Fire Technology Transfer Note

Number - 6 October 1995

Forest and rural fire research in New Zealand[1]

By Liam Fogarty and Grant Prearce

INTRODUCTION

In 1992, a fire research programme was re-initiated in New Zealand after a lapse of 14 years. Since its inception, the programme has set about to quantifying key features of the NZ fire environment and the effect these have on fire behaviour. The major aim of the programme is to adapt and interpret the Canadian Forest Fire Danger Rating System to New Zealand conditions. Improved prevention and preparedness by rural fire authorities is promoted through the use of the New Zealand Fire Danger Rating System (NZFDRS).

The aim of this technology transfer note is to outline the current and expected direction for research in New Zealand. To date, the major effort has been technology transfer through Advanced and Intermediate fire behaviour training courses (specifically aimed at improving the understanding that fire managers have of the use of the NZFDRS) and the collection of fire behaviour data for development of a Fire Behaviour Prediction System for New Zealand.

Both the technology transfer programme and fire behaviour research are expected to be ongoing. When he established the programme, Marty Alexander suggested that the development of a comprehensive fire behaviour prediction system is likely to take at least 10 years. The assessment of the degree of grassland curing using satellite technology is also ongoing and another year of field testing will help us assess the application of this technology to New Zealand. Future plans include research into the interpolation and modelling of weather across complex terrain so that the information from *adequately located* remote automatic weather stations can be used to assess current and expected fire danger conditions throughout most of the country. To achieve this, the components of the NZFDRS are applied to information on fuels, weather and topography stored in a Geographical Information System, using the Vegetation Fire Management Information System (VFMIS) so that outputs can be provided to managers (possibly using the NRFA internet system) to assist decision making.

FIRE IN NEW ZEALAND

The New Zealand fire environment

While the New Zealand fire environment is not among the worst in the world, there is a long history of large and damaging wildfires. Northern and eastern New Zealand are characterised by a mix of flat and steeply divided terrain, occasional drought, strong wind conditions and flammable

[1]*Summary paper prepared as an addition to a poster paper presented at the Bushfire95 Conference; University of Tasmania, Hobart, Australia, September 27 - 30, 1995.*

grass and scrub fuels. Regions such as Canterbury can experience extreme fire weather on more than 40 days per year.

Weather and topography:
The New Zealand climate ranges from sub-tropical in the far north and cool temperate in the south, but the steep and divided relief causes dramatic variation along the length of the country. An example of this variation is provided by the difference in rainfall that occurs between Franz Joseph (20 km north west of Mt Cook) and Twizel (80 km south east of Mt Cook) which receive 4971 mm and 648 mm respectively.

As a frontal system approaches New Zealand, the winds preceding it may reach gale force in open areas due to an increase in the pressure from the effects of blocking by an anticyclone and/or terrain. When the associated cool and moist westerly winds reach mountainous terrain, orographic effects occur, causing rain on the western side of the divide. On the east or lee side, a low pressure trough forms and the resultant warmer and drier winds (i.e., föhn winds) spread over the eastern foothills and plains in a north westerly direction (see Figure 1). These winds often reach gale force in exposed places, and in locations where terrain effects channel the wind (e.g., Cook Strait). The weather patterns that affect the New Zealand climate typically originate from the west (Beatson 1985), as a succession of troughs and anticyclones travel across the country at a rate of 10 to 100 km/hr (Stainer 1992). The synoptic patterns shown in Figures 2a and 2b, are an example of common spring and early summer patterns associated with many of New Zealands major forest and rural wildfires (Pearce and Alexander 1993, Rasmussen 1993).

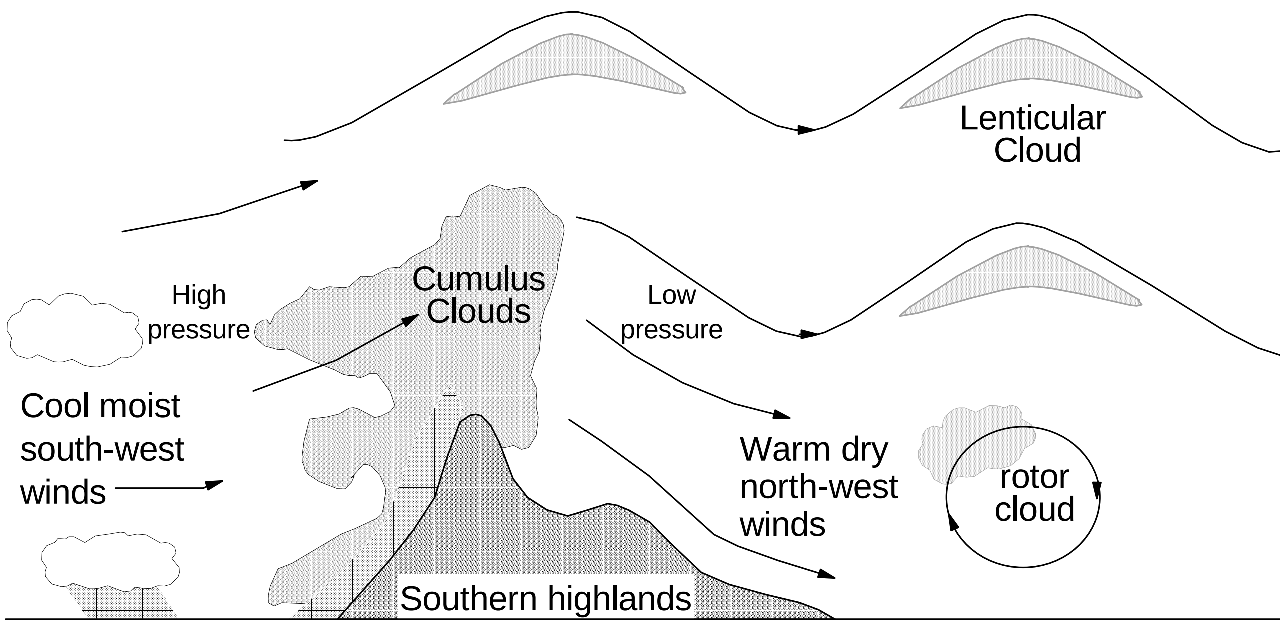

Figure 1. Terrain effects on the establishment of föhn winds over eastern New Zealand

