Assessing the Effectiveness of Landscape Fuel Treatments on Fire Growth and Behavior

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ABSTRACT

This article presents a methodology for assessing the effectiveness of landscape fuel treatments on fire growth and behavior in southern Utah. 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. FireFamily Plus was used to summarize and analyze historical weather and calculate seasonal severity and percentile reports. Information from FireFamily was used in FARSITE and FlamMap to model pre- and post-treatment effects on fire growth, spotting, fireline 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, National Environmental Policy Act (NEPA) documentation, public education, etc.

Keywords: fuel treatments; fire modeling; fuel models; fire behavior; FARSITE; FlamMap; FireFamily Plus; historical weather; fire ignition history

Fuel modifications are receiving renewed interest as protection strategies, particularly in wildland-urban areas (Agee et al. 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), a recognition of a change in fuel composition, structure, and loading, and fire manager's desire, yet limited ability, to control large fires. A common misconception among managers and the public is that fuel treatments stop 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 change in fire behavior is often quantified as a reduction in flame length, intensity, or rate-of-spread, and manifested as a change in severity or growth of the fire. 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, com-

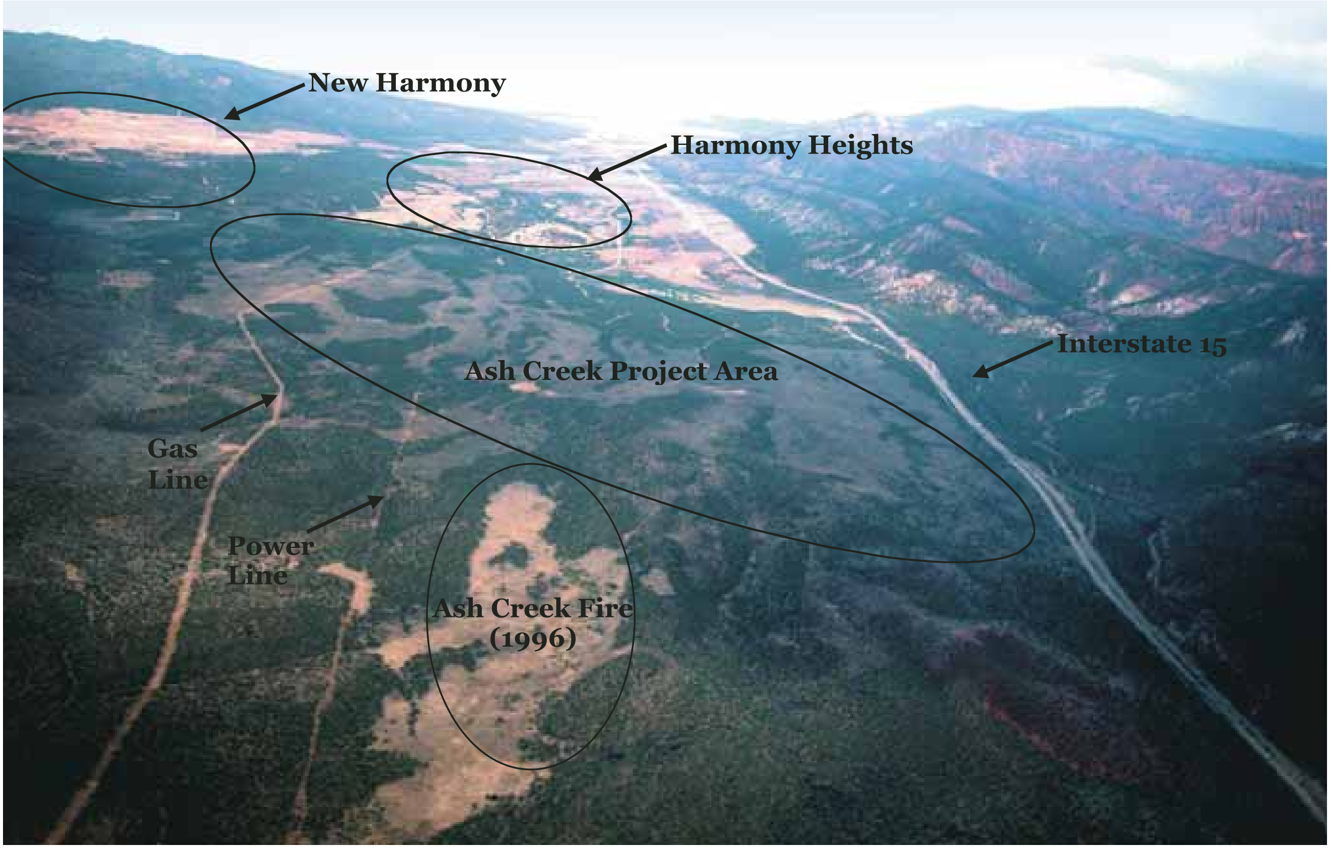

Figure 1. **Aerial view of the Ash Creek project area looking northeast (posttreatment). Photo by Paul Briggs.**

pleteness of the application, treatment design (i.e., placement, pattern, size), and the difficulty 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 article 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.

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 (Figure 1). The project area (~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 inholdings 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)* (1-2 ft), sage brush *(Artemisia tridentata)* (1-3 ft), oak *(Quercus turbinella; Quercus gambelii)* in some draws (4-15 ft), and smaller amounts of Utah serviceberry *(Amelanchier alnifolia)*, bitterbrush *(Purshia tridentata)*, and true mountain mahogany *(Cercocarpus montanus)* (2-15 ft). Utah juniper *(Juniperus osteosperma)* and scattered pinyon pine *(Pinus edulis)*, in varying density, is the dominate overstory species (10-35 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 are evidenced in the Ash Creek Fire of 1996 (~500 ac) (Figure 1). 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 the 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-/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 (1960s), and wildlife needs and is reflected in an asymmetrical, amoeboid design. Sage-dominated areas were applied with several applications of a herbicide (Tebuthiuron or "Spike"). Encroaching juniper was manually cut (lop-and-scatter) and is being followed up with pile and broadcast burning.

