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Use of a Deterministic Fire Growth Model to Test Fuel Treatments

ABSTRACT

Fuel treatments are necessary in many vegetated areas of the Sierra Nevada to mitigate the effects of decades of fire suppression and land-management activities on fuel accumulations and understory canopies. Treating fuels will reduce the severity of wildfires and, as a result, the threat to human lives, the destruction of property and valuable resources, and the alteration of natural fire regimes. This chapter describes the use of a deterministic fire-modeling approach to obtain information about the relative effectiveness of fuel treatments, including fuel breaks, prescribed burning, biomassing, piling and burning, and cutting and scattering. Wildfire spread was simulated under idealized conditions to see how specific fuel and stand treatments affect fire behavior. It was obvious from the simulations that fuel breaks alone do not halt the spread of wildfire. Prescribed burning appears to be the most effective treatment for reducing a fire's rate of spread, fireline intensity, flame length, and heat per unit of area. A management scheme that includes a combination of fuel treatments in conjunction with other land-management scenarios should be successful in reducing the size and intensity of wildfires.

INTRODUCTION

It is evident that it will be necessary to reduce the amount of accumulated fuel in many vegetated areas of the Sierra Nevada to mitigate the effects of decades of fire suppression and management activities on fuel accumulations and understory canopies. Treating fuels should reduce the severity of wildfires and, as a result, should reduce the threat to human lives, the destruction of property and valuable resources, and the alteration of natural fire regimes and ecosystem processes such as succession and nutrient flows. Several fuel-treatment options have been suggested, including the creation of fuel breaks of various widths, the prescribed burning of understory and surface fuels (the duff, live fuels, and dead woody fuels lying on the forest floor), the use of biomassing (thinning and chipping of trees up to a specific size class), and the removal of understory trees and branches to reduce ladder fuels. The efficacy of these treatments is largely unknown, and some means of evaluating them is necessary. Few field examples exist that can provide definitive data on the comparative value of the various treatments, alone or in combination. Information about the effectiveness of fuel treatments is critical for selecting alternatives and setting priorities.

Fuel treatment must be an integral part of any management scenario for the Sierra Nevada. This fact is beginning to be accepted by Congress, land-managing agencies, commodity interests, fire-fighting organizations, and the public. Less agreement exists on the best methods to use to achieve fuel-management objectives. Fuel breaks are the preferred option in the California spotted owl draft environmental statement (U.S. Forest Service [USFS] 1995) and are also mentioned in proposals submitted by the public. Acceptance of any large-scale fuel-treatment program will depend upon costs and threats to perceived values, including landscapes and personal property.

Although fuel breaks may prove useful, their value alone and in conjunction with fuel treatments within areas bounded by breaks must be evaluated. Most land-management agencies generally prefer zones where fuels are reduced with prescribed fires. Industry groups favor salvage logging and biomassing as alternatives to burning. This chapter describes the use of a deterministic fire-modeling approach to test the

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relative effectiveness of fuel treatments, including fuel breaks, prescribed burning, biomassing, piling and burning, and cutting and scattering. In this approach, wildfire spread under idealized conditions is simulated to see how specific fuel and stand treatments affect fire behavior.

The key question addressed by this chapter is, what is the effect on fire behavior of various fuel-treatment alternatives?

BACKGROUND

Fuel treatments have been universally suggested as a means to limit the size and intensity of wildfires, yet little evidence of their effectiveness exists. Fuel breaks have been used in California since 1914 and have included the Ponderosa Way, which linked the Sierra and Sequoia National Forests, and more recent efforts in southern California. Most have failed because of the costs of maintenance. Some of the southern California programs have had examples of successes with fuel breaks, but data on their effectiveness are usually buried in lengthy fire reports.

Some anecdotal information exists about the effectiveness of prescribed burning. Biswell (1963) indicates that when a wildfire burned into an area of the Coast Range in California that had previously been burned under a program of prescribed fires, it was easily controlled. In the treated area scarcely any needles on the trees were scorched, while a majority of the trees outside of the area of the prescribed burn were killed. Similarly, wildfires have burned into Sierra Nevada park areas that have previously been burned by prescribed fires. In 1987, the Pierce fire crowned uphill into the Redwood Mountain Grove in Kings Canyon National Park, where it dropped to the ground in an area that had been burned five years before (Stephenson et al. 1991). The eventual control of the A-Rock fire in Yosemite in 1990 was attributed, in part, to the prescribed burns that had greatly reduced surface and understory fuels (Clark 1990).

No known experiments have tested the effectiveness of various fuel treatments on subsequent wildfire behavior. Although it would be important to include these sorts of experiments in fuel-treatment efforts, they are very difficult and costly to conduct. An alternative method is to use computer simulation, but until recently the tools for such experiments were not available. Quantitative models can now describe surface fuel arrays and canopy characteristics (Albini 1976; Van Wagner 1977). In addition, models for predicting fire behavior, including fire growth, spotting, and crowning, have been developed (Albini 1983; Rothermel 1983, 1991; Van Wagner 1993). The BEHAVE fire behavior prediction system combines the fuel and fire behavior models to make predictions of fire spread and intensity from a point source (Andrews 1986; Burgan and Rothermel 1984). Predictions from BEHAVE are adjusted in the field to account for the coarse temporal and spatial scale of the data used for the calculations (Rothermel and Reinhart 1983).

Finney (1994) developed a fire area simulator called FARSITE as a deterministic model for simulating the spatial and temporal spread and behavior of fires under conditions of heterogeneous terrain, fuels, and weather. Since it also includes spotting and crowning, the FARSITE simulator is an ideal tool to use to evaluate fuel treatments. The simulator has been verified in the field, using prescribed natural fires in Yosemite and Glacier National Parks (Finney and Ryan 1995).

