

# **Tahoe Science Program Final Report**

## **Incorporating project-level analysis and enhanced decision support into the OptFuels fuel treatment planning system for the Lake Tahoe Basin (P083)**

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### **Project Overview**

A GIS-based decision support system, called OptFuels, was developed as part of a SNPLMA-funded project for spatially scheduling forest fuel treatments over multiple planning periods in the Lake Tahoe Basin (P034 “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 the Minimum Travel Time algorithm in FlamMap (FlamMap-MTT), and a heuristic algorithm for scheduling fuel treatments (Figure 1).

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, including no action. In addition to fuel treatment optimization by the heuristic algorithm, users have the option of entering their own treatment alternatives for analyzing effects on fire behavior and conducting trade-off analyses.

Based on feedback from Lake Tahoe Basin managers, the OptFuels team developed a set of objectives for making the system more flexible and user-friendly and for performing project-level analyses. The objectives for this phase of the project were to:

1. Add functionality to OptFuels for users to enter treatment unit polygons with assigned treatments for project alternatives and analyze the effectiveness of those proposed treatments to modify fire behavior and reduce the risk from future wildland fire.
2. Construct a Lake Tahoe Basin-wide OptFuels database and develop a streamlined process for clipping and building OptFuels models that are tailored to specific planning areas.
3. Enhance the fuel treatment information provided by OptFuels that can be used in designing projects to meet various forest management objectives.
4. Enhance the capability of OptFuels to predict wildfire effects on erosion and water quality and on various values at risk both with and without fuel treatments across user-specified fire scenarios.
5. Deliver the enhanced OptFuels system to end users.

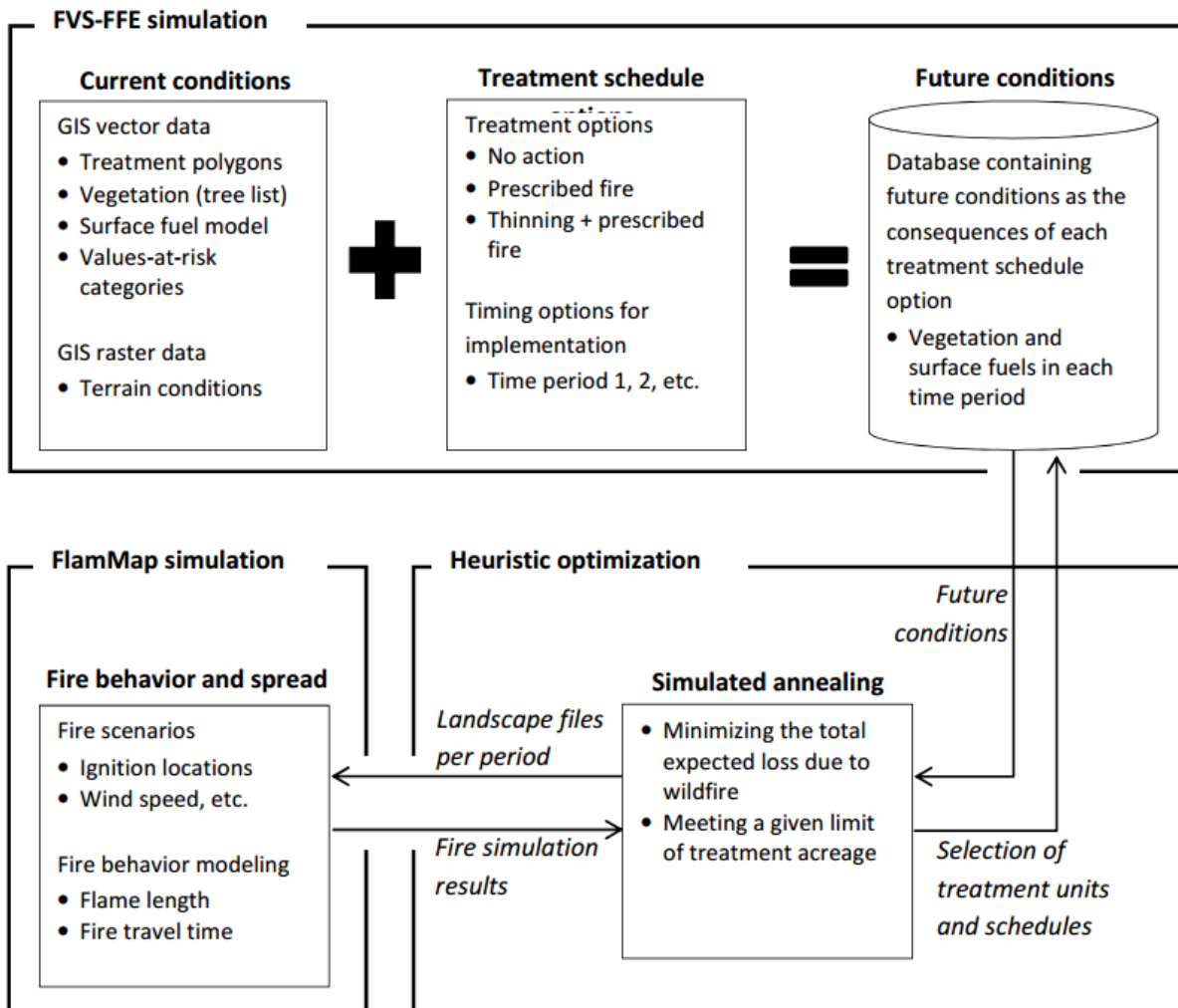


Figure 1. Overview of the OptFuels system consisting of three simulation and optimization components: vegetation and fuel treatment simulation using FVS-FFE, fire behavior and spread simulation with FlamMap, and simulated annealing heuristic solver to schedule fuel treatments to minimize the total expected loss from wildfires over the planning horizon.