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

	75th	85th	95th
1-hour (%)	4	4	3
10-hour (%)	6	5	5
100-hour (%)	9	7	6
Live herbacious (%)[a]	90	80	60
Live woody (%)[a]	110	100	90
Temp. min. (°F)	56	59	64
Temp. max. (°F)	87	89	92
RH min. (°F)	16	14	10
RH max. (°F)	47	40	28
20-ft Windspeed (mph)[b]	17	19	23
Wind direction (°)[c]	190–235	190–235	190–235

[a] *Adjusted from the Seasonal Severity Summary based on local field sampling.*
[b] *Adjusted from the Seasonal Severity Summary to account for wind gusts (Crosby and Chandler 1966).*
[c] *During the burn period (1100–1900 hours).*

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 posttreatment condition of the entire fuel complex, and supporting geographic information system (GIS) data were obtained from the BLM. A 32-year fire ignition layer for the BLM and USDA Forest Service was used to derive a fire density grid, using ArcView/Spatial Analyst (version 3.2; ESRI, Redlands, CA).

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 windspeed and direction (White Reef; 16-year history) and another was used for the weather (Enterprise; 29 years). Historical weather information was downloaded 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, and imported into FireFamily Plus (Bradshaw and McCormick 2000).

FireFamily Plus. FireFamily Plus is a fire climatology and occurrence program that combines and replaces the PCFIRDAT (Main et al. 1990, Cohen et al. 1994), PCSEASON (Main et al. 1990, Cohen et al. 1994), 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 analyze weather observations and compute fire danger indices based on the National Fire Danger Rating System (NFDRS) (Bradshaw et al. 1983, Burgan 1988).

Fuel moistures (i.e., 1-, 10-, 100-hour, live herbaceous, live woody) were obtained from a FireFamily Percentile Weather Report. Calculated fuel moistures were compared with local field sampling to validate and adjust the values. Windspeed, temperature, and relative humidity were obtained from a Seasonal Severity Report; wind direction was obtained from a Windspeed vs. Direction Report. Windspeeds were modified to account for probable maximum 1-minute gusts (Crosby and Chandler 1966), and directions were developed based on actual hourly RAWS data that adequately represented the appropriate percentile weather.

All weather and fuel moisture parameters were identified separately at the 75th (moderate), 85th (high), and 95th (very high) percentiles (Table 1). In other words, values higher than the 75th percentile occur 25% of the time during the reporting period (June 1–Sept. 30), 15% of the time for the 85th 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.

