Nevada. Forest Science: 57: 77-88.

Elliot, W. J., Dayna L.S; Hall,D. E. 1999. Rock:Clime -- Rocky Mountain Research Station Climate Generator, U.S. Department of Agriculture, Rocky Mountain Research Station, Moscow Forestry Sciences Laboratory: http://forest.moscowfsl.wsu.edu/cgi-bin/fswepp/rc/rockclim.pl.

Elliot, W. J; Hall, D. E. 1997. Water Erosion Prediction Project (WEPP) forest applications. Gen. Tech. Rep. INT-GTR-365. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 11 p.

Flanagan, D. C; Livingston, S. J. 1995. WEPP User Summary. NSERL Report No. 11. Lafayette, IN, National Soil Erosion Research Laboratory: 131 p.

Knapp EE, Keeley JE, Ballenger EA, Brennan TJ. 2005. Fuel reduction and coarse woody debris dynamics with early season and late season prescribed fire in a Sierra Nevada mixed conifer forest. Forest Ecology and Management 208:383-397.

Larsen, I. J; MacDonald, Lee; Brown, Ethan; Rough, Daniella; Welsh, Matthew J.; Pietraszek, Joseph, H.; Libohova, Zamir; Benavides-Solorio, Juan de Dios; Schaffrath, Keelin 2009. Causes of Post Fire Runoff and Erosion: Water Repellency, Cover, or Soil Sealing. Soil Science Society of America Volume 73(Number 4), July-August): 1393-1407.

Miller, M. E.; MacDonald Lee; Robichaud, P. R.; Elliot, W. J. 2011. Predicting post-fire hillslope erosion in forest lands of the western United States. International Journal of Wildland Fire 20: 982-999.

Prichard, S.J.; Sandberg, D.V.; Ottmar, R.D. Eagle, P.C., Andreu, A.G, and Swedin, K. 2011. FCCS user's guide, version 2.2. http://www.fs.fed.us/fera/fccs/publications/. (1 November 2011)

Scott, D. W. (1992) Multivariate Density Estimation. Theory, Practice and Visualization. New York: Wiley.

Scott, Joe H.; Burgan, Robert 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.

Seli, Robert C.; Ager, Alan A.; Crookston, Nicholas L.; Finney, Mark A.; Bahro, Berni; Agee, James K.; McHugh, Charles W. 2008. Incorporating landscape fuel treatment modeling into the Forest Vegetation Simulator. In: Havis, Robert N.; Crookston, Nicholas L., comps. 2008. Third Forest Vegetation Simulator Conference; 2007 February 13–15; Fort Collins, CO. Proceedings RMRS-P-54. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. p. 27-39.

Smith, D. F.; Kuchnicki, J. 2010. Final Lake Tahoe TMDL Report. Kings Beach, California Regional Water Quality Board (Lahontan Region). 54p.

Stephens, S.L.; Moghaddas, J.J. 2005. Experimental fuel treatment impacts on forest structure, potential fire behavior, and predicted tree mortality in a mixed conifer forest. Forest Ecology and Management 215:21-36.

Thompson, Matthew P.; Calkin, David E.; Finney, Mark A.; Ager, Alan A.; Gilbertson-Day, Julie W.; 2011a. Integrated national-scale assessment of wildfire risk to human and ecological values. Stochastic Environmental Research and Risk Assessment. Doi:10.1007/s00477-011-0461-0.

Thompson, Matthew P.; Calkin, David E.; Gilbertson-Day, Julie W.; Ager, Alan A. 2011b. Advancing effects analysis for integrated, large-scale wildfire risk assessment. Environmental Monitoring and Assessment. 179: 217-239.

van Wagtendonk, J. W. 1996. Use of a deterministic fire growth model to test fuel treatments. In: Sierra Nevada Ecosystem Project: Final report to Congress, Volume II, Chapter 43. Univ. Calif., Davis, Wildland Resources Center Rep. 37. 1528 p.

Other possible references follow……

Essential Guide to FVS:
*www.fs.fed.us/fmsc/ftp/**fvs**/docs/gtr/**EssentialFVS**.pdf*

Davis et al. 2009:
Davis, Brett; van Wagtendonk, Jan; Beck, Jen; van Wagtendonk, Kent 2009. Modeling fuel succession. Fire Management Today. 69(2): 18-21..

Riccardi et al. 2007:
Riccardi, Cynthia L.; Ottmar, Roger D.; Sandberg, David V.; Andreu, Anne; Elman, Ella; Kopper, Karen; Long, Jennifer 2007. The fuelbed: a key element of the Fuel Characteristic Classification System.. Canadian Journal of Forest Research. 37: 2394-2412.

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

Tables:

Table 1. Treatment options included in default OptFuels models.

---

1. Treatment Name: TR_Hand

    Description: Hand thin followed by a prescribed burn. Thin from below up to 14” dbh to achieve approximate 21’ spacing in the residual stand. There is no residual stand spacing parameter in FVS. This spacing was approximated by thinning to 99 trees per acre.

    Stand criteria for applying treatment: Basal area per acre greater than 100 ft^2

    Spatial criteria for applying treatment to a stand:
    1. Stand center within 1.5 miles of an existing road
    2. Average slope less than or equal to 35%
    3. Treatment excluded from designated wilderness and roadless areas

2. Treatment Name: TR_Burn

    Description: Mechanical thin followed by a prescribed burn. Thin from below up to 30” dbh to a residual basal areas of 100 ft^2.

    Stand criteria for applying treatment: Basal area per acre greater than 100 ft^2

    Spatial criteria for applying treatment to a stand:
    1. Stand center within 0.75 miles of an existing road
    2. Average slope less than or equal to 20% within a stream management zone
    3. Average slope less than or equal to 35% outside stream management zones
    4. Treatment excluded from designated wilderness and roadless areas

3. Treatment Name: TR_Mast

    Description: Mechanical thin followed by mastication. Thin from below up to 30” dbh to a residual basal areas of 100 ft^2.

    Stand criteria for applying treatment: Basal area per acre greater than 100 ft^2

    Spatial criteria for applying treatment to a stand:
    1. Stand center within 0.75 miles of an existing road
    2. Average slope less than or equal to 20% within a stream management zone
    3. Average slope less than or equal to 35% outside stream management zones
    4. Treatment excluded from designated wilderness and roadless areas

---

Table 2. Percent of original value that is lost by flame length category.

Value at Risk Categories	Weights	Flame Length Categories (meters)				
		0 – 0.3	0.3 – 1.0	1.0 – 2.0	2.0 – 4.0	4.0+
Residential	8	5.0%	10.0%	30.0%	50.0%	80.0%
WUI	8	2.5%	5.0%	15.0%	25.0%	40.0%
FS Managed	1	0.0%	10.0%	20.0%	30.0%	30.0%
No Value	1	0.0%	0.0%	0.0%	0.0%	0.0%

Table 3. Fire duration probabilities.

Time Step	Upper Bound of Time Step Category (Spread Minutes)	Probability that Fire Duration will Exceed Time Step
1	240	0.99
2	480	0.88
3	720	0.76
4	960	0.65
5	1,200	0.54
6	1,440	0.46
7	1,680	0.39
8	1,920	0.34
9	2,160	0.29
10	2,400	0.26
11	2,640	0.23
12	2,880	0.21
13	3,120	0.19
14	3,360	0.18
15	3,600	0.17
16	3,840	0.16
17	4,080	0.16
18	4,320	0.15
19	4,560	0.15
20	4,800	0.15
21	5,040	0.15
22	5,280	0.15
23	5,520	0.15
24	5,760	0.14
25	6,000	0.14
26	6,240	0.13
27	6,480	0.11
28	6,720	0.10
29	6,960	0.09
30	7,200	0.08
31	7,440	0.07
32	7,680	0.06
33	7,920	0.05
34	8,160	0.04
35	8,400	0.02

Table 4. Derivation of fire duration probabilities

(1) Time Step	(2) Upper Bound of Time Step Category (Spread Minutes)	(3) Number of Fires by Time Step	(4) Fraction of Fires by Time Step = Estimated Prob. of Fire Duration by Time Step	(5) Cumulative Prob. of Duration = Prob. that Fire Duration will NOT Exceed Time Step	(6) 1 minus Cumulative Prob. of Duration = Prob. that Fire Duration will Exceed Time Step	(7) Statistical Smoothing of Prob. that Fire Duration Will Exceed Time Step
1	240	3	0.19	0.19	0.81	0.99
2	480	2	0.13	0.31	0.69	0.88
3	720	3	0.19	0.50	0.50	0.76
4	960	2	0.13	0.63	0.38	0.65
5	1,200	0	0.00	0.63	0.38	0.54
6	1,440	0	0.00	0.63	0.38	0.46
7	1,680	1	0.06	0.69	0.31	0.39
8	1,920	2	0.13	0.81	0.19	0.34
9	2,160	0	0.00	0.81	0.19	0.29
10	2,400	0	0.00	0.81	0.19	0.26
11	2,640	0	0.00	0.81	0.19	0.23
12	2,880	0	0.00	0.81	0.19	0.21
13	3,120	1	0.06	0.88	0.13	0.19
14	3,360	0	0.00	0.88	0.13	0.18
15	3,600	0	0.00	0.88	0.13	0.17
16	3,840	0	0.00	0.88	0.13	0.16
17	4,080	0	0.00	0.88	0.13	0.16
18	4,320	0	0.00	0.88	0.13	0.15
19	4,560	0	0.00	0.88	0.13	0.15
20	4,800	0	0.00	0.88	0.13	0.15
21	5,040	0	0.00	0.88	0.13	0.15
22	5,280	0	0.00	0.88	0.13	0.15
23	5,520	0	0.00	0.88	0.13	0.15
24	5,760	0	0.00	0.88	0.13	0.14
25	6,000	0	0.00	0.88	0.13	0.14
26	6,240	0	0.00	0.88	0.13	0.13
27	6,480	1	0.06	0.94	0.06	0.11
28	6,720	0	0.00	0.94	0.06	0.10
29	6,960	0	0.00	0.94	0.06	0.09
30	7,200	0	0.00	0.94	0.06	0.08
31	7,440	0	0.00	0.94	0.06	0.07
32	7,680	0	0.00	0.94	0.06	0.06
33	7,920	0	0.00	0.94	0.06	0.05
34	8,160	1	0.06	1.00	0.00	0.04
35	8,400	0	0.00	1.00	0.00	0.02

Table 5. The six cases for which WEPP was used to estimate fine sediment (< 20 microns) loading to stream channels.

Weather	Undisturbed Sites	Treated Sites	High Severity Fire
10-year precipitation event	a[a]	b[a]	c[a]
50-year precipitation event	d[a]	e[a]	f[a]

[a] Sediment amounts computed for combinations of slope, aspect, soils, and vegetation conditions

Table 6. Cover percentages by WEPP vegetation assigned used for predicting sediment loading.

WEPP Vegetation Assignment	**Cover Prior to Wildland Fire**	**Cover after Low Severity Wildland Fire[a]**	**Cover after High Severity Wildland Fire[a]**
Undisturbed Forest	100%	100%	65%
Treated Forest	83%[a]	83%	65%
Undisturbed Shrub	80%	80%	65%
Undisturbed Grass	60%	60%	60%
Bare Ground	20%	20%	20%
Sparsely Stocked Forest on Rocky Ground	80%	80%	65%
Bare rock	20%	20%	20%

[a] Cover percentages estimated for 9-12 months following disturbance.

Figures:

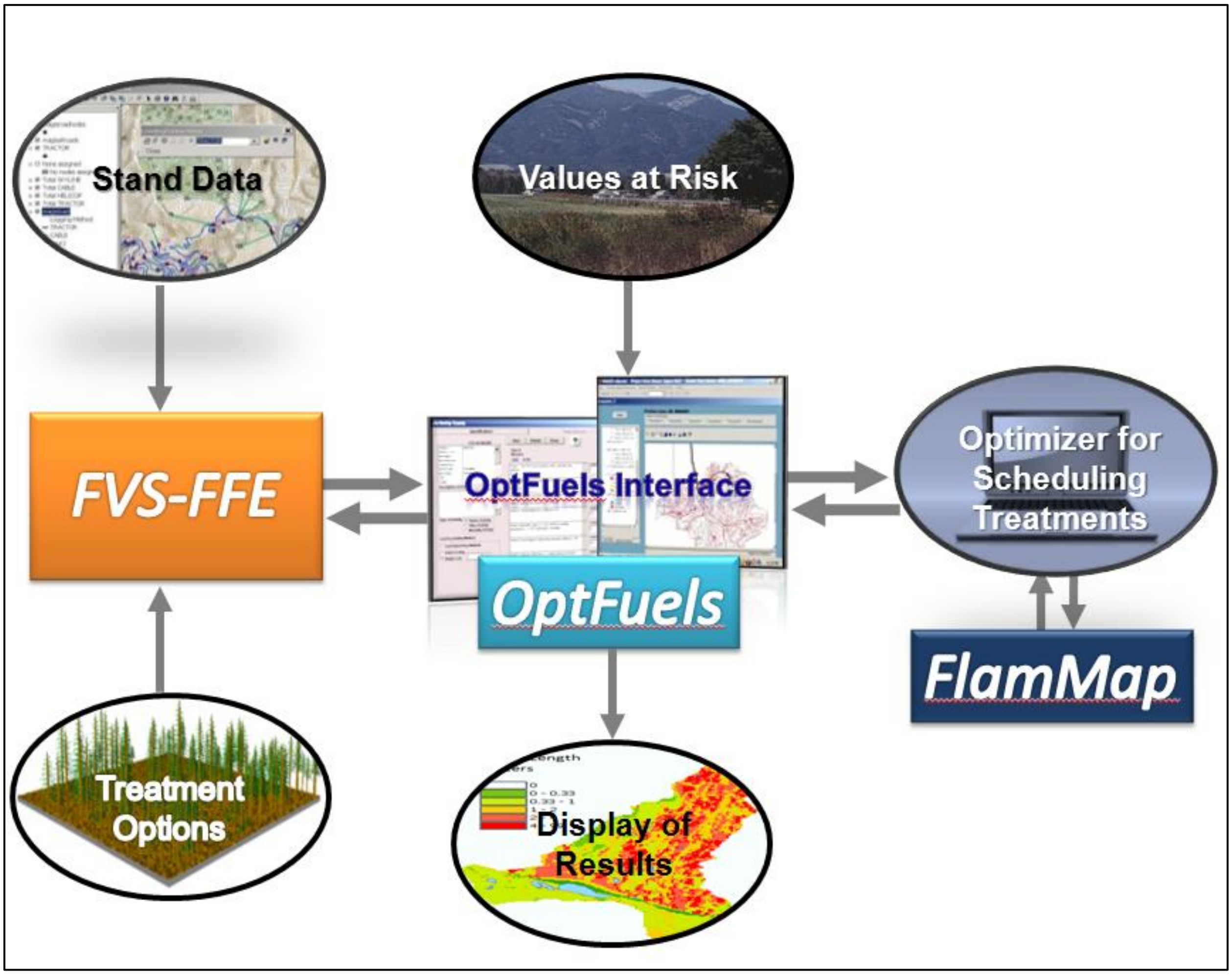


Figure 1. Overview of OptFuels

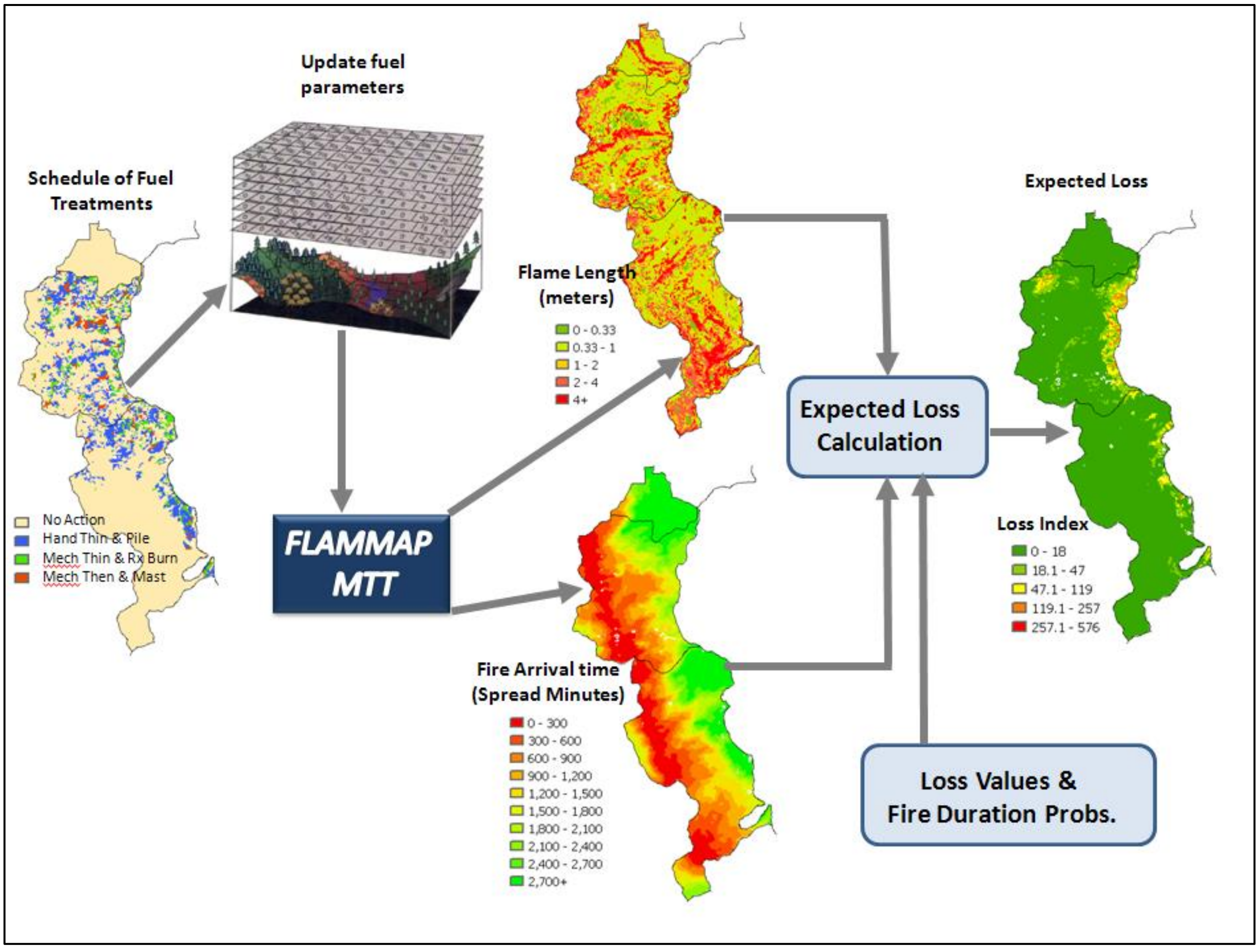


Figure 2. Processes run in each OptFuels iteration to calculate expected loss for a fuel treatment alternative.

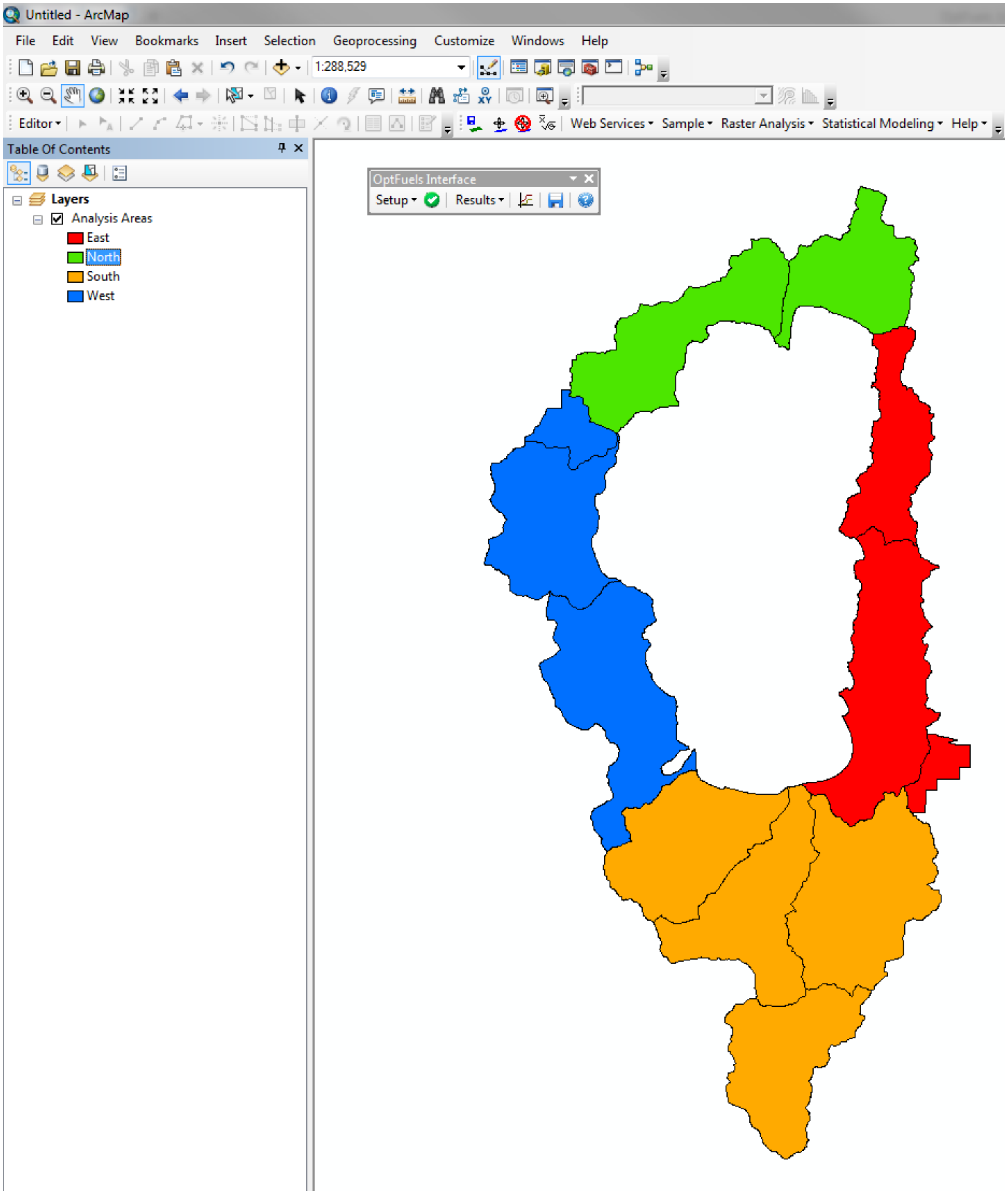


Figure 3. Location of the four OptFuels default models.

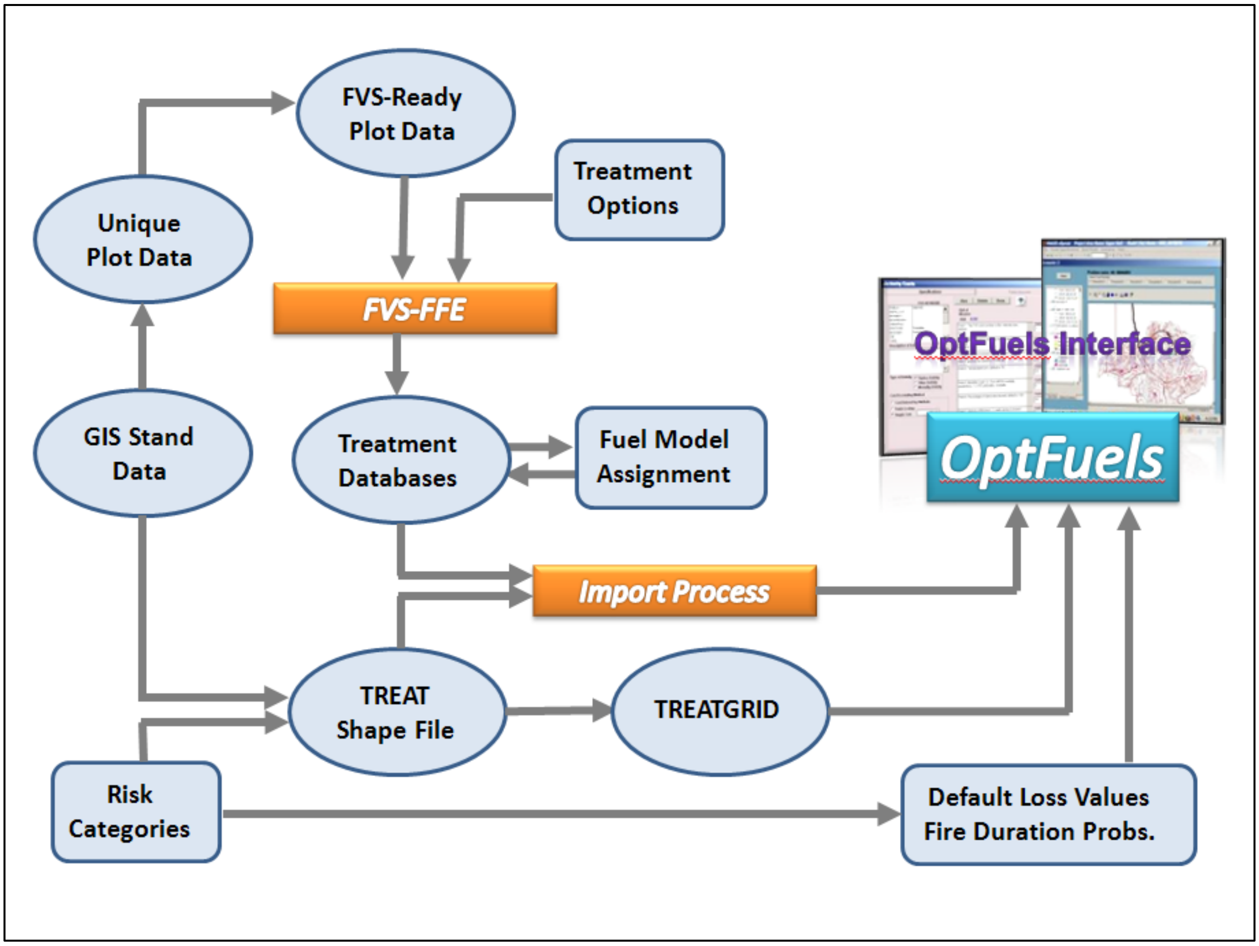


Figure 4. OptFuels model-building process.

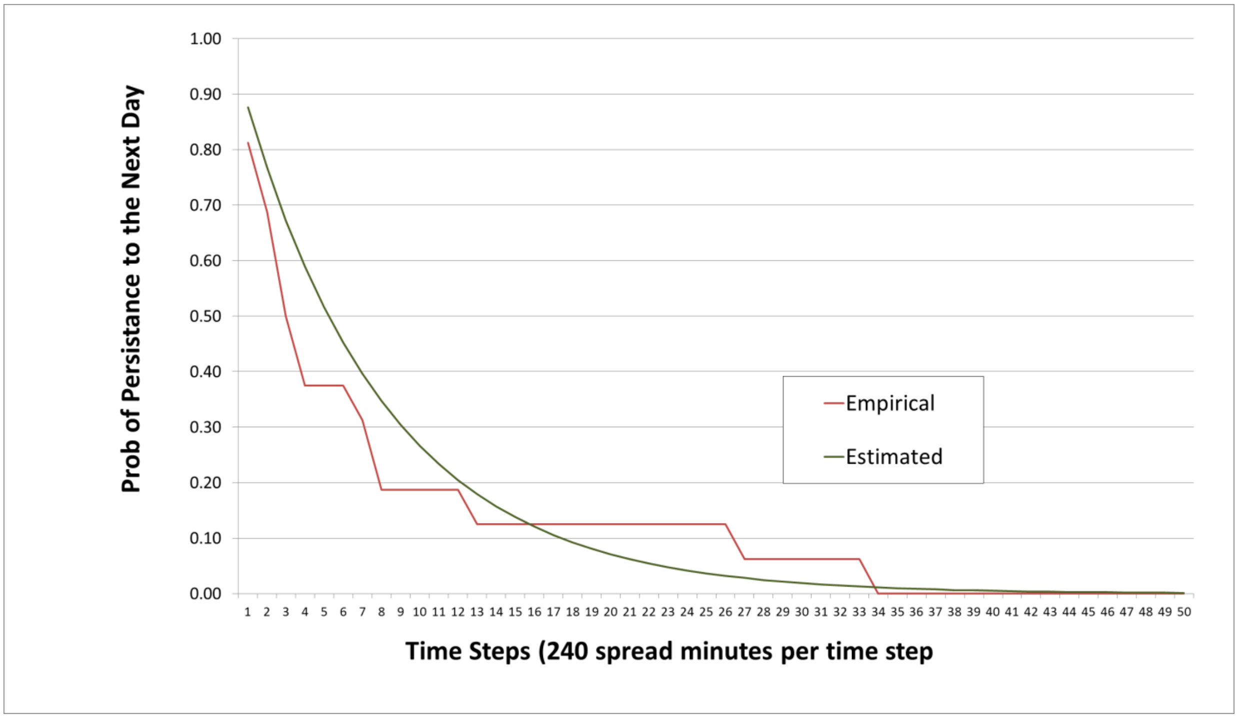


Figure 5. Empirical probabilities of fire duration compared to statistically smoothed probabilities using a technique called nonparametric kernel density estimation (Scott 1992).

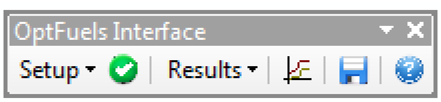


Figure 6. OptFuels Interface Toolbar.