## Summary of Accomplishments

Objective 1. Add functionality to OptFuels for users to enter treatment unit polygons with assigned treatments for project alternatives and analyze the effectiveness of those proposed treatments to modify fire behavior and reduce the risk from future wildland fire.

The OptFuels vegetation and fuels modeling process occurs at the stand level. The current landscape is represented by a stand polygon layer that has been associated with forest inventory data through a statistical imputation procedure. For each stand, FVS is used to model a range of appropriate alternatives through a user-specified timeframe. These alternatives include no action and a wide range of silvicultural options that can be assigned via the FVS Suppose interface. OptFuels utilizes the CalVeg existing vegetation polygons that have associated inventory data provided by the Forest Service Region 5 (R5)

Remote Sensing Lab (Warbington et al. 2000). These CalVeg-based polygons serve as the default treatment units in OptFuels. In the previous version of OptFuels analysis areas had been ‘pre-loaded’ for users based on four geographic zones that made up the entire Tahoe Basin. These pre-loaded zones were adequate for evaluating treatment effects for the Basin, but more flexibility was needed in order to let managers analyze individual project areas. For that reason, additional functionality was added to the GIS Toolbar that allows users to:

- a. Create custom project layers based on existing stand polygons or by using the default data using a ‘click and drag’ GIS interface
- b. Create and model a treatment scenario based on user-defined stands and treatment types, which are termed ‘Decision Variables’ in the OptFuels system
- c. Parameterize and run the OptFuels model and analyze outputs directly from a custom ArcGIS toolbar

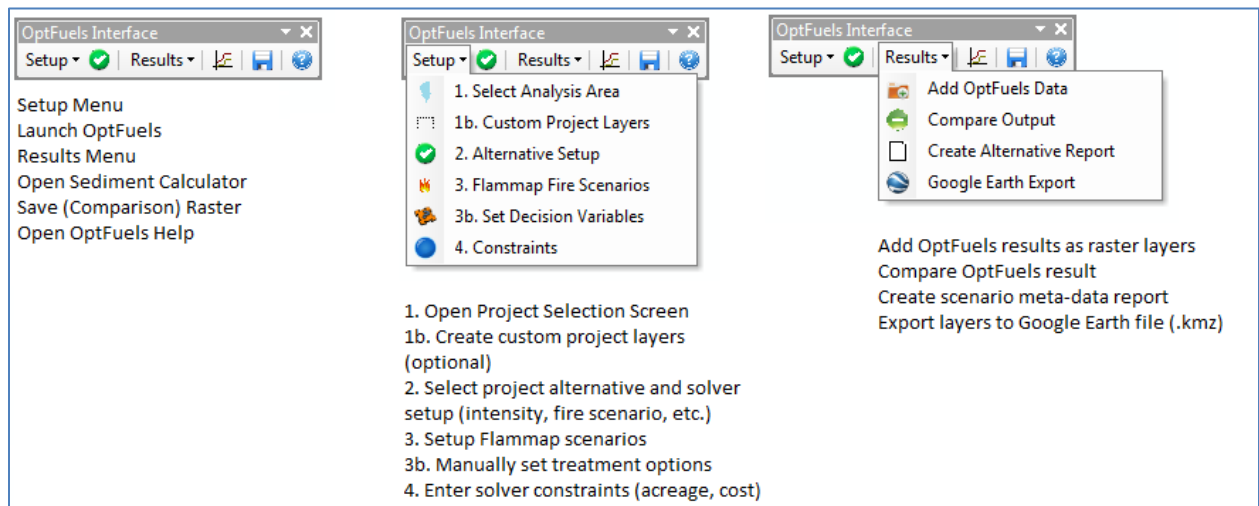


Figure 2. Screenshot of the OptFuels GIS Toolbar for ArcGIS with a brief description of each tool and menu

- a. *Create custom project layers based on existing stand polygons or by using the default data using a ‘click and drag’ GIS interface*

As seen in Figure 2 above, the OptFuels GIS toolbar provides users the ability to select a custom analysis area via a ‘click and drag’ interface within the ArcMap software package using the ‘Select Analysis Area’ option. This feature allows users to define an OptFuels project that coincides with an active project planning area. Data from the default vegetation and fuels database is automatically processed for the custom project area. Figure 3 illustrates output for a custom project area on the west-side of the Tahoe basin comparing modeled flame length for a No Action alternative compared to a proposed treatment arrangement.

