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Appraising Fuels and Flammability in Western Aspen: A Prescribed Fire Guide

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RESEARCH SUMMARY

This report explains how to appraise fuels and flammability in aspen forests as a means for choosing good opportunities for prescribed burning and for determining the environmental conditions favorable for a successful burn. The appraisal process is based on a study of physical fuel properties and vegetation occurring in southeastern Idaho and western Wyoming. Fuels were classified into five types: aspenlshrub, aspenltall forb, aspenllow forb, **mixed/** shrub, and mixedlforb, based on overstory composition, shrub coverage, and quantity of herbaceous vegetation. The fuel types are illustrated with color photographs accompanied by information on fuel loadings, vegetational characteristics, adjective fire behavior ratings, and ratings for probability of a successful burn. To aid in writing fire prescriptions the report includes tables of predicted fireline intensity and rate of spread as a function of fine fuel moisture content, vegetation curing, windspeed, and slope.

Grazing reduced fire behavior potential by 80 to 90 percent of ungrazed conditions. The authors discuss how fire behavior is affected by downed woody fuel accumulations, leaf fall, small conifers, canopy closure, and rodent activity. Adjective ratings of fire intensity, rate of spread, torching, and resistance to contol incorporate the influence of downed woody fuel accumulations and conifers. The aspenlshrub type is the most flammable, followed by mixedlshrub. The aspenltall forb is intermediate in flammabilty and has about one-half of the fire intensity potential of aspenlshrub. The aspenllow forb and mixedlforb types are least flammable. Probabilities of successful burning range from high to low because fuels and flammability varied substantially among fuel types and among certain stands within fuel types.

The guide provides an example of how to determine a range of windspeeds, fine fuel moisture contents, and curing levels for writing fire prescriptions. Moisture contents and curing trends of grasses and forbs are described. Forb moisture contents remained high until late summer, then dropped substantially over a 3-week period, regardless of rainfall. The guide includes a visual method of estimating percentage of curing based on the finding that green and transition-stage moisture contents are similar and differ significantly from those of the cured stage. Details of fuel model development and fire behavior prediction are provided.

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INTRODUCTION

Aspen (*Populus* tremuloides) is widely distributed throughout North America. It occupies approximately 7 million acres in the Western United States (Green and Van Hooser 1983). Aspen forests provide wood products but are especially valued as wildlife habitat, for grazing by domestic livestock, for sources of water, and for esthetics and recreation (DeByle 1978). Fire has played an integral part in the development of aspen forests. The purpose of this report is to assist in planning and conducting prescribed fires to maintain aspen forests.

Aspen exists as both a climax and seral species but is seral on the majority of sites, eventually to be replaced by conifers (Mueggler 1976). On stable aspen sites, frequent fires can maintain a grass-forb community, with aspen suckers confined to the shrub layer (Crane 1982). Infrequent fires produce varying effects on stand structure. Low-intensity fires cause thinning and encourage an all-aged condition. High-intensity fires result in new even-aged stands.

Seral aspen is gradually replaced by conifers. This may take 200 to 400 years or more (Bartos and others 1983), depending on the potential for establishment and growth of conifers. If succession continues without fire, aspen will eventually be crowded out. This successional process reduces forage production from approximately 700 lblacre to 200 lblacre (Kranz and Linder 1973; Reynolds 1969), reduces water yields from about 20 area inches to 16 inches (Jaynes 1978; Gifford and others 1983, 1984), and diminishes vegetation diversity and habitat for many species of wildlife (DeByle 1985).

Prescribed fire may offer an economically and environmentally acceptable means of rejuvenating aspen. Prescribed fire is particularly appropriate in remote areas and areas where cutting is not a feasible tool for regenerating aspen. Fire, when properly applied, also stimulates temporary increases in production of grasses, forbs, and shrubs. It creates a diversity of cover types and tree sizes on the landscape.

Prescribed fire has not been commonly used to regenerate aspen in the Western United States partly because the aspen forest is regarded as difficult to burn. Concerns for fire control have limited burning in aspen during late summer when flammability of adjoining forest types is typically greatest. In autumn, when flammability of the forest has lessened, burning opportunities in aspen are frequently restricted to only a few days and in some years none at all.

Prescribed fire in aspen, however, can be successfully used. Fuels and flammability vary considerably within the aspen and mixed aspen-conifer overstory types. In planning prescribed fire in aspen, it is particularly important to choose locations that are sufficiently flammable to meet fire objectives. The best time of year to burn in aspen varies by the type of understory vegetation. Choosing the proper time to burn is critical to achieving successful prescribed fires.

This paper presents a method for appraising fuels and flammability in aspen forests to assist in choosing good opportunities for using prescribed fire and to help determine the proper conditions for burning. Also, a method is described for evaluating the curing of vegetation to determine when herbaceous fuels are ready to burn.

METHOD DEVELOPMENT

Fuel Types

Fuels were classified into five types that differed substantially in vegetation and potential fire behavior (table 1). The classification of understories was keyed to amount of shrubs and productivity of herbaceous vegetation. Tall forbs dominated the forb component of high productivity herbaceous types and low forbs dominated the forb component of low productivity types. Aspen dominated the overstory in three types: aspenlshrub, aspenltall forb, and aspenllow forb. Productivity and fuel loadings of herbaceous vegetation were greater in the tall forb than in the low forb group. Conifers dominated the overstory in two types: mixedlshrub and mixedlforb. Herbaceous vegetation under the mixed overstories was considerably less varied than under aspen; thus only one forb group was used for classifying flammability. Conifers commonly encountered in the overstory include subalpine fir (*Abies* lasiocarpa), Douglas-fir (*Pseudotsuga* menziesii), and lodgepole pine (*Pinus contorta*).

The fuel type classification was initially formed by grouping community types on the Bridger-Teton National Forest (Youngblood and Mueggler 1981) and the Targhee and Caribou National Forests (Mueggler and Campbell 1982) based on expected differences in flammability. Community types are aggregations of similar plant communities based upon existing vegetation regardless of successional status. Existing understory vegetation significantly influences flammability in aspen forests; thus, flammability is related to community types.

Table 1.—A vegetation classification of aspen fuels and flammability

Characteristics	Vegetation - fuel types				
	Aspen/ shrub	**Aspen/** tall-forb	**Aspen/** **low** forb	**Mixed/** shrub	**Mixed/** forb
Overstory species occupying 50 percent or more of canopy	Aspen	Aspen	Aspen	Conifers	Conifers
Shrub coverage, percent	Greater than 30	Less than 30	Less than 30	Greater than 30	Less than 30
Community type understory indicator species that may be present	*Prunus* *Bromus* *Amelanchier* *Shepherdia* *Symphoricarpos* *Artemisia* *Juniperus* *Pachistima*	*Ranunculus* *Heracleum* *Ligusticum* *Spiraea* *Calamagrostis* *Rudbeckia* *Wyethia*	*Prunus* *Berberis* *Arnica* *Astragalus* *Thalictrum* *Geranium* *Poa*	*Ligusticum* *Shepherdia* *Spiraea* *Amelanchier* *Symphoricarpos*	*Pedicularis* *Berberis* *Arnica* *Calamagrostis* *Thalictrum*

Live and dead fuels were then sampled in 33 stands from southeastern Idaho and western Wyoming, representing the initial fuel types. Stands were selected to provide a diversity of community types. An area that appeared to represent a designated community type was located in each stand and photographed. Fuel loadings and fuel bed bulk densities were sampled within each photographic scene.

Fire behavior was predicted using these fuel data as well as a range of windspeeds and fuel moisture contents as input to Rothermel's (1972) fire-spread model. The fuel and fire behavior data were ranked from high to low. Overlap among fuel types and meaningful breaks in the rankings were evaluated and adjustments made in the initial classification. Primarily, tall shrub and low shrub groups, initially recognized, were consolidated because they overlapped considerably in fuels and flammability.

Although this fuel type classification is based on community types found in southeastern Idaho and western Wyoming, community type descriptions for other areas such as the Bear Lodge Mountains and Black Hills (Severson and Thilenius 1976) could probably be interpreted to fit this classification. This fuel type classification and appraisal of flammability should be applicable to other areas if the structure of understory vegetation is similar. The classification criteria, which distinguish differences in flammability, are keyed to amount of shrubs, grasses, and forbs. Understory species are important only as they influence kinds and amounts of vegetation.

Fire Behavior

Fire behavior was evaluated in three ways:

1. Probability of achieving sustained fire spread with sufficient heat to kill aspen.
2. Ratings of fire behavior potential.
3. Fireline intensity and rate of spread predicted using mathematical models.

Probability of Sustained Spread.—The probability of successfully using prescribed fire was subjectively rated for the aspen fuel types and for the effects of grazing and downed woody fuel accumulations on flammability. A successful fire was defined as having sustained spread and sufficient heat to kill aspen up to 12 inches d.b.h. Probabilities of attaining success were defined on the basis of judgment as:

Low — Fine fuels are insufficient to support fire spread. Windspeed and fine fuel moistures are rarely adequate to sustain spread.

Moderate — Fine fuels mostly from herbaceous vegetation; loadings marginal for sustained spread; fuel continuity is broken and compactness open. Windspeed and fine fuel moisture meet burning prescription every few years.

High — Loading of downed dead woody and herbaceous fuel adequate for sustained fire spread; good fine fuel continuity. Windspeed and fine fuel moistures come into prescription almost annually.

Fire Behavior Potential.—Photographs of each plot were rated in terms of potential fire behavior for an "average bad" fire weather situation. Six fire specialists experienced in prescribed fire and fuel appraisal rated the photographs and accompanying fuel loading data. The assumed weather was: temperature of 80 to 90 °F, relative humidity of 15 to 20 percent, windspeed of 10 to 15 milh at 20-ft level, and last measurable rain some 4 weeks ago. Five expressions of fire behavior were rated: rate of spread, fire intensity, torching, resistance to control, and overall fire potential. This approach to rating fire potential was first introduced by Hornby (1936). Although subjective, it has been used extensively in fuel appraisal. The valuable aspect of these ratings is that facets of fire behavior that are not easily evaluated analytically can be mentally evaluated and related to years of experience.

The adjective ratings "nil," "low," "medium," "high," and "extreme" are defined as follows based on Fischer's (1981) photo guides for appraising fuels:

Intensity:

Nil—fire cannot sustain itself.

Low—cool fire; very little hot spotting required for control.

Medium—fire will burn hot in places; aggressive hot spotting with hand tools likely to be successful.

High—too hot for sustained direct attack with hand tools; aerial tankers or large ground tanker required to cool fire front.

Extreme—direct ground attack not possible; air or ground tanker attack likely to be ineffective.

Rate-of-Spread:

Nil—fire cannot sustain itself.

Low—spread will be slow and discontinuous.

Medium—uniform spread possible but can be stopped by aggressive ground attack with hand tools.

High—spread will be rapid; indirect attack on fire front may be required for control.

Extreme—spread will be explosive; little chance of control until weather changes.

Torching:

Nil—no chance of torching.

Low—occasional tree may torch-out.

Medium—pole-sized understory trees likely to torch-out.

High—most of understory and occasional overstory trees likely to torch-out.

Extreme—entire stand likely to torch-out.

Resistance to Control Action:

Nil—no physical impediments to line building and holding.

Low—occasional tough spots but not enough to cause serious line building and holding problems.

Medium—hand line construction will be difficult and slow but dozers can operate without serious problems.

High—slow work for dozers, very difficult for hand crews; hand line holding will be difficult.

Extreme—neither dozers nor hand crews can effectively build and hold line.

Overall Fire Potential:

Nil—fire will not sustain itself.

Low—fire can be easily controlled by several smokechasers with hand tools.

Medium—aggressive crew-sized (6-10 persons) initial attack required for successful control.

High—aggressive crew-sized (25 persons) initial attack with substantial reinforcement required for successful control; 10 percent chance that control action will fail.

Extreme—90 percent chance that control action will fail.

Mathematical Model.—Rothermel's (1972) fire-spread model provided the basis for predicting rate of spread and fireline intensity using program FIREMOD (Albini 1976). Fuel models, which are input values to the mathematical fire model, were constructed for each aspen fuel type based on average fuel loadings and fuel bed bulk densities determined from sampling. Some adjustments to the fuel models were necessary to maintain realistic differences in fire behavior among the aspen fuel types.

Live Fuel Moisture

Moisture content of perennial grasses and forbs was sampled weekly throughout two growing seasons in western Wyoming to investigate prediction of live fuel moisture from easily determined indexes. Grass and forb moisture contents were correlated with the National Fire-Danger Rating System model of live fuel moistures (Burgan 1979) and with the Keetch-Byram Drought Index (Keetch and Byram 1968).

The moisture content of recognizable curing stages was also sampled to develop a field procedure for estimating curing levels that would be useful in deciding when to burn. Curing refers to the change in moisture content of vegetation as it matures through the growing season into dormancy. Three stages of curing, identifiable by color, are commonly recognized in evaluating fire danger (Burgan 1979): green, transition, and cured.

Results of live fuel moisture sampling as well as details about fuel model development and fire behavior prediction are described in following sections.

FIRE PRESCRIPTION GUIDE

This section provides information for designing fire prescriptions and deciding when live vegetation will burn according to the prescription. As a first step, set objectives for the fire and identify constraints in using it. Next, consult technical aids that describe fuels, summarize weather, and forecast fire behavior and fire effects to help write the fire prescription. This process, described in more detail by Brown (1985), produces prescriptions of when and how to burn specific areas. Additional discussion on planning and evaluating prescribed fires is furnished by Fischer (1978) and Martin and Dell (1978).

The following topics are discussed in a logical sequence for writing and executing a fire prescription in aspen stands:

1. Set objectives
2. Consult technical aids
   a. Select fuel types
   b. Appraise fire behavior potentials
3. Determine the fire prescription
4. Determine when curing of vegetation meets the prescription.

Setting Objectives

Both land management and fire objectives should be clearly defined. First, set the land management objectives. These objectives deal with resource values and are derived from the goals of an organization or landowner. They should focus on the composition, amount, and arrangement of vegetation over time, which are fundamental to describing land management objectives.

Fire is an appropriate means to improve range, wildlife, and watershed resource values of the aspen ecosystem. In this case, the land management goal should be to maintain the aspen cover type, preferably with a mix of agelsize classes. If fire is used to reduce slash and stimulate understory production in conjunction with harvesting, the land management objective might be to develop another commercial stand of aspen. If so, achieving some minimum number of aspen stems per acre might be an objective. When the land management objective is to maintain the aspen cover type, however, number of stems per acre is probably of minor concern because range, wildlife, and watershed values can be enhanced over a wide range of aspen stand densities. An appropriate objective in this situation may be to maintain aspen at or above some minimal canopy coverage; or to maintain aspen at or above some minimal proportion of the overstory composition.

Density of aspen suckers can vary widely following fire. If flammability varies considerably within burn units, a mosaic of burned and unburned patches may result. But if fire of adequate intensity reaches most areas this mosaic of burned and unburned areas should successfully maintain aspen in a diversity of age classes.

