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Separating fire spread prediction and fire danger rating

N. P. CHENEY[1] AND J. S. GOULD[1]

[1] CSIRO Division of Forestry, PO Box 4008, Queen Victoria Terrace, Canberra 2600, ACT.

ABSTRACT

Australian fire danger rating systems have been developed by relating fire danger directly to predictions of fire-spread. In the past when new fire spread models were developed which changed the basis for predicting fire spread they also changed the basis for calculating fire danger.

This paper examines the consequences of linking fire danger directly to rate of spread by comparing a proposed new fire spread model with the models developed by A. G. McArthur and used in his grassland fire danger rating systems.

The paper concludes that grassland fire danger rating should be separated from predictions of rate of spread. The McArthur MkIV Grassland Fire Danger Meter provides a sound system for calculating fire danger and issuing public warnings on a regional basis.

New fire spread equations should be used to predict fire behaviour for specific fuel types within a local area. They will reflect changes in rate of spread in different pasture types but local arrangements need to be made for appropriate fire restrictions and suppression arrangements when pastures are very discontinuous and will not carry fire.

INTRODUCTION

The concept of **fire danger** involves both tangible and intangible factors, physical processes and haphazard events. By one definition:

> 'fire danger is the resultant of both constant and variable fire danger factors affecting the inception, spread and difficulty of control of fires and the damage they cause.' (Chandler *et al.* 1983)

'Constant factors' are those that change slowly and vary with location; e.g. slope and fuel. 'Variable factors' change rapidly with time but can influence extensive areas; e.g. wind speed and temperature.

The potential for ignition, spread and damage must be present. If there is absolutely no chance of ignition there is no fire danger. If fuels are absent or cannot burn there is no fire danger. If fires can start and spread but there is no economic or other value at risk, as is generally perceived in remote and sparsely populated areas such as some of the open woodlands of northern Australia, there is also no fire danger.

The factors contributing to fire danger may involve chance, e.g. human ignition; be difficult to quantify numerically, e.g. suppression capability; or be intangible, e.g. values at risk. It seems impossible to embody the total concept of fire danger into a single quantitative index.

> **Fire danger rating** is defined as:
> 'A fire management system that integrates the facets of selected fire danger factors into one or more qualitative or numerical indices of current protection needs.' (Chandler *et al.* 1983)

Fire danger rating systems vary in complexity and reflect both the severity of the fire weather and the requirement of management to have some relatively simple measure of the flammability of fuels from day to day. The simplest systems use only temperature and relative humidity to provide an index of the potential for fire ignitions. The most complex systems use better theoretical and empirical models to combine a large number of factors into indices of fire occurrence and fire behaviour. The US Forest Service fire danger rating system, for example, offers the user a choice of six indices or components which are combined into an index of fire load (Deeming *et al.* 1977).

If we accept the above definition of fire danger rating, we then need to examine whether the current systems have selected appropriate factors to meet existing protection needs and to evaluate their performance.

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AUSTRALIAN FIRE DANGER RATING SYSTEMS

The McArthur Fire Danger Rating system for dry sclerophyll eucalypt forests was presented to the first Australian Fire Weather Conference in 1957 (McArthur 1958). Fire danger rating tables for grasslands followed soon after (McArthur 1960). These systems were modified and published as both linear and circular slide rules (McArthur 1966, 1967 and 1977) with some modifications to incorporate revised predictions of fire-spread.

Most fire authorities use the fire danger rating system to:

- determine the type and density of fire detection observations;
- determine levels of preparedness for suppression operations within fire districts. This includes setting stand-by rosters for personnel and equipment, hours of duty, pre-location of equipment, etc;
- issue public warnings in an attempt to restrict ignition and, thereby, enhance public safety. This includes restrictions on lighting fires for management or recreation, restrictions on forest and industrial operations, and restrictions on public access;
- provide an appropriate scale for management, research and the law for fire related matters.