Fuels:
The approximate cover of different vegetation types is shown by Figure 3. Native and exotic forests cover less than 20% (5 118 000 ha.) and 6% (1 212 000 ha.) of the New Zealand land area, respectively, and crops and communities with grass or scrub[1] cover approximately 70% (19 051 000 ha.) (Newsome 1987). Areas of tussock and scrub fuels are very flammable, and recent research results show that extreme fire behaviour will often occur under Low to Moderate fire danger conditions (using the forest fire danger classification by Valentine 1981 and the revised classes proposed by Alexander 1994).

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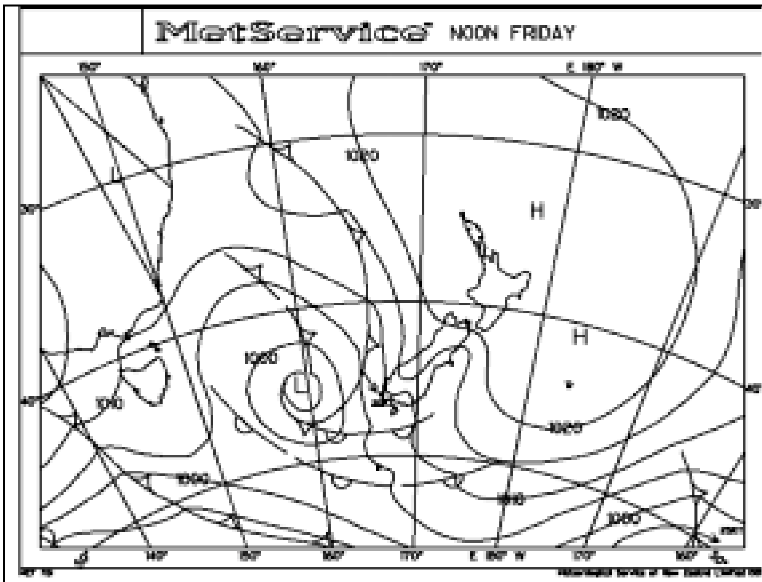
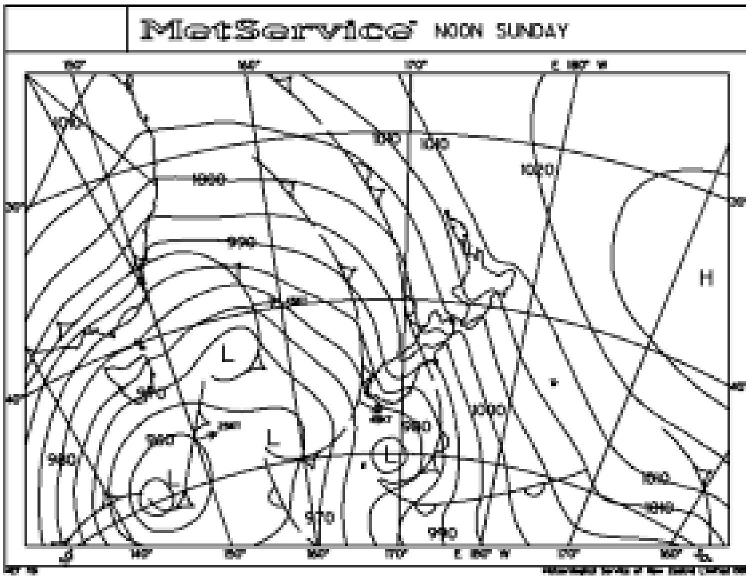
[1]This comprises areas where grass and scrub are mixed with forest and improved pasture (on 6 447 000 ha).



Situation:
A very strong north west flow is expected to cover much of New Zealand over the next 5 days. A series of disturbances embedded in this flow, will cross the country about a day apart. Each disturbance will strengthen surface winds which will reach gale or severe gales in more central, exposed parts of the country. The associated precipitation is expected to be confined mainly to western areas of central and southern New Zealand. A wind warning has been issued for Wellington, Marlborough, Canterbury and Otago for winds gusting as high as 140 km/hr in some localities from this afternoon and persisting through Monday. A heavy rainfall warning has also been issued for rainfall amounts of up to 80 mm on Sunday for west coast areas of the South Island.

Figure 2a Synoptic situation on November 4, 1994; 2 days before the Purakanui wildfire



Situation:
The very strong north west flow will continue over much of New Zealand until about Wednesday, after which time, the flow aloft turns more westerly and eases. This change, signals a return to a more normal weather pattern. In the mean time, a wind warning remains in effect for eastern areas of the country from Canterbury to south of Napier. North west winds in these areas are expected to reach severe gale force in exposed places today. Also, a heavy rain warning is in effect for Fiordland, the ranges of Westland, Buller, Nelson, Marlborough and Canterbury, the Tararua ranges, and for Taranaki. Until Monday night, rainfall amounts ranging from 150 to 200 mm can be expected at higher elevations and from 75 to 100 mm at lower elevations.

Figure 2b Synoptic situation on November 6, 1994; the day of the Purakanui wildfire

Figures 2a and 2b. An example of the synoptic patterns experienced in spring and summer that cause severe burning conditions in eastern areas of New Zealand (example from the Purakanui wildfire, November 6, 1994).

