Simple Question; Difficult Answer: How Much Fuel Is Acceptable?

M.E. Alexander

Fire managers commonly want to know what quantity of wildland fuel is acceptable (Noble 1979). But this question—simple as it may seem—is difficult to answer. A host of factors are involved.

Sound professional judgment is needed to determine what can be considered acceptable fuel loads.

Fire behavior depends not only on fire potential at one location, but on a range of associated factors that include the distribution and characteristics of the individual and collective elements comprising the fuel complex (table 1) and fire behavior potential across surrounding areas that could encompass one or more drainages.

Dr. James K. Brown, seen here inventorying dead-down woody debris, was a research forester with the Forest Service who pioneered many techniques for sampling ground, surface, and crown fuels. This article is adapted, in part, from his work (Brown and others 1977). In March 2007, Dr. Brown received the second annual "Ember Award" from the International Wildland Fire Association. Photo: Forest Service.

Acceptable fuel loads depend on resource values, management objectives for the land, pattern of land ownership, and suppression capability (fig. 1). In some stands, acceptable fuel load might depend on the resistance of trees to crown scorch and cambium kill (Outcalt and Wade 2004; Weatherspoon and Skinner 1995). Sound professional judgment (Haas 2003) is certainly

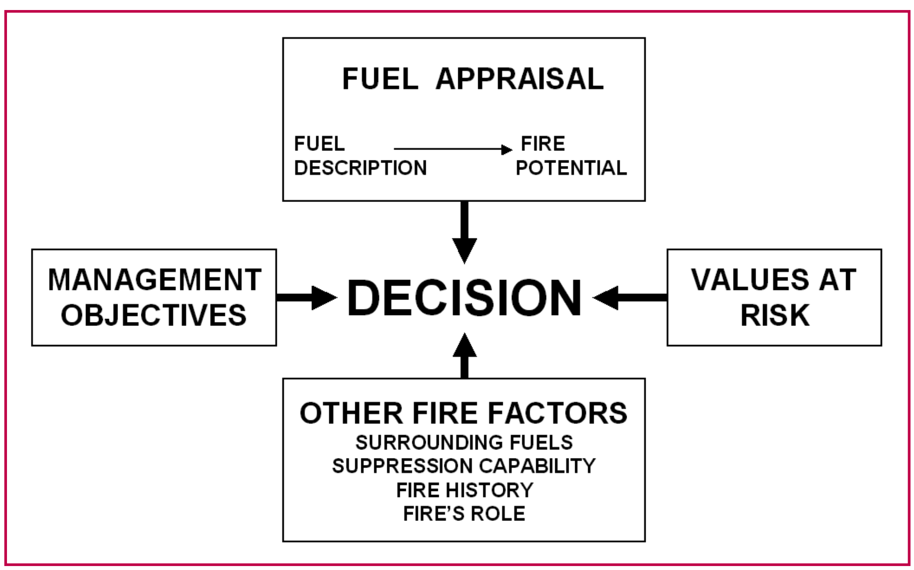

Figure 1—*Factors to consider when deciding how much fuel is considered acceptable (Brown and others 1977).*

Dr. Marty Alexander is a senior fire behavior research officer with the Canadian Forest Service, Northern Forestry Centre; and an adjunct professor of wildland fire science and management in the Department of Renewable Resources, University of Alberta, Edmonton, Alberta, Canada. At the time of this writing, he was on assignment as a senior researcher with the Wildland Fire Operations Research Group of the Forest Engineering Research Institute of Canada located in Hinton, Alberta, Canada.

This article is adapted in part from Brown and others (1977).

Table 1—Fuel properties affecting various elements of fire potential and their relative influence (Anderson 1975).

Fuel properties (dimensionless)	Ignitability		Fire spread		Energy release							Physical obstruction	
	Ignition probability	Spot fire ignition	Linear	Size	Fire intensity	Flame height	Scorch height	Crowning potential	Firebrand generation	Fire duration	Fire persistence	Ground vegetation	Aerial vegetation
PARTICLES:													
Size (diameter, length)	X	X	X	X	X	X	X	X	X	X	X	X	X
Shape (geometric factor, surface area/volume)	X	X	X	X	X	X	X	X	X				
Density (weight/volume)	X	X	X	X	X	X	X	X	X		X	X	
BEDS:													
Load (weight/unit area)	X	X	X	X	X	X	X	X		X	X	X	X
Depth (thickness)			X	X	X	X	X	X		X	X	X	
Continuity: Vertical (length)		X					X	X					X
Horizontal (length)	X	X	X	X				X				X	
Live/Dead ratio	X	X	X	X	X	X			X				X
Extent (% of land area)		X		X								X	X

needed to determine what can be considered acceptable fuel loads.