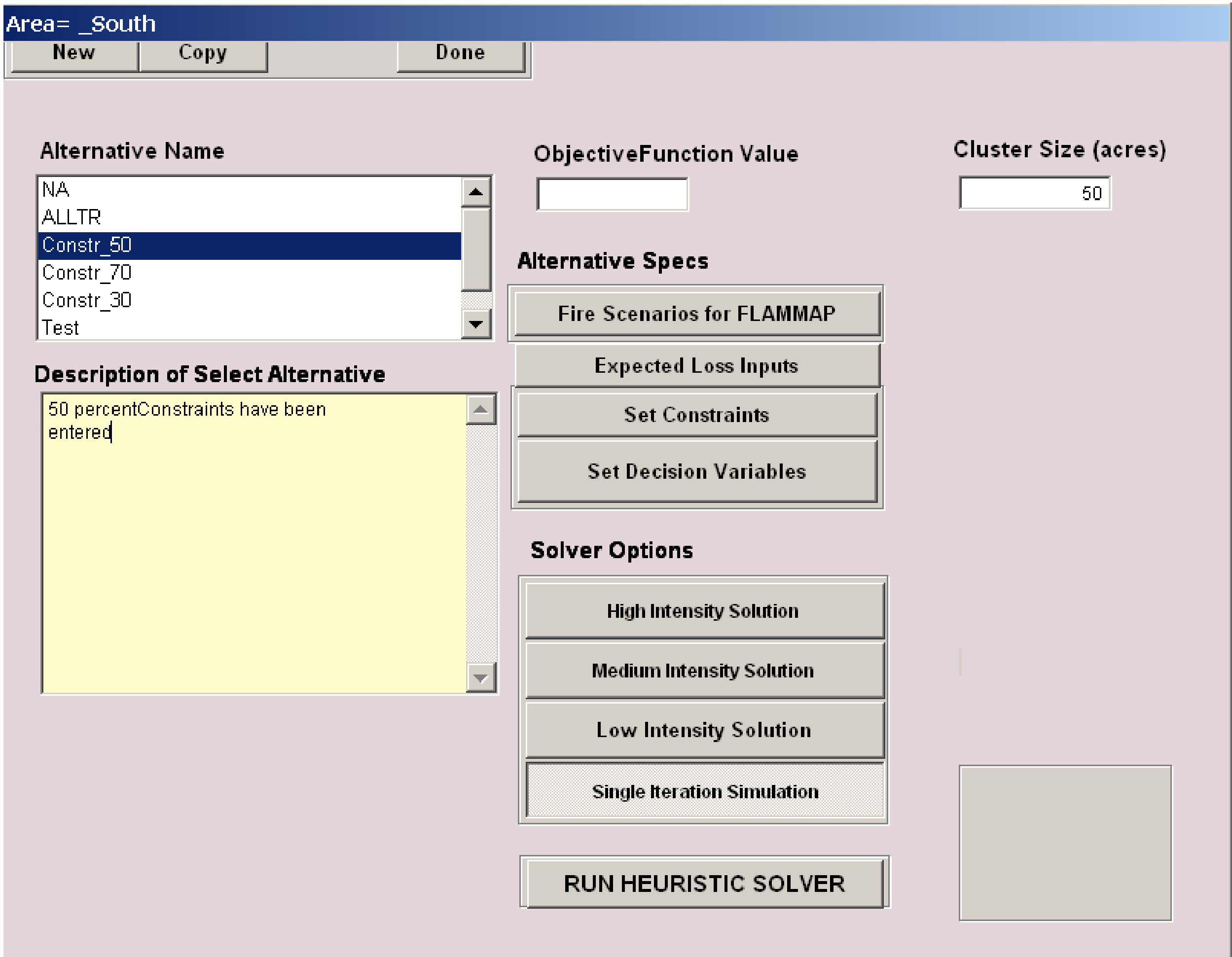


Figure 7. OptFuels Menu for entering the specifications for and solving a fuel treatment alternative.

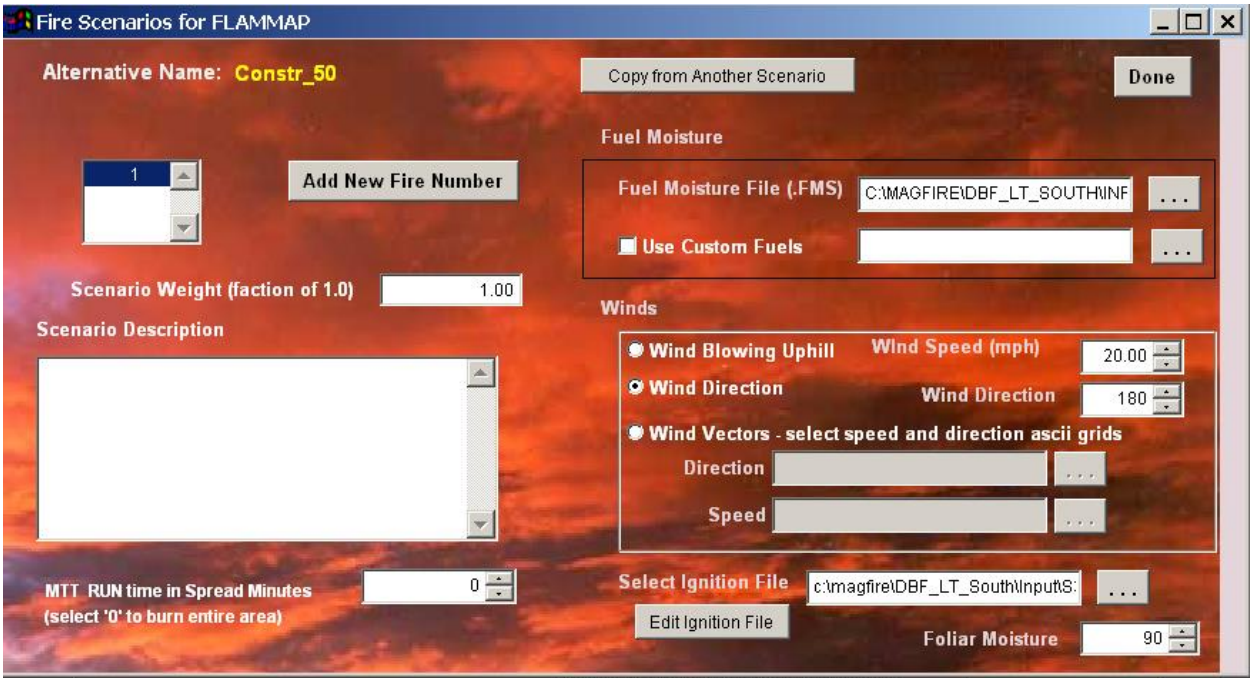
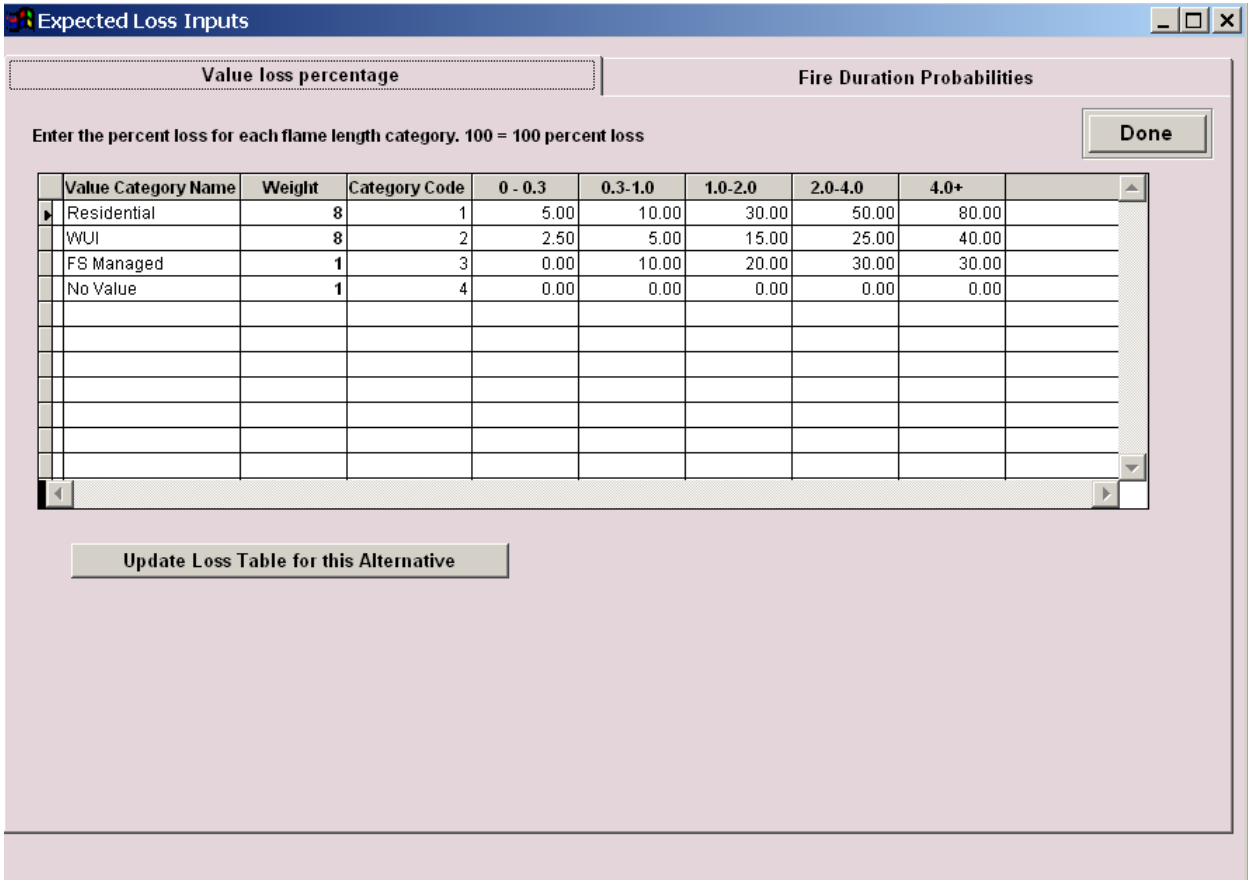


Figure 8. OptFuels screen for entering FLAMMAP input parameters for the fire scenario (or scenarios) to be used in scheduling treatments for the current alternative.



Expected Loss Inputs

Value loss percentage | Fire Duration Probabilities

Enter the percent loss for each flame length category. 100 = 100 percent loss

Done

Value Category Name	Weight	Category Code	0 - 0.3	0.3-1.0	1.0-2.0	2.0-4.0	4.0+
Residential	8	1	5.00	10.00	30.00	50.00	80.00
WUI	8	2	2.50	5.00	15.00	25.00	40.00
FS Managed	1	3	0.00	10.00	20.00	30.00	30.00
No Value	1	4	0.00	0.00	0.00	0.00	0.00

Update Loss Table for this Alternative

Figure 9. Screen for entering percentage value loss by flame length category for values at risk.

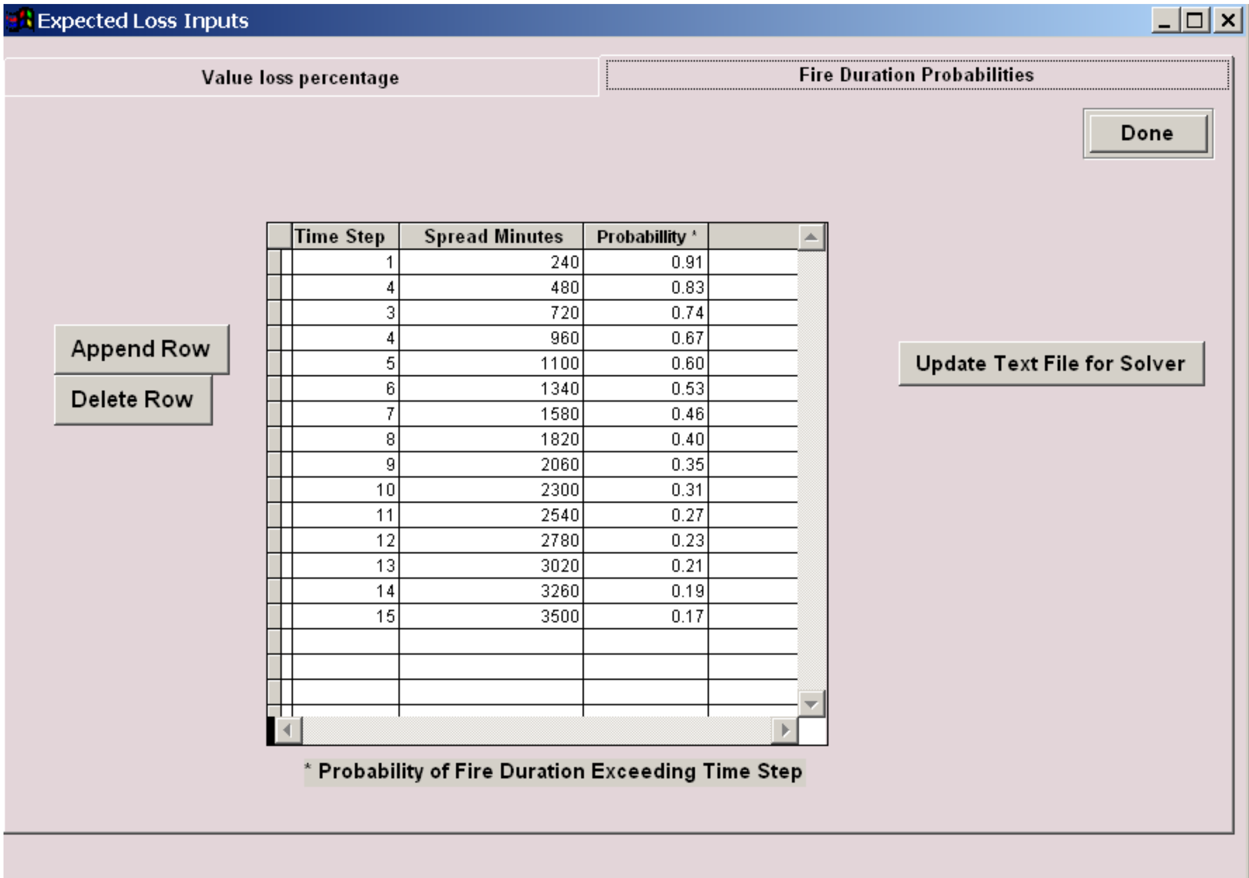


Figure 10. Screen for entering fire duration probabilities.

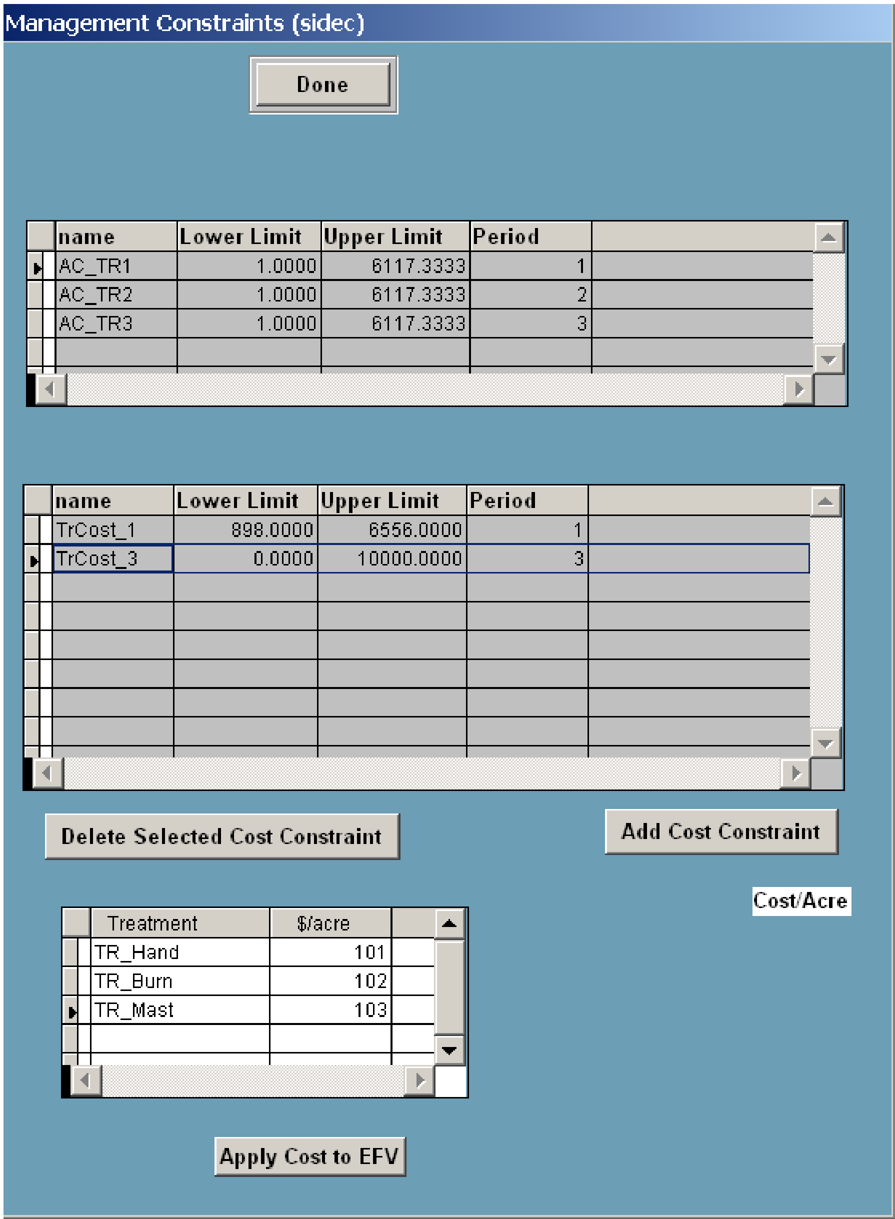


Figure 11. Screen for specifying constraints for a fuel treatment alternative.

