Assessing the Effectiveness of Landscape Fuel Treatments on Fire Growth and Behavior in Southern Utah[1]

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Abstract

This paper presents a methodology for assessing the effectiveness of landscape fuel treatments on fire growth and behavior. Treatment areas were selected by fire managers from the Bureau of Land Management (BLM) based on the threat of fire to communities and the need for range and wildlife improvement. A fire density grid was derived from the BLM's fire start layer to identify historically high ignition areas. Fire Family Plus was used to summarize and analyze historical weather and calculate seasonal severity and percentile reports. Information from Fire Family was used in FARSITE and FlamMap to model pre- and post-treatment effects on fire growth, spotting, fire line intensity, surface flame length, and the occurrence of crown fire. This procedure provides managers with a quantitative measure of treatment effectiveness as well as spatial output that can be used for analyzing fuel treatment effectiveness, burn plan development, NEPA documentation, public education, and etcetera.

Introduction

Fuel modifications are receiving renewed interest as protection strategies, particularly in wildland-urban areas (Agee and others 2000). This is a result of costly fire seasons like 2000 and 2002, new national directives with increased funding (USDA Forest Service and USDI 2000), recognition of a change in fuel composition, structure, and loading, and fire manager's desire, yet limited ability, to control large fires. The primary purpose of a fuel treatment is to change the behavior of a fire entering a fuel-altered zone, thus lessening the impact of that fire to an area of concern. This is best achieved by fragmenting the fuel complex and repeatedly disrupting or locally blocking fire growth, thus increasing the likelihood that suppression will be effective or weather conditions will change (Finney 2000).

Recent research suggests that landscape-scale fuel modifications, such as prescribed fire, are the most effective way to modify the behavior and growth of large fires (Finney 2001). However, the effectiveness of fuel treatments remain a subject of debate due in part to the weather conditions they will or will not perform under, treatment method, completeness of the application, treatment design (i.e., placement, pattern, size), and the difficultly in evaluating the effectiveness of the proposed treatment. Simulation modeling allows the user to partially address these issues under various weather and fuel scenarios and provides a "tested" outcome for field application. This paper presents a methodology for assessing the effectiveness of landscape fuel treatments on fire growth and behavior by utilizing previous fire locations, historical weather, and fire growth and behavior models.

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Analysis Area

Ash Creek is located approximately 20 miles south of Cedar City, Utah and is adjacent to the communities of New Harmony and Harmony Heights. The project area (approximately 2,000 ac; 5,300 ft) is on Bureau of Land Management (BLM) administered land and bounded tightly by private ownership to the north, Interstate 15 (I-15) to the east, the Dixie National Forest and Pine Valley Mountain Wilderness Area to the west, and BLM, State, and private in holdings to the south. The area has seen an increase in urban development due to its rural setting and views of the Kolob Fingers (Zion National Park), inviting climate, and close proximity to various recreational sites and metropolitan areas.

Located on a relatively flat, east, southeast bench, understory vegetation is primarily crested wheatgrass (*Agropyron cristatum*), bluebunch wheatgrass (*Elymus spicatus*), junegrass (*Koeleria macrantha*) (1 to 2 ft), sage brush (*Artemisia tridentata*) (1 to 3 ft), oak (*Quercus turbinella*; *Quercus gambelii*) in some draws (4 to 15 ft), and smaller amounts of Utah serviceberry (*Amelanchier alnifolia*), bitterbrush (*Purshia tridentata*), and true mountain mahogany (*Cercocarpus montanus*) (2 to 15 ft). Utah juniper (*Juniperus osteosperma*) and scattered pinyon pine (*Pinus edulis*), in varying density, is the dominate overstory species (10 to 35 ft).

Summer cold fronts contribute to strong winds that are channeled through the I-15-Black Ridge corridor and into the project area. The effect of these winds on fire shape is evidenced in the Ash Creek Fire of 1996 (approximately 500 ac). The area has a history of fires attributed to recreational use, I-15 through traffic, and lightning on Black Ridge (6,400 ft) to the east and Pine Valley Mountains to the west (10,000 ft).

