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FOREST AND RURAL FIRE DANGER RATING IN NEW ZEALAND

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INTRODUCTION

In order to protect life, property and other important values (e.g., conservation and cultural assets) from wildfire, it is imperative that fire managers have a thorough understanding of the fire environment[1] and a reliable means of both assessing and forecasting fire danger. To assist in decision-making, a means of reliably evaluating all the factors that influence fire danger is required. This can be achieved through a fire danger rating system.

In New Zealand, fire danger across a range of vegetative fuel types is assessed using the New Zealand Fire Danger Rating System (NZFDRS). The NZFDRS consists of a number of core components or modules (Figure 1). The NZFDRS is based upon the Canadian Forest Fire Danger Rating System (CFFDRS), and has been in use in NZ since 1980, when the New Zealand Forest Service adopted the Fire Weather Index (FWI) System module of the CFFDRS. However, the FWI System was never adapted to the NZ fire environment, nor were the other modules of the NZFDRS developed for application in NZ (Fogarty *et al.* 1998). It was only with the re-establishment of a rural fire research programme with Forest Research in 1992 (then the Forest Research Institute) that this process of adapting the CFFDRS for use in NZ (through developing the NZFDRS) commenced. This continues to be the major focus of the Forest and Rural Fire Research programme, based at Forest Research in Christchurch.

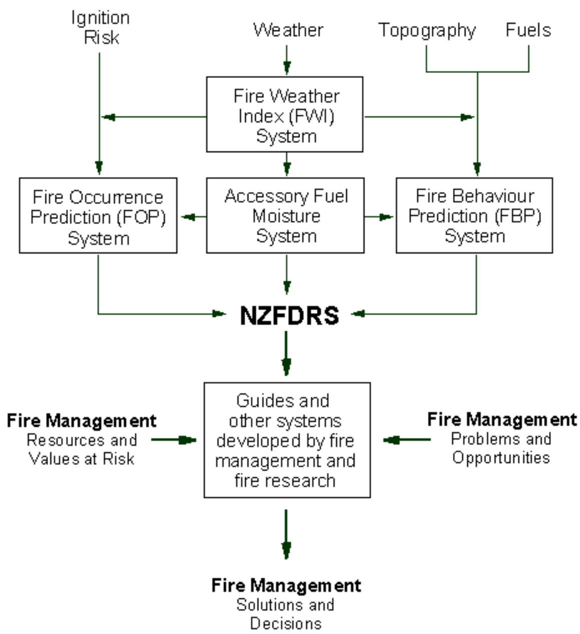

Figure 1. Structure of the New Zealand Fire Danger Rating System (NZFDRS), illustrating the linkage to fire management actions (Fogarty et al. 1998).

[1] The fire environment is defined as “the surrounding conditions, influences and modifying forces of topography, fuel and fire weather that determine fire behaviour” (Merrill and Alexander 1987).

THE NEW ZEALAND FIRE DANGER RATING SYSTEM (NZFDRS)

The NZFDRS comprises four major subsystems (Figure 1): the Fire Weather Index (FWI) System; the Fire Behaviour Prediction (FBP) System; the Accessory Fuel Moisture (AFM) System; and the Fire Occurrence Prediction (FOP) System. Currently, only the first two subsystems (the FWI and FBP Systems) are in use in NZ, with the AFM and FOP Systems yet to be developed. The FWI and FBP Systems also require further development and validation.

The Fire Weather Index (FWI) System

The FWI System is the major subsystem of the NZFDRS, and has been in use in NZ since 1980. Originally implemented for use in rating fire danger in exotic conifer plantations, it was selected because it was simple to use, was based on sound scientific principles, had outstanding interpretative backup, was developed for coniferous forests and was being applied in a maritime climate (British Columbia) similar to that of NZ, and it provided indices that could be correlated to observed fire behaviour characteristics (Valentine 1978[2]).