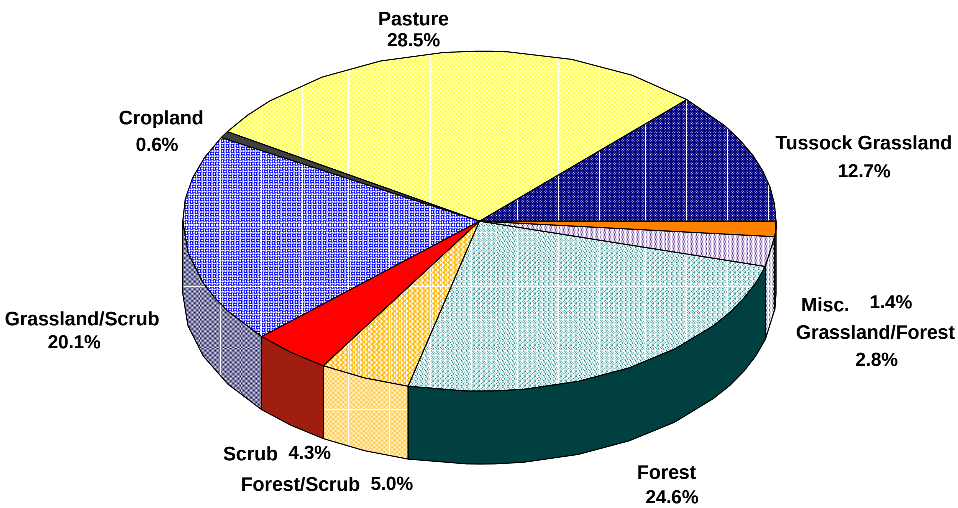


Figure 3. Approximate cover of New Zealand vegetation types (data from Newsome 1987).

New Zealand native ecosystems consist of species that are not specifically adapted to fire, but there are xeromorphic elements thought to be adapted to disturbance from longer term climatic fluctuation, frost (McGlone and Webb 1981), drought, and browsing by moas (Wardle 1985). Margins of beech and podocarp forests are sensitive to fire and, after fire or other disturbance (e.g., landslip), flammable species (e.g., *Leptospermum* spp. and *Dracophyllum* spp.) invade the site so that the potential for further decline and fragmentation by fire is increased.

Historical fire in New Zealand

Prehistorical fire:
Carbon records from the Arrowsmith Range in the Canterbury region of New Zealand indicate the presence of occasional landscape fires from 40 000 yr B.P. (Burrows *et al* 1993). In this area, fires occurred between glacial periods and after 1 800 yr B.P., the climate dried and more frequent natural fires to remove tall woody vegetation and tussock grasslands (Burrows and Russell 1990, Burrows *et al* 1993) were able to expand in area. Polynesian burning in the last 1 000 years further removed tall woody vegetation and this process was continued following European settlement (Burrows and Russell 1990, Burrows *et al* 1993).

Similar patterns of disturbance by pre- and post-Polynesian fire in the late Aranuian (i.e., after 6000 years B.P.) are recorded in palynological records from the Wanganui (Russell 1988) and Far North (Enright *et al.* 1988) areas of New Zealand. But while evidence of fire is frequently recorded in palynological records, it is important to point out that before Polynesian settlement, forests covered most of New Zealand (Wardle 1985), and it is not possible to suggest that fire has influenced the development of adaptive traits among New Zealand taxa. New Zealand native ecosystems consist of species that are not specifically adapted to fire. However, it is evident that throughout the late Aranuian (i.e., after 6 000 yr B.P.), fire has in some areas combined to a greater or lesser extent with the effects of climatic fluctuations (and associated glacial activity, drought and frost) and tectonic activity (Cowan and McGlone 1991) to influence the distribution of some plant species and communities. The most notable example is from the low to middle altitude areas (excluding semi arid or frosty inland basin) of Canterbury and Otago, where frequent Maori burning increased the area of short- and tall tussock grasslands (Wardle 1985).

European fire:
Since European settlement, fire has been a primary agent for land clearing and some large wildfires have caused extensive damage to forest and rural environments of New Zealand. The summer of 1946 represents the most disastrous fire year in recent history when, following periods of drought in Hawkes Bay, Rotorua-Taupo and North Auckland, the State Forest Service lost 6665 ha in 62 fires, 50% of which was indigenous forests. Private owners lost 13 330 ha of exotic plantations, 4460 ha of indigenous forest, and fire overran a further 216 500 ha of cutover forest, tussock and scrub in a total of 311 fires. The most recent statistics on wildfire losses in all vegetation types available for New Zealand has been compiled by the National Rural Fire Authority (the rural branch of the NZ Fire Service) and are presented in Table 1. On average, New Zealand experiences some 1100 wildfires per year totalling around 7000 ha in area burned, of which approximately 350 ha is plantation forest lands, but this figure seems to be increasing as the standard of fire reporting improves.

Table 1. Summary fire statistics for New Zealand 1988/89 - 1991/92.

Fire Season	No. fires/Year	Total Area Burnt (ha)	Forest Area Burnt (ha)
1988/89	1205	12,600	615
1989/90	871	3,037	414
1990/91	1234	10,111	240
1991/92	1153	1,889	152
Average 1988-92	**1116**	**6909**	**355**

Many of the damaging wildfires in New Zealand are a result of wildfire holdovers, or of fires that were not detected and suppressed early enough because of an inadequate appreciation of fire danger (Pearce and Alexander 1993). Tables 2 and 3 contain details on fire location, date, area burnt, specific cause, species and silvicultural treatment, general terrain and weather conditions for some major plantation wildfires. However, it should be recognised that this is not a complete list of plantation fires, and only reflects those fires that had sufficient information to analyse.