The objectives of the project are to reduce fire intensity, occurrence of crown fire, and mid- to long-range spotting and to increase native plant diversity and enhance wildlife forage. This was accomplished through herbicide application and fuel reduction. Treatment boundaries were delineated by ownership, previously chained areas (1960's), and wildlife requirements and is reflected in an asymmetrical, amoeboid design. Sage-dominated areas were applied with several applications of an herbicide (Tebuthiuron or "Spike"). Encroaching juniper was manually cut (lop-and-scatter) and is being followed up with pile and broadcast burning.

Methods

Specific information about the project area, such as objectives of the proposed treatment (e.g., wildfire control, wildlife enhancement), type of treatment (e.g., prescribed fire, manual thinning), pre- and post-treatment condition of the entire fuel complex, and supporting Geographic Information System (GIS) data were obtained from the BLM. A thirty-three year fire ignition layer for the BLM and Forest Service was used to derive a fire density GRID, using ArcView/Spatial Analyst (ESRI 2000) [When local fire data is unavailable, this information can be retrieved for Forest Service units from the National Interagency Fire Management Integrated Database (NIFMID) (USDA Forest Service 1993), using the Kansas City Fire Access Software (KCFAST) (USDA Forest Service 1996), fire occurrence information retrieval site; fire information for the Department of Interior is available on a yearly basis via a CD-ROM (USDI Park Service 2001)]. The locations of the nearest Remote Automated Weather Stations (RAWS) were identified and reporting history and site characteristics were analyzed to determine the most adequate station for the project area. Due to the channeling effect of the winds through the project area, one station was used to obtain wind speed and direction (White Reef; 16 yr history), and another was used to for the weather (Enterprise; 29 yr). Historical weather information was downloaded from NIFMID/KCFAST, fire occurrence information retrieval site and imported into Fire Family Plus (Bradshaw and McCormick 2000).

Fire Family Plus

Fire Family Plus is a fire climatology and occurrence program that combines and replaces the PCFIRDAT (Cohen and others 1994; Main and others 1990), PCSEASON (Cohen and others 1994; Main and others 1990), FIRES (Andrews and Bradshaw 1997), and CLIMATOLOGY (Bradshaw and Fischer 1984) programs into a single package with a graphical user interface. It allows the user to summarize and analyzing weather observations and compute fire danger indexes based on the National Fire Danger Rating System (NFDRS) (Bradshaw and others 1983; Burgan 1988).

Fuel moistures (i.e., 1-, 10-, 100-hr, live herbaceous, live woody) were obtained from a Fire Family Percentile *Weather Report*. Calculated fuel moistures were compared with local field sampling to validate and adjust the values. Wind speed, temperature, and relative humidity were obtained from a S*easonal Severity Report*; wind direction was obtained from a *Wind Speed vs. Direction Report*. Wind speeds were modified to account for persistent gusts (NOAA 2003) and directions were developed based on actual hourly RAWS data that adequately represented the appropriate percentile weather.

All weather and fuel moisture information was recorded at the 75^{th} (moderate), 85^{th} (high), and 95^{th} (very high) percentile (*table 1*). In other words, weather occurring during the reporting period (June 1-September 30) 25 percent of the time is represented by the 75^{th} percentile, 15 percent of the time for the 85^{th} percentile, and so forth. All climatological and fuel variables were then used to develop the required weather and wind files/inputs for FARSITE and FlamMap.

Table 1—*Weather and fuel moisture information for the 75th, 85th, and 95th percentile as reported by Fire Family Plus and modified as noted.*

	Hour pct			**Live pct**		**Temp.°F**		**RH pct**		**Wind**	
	1	10	100	Herb.	Wood.[1]	Min.	Max.	Min.	Max	mph[2]	Direction[3]
75	4	6	9	90	110	56	87	16	47	17	190-235
85	4	5	7	80	100	59	89	14	40	19	190-235
95	3	5	6	60	90	64	92	10	28	23	190-235

[1]Adjusted from the Seasonal Severity Report based on local field sampling.
[2]Adjusted from the Seasonal Severity Report to account for wind gusts (NOAA 2003).
[3]During the burn period (1100 to 1900 hr).

FARSITE (Fire Area Simulator)

FARSITE (Fire Area Simulator) is a two-dimensional deterministic model for spatially and temporally simulating the spread and behavior of fires under conditions of heterogeneous terrain (i.e., elevation, slope, and aspect), fuels, and weather (Finney 1998). To do this, FARSITE incorporates existing fire behavior models of surface fire spread (Roth 1972; Albini 1976), crown fire spread (Van Wagner 1977, 1993), spotting (Albini 1979), point-source fire acceleration (Forestry Canada Fire Danger Group 1992), and fuel moisture (Nelson 2000) with GIS data. Simulation output is in tabular, vector, and raster formats.