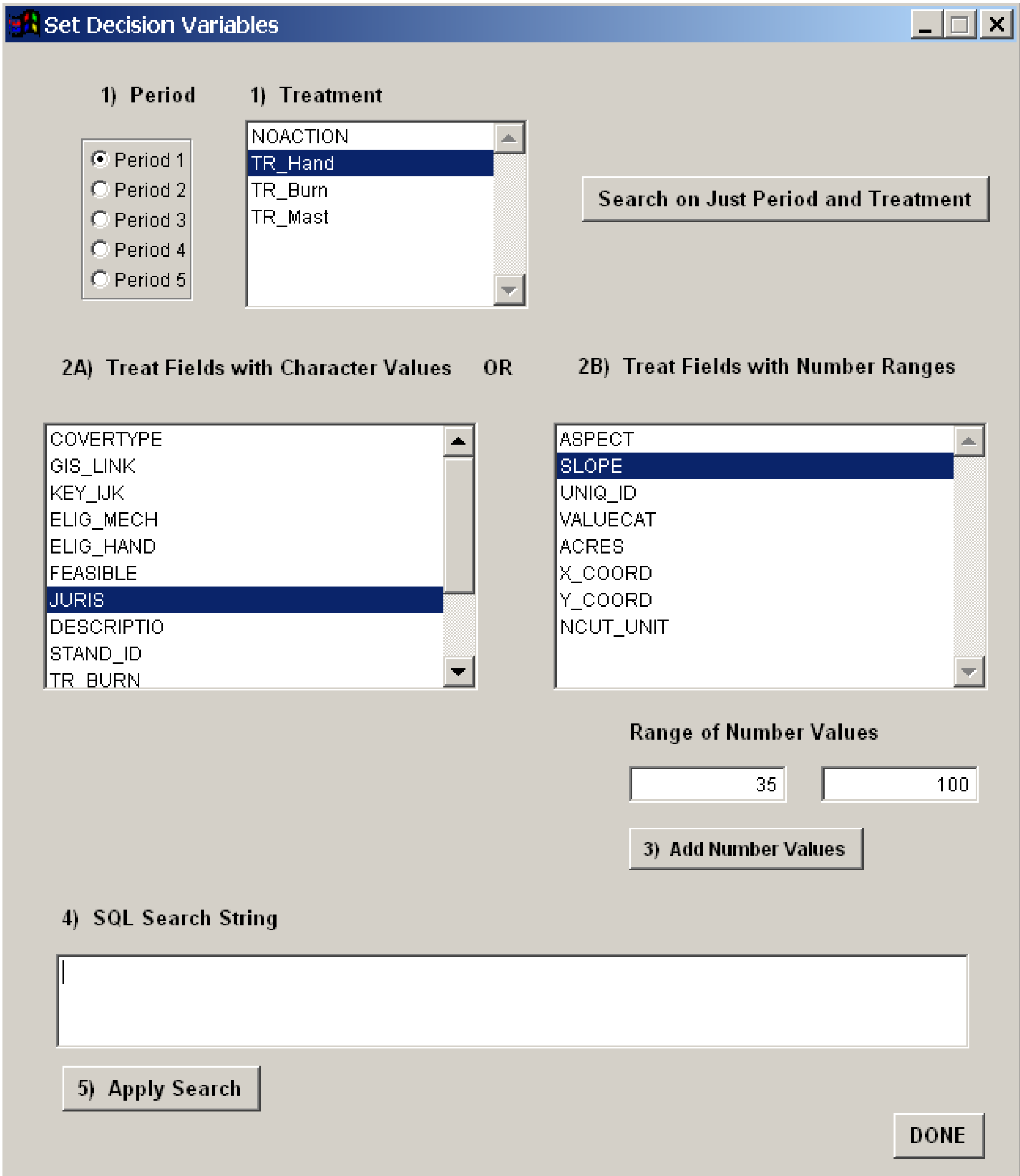


Figure 12. Screen using SQL search of potential treatments to assign treatment options to stands.

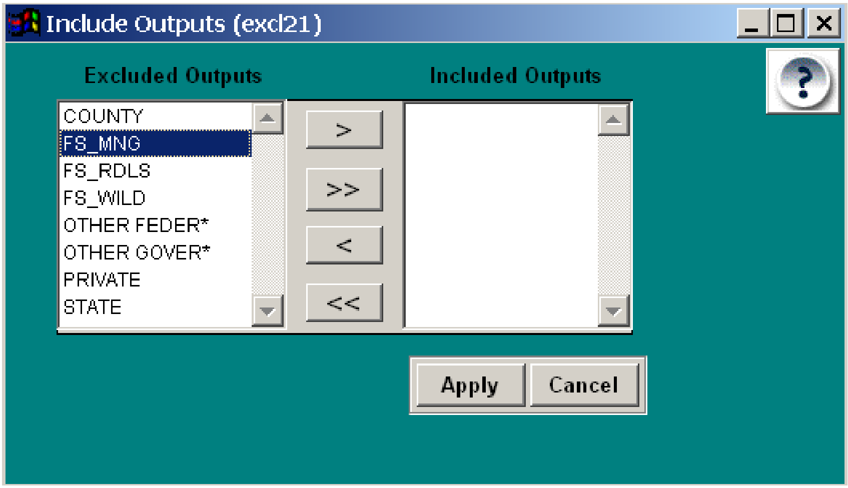


Figure 13. Dialogue box for selecting attribute categories.   The treatment will only be applied to stand polygons having the selected categories.

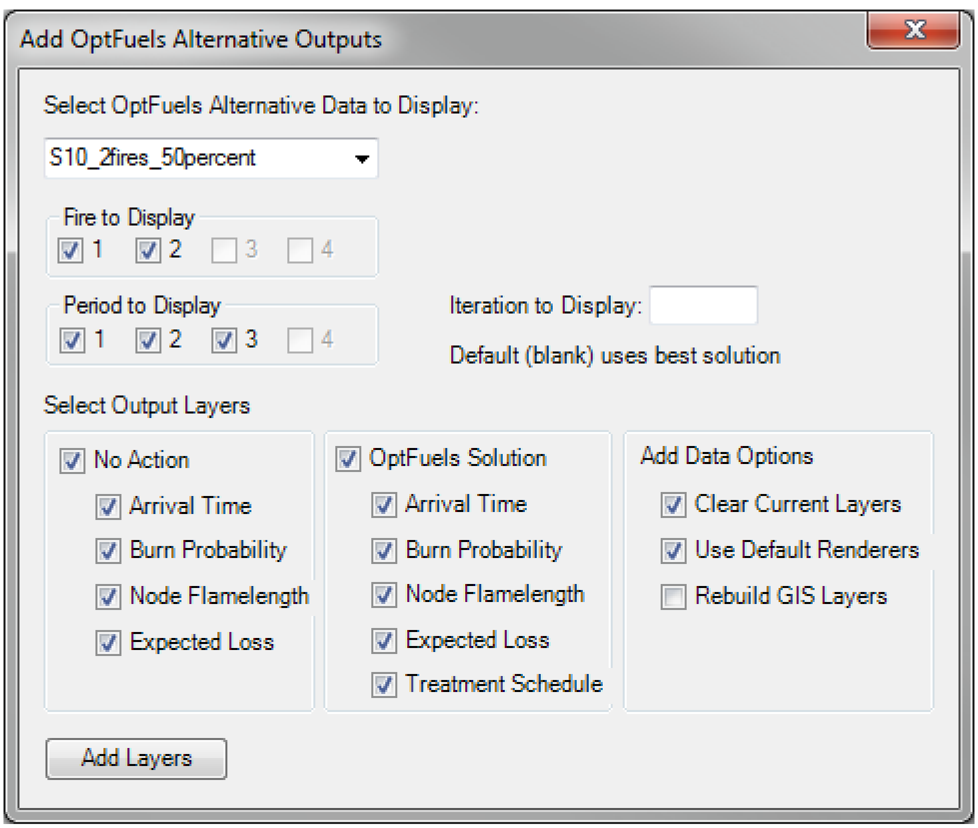


Figure 14. Dialogue box for creating GIS displays of OptFuels results.

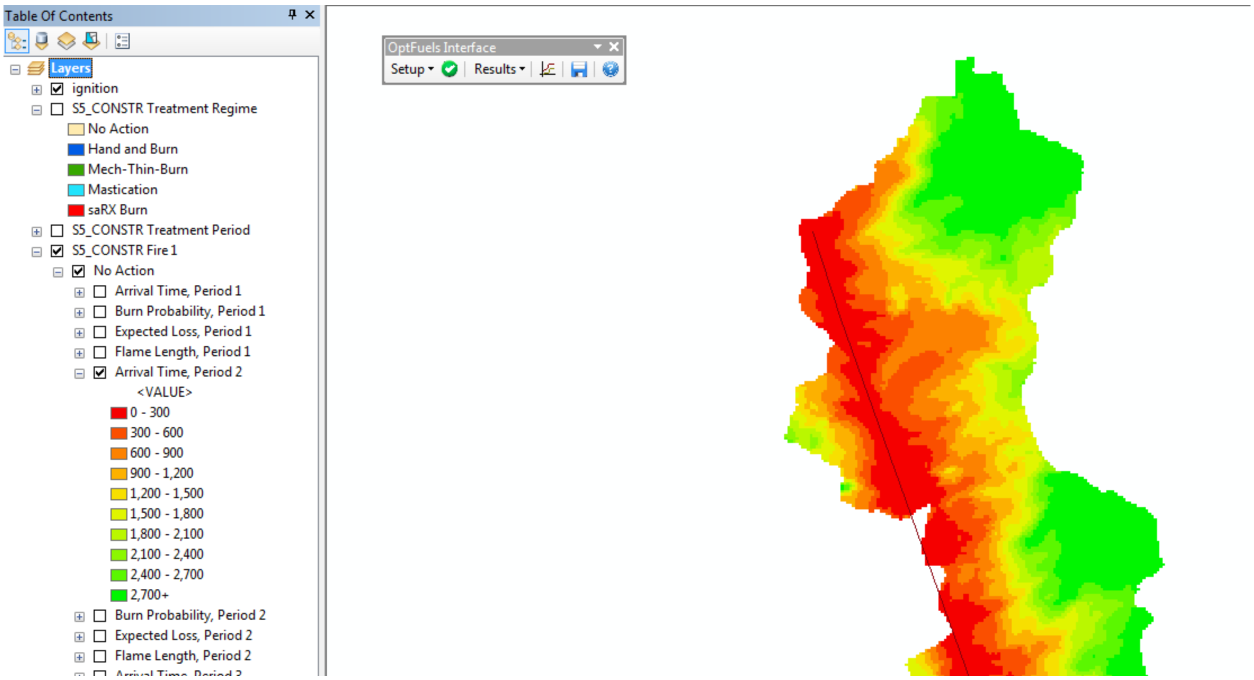


Figure 16. The base map and ignition location(s) layers are generated automatically.

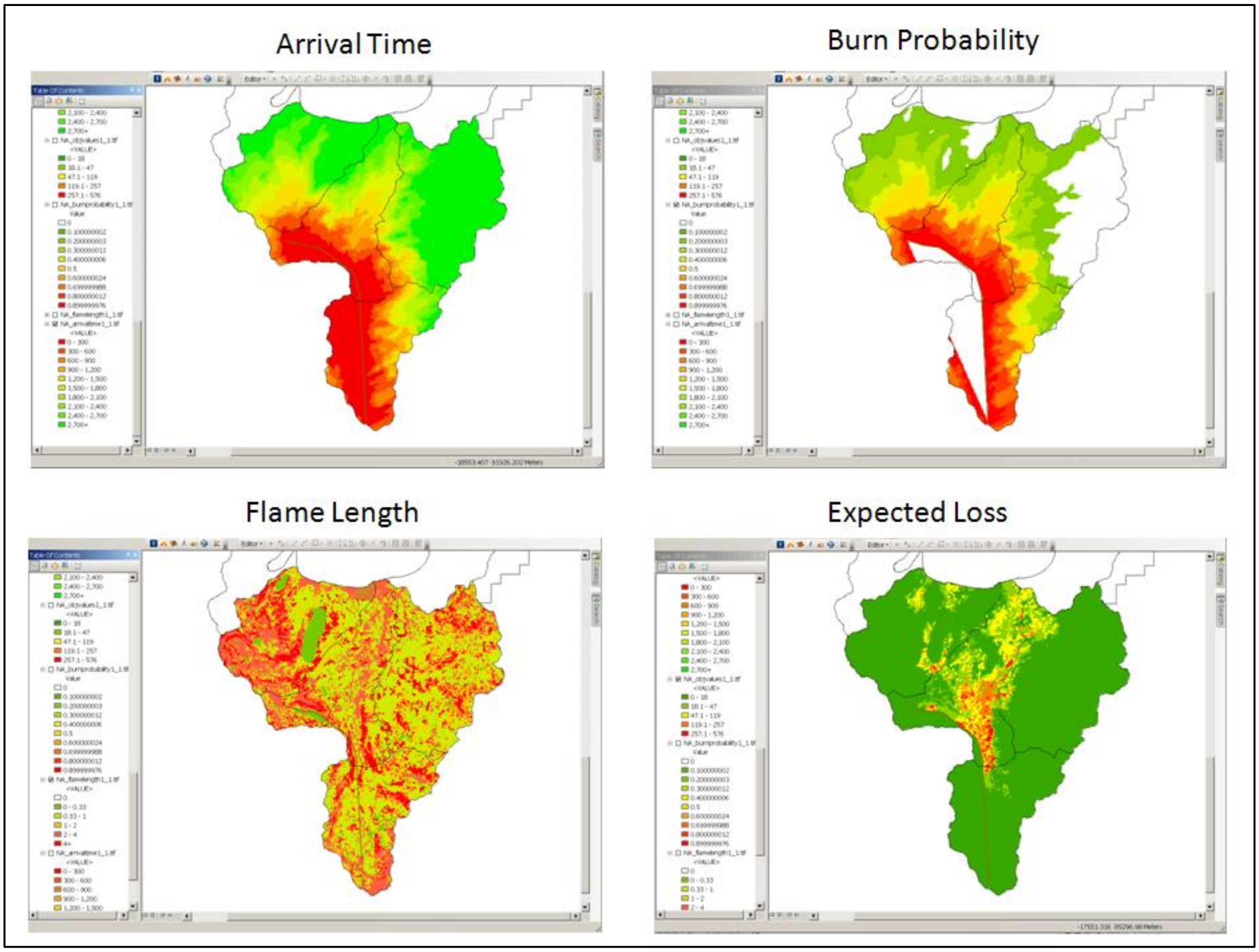


Figure 16. The four output layers available for the No Action alternative.