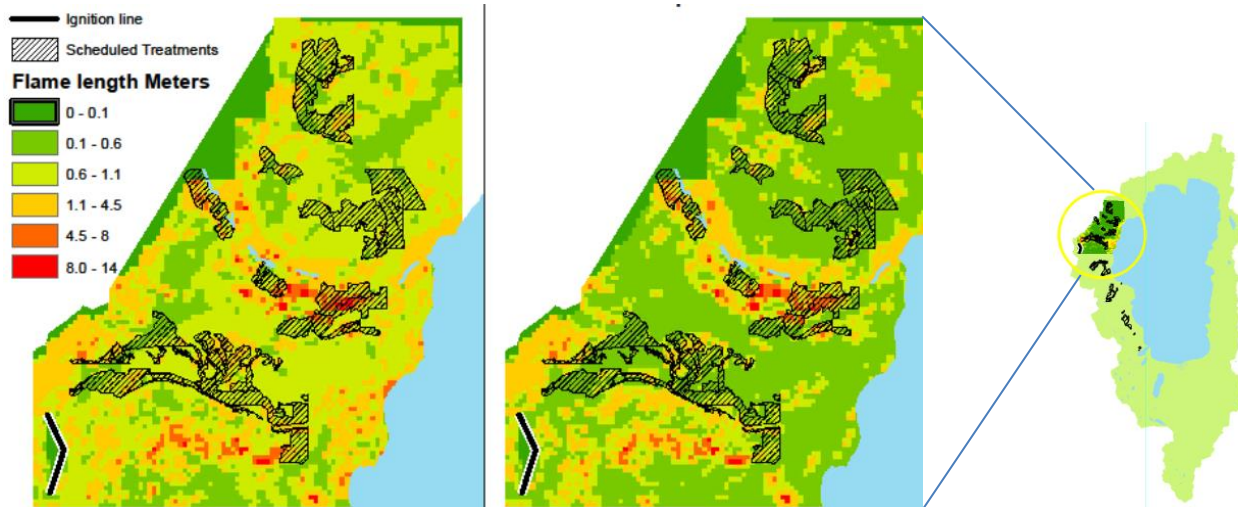


Figure 3. Example of the Flexible Project Analysis tool at work in analyzing the potential effects of proposed fuel treatments on the west side of the Tahoe basin. The No Action alternative results are on the left and the Treatment alternative is on the right

In addition, a 'Create Custom Project Layers' tool was added to the GIS Toolbar (Figure 4). This GIS functionality allows users to input polygon data for treatment units from sources such as the Forest Service Activity Tracking System (FACTS). OptFuels outputs related to potential fire behavior, expected loss to values at risk, and sediment are reported at the custom polygon unit, allowing managers to efficiently analyze the potential impacts and benefits for a range of different treatment alternatives.

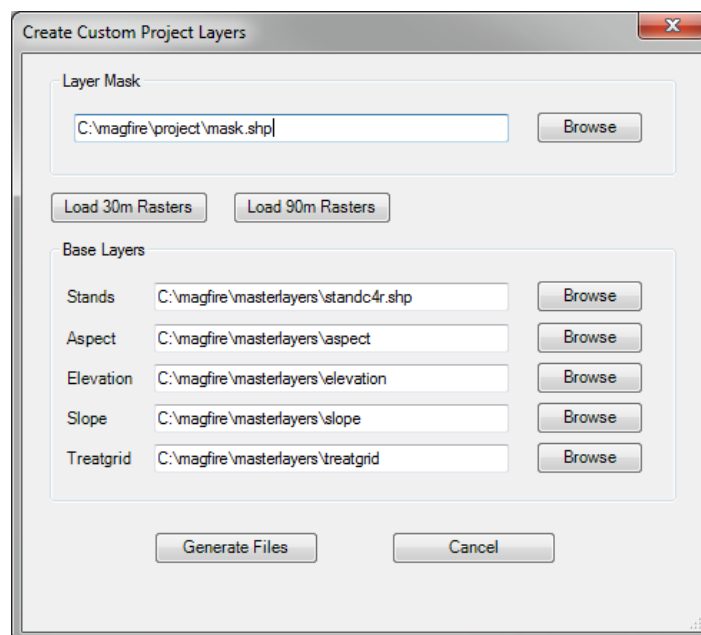


Figure 4. User interface that allows users to provide an input mask defining a custom project area

*b. Create and model a treatment scenario based on user-defined stands and treatment types*

Two analysis modes can be used in the OptFuels system: 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 then use the OptFuels solver to compute the expected loss from future fire to measure treatment effectiveness. Simulation mode is especially well suited to comparing a number of different treatment alternatives to evaluate their effectiveness at minimizing expected loss from wildfire. The OptFuels team added the ability for users to define the arrangement of treatments using the Set Decision Variable selection tool in order to analyze outcomes from one or more proposed treatment alternatives (Figure 5). The new Decision Variable form hooks into ArcMap's selection API for easier selection of polygons for treatment. Users can pick any combination of polygons, select a treatment and treatment period, and append them to the solver's decision variable file. Treatment choices include mechanical thinning followed by a prescribed burn or mastication, hand thinning followed by a prescribed burn, and a burn-only option.

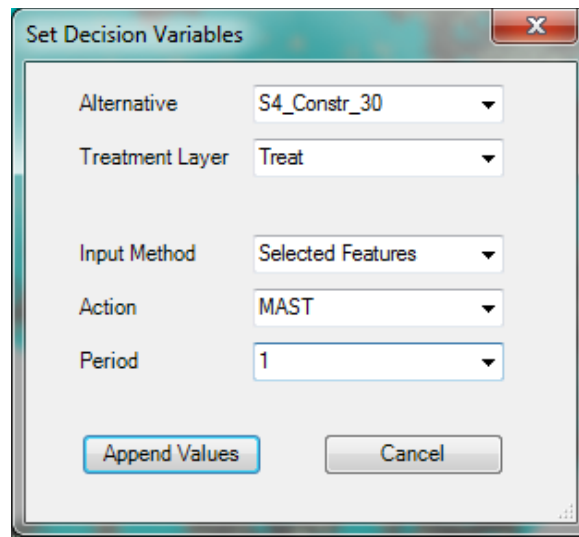


Figure 5. Input screen that is presented after a user selects a stand with the 'Set Decision Variable' tool.