The FWI System's six components (Figure 2) individually and collectively account for the effects of fuel moisture and wind on ignition potential and probable fire behaviour based solely on selected weather inputs for a reference fuel type (mature pine) on level terrain. The six components comprise three fuel moisture codes and three fire behaviour indices. The three fuel moisture codes, and the moisture contents of the fuel layers they represent, are:

- Fine Fuel Moisture Code (FFMC) – fine surface litter,
- Duff Moisture Code (DMC) – loosely compacted duff of moderate depth,
- Drought Code (DC) – deep compact organic matter.

These fuel moisture codes act as bookkeeping systems, adding moisture after rain and subtracting some for each day's drying. The codes all have built-in time lags and rainfall thresholds (below which the moisture will not lower the value of the code) for the particular fuel layer represented. Higher values of these three fuel moisture codes correspond to lower moisture contents (and greater flammability) (Stocks *et al.* 1989).

The three fuel moisture codes (and wind speed) are linked in pairs to form two intermediate and one final index of fire behaviour. These indices are:

- Initial Spread Index (ISI) – combines the effect of wind speed and fine fuel moisture content (represented by the FFMC), providing a numerical rating of fire spread rate (without the influence of fuel quantity),
- Buildup Index (BUI) – combines the DMC and DC and represents the total amount of fuel available for combustion,
- Fire Weather Index (FWI) – combines the ISI and BUI to indicate the intensity of a spreading fire (on level terrain).

[2] Valentine, J.M., 1978. Fire danger rating in New Zealand: review and evaluation. New Zealand Forest Service, Forest Research Institute. *Forest Establishment Report No. 123. (unpublished).*

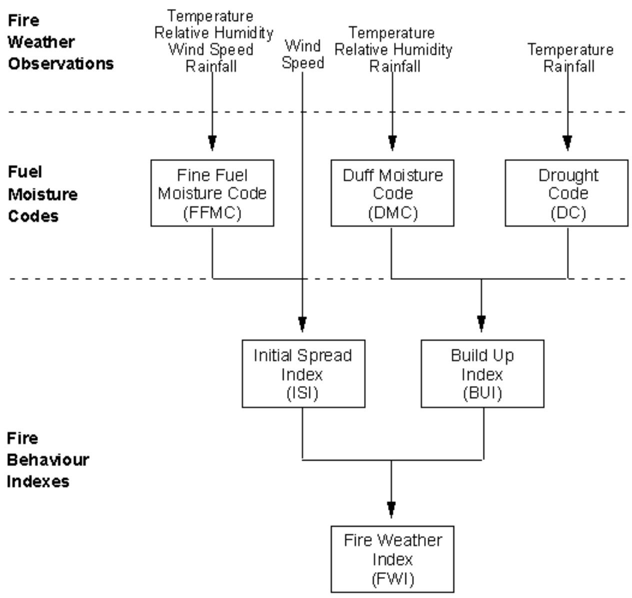

Figure 2. Structure diagram for the Fire Weather Index (FWI) System (Anon. 1993).

Calculation of these components of the FWI System requires only four weather inputs, namely dry bulb temperature, relative humidity, 10-metre open wind speed, and 24-hour accumulated rainfall, recorded at noon local standard time (i.e., 1200 NZST). FWI calculations are run daily for more than 170 weather stations across the country, and the National Rural Fire Authority carries out this function. Since only these four weather inputs are required, it is also possible to forecast FWI values. Hourly values of FFMC, ISI and FWI can also be calculated and forecasted. This is especially useful for fire behaviour prediction and fire danger forecasting. The FWI values can be calculated manually using tables (Anon. 1993), or using commercially developed software packages suited for this purpose.