A number of fires occur in other fuel types such as indigenous forest, scrub or grasslands. The economic loss from these fires is not easily recorded, but some, such as the Awarua Wetland fire burnt large areas of habitat for rare and threatened plant (e.g., cushion bog or *Donatia* spp.) and animal (e.g., the fern bird or *Bowdleria punctata*) species (Pearce *et al.* 1993). Examples of significant fires in these fuel types include:

1973 Mt White (700 ha tussock, beech forest)
1980 Mt Thomas (900 ha beech forest)
1982 Haldon/Waitangi Stations (2000 ha tussock)
1983 Ohinewairua (15 000 ha tussock, beech, manuka/kanuka forest)
1986 Awarua Wetlands (1360 ha wetlands)
1988 Kaimaumau Peat Bog (3500 ha wetlands)
1989 Whangamarino Peat Bog (2100 ha wetlands).

Ignition by lightning accounts for only 2% of all fires in New Zealand, yet from 1987 to 1993 wildfires have burnt 9803 hectares of the Department of Conservation (DOC) estate. Over a twenty year period, one large New Zealand forest company has had to attend 372 fires that have threatened forest resources. Approximately 22% of these were from escaped burns from adjacent scrub, gorse or tussock, 6% from arson, 10% from carelessness by smokers or picnickers, 22% from logging operations, 6% from farming activities and 8% from power or rail easements and rubbish tips. An even higher proportion of DOC fires are started by the general public (25% from smokers or picnickers and 25% from arson), and with the expansion of the rural/urban interface, not only is there a greater potential for damage to property and natural ecosystems, but there is a greater risk of escaped fires and arson.

Table 2. Statistical information and details on the fuel types, topography, and fire behaviour associated with nine of the most significant New Zealand wildfires involving exotic pine plantations selected for study.

Name of fire	Date of major run	Area burnt: Total (ha)	Area burnt: Pine (%)	Specific cause of the fire	Major tree species[1]	Primary age(s) (years)	Silviculture treatment(s) completed[2]	Generalised type of terrain	Predominant type of fire activity
Tahorakuri	09.02.46	30,738	43	Wildfire escape	RP,PP,MP	14 & 15	U	Undulating	Crown
Balmoral	26.11.55	3,152	100	Wildfire holdover	RP;CP,PP	24-32	PU;U	Flat	Crown
Ashley	07.02.73	194	100	Spark from grader	RP	11	TP	Broken	Crown
Mohaka	03.11.73	368	67	Debris burning escape	RP;CP	8-11	TP;U	Broken	Surface & Crown
Hanmer	22.03.73	798	67	Slash burn holdover	CP,PP	51 & 52	TP	Upsloping	Crown
Wairapukao	05.12.77	432	84	Slash burn escape	RP/PP	8/48	TP/U	Flat	Surface & Crown
Hira	05.02.81	1,972	47	Unknown (human)	RP	7-12	U & TP	Very broken	Crown
Oxford	04.02.87	≈6,046	0	Wildfire holdover	(grass)	-	-	Flat	Surface
Dunsandel	12.12.87	185	89	Lightning	RP	10	TP	Flat	Crown

[1] RP = radiata pine (*Pinus radiata*); MP = maritime pine (*P. pinaster*); CP = corsican pine (*P. nigra* ssp. *laricio*); and PP = ponderosa pine (*P. ponderosa*).
[2] U = unthinned and unpruned, PU = pruned and unthinned, and TP = thinned and pruned.

Table 3. Fire weather observations, fuel moisture stick and fire danger ratings associated with the major run of nine of the most significant New Zealand wildfires involving exotic pine plantations selected for study; two globally well-known wildfires are included for comparison sake. NZ Forest Service Fire Danger Meter (FDM) ratings are given if they were available.

Name of fire	Dry-bulb temperature (°C)	RH (%)	10-m open wind: Direction (from)	10-m open wind: Speed (km/h)	Days since ≥ 0.6 mm rain	"Fire hazard" sticks: 100 g (%)	"Fire hazard" sticks: 400 g (%)	NZ Forest Service FDM: Index	NZ Forest Service FDM: Class	Fire Weather Index System components: FFMC	DMC	DC	ISI	BUI	FWI
Tahorakuri	28.9	29	SW	24	13	-	-	-	-	92.8	117	602	21.3	157	60
Balmoral	15.6	42	NW	55	3	11	≈11	7.2	H	88.5	64	205	55.0	72	79
Ashley	39.0	18	NW	24	9	11	10	9.5	E	96.8	37	378	36.9	60	57
Mohaka	20.0	55	NW	44	6	19	24	4.4	L	87.4	15	67	27.1	19	28
Hanmer	25.0	36	NW	34	12	12	11	8.0	E	90.9	37	168	26.9	48	42
Wairapukao[1]	25.0	28	NW	16	12	12	16	7.2	H	92.3	38	160	13.2	48	26
"	22.0	24	NW	24	10	12	15	7.7	H	92.6	27	74	20.8	28	28
Hira[2]	25.0	41	SW	46	5	-	-	-	-	90.1	45	384	44.3	70	69
"	25.0	44	S	44	5	-	-	-	-	89.0	33	422	34.2	55	52
"	25.0	35	SW	44	5	-	-	-	-	92.5	47	436	56.0	74	81
Oxford	20.6	34	NW	34	12	-	-	-	-	90.1	107	497	24.1	139	63
Dunsandel	29.0	39	NW/S	25	5	-	-	-	-	92.4	51	378	21.2	76	45
Ash Wednesday	40.2	9	NW/SW	36	20	-	-	-	-	98.9	142	832	88.6	199	142
Old Faithful	19.4	24	SW	25	25	-	-	-	-	93.9	183	787	25.0	232	70

[1] Values for Wairapukao (located 18 km north of the fire area) and Waimihia (located 24 km south of the fire area) fire weather stations, respectively.
[2] Values for Nelson Airport meteorological station (also used for missing data at Spring Grove) and fire weather stations at Rabbit Island and Spring Grove, respectively.