Once land management objectives are established, objectives of the fire can be defined. These should state what fire itself can directly accomplish. Basically this involves specifying the vegetation to be killed and the organic matter to be consumed. To achieve effective suckering, the objective should be to kill all or most (probably at least 80 percent) of the aspen in a stand. Sucker production is most prolific when all or most of the aspen stems are killed. Within each tree killed, the balance between growth-inhibiting and growth-promoting hormones is altered which, in turn, promotes suckering (Schier 1981). Full sunlight reaching the forest floor after killing the overstory enhances both production and survival of suckers. Sucker production after less than half of the overstory aspen is killed is apt to be ineffective (Horton and Hopkins 1965). In some mixed stands, it may be unnecessary to kill patches of pure aspen if surrounding conifers can be removed by fire or harvesting. Regardless of whether fire carries through patches of aspen, reduction of conifer cover may be the primary objective for treating mixed conifer-aspen stands.

Constraints on achieving the fire objectives must also be defined. Constraints affecting the fire prescription deal primarily with controlling the fire and managing smoke. Getting the fire to spread can be considered a constraint. too.

Fuel Type Appraisal

To appraise fire behavior, select a fuel type that best fits a prospective burn area. If necessary, select more than one type to represent a mosaic of aspen types. Consult the following descriptions and photographs to assist in selecting fuel types. The photographs serve as examples of vegetation and fuels that typify the fuel types. The photographs do not represent all community types or floristic arrangements that occur across the landscape but are a sample of them. An idea of variability in fuels and vegetation within fuel types can be visualized by comparing scenes that represent the same fuel type.

The key features that distinguish fuel types are overstory composition, shrub coverage, and quantity of herbaceous vegetation (table 1). Species composition of the understory relates to shrub coverages and herb quantities. Small woody plants such as ***Spiraea betulifolia*** and ***Berberis repens*** are included with herbaceous species in this fuel classification. Even though they can occur with high coverage, their contribution to fuel loading is minor compared to other shrubs. Where small woody plants are abundant, they should be considered as part of the herbaceous component for determining classification.

Each photograph is accompanied by information on fuel loading, vegetation characteristics, and adjective ratings of fire behavior, and probability of successful burn.

The fuel loading components include:

Herbaceous · live and dead nonwoody vegetation, primarily grasses and forbs.

Shrub · foliage and all live and dead standing stemwood of woody plants (except for some small woody species).

Litter · freshly cast leaves, bark flakes, and miscellaneous vegetative parts and matted grass that are expected to burn during passage of a flaming fire front. This is a liberal interpretation of the 01 horizon or L layer of the forest floor because some partially decomposed aspen leaves were included in the samples.

Downed woody material · dead twigs, branches, and stemwood by diameter classes in inches that lie in or above the litter.

Fines · the sum of fuel less than one-fourth inch in thickness, which includes herbaceous vegetation, shrub foliage, shrub stemwood less than one-fourth inch diameter, litter, and downed woody material less than one-fourth inch diameter.

This information is specific to each scene and is intended to help appraise flammability and the likelihood of successfully using prescribed fire. Use photographs to help classify areas of interest based on the kind and amount of understory vegetation.

ASPEN/SHRUB

Aspen dominates the overstory. It occupies at least 50 percent of the canopy, and typically 80 to 100 percent of it. Shrub coverage and biomass may vary considerably, but coverage must be 30 percent or more. Low shrub situations, however, such as those dominated by ***Symphoricarpos*** or ***Pachistima*** spp., fit the flammability characteristics of the shrub type more realistically when shrub cover exceeds 40 to 50 percent. Other shrubs commonly found in this fuel type include ***Artemisia tridentata, Prunus virginiana, Shepherdia canadensis, Amelanchier alnifolia,*** and ***Ceanothus velutinus.***

Fuel class: Aspenlshrub — Stand No. **2**

Community type: Populus *tremuloides/Artemisia tridentata*

FUEL LOADINGS

	Lb/acre	*kg/m²*
a. Herbaceous	1,000	0.112
b. Shrub	1,860	.209
c. Litter	1,540	.172
Downed woody		
d. 0 to ¼	210	.023
e. ¼ to 3	7,640	.856
f. 3+	13,430	1.505
Subtotals		
Fines	3,980	.445
D. woody 0-3	7,850	.879

VEGETATION CHARACTERISTICS

Shrub cover, %	31
Basal area, ft²/acre	
Aspen	36
Conifer	0

FIRE RATING

Intensity	Medium
Rate of spread	Medium
Torching	Nil
Resistance to control	Low
Overall	Medium
Probability of a successful burn	High

STAND LOCATION

National Forest	Bridger-Teton
Ranger District	Kemmerer
Drainage	Little Bear Creek
Photo date	August 1982

Fuel class: Aspenlshrub Stand No. 15

Community type: ***Populus tremuloides/Pachistima myrsinites***

FUEL LOADINGS	Lb/acre	kg/m²
a. Herbaceous	740	0.084
b. Shrub	4,530	.508
c. Litter	2,510	.281
Downed woody		
d. 0 to ¼	720	.081
e. ¼ to 3	7,450	.835
f. 3+	34,460	3.863
Subtotals		
Fines	7,150	.802
D. woody 0-3	8,170	.916

VEGETATION CHARACTERISTICS	
Shrub cover, %	43
Basal area, ft²/acre	
Aspen	102
Conifer	0

FIRE RATING	
Intensity	Medium
Rate of spread	Medium
Torching	Low
Resistance to control	Medium
Overall	Medium
Probability of a successful burn	High

STAND LOCATION	
National Forest	Bridger-Teton
Ranger District	Kemmerer
Drainage	Allred Campground
Photo date	August 1982

Fuel class: Aspenlshrub — Stand No. 20

Community type: ***Populus tremuloides/Prunus virginiana***

FUEL LOADINGS	Lb/acre	kg/m²
a. Herbaceous	390	0.044
b. Shrub	4,000	.448
c. Litter	2,350	.263
Downed woody		
d. 0 to ¼	430	.048
e. ¼ to 3	3,150	.353
f. 3+	6,320	.708
Subtotals		
Fines	5,270	.591
D. woody 0-3	3,580	.401

VEGETATION CHARACTERISTICS	
Shrub cover, %	56
Basal area, ft²/acre	
Aspen	47
Conifer	0

FIRE RATING	
Intensity	Medium
Rate of spread	Medium
Torching	Nil
Resistance to control	Medium
Overall	Medium
Probability of a successful burn	High

STAND LOCATION	
National Forest	Bridger-Teton
Ranger District	Jackson
Drainage	Little Cotton-wood Creek
Photo date	September 1982

Fuel class: Aspenlshrub — Stand No. 23

Community type: ***Populus tremuloides/Shepherdia canadensis***

FUEL LOADINGS	*Lb/acre*	*kg/m²*
a. Herbaceous	810	0.091
b. Shrub	2,200	.247
c. Litter	2,810	.315
Downed woody		
d. 0 to ¼	260	.029
e. ¼ to 3	5,230	.586
f. 3+	5,520	.619
Subtotals		
Fines	5,020	.563
D. woody 0-3	5,490	.615

VEGETATION CHARACTERISTICS	
Shrub cover, %	32
Basal area, ft²/acre	
Aspen	62
Conifer	7

FIRE RATING	
Intensity	Medium
Rate of spread	Med-High
Torching	Low-Med
Resistance to control	Medium
Overall	Med-High
Probability of a successful burn	High

STAND LOCATION	
National Forest	Bridger-Teton
Ranger District	Jackson
Drainage	Goosewing Creek
Photo date	September 1982

ASPEN/TALL FORB

Aspen dominates the overstory. It occupies at least 50 percent of the canopy, and typically 80 to 100 percent of it, Shrubs are sparse. Shrub coverage is less than 30 percent and frequently less than 10 percent. Productivity of herbaceous vegetation typically exceeds 1,000 **lb/acre/yr.** Tall forbs and grasses commonly found in this fuel type include ***Calamagrostis rubescens, Bromus*** sp., ***Elymus glaucus, Balsamorhiza macrophylla, Ligusticum filicinum, Lupinus argenteus, Osmorhiza occidentalis, Rudbeckia occidentalis,*** and ***Wyethia amplexicaulis.***

Stand No. ***19*** illustrates an understory dominated by a small woody plant, ***Spiraea betulifolia,*** but still classified in the aspenltall forb fuel type. Stands No. 9 and 31 show heavily grazed situations.

Fuel class: Aspen/tall forb — Stand No. 5

Community type: *Populus tremuloides/Rudbeckia* occidentalis

FUEL LOADINGS	Lb/acre	kg/m²
a. Herbaceous	2,020	0.226
b. Shrub	0	0
c. Litter	1,760	.197
Downed woody		
d. 0 to ¼	40	.004
e. ¼ to 3	7,100	.796
f. 3 +	60,300	6.759
Subtotals		
Fines	3,820	.427
D. woody 0-3	7,140	.800

VEGETATION CHARACTERISTICS	
Shrub cover, %	0
Basal area, ft²/acre	
Aspen	82
Conifer	0

FIRE RATING	
Intensity	Low
Rate of spread	Low
Torching	Nil
Resistance to control	Low
Overall	Low
Probability of a successful burn	Moderate

STAND LOCATION	
National Forest	Bridger-Teton
Ranger District	Kemmerer
Drainage	Little Bear Creek
Photo date	August 1982

Fuel class: Aspenltall forb — Stand No. 9

Community type: ***Populus tremuloides/Rudbeckia occidentalis***

FUEL LOADINGS	*Lb/acre*	*kg/m²*	FIRE RATING	
a. Herbaceous	450	0.050	Intensity	Nil
b. Shrub	0	0	Rate of spread	Nil
c. Litter	2,880	.323	Torching	Nil
Downed woody			Resistance	
d. 0 to ¼	120	.014	to control	Low
e. ¼ to 3	2,810	.315	Overall	Nil
f. 3 +	70,180	7.866	Probability of a	
Subtotals			successful burn	Low
Fines	3,460	.387		
D. woody 0-3	2,930	.329	STAND LOCATION	

VEGETATION CHARACTERISTICS		STAND LOCATION	
		National Forest	Bridger-Teton
		Ranger District	Kemmerer
Shrub cover, %	0	Drainage	Stepp Creek
Basal area, ft^2/acre			
Aspen	102		
Conifer	17	Photo date	September 1983

Fuel class: **Aspen/tall** forb — Stand No. 10
Community type: ***Populus tremuloides/Wyethia*** amplexicaulis

FUEL LOADINGS	*Lb/acre*	*kg/m²*
a. Herbaceous	1,450	0.162
b. Shrub	30	.003
c. Litter	2,060	.231
Downed woody		
d. 0 to ¼	110	.012
e. ¼ to 3	4,590	.514
f. 3 +	7,200	.807
Subtotals		
Fines	3,650	.409
D. woody 0-3	4,700	.526

VEGETATION CHARACTERISTICS	
Shrub cover, %	6
Basal area, ft^2/acre	
Aspen	63
Conifer	3

FIRE RATING	
Intensity	LOW
Rate of spread	Low
Torching	Low
Resistance to control	Nil
Overall	Low
Probability of a successful burn	Moderate

STAND LOCATION	
National Forest	Bridger-Teton
Ranger District	Kemmerer
Drainage	**Bluejay** Creek
Photo date	September 1982

Fuel class: **Aspen/tall** forb — Stand No. 19

Community type: ***Populus tremuloides/Spiraea betulifolia***

FUEL LOADINGS	*Lb/acre*	*kg/m²*
a. Herbaceous	230	0.025
b. Shrub	980	.110
c. Litter	2,600	.292
Downed woody		
d. 0 to ¼	540	.060
e. ¼ to 3	4,690	.526
f. 3+	7,950	.891
Subtotals		
Fines	4,320	.484
D. woody 0-3	5,230	.586

VEGETATION CHARACTERISTICS	
Shrub cover, %	58
Basal area, ft²/acre	
Aspen	62
Conifer	2

FIRE RATING	
Intensity	Low
Rate of spread	Low
Torching	Low
Resistance to control	Low
Overall	Low
Probability of a successful burn	Moderate

STAND LOCATION	
National Forest	Bridger-Teton
Ranger District	Jackson
Drainage	Sheep Gulch
Photo date	September 1983

Fuel class: **Aspen/tall** forb — Stand No. **21**

Community type: *Populus tremuloides/Ligusticum filicinum*

FUEL LOADINGS	*Lb/acre*	*kg/m²*
a. Herbaceous	1,060	0.119
b. Shrub	40	.004
c. Litter	1,130	.127
Downed woody		
d. 0 to ¼	180	.020
e. ¼ to 3	16,030	1.797
f. 3+	59,510	6.670
Subtotals		
Fines	2,400	.270
D. woody 0-3	16,210	1.816

VEGETATION CHARACTERISTICS	
Shrub cover, %	3
Basal area, ft²/acre	
Aspen	203
Conifer	0

FIRE RATING	
Intensity	Low-Med
Rate of spread	Low
Torching	Low
Resistance to control	Medium
Overall	Low-Med
Probability of a successful burn	Moderate

STAND LOCATION	
National Forest	Btidger-Teton
Ranger District	Jackson
Drainage	Little Dry Cottonwood Creek
Photo date	September 1983

Fuel class: **Aspen/tall** forb Stand No. 25
Community type: ***Populus tremuloides/Calamagrostis rubescens***

FUEL LOADINGS	*Lb/acre*	*kg/m²*
a. Herbaceous	1,030	0.116
b. Shrub	440	.049
c. Litter	2,240	.251
Downed woody		
d. 0 to ¼	270	.030
e. ¼ to 3	1,240	.139
f. 3+	0	0
Subtotals		
Fines	3,890	.435
D. woody 0-3	1,510	.169

VEGETATION CHARACTERISTICS	
Shrub cover, %	21
Basal area, ft²/acre	
Aspen	107
Conifer	0

FIRE RATING	
Intensity	Low
Rate of spread	Low
Torching	Nil
Resistance to control	Low
Overall	Low
Probability of a successful burn	Moderate

STAND LOCATION	
National Forest	Bridger-Teton
Ranger District	Jackson
Drainage	Horsetail Creek
Photo date	September 1982

Fuel class: Aspen/tall forb — Stand No. 31

Community type: *Populus tremuloides/Rudbeckia occidentalis*

FUEL LOADINGS

	Lb/acre	kg/m²
a. Herbaceous	790	0.088
b. Shrub	0	0
c. Litter	1,150	.129
Downed woody		
d. 0 to ¼	160	.018
e. ¼ to 3	9,100	1.020
f. 3+	11,710	1.312
Subtotals		
Fines	2,100	.235
D. woody 0-3	9,260	1.038

VEGETATION CHARACTERISTICS

Shrub cover, %	0
Basal area, ft²/acre	
Aspen	63
Conifer	0

FIRE RATING

Intensity	Nil
Rate of spread	Nil
Torching	Nil
Resistance to control	Nil
Overall	Nil
Probability of a successful burn	Low

STAND LOCATION

National Forest	Caribou
Ranger District	Soda Springs
Drainage	Diamond Creek
Photo date	September 1983