FARSITE. 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, aspect), fuels, and weather (Finney 1998). To do this, FARSITE incorporates existing fire behavior models of surface fire spread (Rothermel 1972, Albini 1976), crown fire spread (Van Wagner 1977, Rothermel 1991, Van Wagner 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 that requires a FARSITE landscape file (*.LCP), as well as fuel moisture and weather data. However, unlike FARSITE, FlamMap assumes that every pixel on the raster landscape burns and makes fire behavior calculations (e.g., fireline intensity, flame length) for each location (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 posttreatment 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 et al., in preparation). A supervised classification of LANDSAT Thematic Mapper data—path 33 and rows 37 and 38—was used with ERDAS IMAGINE software (version 8.5; ERDAS, Atlanta, GA), 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 sam-

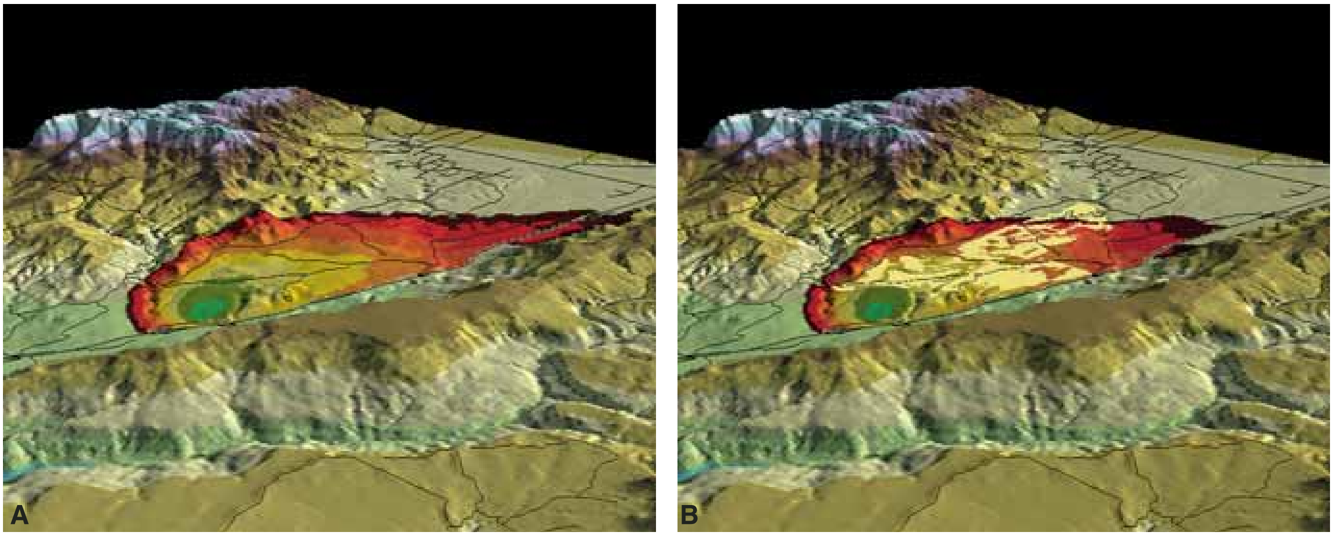

Figure 2. **Eight-hour FARSITE simulation for the 85th percentile weather and fuel condition, pretreatment (A) and posttreatment (B). Each color represents a 1-hour progression of the fire overlaid with roads (black) and the treated landscape (light yellow) (B only). Black Ridge is in the foreground and the Pine Valley Mountains in the background (NW). Fuel modifications reduced the size of the fire by approximately 1,500 ac (18%).**

pling. 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 crosswalked 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 grassforb; 35: sparse shrub). Canopy cover, stand height, crown-base height, and crown bulk density were developed based on field data, anecdotal observations, and 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: pretreatment and posttreatment. 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% change in the loading and depth). To simulate the effect of the Tebuthiuron, treated areas were reassigned a fuel model representing a 10–30% 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.

Pretreatment 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 (Apr. –June 2002; 78,000 ac) and the Langston Fire Use (Aug. 2001; 600 ac). The Sanford Fire (Panguitch, UT) was useful in modeling low to extreme climatic conditions, with substantial elevational, 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 were 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 1100–1900 hours, 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 and distance, etc. Based on these multiple runs, the "most representative" simulation was selected pre- and posttreatment for each percentile level (six in all).