Whilst the FWI itself is a good indicator of key aspects of fire activity, it is impossible to use one number to summarise daily fire potential. It is essential that all six components of the FWI System be assessed in order to gain a complete picture of trends over time with respect to fuel moisture (and flammability) and expected fire behaviour. These individual components each provide useful indicators of fire potential. For example, the FFMC is a useful indicator of ignition potential (i.e., the likelihood of fire starts), the DC and BUI provide indicators of the potential for deep-seated burning in organic layers, stump and root systems, and the ISI indicates the potential for rapid rates of spread and fire development. A detailed description of the development and structure of the FWI System is contained in Van Wagner (1987).

The Fire Behaviour Prediction (FBP) System

The FWI System has been developed to rate fire potential in a reference fuel type (mature pine); therefore, components and their values have different interpretations in fuel types other than the reference[3] fuel type in which it was developed. In NZ, this applies to any fuel type other than the mature pine plantation fuel type (e.g., tussock grasslands, scrub fuels, pasture grasslands). Fire behaviour variation with fuel type is accounted for by the FBP System, as well as variations in topography (the FWI System assumes level terrain).

[3] The reference fuel type is mature jack (*Pinus banksiana*) and lodgepole (*Pinus contorta*) pine stands (Van Wagner 1987), as represented by FBP System fuel type C-3 (Forestry Canada 1992).

The FBP System has a number of primary and secondary outputs describing fire behaviour characteristics. The primary outputs consist of rate of fire spread, fuel consumption, head fire intensity, and fire description (i.e., fire type – crown fire, surface fire). The secondary outputs consist of: head, flank and back fire spread distances; flank and back fire rates of spread and intensities; fire area and perimeter; rate of perimeter growth; and length-to-breadth ratio. A simple elliptical fire growth model is assumed to estimate the size and shape of fires, and from this it is possible to determine area and perimeter growth rates. These are obviously important outputs for fire managers in terms of fire suppression actions. These outputs are determined by prevailing weather conditions, which are based on wind speed and certain FWI components, and on fuel type and slope steepness. A full description of the development of the Canadian FBP System can be found in Forestry Canada Fire Danger Group (1992) and Hirsch (1993).

The development of the FBP System in NZ has followed the same empirical approach as that used in Canada. This includes correlation of numerical FWI System outputs with observed fire behaviour from experimental fires (and limited wildfires) in a range of fuel types. This work is a major focus of the Rural Fire Research programme at Forest Research. The Canadian FBP System is based on 16 benchmark fuel types whilst, in NZ, models for three benchmark fuel types are currently used for daily fire danger rating purposes (Forest, Grassland and Scrub). A number of fire behaviour models for other fuel types are also in use, although mostly in interim format that still require further validation (Pearce & Anderson 2004[4]). Fire intensity, as represented by the FWI, is directly related to flame size and in this way can determine the limits of effectiveness of suppression resources (Table 1). The fire danger class scheme is based upon fire intensity and provides an indication of suppression difficulty for the three different fuel types. There are five fire danger classes in use – LOW, MODERATE, HIGH, VERY HIGH, and EXTREME. Table 2 provides an interpretation for each of these classes, and the subsequent implications for fire suppression (Alexander 1994).

Table 1. General limits of fire suppression effectiveness in relation to fire intensity (Alexander 2000).

Fire Intensity (kW/m)	Control requirements
< 500	Ground crews with hand tools
500-2000	Water under pressure and/or heavy machinery
2000-4000	Helitanks and airtankers using chemical fire retardants
> 4000	Very difficult if not impossible to control

4 Pearce, H.G., & Anderson, S.A.J., 2004. Field Guide to Fire Behaviour in New Zealand Fuel Types. Forest Research Forest and Rural Fire Research Programme, Christchurch. (in prep.).

Table 2. Fire danger class interpretations (Alexander 1994).