The limitations of the FARSITE model include those of Rothermel's (1972) original fire-spread equation. His model describes a fire consisting of a flaming front advancing steadily in uniform and continuous surface fuels within 2 m (6 ft) of, and contiguous to, the ground (Rothermel 1983). Fuel models also simplify the array of burnable material on the ground into a set of parameters that are measurable and repeatable. FARSITE uses simplified weather and wind inputs, and assumes that fire spread is elliptical and independent of the shape of the fire front (Finney 1995). The uniform fuel constraint is limited only by the resolution of the fuel-model map.

Since simulation models are simplifications of reality and are based on numerous assumptions, their results are often in question. Models can serve as one source of information for decision making, but their primary usefulness is to gain understanding of complex systems. Deterministic models suffer from having enormous data requirements and practically infinite combinations of input variables. Researchers can overcome this limitation somewhat by simplifying the conditions under which the models operate. Simulations of fire processes are subject to all of these limitations but are often the only way, short of actual tests on the ground, of analyzing proposed scenarios.

METHODS

The FARSITE model was used to test the various fuel treatments in mixed conifer vegetation and fuels. One of the assumptions made in the simulations performed for this chapter is that the fires are unconstrained. This was necessary in order to isolate the effect of fuel treatments from the effects that might result from any number of suppression actions. Obviously, fire suppression during the simulation period would affect the results, making extrapolations to future conditions problematic. The simulation will, however, indicate the fire behavior that could be expected when suppression forces reached the fire.

Uniform terrain and weather were used to simplify the conditions in order to isolate the treatment effects. The simulation surface was a 3,000 m by 6,000 m (9,843 ft by 19,686 ft) area, with the long axis in a north-south direction. The first 3,000 m (9,843 ft) of the surface was at a 20% slope facing south, and the remaining 3,000 m (9,843 ft) was flat. Although some areas of the Sierra Nevada are steeper, 20% was selected as representing the majority of the areas subject to treatment. For instance, in Yosemite National Park, more than two-thirds of the park is on slopes of less than 20% (van Wagtendonk 1991). The mean elevation of the simulation surface was 1,500 m (4,921 ft), and the latitude was 38°. The forest was mixed conifer–pine typical of the Sierra Nevada, with an average tree height of 20 m (66 ft).

Eight different fuel-treatment scenarios were run with both 95th percentile and 75th percentile weather. These weather conditions are exceeded only 5% and 25% of the time, respectively, during the fire season. Fuel treatments were confined to the sloped portion of the simulation surface. The effectiveness of 90 m and 390 m (295 ft and 1,280 ft) fuel breaks was tested. The simulation was set to begin on August 1 and run for a twenty-four-hour period, until noon the next day. A single fire was started at the center of the simulation surface at a point 500 m (1,640 ft) from the bottom of the slope. Crown fires, embers from torching trees, and spot fire growth were all enabled. The trees most likely to be engaged in torching are ponderosa pines, which have a low tolerance for shade.

Fuel-Treatment Scenarios

The simulation model differentiates among fuel treatments by changing the fuel-model values for load and depth (table 43.1); the canopy characteristics for canopy cover, crown base height, and crown density; and the wind reduction factors (table 43.2). Fuels are categorized according to the time it takes for a fuel particle to reach 63% of its equilibrium moisture content (Lancaster 1970). Fuels with a 1-hour time lag consist of dead herbaceous plants and branchwood less than 0.64 cm (0.25 in) in diameter, as well as the uppermost litter layer. Dead branchwood fuels from 0.64 cm to 2.54 cm (0.25 in to 1 in) in diameter have a 10-hour time lag. Fuels with a 100-hour time lag include dead branchwood from 2.54 cm to 7.62 cm (1 in to 3 in) in diameter. Live fuels consist of forbs, grasses, and understory foliage within 1 m (3 ft) of the surface.

TABLE 43.1

Custom fuel-model values used in the simulations.

Fuel Variable	Model 14	Model 15	Model 16	Model 17
1-hour load (tons/acre)	3.0	1.5	4.5	1.0
10-hour load (tons/acre)	2.0	1.0	3.0	0.5
100-hour load (tons/acre)	2.0	1.0	3.0	0.5
Live load (tons/acre)	2.0	0.0	2.0	0.0
1-hour surface:volume ratio	2,000	2,000	2,000	3,000
Live surface:volume ratio	1,500	1,500	1,500	1,500
Depth (feet)	1.0	0.5	1.5	0.5
Moisture of extinction (%)	35	35	35	12
Dead heat content (BTU/lb)	9,000	9,000	9,000	9,000
Live heat content (BTU/lb)	8,000	8,000	8,000	8,000
Adjustment factor	0.5	0.5	0.5	0.5

The fuels and canopies of the eight treatments and fuel breaks were defined by custom fuel models (Burgan and Rothermel 1984) and canopy characteristics. The control custom model (model 14) is identical to Albini's (1976) fuel model 10 (timber with litter and understory), although the 100-hour fuel load has been reduced to 2 tons per acre and the depth of the fuel bed has been increased to 1 foot to more accurately depict Sierra Nevada conditions. In the prescribed-burn model (model 15), the load in each fuel class and the fuel-bed depth are reduced by 50% compared to those of the control model. The cut-and-scatter model (model 16) increases loads and depth by 50% compared to the control model. The fuel-break model (model 17) keeps a fuel load of only 1 ton per acre of 1-hour fuels and half a ton each in the two larger classes.

Crown densities for each treatment were based on values derived by Brown (1978). Since crown base height is the only measurement of understory fuels, treatments were assumed to remove all of these fuels up to the specified height. Changes in surface fuels as a result of each treatment were represented in the custom fuel models by increases or decreases in fuel load and depth (table 43.1). Adjustment factors were used to tune the simulation to actual fire-spread patterns (van Wagtendonk and Botti 1984).