FlamMap

FlamMap (Finney, in preparation) is a spatial fire behavior mapping and analysis program, which requires a FARSITE landscape file (*.LCP), as well as terrain, fuel, and weather data. However, unlike FARSITE, FlamMap assumes that *every* pixel on the raster landscape burns and makes fire behavior calculations (e.g., fire line intensity, flame length) for each location (i.e., cell), *independent* of one another. That is, there is no predictor of fire movement across the landscape and weather and wind information can be held constant. By so doing, FlamMap output lends itself well to landscape comparisons (e.g., pre- and post-treatment effectiveness) and for identifying hazardous fuel and topographic combinations, thus aiding in prioritization and assessments.

Vegetation and Fuel Models

Spatial vegetation data for the project area was extracted from a larger 15 million acre study area (Long and others, in preparation). A supervised classification of LANDSAT Thematic Mapper data—path 33 and rows 37 and 38—was used with ERDAS IMAGINE software (ERDAS 1999), incorporating polygons created by the IPW image processing program (Frew 1990). A maximum likelihood algorithm in ERDAS was used to classify the imagery based on a statistical representation of spectral signatures for each vegetation class created from field sampling. Ancillary layers, including land use and land cover, were used in combination with the classified imagery to assign polygons to one of 65 final vegetation classes.

The vegetation classes were cross-walked to 44 fuel models (including barren and water), 35 of which were "customized" models (i.e., the standardized model parameters (Anderson 1982) were altered to reflect a condition not adequately represented by the fire behavior models) and two, were custom models (i.e., 14: sparse grass-forb; 35: sparse shrub). Canopy cover, stand height, crown-base height, and crown bulk density were developed based on field data, anecdotal observations, and previously published work. Moderate and severe custom fuel files (*.FMD) were built to reflect the differences in fire behavior between moderate and high/severe conditions.

Terrain, fuel model, and canopy information was used to construct two modeling landscapes: pre-treatment and post-treatment. Sage-dominated areas were assigned either a fire behavior model (2, 6) or a customized model (e.g., 2-, 5+, 6-, etc; where the "-" or "+" represents a 20 percent change in the loading and depth). To simulate the effect of the Tebuthiuron, treated areas were reassigned a fuel model representing a 10-30 percent reduction in the shrub component. In some areas an adjustment factor (*.ADJ) was used to change the rate-of-spread without affecting other fire behavior outputs.

Pre-treatment stands of pinyon-juniper were assigned a standardized fuel model (4, 6) or a customized model (4-, 6-, 6--), *each with varying canopy characteristics*. Lop-and-scattered pinyon-juniper that was later pile and/or broadcast burned was reassigned a fire behavior fuel model (2, 5, 6, 11, 12), a customized model (4-, 5+, 6-, 6--), or a custom model (i.e., 14, 35); in general stand height, canopy cover, crown bulk density, and crown base height was eliminated, or reduced substantially.

Calibration

To produce fire growth and behavior output consistent with observations, model checking, modifications, and comparisons are done (i.e., calibration) with known fire perimeters and weather conditions (Finney 2000). Two fires were used to calibrate the model output, the Sanford Fire (April-June 2002; 78,000 ac) and the Langston Fire Use (August 2001; 600 ac). The Sanford Fire (Panguitch, UT) was useful in modeling low to extreme climatic conditions, with substantial elevation, topographic, and vegetative variation. Most fuel models were represented in the fire area, and canopy characteristics and their influence on crown fire transitions, spotting, and spread was analyzed. The Langston Fire Use (Zion National Park, UT) allowed testing of flanking and backing surface rates-of-spread in moderate weather conditions, on relatively flat terrain, and in fuel models 5, 8, 9, and 10.