Decision Steps

To decide how much fuel is acceptable requires the integration of many factors (fig. 1). This can be done systematically in a three-step process (Brown and others 1977):

Step 1: Consider management objectives and values-at-risk. For the latter, both resource values *and* risk of a fire during periods of critical fire weather and fire danger causing damage are jointly considered.

Step 2: Appraise fuels by (a) describing fuels from inventory (Brown and others 1982), prediction (Brown and others 1977), or ocular estimation using a photo series (Wendell and others 1962; Fischer 1979) and (b) interpreting fire behavior and fire impact potential such as rate-of-spreading, intensity, flame length, crown scorch height, and degree of flame defoliation.

Step 3: Consider other fire-related factors, such as fuel and fire behavior potential on adjoining lands, suppression capability, frequency and severity of historical fires, and fire's ecological role.

Acceptable fuel loads can depend to a high degree on the factors considered in *Step 3*. For example, a very high fuel load would be acceptable on a unit surrounded by sparse fuels with little chance of ignition than on a unit surrounded by very heavy fuel loads with a more certain probability of ignition. Once management objectives have been

Too much reliance can be placed on models. After all, predicting fire behavior is a science *and* an art.

Explosive Potential

"Fuels contain energy, stored over extended periods through photosynthetic processes, that is released rapidly, occasionally explosively, in combustion."

–From Martin and others (1979)

specified, Omi (1996) has suggested a conceptual framework that can be used for assessing the viability of landscape-scale fuel treatments (fig. 2).

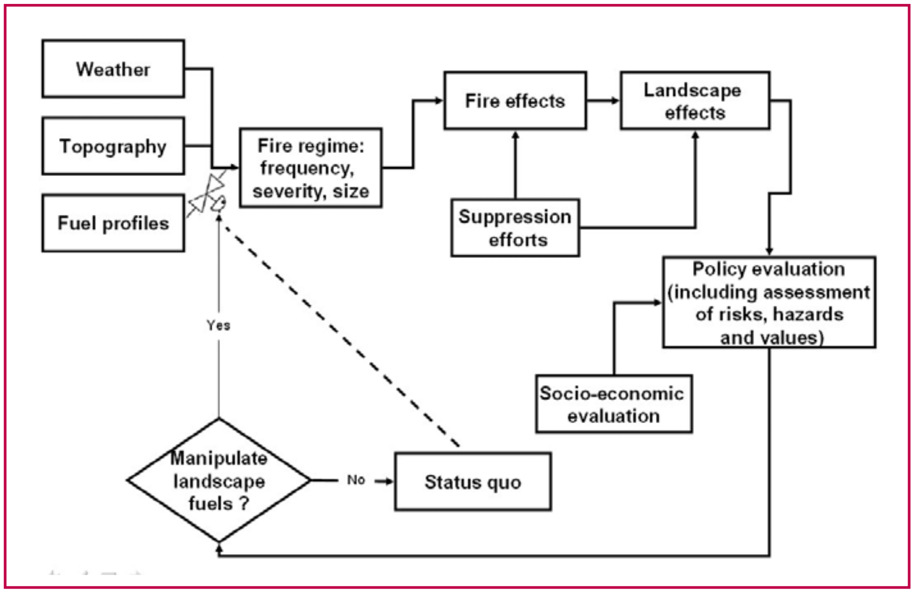

Figure 2—*Framework for assessing the impact of landscape-scale fuels management versus status quo (Omi 1996).*

Fuel Appraisal

Appraising the potential fire behavior of fuels is often termed "fuel appraisal" (Brown 1972, 1978) and is the process of: (1) describing fuel characteristics, such as quantity and size (table 1) and (2) interpreting the fuel in terms of fire behavior, such as rate-of-spread, fire intensity, and flame length (fig. 3).

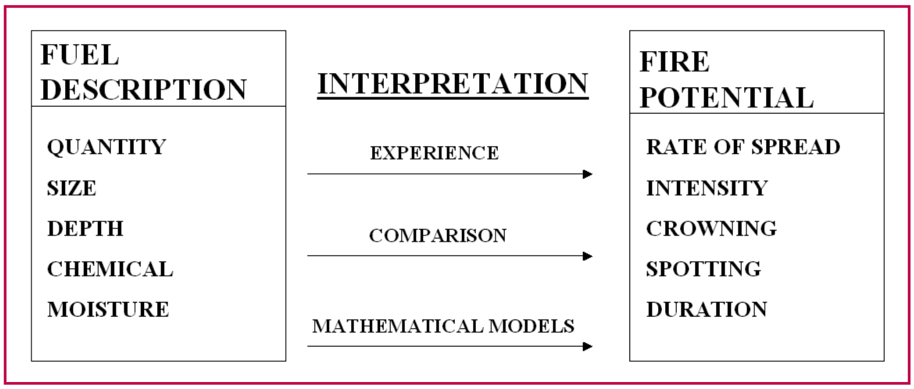

Figure 3—*The process of fuel appraisal (Brown 1972).*

Thus, the appraisal process attempts to answer the question: Given steepness of slope and weather conditions, what is the expected fire behavior for different fuels?