Control

The control scenario assumes that the simulation area has been subjected to effective fire suppression for at least fifty years. Surface fuels have accumulated over that period to 9 tons per acre and are 0.3 m (1 ft) deep. The understory is crowded with small trees, and crown bases are within 1 m (3 ft) of the ground, providing numerous fuel ladders. Canopy cover ranges from 81% to 100% closure, and crown densities are high. Although many stands in the Sierra Nevada that have been subjected to logging might have heavier and deeper accumulations than those modeled here, the results from this scenario will serve as a minimum example. More accumulated fuel will only exacerbate the resulting fire behavior.

Prescribed Burn

The prescribed-burn treatment reduces surface fuels by 50% in both load and depth compared to the control model (table 43.1). Duff and small branchwood up to 0.64 cm (0.25 in) in diameter are reduced from 3 tons per acre to 1.5 tons, while woody fuels up to 7.62 cm (3 in) are reduced to 2 tons per acre. Fuel-bed depth is decreased from 0.3 m (1 ft) to 0.15 m (0.5 ft). This approximates the effects of a safe and effective prescribed burn for this type (van Wagtendonk 1974). Two tons per acre of understory trees, brush, and branches up to 2 m (6 ft) in height are removed by this treatment, but canopies are not opened up or thinned. Complete removal of the understory had to be assumed because of limitations in the model. As a result, simulated subsequent fires are slightly less intense than might occur under actual conditions.

TABLE 43.2

Fuel models and canopy characteristics for fuel treatments and fuel breaks.

Scenario	Custom Fuel Model	Canopy Cover (Percentage)	Crown Density (kg/m^3)	Crown Base Height (m)	Wind Reduction Factor
Control	14	81–100	0.30	1	0.22
Prescribed burn	15	81–100	0.30	2	0.22
Pile and burn	14	81–100	0.30	2	0.22
Cut and scatter	16	81–100	0.30	2	0.22
Biomassing	14	50–80	0.15	1	0.32
Biomassing and prescribed burn	15	50–80	0.15	2	0.32
Biomassing and pile and burn	14	50–80	0.15	2	0.32
Biomassing and cut and scatter	16	50–80	0.15	2	0.32
Fuel breaks	17	1–20	0.05	3	0.69

Pile and Burn

The pile-and-burn model assumes that hand crews are used to remove and pile all of the small understory trees, brush, and branches up to 2 m (6 ft) in height. This removal results in a reduction of 2 tons per acre of live fine fuels. The vertical and horizontal continuity of the fuels that constitute "ladder" fuels is eliminated. The piles are then covered with a tarp until after the fall rains have soaked through the surface fuels, and then they are ignited. This is a common practice in areas where it is thought to be too risky to use prescribed fire. Since the piles are burned during conditions when surface fuels will not ignite, there is no reduction in surface fuel load or depth. Areas underneath the piles are assumed not to burn, since the piles are smaller than the 30 m (98 ft) resolution of the input maps used for the simulation. This scenario does not include cutting or thinning in the upper canopy.

Cut and Scatter

The cut-and-scatter treatment is similar to the pile-and-burn treatment except that the understory trees and branches are cut, lopped, and scattered over the treatment unit. This situation often occurs when there are insufficient funds to remove the material resulting from an understory cutting operation. Surface fuel loads in each size class and fuel depth are increased from a total of 7 tons per acre in the control model to 10.5 tons per acre. Some of the increase in the fine dead fuel loads comes from the cut live fuels. Crown bases are raised to 2 m (6 ft) and no upper canopy thinning occurs.

Biomassing

The biomassing model includes the cutting, chipping, and hauling away of overstory trees up to a certain size class. This treatment has been proposed for many areas of the Sierra Nevada. This scenario assumes that 50% of the overstory trees are removed. The associated live and dead crown fuels are also removed from the site, but not the surface fuels. Although biomassing sometimes results in the crushing of surface fuels and the removal of some understory trees, fuel depth and crown base height are assumed not to change.

Biomassing and Prescribed Burning

Biomassing and prescribed burning involve thinning the overstory trees and canopies 50% through biomassing and treating the remaining surface fuels with prescribed fire. Surface fuel loads and depths are decreased by 50% compared to the control model, and crown base height is raised to 2 m (6 ft).

Biomassing and Piling and Burning

Biomassing and piling and burning treatment combines overstory biomassing with the cutting, piling, and burning of understory trees and branches during moist conditions. This treatment increases crown base height to 2 m (6 ft) but does not reduce surface fuels.

Biomassing and Cutting and Scattering

When biomassing is combined with the cut-and-scatter treatment, 50% of the overstory canopy is removed, and the remaining understory trees and branches are cut, lopped, and scattered. Surface fuel load and depth are not changed.

Fuel-Break Alternatives

Fuel breaks are often seen as an option when time or money is limited and surface fuel treatments are not considered feasible. Although fuel breaks are not intended to stand alone and should be integrated with other fuel treatments on adjacent lands, very often there is only enough money to construct the break. The fuel-break alternatives were designed to test their efficacy against the range of fuel-treatment scenarios, including one involving no treatment. The first alternative is a 90 m (295 ft) wide fuel break at the crest of the slope. This width corresponds to that suggested by Green and Schimke (1971) for fuel breaks in the Sierra Nevada. The second alternative is a fuel break 390 m (0.24 mi) in width that is also located at the top of the slope. These breaks were designed to approximate the widths proposed by a public group and the California spotted owl draft environmental statement (USFS 1995). The breaks have sparse crowns (1% to 20%) that have been pruned to a height of 3 m (10 ft) and shelter grass understories.

TABLE 43.3

Weather scenarios.

Variable	95th Percentile	75th Percentile
Maximum temperature (°F)	90	65
Minimum temperature (°F)	60	45
Maximum humidity (%)	40	60
Minimum humidity (%)	10	20
Wind speed (mph)	18	6
Wind direction (degrees from north)	180	180
1-hour fuel moisture (%)	4	6
10-hour fuel moisture (%)	6	8
100-hour fuel moisture (%)	8	10
Live herbaceous fuel moisture (%)	90	110
Live woody fuel moisture (%)	90	110
Foliar moisture (%)	80	100

Weather Scenarios

The values for the two weather scenarios are listed in table 43.3. These are based on readings taken at the Crane Flat weather station in Yosemite National Park. The percentiles are based on the normal fire season, which runs from May through October.