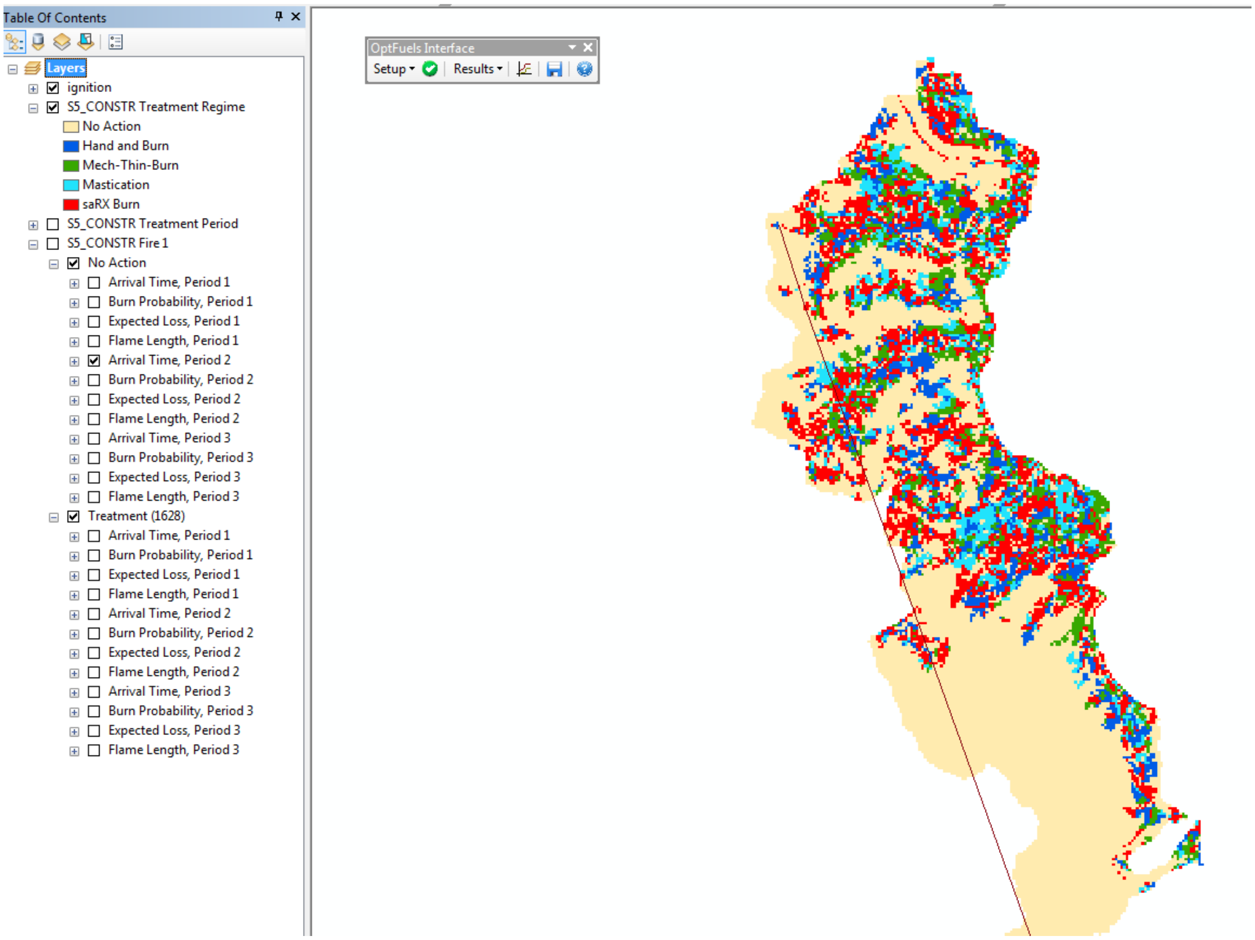


Figure 17. Layer showing the fuel treatments selected for the alternative.

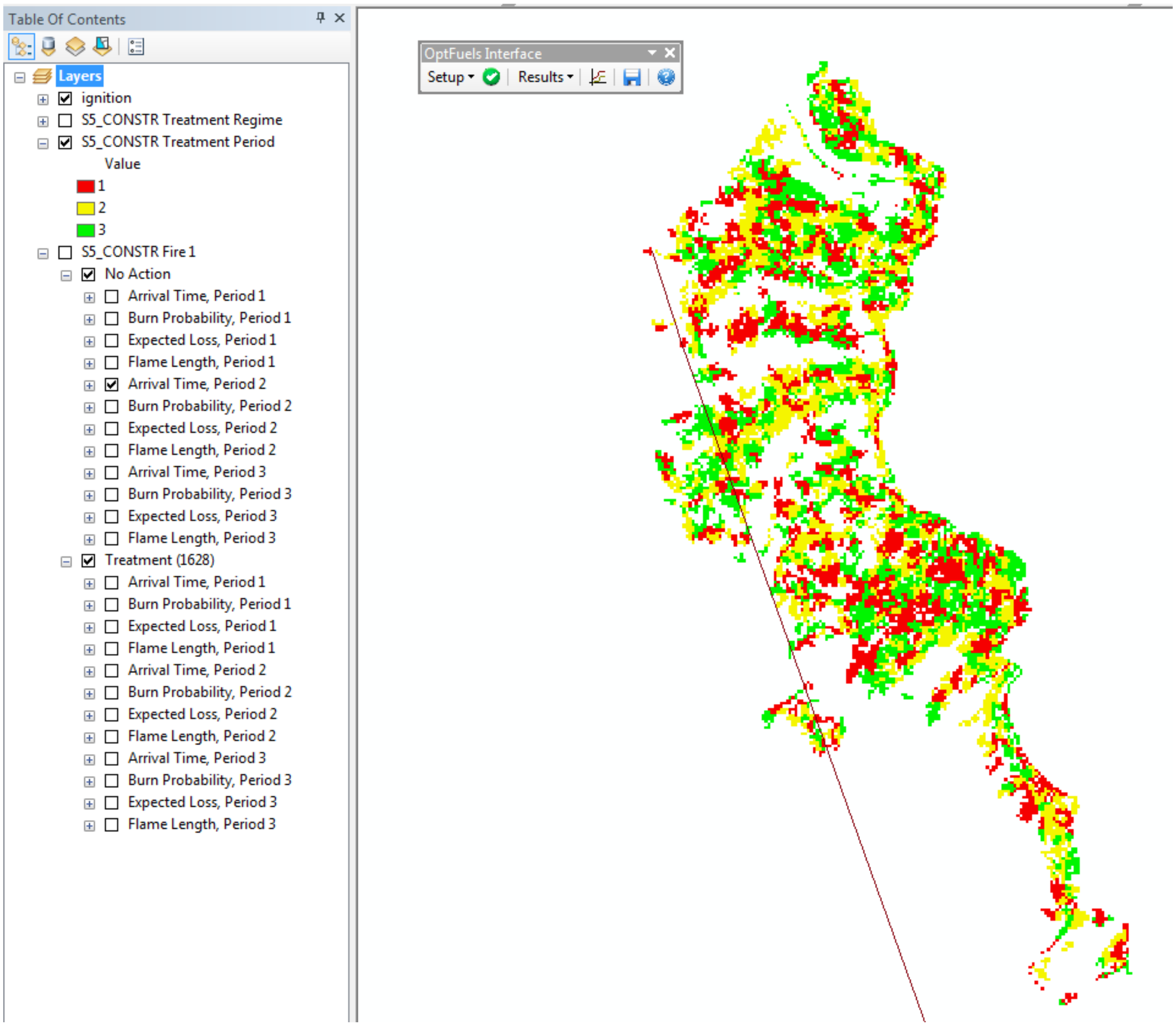


Figure 18. Layer showing the location of fuel treatments that were selected for each planning period.

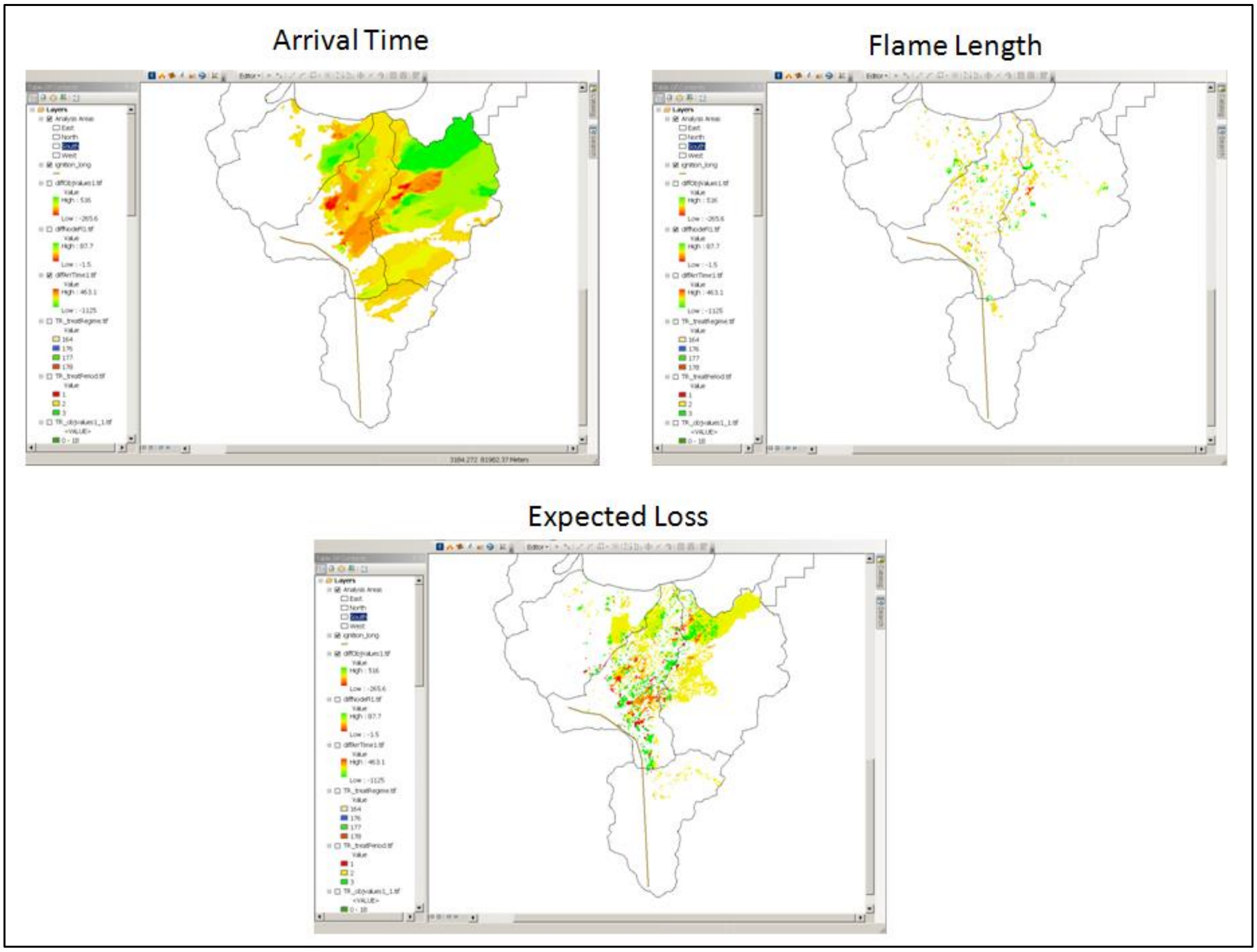


Figure 19. Three layers comparing no action with the treatment alternative (no action values minus treatment alternative values).

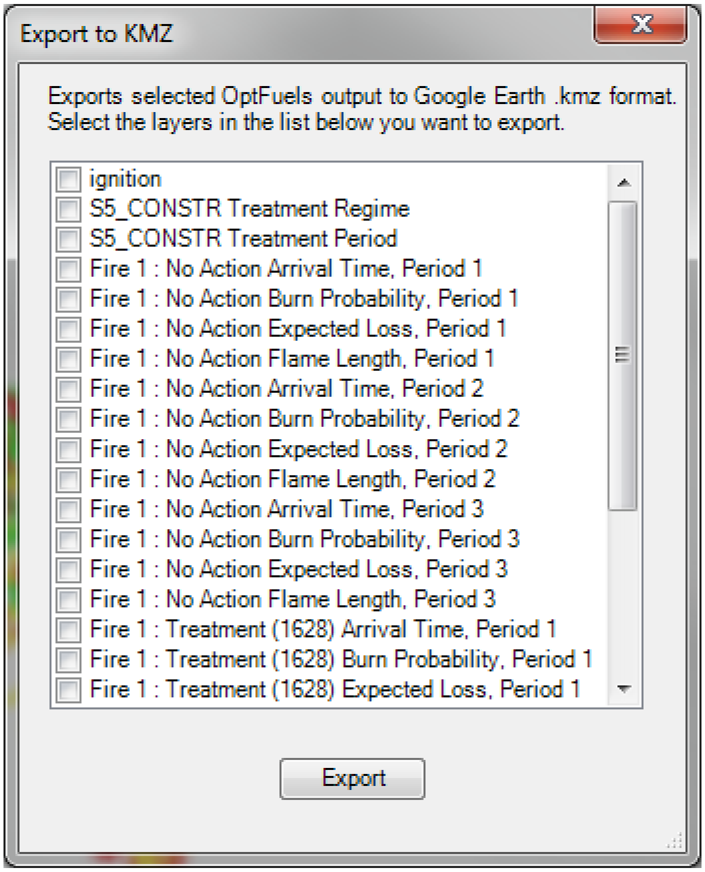


Figure 20. Dialogue screen for selecting output layers to export to GoogleEarth.

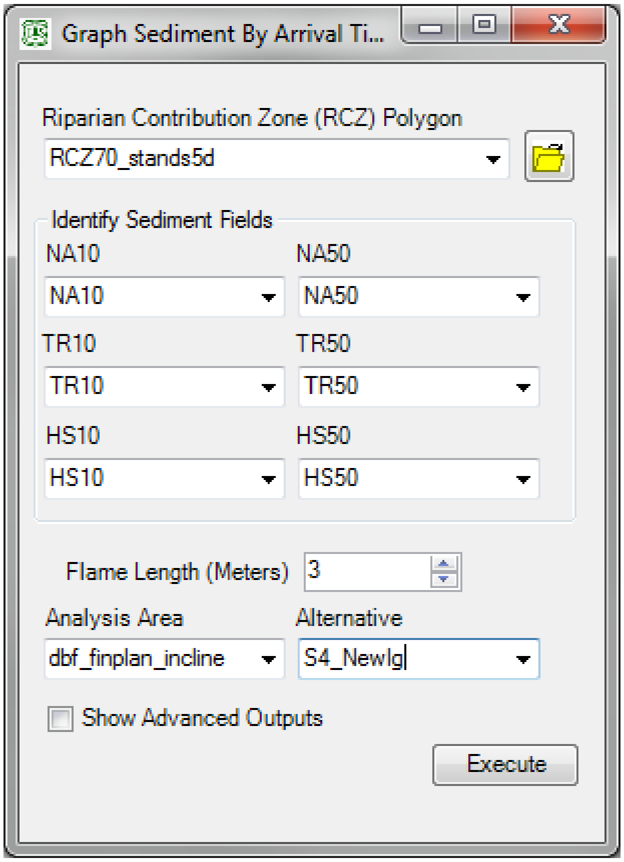


Figure 21. Dialogue screen for computing fine sediment loading following potential future wildland fire for both untreated and treated landscapes.