FIRE RESEARCH IN NEW ZEALAND

Programme rationale and background

The New Zealand Forest Research Institute (NZ FRI) fire research programme is a relatively new initiative to support a long-needed effort in rural fire research. In the first 18 months of the programme the aim was to increase the awareness of fire managers of their fire environment, and of the need to use fire behaviour information to improve fire protection standards (see Appendix 1 for Fire Research Publications and Presentations). Although environmental and economic losses from wildfires in New Zealand are much less than in other countries such as Australia and Canada, they are of sufficient importance to necessitate the initiation of a new research programme on rural fire management. To meet this need, in 1992 the National Rural Fire Authority, with the support of the Department of Conservation, Local Government Association, Federated Farmers, Forest Owners Association, Ministry of Defence, and Ministry of Forestry established a new rural fire research and technology transfer programme based at the Forest Research Institute. Research is aimed at both forest and rural fire managers, not just because the greatest threat to plantation resources comes from outside the forest area, but because fire is a significant threat to rural and rural/urban interface populations and their property, and can have devastating effects on indigenous flora and fauna.

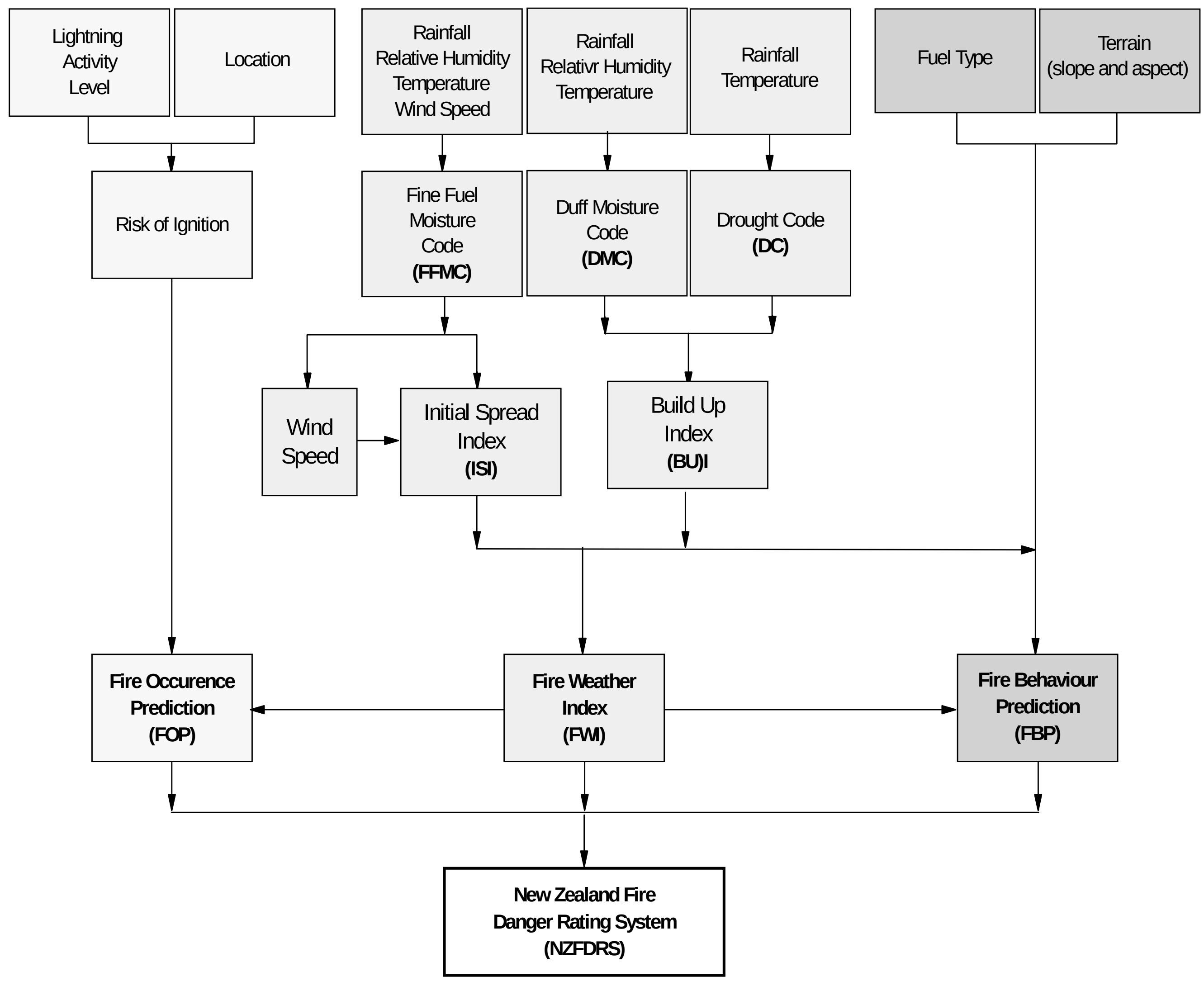
This research is regarded as particularly urgent because before its demise, the New Zealand Forest Service assumed the responsibility for rural and forest fire protection in New Zealand, but now no large and well organised fire protection authority with staff who are regularly exposed to wild and prescribed fire exists. The current structure is far more fragmented and fire managers cannot develop enough expertise and knowledge of fire behaviour to adequately manage most fire situations. There is now an increased risk of unplanned fires burning greater areas and threatening property, conservation values and life. Even with the levels of expertise that existed within the NZ Forest Service, fatalities and "near misses" occurred when personnel found themselves in life threatening situations because of *"unexpected fire behaviour"* (Millman 1993). With increased risk and reduced expertise and resources, New Zealand has no choice but to be "smarter in the future" (M. Alexander, Forestry Canada, pers. comm.).

The Canadian Forest Fire Danger Rating System (CFFDRS) (Hirsch 1993), was adopted by New Zealand in 1980, because it had the following favourable characteristics (Valentine 1978):

- simple and easy to understand;
- soundly based (on underpinning research);
- outstanding interpretive back up; and
- because New Zealand has a similar (although windier and sunnier) climate to British Columbia.