Mostly the fire danger rating systems are used for setting levels of preparedness and issuing of public warnings. A survey of rural fire authorities in 1990 found that, by and large, the McArthur fire danger rating systems were satisfactory for determining the functions above (Cheney *et al.* 1990).

The McArthur Grassland Fire Danger Rating Systems (MkIV and MkV) were originally designed for annual grasslands in south-eastern Australia and computed an index between 1 and 100 from fine fuel moisture content and wind speed. Fuel moisture was computed from variables of ambient air temperature, relative humidity and the state of grass curing (Cheney 1991). The grassland fire danger index (GFDI) was directly related to rate of spread (ROS) and the McArthur fire danger meters could be used to predict ROS. The relationships used to predict ROS are given in Nobel *et al.* (1980), and a multiplier of 7.692 is applied to ROS to produce the GFDI on both meters.

Fire danger rating classes were McArthur's expert assessment of degree of suppression difficulty in average pastures (see Table 1).

The MkIV and the MkV meters use different power functions to relate ROS to wind speed and the two meters compute different rates of spread for the same weather conditions. The Mk V meter introduced fuel load (W) - directly proportional to ROS. Both meters have the same FDI which defines the fire danger classes, but these values represented quite different weather conditions. For example, Figure 1 illustrates the different values of the FDI from the MkIV and MkV meters rate of spread predictions for different wind speeds at a fuel moisture of 3.5 per cent.

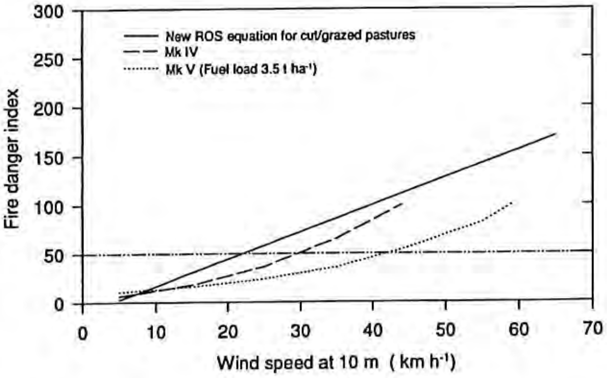

Figure 1. Comparison of the fire danger index for different wind speeds at fuel moisture of 3.5 per cent from the three predicted ROS models (Curing = 100 per cent).

TABLE 1

Grassland fire danger classes, rate of spread (ROS) and difficulty of suppression in annual and perennial pastures that carry a continuous fuel and occur on level to undulating ground (after McArthur 1966).

FIRE DANGER CLASS	FIRE DANGER INDEX	ROS AT MAX FDI IN CLASS (km h^{-1})	DIFFICULTY OF SUPPRESSION
Low	0 - 2.5	0.3	Low : Headfire stopped by roads and tracks.
Moderate	3 - 7.5	1.0	Moderate : Headfire easily attacked with water.
High	8 - 20	2.6	High : Head attack generally successful with water.
Very High	20.5 - 50	6.4	Very High : Head attack may fail except under favourable circumstances and back burning close to the head may be necessary.
Extreme	50.5 - 100	12.8	Direct attack will generally fail - backburns difficult to hold because of blown embers. Flanks must be held at all costs.

Effect of New Rate-of-Spread Equations on Grassland Fire Danger

An exhaustive study into grass fire behaviour (Cheney *et al.* 1993) showed that rate of spread was:

- independent of fuel load if grass cover was continuous;
- directly proportional to wind speed when the wind speed exceeded 5 km h^{-1} at 10 m height above ground; and,
- dependent on whether grasses were undisturbed or were close cropped either by cutting or grazing.

These findings were used to develop new equations to predict fire spread (Cheney *et al.* unpublished). Although these equations are still under development they provide a useful example of the consequences of keeping FDI tied to ROS if the new equations are used to predict ROS. The research results and the fire spread model developed from them show that the previous fire danger meters under-estimated spread rates at moderate wind speeds and over-estimated spread rates if extrapolated to very high wind speeds.