Calculating fireline intensity, flame length, and crown fire activity: FlamMap. To calculate pre- and posttreatment fireline 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

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

	Pre	Post	Change from pre (%)
75th percentile			
Size (ac)	5,880	5,297	–9.91
Perimeter (mi)	18	18	0.00
Spot fires[a]	326	228	–30.06
Surface flame length (ft)[b]	2.97	2.53	–14.81
Fireline intensity (BTU/(ft-s))[b]	84	73	–13.10
Crown fire (ac)[c]	5,756	2,311	–59.85
85th percentile			
Size (ac)	8,588	7,056	–17.84
Perimeter (mi)	28	22	–21.43
Spot fires[a]	434	301	–30.65
Surface flame length (ft)[b]	14.93	8.41	–43.67
Fireline intensity (BTU/(ft-s))[b]	2,064	851	–58.77
Crown fire (ac)[c]	10,924	5,761	–47.26
95th percentile			
Size (ac)	24,881	23,202	–6.75
Perimeter (mi)	59	60	1.32
Spot fires[a]	1,139	1,054	–7.46
Surface flame length (ft)[b]	17.27	10.44	–39.55
Fireline intensity (BTU/(ft-s))[b]	2,843	1,343	–52.76
Crown fire (ac)[c]	10,924	5,761	–47.26

[a] Number of spot fires initiated in the treatment area during a 6-hour period.
[b] Mean flame length and intensity.
[c] Passive and active crown fire.

percentile were used to generate the fire behavior data (18 output grids).

Results

Figure 2 shows pre- and posttreatment FARSITE simulations for the 85th percentile draped over a three-dimensional landscape. Each color represents a 1-hour time-step or progression of the fire. Table 2 summarizes fire size and spotting for each of the three percentiles, pre- and posttreatment.

Figure 3 displays FlamMap area maps of the 85th percentile pre- and posttreatment for flame length, fireline intensity, and crown fire activity. Tabular data for these fire behavior outputs are displayed in Table 2 as well as histograms for flame length and intensity, summarized by the treated area (Figure 4).

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

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 expansion of the fire equal to that of the pretreated landscape. In the 85th percentile pretreatment simulation, crown fire runs and spotting in shrub fuels resulted in greater growth of the fire than the posttreatment landscape surface fire spread. For the 95th percentile simulation, the slight increase in perimeter growth is likely due to the convoluting effect of the progressions through the treated landscape.

Spot fires. A reduction in new ignitions ahead of the main fire front is evident under all three weather conditions. This is largely due 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.

Intensity and flame length. Changes in both intensity and flame length for all three percentile classes were realized in the project area and are recorded in Table 2 and plotted in Figure 4. The histograms more adequately display the changes in fire behavior between percentiles and treatment conditions than the single mean value for flame length and fireline intensity (Table 2).

Crown fire. Although FlamMap differentiates between passive and active crown fire, Table 2 summarizes both types of crown fire as one. 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. Crown fire values are identical between the 85th and 95th percentiles because all available crown fuels were burned at the 85th percentile. Underprediction of active crown fire in FlamMap and FARSITE as compared to observed conditions is common (Fulé et al. 2001, Scott and Reinhardt 2001, Cruz et al. 2003); additional reasons for combining crown fire values include model limitations in predicting the transition between passive and active crown fire, poor parameterization of canopy fuels, and little need to differentiate between crown fire types for practical purposes.

Discussion

Modeling assumptions and limitations. There are several assumptions and limitations to the methodology presented in this article. FARSITE and