The CFFDRS has undergone considerable development since 1980 and today it is one of the most comprehensive and scientifically-based decision support systems in the world. The CFFDRS enables Canadian fire managers to predict fire behaviour in most of their major fuel types and it is extensively used for fire protection planning and operations. The system is modular, computer and manually based, and can be used in other countries such as New Zealand by incorporating additional fuel types, provided the underpinning research is done to the standards developed by Forestry Canada fire researchers. The aim of this research programme is to interpret and adapt the CFFDRS to the New Zealand fire environment to produce a comprehensive New Zealand Fire Danger Rating System (NZFDRS).

The present structure of the NZFDRS is shown in Figure 4. The Fire Weather Index (FWI) System (Van Wagner 1987) uses basic weather data to provide a standard indicator of fire danger. The FWI System components are then combined with fuel type and terrain factors to determine expected fire behaviour using the Fire Behaviour Prediction (FBP) System (Forestry Canada Fire Danger Group 1992).



FFMC	A numerical rating of the moisture content of litter and other cured fine fuels. This code is an indicator of the relative ease of ignition and flammability of fine fuel.
DMC	A numerical rating of the average moisture content of loosely compacted organic layers of moderate depth. This code gives an indication of fuel consumption in moderate duff layers and medium-size woody material.
DC	A numerical rating of the average moisture content of deep, compact, organic layers. This code is a useful indicator of seasonal effects on forest fuels, and amount of smouldering in deep duff layers and large logs.
ISI	A numerical rating of the expected rate of fire spread. It combines the effects of wind and FFMC on rate of spread without the influence of variable quantities of fuel.
BUI	A numerical rating of the total amount of fuel available for combustion that combines DMC and DC.
FWI	A numerical rating of fire intensity that combines ISI and BUI. It is suitable as a general index of fire danger.

Figure 4. Structure of the New Zealand Fire Danger Rating System (adapted from Hirsch 1993).

The NZFDRS has not been validated under New Zealand conditions, and no adequate fire behaviour information exists for many New Zealand fuel types such as manuka/kanuka, gorse or tussock grasslands. The underpinning relationships of the Fire Weather Index System (the system from which fire behaviour predictions are made) are based on factors derived from empirical fire behaviour studies in red pine (*Pinus resinosa*), white pine (*Pinus strobus*) and jack pine (*Pinus banksiana*) (Van Wagner 1987, Forestry Canada Fire Danger Group 1992). These models are not directly applicable to the non forested and "elevated" fuel types that are common in New Zealand. Elevated fuels dry more quickly and fires are generally more responsive to changes in wind speed and fuel moisture content (Burrows 1984), so a greater knowledge of fire behaviour in these fuel types is needed, and some adjustment to the FWI System components may be necessary. The major objective of this research programme is the modelling of fire behaviour in key fuel types, which is essential for the development of a New Zealand Fire Danger Rating System (NZFDRS).

This research programme is multi-disciplinary, because fire danger conditions vary temporally and spatially due to differences in climate, weather, fuel type, fuel condition and terrain. Collaborative research with remote sensing specialists (Landcare Research) and Geographical Information System specialists (NZ FRI Resource Management Unit) is needed to develop a Vegetation Fire Management Information System for New Zealand (VMIS) will provide the essential inputs for the NZFDRS. Figure 5 shows the objectives of this programme for the next 3 to 5 years, which are as follows:

- Objective 1, the development of fire behaviour models for priority New Zealand fuel types;
- Objective 2, the development of satellite image analysis techniques for the assessment of grassland curing, which is an essential input for the modelling of grassland fire behaviour;
- Objective 3, the interpolation of weather parameters between remote automatic weather station sites, so that FWI values can be estimated for a greater area of New Zealand;
- Objective 4, the use of GIS to integrate the models produced from Objectives 1 to 3, with the meteorological and biophysical factors that influence fire behaviour, so that maps of current or expected fire danger conditions can be produced.
- Objective 5, the transfer of research results and technology to New Zealand fire managers so that they can use the new and improved prediction capabilities developed by this programme to prevent damaging wildfires.