*c. Parameterize and run the OptFuels model and analyze outputs directly from the custom ArcGIS toolbar*

Previous versions of OptFuels were based on a desktop software-based interface that included some GIS add-ons, which provided the user limited ability to perform spatial analysis on the output datasets. In the updated version of OptFuels, the team has upgraded the entire interface to operate within ESRI ArcMap GIS. This allows the user the flexibility to use all of the built-in functionality of ArcGIS in analyzing OptFuels outputs and creating input data. Buttons on the new toolbar can launch external screens, allowing users to set up the necessary parameters for the OptFuels model, including Flammap fire scenario inputs.

Tools are also provided that facilitate user-friendly viewing and analysis of outputs, including a 'Compare Outputs' utility that provides a numerical comparison of outputs for No Action and Treatment alternatives

(Figure 6), an 'Export to Google Earth' utility, and a 'Create Alternative Report' option that provides estimates of cost and potential hazard for each alternative.

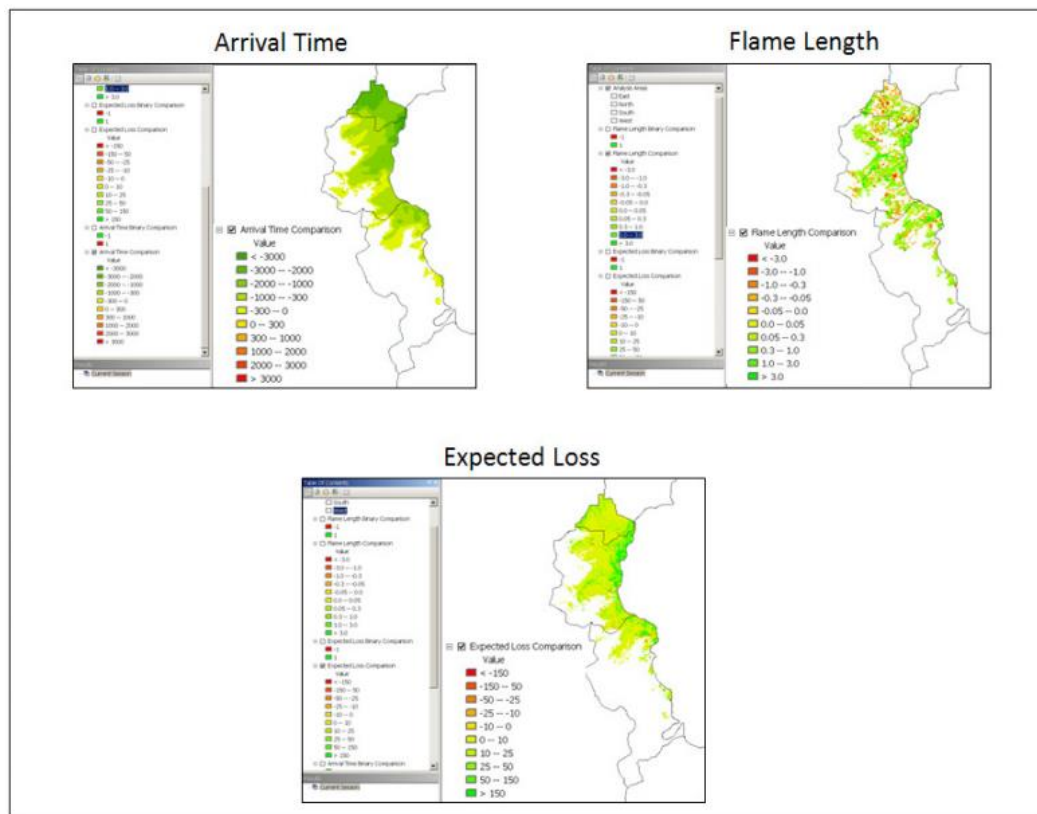


Figure 6. Results from the 'Compare Outputs' tool showing the difference in Arrival Time, Flame Length, and Expected Loss between No Action and Treatment

Objective 2. Construct a Lake Tahoe Basin-wide OptFuels database and develop a streamlined process for clipping and building planning-area specific OptFuels models.

Four treatments were selected as the candidate treatments after discussing treatment options with Basin Managers: 1) hand thin followed by a prescribed burn, 2) mechanical thin followed by a prescribed burn, 3) mechanical thin followed by mastication, and 4) prescribed burn only. The Western Sierra variant of FVS (<http://www.fs.fed.us/fmfc/fvs/software/variantinstaller.php>) was used to simulate applying these treatments to the plots. Using FVS Suppose software (<http://www.fs.fed.us/fmfc/fvs/software/suppose.php>), separate FVS runs were made for applying each treatment to each plot in each of three 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. FVS runs were also made for No Action (no treatment applied) to project the untreated plot data through the three 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-MTT's crown fire model is sensitive to crown base height. The default base height values from FVS-FFE 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 FVS-FFE data, the predicted increases in crown base height values were adjusted downward by 50%. This adjustment resulted in more realistic modeled crown fire behavior based on consultation with a Fire Ecologist familiar with Sierra Nevada and with LTBMU Managers.

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 and others 2011, Seli and others 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 Forest Inventory and Analysis (FIA) 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.