Output Measures

After the simulation runs had been completed, their output was compared. Maps and tables were created that display the amount of the simulation surface within treated and fuel-break areas that had been exposed to various levels of fire-behavior parameters. These parameters include rate of spread, fireline intensity, flame length, and heat per unit of area. In addition, severe fire behavior, such as torching, spotting, and crowning, was listed for each scenario. The fuel-break alternatives were evaluated based on whether or not they were sufficiently wide to prevent spot fires from occurring beyond the break.

RESULTS

Treatment of surface and understory fuels affected the behavior of fires within the treated areas and, to a lesser extent, initial fire behavior within the fuel breaks. Treatments also affected severe fire behavior such as spotting and crowning, which spread the fire beyond the fuel breaks.

Fire Behavior within Treated Areas with 95th Percentile Weather

Fires in the treated areas burning with 95th percentile weather showed considerable variation in their behavior (table 43.4). The prescribed-burn treatment without any overstory thinning produced the lowest average values for rate of spread, fireline intensity, and flame length. The prescribed-burning treatment and the biomassing and prescribed-burning treatment had the lowest average values for heat per unit of area because surface and understory fuels had been treated and no crowns were involved. Biomassing combined with cutting and scattering of the understory fuels had the highest values for all parameters except heat per unit area and exceeded the behavior in the control area. The additional surface fuel load and depth resulting from cutting and scattering contributed to the more extreme behavior. The four biomassing treatments produced more intense fires than the equivalent treatments without overstory thinning. The sparser overstory left fuels more exposed to the sun, resulting in lower fuel moisture. In addition, wind speed was not reduced as much as in denser canopies, resulting in higher midflame winds.

Table 43.5 lists the total area burned within the treatments during the first twenty-four hours, as well as whether or not those fires torched, spotted, or crowned. The biomassing, cutting, and scattering treatment resulted in the largest burned area, while the prescribed-burning treatment without biomassing had the smallest burned area. Torching and spotting occurred in all scenarios except the two prescribed-burning treatments, while crowning was present only in the control, pile-and-burn, and cut-and-scatter treatments.

Control Simulation

The fire that burned in the area that was not treated spread quickly upslope, aided by torching trees, spot fires, and crowning, finally covering a total of 414 ha (1,023 acres). The fire had an average rate of spread of 1.88 m/min (9.84 ft/min) and a maximum spread rate of 11.65 m/min (38.22 ft/min). Fireline intensities averaged 490.83 kW/m and ranged up to 4,854 kW/m (figure 43.1). Flame length varied throughout the burn, reaching a maximum of 3.85 m (12.63 ft) in the area of fastest spread. Fire behavior was greatly influenced by heavy surface fuels, low crown base heights, and dense canopies. Sufficient heat was generated by the surface fuels to create spot fires and to initiate crowning. The addition of crown fuels contributed to the high maximum heat per unit of area of 43,549 kJ/m^2.

Plate 43.1 displays flame length for the eight scenarios with 95th percentile weather. The inclined portion of the simulation surface is the treated area for each scenario, and the level portion is untreated. The ignition point is indicated by the yellow pointer. Head fires burn upslope from that point, while backing fires burn downslope, and flanking fires spread laterally. The red flames are from 0 to 1 m (0 to 3 ft) in length, while the yellow flames are from 4 to 5 m (12 to 15 ft). The high "ridge" of yellow and orange flames in the control, pile-and-burn, and cut-and-scatter scenarios indicates when crowning occurred. The lower flame lengths in the treated areas are a result of flanking and backing fires and, in the untreated areas, are the result of the flat terrain. Rates of spread for flanking and backing fires are determined by the model, and flame lengths are calculated based on the amount of fuel

TABLE 43.4

Average fire behavior for fires within fuel-treatment areas with 95th percentile weather.

Scenario	Rate of Spread (m/min)	Fireline Intensity (kW/m)	Flame Length (m)	Heat/ Unit of Area (kJ/m^2)
Control	1.88	490.83	1.27	14,629
Prescribed burn	1.74	117.80	0.68	4,015
Pile and burn	1.86	457.78	1.25	14,389
Cut and scatter	2.86	964.53	1.75	19,360
Biomassing	2.15	516.26	1.34	14,266
Biomassing and prescribed burn	2.10	142.17	0.74	4,007
Biomassing and pile and burn	2.15	515.71	1.34	14,268
Biomassing and cut and scatter	3.28	1,070.74	1.85	19,243

present. The effect of each treatment can be seen by comparing the lower flame lengths in the prescribed-burn area and the higher flames in the cut-and-scatter area to the flame lengths in the control and pile-and-burn areas.

Prescribed-Burning Simulation

The 50% reduction in surface fuels and the complete removal of understory fuels up to 2 m (6 ft) using prescribed fire reduced the magnitude of subsequent fire behavior. No torching, spotting, or crowning occurred. The average rate of spread dropped to 1.74 m/min (5.71 ft/min), the maximum rate of spread dropped to 3.32 m/min (10.89 ft/min), and the size after twenty-four hours of burning was 2,608 ha (6,444.5 acres). The average fireline intensity was reduced by 76 percent to 117.80 kW/m (figure 43.1), while the maximum intensity was reduced by 95 percent to 272 kW/m. This drop in intensity can be attributed to the fact that crown fuels were not involved. The flame lengths depicted in plate 43.1 show a typical pattern for fires burning under uniform conditions without spotting and crowning. The lack of crown fuel involvement is also evident in the low average heat per unit of area of 4,015 kJ/m^2.