ASPEN/LOW FORB

Aspen dominates the overstory. It occupies at least 50 percent of the canopy, and typically 80 to 100 percent of it. Shrubs are sparse. Shrub coverage is less than 30 percent and frequently less than 10 percent. Productivity of herbaceous vegetation is low, usually less than 900 lb/acre/yr. Plants commonly encountered in this fuel type include *Poa* sp., *Arnica cordifolia, Geranium* sp., and *Berberis repens.*

Fuel class: Aspen/low forb — Stand No. 7

Community type: *Populus tremuloides/Berberis repens*

FUEL LOADINGS	Lb/acre	kg/m²
a. Herbaceous	280	0.031
b. Shrub	330	.037
c. Litter	2,000	.225
Downed woody		
d. 0 to ¼	370	.042
e. ¼ to 3	4,550	.510
f. 3+	2,370	.266
Subtotals		
Fines	2,980	.335
D. woody 0-3	4,920	.552

VEGETATION CHARACTERISTICS	
Shrub cover, %	18
Basal area, ft²/acre	
Aspen	140
Conifer	0

FIRE RATING	
Intensity	Low
Rate of spread	Low
Torching	Nil
Resistance to control	Low
Overall	Low
Probability of a successful burn	Low

STAND LOCATION	
National Forest	Bridger-Teton
Ranger District	Kemmerer
Drainage	Fontenelle Creek
Photo date	September 1983

Fuel class: Aspenllow forb　　　　Stand No. 8

Community type: ***Populus tremuloides/Arnica*** cordifolia

FUEL LOADINGS	Lb/acre	kg/m²
a. Herbaceous	180	0.02
b. Shrub	0	0
c. Litter	2,740	.307
Downed woody		
d. 0 to ¼	420	.047
e. ¼ to 3	5,680	.636
f. 3+	5,840	.654
Subtotals		
Fines	3,330	.374
D. woody 0-3	6,100	.683

VEGETATION CHARACTERISTICS	
Shrub cover, %	0
Basal area, ft²/acre	
Aspen	143
Conifer	0

FIRE RATING	
Intensity	Nil
Rate of spread	Nil
Torching	Nil
Resistance to control	Nil
Overall	Nil
Probability of a successful burn	Low

STAND LOCATION	
National Forest	Bridger-Teton
Ranger District	Kemmerer
Drainage	Little Fall Creek
Photo date	September 1983

MIXED/SHRUB

Conifers comprise more than 50 percent of the overstory, but aspen is still a substantial component. Shrub coverage comprised of tall or low shrubs is 30 percent or more.

Fuel class: Mixedlshrub Stand No. 17

Community type: *Populus tremuloides-Pseudotsuga menziesii/Spiraea* betulifolia

FUEL LOADINGS	*Lb/acre*	*kg/m²*	FIRE RATING	
a. Herbaceous	80	0.010	Intensity	Medium
b. Shrub	2,480	.278	Rate of spread	Medium
c. Litter	2,040	.228	Torching	Medium
Downed woody			Resistance to control	Medium
d. 0 to ¼	1,250	.140		
e. ¼ to 3	7,130	.800	Overall	Medium
f. 3+	1,280	.143	Probability of a successful burn	High
Subtotals				
Fines	4,850	.543		
D. woody 0-3	8,380	.940		

VEGETATION CHARACTERISTICS		STAND LOCATION	
Shrub cover, %	56	National Forest	Bridger-Teton
Basal area, ft²/acre		Ranger District	Greys River
Aspen	101	Drainage	Greys River
Conifer	70	Photo date	August 1982

Fuel class: Mixedlshrub

Stand No. 29

Community type: ***Populus tremuloides-Pseudotsuga menziesii/Spiraea betulifolia***

FUEL LOADINGS

	Lb/acre	*kg/m²*
a. Herbaceous	90	0.011
b. Shrub	3,670	.411
c. Litter	1,920	.215
Downed woody		
d. 0 to ¼	630	.070
e. ¼ to 3	4,920	.551
f. 3+	3,400	.381
Subtotals		
Fines	5,020	.563
D. woody 0-3	5,550	.622

VEGETATION CHARACTERISTICS

Shrub cover, %	70
Basal area, ft^2/acre	
Aspen	46
Conifer	37

FIRE RATING

Intensity	Medium
Rate of spread	Medium
Torching	Medium
Resistance to control	Medium
Overall	Medium
Probability of a successful burn	High

STAND LOCATION

National Forest	Bridger-Teton
Ranger District	Greys River
Drainage	Greys Rivet
Photo date	September 1983

MIXED/FORBS

Conifers comprise more than 50 percent of the overstory, but aspen is still a substantial component. Shrub coverage is less than 30 percent. Herbaceous vegetation is often poorly developed. Productivity is low, usually less than 800 Iblacrelyr. Stands No. 1 and 29 illustrate heavy accumulations of downed woody material, which raises the flammability ratings of these and similar stands.

Fuel class: Mixedlforb — Stand No. 1

Community type: *Populus tremuloides-Abies lasiocarpa/Arnica cordifolia*

FUEL LOADINGS	*Lb/acre*	*kg/m²*
a. Herbaceous	50	0.005
b. Shrub	80	.008
c. Litter	3,660	.411
Downed woody		
d. 0 to ¼	2,070	.232
e. ¼ to 3	12,400	1.390
f 3+	52,440	5.877
Subtotals		
Fines	5,860	.656
D. woody 0-3	14,470	1.622

VEGETATION CHARACTERISTICS	
Shrub cover, %	4
Basal area, ft²/acre	
Aspen	37
Conifer	160

FIRE RATING	
Intensity	High
Rate of spread	Medium
Torching	High
Resistance to control	High
Overall	High
Probability of a successful burn	High

STAND LOCATION	
National Forest	Bridger-Teton
Ranger District	Kemmerer
Drainage	Bluejay Creek
Photo date	August 1982

Fuel class: Mixedlforb — Stand No. 3

Community type: *Populus tremuloides-Abies lasiocarpa/Arnica cordifolia*

FUEL LOADINGS

	Lb/acre	kg/m2
a. Herbaceous	260	0.030
b. Shrub	100	.011
c. Litter	2,310	.259
Downed woody		
d. 0 to ¼	260	.030
e. ¼ to 3	3,830	.429
f. 3+	8,620	.966
Subtotals		
Fines	2,930	.329
D. woody 0-3	4,090	.459

VEGETATION CHARACTERISTICS

Shrub cover, %	14
Basal area, ft²/acre	
Aspen	79
Conifer	42

FIRE RATING

Intensity	Low
Rate of spread	Low
Torching	Low
Resistance to control	Nil
Overall	Low
Probability of a successful burn	Low

STAND LOCATION

National Forest	Bridger-Teton
Ranger District	Kemrnerer
Drainage	Little Bear Creek
Photo date	August 1982

Fuel class: Mixedlforb — Stand No. 16

Community type: ***Populus tremuloides-Abies lasiocarpa/Arnica*** cordifolia

FUEL LOADINGS	*Lb/acre*	*kg/m²*
a. Herbaceous	10	0.001
b. Shrub	480	.054
c. Litter	2,560	.287
Downed woody		
d. 0 to ¼	260	.029
e. ¼ to 3	5,010	.561
f. 3+	9,490	1.064
Subtotals		
Fines	3,020	.339
D. woody 0-3	5,270	.590

VEGETATION CHARACTERISTICS	
Shrub cover, %	7
Basal area, ft²/acre	
Aspen	118
Conifer	63

FIRE RATING	
Intensity	Medium
Rate of spread	Low
Torching	Medium
Resistance to control	Low
Overall	Low-Med
Probability of a successful burn	Moderate

STAND LOCATION	
National Forest	Bridger-Teton
Ranger District	Greys River
Drainage	Smith Fork
Photo date	August 1982

Fuel class: Mixedlforb Stand No. **28**

Community type: *Populus tremuloides-Pinus contorta/Calamagrostis rubescens*

FUEL LOADINGS	Lb/acre	kg/m²
a. Herbaceous	550	0.062
b. Shrub	1,400	.157
c. Litter	1,260	.141
Downed woody		
d. 0 to ¼	400	.045
e. ¼ to 3	10,120	1.134
f. 3+	31,040	3.479
Subtotals		
Fines	3,150	.354
D. woody 0-3	10,520	1.179

VEGETATION CHARACTERISTICS	
Shrub cover, %	19
Basal area, ft²/acre	
Aspen	59
Conifer	21

FIRE RATING	
Intensity	Medium
Rate of spread	Medium
Torching	Low
Resistance to control	Medium
Overall	Medium
Probability of a successful burn	Moderate

STAND LOCATION	
National Forest	Caribou
Ranger District	Soda Springs
Drainage	Slug Creek
Photo date	September 1983

FUEL CHARACTERISTICS

A summary of data from the sampled stands (table **2**) illustrates several important differences and similarities among the fuel classes:

1. Shrubs contributed significantly to fine fuel loadings, as shown by comparing fine fuel loadings and shrub coverages.

2. Fine fuel loadings differed substantially between the shrub and forb understory types and between the aspenltall forb and aspenllow forb types.

3. Herbaceous vegetation in the aspenltall forb class averaged two to four times greater than in the other classes.

4. Litter loadings differed greatly among individual stands within types, but the average difference among types was small and not meaningful.

5. Loadings of downed woody fuel 0 to **1** inch and 0 to **3** inches in diameter also varied substantially from stand to stand. The mixed types appear to have slightly more downed woody fuel than the other types, which is understandable because conifer crowns shed more small dead twigs and branches than aspen. However, considering the variation among stands, the differences among types appear insignificant. This emphasizes a need to appraise downed woody fuels on an individual stand basis.

6. Differences in dead fuel loading between the aspenlshrub and mixedlshrub types are small. Nevertheless, these types should be regarded separately because conifers in the mixed type are likely to torch, thus creating a more intense fire. Similarly, the aspenllow forb and mixedllow forb classes should remain distinct, even though differences in dead fuel loadings are reasonably small.

Predicted fireline intensities for typical late summer conditions (fig. **1**) reflect the differences among fuel types due to fine fuel loadings, particularly the high herbaceous component (table **2**). In general, the aspenlshrub type is the most flammable, followed by mixedlshrub. The aspenltall forb type has about one-half the fire intensity potential of aspenlshrub. The aspenllow forb and mixedlforb types are the least flammable. The relative differences among fuel types remain about the same over a range of windspeeds, live fuel moisture contents, and curing percentages normally experienced during late summer and early fall.

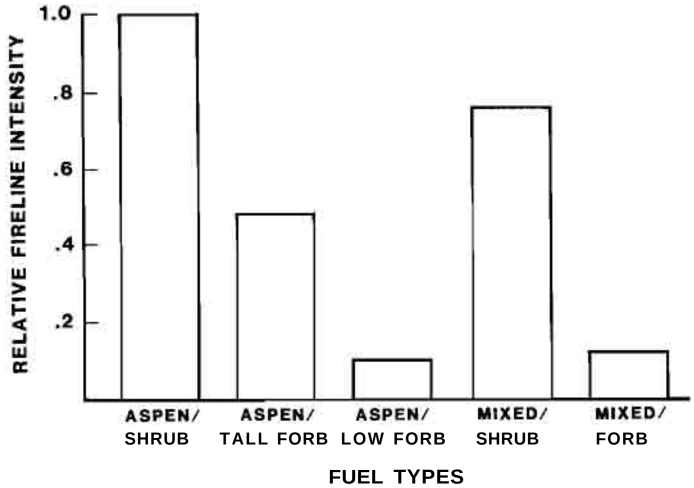

Figure 1.—Fireline intensity calculated under the assumption that 50 percent of the herbaceous vegetation is cured, fine fuel moisture content is 8 percent, slope is 0 percent, and midflame windspeed is 4 mi/h. The intensities are relative, being expressed as a fraction of the intensity for aspenlshrub.

Table 2.—Average fuel loadings and shrub cover from sampled stands representing the aspen fuel types. Ranges in values are in parentheses

Fuel	Aspen/ shrub	Aspen/ tall forb	Aspen/ low forb	Mixed/ shrub	Mixed/ forb
			Lb/acre		
Herbaceous	670 (230 to 1,000)	1,330 (1,030 to 2,020)	300 (180 to 460)	90 (80 to 90)	290 (10 to 550)
Shrubs[1]	3,170 (980 to 6,150)	110 (0 to 440)	260 (0 to 630)	3,040 (2,480 to 3,610)	630 (100 to 1,350)
Litter	1,810 (420 to 2,810)	1,600 (790 to 2,240)	1,350 (170 to 2,740)	1,980 (1,920 to 2,040)	1,680 (740 to 2,560)
Fines[2]	6,140 (4,030 to 9,390)	3,170 (1,970 to 3,990)	2,430 (1,640 to 3,330)	6,050 (5,850 to 6,250)	3,070 (2,150 to 3,560)
Downed woody 0 to 1 inch	2,440 (710 to 4,220)	1,080 (620 to 1,440)	2,600 (1,460 to 3,690)	4,240 (3,400 to 5,080)	2,710 (1,440 to 3,900)
Downed woody 0 to 3 inch	7,020 (3,580 to 12,510)	7,340 (1,510 to 16,210)	5,720 (3,290 to 7,600)	6,970 (5,550 to 8,390)	7,810 (4,090 to 12,250)
			Percent		
Shrub cover	40 (30 - 60)	10 (0 - 20)	10 (0 - 30)	60 (60 - 70)	20 (10 - 30)

[1]Shrubs include foliage and stemwood.
[2]Fines include live and dead herbaceous plants and shrubs, litter, and 0- to ¼-inch downed woody fuel

Appraising Flammability

Flammability is altered by many factors, some of which are difficult to evaluate analytically. The approaches presented here to appraising flammability involve expert opinion and mathematical prediction of fire behavior. Each approach has advantages and disadvantages. The appraisals differ in form and are useful in different ways.

PROBABILITY OF SUCCESSFUL BURNING

The probability-of-success ratings in table 3 reflect the influence of grazing and quantities of downed woody fuel.

The grazing and fuel conditions are as follows:

Ungrazed - very light or no grazing

Grazed - moderately or heavily grazed

Light downed woody fuel - average or less than average accumulations

Heavy downed woody fuel - much greater than average accumulations

In planning prescribed fires, categories rated as poor success suggest situations that should be avoided. Other means of disturbance, particularly cutting, should be used if possible. Efforts to use prescribed fire in aspen should focus on situations having moderate to high probabilities of success. The aspenlshrub and mixedlshrub fuel types provide the best opportunities. The aspenltall forb and mixedlforb fuel types provide marginal opportunities. Careful appraisal of individual sites is essential in these fuel types to determine whether a successful prescription can be written.

FIRE POTENTIAL RATINGS

The fire intensity and rate-of-spread ratings determined for each sampled plot were summarized for the fuel types and combinations of grazing intensity and downed woody fuel accumulations (table 4).

General trends from table 4 are:

1. The mixedlforb class has higher fire potential than the aspenllow forb class due to differences in downed woody fuel loadings and torching potentials. The differences between these two classes are greater in table 4 than indicated by the fire behavior predictions.
2. Grazing reduces fire intensity and rate of spread by at least one rating level.
3. Heavy fuel loadings result in increased intensities except where substantial grazing is expected.
4. Heavy fuel loadings increase rate of spread in stands with mixed overstories, but not aspen overstories.