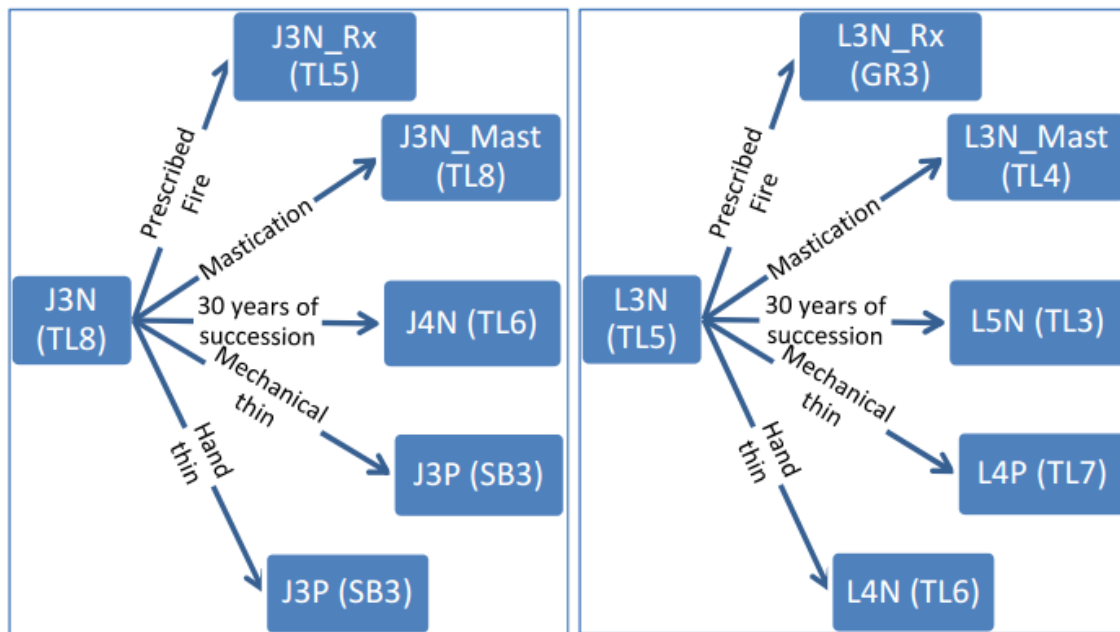


Figure 7. Illustration of the modeled fuelbed pathway for a Jeffrey Pine vegetation strata (left) and Lodgepole pine (right) given several treatment alternatives. The treatments take the stand from a Timber-Litter (TL) fuel model state to a grass (GR), slash/blowdown (SB), or a different Timber-Litter model which changes the resulting modeled fire behavior

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 (Figure 7). FVS was used to project stand growth for each stratum, 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 Wagendonk 1996; Knapp and others 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 results from the FVS runs and the surface fuel model assignments were stored in the Treatment Databases for the entire Lake Tahoe Basin (Figure 8). These results include the fuel parameters computed for each plot for each period for the No Action alternative, and for each of the four treatment options. Treatment options were included for each period for each plot where the treatment criteria were met by the projected stand.

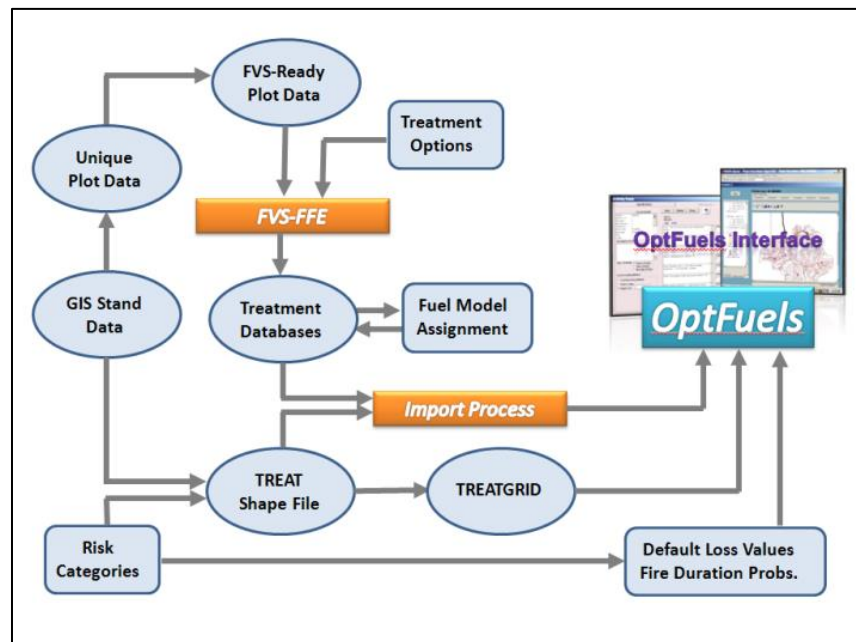


Figure 8. Schematic of the OptFuels model-building process.

Objective 3. Enhance the fuel treatment information provided by OptFuels so it can be used in designing projects to meet various forest management objectives.

Harvest costs were estimated for the three treatments using several individual activity models, and the results combined for an estimate of total costs per acre treated. A series of costs were estimated for applying the prescriptions beginning with the inventory year 2011, and then projecting the stands 30 years beyond 2011, and estimating costs at five-year planning period intervals. For example, cost estimates for 2036 are based upon each stand's condition in 2036 having been projected from 2011. Costs were estimated individually for mechanical ground based whole tree harvesting, manual whole tree harvesting, hand piling the cut trees, pile burning, and wheeled mastication. All costs were converted to 2009 dollars using the GDP deflator.

To simulate the stands' growth into the future, we used the Western Sierra variant of the Forest Vegetation Simulator (FVS: <http://www.fs.fed.us/fmssc/fvs/>) and independently applied the three prescriptions in planning period years 2016, 2021, 2026, 2031, 2036, and 2041. A combination of standard



FVS outputs and specialized calculations coded and embedded in FVS were generated for each planning period for use in the subsequent cost modeling. Examples of the outputs included are trees per acre cut, and the residue fraction of cut trees.