This question is difficult to answer, partly because the answer is made up of different elements of fire behavior (Anderson 1974)—including rate-of-spread, intensity, flame dimensions, torching potential, crowning potential, spotting potential, blowup potential, and duration of heat (flame front residence time and burn-out time, or smoldering potential).

One or more of these elements may have to be appraised when a specific fuel management situation is being evaluated. Furthermore, the overall assessment of fire behavior potential must ultimately be interpreted in terms of the implications for fire suppression (Murray 1983).

Potential fire behavior of litter, downed woody debris, and understory vegetation can be appraised by (fig. 3): (1) mathematical modeling, (2) experienced judgment, and (3) comparison (such as case studies). Mathematical modeling of fire behavior characteristics such as rate-of-spread, fire intensity, flame length, crowning potential, and fire size (Alexander 2006; Anderson 1974; Brown 1974; Brown and Johnson 1987; Hirsch and others 1979; Lavoie 2004; Radloff and others 1982; Salazar and Bevins 1984) offers the most objective means of appraising potential fire behavior.

Systems have been developed specifically for this purpose (Hirsch and others 1981; Puckett and others 1979; Radloff and others 1982; Roussopoulos and Johnson 1975).

Such modeling, however, does have its limitations (Albini 1976; Alexander 2004a). Furthermore, too much reliance can be placed on models (Alexander 2004b). After all, predicting fire behavior is a science *and* an art (Alexander and Thomas 2004).

Experienced Judgment

Experienced judgment is an important means of appraising fuels. An experienced person can integrate many factors that elude quantification. Even when more sophisticated methods are available, judgment is still important. However, even experienced judgment has its limitations (Gisborne 1948).

One way of using experienced judgment is to establish a reference fuel

Forest Fuels and Free-Burning Fire Behavior

"The ignition, buildup, and behavior of fire depends on fuels more than any other single factor. It is the fuel that burns, that generates the energy with which the firefighter must cope, and that largely determines the rate and level of intensity of that energy. Other factors that are important to fire behavior (that is, moisture, wind, and so forth) must always be considered in relation to fuels. In short, no fuel—no fire!

Discussion of fuels is significant only in relation to fire, yet the makeup of forest fuel complexes must be understood before the interactions between fire and its environment can be examined constructively. To achieve this, the student must be able to appraise forests and wildlands in general from the point-of-view of their fire potential. In figurative terms, it is like viewing the forest through a different pair of glasses—the kind worn constantly by skilled fire control men [and women]. The vegetative cover, living and dead, is then perceived as potential fuel, capable of being ignited and burned under certain conditions."

–From Brown and Davis (1973)

> Experienced judgment is an important means of appraising fuels. An experienced person can integrate many factors that elude quantification.

load that can be used to compare against other fuel loads. The reference fuel load could represent fuels for which a consensus of fire control-experienced land managers could agree on a rating. This might be in terms of resistance to fireguard construction or resistance to control (Murphy and Quintilio 1978; Ponto 1990).

Alternatively, wildland fire research may suggest a reference fuel load. For example, Wendell and others (1962) indicated that the probability of blowup fires decreased rapidly when "available fuel" loads—those readily consumed in the active flaming front—were less than 6 tons per acre (13.5 tons per hectare).

Ratings, for example, might be for low-, medium-, or high-fire intensity potential (Fahnestock 1968; Fischer 1979), or for fuels being either acceptable or unacceptable regarding the ability of an initial attack crew to gain control (McCarthy and Tolhurst 1998).

After setting a reference fuel load, fuels are then appraised on a relative basis. For example, for material less than 3.0 inches (7.6 cm) in diameter, if a load of 10 tons per acre (22.4 tons per hectare) is established as the reference fuel load, then a load of 20 tons per acre (44.8 tons per hectare) would exhibit approximately twice the potential fire behavior.

Case-study knowledge (Alexander and Thomas 2003a, 2003b, 2006) coupled with experienced judgment and fire behavior modeling is considered an effective operational technique for appraising fire potential for fuels management (Brown 1978). The article written by Salazar and Gonzalez (1987) represents a good example of the wildfire case study approach regarding fuel management.

Fuel Load Standards

No single fuel load may be acceptable for a large administrative area. Herein lies the dilemma of setting fuel load standards. Establishing standards would permit the setting of clear objectives for residue management and provide benchmarks with which to measure accomplishments. However, standards could easily circumvent professional judgment for determining the maximum acceptable level of fuel for specific sites.