Table 3.—Probabilities of successfully applying prescribed fire in aspen forests according to fuel types and the influence of grazing and quantities of downed woody material

Grazing	Woody fuel	Fuel types Aspen/ shrub	Aspen/ tall forb	Aspen/ low forb	Mixed/ shrub	Mixed/ forb
Ungrazed	Light	high	moderate	low	high	moderate
Ungrazed	Heavy	high	moderate	low	high	high
Grazed	Light	moderate	low	low	moderate	low
Grazed	Heavy	high	low	low	high	moderate

Table 4.—Fire intensity and rate of spread adjective ratings according to fuel types, grazing intensity, and downed woody fuel quantities. The first rating is for intensity and the second for rate of spread. **H,** M, L, N mean high, moderate, low, and nil, respectively

Grazing	Woody fuel	Fuel types Aspenl shrub	Aspenl tall forb	Aspenl low forb	Mixedl shrub	Mixedl forb
Ungrazed	Light	M-M	L-L	N-N	M-M	L-L
Ungrazed	Heavy	H-M	M-L	L-L	H-H	M-M
Grazed	Light	L-L	N-N	N-N	L-L	N-N
Grazed	Heavy	M-L	N-N	N-N	M-L	L-L

FIRE BEHAVIOR PREDICTIONS

Fireline intensity (table 5) and rate-of-spread (table 6) values were determined for the aspen fuel types using the BEHAVE fire behavior prediction and fuel modeling system (described in detail later). Tables 5 and 6 show variation in fire behavior by fuel types, midflame windspeed, fine dead fuel moisture content, and level of curing. They are based on a live fuel moisture content of 150 percent for herbaceous vegetation and 55 to 85 percent for live woody plants. These moisture contents represent late summer and early fall conditions. Tables 5 and 6, adjusted for 20-ft wind and slope, can be used to judge the likelihood of achieving successful prescribed fires and to determine a range in level of curing, fine fuel moisture content, windspeed, and slope for preparing fire prescriptions.

The fine fuel moisture contents in tables 5 and 6 reflect the range in moistures over which prescribed burning may be possible. The 1- and 10-hour timelag fuel categories are the standard size classes of 0 to ¼ inch and ¼ to 1 inch used in fire-danger rating and fire behavior prediction (Rothermel 1983). In these tables, the 10-hour fuel moisture contents were set slightly higher than the 1-hour moisture contents because this reflects typical field conditions. Fire behavior can be readily interpolated between fuel moisture levels in the tables.

Table 5. (Con.)—Aspen/tall forb fuel type

Fuel moisture 1-h	Fuel moisture 10-h	Midflame windspeed (mi/h) 0	1	2	3	4	5	6	8	10	12	14	16	18
Pct		*Btu/ft/s*												
30 percent cured														
4	6	2	5	10	17	25	35	46	75	105	140	175	220	265
8	10	2	4	7	12	18	26	34	50	75	100	130	160	195
12	14	2	3	6	11	16	22	29	46	65	90	110	140	170
16	18	2	3	6	10	15	21	28	44	60	85	105	130	160
50 percent cured														
4	6	3	7	13	23	34	48	65	100	140	190	240	300	360
8	10	2	5	9	16	24	34	44	70	100	130	170	210	255
12	14	2	4	8	14	20	28	38	60	85	110	145	180	215
16	18	2	3	7	11	17	24	32	50	70	95	120	150	180
70 percent cured														
4	6	5	9	19	32	48	65	90	140	195	260	335	415	505
8	10	3	6	13	21	32	45	60	95	135	180	225	280	340
12	14	3	5	10	18	27	38	50	80	110	150	190	235	285
16	18	2	4	9	15	22	31	41	65	90	120	155	195	235
90 percent cured														
4	6	7	14	27	46	70	100	130	200	290	385	495	610	740
8	10	4	8	17	29	44	60	80	130	180	244	310	385	465
12	14	4	7	14	24	36	50	65	105	150	200	255	315	380
16	18	3	6	12	20	29	41	55	85	120	160	205	255	310

(con.)

Table 5.—Fireline intensity, Aspen/shrub fuel type

Fuel moisture 1-h	Fuel moisture 10-h	Midflame windspeed (mi/h) 0	1	2	3	4	5	6	8	10	12	14	16	18
Pct		*Btu/ft/s*												
30 percent cured														
4	6	4	9	19	32	48	65	85	135	190	250	315	385	460
8	10	3	7	14	24	36	50	65	100	140	185	235	285	345
12	14	3	6	12	21	31	43	55	85	120	160	205	250	300
16	18	2	5	11	18	27	37	49	75	105	140	175	215	260
50 percent cured														
4	6	6	14	28	47	70	95	125	195	275	360	455	560	675
8	10	4	10	20	34	50	70	90	140	195	260	330	405	485
12	14	4	8	17	28	42	60	75	120	165	220	275	340	410
16	18	3	7	14	24	35	49	65	100	140	180	230	285	340
70 percent cured														
4	6	9	19	40	70	100	140	180	280	395	525	665	815	980
8	10	6	14	28	47	70	100	130	195	275	365	465	570	685
12	14	5	11	23	40	60	80	105	165	230	305	390	475	575
16	18	4	9	19	32	48	65	85	135	190	250	315	390	465
90 percent cured														
4	6	13	28	60	100	150	205	270	415	585	770	980	1,205	1,450
8	10	9	19	40	65	100	140	180	280	395	525	665	815	980
12	14	7	16	33	55	85	115	150	230	325	430	550	675	810
16	18	6	13	27	45	65	95	120	190	265	350	445	550	660

(con.)

Table 5. (Con.)—**Aspenllow forb** fuel type

Fuel moisture		Midflame windspeed (milh)												
1-h	10-h	0	1	2	3	4	5	6	8	10	12	14	16	18
Pct		Btu/ft/s												
		30 percent cured												
4	6	1	2	3	5	7	9	11	16	22	28	34	41	48
8	10	1	1	2	3	5	6	8	11	15	19	24	29	34
12	14	0	1	2	3	4	5	6	10	13	16	20	24	29
16	18	0	1	2	2	3	4	5	8	11	14	17	20	24
		50 percent cured												
4	6	1	2	4	6	8	10	13	19	25	32	40	48	55
8	10	1	1	2	4	5	7	9	13	17	22	27	32	38
12	14	1	1	2	3	4	6	7	11	14	18	23	27	32
16	18	0	1	2	3	4	5	6	9	12	15	19	22	26
		70 percent cured												
4	6	1	2	4	6	9	12	15	22	30	38	47	55	65
8	10	1	2	3	4	6	8	10	15	20	25	31	37	44
12	14	1	1	2	4	5	7	8	12	16	21	25	31	36
16	18	1	1	2	3	4	5	7	10	13	17	21	25	30
		90 percent cured												
4	6	1	3	5	8	12	15	19	28	38	48	60	70	85
8	10	1	2	3	5	7	10	12	18	24	30	37	44	50
12	14	1	1	3	4	6	8	10	14	19	24	30	35	42
16	18	1	1	2	3	5	6	8	11	15	19	24	29	34

(con.)

Table 5. (Con.)—**Mixedlshrub** fuel type

Fuel moisture		Midflame windspeed (milh)												
1-h	10-h	0	1	2	3	4	5	6	8	10	12	14	16	18
Pct		Btu/ft/s												
		30 percent cured												
4	6	4	8	16	26	38	50	65	100	140	185	230	280	330
8	10	3	6	12	19	28	39	50	75	105	135	170	205	245
12	14	2	5	10	16	24	33	42	65	90	115	145	175	210
16	18	2	4	8	14	20	27	35	55	75	95	120	145	175
		50 percent cured												
4	6	5	11	22	36	55	70	90	140	190	250	310	380	450
8	10	4	8	16	26	38	50	65	100	135	180	225	270	325
12	14	3	7	13	22	32	43	55	85	115	150	190	230	275
16	18	2	6	11	18	26	35	46	70	95	125	155	185	220
		70 percent cured												
4	6	7	15	29	48	70	95	125	185	255	330	415	510	605
8	10	5	10	20	35	49	65	85	130	180	235	290	355	420
12	14	4	9	17	28	41	55	70	110	150	195	245	300	355
16	18	3	7	14	23	36	46	60	90	120	160	200	245	290
		90 percent cured												
4	6	9	20	40	65	95	130	165	255	350	460	575	700	835
8	10	6	13	26	43	65	85	110	165	230	300	380	465	550
12	14	5	11	22	36	50	70	90	140	190	250	315	385	455
16	18	4	9	18	29	42	60	75	115	155	205	255	315	375

(con.)

Table 5. (Con.)—Mixedlforb fuel type

Fuel moisture		Midflame windspeed (mi/h)												
1-h	10-h	0	1	2	3	4	5	6	8	10	12	14	16	18
-- *Pct* --		*Btu/ft/s*												
		30 percent cured												
4	6	1	2	4	6	8	11	14	20	27	34	42	50	60
8	10	1	1	3	4	6	7	9	14	18	23	29	34	40
12	14	1	1	2	3	5	6	8	12	15	20	24	29	34
16	18	1	1	2	3	4	5	6	10	13	16	20	24	28
		50 percent cured												
4	6	1	2	4	7	10	13	16	23	31	39	48	60	70
8	10	1	2	3	4	6	8	10	15	21	26	32	38	45
12	14	1	1	2	4	5	7	9	13	17	22	27	32	38
16	18	1	1	2	3	4	6	7	11	14	18	22	27	31
		70 percent cured												
4	6	1	3	5	8	11	15	19	27	36	46	55	70	80
8	10	1	2	3	5	7	10	12	17	23	30	37	44	50
12	14	1	2	3	4	6	8	10	14	19	24	30	36	42
16	18	1	1	2	4	5	6	8	12	16	20	27	30	35
		90 percent cured												
4	6	2	4	6	10	14	18	23	33	44	55	70	85	95
8	10	1	2	4	6	8	11	14	20	27	35	43	50	60
12	14	1	2	3	5	7	9	11	16	22	28	34	41	48
16	18	1	1	2	4	6	7	9	13	18	22	28	33	39

Table 6.—Rate of spread, Aspenlshrub fuel type

Fuel moisture		Midflame windspeed (mi/h)												
1-h	10-h	0	1	2	3	4	5	6	8	10	12	14	16	18
-- *Pct* --		*Ftlmin*												
		30 percent cured												
4	6	1	1	3	5	7	9	12	19	26	35	44	54	65
8	10	1	1	2	4	6	8	10	16	23	30	38	46	56
12	14	<1	1	2	4	5	7	10	15	21	28	35	43	51
16	18	<1	1	2	3	5	7	9	14	19	25	32	39	47
		50 percent cured												
4	6	1	2	4	6	9	13	17	26	36	48	60	74	89
8	10	1	1	3	5	8	11	14	21	30	40	50	62	74
12	14	1	1	3	5	7	10	13	19	27	36	45	56	67
16	18	1	1	2	4	6	9	11	17	24	32	41	50	60
		70 percent cured												
4	6	1	2	5	9	13	18	23	35	50	66	84	103	124
8	10	1	2	4	7	10	14	19	29	41	54	68	84	100
12	14	1	2	4	6	9	13	17	26	36	48	60	74	89
16	18	1	2	3	5	8	11	15	22	32	42	53	65	78
		90 percent cured												
4	6	2	3	7	12	18	24	32	49	69	92	117	144	173
8	10	1	3	5	9	14	19	25	39	55	72	92	113	136
12	14	1	2	5	8	12	17	22	34	48	63	80	99	118
16	18	1	2	4	7	10	15	19	29	41	55	70	86	103

(con.)

Table 6. (Con.)—**Aspen/tall forb fuel type**

Fuel moisture		Midflame windspeed (mi/h)												
1-h	10-h	0	1	2	3	4	5	6	8	10	12	14	16	18
-- *Pct* --		*Ft/min*												
						30 percent cured								
4	6	<1	1	2	3	4	6	8	12	17	23	30	37	45
8	10	<1	1	1	2	4	5	7	10	15	20	25	31	38
12	14	<1	1	1	2	3	5	6	10	14	18	23	29	35
16	18	<1	1	1	2	3	4	6	9	13	18	22	28	34
						50 percent cured								
4	6	1	1	2	4	6	8	10	16	23	31	39	48	59
8	10	<1	1	2	3	5	6	8	13	19	25	32	40	48
12	14	<1	1	2	3	4	6	8	12	17	23	29	36	43
16	18	<1	1	1	2	4	5	7	11	15	20	26	32	39
						70 percent cured								
4	6	1	1	3	5	8	11	14	22	31	42	53	66	80
8	10	1	1	2	4	6	8	11	18	25	33	43	52	64
12	14	1	1	2	4	5	8	10	16	22	30	38	47	57
16	18	<1	1	2	3	5	7	9	14	20	26	33	41	50
						90 percent cured								
4	6	1	2	4	7	11	16	21	33	46	62	79	98	119
8	10	1	2	3	6	9	12	16	25	35	47	60	74	90
12	14	1	1	3	5	7	10	14	21	30	40	52	64	77
16	18	1	1	2	4	6	9	12	18	26	35	45	55	67

(con.)

Table 6. (Con.)—Aspen/low forb fuel type

Fuel moisture		Midflame windspeed (mi/h)												
1-h	10-h	0	1	2	3	4	5	6	8	10	12	14	16	18
Pct		*Ft/min*												
						30 percent cured								
4	6	<1	<1	1	1	2	2	3	4	5	7	8	10	11
8	10	<1	<1	1	1	1	2	2	3	4	5	7	8	9
12	14	<1	<1	1	1	1	2	2	3	4	5	6	7	8
16	18	<1	<1	<1	1	1	1	2	2	3	4	5	6	7
						50 percent cured								
4	6	<1	<1	1	1	2	2	3	4	6	7	9	11	13
8	10	<1	<1	1	1	1	2	2	4	5	6	7	9	11
12	14	<1	<1	1	1	1	2	2	3	4	5	7	8	9
16	18	<1	<1	1	1	1	2	2	3	4	5	6	7	8
						70 percent cured								
4	6	<1	1	1	2	2	3	4	5	7	9	11	14	16
8	10	<1	<1	1	1	2	2	3	4	6	7	9	10	12
12	14	<1	<1	1	1	1	2	2	4	5	6	8	9	11
16	18	<1	<1	1	1	1	2	2	3	4	5	7	8	9
						90 percent cured								
4	6	<1	1	1	2	3	4	5	7	9	12	14	17	20
8	10	<1	1	1	1	2	3	3	5	7	9	11	13	15
12	14	<1	<1	1	1	2	2	3	4	6	7	9	11	13
16	18	<1	<1	1	1	2	2	3	4	5	6	8	9	12

(con.)