Modeling Fire Growth and Spotting; FARSITE

To model fire growth and spotting potential, a single-source ignition in FARSITE was started in a historically high ignition area, as identified by the fire density grid. I-15 was imported as a barrier to surface spread, but was not impermeable to spotting. All fire simulations were modeled *without* suppression. One-day simulations, with a burn period of 1100 to 1900 hr, were run representing the 75th, 85th, and 95th, percentile weather and fuel conditions. The simulation process was repeated multiple times—with the same ignition point, as well as in other high ignition areas—to sample the variation in predicted fire size, shape, common spread pathways, spotting frequency, distance, and etc. Based on multiple runs, two of the "most representative" simulations were selected for each percentile level (six in all).

Calculating Fire line Intensity, Flame Length, and Crown Fire Activity: FlamMap

To calculate pre- and post-treatment fire line intensity, surface flame length, and crown fire activity, FARSITE terrain, fuel, and weather information was imported into FlamMap. Weather and fuel moisture conditions representing the 75th, 85th, and 95th percentile were used to generate the fire behavior data (18 output grids).

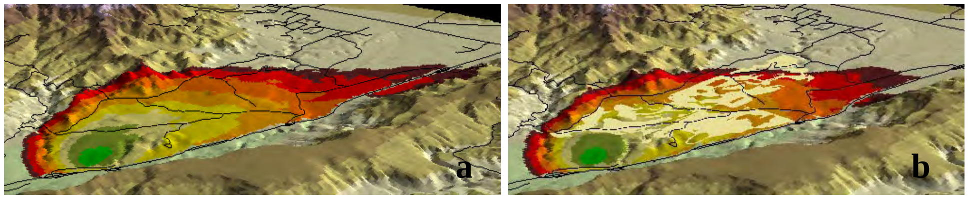
Results

Figure 2 are pre- and post-treatment FARSITE simulations for the 85th percentile draped over a 3-D landscape. Each color represents a 1 hr time-step or progression of the fire. *Table 2* summarizes fire size and spotting for each of the three percentiles, pre- and post-treatment.

Figure 3 displays FlamMap *area maps* of the 85th percentile pre- and post-treatment for flame length, fire line intensity, and crown fire activity. Tabular data for these fire behavior outputs are displayed in *table 2.*

Fire Size and Perimeter Growth

A modest reduction in fire size is apparent for each of the percentile weather and fuel conditions. The 85th showed the greatest percent change from the untreated condition (approximately 18 percent), which is likely do to the removal of most of the pinyon-juniper (i.e., fuel model "4s"/"6s"), thus reducing the spotting distance and the number of embers lofted. The 75th percentile simulation shows little change due to the similar surface rates-of-spread in dense, yet sparse pinyon-juniper stands and in recently burned/residual slash areas. As the weather conditions got more severe (95th percentile) and the fire size increased, the effectiveness of the treatments on fire growth diminished.



Figure—2 Eight-hr FARSITE simulation for the 85th percentile weather and fuel condition, pre-treatment (a) and post-treatment (b). Each color represents a 1 hr progression of the fire overlaid with roads (black) and the treated landscape (light yellow). Black Ridge is in the foreground and the Pine Valley Mountains in the background (NW). Fuel modifications reduced the size of the fire by approximately 1,500 ac (18 percent).

Table 2—*FARSITE and FlamMap fire growth and behavior output for 75th, 85th, and 95th percentile weather and fuel moisture conditions.*

[1] Percentile		Size ac	Perimeter mi	Spot fires	Flame lgth ft	Intensity[2] BTU $ft^{-1} \cdot sec^{-1}$	Crown[3] ac
75th	Pre	5,880	18	326	2.6	72	12,883
	Post	5,297	18	228	2.43	68	9,242
	Pct change	-9.91	0.00	-30.06	-6.54	-5.56	-28.26
85th	Pre	8,588	28	434	13.96	1,885	27,600
	Post	7,056	22	301	10.77	1,262	22,093
	Pct change	-17.84	-21.43	-30.65	-22.85	-33.05	-19.95
95th	Pre	24,881	59	1,139	16.12	2,588	27,600
	Post	23,202	60	1,054	13.4	1,992	22,093
	Pct change	-6.75	1.32	-7.46	-16.87	-23.03	-19.95

[1]Number of spot fires initiated in the treatment area during a 6 hour period
[2]Mean flame length and intensity
[3]Passive and active crown fire

Although reductions in fire size are evident in all three percentiles, a decline in perimeter growth was only predicted in the 85th percentile. In the case of the 75th percentile, while the treatment reduced surface fuel, the effective wind speed was increased due to the removal of the pinyon-juniper, thus increasing the perimeter and rate-of-spread of the fire—this is also likely the case for the 95th percentile. In the 85th pre-treatment simulation, crown fire runs and spotting in fuel model "4s" and "6s" outpaced the increased effective wind speed.