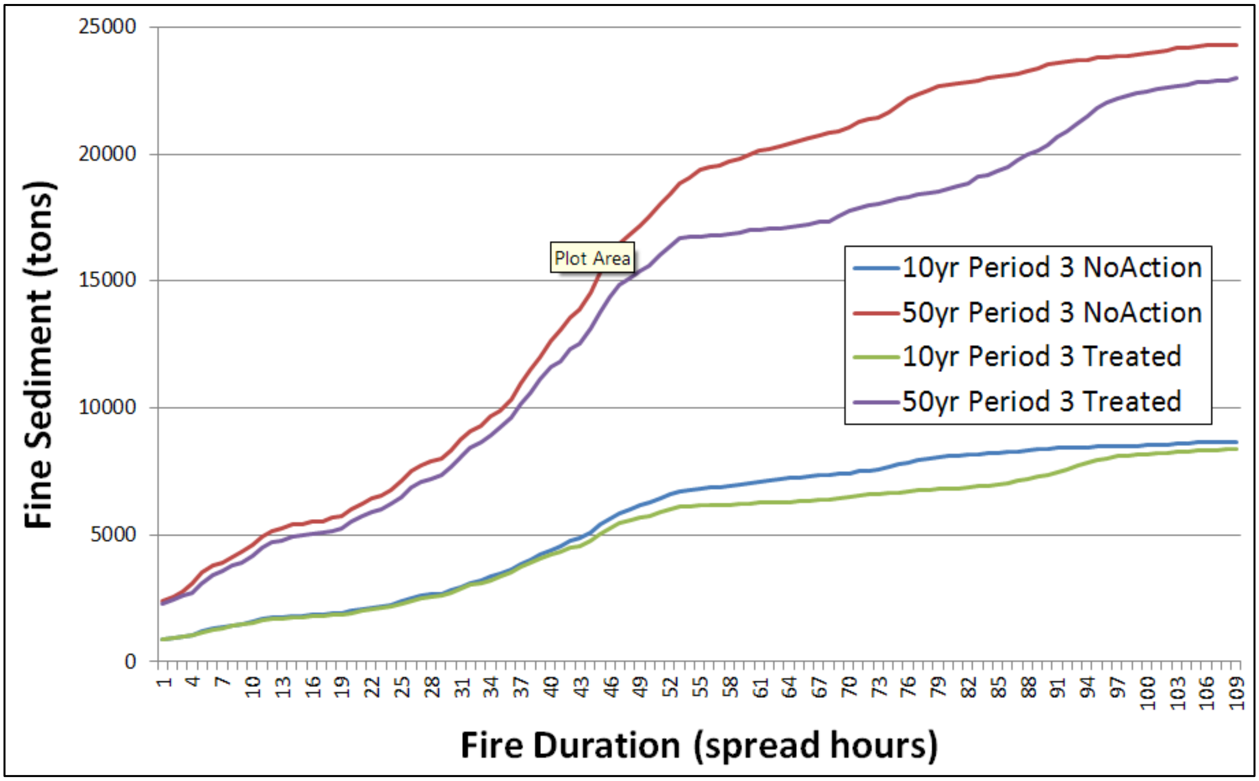


Figure 22. Example graph showing predicted post-fire fine sediment loading for 10-year and 50-year precipitation events for a range of potential future wildland fire durations for both untreated and treated landscapes.

Appendix A. Fuel model assignment process used to develop the default OptFuels models for the Lake Tahoe Basin.

Because FlamMap is a critical component of OptFuels, we needed to spatially assign fire behavior fuel models to stands rather than direct estimates of fire behavior such as flamelength or rate of spread. We required fuel models for a number of forest stands both before and after simulated fuel treatments and for both current stand conditions and conditions projected one, two, and three decades into the future. Despite trying all three FFE-FVS (Fire and Fuel Extension to the Forest Vegetation Simulator) fuel model selection methods, assigned fuel models, and therefore fire behavior predicted by FlamMap, did not match our expectations. We developed an alternative approach for assigning a fuel model to a forest stand after simulating the effects of future growth and/or proposed fuel treatments. This method retains the capacity of FVS to project vegetation changes due to growth, mortality, disturbance, and treatment while incorporating additional data (FIA [Forest Inventory and Analysis]) and models (Consume and FCCS, the Fuel Characteristic Classification System) to characterize a stand's potential fire behavior.

Methods

Ideally we could have utilized the FFE-FVS fuel submodel to track changes in surface fuels. We could have then fed these surface fuels into FCCS to assign a fire behavior fuel model using the process described below. This approach was deemed impractical because we would have needed to run FCCS multiple times (different decades, treatments, etc.) for approximately 105 stands. As a compromise we attached a "strata label", as defined by the Region 5 Remote Sensing Laboratory (RSL), to each stand. A stratum is composed of forest type (e.g., red fir or Jeffrey pine), average tree diameter (classified as 1-5), and average canopy cover (classified as S-G) and provides a method to aggregate similar stands. The data represented by a stratum come from between 1 and 15 FIA plots within a given National Forest.

Our general approach was as follows and is described in more detail below:

1. Build a list of the mapped strata of interest.
2. Build fuelbeds for the chosen strata and compile a list of their fuel model assignments.
3. Project the FIA stands for the chosen strata into the future as desired using FVS.
4. Attach strata labels to the FVS stand projections and list the new, unmapped strata (if any).
5. If FIA data exist for the new projected strata, build those fuelbeds; if not, base the new fuelbeds on similar existing fuelbeds. Add additional fuel model assignments to the list developed in step 2.
6. Simulate the desired thinning and mastication fuel treatments against all strata using FVS and repeat steps 4 and 5.

7. Use Consume to simulate a prescribed fire for each stratum and export fuel consumption reports.
8. Convert fuel consumption data into new post-prescribed fire FCCS inputs.
9. Build post-prescribed fire fuelbeds and add their fuel model assignments to the master list.
10. Attach fuel models as attributes to the strata map..

FCCS summarizes fuel conditions from the ground to the canopy in a “fuelbed” and reports several measures of potential fire behavior associated with that fuelbed. FCCS is based on the standard one-dimensional Rothermel (1972) fire spread equations but the equations are reformulated to use the entire set of fuelbed parameters rather than a stylized mathematical fuel model (i.e., Anderson 1982). In addition to other outputs, FCCS will choose a best-matching standard fuel model from both the Anderson (1982) set and the Scott and Burgan (2005) set for the specified environmental conditions (fuel moistures, slope, etc.). The match is made by comparing predicted flamelength and rate of spread for the fuelbed with those of the standard fuel models under the user-specified environmental conditions (Table A1).

Table A1. FCCS D2L2C3 default environmental condition scenario.

Environmental Condition	**Value**
1-hr fuel moisture	6%
10-hr fuel moisture	7%
100-hr fuel moisture	8%
1000-hr fuel moisture	12%
Nonwoody fuel moisture	60%
Shrub fuel moisture	90%
Duff fuel moisture	50%
Midflame Windspeed	4 mph
Slope	0%

We used Consume to simulate the effects of a prescribed fire on each fuelbed. For our prescribed fire conditions we specified that 10-hr fuel moisture was 9%, 1,000-hr fuel moisture was 11%, duff fuel moisture was 70%, 80% of the shrub layer was killed, and 0% of the canopy was consumed. Consume then estimated fuel mass consumed from each of the six layers that comprise a fuelbed. We modified the original FCCS fuelbeds to reflect post-prescribed fire fuel loads and reduced fuel depth by 50% based on the literature (van Wagtendonk 1996; Knapp *et al*. 2005; Stephens and Moghaddas 2005). Because Consume’s output values are fuel consumed per unit area for each fuelbed layer, we had to convert those values to a format useful for input to

FCCS which requires vegetation-based inputs such as shrub height or fuelbed depth. We then re-ran FCCS on the post-prescribed fire fuelbeds to build a second fuel model assignment list.

We also simulated the effects of masticating surface fuels by calculating the relative percent change for several classes of surface fuels using the post-mastication tables in Stephens and Moghaddas (2005). We also reduced the canopy and shrub layers. We used FCCS to assign new fuel models to these modified fuelbeds as we did for the post-prescribed fire fuelbeds.

As the FCCS documentation points out, the fuel model assignment is only applicable under similar environmental conditions and is not generally valid for simulating fire spread (Prichard *et al.* 2011). Our application uses FlamMap (static fuel moistures and wind) rather than FARSITE (variable weather conditions).

Results

The existing strata that are mapped on the Basin are listed in Table A2. Note that 'ZBR' is an aggregation of non-productive shrub vegetation types. We later split this out into specific shrub types. Strata are defined by a 3-character code with the first representing forest type (A = subalpine, F = eastside mixed conifer, J = Jeffrey pine, L = lodgepole pine, and R = red fir), the second average tree diameter (N = non-stocked, 0 = seedlings, 1 = saplings, 2 = poles, 3 = small, 4 = medium, 5 = large), and the last character average canopy cover (O = non-stocked, S = sparse, P = light, N = medium, G = heavy, and X = not-determined).

FFE-FVS provides multiple fuel model assignments for each stand, so we report the most common assignment for each stratum below (Table A3). We parameterized FFE-FVS with the same environmental conditions as in FCCS and initialized the surface fuel loads to match those of the FCCS fuelbeds.

We determined post-prescribed fire and post-mastication fuel models using FCCS as described above (Table A4). The stratum label is unchanged because prescribed fire or mastication are unlikely to change average tree diameter and canopy cover enough to result in a new stratum label. Therefore we use a modified label to represent these cases (e.g., a stand of F3N is assigned F3N_Rx after prescribed burning or F3N_Mast after mastication).

Table A2. Strata represented in the LTBMU (ZBR = aggregated shrub types, IQQ = aspen, AWB = whitebark pine).

Stratum	**Acres**	**Percent of Landscape**
ZBR	55,082	27.0%
F3N	42,976	21.0%
J3N	28,374	13.9%
F4N	16,310	8.0%
L3N	10,830	5.3%
R3N	10,002	4.9%
R4P	8,300	4.1%
F3P	6,876	3.4%
L4N	6,697	3.3%
L3P	4,207	2.1%
J3P	3,521	1.7%
R1X	2,866	1.4%
R3P	1,876	0.9%
FNO	1,305	0.6%
IQQ	1,261	0.6%
AWB	1,117	0.5%
J4N	1,062	0.5%
R4N	686	0.3%
R2N	476	0.2%
A3S	347	0.2%
A3P	26	< 0.1%
A2P	26	< 0.1%
L2N	9	< 0.1%
A3N	1	< 0.1%

Table A3. FCCS and FFE-FVS fuel model assignments

Stratum	FCCS Fuel Model	FFE-FVS
ZBR	TU4 (164)	5
F3N	TL8 (188)	SB2 (202)
J3N	TL8 (188)	GS2 (122)
F4N	TL8 (188)	SB2 (202)
L3N	TL5 (185)	GS1 (121)
R3N	TU4 (164)	SB2 (202)
R4P	TL4 (184)	GS2 (122)
F3P	TL8 (188)	SH2 (142)
L4N	TL6 (186)	SB2 (202)
L3P	TL7 (187)	GS2 (122)
J3P	SB3 (203)	SH1 (141)
R1X	TL6 (186)	10
R3P	TL6 (186)	10
FNO	TU1 (161)	5
IQQ	SB1 (201)	No data
AWB	TL3 (183)	GS2 (122)
J4N	TL6 (186)	TL6 (186)
R4N	TL4 (184)	TL9 (189)
R2N	6	5
A3S	TL3 (183)	SH2 (142)
A3P	TL3 (183)	10
A2P	TL3 (183)	No data
L2N	TL5 (185)	TL5 (185)
A3N	TU1 (161)	SH2 (202)

.

Table A4. Untreated, post-prescribed fire, and post-mastication fuel model assignments.

Stratum	**FCCS Fuel Model**	**Post-Rx Fuel Model**	**Post-Mastication Fuel Model**
ZBR	TU4 (164)	GR3 (103)	TL6 (186)
F3N	TL8 (188)	TL5 (185)	TL4 (184)
J3N	TL8 (188)	TL5 (185)	TL8 (188)
F4N	TL8 (188)	TL4 (184)	TL4 (184)
L3N	TL5 (185)	GR3 (103)	TL4 (184)
R3N	TU4 (164)	TL5 (185)	TL3 (183)
R4P	TL4 (184)	TL3 (183)	TL4 (184)
F3P	TL8 (188)	TL5 (185)	TL5 (185)
L4N	TL6 (186)	TL1 (181)	TL3 (183)
L3P	TL7 (187)	GR3 (103)	TL7 (187)
J3P	SB3 (203)	TL4 (184)	TL8 (188)
R1X	TL6 (186)	TL3 (183)	TL4 (184)
R3P	TL6 (186)	TL3 (183)	TU1 (161)
FNO	TU1 (161)	TL1 (181)	TL4 (184)
IQQ	SB1 (201)	GR3 (103)	TU4 (164)
AWB	TL3 (183)	TL1 (181)	TL3 (183)
J4N	TL6 (186)	TL1 (181)	TL3 (183)
R4N	TL4 (184)	TL1 (181)	TL4 (184)
R2N	6	TL5 (185)	TL9 (189)
A3S	TL3 (183)	TL3 (183)	TU1 (161)
A3P	TL3 (183)	TL1 (181)	TL3 (183)
A2P	TL3 (183)	TL1 (181)	TL3 (183)
L2N	TL5 (185)	TL3 (183)	TL5 (185)
A3N	TU1 (161)	TL1 (181)	TU1 (161)

We developed representative hand and mechanical thinning prescriptions for FVS simulations based on discussions with an LTBMU forester (Parsons 2011, pers. comm.). Simulating both undisturbed growth and fuel treatments on the mapped strata resulted in stands representing 35 additional, unmapped strata. We built fuelbeds to represent these new strata. In some cases we were able to use FIA data formatted by RSL but generally we did not have FIA data and had to base a stratum's fuelbed on the most similar stratum for which we had data. This typically resulted in new strata having the same fuel model assignments as the strata on which they were based because we only changed the canopy parameters, and not the surface fuel loads from which FCCS determines a fuel model assignment.

To illustrate the results we chose the most widespread stratum from each of six major vegetation types present at the Basin (Figs. A1-A3). The result of undisturbed succession is only shown once at the end of 30 years of growth rather than for every five-year increment we simulated. The four other transitions are a result of fuel treatment (prescribed fire, mastication, mechanical thin, hand thin) whose effects are shown immediately after treatment.

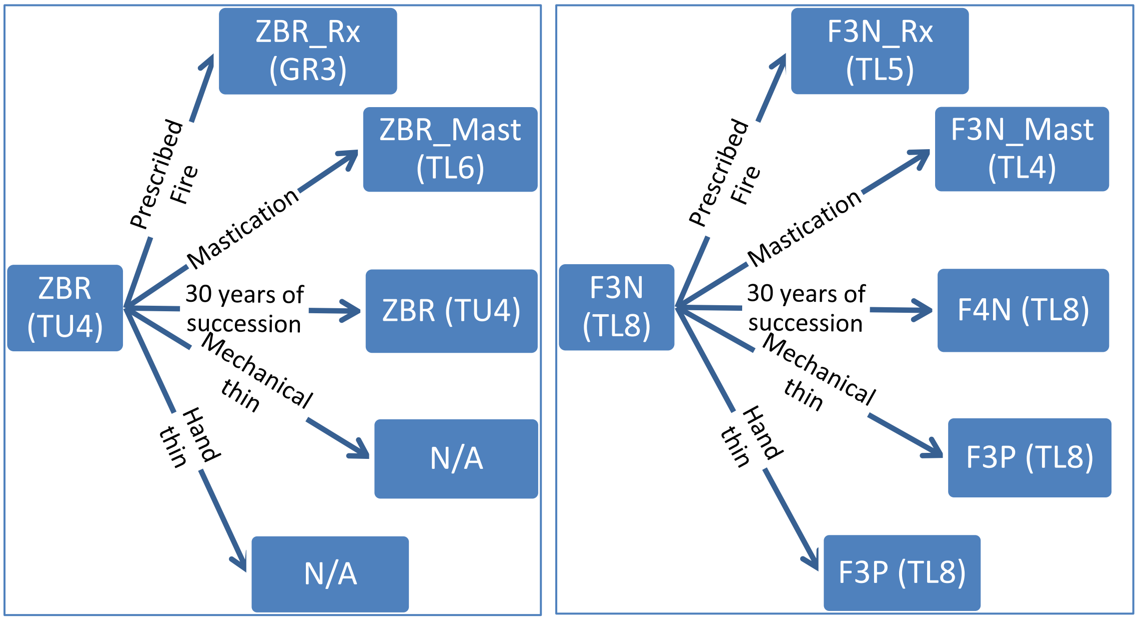


Figure A1. Shrub strata are represented by ZBR and eastside mixed conifer strata are represented by F3N.