Pile-and-Burn Simulation

When a scenario in which understory fuels are cut, piled, and then burned at a time when surface fuels will not ignite was simulated, the results were very similar to those of the control treatment. Only slight decreases in each of the fire behavior parameters were observed (table 43.4; figure 43.1). Torching, spotting, and crowning did occur, since understory ladder fuel removal without treatment of the surface woody and duff fuels is not sufficient to prevent severe fire behavior. Flames were long enough to reach into the upper canopy (plate 43.1), reaching a maximum of 3.11 m (10.20 ft). Heat per unit of area (table 43.4) and fire size after twenty-four hours (table 43.5) were also similar to the control simulation.

Cut-and-Scatter Simulation

Although the understory trees are removed up to 2 m (6 ft) in the cut-and-scatter scenario, the 50% increase in surface fuel loads and depth resulted in significant increases in fire behavior. The average rate of spread increased to 2.86 m/min (9.38 ft/min), and maximums exceeded 15 m/min (49 ft/min). Fireline intensities were also nearly double those of the control simulation (table 43.4). Flame lengths averaged 1.75 m (5.74 ft) and reached a maximum of 4.83 m (15.85 ft). Plate 43.1 depicts the flame lengths over the simulation surface. The average heat per unit of area exceeded that of the control simulation by nearly 5,000 kJ/m^2.

Biomassing Simulation

The biomassing scenarios all have 50% of the overstory canopy removed, both in density and in cover. This removal has the effect of slightly increasing fire behavior parameters because surface fuels are less shaded and are therefore drier (table 43.4). Crowning does not occur, since fire is not able to spread through the less dense canopies (table 43.5). In the biomassing scenario without surface fuel treatment, the rate of spread averaged 2.15 m/min (7.05 ft/min), and fireline intensity averaged 516.26 kW/m (figure 43.2). Flame length reached a maximum of 2.01 m (6.59 ft) and averaged 1.34 m (4.40 ft). Plate 43.1 shows the flame lengths for this scenario. Although a limited amount of torching and spotting occurred, the average heat per unit of area was slightly less than that of the control simulation, since crowns were not involved.

TABLE 43.5

Area burned in treatment areas and severe fire behavior for fires with 95th percentile weather.

Scenario	Area Burned (ha)	Torching	Spotting	Crowning
Control	414.0	Yes	Yes	Yes
Prescribed burn	260.8	No	No	No
Pile and burn	404.6	Yes	Yes	Yes
Cut and scatter	708.1	Yes	Yes	Yes
Biomassing	457.2	Yes	Yes	No
Biomassing and prescribed burn	348.3	No	No	No
Biomassing and pile and burn	455.4	Yes	Yes	No
Biomassing and cut and scatter	730.9	Yes	Yes	No

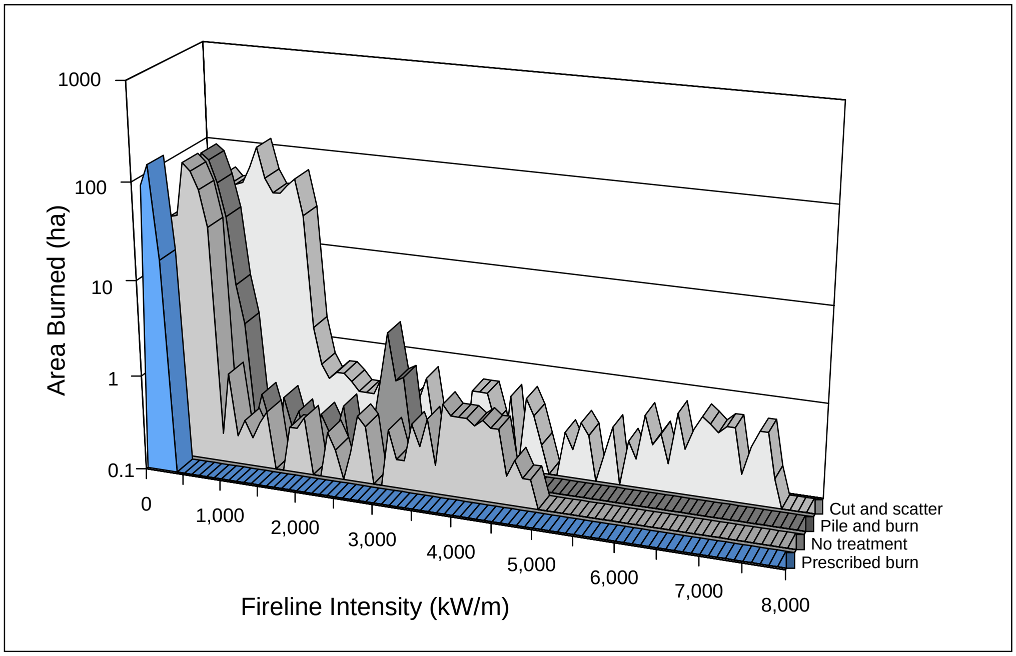

FIGURE 43.1

Fireline intensity for surface fuel treatments with no crown thinning under 95th percentile weather.

Although crowning did not occur with any of the biomassing treatments, because of the thinned canopies, flames approached the crowns when fuels were cut and scattered. The biomassing with prescribed-burning treatment had the smallest flame lengths. Since the surface fuels were the same between the biomassing treatment and the biomassing with piling and burning treatments, their flame lengths were similar. Biomassing combined with cutting and scattering the fuels resulted in the highest flames and the largest area burned.