Table 6. (Con.) — Mixedlshrub fuel type

Fuel moisture		Midflame windspeed (rnilh)												
1-h	10-h	0	1	2	3	4	5	6	8	10	12	14	16	18
Pct --	--					---------- Ft/min ----------								
						30 percent cured								
4	6	< 1	1	2	3	5	7	9	13	18	24	30	36	43
8	10	< 1	1	2	3	4	6	7	11	16	20	25	31	37
12	14	< 1	1	2	3	4	5	7	10	14	18	23	28	33
16	18	< 1	1	1	2	4	5	6	9	13	17	21	25	30
						50 percent cured								
4	6	1	1	3	5	7	9	12	17	24	31	39	47	56
8	10	1	1	2	4	5	7	10	14	20	26	32	39	47
12	14	< 1	1	2	3	5	7	9	13	18	23	29	35	42
16	18	< 1	1	2	3	4	6	8	11	16	21	26	31	37
						70 percent cured								
4	6	1	2	4	6	9	12	15	23	31	41	51	63	74
8	10	1	1	3	5	7	9	12	18	25	33	42	51	60
12	14	1	1	3	4	6	8	11	16	23	29	37	45	53
16	18	1	1	2	4	5	7	10	14	20	26	32	39	47
						90 percent cured								
4	6	1	2	5	8	11	15	20	30	42	54	68	83	99
8	10	1	2	4	6	9	12	15	23	32	42	52	64	76
12	14	1	2	3	5	8	10	13	20	28	36	46	56	66
16	18	1	1	3	4	7	9	12	17	24	32	40	48	58

(con.)

Table 6. (Con.) — Mixedlforb fuel type

Fuel moisture		Midflarne windspeed (rnilh)												
1-h	10-h	0	1	2	3	4	5	6	8	10	12	14	16	18
Pct --	——					---------- Ft/min ----------								
						30 percent cured								
4	6	< 1	< 1	1	1	2	2	3	4	5	7	9	10	12
8	10	< 1	< 1	1	1	1	2	2	3	4	6	7	8	10
12	14	< 1	< 1	1	1	1	2	2	3	4	5	6	7	9
16	18	< 1	< 1	< 1	1	1	1	2	3	3	4	5	7	8
						50 percent cured								
4	6	< 1	< 1	1	1	2	3	3	5	6	8	10	12	14
8	10	< 1	< 1	1	1	2	2	3	4	5	6	8	9	11
12	14	< 1	< 1	1	1	1	2	2	3	4	6	7	8	10
16	18	< 1	< 1	1	1	1	2	2	3	4	5	6	7	9
						70 percent cured								
4	6	< 1	1	1	2	2	3	4	6	7	10	12	14	16
8	10	< 1	< 1	1	1	2	2	3	4	6	7	9	11	13
12	14	< 1	< 1	1	1	2	2	3	4	5	6	8	9	11
16	18	< 1	< 1	1	1	1	2	2	3	4	5	7	8	10
						90 percent cured								
4	6	< 1	1	1	2	3	4	5	7	9	12	15	17	20
8	10	< 1	< 1	1	2	2	3	4	5	7	9	11	13	15
12	14	< 1	< 1	1	1	2	2	3	4	6	7	9	11	13
16	18	< 1	< 1	1	1	2	2	3	4	5	6	8	9	11

Windspeeds are for midflame heights. They can be related to winds 20 ft above vegetation in order to use weather forecasts and prepare fire prescriptions. Table 7, condensed from Rothermel (1983), shows the correspondence between windspeeds at midflame and 20-ft heights. Fuels in aspen stands can be exposed, partially sheltered, or fully sheltered depending on canopy closure and topography. Usually aspen stands are partially sheltered or fully sheltered. Winds 20 ft above vegetation are frequently 2 to 4 times greater than at midflame height. Whether windspeeds will be adequate to sustain fire spread can be a major obstacle in prescribed burning of aspen. Stands topographically protected from prevailing winds can be especially troublesome to burn.

The effects of slope on fireline intensity and rate of spread are included in a new artificial windspeed called effective windspeed (fig. 2). Topographic slope has the same effect as increased windspeed in the fire behavior predictions presented here. To determine an effective windspeed that corresponds to a given wind and slope in figure 2, extend a vertical line from a chosen slope percentage until it intersects a midflame windspeed line of interest. Then extend a line horizontally to meet the y axis where an effective windspeed is read. For example, a 2-milh windspeed on a 60 percent slope is effectively the same as a 4.6-milh windspeed on the flat. Use effective windspeed by entering it at the top of tables 5 and 6.

A reverse process can be followed in figure 2 to determine a midflame windspeed that corresponds to an effective windspeed at a given slope. This process can help in writing fire prescriptions. Minimum windspeeds for fire prescriptions that correspond to minimally acceptable fireline intensities in table 5 can be determined from effective windspeeds that incorporate both wind and slope.

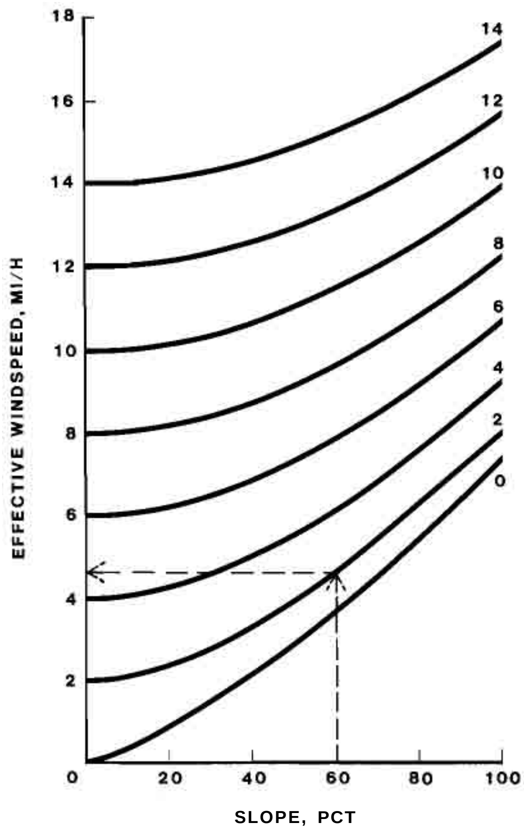

Figure 2.—Effective windspeed at midflame height for all of the aspen fuel models depends upon topographic slope. For example (shown by the dashed arrows), at a slope of 60 percent an actual midflame windspeed of 2 mi/h corresponds to an effective windspeed of 4.6 milh.

Table 7.—Wind adjustment table shows approximate midflame windspeeds for 20-ft windspeeds at the top of column[1]

Fuel exposure		20-ft windspeed (milh)						
		0-3	4-7	8-12	13-18	19.24	25-31	32-38
		Midflame windspeed (mi/h)						
EXPOSED FUELS Fuels exposed directly to wind—no overstory or sparse overstory; overstory without foliage; near clearings; on high ridges		1	2	4	6	9	11	14
PARTIALLY SHELTERED FUELS Fuels beneath patchy overstory canopies; beneath full canopies with wind blowing directly at the slope		1	2	3	5	7	8	11
FULLY SHELTERED FUELS Fuels beneath overstories on flat or gentle slopes	-Open stands	0	1	2	3	4	6	7
	-Dense stands	0	1	1	2	2	3	4

[1]Windspeed at 20 ft multiplied by wind adjustment factors gives midflame windspeed. Wind adjustment factors from Rothermel (1983) used to generate this table were exposed fuels, 0.4; partially sheltered fuels, 0.3; fully sheltered open stands, 0.2; fully sheltered dense stands, 0.1

Table 8.—Tabulation of curing levels, fine fuel moisture contents, and midflame windspeeds that provide at least the minimum fireline intensity of 28 Btulftls as an illustration of steps 2b, 2c, and 3

	Step 2b			Step 2c	Step 3
Curing	Fine fuel moisture (1-h)	Midflame windspeed	Fireline intensity	Minimum windspeed (20 ft)	Maximum windspeed (20 ft)
------ Percent ------		Milh	Btu/ft/s	-------- Milh --------	
50	4	2	28	0 - 5	20
50	8	3	34	6 - 11	25
50	12	3	28	6 - 11	25
50	16	4	35	12 - 17	25
70	4	2	40	0 - 5	20
70	8	2	28	0 - 5	25
70	12	3	40	6-11	25
70	16	3	32	6-11	25

Table 8, which was derived from figure 2 and table 7, simplifies the task of relating midflame windspeed to 20-ft windspeed and adjusting for slope by incorporating these relationships in one table. An example of determining a fire prescription using table 8 and a minimally acceptable fireline intensity is illustrated later.

Wind is assumed to blow directly at the slope and not from the sides for the intensity and spread rate values in tables 5 and 6. When winds blow across the slope, the intensities and spread rates are reduced depending on the angle of the wind across the slope. For winds blowing at a 45" angle to the slope, intensities and spread rates will only be reduced about 5 percent or less. This reduction is too small to be of practical significance and can be ignored. Winds blowing at 90° to the slope (directly across the slope) reduce fireline intensities and rates of spread from 5 to 25 percent, depending upon slope percentage and midflame windspeed (fig. 3). As a rule-of-thumb, reduce fireline intensity and rate of spread by 20 percent for winds blowing across slope. This small reduction may be significant when dealing with marginal intensities for successful prescribed fire. If predicted fireline intensities are not marginal for success, the adjustments can be disregarded.

Use the 30 percent curing level in tables 5 and 6 for curing less than 30 percent. Curing of vegetation from completely green to about 30 percent cured has little effect on fire behavior. As curing continues beyond 30 percent, however, fire behavior increases significantly for the aspenlshrub, aspenltall forb, and mixedlforb fuel types (fig. 4).

Fireline intensity in table 5 is the amount of heat released per second through a 1-ft wide swath of the fire front. Flame length, which is the distance between the tip of the flame and the ground midway in the zone of active flaming, relates directly to fireline intensity. Because flame length can be more easily visualized than fireline intensity, the relationship between the two variables is shown in figure 5.

More resolution in fire behavior prediction than provided here can be obtained using the BEHAVE computer programs (Burgan and Rothermel 1984; Andrews 1986). Suggestions for using BEHAVE with the aspen fuel types are discussed in the appendix.

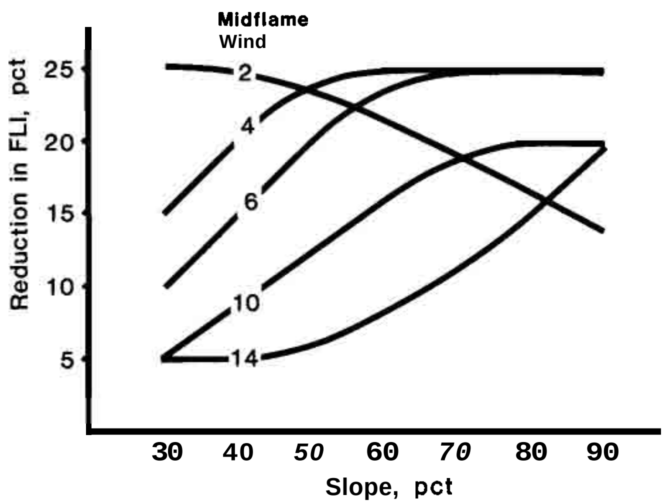

Figure 3.—Reduction in fireline intensity (FLI)due to winds blowing directly across the slope (90° to the slope), according to slope percentage and midflame windspeed.

LIMITATIONS

The fire behavior predictions must be interpreted with an awareness of limitations. The predictions are based on the assumption that fuels are uniform and continuous. The predictions apply to the propagating front of fire spreading in surface fuels. Crowning and spotting are not predicted by the model.

Perhaps the biggest limitation to planning prescribed fires in aspen forests is that a fire often will not spread even though the mathematical model predicts fire behavior. The values in tables 5 and 6 must be viewed as expected intensities and rates of spread providing fires will spread. Determining whether fire will sustain spread requires experience and judgment. Experience gathered in a study of fire in aspen (Brown and DeByle 1982) indicates that flame lengths should exceed 1 to 1.5 ft before sustained spread is possible. To accomplish this, herbaceous vegetation in the aspenlshrub and aspenltall forb types should be at least 50 percent cured.

Although the fire behavior predictions and ratings provided here are based on sound technical knowledge,

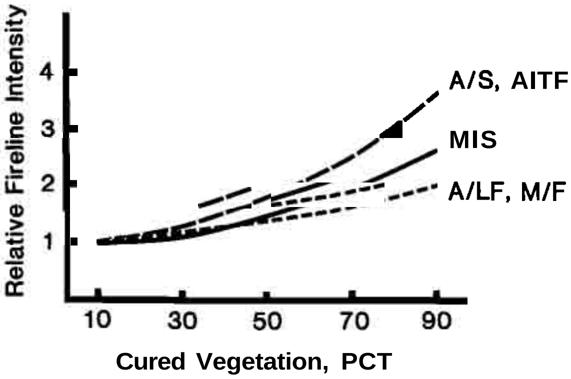

Figure 4.—Relative fireline intensities influenced by percentage of herbaceous vegetation that is cured. Relative intensities were calculated for each fuel type as the intensity at any curing level divided by the intensity at 0 percent curing. Fuel types are abbreviated as aspenlshrub · A/S, aspenltall forb · AITF, aspenllow forb · AILF, mixedlshrub · MIS, and mixedlforb · MIF. Assumed conditions were 4 milh windspeed and no slope. Moisture contents were 1- and 10-hour tirnelag, 4 and 6 percent; herbs, 150 percent; and live woody plants, 55 to 85 percent.

they are largely untested in aspen forests. The appraisals should be regarded as approximate and applied with full awareness of variability expected in predicting fire behavior in forest and rangeland situations. Accuracy of fire behavior predictions in aspen fuels is discussed further in the appendix.

OTHER FLAMMABILITY FACTORS

Factors in addition to those in tables 5 and 6 can alter fireline intensity and rate of spread: grazing, downed woody fuel accumulations, autumn leaf fall, small patches of conifers, canopy closure, and pocket gopher activity. Except for grazing, the influence of these factors on fireline intensity and rate of spread must be interpreted with judgment. The influence of these factors on flammability is discussed to assist in interpreting tables 5 and 6.

Grazing.—Grazing can greatly reduce flammability where herbaceous vegetation is a significant fuel. Our sampling showed a two-thirds reduction of herbaceous vegetation due to grazing in aspenlshrub and aspenltall forb types. Fire behavior predictions of this grazing impact resulted in fireline intensities that were 0.1 of the ungrazed situation. The grazing impact on fire intensity should be less in other aspen fuel types because grasses and forbs are a smaller component of the fine fuels. Nonetheless, the impact is substantial.

Fireline intensities and rates of spread can be adjusted for heavy grazing by multiplying the values in tables 5 and 6 by the following numbers:

Aspenlshrub	0.1
Aspenltall forb	0.1
Aspenllow forb	0.2
Mixedlshrub	0.2
Mixedllow forb	0.2

Heavy grazing, with few exceptions, negates the opportunity to use prescribed fire in aspen forests. Light grazing prior to burning may be possible, depending upon other factors influencing flammability. For example, mostly cured vegetation and high windspeed may overcome disruption of the fuel bed caused by grazing. Flammability in adjacent areas may be too high, however, to risk an escaped fire from a prescribed burn under these conditions.