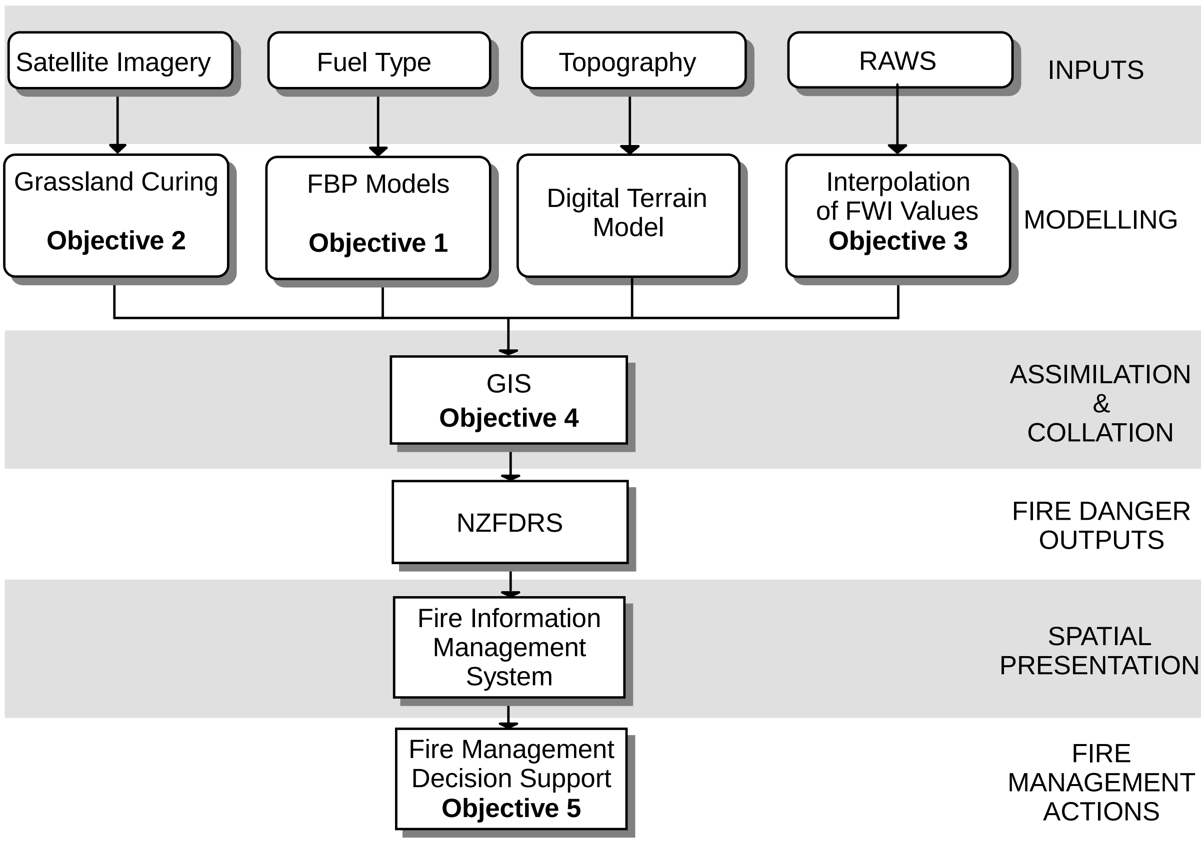


Figure 5. Interrelationships between the objectives of the Fire Research Programme.

This programme involves joint research with Canadian and Australian fire researchers. Forestry Canada fire researcher, Marty Alexander, who initially established the programme, continues to advise on programme priorities and scientific and technical issues. Australia has a number of fuel types that have the same fuel bed structure and consist of the same genera as New Zealand fuel types (e.g., *Leptospermum* species such as Manuka). NZ FRI fire research is contributing to the collaborative heathland fire behaviour project being coordinated by Wendy Catchpole (Mathematics Department of the University of New South Wales) and involving a number of other fire authorities.

Fire behaviour modelling

Aims:
Develop fire behaviour models for major New Zealand fuel types to upgrade the NZFDRS, in order to improve the standard of fire protection planning and reduce the costs of wildfire to the community (this covers experimental burning research and is the main thrust of the fire research programme).

(a) Establish research plots and conduct experimental burning trials in the following fuel types :
  1. Gorse;
  2. Crop stubble;
  3. Tussock grasslands;
  4. Manuka/kanuka;
  5. Exotic forest.

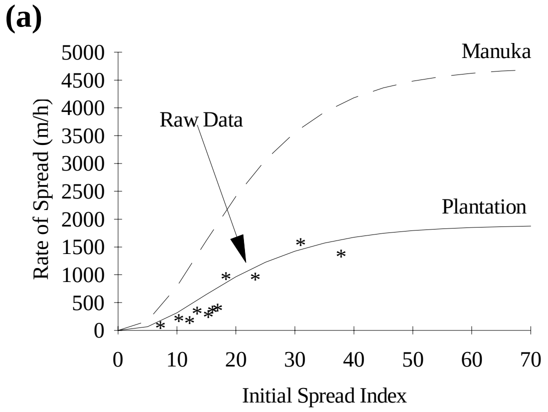
(b) Test and evaluate the applicability of existing fire behaviour models from the CFFDRS to New Zealand conditions using data derived locally from experimental burning.

(c) Extend fire behaviour models developed for the priority New Zealand fuel types to include high to extreme conditions under which experimental burning cannot safely be carried out, by monitoring and documenting wildfire behaviour as practicable, and through the analysis of historical wildfire information.

(d) Establish and maintain a database on fire behaviour in specific fuel types.

Background:
Inadequate evaluation of the fire situation is one of the most common causes of inappropriate resource deployment (Beck 1991), and can lead to fire fighters being placed in life threatening situations (Millman 1993, Rasmussen 1993). The fire danger rating system that has been used in New Zealand over the last 13 years was based on fire behaviour in the Canadian red pine fuel type (C-5) (Anon. 1992), but following a review of fire danger rating will be changed to CFFDRS models for grassland (O-1) and coniferous plantation forest (C-6), depending on location (Alexander *in prep*). Currently, New Zealand has no choice but to use this information because it is the best available.

Figure 6 illustrates the risks involved when fire management decisions are based on inadequate fire behaviour information. In this example, it is assumed that at a constant Build Up Index of 65, a fire burning in manuka will spread at 2.5 times the rate of spread of a fire in the coniferous plantation fuel type (C-6). With 15 t/ha of available fuel, the intensity at which the fire becomes uncontrollable (i.e., 4 000 kW/m) is reached at an Initial Spread Index (ISI) of 7 in manuka, compared to an ISI of 13 in a coniferous plantation. More importantly, the fire danger levels that must be reached before a fire becomes uncontrollable in the manuka and plantation fuel types are moderate and very high respectively, so if preparedness levels are based on a forest fuel type only (which has been the situation in New Zealand for the last 13 years), they will be lower than needed to effectively respond to a fire in manuka, gorse or other elevated fuels. When suppressing a wildfire, an underestimate of fire behaviour increases the chance of strategic failure and of *unexpected fire behaviour* occurring. Fire behaviour models are imperative for safe and efficient fire management.