Spot Fires

A reduction in new ignitions ahead of the main fire front is evident under all three weather conditions. This is due largely to the removal of the pinyon-juniper. It is worthy to remember that spotting in FARSITE is stochastic and the numbers of embers lofted and burning when they reach the ground are dependent on the spotting model (Albini 1979) and largely influenced by the ignition frequency and canopy characteristics. Thus, this information is imprecise and more emphasis should be given to the percent change, rather than the actual number of fires.

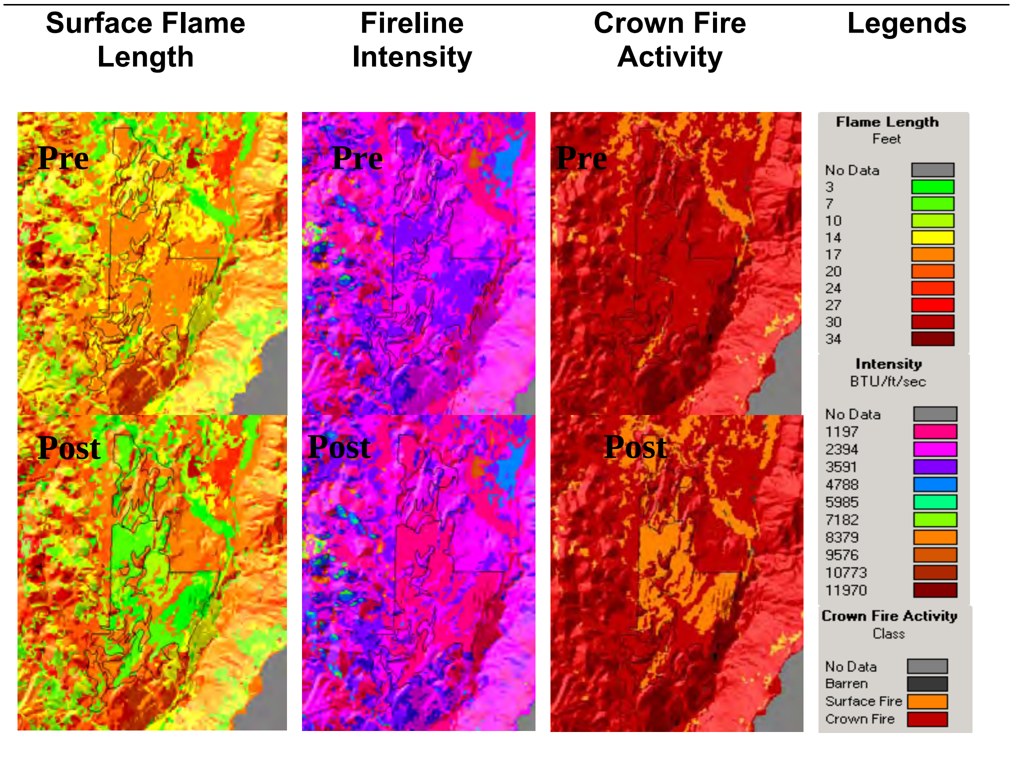


Figure 3—FlamMap output for the 85th percentile condition, pre-treatment (top) and post-treatment (bottom). The project area boundary is overlaid in black and runs north to south—about 4.5 miles.

Crown Fire

Although FlamMap differentiates between passive and active crown fire, *table 2* summarizes both types of crown fire as one. This was done due to the under prediction of active crown fire in FlamMap and FARSITE as compared to observed conditions (Cruz and others 2003; Fulé and others 2001; Scott and Reinhardt 2001). For example, in the 85th percentile condition, all crown fire was termed "passive;" in the 95th, only a slight amount (190 ac) had transitioned to an active crown fire, thus the identical values between pre- and post-treatment landscapes.