Fire Danger Class	Description of Probable Fire Potential and Implications for Fire Suppression[1]	Nominal Max. Flame Height
EXTREME	The situation should be considered "explosive". The characteristics associated with the violent physical behaviour of conflagrations or firestorms is a certainty (e.g., rapid spread rates, crowning in forests, medium- to long-range mass spotting, firewhirls, towering convection columns, great walls of flame). As a result, fires pose an especially grave threat to persons and their property. Breaching of roads and firebreaks occurs with regularity as fires sweep across the landscape. Direct attack is rarely possible given the fire's probable ferocity except immediately after ignition and should only be attempted with the utmost caution. The only effective and safe control action that can be taken until the fire run expires is at the back and along the flanks.	3.6+ metres
VERY HIGH	Burning conditions have become critical as the likelihood of intense surface fires is a distinct possibility, torching and intermittent crowning in forests can take place. Direct attack on the head of a fire by ground forces is feasible for only the first few minutes after ignition has occurred. Otherwise, any attempt to attack the fire's head should be limited to helicopters with buckets or fixed-wing aircraft, preferably dropping long-term chemical fire retardants. Until the fire weather severity abates, resulting in a subsidence of the fire run, the uncertainty of successful control exists.	2.6 to 3.5 metres
HIGH	Running or vigorous surface fires are most likely to occur. Any fire outbreak constitutes a serious problem. Control becomes gradually more difficult if it's not completed during the early stages of fire growth following ignition. Water under pressure (from ground tankers or fire pumps with hose lays) and bulldozers are required for effective action at the fire's head.	1.4 to 2.5 metres
MODERATE	From the standpoint of moisture content, fuels are considered to be sufficiently receptive to sustain ignition and combustion from both flaming and most non-flaming (e.g., glowing) firebrands. Creeping or gentle surface fire activity is commonplace. Control of such fires is comparatively easy but can become troublesome as fire damages can still result and fires can become costly to suppress if they aren't attended to immediately. Direct manual attack around the entire fire perimeter by firefighters with only hand tools and back-pack pumps is possible.	up to 1.3 metres
LOW	New fire starts are unlikely to sustain themselves due to moist surface fuel conditions. However, ignitions may take place near large and prolonged or intense heat sources (e.g., camp fires, windrowed slash piles) but the resulting fires generally do not spread much beyond their point of origin and, if they do, control is easily achieved. Mop-up or complete extinguishment of fires that are already burning may still be required provided there is sufficient dry fuel to support smouldering combustion.	no visible flame

[1] **THE ABOVE SHOULD NOT BE USED AS A GUIDE TO FIREFIGHTER SAFETY, AS FIRES CAN BE POTENTIALLY DANGEROUS OR LIFE-THREATENING AT ANY LEVEL OF FIRE DANGER!**

Fire Occurrence Prediction (FOP) System

The FOP System is currently under development in Canada, and is aimed at developing a system to predict fire occurrence from both human and natural (lightning) causes, which will also rely on certain FWI components. This work has not yet been progressed here, although work into prediction or probability assessment of ignition from human factors would be of benefit to fire management in NZ. However, to examine probabilities of ignition from human factors requires reliable and long-term records of fire occurrences and causes. Sadly, this information is lacking in NZ due to incomplete and inaccurate fire records.

Accessory Fuel Moisture (AFM) System

The AFM System is intended to supplement or support special applications and requirements of the FWI, FBP and FOP Systems. However, this system is incomplete in Canada (Stocks *et al.* 1989), and no work has commenced on this in NZ. This system is intended to include fuel-specific moisture codes not represented by the standard fuel moisture codes within the FWI

System. This is of particular relevance here, given the fact that the FWI System has been developed in a reference fuel type (mature pine), but is being applied to various other fuel types with very different physical characteristics and drying trends (e.g., grasses and scrub fuels). This could provide the key to more accurate fire danger rating in unique NZ fuels, such as gorse and other scrub fuels (M.E. Alexander[5], *pers. comm.*). The AFM System is also intended to include corrections or adjustments for aspect, foliar moisture content determination, and diurnal trends in FWI System values (Stocks *et al.* 1989).