One approach to determining acceptable fuel levels is to develop different standards for each of the major decision circumstances encountered on a large administrative unit. To accomplish this, the various factors noted in figure 1 need to be evaluated for the different management circumstances found on a large administrative unit.

Acceptable loadings of debris also depend on requirements of other disciplines for attaining land management objectives. Thus, even if fuel load standards are set, the final decision on how much downed debris is acceptable needs to be coordinated among all management interests (e.g., Graham and others 1994; Brown and others 2003).

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Fire Dynamics and Wildland Fuel Complexes

"The best chance for success in fire behavior prediction requires a mix of fire experience with analytical modeling methods. But in situations where conditions are beyond the limits or outside the assumptions of the models, fire predictions must rely even more on intuitive judgements. Such judgements could be more easily made if managers know general patterns of fire behavior through a full range of burning conditions."

–From Williams and Rothermel (1992)

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Summary of the 2006 Wildland Fire-Related Deaths

A total of 24 wildland fire management-related deaths occurred in this country in 2006, according to the National Wildfire Coordinating Group. In 2005, a total of 12 wildland fire management-related fatalities occurred.

The 24 2006 deaths were attributed to:

- **Aviation.** Eight fatalities occurred in two helicopter accidents and one lead plane accident.
- **Entrapments/Burnovers.** Seven fatalities occurred when firefighters were entrapped or burned over by fire.
- **Driving/Motor Vehicle:** Four persons were killed in driving-related accidents.
- **Heart Attacks:** Three individuals died when they suffered heat attacks while firefighting.
- **Hazard Tree/Felling:** One person was killed when a snag fell during a prescribed fire operation.
- **Other/(Fall):** One person died from injuries that occurred by falling from the stairs of a fire lookout tower. ■

For more information, contact <michelle_ryerson@nifc.blm.gov>.

Software Can Assess Fuel Treatment Effectiveness on Crown Fire Behavior

CFIS—Crown Fire Initiation and Spread—is a new (nonprofit) software system that incorporates several recently developed models designed to simulate crown fire behavior (Alexander and others 2006).

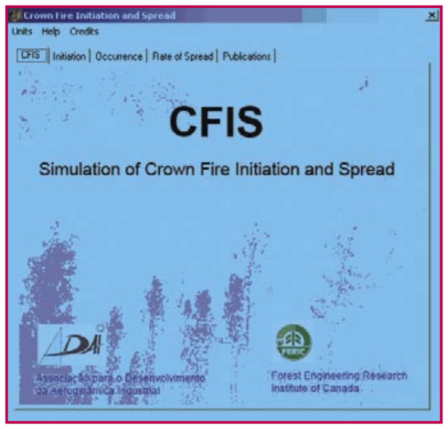
> This new software application can serve as a decision support aid in a wide variety of fire management activities—ranging from near real-time prediction of fire behavior to analyzing the impacts of fuel treatments on potential crown fire behavior.

The main outputs of CFIS are its ability to determine the:

- Likelihood of crown fire initiation or occurrence,
- Type of crown fire (active vs. passive) and its rate-of-spread, and
- Minimum spotting distance required to increase a fire's overall forward rate-of-spread.

The onset of fire crowning can be predicted through two distinct approaches via this software tool. One method relies on the knowledge of canopy base height and certain components of the Canadian Forest Fire Weather Index System or the 10-m (33-feet) open wind speed. The other requires the 10-m (33-feet) open wind, the estimated fine fuel moisture, fuel strata gap (or canopy base height), and an estimate of surface fuel consumption as inputs.

Required inputs to predict crown fire rate-of-spread are 10-m (33-feet) open wind speed, estimated fine fuel moisture, and canopy bulk density. The minimum spotting distance to affect overall crown fire rate-of-spread—which assumes a point ignition and subsequent fire acceleration to an equilibrium rate-of-spread—requires the predicted crown fire spread rate and an ignition delay as inputs.



CFIS is available for downloading—at no charge—at <http://www2.dem.uc.pt/antonio.gameiro/ficheiros/CFIS.exe>.

The primary models incorporated into CFIS have been evaluated against experimental and wildfire observations (Alexander and Cruz 2006; Cruz and others 2005), as well as other available fire behavior decision support systems with good results (Alexander 2006).

In addition, CFIS has applicability as a decision support aid in a wide variety of fire management activities—ranging from near real-time prediction of fire behavior to analyzing the impacts of fuel treatments on potential crown fire behavior.

The development of CFIS was a joint venture between the Forest Fire Research Centre of the Association for the Development of Industrial Aerodynamics in Coimbra, Portugal (a private, nonprofit research organization linked to the Department of Mechanical Engineering at the University of Coimbra), and the Wildland Fire Operations Research Group of the Forest Engineering Research Institute of Canada.

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