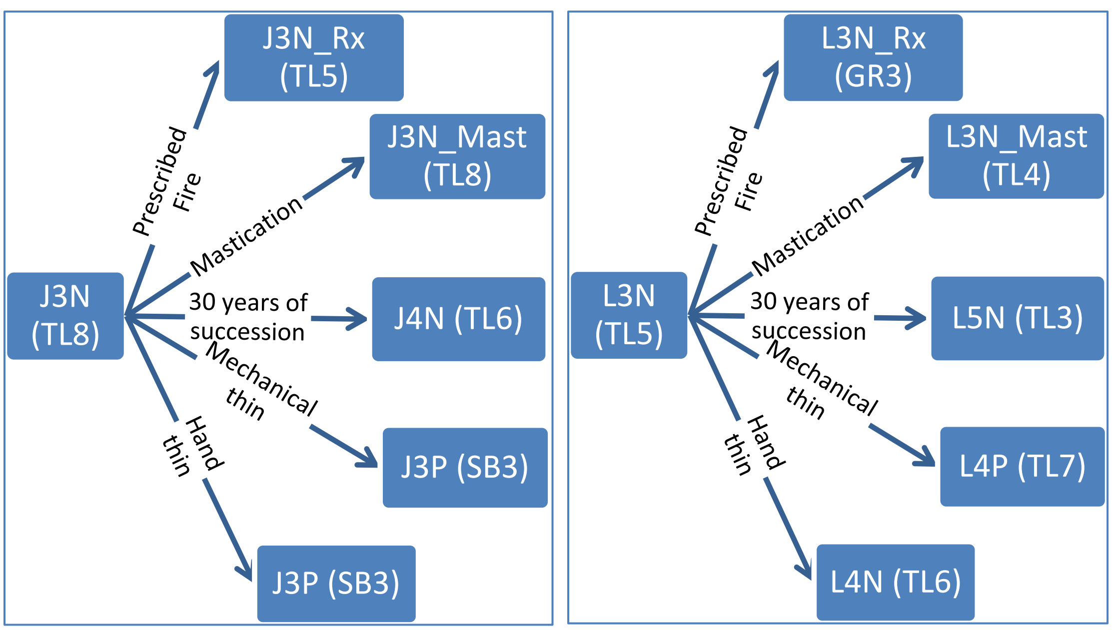


Figure A2. Jeffrey pine strata are represented by J3N and lodgepole pine strata are represented by L3N.

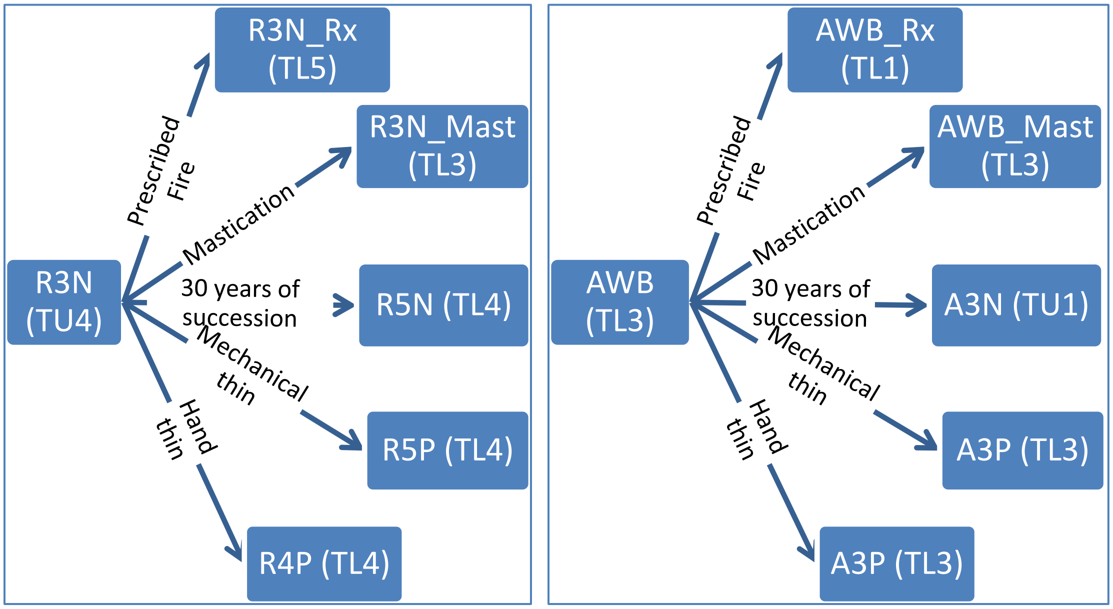


Figure A3. Red fir strata are represented by R3N and subalpine strata are represented by AWB (whitepark pine).

In our application, the two thinning treatments only resulted in a changed fuel model assignment if the treatment had enough intensity to shift the stand from one stratum to another (assuming the two strata had even been assigned different fuel models). Only the canopy layer was assumed to change, and as mentioned above, FCCS does not use fuels in the canopy layer or ladder fuels to assign surface fuel models. However, in reality mechanical fuels treatment is usually followed by surface fuel treatment such as mastication or prescribed fire. When this is the case, a post-surface fuel treatment fuel model, as described in steps 7-9 above, should be assigned. For example, mechanically thinning a stand of F3N will shift it to F3P which happens to have the same fuel model as F3N (TL8). However, if that stand is then prescribed burned, its new fuel model is TL5 (F3P_Rx).

References for Appendix A

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

Knapp EE, Keeley JE, Ballenger EA, Brennan TJ. 2005. Fuel reduction and coarse woody debris dynamics with early season and late season prescribed fire in a Sierra Nevada mixed conifer forest. Forest Ecology and Management 208:383-397.

Prichard, S.J.; Sandberg, D.V.; Ottmar, R.D. Eagle, P.C., Andreu, A.G, and Swedin, K. 2011. FCCS user's guide, version 2.2. http://www.fs.fed.us/fera/fccs/publications/. (1 November 2011)

Scott, Joe H.; Burgan, Robert 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.

Stephens, S.L.; Moghaddas, J.J. 2005. Experimental fuel treatment impacts on forest structure, potential fire behavior, and predicted tree mortality in a mixed conifer forest. Forest Ecology and Management 215:21-36.

van Wagtendonk, J. W. 1996. Use of a deterministic fire growth model to test fuel treatments. In: Sierra Nevada Ecosystem Project: Final report to Congress, Volume II, Chapter 43. Univ. Calif., Davis, Wildland Resources Center Rep. 37. 1528 p.

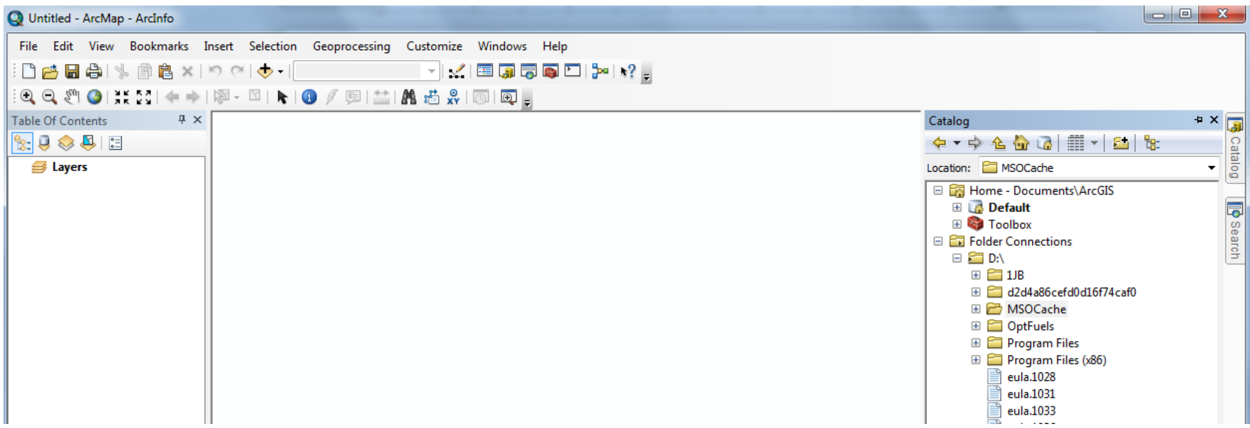
Appendix B. Making ignition files for use in OptFuels

Creating and Editing Shapefiles in ArcMap 10

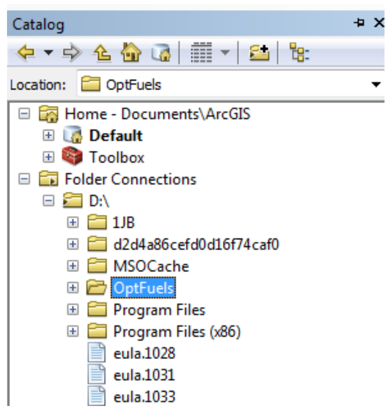
CREATING

Creating a New Shapefile (Points, Polylines, and Polygons)

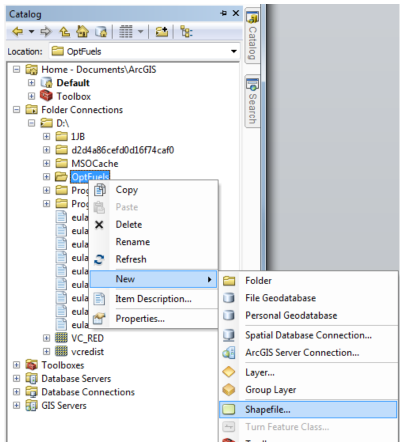
1. Open ArcMap, then open the Catalog tab as shown below.



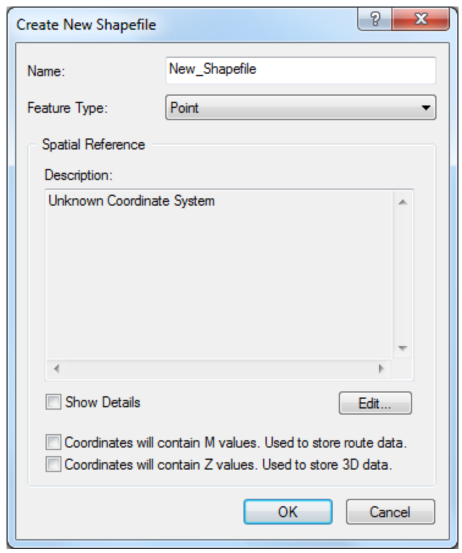
2. Highlight the folder that will contain your new shapefile.



3. Right-click on the folder and select New > Shapefile.



4. The Create New Shapefile dialog box opens.



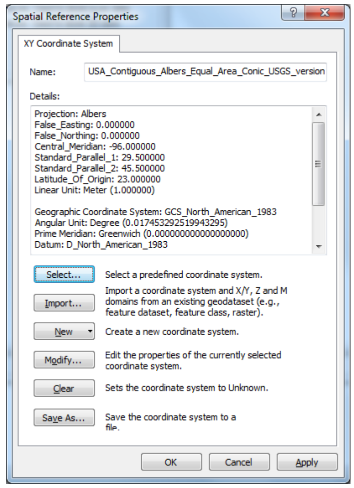
a. Name the shapefile and select the feature type (Point, PolyLine, or Polygon) from the drop-down menu. For OptFuels ignitions you will choose either Point or PolyLine.

b. Set the Spatial Reference (Projection/Datum) by clicking the Edit button. This opens the Spatial Reference Properties dialog box. Below are two methods to set the spatial reference.

1. Choose Import > navigate to your folder that contains data with the coordinate system already defined > click on the dataset > click the Add button > click OK in the Spatial Reference Properties dialog box > click OK in the Create New Shapefile dialog box.

OR

2. Choose Select > Projected Coordinate Systems > The Appropriate Projection File > click the Add button > click OK in the Spatial Reference Properties dialog box > click OK in the Create New Shapefile dialog box.



ADDING THE NEW SHAPEFILE TO THE ARCMAP PROJECT

The new point will be added to the current ArcMap session automatically if the shapefile was created from the ArcCatalog tab within ArcMap. If the shapefile is not added automatically, add the new (empty) shapefile to your project by:

1. File > Add Data

OR

2. Click-on the Add Data icon on the Standard Toolbar in ArcMap 

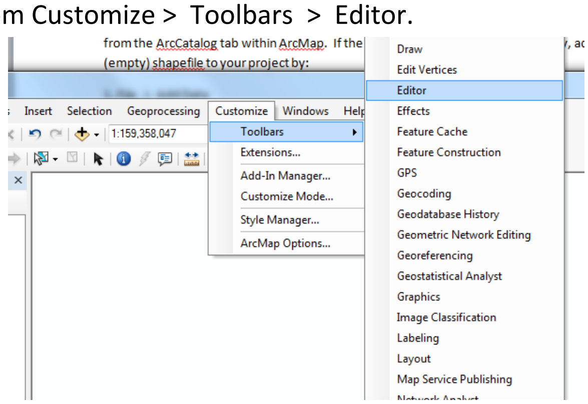
OR

3. Drag the file from Catalog to the Table of Contents of your ArcMap project

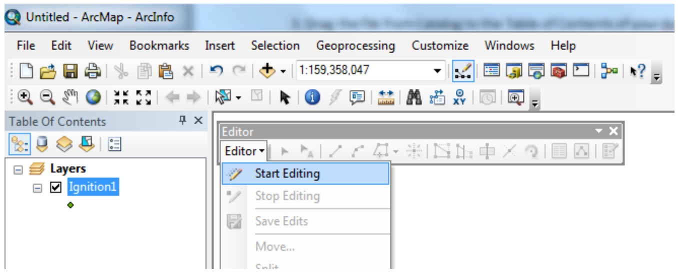
EDITING

STARTING, SAVING, AND STOPPING THE EDITING SESSION

1. Open the Editor Toolbar from Customize > Toolbars > Editor.



2. From the Editor drop-down menu select Start Editing. This opens the Start Editing dialog box.



3. Select the shapefile that you will be editing > Click OK to close the dialog box.

EDITING POINT SHAPEFILES

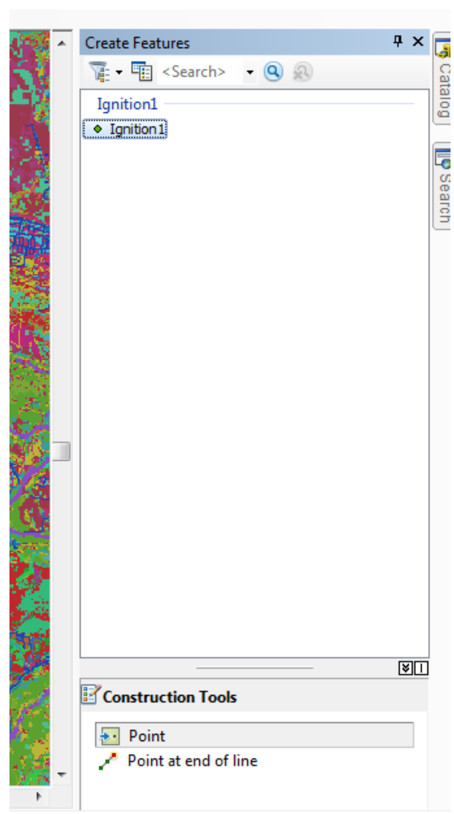
Create a new point

(Creating ignition files from points is not recommended—create simple lines or polygons)

1. Select the point layer in the Create Features dialog

2. Choose the Point Construction Tools

3. Click once to enter a point on your map.



Edit a point

1. Select the point layer in the Create Features dialog

2. Choose the Edit Tool (Arrow) on the Editor Toolbar.

3. Click on the point to modify. The point is now highlighted.

4. Hit the delete key to delete the point

5. Drag the point to a new location

Move a point to an X,Y location

1. Select the point layer in the Create Features dialog

2. Double-click the point you want to move.

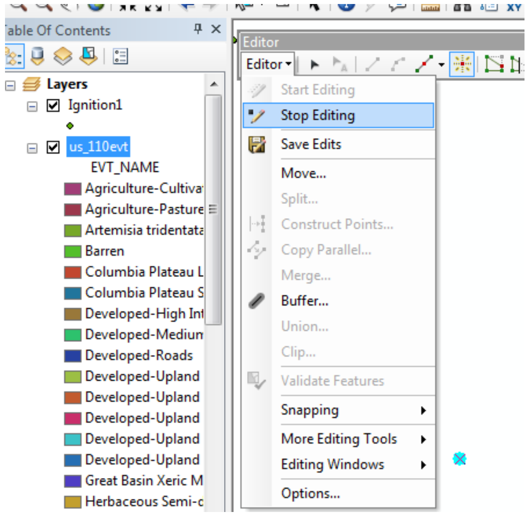
3. Right-click on the point and select Move To…

4. Type the new coordinates in the dialog box.

5. Click anywhere on the map to complete move.

Save your edits during the edit session by selecting Save Edits from the drop-down menu on the editor toolbar.