Applying the original multiplier of 7.692 on the ROS predicted by the new equations to calculate the GFDI for given combinations of weather conditions (Figs 1 and 2), causes the ratings to be very different from McArthur's original definition (Table 1). The new equations will produce more GFDIs in the Very High and Extreme fire danger classes and as a consequence more total fire bans will be declared.

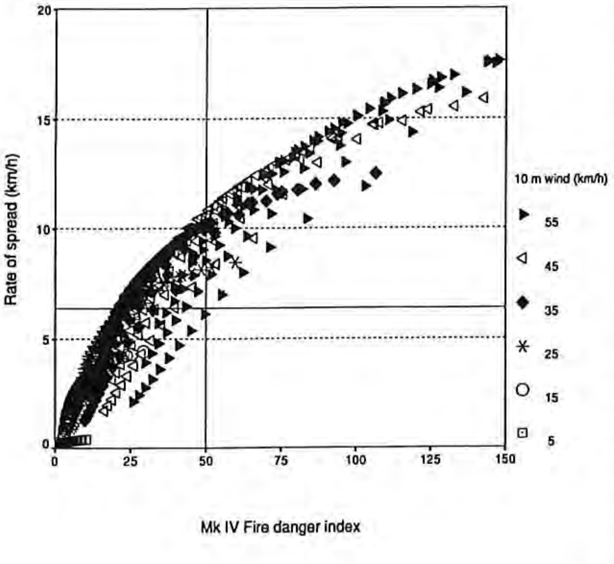

Figure 2. The predicted spread rates by the new equation for cut or grazed pastures for a range of temperature, relative humidity and wind speed conditions related to the MkIV grassland fire danger index for the same weather conditions (Curing = 100 per cent).

The spread rates predicted by the new equations cannot simply be related to the previous GFDI as is shown in Figure 2. The new wind speed algorithm for cut/grazed pastures alone results in a rate of spread of between 6 and 11 km h^{-1} for the combination of weather conditions possible at a MkIV GFDI of 50.

Conversely, if we accept that a rate of spread of 6.4 km h^{-1} represents the boundary between very high suppression difficulty and extreme suppression difficulty as per Table 1 then the new equations will predict extreme fire danger over the range of weather conditions represented by MkIV GFDI between 20 and 50. In general terms this would cause an extreme rating when wind speeds exceeded 30 km h^{-1} over a wide range of temperature and humidity.

Fire authorities were generally satisfied with the performance of the McArthur MkIV meter as a fire weather index (Cheney *et al.* 1990) and this suggests that the McArthur's fire danger classes fairly represented the difficulty of suppression under the prevailing fire weather conditions. Even though we now find that fires have the potential to spread faster than was defined by the original GFDI we consider this does not justify changing the index scale and the weather conditions it represents. Therefore, we believe that fire authorities should retain the GFDI and fire danger classes as defined by the McArthur MkIV Grassland Fire Danger Meter as an index of the severity of fire weather and calculate ROS separately for specific pasture types.

DISCUSSION

Generally, a fire danger rating should be simple and easy to apply (Johnston 1991). We believe that this can only be achieved by separating the functions of public warnings of fire danger from prediction of fire-spread for specific fuel types. Fire control authorities can and do make adjustments for setting general levels of preparedness to account for local variations in fuel load, suppression capability, and resources at risk.

There is considerable misunderstanding of fire danger rating systems. In South Australia, where fire danger rating was given great publicity by news media and roadside signs, few people knew what a fire danger class meant (Dawson 1991). In most cases the only fire danger rating that affects the livelihood of most urban-based people is the EXTREME rating when a Total Fire Ban may prevent the rural barbecue. On the other hand, rural people generally have a good understanding of the preparedness required for different levels of fire danger. This level of preparedness may change during the fire season as the immediate threat to their livelihood changes. For example, wheat growers may request restrictions on the lighting of fires at lower fire danger levels early in the season before they have harvested their crops, than later in the season when they may be keen to burn stubble.