Biomassing and Prescribed-Burning Simulation

Adding burning of surface fuels to the biomassing scenario resulted in reduced fire behavior values for subsequent fires. The average rate of spread, fireline intensity, and flame length were slightly greater than in the prescribed-burning scenario

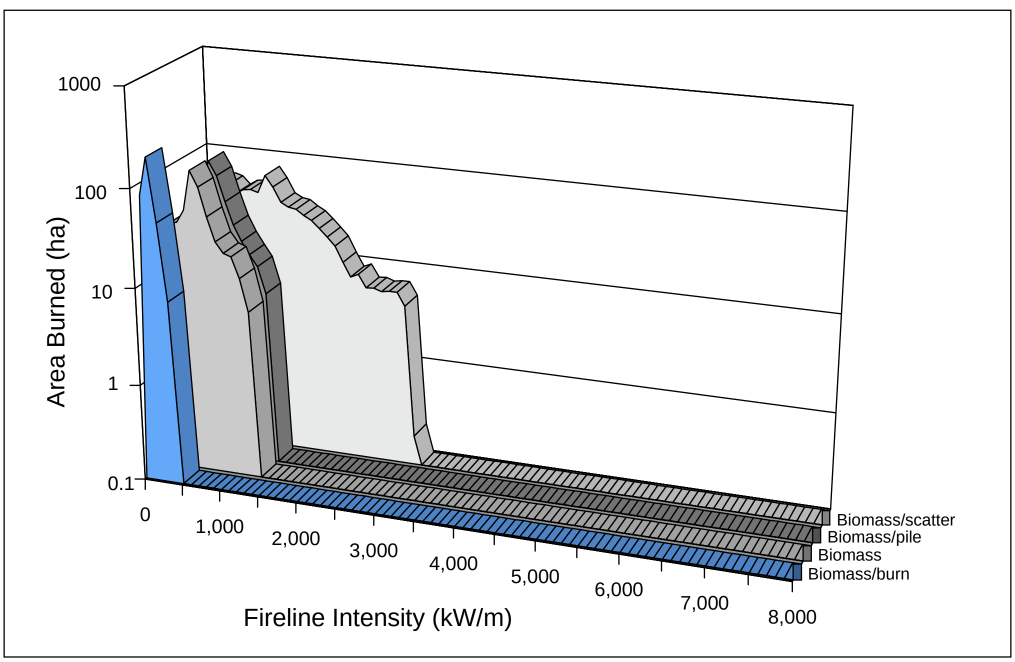

FIGURE 43.2

Fireline intensity for surface fuel treatments with crown thinning under 95th percentile weather.

without biomassing (table 43.4). The pattern of flame lengths over the simulation surface was also similar (plate 43.1), as was the heat per unit of area.

Biomassing and Piling and Burning Simulation

The results from the biomassing and piling and burning simulation were nearly identical to those of the biomassing simulation without surface fuel treatment (table 43.4). Since no crowning occurred in either scenario, the removal of understory fuels had no appreciable effect. Flame lengths were also virtually the same (plate 43.1).

Biomassing and Cutting and Scattering Simulation

Scattering the cut and lopped fuels on the surface in the more open conditions created by thinning significantly increased subsequent fire behavior. The average rate of spread increased to 3.28 m/min (10.76 ft/min). The maximum rate of spread was 7.75 m/min (25.43 ft/min), which was less than those of the control simulation and the cut-and-scatter simulation without biomassing, because there was no crowning. The average fireline intensity, however, at 1,070.74 kW/m was the highest of any scenario (table 43.4). The average heat per unit of area was only slightly less than that of the cut-and-scatter simulation. Flame length patterns approached those of the cut-and-scatter scenario, although the maximum flame lengths were shorter as a result of the lack of crowning in the thinned canopies (plate 43.1).

Fire Behavior within Treated Areas with 75th Percentile Weather

As would be expected, fire behavior for all scenarios was reduced when run with 75th percentile weather (table 43.6). Reductions ranged from 72% for fireline intensity in the biomassing and cutting and scattering scenario to 8% for heat per unit of area in the biomassing and piling and burning scenario. The lowest values for all behavior characteristics were for the prescribed-burning treatment, while the highest values were for the biomassing and cutting and scattering treatment. Torching and spotting occurred only in the two cut-and-scatter simulations. There was no crowning in any of the scenarios, although the cut-and-scatter simulations approached the crowning level. No fires reached the fuel-break location during the twenty-four-hour burn period.

Fire behavior for weather scenarios between the 75th and 95th percentiles would fall between the values presented here. The change in values as the 95th percentile is approached is nonlinear and would increase dramatically beyond that point.

Fire Behavior within Fuel Breaks

Fire behavior within a fuel break is an indicator of the difficulty that suppression forces will have in controlling a fire once it reaches the break. This situation would occur if the forces have not had time to prepare the break prior to the arrival of the fire. In addition, the fire behavior within the break is indicative of the behavior that crews would encounter when setting backfires in the break.

Only 95th percentile weather produced fires that spread fast enough to reach the fuel breaks within twenty-four hours. The fire in the area that had been treated with prescribed burning, however, did not reach the fuel break within that time. Although fire behavior within fuel breaks was initially influenced by the rate of spread and fireline intensity of the fire when it reached the breaks, the behavior quickly adjusted, becoming determined by conditions within the break. The grass fuels with a sparse overstory of trees burned with an average rate of spread of 3.35 m/min (10.99 ft/min). The maximum rate of spread of 7.35 m/min (24.11 ft/min) within the breaks occurred on the sloped portion of the breaks. Fireline intensity averaged 99.80 kW/m and reached a maximum of 267.27 kW/m. The average flame length in the fuel breaks was 0.63 m (2.07 ft), with a maximum of 1.01 m (3.31 ft). Heat per unit of area was typical for grass fuels, with an average of 1,759 kJ/m^2 and a maximum of 2,195 kJ/m^2.

Knowing the time necessary for a fire to reach the fuel breaks, and whether or not those fires spotted across the fuel breaks, gives managers an indication of how quickly they must respond to a fire and how likely they are to contain it once it reaches the fuel break (table 43.7). The fastest fire was in the cut-and-scatter scenario with no thinning of the canopy, taking only 1.5 hours to reach the break. Although the fire in

TABLE 43.6

Average fire behavior for fires within fuel-treatment areas with 75th percentile weather.