6. Stop the editing session by selecting Stop Editing from the drop-down menu on the editor toolbar. The Save edits dialog box will open. Select Yes, No, or Cancel.



EDITING POLYLINE SHAPEFILES

Creating a new line file is very similar to creating a point shapefile. The instructions are the same as above, except to add to/edit a line:

1. Select the Line layer in the Create Features dialog

2. Choose the Edit Tool (Arrow) on the Editor Toolbar.

3. Double-click on the line to modify. The line is now highlighted with the vertices shown.

4. Hit the delete key to delete the line.

5. Click and drag a vertex to a new location to move a vertex.

6. Right-click on the line to add a vertex.

7. Mouse-over and right-click on a vertex to delete the vertex.

8. Click somewhere on the map (not on the line) to deselect the line

4. Save the shapefile when finished

Appendix C. Description of the OptFuels Heuristic Solver.

The heuristic solver employed in OptFuels is designed to develop a number of alternative fuel treatment schedules (solutions), evaluate the cumulative effects of each alternative treatment schedule, and choose the best fuel treatment schedule that produces maximum treatment effects (minimize overall expected loss) over time. Figure C1 provides an overview of the implementation of the heuristic solver within the OptFuels system. The solver includes a subroutine to develop FlamMap landscape (LCP) files that represent vegetation and fuels attributes in each time period as treatment effects. Through the use of dynamic link libraries (DLLs), the solver automatically runs the MTT algorithm on each LCP file and stores the outputs (i.e., flame length and fire arrival time in each pixel) for solution evaluation. Each solution is evaluated as the sum of expected loss value for a given study landscape over time (Equation 1). Expected loss value in each pixel depends on user-defined relative value of the pixel and burn probability, and estimated flame length and fire arrival time retrieved from the MTT output.

$$\textit{Minimize Expected loss}_s = \sum_{t} \sum_{c} \sum_{r} P_{c,s,t} \times W_r \times Loss_{c,r,f,t} \qquad [1]$$

where:

c is an index of grid cells (pixels),

t is a time period,

r is an index for risk category,

f is an index for flame length category,

s is an index for fire scenario, which has specified fire ignition locations, wind direction and speed, fuel conditions.

$P_{c,t}$ is the probability of cell c being burned by fire scenario s in time period t,

W_r is the weight factor for risk category r,

$Loss_{c,r,f,t}$ is the expected loss for value at risk category r for grid cell c given a predicted flame length category f in time period t.

A simulated annealing (SA) algorithm is employed in the solver for the optimization engine. Simulated Annealing (SA) is a heuristic search technique that has been widely used to solve large combinatorial problems in various fields (Kirkpatrick and others 1983). The ideas that form the basis for SA were first published by Metropolis and others (1953) in an algorithm to simulate the cooling of materials in a heat bath - a process known as annealing.

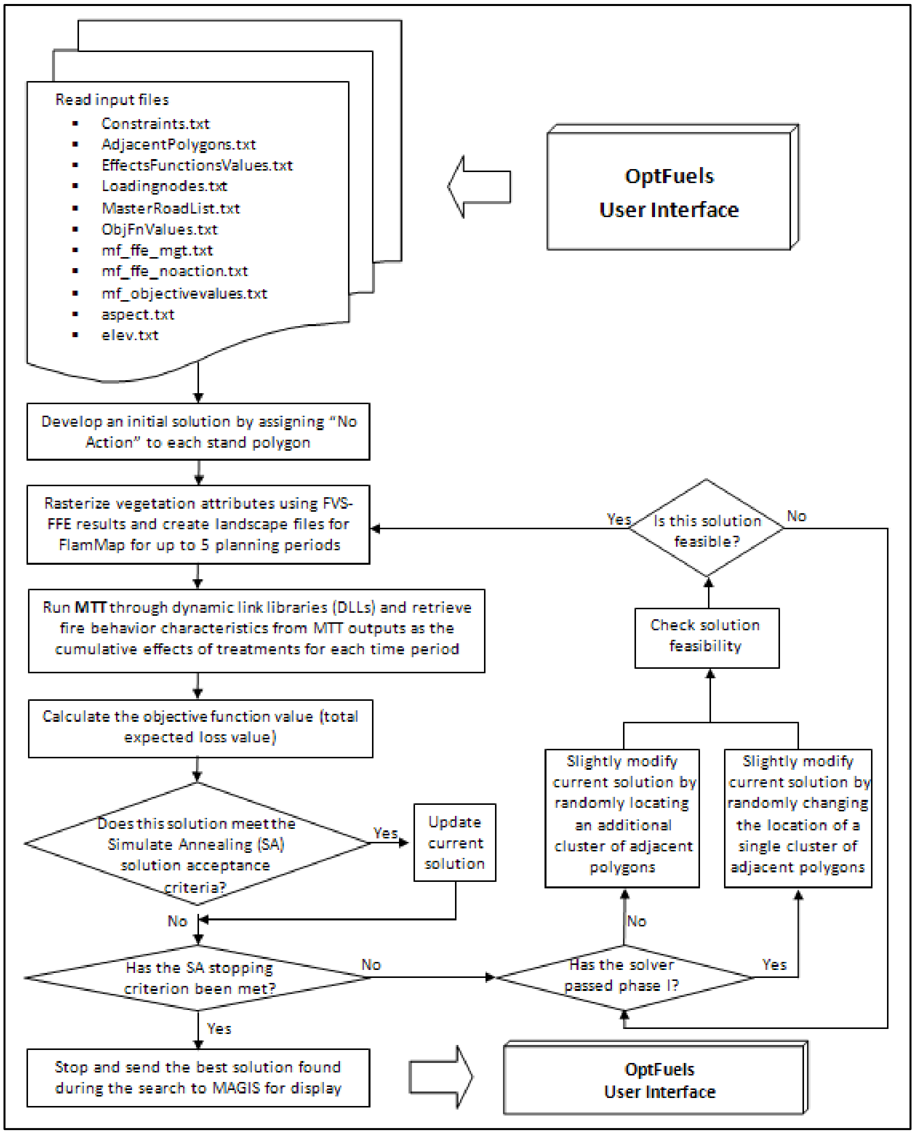


Figure C1. Data flow and analysis employed in the Heuristic Solver to optimize fuel treatment schedules.

The approach is a Monte Carlo method that uses a local search in which a subset of solutions is explored by moving from one solution to a neighboring solution. To avoid becoming trapped in a local optimum, the procedure provides for an occasional acceptance of an inferior solution to allow it to move away from a local optimum. The SA algorithm employed in the heuristic solver is briefly explained below and illustrated in Figure C2. Any combinations of budget and acreage constraints can be considered during the optimization process.

Step 1. Develop and evaluate an initial solution (no action). Store the solution as the current solution.

Step 2. Create a new solution by slightly modifying the current solution (randomly select a set of treatment polygons and assign new fuel treatment options other than no action).

Step 3. Check the feasibility of the new solution. If the solution violates any of the constraints, discard the solution and go back to Step 2. Otherwise, go to Step 4.

Step 4. Accept or discard the new solution based on the SA solution acceptance rule.

Step 5. Go to Step 2 until predefined stopping criterion (i.e., ending temperature) is met.

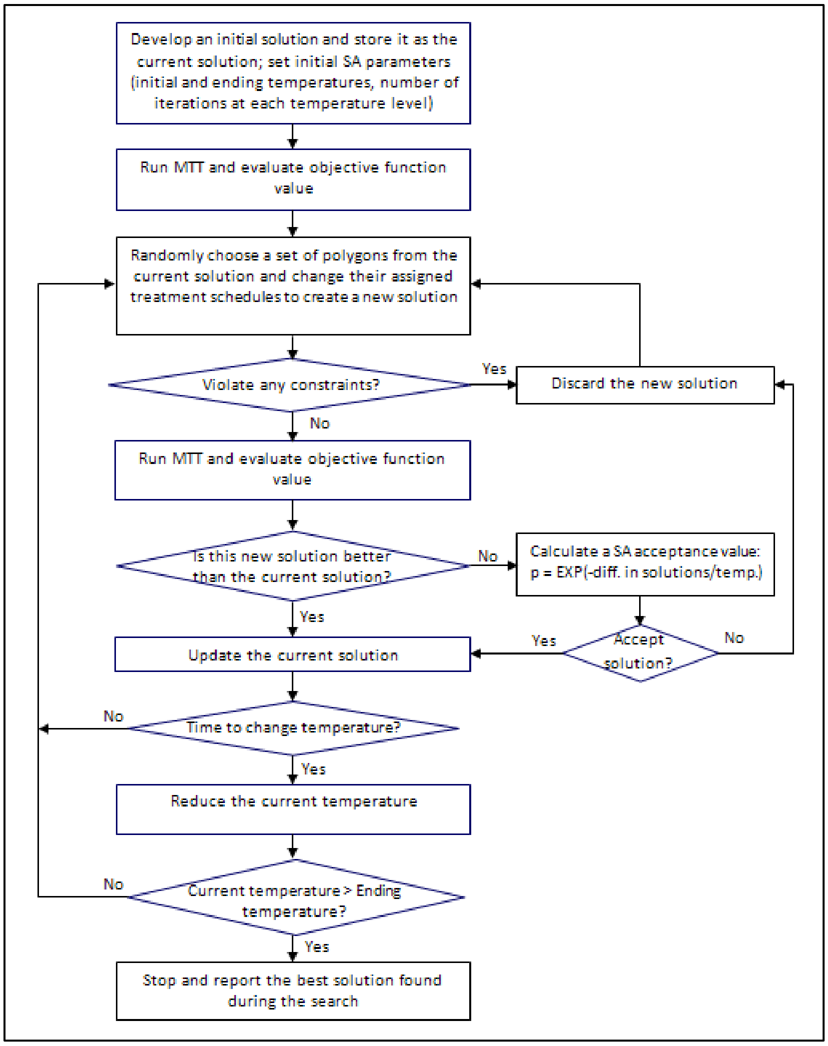


Figure C2. Simulated Annealing algorithm employed in the Heuristic Solver to optimize fuel treatment schedules.

The heuristic solver uses a GIS layer of stand polygons to assign fuel treatments. Because treating individual stands is generally not effective at changing fire behavior at the landscape scale (Finney 2006), stands are clustered by the solver to serve as the treatment units. This is accomplished by developing clusters of adjacent polygons with the same available treatment type and period. A cluster is generated by randomly selecting an unassigned polygon and an available treatment for that polygon other than no action (treatment type and period). Then, an unassigned adjacent polygon to the seed polygon with the same available treatment is randomly selected, and the cluster's area is updated. The process of adding unassigned adjacent polygons continues until the target cluster size is achieved.

The selection of treatments and treatment clusters to develop alternative solutions is done in two phases.

Phase One - The solver starts with a "no action" solution as iteration zero (i = 0), solution feasibility and penalty are evaluated, FlamMap and the MTT algorithm are run for each period, and expected loss is calculated. For the first iteration (i = 1), a cluster of adjacent polygons is randomly located within the treatment area. Then solution feasibility is evaluated, FlamMap and the MTT algorithm are run, and expected loss is calculated. For the next iteration (i = 2), another cluster is randomly located within the treatment area. Again, feasibility is evaluated, FlamMap and the MTT algorithm are run, and expected loss is calculated. The treatment options are screened to have a desirable effect in altering fire behavior; smaller flame lengths and/or slower spread rates. Consequently, as the solver iteratively places clusters, expected loss decreases, and the associated penalty associated with any lower limit constraints also decreases as the solution attributes (i.e., acreage, costs, etc.) approach the lower limit of these constraints. When penalty reaches zero, the lower limits of the set of constraints are exceeded, and solutions become feasible. The solver stops adding additional clusters when solutions become infeasible because the upper limit of one or constraint is exceeded. This indicates the maximum area feasible to treat for each period has been reached.

Phase Two - During phase two, the solver improves the random allocation of clusters assigned during phase one by iteratively changing the location of treatments, one cluster at a time. At each iteration a previously selected cluster is randomly selected for removal from current solution. This means, the selected treatment (type and period) for the stand polygons in that cluster are changed to no action. Then, another cluster is randomly selected and solution feasibility is evaluated. If the solution is infeasible, the new cluster location is ignored and another random cluster location is generated. If the solution is feasible, then FlamMap and the MTT algorithm are run, and expected loss is evaluated. During phase two, only feasible solutions are considered, and the solver continues changing the location of single clusters at each iteration. The process stops when the simulated annealing ending temperature is reached, the stopping rule for SA.

In order to implement the SA search process, several control parameters need to be set. These include beginning and ending temperatures, repetitions at each temperature level, and temperature cooling rate. The OptFuels interface provides three options with pre-set parameter values to choose from: low intensity, medium intensity, high intensity, as well as a custom option where users can define values for each parameter. The higher intensity option runs more iterations and thus can likely provide a better solution than the other two lower intensity search options, but requires a larger amount of computation time.

Test runs of the initial version of the solver indicated that the solver required a considerable amount of computation time due to the fire simulation process by MTT and the complexity of spatial and temporal scheduling problems. To improve the efficiency of the solution process, the current version of the heuristic solver was designed for multi-threading and multi-processing using OpenMP with Visual C++. As a result, the solver can now simultaneously run MTT for multiple time periods, and the computation time can be significantly reduced. For example, using an 8-processor computer, the solver takes about 30 seconds to locate treatments within the landscape and run FlamMap and the MTT algorithm for a 3-period problem over an area of about 20,000 acres using a 90-meter cell resolution. Based on the respective SA parameters, the solver takes about 4 hours, 25 hours, and 8 days to find best allocation and schedule of fuel treatments under the low, medium, and high intensity options, respectively.

References for Appendix C

Finney, Mark A. 2006. A computational method for optimizing fuel treatment locations. In: Andrews, Patricia L.; Butler, Bret W., comps. 2006. Fuels Management-How to Measure Success: Conference Proceedings. 28-30 March 2006; Portland, OR. Proceedings RMRS-P-41. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. p. 107-123.

Kirkpatrick, S.; Gelatt, C.D. ; Vecchi, M.P. 1983. Optimization by simulated annealing. Science 220: 671-680.

Metropolis, N.; Rosenbluth, A.; Rosenbluth, M.; Teller, A.; Teller, E. 1953. Equation of state calculations by fast computing machines. Journal of Chemical Physics 21: 1087-1101.

Appendix D. Listing of system files by subdirectory