Most public criticism of a fire danger rating system occurs when a Fire Ban District (over which a fire ban is to apply) is too large and there are large differences in the fuel state or weather within the district (e.g. Southern Tablelands of NSW) or when predicted extreme fire danger weather does not eventuate. For example, when frontal systems with dangerous fire weather ahead of a cool change progress more rapidly than forecast, there can be the embarrassment of a warning of extreme fire danger and restrictions on lighting of fires when rain is falling over extensive areas.

Perhaps more confusion arises when fire ban districts are too small (Dawson 1991) and too many fire weather warnings or fire ban restrictions are issued. Many of these issues can be rectified by common sense, with media explanations, or by withdrawing total bans when expected weather conditions do not eventuate.

Forecasts of fire danger indices cannot be very precise because the weather factors contributing to fire danger are additive. Using the Grassland Fire Danger Meter MkIV, errors in forecast variables of:

Curing	100	
Temperature	35	± 4 °C
Dew Point Temperature	15	± 4 °C (RH @ 30 per cent, + 19 per cent or - 11 per cent)
Wind Speed	35	± 10 km h^{-1}

means that the forecast grassland fire danger index (GFDI) of 40 could range from 12 (High) to 90 (Extreme). Considering these errors, one should expect GFDI forecast to vary by at least one fire danger rating class. By and large forecasters do much better than this but even so, one can understand that forecasters and fire authorities may be conservative when the forecast index is within a few points of 50 or whatever index value has been selected for setting a Total Fire Ban.

The same difficulty will, of course, apply to early forecasts of ROS. Predictions of ROS will be most accurate when based on short-term forecasts confirmed or adjusted by measurements of the local weather at the fire site.

The McArthur MkIV Fire Danger Rating System was developed using data mainly from wildfires with some results from experimental fires (Luke and McArthur 1978). The new grassland fire spread equations are designed to predict the potential ROS of grassfires burning in continuous fuels. We believe that the McArthur MkIV Grassland Fire Danger Meter is the most appropriate system for rating the suppression difficulty of grassfires spreading across the landscape in a standard fuel type most commonly represented in that landscape. Some variables have a functional relationship with fire danger which is different to that used for predicting ROS. This is appropriate because some factors will influence suppression difficulty differently than they influence ROS.

The following factors have to be considered when comparing the fire danger index with fire spread models.

Fuel load The fuel factor which most effects fire spread is fuel continuity and not fuel load. Fires will not spread in discontinuous fuels until wind speeds exceed a threshold value related to the degree of discontinuity (Griffin and Allan 1984; Burrows *et al.* 1991). Fuel load is not necessarily related to fuel continuity; for example, a light cover of ephemeral grasses in the inter-tussock spaces may form a continuous fuel bed without significantly adding to the total fuel load.

The introduction of fuel load into the grassland fire danger rating system (McArthur 1977; Purton 1982) was an attempt to provide a practical solution to the situation where grasses are absent or eaten out after prolonged droughts (a condition common in the arid zone of the country) where it did not seem sensible to forecast high levels of fire danger when fires would not spread because of lack of fuel. However, the different results of the MkIV and MkV fire danger meters created confusion because fuel load was incorrectly assumed to directly influence ROS.

It may be feasible to introduce fuel load into a fire weather warning system when it can be reliably estimated on a regional basis using grassland production models (Dawson *et al.* 1991) or estimated directly from satellite imagery. However, we consider it to be more practical to calculate fire danger assuming a standard grass cover and calculate fire spread for specific fuel types using the new equations. If continuous fuels are absent local arrangements can be made concerning fire restrictions and suppression preparedness.