Downed Woody Fuel.—Quantities of large downed woody fuels (pieces greater than 3 inches diameter) vary substantially between stands. Fivefold to tenfold differences in loading can be expected between stands. The influence of large woody fuel on fire behavior and fire effects can be substantial, but meaningful quantification of these influences has not been developed.

In mixed stands, accumulations of large woody fuels usually occur with ample quantities of small woody fuels (pieces less than 3 inches diameter). These accumulations contribute to torching of conifers, longer burnout times, and ignition of adjacent fuels. Chances of successful prescribed fire are enhanced by accumulations of large woody fuels. In aspen stands without overstory conifers, however, large woody fuels tend to be less important to fire behavior and successful burning because small woody fuel quantities are inadequate to ignite the large woody fuels (Brown and DeByle 1982).

Substantial quantities of small woody fuels increase fire intensity and hence chances for successful burning. Nevertheless. significant departures from the fireline intensities in table 5 would require extremely high or low quantities of small woody fuels. Such extremes in loading usually occur in patches within burn units, but are not representative of whole burn units.

Autumn Leaf Fall.—Leaf fall does not add greatly to flammability, but in marginal situations it can help sustain fire. The biggest benefit to prescribed burning may be by allowing increased windspeed within aspen stands. Leaf fall, however, often comes when fuel moistures are too high for burning due to rainfall and poor drying conditions.

Small Conifers.—If they can be ignited, patches of conifers in the understory of aspen stands can contribute to successful prescribed burning. Appraising this possibility requires judgment. Rating of fire potential and probabilities of success in the next sections reflect the contribution of conifers to flammability.

Canopy Closure.—Stands having open canopies are more flammable than closed canopies because understory grasses and forbs cure 2 to 4 weeks sooner. Windspeeds at the surface are greater due to reduced wind resistance.

Rodent Activity.—Large populations of pocket gophers reduce the chance of successful prescribed fire by creating mounds of mineral soil that break surface fuel continuity. High windspeeds may be necessary to overcome the fuel discontinuities caused by pocket gopher activity.

Determining Fire Prescriptions

The first step in determining fire prescriptions is to choose good burning opportunities. The previous section on appraising flammability shows that fire behavior varies considerably in aspen forests. Thus, careful attention to selecting sites capable of sustaining fire spread under prescribed conditions can greatly increase chances of successful prescribed fire.

Table **3** indicates the likelihood of successful prescribed fires according to fuel types. Recent research (Brown 1985) indicates that fires having flame lengths of at least 1.7 to 2.1 ft are required to kill aspen trees. Flame duration should be a minimum of 1 minute. Observations of several prescribed fires also indicate that fires of this intensity should spread unless fuel continuity is broken. Flame lengths and related fireline intensities that can be expected to kill aspen trees and sustain spread are shown in figure **5.** Fireline intensities in table **5** should be interpreted with figure **5** to judge the likelihood of prescribed fires being successful.

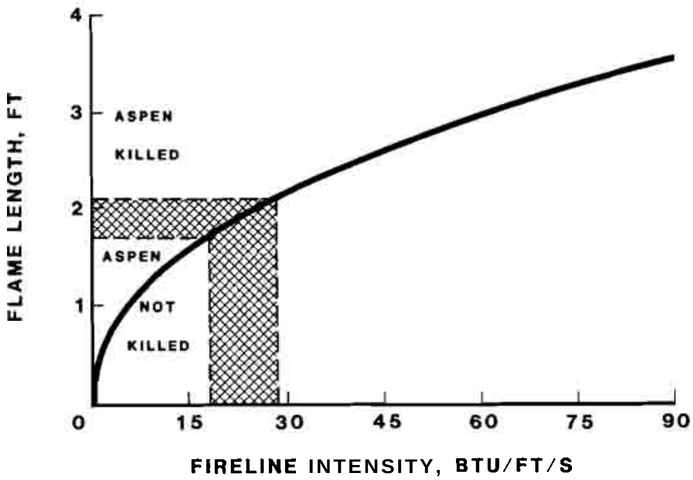

Figure 5.—Flame length versus Byram's (1959) fireline intensity. Flame lengths less than the band at 1.7 to 2.1 ft indicate insufficient fire to kill aspen trees. Fires having flame lengths greater than 1.7 to 2.1 ft are expected to kill aspen trees.

Other factors to consider in planning prescribed fire opportunities include regulation of postfire grazing and size of burn unit. Postburn vegetation is often attractive to big game animals and livestock; thus, the opportunity for animal damage is great. Damage and mortality to aspen sprouts and other vegetation is directly related to intensity of grazing. Tew (1981) reported that a stand of aspen sprouts can be destroyed by **3** successive years of browsing. Sheep are more destructive than cattle. Sprout height regulates the amount of damage by livestock. After sprouts reach 45 inches in height, damage by sheep ceases to be a problem. This requires **3** years of growth on most aspen sites. For cattle, 4 or **5** years are required for suckers to grow out of reach (Sampson 1919). Light browsing of new aspen sprouts can be tolerated because lateral shoots can develop in place of occasional decapitated terminal shoots. In the Intermountain Region the Forest Service recommends that grazing be deferred the first year after burning or until perennials dominate the site and suckers can withstand browsing (USDA 1982). When burning in highly decadent aspen, exclude all ungulate use if possible until new stands have regained vigor. This may require restricted grazing for a number of years.

Large burns of several hundred acres or larger are more cost effective than smaller burns and are less vulnerable to big game damage. Big game, particularly elk, concentrated on wintering grounds can cause extensive damage to aspen sprouts and outweigh the benefits of fire disturbance in aspen (Gruell and Loope 1974; DeByle 1985).

Burning small units close together the same year is one approach to dispersing animal impacts. A single large burn is another approach. In large burn units, flammability typically varies so that a mosaic of burned and unburned vegetation is possible. This may be desirable for wildlife and esthetic reasons. To appraise fire behavior in large burn units, consider the different vegetation and fuel types separately. Whenever possible, large areas should be incorporated in burn units to be most effective in rejuvenating aspen forests. Once good opportunities are identified, prescriptions can be written.

PRESCRIPTION ELEMENTS

Prescription development is the process of first determining the curing, fuel moisture, and wind conditions necessary for a fire to meet the burn objectives. In aspen this primarily involves specifying the marginal burning conditions for a successful fire. Secondly, determine the wind and fuel moisture conditions acceptable for controlling the fire. Also, consider other possible constraints in addition to control.

Wind at midflame height strongly influences fireline intensity as reflected in table **5** and emphasized in figure 6. Judging windspeeds at midflame height is often necessary but results are often imprecise. Many terrain and vegetation features influence wind near the ground. Variability in the windspeed adds uncertainty to writing fire prescriptions and carrying them out. In spite of these difficulties, the technical aids presented here together with experience will lead to effective fire prescriptions.

The following steps illustrate use of fire behavior appraisals to construct a fire prescription:

1. Determine site characteristics such as fuel type and slope. Assume the area to be burned is on a **40** percent slope and in the aspenlshrub fuel type.

2. Determine minimal fuel moisture and windspeeds to achieve a successful prescribed fire.

a. Determine a minimum fireline intensity to achieve a successful prescribed fire. As shown in figure 5, aspen may be killed at fireline intensities of 18 to 28 Btulftls and should be killed at intensities greater than 28 Btulftls. Assume you want to be reasonably certain of an adequately intense fire; thus, choose 28 Btulftls as a minimum fireline intensity. This intensity, corresponding to a flame length of 2.1 ft, also indicates a fire that should maintain sustained spread.

b. Tabulate from table 5 the curing levels, fine fuel moisture contents, and midflame windspeeds that provide at least the minimum fireline intensity of 28 Btulftls. Assume that **30** percent curing is insufficient to sustain fire spread, so begin the tabulation with **50** percent cur-

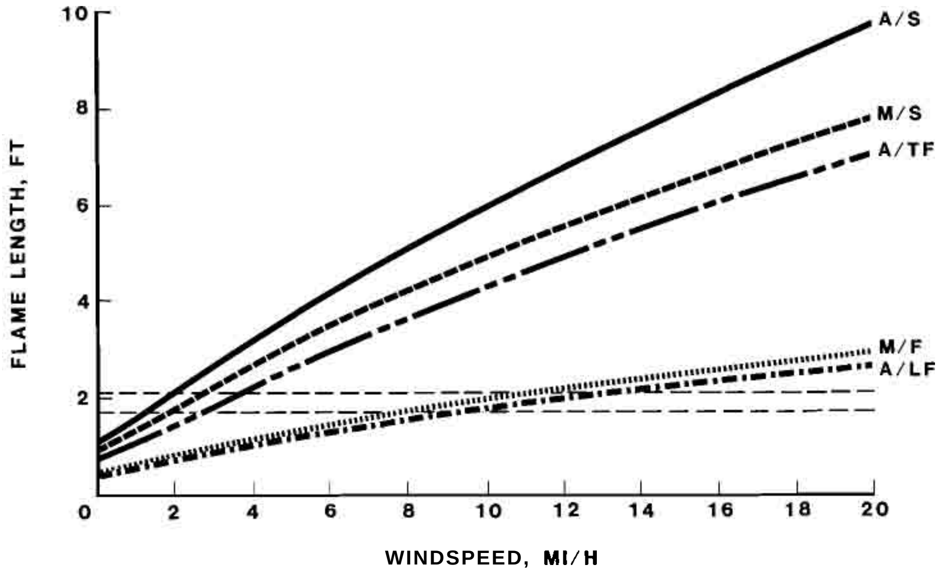

Figure 6.—Flame length influenced by midflame windspeed by fuel types. The dashed lines indicate minimum flame lengths needed to kill aspen trees. Fuel types are abbreviated as in figure 4. Moisture contents were assumed to be 8 and 10 percent for the 1- and 10-hour classes respectively, and curing was assumed to be 70 percent (table 5).

ing (table 8). If desired, the 90 percent curing level could also be tabulated, but preferably the fire prescribed should be possible before this amount of curing. When herbaceous vegetation reaches a highly cured stage, dead fuel moisture contents often remain too high for burning.

c. For each tabulated midflame windspeed, determine windspeeds at 20 ft adjusted for the effects of slope (table 9). Assume fully sheltered fuels in open stands. These are minimum windspeeds for meeting fire objectives.

3. Determine upper limits of flammability for maintaining control of fire. Consider flammability of adjoining areas by evaluating potential for spotting outside of unit and appraising fireline intensity and rate-of-spread potentials in adjoining areas. Rothermel (1983) provides detailed procedures to assist in this task. Also consider values at risk outside the unit and where control of escaped fire is likely. For this example, assume the acceptable limits for fine fuel moisture and windspeed to be 6 percent or less and 20 milh or greater than 6 percent and 25 milh. The last column in table 8 shows the maximum acceptable windspeed.

4. Summarize the prescription parameters gathered in steps 1 and 2:

Curing	Fine fuel moisture (1-h)	Acceptable 20-ft windspeed
Percent	*Percent*	*Mi/h*
50	4	0-20
50	8-12	6-25
50	16	12-25
70	4	0-20
70	8	0-25
70	12-16	6-25

This summary of fine fuel moistures and adjusted windspeeds is taken directly from the tables provided. Interpolation is necessary when using fine fuel moistures other than those given.

The conditions in step 4 are the most important and also most variable components of a fire prescription. Other components such as relative humidity, air temperature, and National Fire-Danger Rating System indices may be added. They relate to fuel moisture and windspeeds, but can also be useful in themselves to indicate proper burning conditions.

METHOD OF IGNITION

Method of ignition should be carefully considered in planning prescribed fire in aspen because it affects the conditions chosen for burning and chances of success. Both hand-held and aerial ignition methods can be used successfully; however, aerial ignition can be especially effective in burning aspen. Aerial ignition with jelled gasoline permits burning at higher fine fuel moisture contents than possible using hand ignition because more heat can be generated for preheating adjacent fuels, particularly where fuels are abundant and continuous.

Aerial ignition can create larger flames to kill unwanted vegetation and get the fire to spread in marginal fuels. Precise, rapid ignitions are significant advantages of this technique. For example, fuels in aspen forests are frequently sparse and contain high proportions of live vegetation. Aerial ignitions can ignite large areas in a short time, thus helping to draw fire through shrubs and herbaceous vegetation that require substantial preheating for ignition. A better coordinated and more effective ignition pattern is possible, using aerial ignition compared to hand ignition by different

Table 9.—Windspeed at 20 ft adjusted for fuel exposure, slope percent, and midflame windspeed. Dashes indicate small but undefined windspeeds

Slope	Midflame windspeed (mi/h) 0	1	2	3	4	5	6	7	8	9	10
Pct						*Mi/h*					
						Exposed					
20	-	0-2	3-5	5-8	8-11	10-14	13-15	15-19	17-22	20-24	22-27
40	-	-	-	3-5	5-9	8-12	10-15	13-18	16-20	18-23	21-26
60	-	-	-		1-4	4-8	8-11	10-15	13-18	16-21	19-23
80	-	-	-				3-5	6-10	10-13	12-17	15-20
100	-	-	-						3-6	7-11	10-15
						Partially Exposed Fuel					
20	-	0-3	4-7	7-11	11-14	14-18	17-22	20-25	24-28	27-32	30-36
40	-	-	-	4-7	7-12	11-16	15-19	18-23	22-26	25-30	29-33
60	-	-	-		2-5	6-10	10-15	15-19	18-23	22-27	26-30
80	-	-	-				4-8	9-12	13-17	17-22	21-26
100	-	-	-						4-9	10-14	15-19
						Fully Sheltered, Open Stands					
20	-	1-4	5-10	11-16	16-22	22-26	27-31	32-36			
40	-	-	-	6-11	12-17	18-22	23-28	29-33	34-38		
60	-	-	-		3-8	9-15	16-21	22-27	28-33	34-39	
80	-	-	-				6-11	12-18	19-26	26-32	33-38
100	-	-	-						7-13	14-21	22-28
						Fully Sheltered, Dense Stands					
20	-	2-8	9-22	23-32	33-40						
40				12-22	23-34	35-43					
60					6-17	18-30	31-41				
80							13-23	24-35			
100								-	16-25	26-39	

individuals, especially where visibility and mobility are hampered at ground level.

The use of fire behavior predictions to determine fire prescriptions applies most appropriately to head fires. Although certain firing patterns, especially when aided by aerial ignition, can develop more intensity than predicted for head fires, fire behavior predictions can help determine prescriptions. Judgment may be required to adjust fire prescriptions based on mathematical predictions for firing patterns expected to generate more intensity than head fires.

Determining When in Prescription

Determining when fuels are ready to burn is more complicated in aspen forests than in most other vegetation types. Curing is probably the most important variable to monitor. Finding the proper time for ignition requires waiting until live fuels are adequately cured and selecting the time when windspeed and dead fuel moistures are in prescription. Adequate curing is particularly important where herbaceous vegetation is the primary fine fuel, such as in the aspenlshrub and aspenltall forb types (fig. 4). Curing increases flammability considerably in these types. The tradeoff, however, between waiting for further curing to increase flammability and autumn rains that end the burning season means that aspen stands should be burned as soon as possible. Delays in burning will result in fewer accomplishments because the time in prescription is usually short.