To estimate mechanical and manual harvest costs, we used the West variant of the Fuel Reduction Cost Simulator (FRCS; <http://www.fs.fed.us/pnw/data/frcs/frcs.shtml>). In addition to using stand specific information generated with FVS, the FRCS required additional variables. Mean slope and mean elevation were calculated through geospatial analysis of the treatment areas in GIS. The mean slope was estimated at 15.36%, and mean elevation was estimated at 6,770 feet. Through consultation with principal investigators, average yarding distance was assumed to be 1,600 feet, move in distance of 30 miles, and average treatment area at 100 acres. The average weight of cut trees was calculated as the average of species present on the treatment areas at 22.6 pounds per cubic foot. Total treatment costs per acre for each prescription using every available stand was then estimated and combined with additional treatment costs.

Costs of hand piling and prescribed burning were estimated using regression models developed by Calkin and Gebert (2006). For both models we assume a 100 acre treatment size. The hand piling baseline model required output from FVS and results from GIS analysis of the study area. Fuel load (tons per acre) was obtained from FVS; elevation of 6,770, majority aspect other than south, southeast, or southwest was obtained from GIS, and fire regime 3 was obtained from LANDFIRE maps of the Tahoe Basin. For the prescribed burning model, we stated that this activity occurs in the WUI and that the cut trees are hand piled.

For the Lake Tahoe region, no mastication models could be located in the searchable literature. However, the My Fuels Treatment Planner (MyFTP; <http://www.fs.fed.us/pnw/data/myftp/myftp.shtml>) contains an unpublished mastication submodel, which was used to estimate mastication costs. The model was parameterized with the same ground slope as the models previously described, and we assumed a maximum diameter of 15 inches for mastication.

Combining the various activity cost estimates according to the requirements of the prescriptions yielded total cost per acre. Table 1 displays the mean cost for each prescription, by planning year. This information has been included in the GIS Toolbar default data, and cost reporting is now included in the analysis reports for each alternative.

Table 1. Mean cost of each modeled treatment type, by planning year in dollars per acre.

Planning Year	Mechanical/Mastication	Hand Thinning/Burn	Mechanical/Burn
2011	\$1,445	\$1,633	\$1,504
2016	\$1,454	\$1,860	\$1,507
2021	\$1,553	\$1,850	\$1,582
2026	\$1,707	\$1,907	\$1,711
2031	\$1,846	\$2,021	\$1,833
2036	\$1,868	\$2,221	\$1,832
2041	\$2,010	\$2,156	\$1,954

Objective 4. Enhance the capability of OptFuels to predict wildfire effects on erosion and water quality and on various values at risk both with and without fuel treatments across user-specified fire scenarios.

*Statistical Tools for comparing treatment scenario results*

The new comparison utility uses a paired t-test analysis to determine statistical likelihood of observed results (Figure 9). Statistical functionality is taken from a Forest Service Rocky Mountain Research Station-designed raster utility (Hogland et al. 2013, <http://www.fs.fed.us/rm/raster-utility/>). To increase accuracy, we further broke up the analysis by running the test for each ownership type (Residential, Urban, Managed, and Wilderness/Non-Managed). The column “Label” refers to the ownership type (which comes from the “VALUECAT” attribute in treat.shp) (Figure 6). The next column shows which way the difference was taken (in this case, V1 – V2 where V1 is alternative 1 S5\_NewWind and V2 is alternative 2 S1\_NA). The next columns show the number of samples in that category (N) and the total mean difference between rasters (Dif). Finally, the statistical values T and P are given. In this case, all P values were very small which indicates high statistical significance; the change observed from one raster to the other is not likely due to chance, but rather due to treatments the solver applied to the landscape.

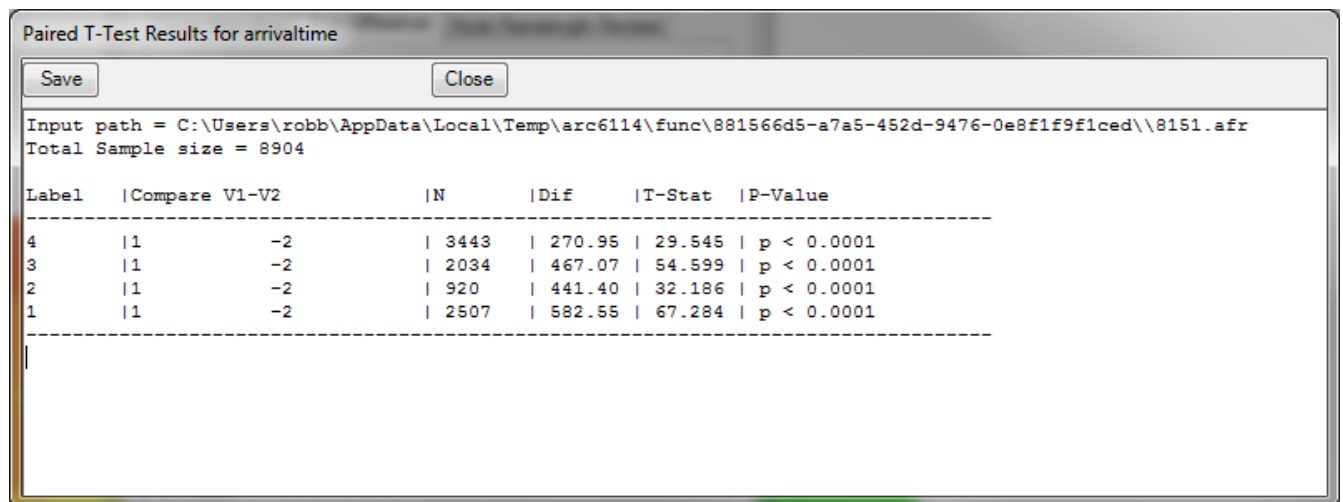


Figure 9. Sample output from the OptFuels Statistical Comparison Tool

*Metadata Report for assessing quality of model inputs*

The metadata report allows users to view solver inputs and preliminary results in one place, and save the information to a log file (Figure 10). This makes it much easier to compare different scenarios to one another. The report compiles the Flammap input scenario, the constraints put on the solver, the difference in expected loss between the selected scenario versus taking no action, and the best iteration (treatment solution) identified by the solver.