Fuel height Fuel height has some effect on ROS (Cheney *et al.* 1993). The effect of fuel height on suppression difficulty is not known quantitatively but can be described qualitatively. Tall standing grasses produce fires with high flames and high radiation loads: these fires may be difficult to approach directly but often present few mop-up problems once extinguished. Fires in low, compacted fuel beds may be easier to approach and suppress directly, but the compacted fuel bed may remain smouldering for long periods causing problems with mop-up and reignition from wind-blown embers. The effect of fuel height on suppression difficulty will vary widely in local areas and cannot be easily accounted for in a regional fire danger rating system.

Fuel curing New ROS equations (Cheney *et al.* unpublished) use a sigmoidal function between ROS and curing state between 50 and 100 per cent. In the MkIV GFDM, FDI increases exponentially with curing state which may well reflect changes in suppression difficulty across the landscape.

Fuel state expressed as a fraction of fully cured grass is rarely uniform over large areas early in the season because there are large differences in soil moisture between ridge-tops and gullies. Conditions can arise when grasses on ridges are fully cured and burn rapidly while grasses in gully locations are less then 50 per cent cured and will not burn. A satellite estimate of curing state based on the greenness index of 1 km square might produce an integrated curing value of 75 per cent in undulating topography. Fires will not spread uniformly but will spread rapidly on fully-cured ridges and be stopped by the green gullies. Under these circumstances suppression is greatly assisted by natural barriers. It is only when the landscape is more than 90 per cent cured that there is potential for wide-spread and devastating grass fires.

As a result fire controllers should not expect accurate predictions of fire spread across the landscape before grasses are fully cured even though the new equations may give an accurate prediction of ROS in a uniformly cured pasture.

Wind speed The new ROS equations propose a direct relationship been ROS and wind speed above a minimum threshold level. It may be that rates of spread do not continue to increase directly with windspeed at very high wind speeds (> 70 km h^{-1}). However, there is no experimental evidence to support the contention that rate of spread slows down under high winds and we consider the interpretation of field data by McArthur (1968) to be unreliable.

The exponential relationship between FDI and wind speed used in the MkIV GFDM may also be a reasonable description on the effect of wind on suppression difficulty. There is little doubt that, due to spotting, fanning smouldering combustion, and erratic behaviour, fires at high wind speeds are more difficult to suppress than fires at low wind speeds, and it well may be that suppression difficulty increases exponentially as wind speed increases.

In grass fires, the effect of fire breaks on the progress of the fire needs to be considered. At relatively low wind speeds, the potential ROS may be high in continuous fuels, but fire-spread across the landscape can be easily slowed, stopped or held up by narrow barriers such as roads and creeks. As wind speed increases fires will breach progressively larger breaks by either flame contact or by blown embers (Wilson 1988) and at very high wind speeds there will be little if any retardation of rate of spread.

CONCLUSION

We recommend that fire danger and fire spread be considered and calculated quite separately. This will allow revision of fire spread equations to be made without altering the fire danger rating systems.

Fuel load has no effect on ROS and its effect on suppression difficulty is complicated by questions of fuel continuity, fuel height and fuel compaction. Therefore, fuel load cannot be easily built into a general fire danger rating system. Use of McArthur MkV GFDM and the Purton modification of the MkIV GFDM should be discontinued.

The McArthur MkIV grassland fire danger rating system has been used successfully for three decades to provide a guide for levels of preparedness and public warning in the pastoral areas of most States of Australia. The functions used in this meter are appropriate for estimating suppression difficulty and fire authorities should continue to use this system to provide regional fire danger or fire weather warnings. The scale should be open-ended to reflect increasing suppression difficulty at very high wind speeds.

The potential rate of spread in continuous grassland fuels can be calculated for three pasture conditions: (i) undisturbed pastures or natural ungrazed grasslands, (ii) grazed or close-mown pastures, and (iii) eaten out pastures. Local adjustments to fire restrictions and suppression arrangements can be made on the basis of these calculations. The potential rate of spread in all three pasture types is likely to be higher than the average spread rate across the landscape, when wind speeds are low and before the landscape is fully cured.

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