Scenario	Rate of Spread (m/min)	Fireline Intensity (kW/m)	Flame Length (m)	Heat/ Unit of Area (kJ/m^2)
Control	0.81	177.20	0.83	13,049
Prescribed burn	0.59	36.44	0.40	3,638
Pile and burn	0.83	181.84	0.84	13,095
Cut and scatter	1.36	393.84	1.19	17,321
Biomassing	0.89	196.28	0.87	13,106
Biomassing and prescribed burn	0.65	40.37	0.42	3,666
Biomassing and pile and burn	0.90	199.28	0.87	13,147
Biomassing and cut and scatter	1.49	435.56	1.25	17,434

TABLE 43.7

Time to reach fuel breaks and spot fire occurrence beyond fuel breaks for fires burning with 95th percentile weather.

Scenario	Hours to Reach Fuel Break	Spot Fires beyond 90 m Fuel Break	Spot Fires beyond 390 m Fuel Break
Control	2.5	Yes	No
Prescribed burn	—	No	No
Pile and burn	3.0	Yes	No
Cut and scatter	1.5	Yes	No
Biomassing	4.0	Yes	No
Biomassing and prescribed burn	20.5	No	No
Biomassing and pile and burn	4.0	Yes	No
Biomassing and cut and scatter	3.5	Yes	No

the prescribed-burn treatment area did not reach the break in 24 hours, when the canopy was thinned, it took 20.5 hours for a fire to burn into the break.

If it is assumed that control efforts make the fuel breaks impermeable to fire, their effectiveness in stopping fires is directly related to the ability of the fire to loft embers over the break to start spot fires. Table 43.7 shows that all scenarios except the prescribed-burn treatments produced fires that spotted across the 90 m (295 ft) breaks and that no fires spotted across the 390 m (0.24 mi) breaks.

DISCUSSION

Like any model, FARSITE is based on simplifying assumptions and has its limitations. Inherent in the model are the assumptions of homogeneous fuels within the map resolution, surface fire spread in an elliptical shape, simplified weather and wind inputs, and no extreme behavior such as fire whirlwinds, plume-dominated fires, or fire-induced weather. Albini (1976) points out, however, that the internal consistency of a well-disciplined model allows it to be used to assess the impacts of changes in important variables.

A serious limitation in applying models such as FARSITE to actual situations is the need for spatially accurate fuels data (Finney and Ryan 1995). Efforts are underway in Yosemite to use satellite imagery from the Thematic Mapper to provide high-resolution fuels data for research and management purposes. The techniques, when developed, will enable managers throughout the Sierra Nevada to acquire the needed data in a relatively simple and inexpensive manner. Currently, weather and wind data are provided from the nearest station, but these need to be supplemented with on-site observations. Given these limitations, however, the results from this study can be applied to similar situations in the Sierra Nevada. In fact, if information is available to accurately model fuels for the various treatment scenarios, there is no reason why these results would not hold for other areas as well.

The results described in this chapter amplify the proposal by Weatherspoon and Skinner (1996) for a landscape-level strategy for fuels management in Sierra Nevada forests. They recommend a strategy of establishing a network of defensible fuel profile zones, enhancing the use of prescribed fire for restoring natural processes and meeting other ecosystem goals, and expanding fuel treatments to other appropriate areas of the landscape consistent with management goals. The fuel zones are envisioned to be similar to the 390 m (0.24 mi) wide fuel breaks tested here, except that crown cover would be reduced to between 20% and 50% rather than to between 1% and 20%. Weatherspoon and Skinner (1996) emphasize that construction of the fuel zones must be combined with treating fuels within areas bounded by the zones. This point is reinforced by this chapter, which indicates that fuel breaks alone will not be sufficient to stop all wildfires without some internal fuel treatment and active fire suppression.

The use of FARSITE to test fuel-treatment scenarios on simulated terrain has been extended to actual conditions in Yosemite National Park and Eldorado National Forest. Stephens (1995) used the FARSITE model to test fuel treatments for protecting the Tuolumne Grove of giant sequoias at the head of North Crane Creek in Yosemite. He tested prescribed burns of moderate intensity as well as the mechanical removal of ladder fuels and salvage logging with and without slash treatments. His results complement those of this chapter, reiterating the importance of fuel treatments such as prescribed burning and defensible fuel profile zones in areas requiring protection.

The policy scenarios proposed by Johnson et al. (1996) for managing late successional old-growth forests in the Sierra Nevada include four of the fuel treatments tested with FARSITE in this chapter. These are (1) no active management of fuels, (2) prescribed burning, (3) reduction of stand density with prescribed burning, and (4) fuel breaks with prescribed burning. They ran their analyses with and without budget constraints to learn which approaches would be most effective in protecting and restoring late successional forests. Their budget constraints were to require each treatment to pay for itself at the stand level and that the total budget spent on treatments must be less than a specified amount.

Recent work on mapping fire risk and fire hazard will make it possible to set priorities for treating areas. Using twentieth-century fire data from Sierra Nevada national forests, McKelvey and Busse (1996) found a strong correlation between elevation and fire frequency, with low elevations burning more frequently. Areas that burned more than three times were associated with special features such as roads. Greenwood (Sapsis et al. 1996) developed a fire hazard map of the Sierra Nevada by relating forest stand areas to fuel models and expected fire behavior. He found that low-elevation forests had the highest hazard and, because of their proximity to developed areas, the highest risk as well. These analyses indicate that the effective fuel treatments determined by this study would be most proficiently applied to low-elevation forests near high-risk areas.

CONCLUSION

The key mechanisms at work that affected the results of the simulations were the amount of surface fuels and the presence of low crowns or ladder fuels. If there is insufficient fuel on the ground either to cause the fire to spread quickly or to generate enough heat to move it into the crowns, sufficient time will be available either to suppress the fire or to use a fuel break ahead of the fire. Scenarios that did not treat surface fuels, such as biomassing only the overstory or piling and burning, did not appreciably change fire behavior. Adding the additional fuels resulting from cutting, lopping, and scattering understory trees and branches exacerbated fire behavior.