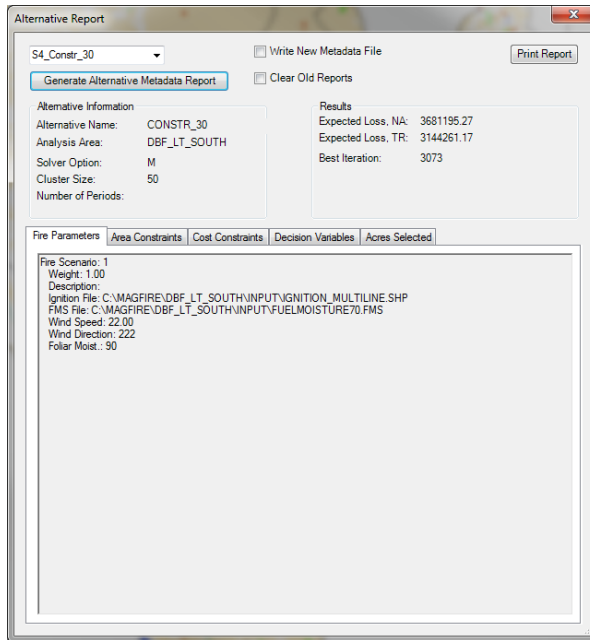


Figure 10. Screenshot showing the OptFuels Metadata Reporting tool

### Graph Sediment by Arrival Time Tool

A new post-processing tool, 'Graph Sediment by Arrival Time', has been added to the OptFuels GIS Toolbar (Figure 11). The 'Graph Sediment' tool allows managers to analyze the potential sediment production resulting from a given fire scenario and easily compare those results to predicted outcomes from alternative scenarios. Default sediment data for the tool was produced using a WEPP sediment prediction model (Elliott 2004), which was developed for the Tahoe Basin. Alternatively, users can override the default WEPP inputs. Outputs are provided in a common spreadsheet format that stores incremental and cumulative tons of sediment by a given arrival time (spread minutes in hour increments), period, erosion event (10 and 50 year), and treatment across an OptFuels landscape. Users can quickly and easily graph tons of sediment by arrival time using the output file with Microsoft Excel.

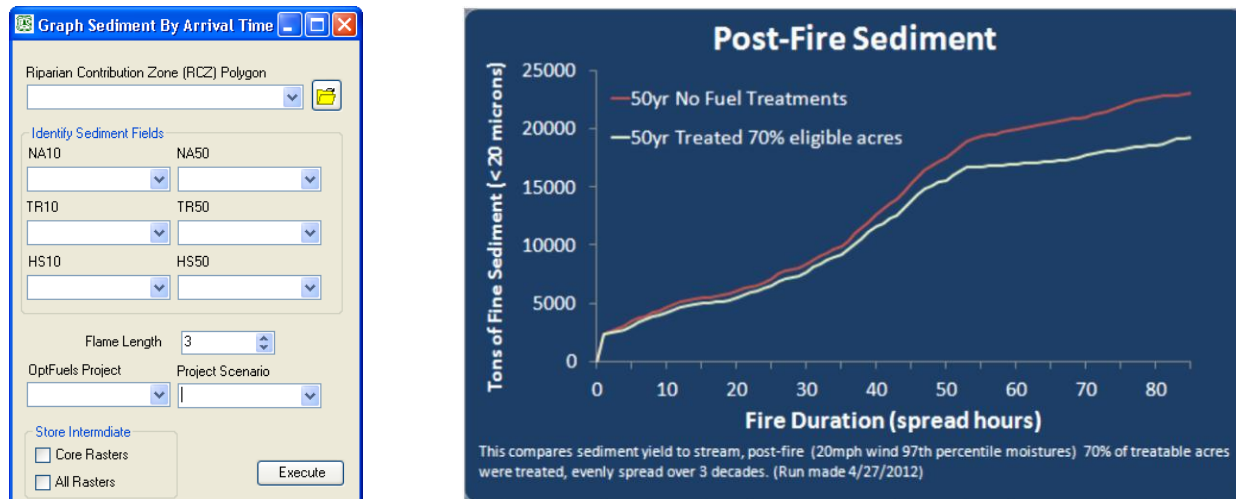


Figure 11. Screenshot showing the user interface for the 'Graph Sediment by Arrival Time' tool (left) and example output (right) showing potential sediment yield from a fire scenario with and without treatment

## Objective 5. Deliver the enhanced OptFuels system to end users.

### *Engagement with Lake Tahoe Basin Fuels Treatment Planning Efforts*

The OptFuels team has assisted LTBMU personnel in analysis related to planning efforts in the Incline Village and West Side treatment areas. On May 18<sup>th</sup> – 20<sup>th</sup> 2014, a member of the team traveled to South Lake Tahoe and held a series of workshops with Scott Dailey of the Forest Service Adaptive Management Services (AMSET) Team and LTBMU Staff. Following those workshops, the OptFuels team has continued to make enhancements to the model to make it more suitable for planning and modeling efforts related to the rewrite of a Multi-Jurisdictional Fuels Treatment Plan for the Lake Tahoe Basin. An intra-agency agreement is currently under development that would enable the continued involvement of the OptFuels research team in this Fuels Planning effort.