Discussion

Modeling Assumptions and Limitations

There are several assumptions and limitations to the methodology presented in this paper. FARSITE and FlamMap, as well as the models utilized by these modeling systems (e.g., surface fire spread, crown fire spread), operate under a broad range of assumptions and have specific limitations. Spatial data has resolution and accuracy limits inherit to mapping of heterogeneous surface and canopy fuels and terrain. Vegetation cross-walked to fuel model and fuel model assignments of treated landscapes are occasionally problematic and model output is largely a reflection of these "conversions." Moreover, RAWS information can be incorrect, unavailable, or influenced by local factors not known to the end-user. It is important that users understand model constraints, and more importantly utilize models and output within accepted bounds.

FARSITE or FlamMap?

FARSITE was used to simulate fire spread and spotting potential, although several other outputs are available, including fire line intensity, flame length, and crown fire activity. Instead, FlamMap was used to calculate these fire behavior outputs, for a number of reasons, including: 1) FlamMap calculations are near instantaneous where as FARSITE simulations can oftentimes take several hours; 2) FlamMap's primary design is to distinguish hazardous fuel and topographic conditions, making pre- and post-treatment comparisons and contrasts across landscapes much easier and more suitable than in FARSITE; 3) Although historical fire occurrence was used in this analysis, there is no guarantee future fires will occur in these areas. While a pattern is often evident, demographics, human activities, and climatic conditions can change. Therefore, selecting a specific fire start is often subjective—particularly with little or no ignition data—yet tremendously significant to the outcome of the simulation(s), thus not requiring this input (FlamMap) is advantageous; 4) Other parameters such as determining the distance to the treated area, developing the wind file, specifying the simulation duration, and setting fire behavior parameters, are largely at the discretion of the modeler and difficult to fully substantiate, whereas fewer parameters are required in FlamMap; 5) Many fires that often impact an area of concern, such as a community like Harmony Heights, start considerable distances away from the area they threat, so assessing an area with a single, localized run is limiting.

Modeling Discussion

A great deal of information can be obtained by modeling the effect of fuel treatments on fire growth and behavior and analyzing model outputs. Ideally, modeling will be done *before* the actual treatment is implemented so model findings can be incorporated to modify the treatment pattern, size, methods, etc. However, post analysis of fuel breaks, as in this case, can substantiate management decisions, yield useful findings for future projects, and identify weaknesses in treatment design and application.

At first glance, fuel modifications seem to have had little effect on the fire (*fig. 2*). In respect to fire growth, this is the case under certain weather conditions. Indeed, some modifications may have even *increased* the rate of spread, by exposing previously sheltered fuels. However, changes in other fire behavior characteristics are considerable, thus accomplishing the objectives of the treatment (*table 2*).

An area where modeling suggests additional landscape treatment may be beneficial is along the southeast corner of I-15. The large, southeastern most treatment polygon stands alone if a fire approaches from the south. This is due to private ownership directly to the north. Previous modeling indicates the most effective treatment design tends to be those that have fuel modifications in succession and distributed across the landscape (Finney 2001). Moreover, the *sooner* a fire encounters a fragmented fuel complex the greater will be the effectiveness of that treatment on disrupting or locally blocking fire growth. Therefore, a second phase of this project might consider additional polygons to the south, like those in succession to the west. By so doing, a fire spreading to the north would encounter several fuel breaks before reaching the public land to the north, thus reducing the forward fire spread rate and assisting firefighting efforts.

Finally, modeling allows for hypotheses testing. For example, "what is the 'breaking point' of the Ash Creek treatment when the weather and fuel conditions are such that treatment effectiveness is minimized in respect to fire growth?" Through multiple simulations with varying weather scenarios, this question can be theorized at the 88^{th} to 92^{nd} percentile.

Conclusion

Managers have a growing need to assess the effectiveness of landscape fuel treatments, however this need has outpaced the development of spatial models to accomplish the task. FARSITE, although not originally intended to do so, has been used to assess treatment effectiveness on fire growth and behavior (Stephens 1998; van Wagtendonk 1996). The methodology presented in this paper uses FARSITE, but also incorporates FlamMap, Fire Family Plus, and previous ignition history to assess fuel treatment effectiveness. Although the approach has limitations, model outputs yield useful information for planning, assessing, and prioritizing fuel treatments. In the future, planned enhancements to Flammap will enable users to evaluate landscape alterations on fire spread utilizing minimum travel time methods (Finney 2002) and eventually aid in optimizing treatment design to mitigate fire behavior and spread.

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