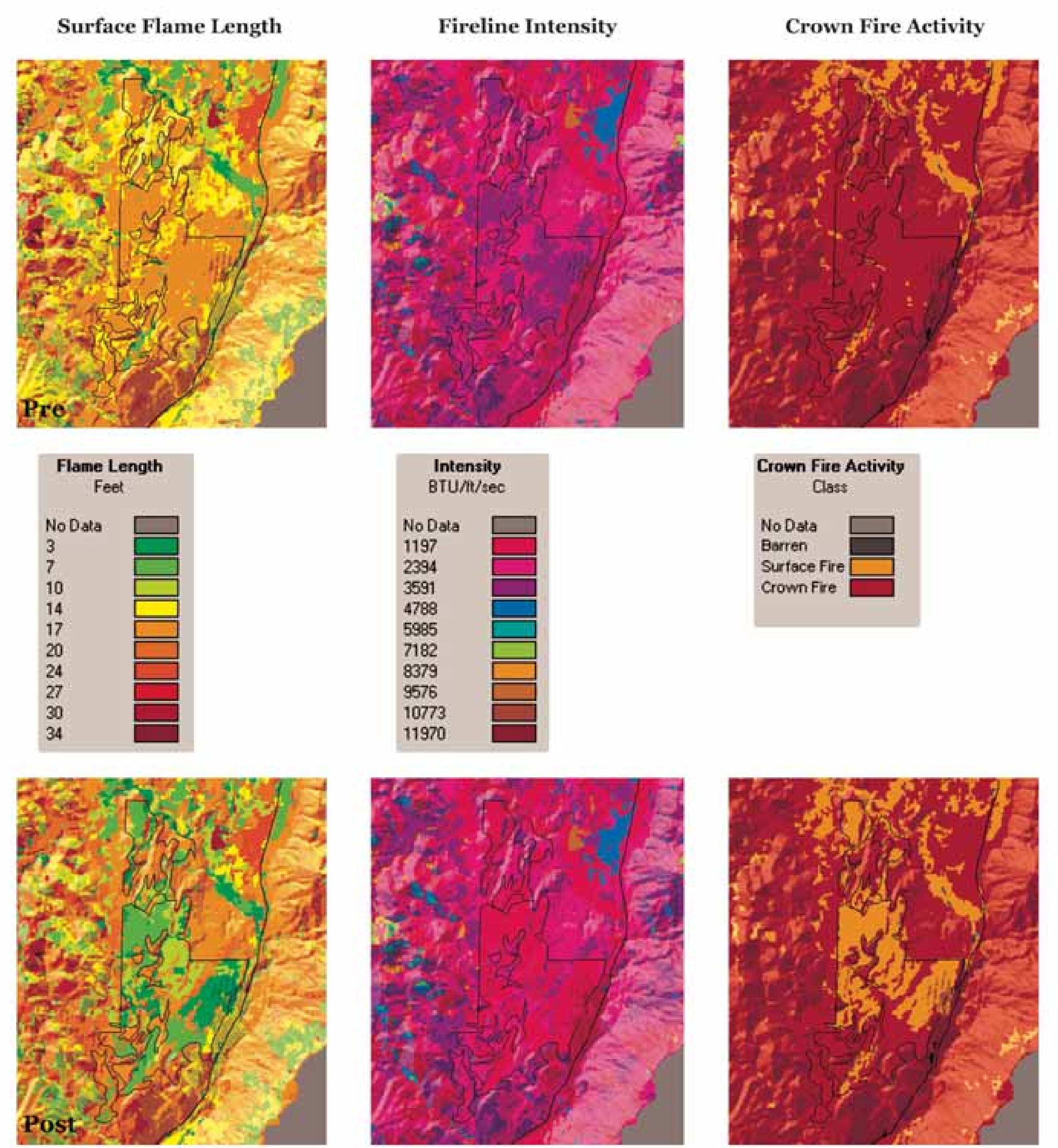

Figure 3. **FlamMap output for the 85th percentile condition, pretreatment (top) and posttreatment (bottom). The project area boundary is overlaid in black and runs north to south—about 4.5 miles. Interstate 15 is the long linear feature to the east.**

FlamMap, as well as the models used 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 use 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 fireline intensity, flame length, and crown fire activity. Instead, FlamMap was used