### *Presentation*

On May 19<sup>th</sup> Edward Butler made a presentation to the Lake Tahoe Basin Multi-Jurisdictional Fuels Reduction and Wildfire Prevention Strategy Working Group titled 'OptFuels: Assessing fire risk and scheduling fuel treatments spatially over time to minimize expected loss from future fire'.

### *Website and Tutorial Updates*

The OptFuels website (<http://www.fs.fed.us/rm/human-dimensions/optfuels/>) has been updated with the latest installers and supporting documentation, including a User Guide document and a 'Quick Start' Tutorial. The installer puts the necessary prerequisites for the base OptFuels program and ArcMap toolbar on the user's computer. In addition, the website contains overviews of OptFuels, the heuristic solver, WEPP integration, downloadable PDFs of past OptFuels presentations, contact information, and miscellaneous other information.

### *Google Code Site*

A Google Code website has been developed as a mechanism for the OptFuels software developers to share code with interested parties and track changes to the system (Figure 12). In addition, the site provides an alternative download location for the GIS Toolbar and base system installers.

Project Home Wiki Issues **Source**

Checkout Browse Changes

Source path: svn/

Directories	Filename	Size	Rev	Date
▼ svn	<a href="#">AddOptFuelsDataButton.cs</a>	1.1 KB	r2	May 30, 2013
branches	<a href="#">AlternativeSelectBox.cs</a>	1.9 KB	r2	May 30, 2013
tags	<a href="#">AlternativeSetupButton.cs</a>	938 bytes	r2	May 30, 2013
▼ trunk	<a href="#">AsciiDump.cs</a>	712 bytes	r2	May 30, 2013
▼ ODM_AddIn	<a href="#">ComparisonButton.cs</a>	1015 bytes	r2	May 30, 2013
Images	<a href="#">Config_Designer.cs</a>	21.6 KB	r3	May 30, 2013
Properties	<a href="#">Config_esriaddinx</a>	7.8 KB	r3	May 30, 2013
► bin	<a href="#">ConstraintsButton.cs</a>	578 bytes	r2	May 30, 2013
► ODM_Code	<a href="#">CreateBaselayersButton.cs</a>	953 bytes	r2	May 30, 2013
► ODM_Console	<a href="#">FlammapButton.cs</a>	894 bytes	r2	May 30, 2013
wiki	<a href="#">HelpButton.cs</a>	541 bytes	r2	May 30, 2013
	<a href="#">LaunchScenarioButton.cs</a>	815 bytes	r2	May 30, 2013
	<a href="#">ODM_AddIn.csproj</a>	9.7 KB	r2	May 30, 2013
	<a href="#">SaveButton.cs</a>	793 bytes	r2	May 30, 2013

Figure 12. Screenshot of OptFuels Google Code site, where interested parties can download the source code for the project as well as program installation packages

### Manuscripts

#### Published:

Chung, Woodam; Jones, J Greg; Krueger, Kurt; Bramel, Jody; Contreras, Marco. 2013. Optimizing fuel treatments over time and space. *International Journal of Wildland Fire*.  
<http://dx.doi.org/10.1071/WF12138>

#### Completed:

Schmidt, David; Bramel, Jody P.; Chung, Woodam; and Jones, J. Greg. 2012. An inventory-based process for assigning surface fuel models to projected forest stands. Unsuccessfully submitted to *Fire Ecology*, currently modifying for submittal to another journal.

The research team has successfully completed all obligations and deliverables for the SNPLMA grant P083 titled *Incorporating project-level analysis and enhanced decision support into the OptFuels fuel treatment planning system for the Lake Tahoe Basin* (Table 2). Members of the team will continue to help key stakeholders operationalize the OptFuels system, including the U.S. Forest Service Adaptive Management Services (AMSET) Team and LTBMU Staff, as resources allow. This work brings to fruition over a decade of research and development to create a GIS-based decision support system that provides land managers with a streamlined ability to develop spatiotemporal fuel treatment alternatives and assess trade-offs among various alternatives in a complex decision making environment.

## Summary of Tasks and Deliverables

Deliverables	Task	Start Date	End Date	Status Update	Percent Complete
IGO, Task Order, or Initial Funding Transfer	Initiate project	7/1/2012	8/31/2012	Complete	100%
Contract or Agreement	Establish agreement	8/1/2012	9/30/2012	Complete	100%
Inventory/assessment/monitoring	Default database for the Lake Tahoe Basin	8/1/2012	12/31/2012	Complete	100%
	Initial version of Enhanced OptFuels	8/1/2012	3/31/2013	Complete	100%
	Intermediate version of Enhanced OptFuels	4/1/2013	6/30/2013	Complete	100%
	Final version of Enhanced OptFuels	7/1/2013	10/31/2013	Complete	100%
Scientific reports, systems, or related products	DSS Distribution System	11/1/2013	1/31/2014	Complete	100%
	System documentation	11/1/2013	1/31/2014	Complete	100%
	Final report	11/1/2013	2/28/2014	Complete	100%
	Publication	8/1/2013	12/31/2013	Complete	100%
	Presentations	8/1/2013	12/31/2013	Complete	100%
Outreach/training	Workshop	10/1/2013	1/31/2014	Complete	100%
Contract Administration	Quarterly report	8/1/2012	4/30/2014	Complete	100%
	Yearly report	8/1/2012	9/30/2014	Complete	100%

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