FIRE DANGER RATING SYSTEM APPLICATIONS

If fire management is to be effective, it is vital that fire managers have a thorough understanding of fire behaviour. Armed with this knowledge, it will be easier to identify and mitigate the risks from wildfires, providing better levels of protection to life and property. The NZFDRS provides a comprehensive "toolbox" for fire management and forms the core of a number of fire management applications in NZ, including (after Stocks et al. 1989):

- Prevention planning (e.g., notification of fire danger levels to the public through display boards, determining fire season status, and imposition of restrictions and other measures such as forest closures);
- Preparedness planning (determining levels of readiness and pre-positioning of suppression resources in readiness for a fire start);
- Detection planning (e.g., lookouts, patrols);
- Initial attack dispatching (the number and types of resources to be responded);
- Determining effective suppression strategies for active fires;
- Prescribed fire planning and execution; and
- Fire behaviour training.

It is worthwhile emphasising that fire management is often referred to as both "an art and a science". It is therefore critical to apply the scientific outputs from decision support tools such the NZFDRS to "real-life" situations by adapting and modifying these outputs to suit local conditions. This is achieved through combining a detailed knowledge of the systems and models (the underlying assumptions behind their development, limitations of models, and the meaning of the outputs) with practical experience and knowledge of local conditions.

FUTURE DEVELOPMENTS

The ongoing development and validation of the NZFDRS is the major focus of the Rural Fire Research programme at Forest Research. The validation of existing fire behaviour models (forest and grassland) within the FBP System, and the development of new fire behaviour models for NZ fuel types (in particular scrub fuels and tussock grasslands), is a major priority. There are also other fuel types that require development of fire behaviour models (such as pine plantations of different age classes, and native wetlands and forests), and then there is the development and application of fire behaviour models for mixed fuel types, perhaps a more common scenario in many areas of NZ than stands of "pure" fuel types.

As mentioned in the discussion on the FWI System, the moisture codes and fire behaviour indices are based on a reference fuel type (mature pine), and the application and extension of these codes and indices to vastly different fuel types in NZ raises many questions as to their validity in these fuel types. This is an area that warrants further research. The development of the FOP and AFM Systems has not yet commenced in NZ and, even in Canada, progress on these modules has been slow.

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[5] M.E. Alexander, Senior Fire Behaviour Research Officer, Canadian Forest Service, Northern Forestry Centre, Edmonton, Alberta, Canada.

Advances in technology in recent years have significantly enhanced the potential for improvements to fire danger rating systems and their outputs, as well as improved display and dissemination of fire behaviour and fire danger information by fire management agencies. This includes spatial displays of fire behaviour information and the use of GIS software, such as those products recently developed by the National Rural Fire Authority and MetService. The NZFDRS predicts fire potential from point-source weather measurements (i.e., at a single weather station). It does not take account of spatial variation in weather elements and fuel characteristics between points of measurement. This is highly relevant in NZ given the large fluctuations in topography, fuels and weather over relatively short distances. Use of technology and modern interpolation techniques will greatly enhance the accuracy of the NZFDRS regionally.

With the challenges facing NZ rural fire management (loss of experienced personnel, increasing public expectations for excellence in emergency management, changing legislation, etc.) and the ever-changing "rural fire hazardscape" (changes in land-use and fuel complexes, urban spread into rural areas), fire management actions need to be based on sound scientific knowledge and systems. It is also important to recognise the balance between operational need and scientific rigour. The development of the NZFDRS needs to meet the requirements of fire managers, but at the same time be based on credible science (Pearce 2001). The effective transfer of technology to fire managers, and landowners and the general public, is also of paramount importance. Continued development of the NZ Fire Danger Rating System, coupled with further advances in technology, will lead to significant improvements in the effectiveness of forest and rural fire management in NZ, reducing both the incidence and consequences of wildfires.

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