Where herbaceous vegetation is a minor component of the fine fuels, little curing may be necessary. It may be advantageous to burn in the mixedlforb type during late summer when dead fuel moisture contents are at their lowest even though live vegetation shows little curing. Conifers may be more readily ignited then to help carry the fire.

CURING TRENDS

Our current study (Brown and DeByle 1982) illustrates curing trends and moisture content of live fuels in aspen stands.

1. Grasses (primarily ***Bromus*** and ***Elymus*** spp.) had substantially lower moisture contents and cured at faster rates during early summer than forbs (fig. 7).
2. Forb moisture contents remained very high (200 to 400 percent) during the summer, then dropped substantially over about a 3-week period. Individual forb species apparently vary in the date that an abrupt decline in moisture content begins, as illustrated by comparing ***Geranium*** with other species (fig. 7). ***Rudbeckia, Wyethia,*** and ***Balsamorhiza*** had similar trends.
3. Rainfall during July and August increased moisture contents of grasses and forbs. By September, however, the downward drying trend was set and rain showers did not prolong the curing (fig. 7).
4. Moisture content of shrub foliage and stems varied little throughout August and September. Moisture content of shrub leaves usually remains high until an abscission layer is formed and color change is pronounced.
5. Temperatures in aspen stands at midslope positions are moderate compared to temperatures experienced in openings and valley bottoms. Grasses and forbs cure

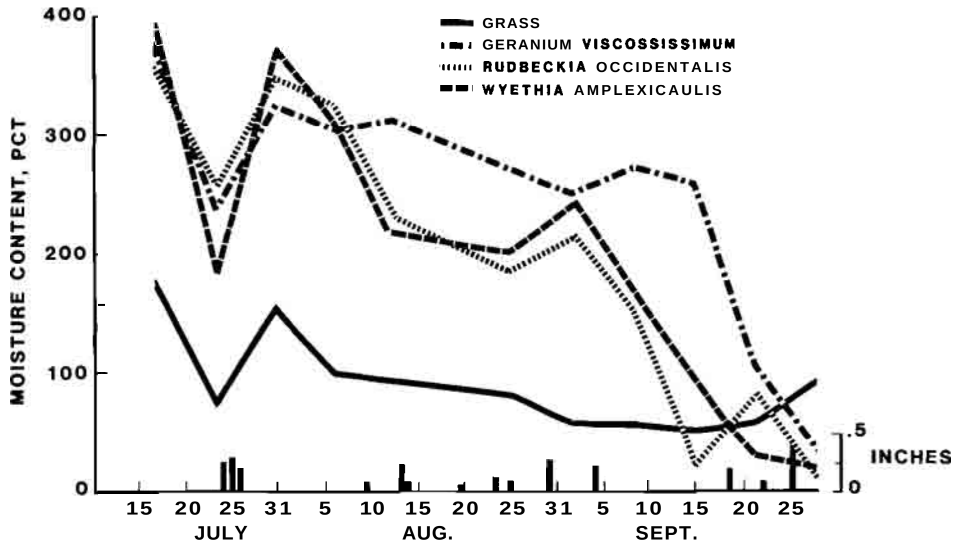

Figure 7.—Moisture content of grasses *(Elymus* and *Bromus* spp.) and forbs from an aspen stand on the Kemmerer Ranger District, Bridger-Teton National Forest, WY, 1981. The bars along the horizontal axis show precipitation.

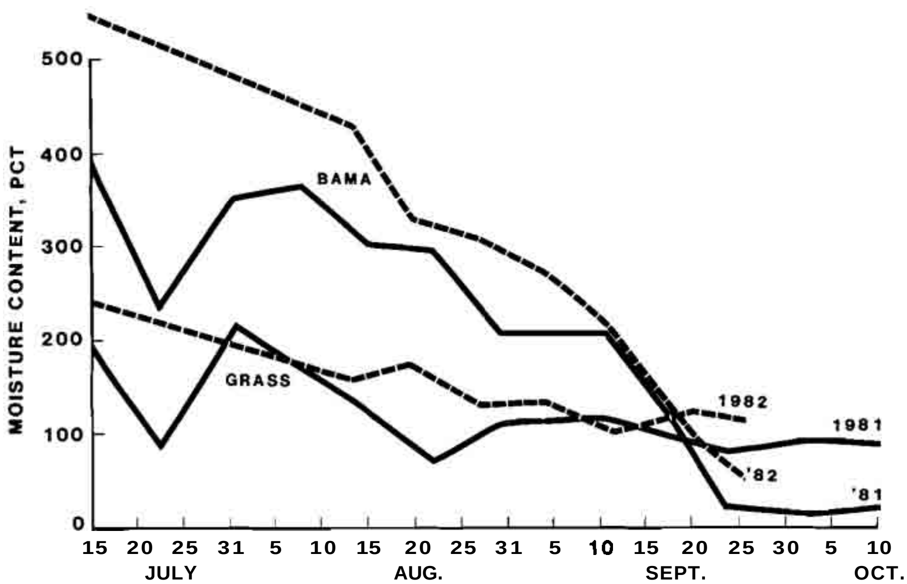

Figure 8.—Moisture content of *Balsamorhiza macrophylla* and grass *(Elymus* and *Bromus* spp.) from an aspen stand on the Kemmerer Ranger District, Bridger-Teton National Forest, WY. Precipitation during August and September was 1.56 inches in 1981 and 4.66 inches in 1982.

more rapidly in openings and under sparse tree canopies. Flammable conditions can be reached 2 to 3 weeks sooner than under full canopies.

6. Under aspen canopies frost damage occurs later than in open areas or than in low-lying areas where cold air collects. Under aspen canopies frost-assisted curing is also delayed. A hard freeze, however, can cure live vegetation quickly. Temperatures less than 15 to 20 °F can cure forbs and shrub foliage in just a few days. If the freeze occurs before abscission layers form, the shrub leaves will remain attached to the stems. This adds to the flammability of surface fuels.

7. In autumn, after most of the herbaceous vegetation is cured and rainfall occurs, some grasses begin growth and greenup near the ground. If the lower 2 inches or more of grass greens up, sustained fire spread becomes very difficult.

8. Drying patterns of herbaceous plants appear to be similar during different years even though precipitation differs through the summer and early fall (fig. 8). Moisture contents in figure 8 were based on small plot samples of all current year's growth, including both live and dead vegetation.

Correlations of live fuel moisture contents with the National Fire-Danger Rating System model of live fuel moistures (Burgan 1979) and with the Keetch-Byram Drought Index (Keetch and Byram 1968) were poor and unsuitable as aids for planning prescribed fires (Brown and others 1983). The best off-site indicator of live fuel moisture contents appears to be simply time of year. Curing progresses steadily through the summer. By early September moisture contents of some plants may have lowered enough to permit fire spread. At this time, on-site evaluation of curing is needed to judge readiness to burn.

ESTIMATION OF CURING

On-site evaluation requires an estimate of the proportion of herbaceous vegetation that is cured. Moisture content of cured vegetation responds like dead fuel to rainfall and atmospheric conditions. Moisture contents of green and transition stage vegetation remain much higher than the cured stage. The difference in moisture contents between green and transition stages in this study was relatively small, especially for forbs (fig. 9). Thus, moisture contents of the green and transition stages can be considered the same for purposes of estimating curing and judging flammability. The transition stage typically is characterized by yellowing of plant parts. Cured leaf tissue shows brown coloration rather than yellow. Cured grass stalks remain straw-colored, but the yellow is largely washed out.

To determine cured vegetation, estimate the proportion of vegetation based on aboveground biomass that is (1) cured, and (2) green, and transition at five or more points in the area to be burned. Locate the points objectively (systematically or randomly) where herbaceous fuels are believed to be important to the success of the fire. Average the estimates and adjust them to total 100 percent. This procedure is simple, but must be carefully done. We have observed a tendency to overestimate the stage of curing that dominates an area by about 10 percent. For example, if most of an area is green, say 70 percent, the visual estimate will be about 80 percent. Look carefully at all herbaceous plant parts from the ground upward. Leaves and small stems should be carefully observed because this material is the fine fuel essential to sustaining fire spread.

Judging the percentage cured is easiest where forbs dominate because differences between stages are distinct. For example, the difference in color and texture of *Wyethia* between transition and cured is evident in comparing figures 10 and 11. The many yellowish leaves in figure 10 are in transition, whereas the brown, curled leaves in figure 11 are cured.

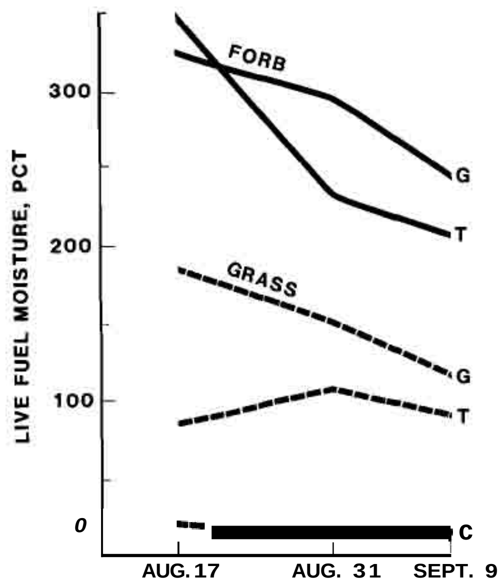

Figure 9.—Moisture contents of green (G), transition (T), and cured (C) components of forbs *(Wyethia amplexicaulis* and *Rudbeckia occidentalis)* and grasses (*Bromus* and *Elymus* spp.) from an aspen stand on the three dates in 1982.

Figure 10.—The dominant forb is mulesears ***(Wyethia amplexicaulis)*** sheltered beneath an aspen canopy. The proportions of biomass and moisture content were:

	Green	Transition	Cured
	Percent		
Biomass	60	30	10
Moisture	270	235	16

Figure 11.—The dominant forb is mulesears in this open setting. The proportions of biomass and moisture content were:

	Green	Transition	Cured
	Percent		
Biomass	25	20	55
Moisture	200	100	10

Mixtures of grasses and forbs are more difficult to judge because they cure at different rates. Notice, in figure 12, the three stages of curing for the tall forb *Rudbeckia occidentalis.* The cured stage is indicated by the tan- to brown-colored leaves and transition by yellowish leaves. The grass appears green and yellow-green in color and is nearly all in the green and transition stages.

Curing of grasses, particularly perennials, can be deceptive because the seed stalks usually cure before the leaves. Viewed from a distance, this gives a false impression of being mostly cured (fig. 13). A closer look, however, shows that most of the leaves are green. The basal portion of grasses as well as the stalks must be viewed to determine curing level.

After most vegetation has cured, fire spread may still be questionable because grasses green up near the ground following early fall rain (fig. 14).

In addition to estimating curing, it is helpful to evaluate dead fuel moisture contents by either collecting samples of 1- and 10-hour timelag fuels for ovendrying or by measuring moisture content of standard half-inch fuel sticks exposed in or nearby the burn site.

Figure 12.—The mixture of grass and the forb *Rudbeckia occidentalis* occurs in an open stand of aspen and subalpine fir. The grass was 10 percent cured. The proportions of biomass and moisture content for *Rudbeckia* were:

	Green	Transition	Cured
	----------	*Percent*	----------
Biomass	20	30	50
Moisture	300	180	12

Figure 13.—Although the grass appears mostly cured, only 30 percent of it is cured. The basal leaves are green. The proportions of biomass and moisture content of the grass were:

	Green	Transition	Cured
		Percent	
Biomass	35	35	30
Moisture	100	75	15

Figure 14.—The forbs, primarily ***Rudbeckia,*** are 100 percent cured. The perennial grasses, primarily *Elymus* spp. and *Bromus* spp., however, have greened up within 2 inches of the ground, making fire spread improbable.

FUEL MODEL DEVELOPMENT

This section describes additional information about the sampling methods, analysis, and fuel characteristics used to develop the fuel models. First, we grouped aspen forest community types expected to have similar fuels and fire behavior. Community types from each group were then selected for sampling, based on the criteria of having widespread occurrence and being desirable to manage with prescribed fire. Stands were located that represented the chosen community types; then areas of about 0.1 acre were selected within stands for sampling. The vegetation and surface fuels in each selected area appeared to be representative of the stand and community type.

Sampling Procedures

The selected areas were photographed. Three transects were established in a radial pattern from the camera to fully occupy the field of view similar to the method by Fischer (1981). Five sample points were located along each transect. The first sample point was 20 ft from the camera and the others at 15-ft intervals. The following information was obtained at each sample point based primarily upon procedures described by Brown and others (1982):

1. Fuel loading of
   a. herbaceous vegetation (live and dead)
   b. shrubs (live and dead)
   c. downed woody material by diameter classes
   d. forest floor litter or the 01 horizon which includes freshly fallen leaves, needles, bark flakes, other miscellaneous plant parts, and dead matted grass.
2. Duff depth.
3. Cover (percent) of herbaceous vegetation, shrubs, and mineral soil.
4. Density of aspen and conifers.

Fuel depth for use in fire behavior modeling was measured at four equidistant points along the centerline of a 1- by 2-ft subplot. Six subplots were located systematically along the photo plot transects.

Depth was viewed as the average height of vegetation in quarter sections of each subplot. All vegetation less than ¼-inch in diameter in the surface fuel strata was viewed to determine height, except that isolated or spurious pieces of vegetation were disregarded. A gap of 1 ft or more between fuel particles constituted a discontinuity and terminated the upward extent of the surface strata. All vegetation within a vertical extension of the subplot boundary was clipped, dried, and weighed to permit calculation of fuel bed bulk density. Bulk density of litter was determined similarly in five stands.

Fuel Results

Differences and similarities among the fuel types can be evaluated by comparing averages and examining the overlap in ranges (table 10). The community types sampled by fuel type were:

Aspenlshrub
- *Populus tremuloides/Artemisia tridentata*
- *Populus tremuloides/Pachistima myrsinites*
- *Populus tremuloides/Spiraea betulifolia*
- *Populus tremuloides/Prunus virginiana*
- *Populus tremuloides/Shepherdia canadensis*
- *Populus tremuloides/Amelanchier alnifolia*

Aspen/tall forb
- *Populus tremuloides/Rudbeckia occidentalis*
- *Populus tremuloides/Wyethia amplexicaulis*
- *Populus tremuloides/Ligusticum filicinum*
- *Populus tremuloides/Calamagrostis rubescens*
- *Populus tremuloides/Poa pratensis*

Aspenllow forb
- *Populus tremuloides/Berberis repens*
- *Populus tremuloides/Arnica cordifolia*
- *Populus tremuloides/Symphoricarpos oreophilus*

Mixedlshrub
- *Populus tremuloides-Pseudotsuga menziesii/Spiraea betulifolia*

Mixedlforb
- *Populus tremuloides-Abies lasiocarpa/Arnica cordifolia*
- *Populus tremuloides-Abies lasiocarpa/Ligusticum filicinum*
- *Populus tremuloides-Pinus contorta/Calamagrostis rubescens*
- *Populus tremuloides-Pseudotsuga menziesii/Calamagrostis rubescens*

The grouping of community types was tested using data from a different study on fire effects in aspen (Brown and DeByle 1982). Loadings of 0- to %-inch downed woody fuel, herbaceous vegetation, shrubs, and total fine fuels, and percentage of shrub cover from 15 stands were compared with the range in loadings for the fuel types in table 9. Only shrub loadings for two of the 15 stands fell outside the fuel type ranges. The fuel classification appeared to be reasonable based on this test.