In those scenarios where surface fuels were not treated or were increased, fires spread rapidly, were very intense, spotted ahead of the main fire, and moved into the crowns. High flame lengths and large values for heat per unit of area were associated with this behavior. This extreme fire behavior occurred when large accumulations of woody and duff fuels burned uphill, with the wind producing flames that reached the low crown bases. Not only are these fires difficult to suppress, they also do not provide adequate time for treating fuel breaks ahead of the fire.

An obvious next step is to assess the costs and benefits of the various treatments. If fuel breaks are not effective until they reach a certain width, the additional costs of widening and maintaining the breaks must be compared to the cost of treating fuels within areas bounded by them, with and without the appropriate use of fuel breaks. Future applications of FARSITE should include the testing of various control strategies, using various combinations of fuel breaks and fuel treatments. The model can simulate the setting of backfires and the creation of fire breaks by hand crews, mechanized equipment, and aerial retardants.

It is obvious from this simulation project and from actual experience that fuel breaks alone will not alleviate the spread of wildfire. Although fuel breaks can form effective barriers to a fire during a suppression action if they are cleared of all flammable fuels and they are wide enough, the time available to defend them is critical to their success. This time can be greatly increased if adjacent fuel treatments are accomplished beforehand. Prescribed burning appears to be the most effective treatment for reducing a fire's rate of spread, fireline intensity, flame length, and heat per unit of area. Not only are surface fuels reduced by this treatment, but understory and ladder fuels are also reduced to the point where spotting and crowning are not a serious threat. Removing a portion of the canopy has the obvious effect of reducing the chance of a crown fire with or without surface fuel treatment. A management scheme that includes a combination of fuel treatments in combination with other land-management scenarios is critical for successfully reducing the size and intensity of wildfires. Land-management agencies and private landowners must cooperate to take the necessary steps on their lands to reduce the risk of catastrophic fire. Prescribed fire, in conjunction with fuel profile zones, appears to be the most effective strategy to accomplish that goal.

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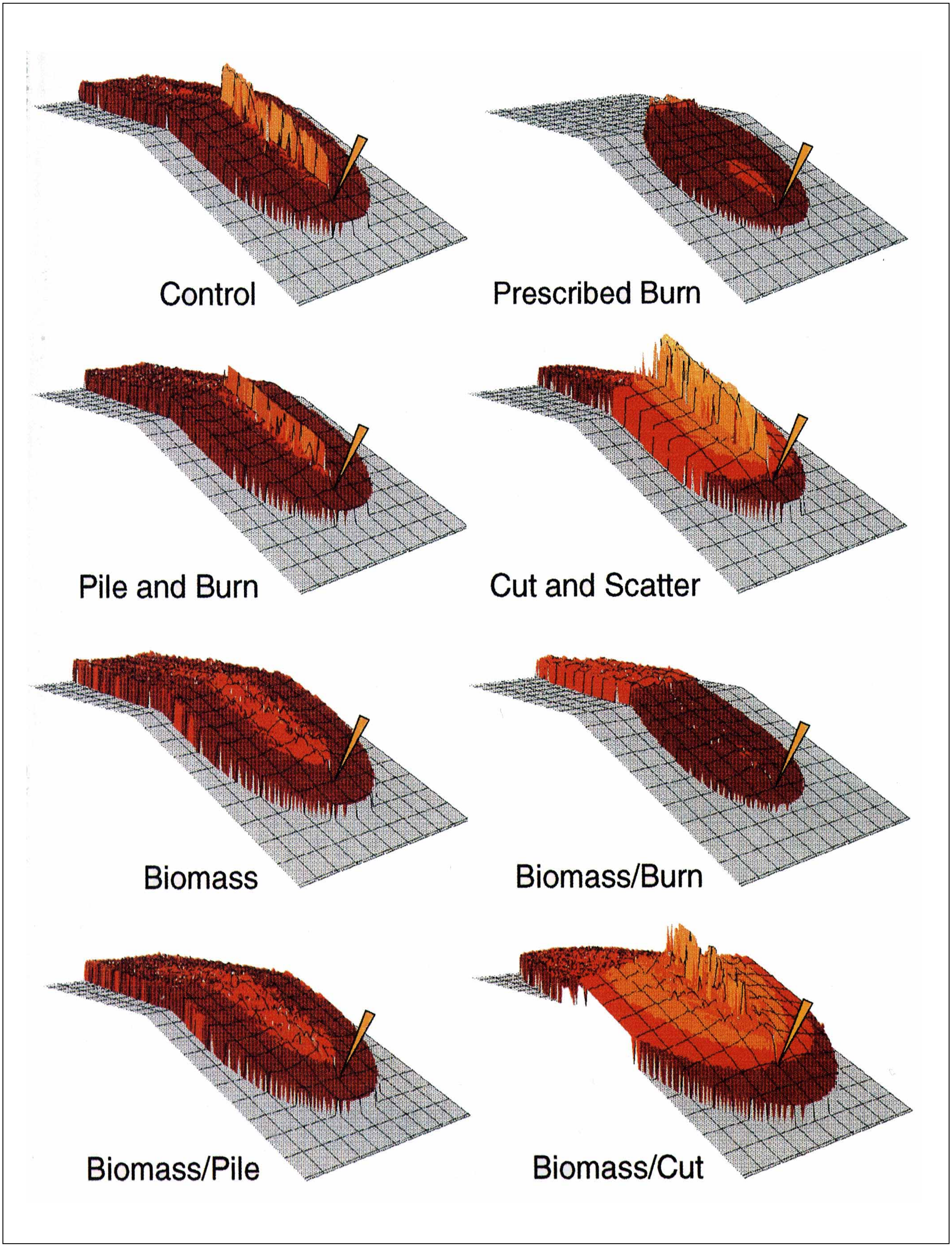

PLATE 43.1

Flame length for fuel-treatment simulations with 95th percentile weather.

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