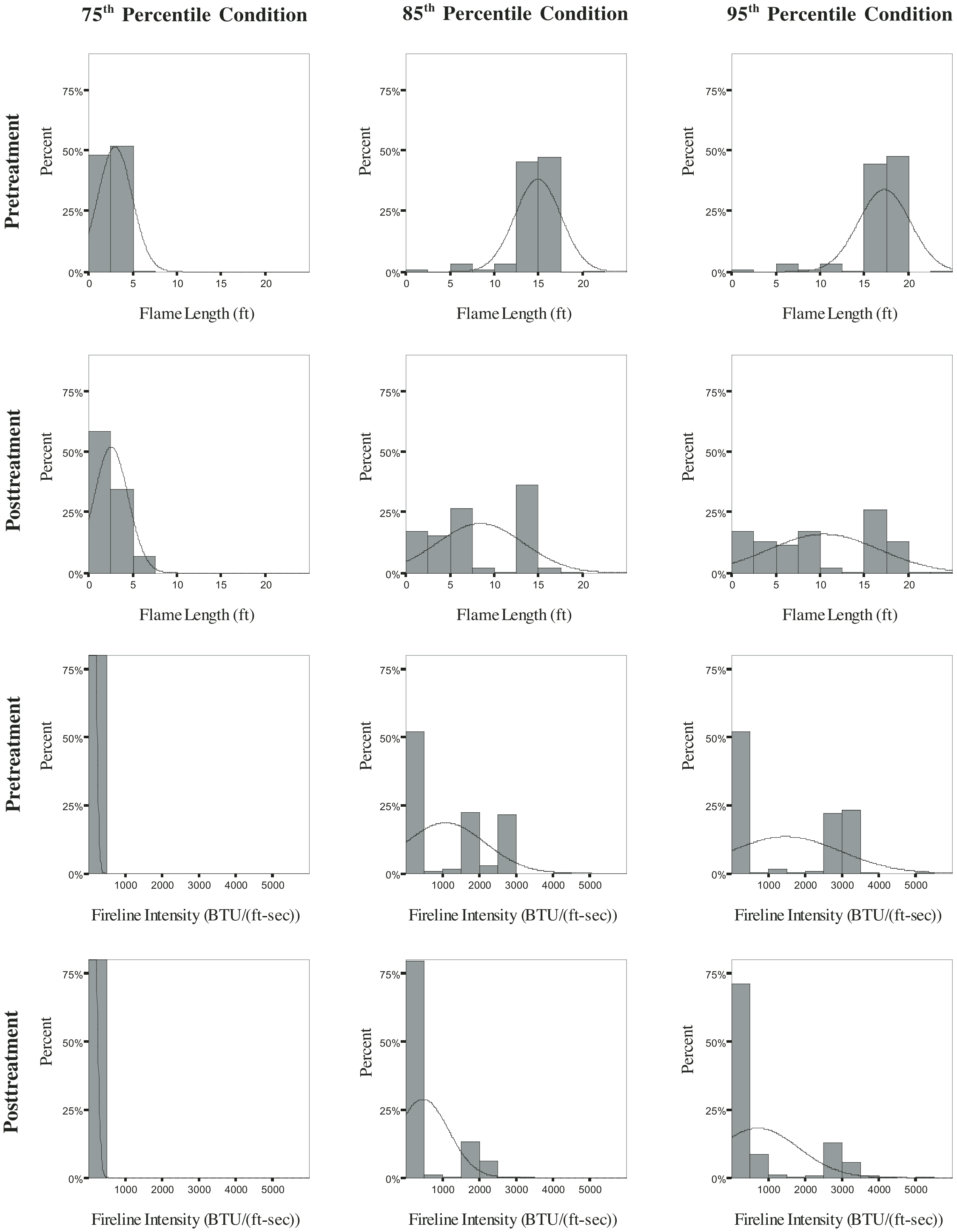

Figure 4. **Histograms of FlamMap output for flame length (ft) and fireline intensity (BTU/(ft-s)), pre- and posttreatment for the 75th, 85th, and 95th percentile weather and fuel condition. The normal curve is displayed.**

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 posttreatment 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 threaten, 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, postanalysis of fuel treatments, 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 (Figure 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 treatments may be beneficial are along the southeast corner of I-15. The large, southeastern most polygon stands alone if a fire approaches from the south. This is in-part due to private ownership directly north. Theoretical modeling indicates the most effective treatment design tends to be those that have fuel modifications in succession and distributed strategically 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 with considerable overlap to the northwest. By so doing, a fire spreading to the north would encounter several fuel treatments before reaching public land, potentially modifying fire growth and behavior and aiding 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 88th to 92nd 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 (Van Wagtendonk 1996, Stephens 1998). The methodology presented in this article uses FARSITE, but also incorporates FlamMap, FireFamily 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, enhancements to FlamMap will enable users to evaluate landscape alterations on fire spread utilizing minimum travel time methods (Finney 2002) and aid in optimizing treatment design to mitigate fire behavior and spread.

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