In our data shrub cover and shrub loadings were imprecisely related, primarily because of the large range in shrub sizes sampled. Thus, shrub loadings can vary widely with coverage. The practical implication is that the 30 percent coverage, which separates the shrub understory classes from the forb understory classes, is only an approximate guide to appraising flammability.

Table 10.—Average and range in values of the sampled fuel quantities, shrub and mineral soil coverages, and duff depths by the standard aspen fuel types and modified fuel types

Fuel type	N	Downed woody material (inches) 0-¼	¼-1	1.3	3+	Litter	Herb	Shrub Foliage	Shrub Stems 0-0.25	Shrub Stems in Total	Small conifer	Coverage Shrub	Coverage Mineral soil	Duff depth
		Pounds/acre										Percent		Inches
							Standard							
Aspenlshrub														
mean	9	500	1,980	4,760	16,680	1,710	720	750	1,140	3,440	30	41	6	1.1
high		720	3,580	8,660	34,460	2,810	1,000	1,740	1,810	6,140	210	58	19	2.3
low		210	450	2,140	5,520	420	390	430	620	980	0	31	2	0
Aspenltall forb														
mean	5	210	1,050	5,730	23,460	1,760	1,140	120	110	250	20	15	6	1.5
high		540	1,590	14,770	60,300	2,600	2,020	550	400	980	90	58	15	2.6
low		40	520	610	0	790	230	0	0	0	0	0	2	.4
Aspenllow forb														
mean	5	530	2,070	3,120	4,460	1,350	300	90	60	260	180	11	12	.6
high		750	3,170	4,090	8,880	2,740	460	220	110	630	440	25	23	1.2
low		370	880	1,830	1,350	170	180	0	0	0	0	0	2	.4
Mixedlshrub														
mean	2	940	3,300	2,730	2,340	1,980	90	830	1,100	3,040	20	63	2	.8
high		1,250	3,830	3,310	3,400	2,040	90	1,040	1,340	3,670	30	70	2	1.3
low		630	2,770	2,150	1,280	1,920	80	610	860	2,480	0	56	2	.3
Mixedlforb														
mean	5	480	2,230	5,100	17,080	1,680	290	160	190	630	940	15	6	1.4
high		1,180	3,700	8,350	31,040	2,560	550	370	570	1,400	4,150	29	14	2
low		260	1,180	2,650	8,620	740	10	20	70	100	0	6	3	1
							Heavy Downed Wood							
Mixedlforb														
mean	2	1,250	4,290	6,310	61,850	2,720	170	20	20	40	900	4	5	2.1
high		2,070	5,410	6,990	71,260	3,660	290	40	30	80	1,550	4	2	2.8
low		420	3,170	5,640	52,440	1,770	50	0	10	10	240	4	2	1.3
							Grazed							
Aspenlshrub														
mean	1	210	770	970	6,500	1,060	330	250	420	1,000	10	14	38	0
Aspen/tall forb														
mean	4	220	1,480	3,450	22,450	1,320	480	20	40	80	70	3	8	.4
high		410	3,090	6,010	70,180	2,880	790	70	110	210	264	9	14	1
low		120	280	2,520	3,140	380	340	0	0	0	0	0	3	.1

Fuel bulk densities ranged from 0.47 to 1.26 lblft^3 for litter and from 0.006 to 0.095 lblft^3 for grasses, forbs, and shrubs (upright vegetation). The average bulk densities, surface fuel depths, and number of stands sampled were as follows:

Fuel	Number stands	Depth	Bulk density
		Feet	*Lb/ft^3*
Litter	5	0.043	0.95
Upright			
Aspenlshrub	8	1.3	.068
Aspenltall forb	2	1.1	.026
Aspenllow forb	4	.5	.023
Mixedlshrub	2	1.1	.066
Mixedlforb	3	.6	.022

Shrub understories were about 3 times more dense than forb understories. The litter fuel was 15 to 45 times more densely packed than the upright fuel. The aspen litter and upright fuels were 2 to 5 times less dense than observed in conifer surface fuels (Brown 1981).

Loading of litter, which is primarily comprised of aspen leaves where aspen dominates the overstory, is not easily predicted. Litter loadings varied greatly among stands (table 10). Examination of scattergrams revealed lack of relationships between stand basal area and loading of litter as well as loading of herbaceous vegetation. The absence of relationship between aspen basal area and understory production was also observed by Severson and Kranz (1976). Woods and others (1982), however, found a relationship between understory production and basal area for stands having similar site characteristics. Productivity increased substantially for canopy coverage of less than about 50 percent.

Aspen leaves are a potentially flammable fine fuel. More than 1,000 lb/acre of leaves and twigs may be added to the forest floor at the time of leaf fall (Bartos and DeByle 1981). But the leaves often are not on the ground at the right time for burning or arranged to favor combustion. Leaves shed in the autumn decompose and deteriorate considerably over winter, spring, and summer prior to the next burning season. Leaves may fall too late to be available for burning during the current year. In stands without a high coverage of ungrazed herbaceous vegetation, the leaves fall flat on the ground, which is unfavorable for combustion. The importance of leaf litter to attaining successful prescribed fire must be evaluated on a site-specific basis.

Fire Prediction

The fuel models for the five aspen and mixed fuel types were established by using average loadings of fuel components to generate fire behavior predictions using program FIREMOD (Albini 1976) for each fuel type.

This fire behavior was compared with fire behavior averaged from predictions made for individual sample stands. Based on this comparison, some loadings of individual fuel components were then altered to yield fire behavior that we believe better reflected the relative differences between fuel types. Lastly, four fuel components were formed by condensing the 11 fuel components; then, the BEHAVE system was used to generate the fire predictions shown in this guide. The original and final fuel components were:

Original components	Final components
Dead fuel	
Herbaceous vegetation Shrub foliage Shrub stemwood, 0- to %-inch diameter Downed woody fuel, 0- to %-inch diameter Litter	1-hour timelag
Shrub stemwood, ¼- to 1-inch diameter Downed woody fuel, ¼- to 1-inch diameter	10-hour timelag
Live fuel	
Herbaceous vegetation	Herbaceous
Shrub foliage Shrub stems. 0- to ¼-inch diameter Shrub stems, ¼- to 0.8-inch diameter	Woody plants

Net loadings and surface area-to-volume ratios of the final fuel components were weighted by a surface area factor based on the proportion of surface area in a set of defined fuel component subclasses (Albini 1976). As a result, the loadings of the final components in the fuel models are less than the loadings actually sampled in the field.

Fuel properties held constant in predicting all fire behavior were:

Property	Value
Low heat value, Btu/lb	8,000
Particle density, lb/ft^3	32
Total mineral content, fraction dry	0.055
Effective mineral content, fraction dry	0.01
Dead fuel moisture of extinction, fraction dry	0.25

Particle surface area-to-volume ratios were:

Component	Ratio
	Ft²/ft³
Shrub foliage	3,000
Herbaceous vegetation	2,800
Shrub stems, 0- to ¼-inch diameter	600
Shrub stems, ¼- to 1-inch diameter	175
Downed woody fuel, 0- to %-inch diameter	400
Downed woody fuel, ¼- to 1-inch diameter	90
Litter	1,500

BEHAVE Fuel Models.—Fuel loadings, particle surface area-to-volume ratios, and fuel depths used in BEHAVE to generate tables 5 and 6 are shown in table 11. Fuel depth was determined by weighting litter and upright surface fuel depths by their respective loadings:

$$D = \frac{L_w \times L_d + S_w \times S_d}{L_w + S_w}$$

where

D = fuel depth, ft
L_w = loading of litter, lb/ft^2
L_d = depth of litter, ft
S_w = loading of live and dead herbaceous vegetation and shrubs, lb/ft^2
S_d = depth of herbs and shrubs, ft.

Moisture contents of live herbaceous vegetation remained constant for all curing levels, but varied with curing levels for live shrubs (table 12). Quantities of cured herbaceous vegetation and shrub foliage were treated as dead fuel in predicting fire behavior. Thus, as curing increased, loadings of dead herbaceous vegetation and shrub foliage increased, while the live loading decreased. Transferring live fuel to the dead fuel category produced an effect on fire behavior analogous to a large change in live fuel moisture content.

Additional fire behavior predictions can be generated using the aspen fuel model parameters (table 11) in the BEHAVE system. If you want to change the fuel inputs in table 11 because you have fuel data from the field, we suggest that you compare your fuel loading values with the range of values in table 10. If your fuel loadings fall within the range of our data, we advise against making changes because fuel loadings determined in the field often need interpretation before they can be used appropriately in a fuel model.

The 1-hour fuel loading inputs to BEHAVE are not direct field weights. They contain several 1-hour fuel size class components that were combined through a surface area weighing procedure using program FIREMOD (Albini 1976). If you do choose to alter fuel loading inputs, we suggest changing the values in table 11 in proportion to the difference between your field values and the average loadings in table 10.

The fuel appraisal and fire prediction information presented here is intended to assist managers in planning and conducting prescribed fires. It is largely new information to applying prescribed fire in aspen and should be used with judgment in making plans and decisions.

Table 11.—Aspen fuel model parameters used in BEHAVE[1]

Curing level	Loading 1-hour	Loading 10-hour	Loading Live Herb	Loading Live Woody	Surface area/volume 1-hour	Surface area/volume 10-hour	Surface area/volume Live Herb	Surface area/volume Live Woody	Depth
Pct	*Tons/acre*				*Ft²/ft³*				*Ft*
				Aspen/shrub					
0	0.800	0.975	0.335	0.403	1,400	109	2,800	2,440	0.65
30	.893	.975	.234	.403	1,620	109	2,800	2,440	.65
50	1.056	.975	.167	.333	1,910	109	2,800	2,310	.65
70	1.218	.975	.100	.283	2,090	109	2,800	2,090	.65
90	1.379	.975	.033	.277	2,220	109	2,800	1,670	.65
				Aspen/tall forb					
0	.738	.475	.665	0	1,480	109	2,800	-	.30
30	.930	.475	.465	0	1,890	109	2,800	-	.30
50	1.056	.475	.332	0	2,050	109	2,800	-	.30
70	1.183	.475	.199	0	2,160	109	2,800	-	.30
90	1.309	.475	.067	0	2,240	109	2,800	-	.30
				Aspen/low forb					
0	.601	1.035	.150	0	1,400	109	2,800	-	.18
30	.645	1.035	.105	0	1,540	109	2,800	-	.18
50	.671	1.035	.075	0	1,620	109	2,800	-	.18
70	.699	1.035	.045	0	1,690	109	2,800	-	.18
90	.730	1.035	.015	0	1,750	109	2,800	-	.18
				Mixed/shrub					
0	.880	1.340	.100	.455	1,350	109	2,800	2,530	.50
30	.906	1.340	.070	.455	1,420	109	2,800	2,530	.50
50	1.037	1.340	.050	.364	1,710	109	2,800	2,410	.50
70	1.167	1.340	.030	.290	1,910	109	2,800	2,210	.50
90	1.300	1.340	.010	.261	2,060	109	2,800	1,800	.50
				Mixed/forb					
0	.754	1.115	.150	0	1,420	109	2,800	-	.18
30	.797	1.115	.105	0	1,540	109	2,800	-	.18
50	.825	1.115	.075	0	1,610	109	2,800	-	.18
70	1.167	1.115	.045	0	1,670	109	2,800	-	.18
90	.884	1.115	.015	0	1,720	109	2,800	-	.18

[1]Heat content of 8,000 Btu/lb and moisture of extinction of 25 percent were used for all models.

Table 12.—Live fuel moisture contents and percentage of dead shrub foliage related to herbaceous curing levels

Curing level	Shrub foliage dead	Live fuel moisture Herb	Live fuel moisture Shrub
Percent			
10	0	150	85
30	0	150	85
50	25	150	75
70	50	150	65
90	75	150	55

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APPENDIX: ACCURACY OF FIRE BEHAVIOR PREDICTIONS

The fire spread model (Rothermel 1972) used as a basis to predict fireline intensity and rate of spread is largely untested in aspen fuels. Only results of the limited tests described here have been reported. We conducted four test fires on the Bridger-Teton National Forest in a ***Populus tremuloides/Rudbeckia occidentalis*** community type (Youngblood and Mueggler 1981) where the primary fine fuel was grass (***Elymus*** and ***Bromus*** spp.). Three of four fires did not sustain fire spread (table 13) because the herbaceous fuels were too green. In the fire that did sustain spread, there was good agreement between predicted and observed flame lengths.

The mathematical fire model (Rothermel 1972) has demonstrated reasonable accuracy in a variety of fuels, including conifer slash, grass, southern rough (Andrews 1980), and black spruce in Alaska (Norum 1982). In 131 experimental fires (Andrews 1980), nearly half of the observations were within 25 percent of over- or under-prediction. Observed and predicted flame lengths in the black spruce agreed closely.

When applied to aspen fuels, the model's accuracy remains uncertain. Experience and observations gained on fires in aspen should be used to help interpret the fire model results in this publication. Improved application of fire behavior predictions can result.

Table 13.—Observed and predicted flame lengths according to fuel conditions and windspeed on test fires in aspen stands having an understory dominated by herbaceous plants

Fire	Date	Loadings: Shrub	Loadings: Herb	Loadings: Downed woody[1]	Litter	Cured herb[2]	Moisture content: 1-h	Moisture content: Litter	Moisture content: Herb[3]	Midflame wind-speed	Flame length: Obs.	Flame length: Pred.
		Lb/acre				Percent				Mi/h	Ft	
1	8/18	0	130	730	1,690	15	7	7	150	1.5	0	0.3
2	8/18	0	670	200	1,040	25	7	8	130	8	0	1.0
3	8/19	0	670	200	1,040	25	7	8	130	2.0	0	1.4
4	9/23	0	700	220	360	50	5	7	75	3.5	1.5	1.3

[1]Twigs and branches 0 to 1 inch in diameter.
[2]Percent of herbaceous biomass that is dead.
[3]As average moisture content of all live and dead grasses and forbs occurring at sample locations

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Brown, James K.; Simmerman, Dennis G. Appraising fuels and flammability in western aspen: a prescribed fire guide. General Technical Report INT-205. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station; 1986. 48 p.

Describes a method for appraising fuels and fire behavior potential in aspen forests to guide the use of prescribed fire and the preparation of fire prescriptions. Includes an illustrated classification of aspen fuels; appraisals of fireline intensity, rate of spread, adjective ratings for fire behavior and probability of burn success; and evaluations of seasonal change in live fuel moisture contents.

KEYWORDS: fuel moisture, fire behavior, fuel model, fire effects, community type