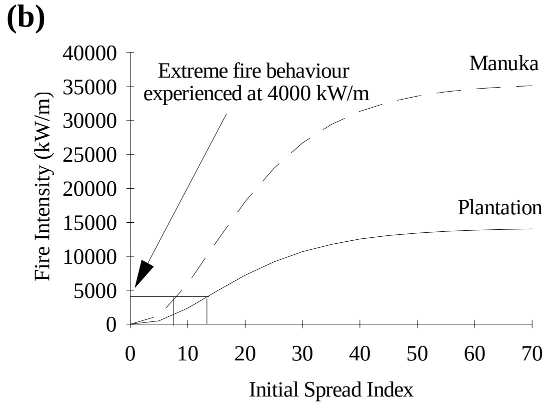


Figure 6. (a) Hypothetical rate of spread (assuming a BUI of 65) for fire in manuka compared to predicted rate of spread of fire in coniferous plantation; and **(b)** Hypothetical fire intensity (based on an available fuel load of 15 t/ha) in manuka compared to predicted intensity of fire in coniferous plantation (fuel type C-6) (Anon. 1992).

A knowledge of fire behaviour enables forest owners and fire managers to assess fire danger conditions and put in place appropriate practices and procedures for the rapid detection and suppression of wildfires. Figure 7 illustrates the importance of this approach if damage and suppression costs are to be kept to a minimum. In this example, a fire is burning under "average"[1] fire danger conditions in a mature plantation. Detection, initial attack (1 crew and 1 helicopter), first backup (2 crews and 1 helicopter) and second backup (2 crews and 1 helicopter) occurred at 15 minutes, 30 minutes, 60 minutes and 120 minutes respectively for the rapid initial attack scenario, and at 45 minutes, 90 minutes, 120 minutes and 180 minutes for the slow initial attack scenario. As a result of a high standard of detection and suppression planning (and an adequate infrastructure), the fire was controlled in two, rather than four hours, and the fire size from rapid initial attack was approximately 30% of the fire that resulted from the slower response.

[1] No fire climate analysis has been conducted for New Zealand, but for this example "average"conditions are assumed to be a wind speed of 22 km/hr, a Fine Fuel Moisture Code of 89 (i.e., Relative Humididty 45% and Temperature 24ºC), an Initial Spread Index of 11 and a Build Up Index of 50.

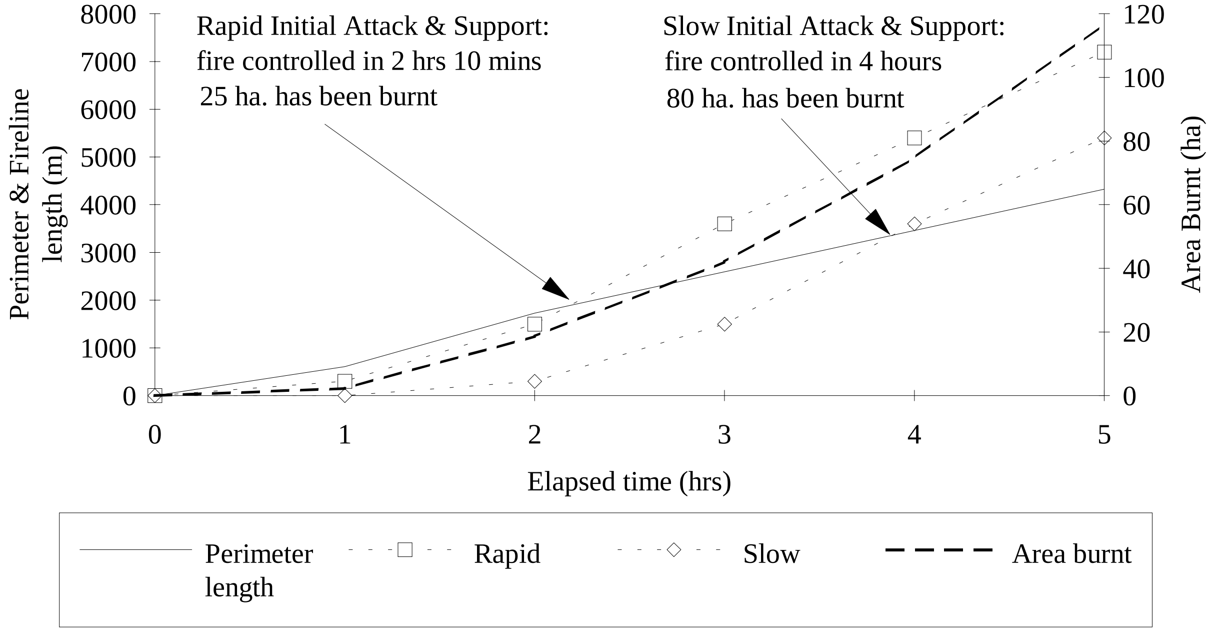


Figure 7. A comparison of the effects of elapsed time between ignition, detection and suppression as a result of rapid and slow initial attack.

Future plans:
The programme will continue research into fire behaviour in the priority rural fuel types, and as sufficient data for each fuel type becomes available, it will be analysed using the procedures outlined by Stocks (1986, 1989) and the Forestry Canada Fire Danger Group (1992). If applicable and available, Australian fire behaviour data that has similarities with New Zealand fuel types (e.g., coastal heath and manuka/kanuka, and button grass and tussock grass fuels) will be analysed and incorporated into the NZFDRS. To test the applicability of the FWI System to New Zealand conditions, more fundamental analysis of the data will also be conducted to test the underpinning relationships that were developed by Van Wagner (1987).

As fire behaviour models are developed, the computer and manual components of the NZFDRS will be updated. Published reports, the Fire Technology Transfer Note, conferences, training programmes and workshops will be utilised to illustrate the use of fire behaviour information to fire managers and fire fighters for prevention, pre-suppression and suppression planning and operations.

Satellite assessment of grassland curing

Aims:
Grasslands are one of the most widespread fuel types in New Zealand. The flammability of grass is strongly influenced by the fine fuel moisture content of the grass, which in turn is related to the degree of grassland curing. This objective aims to evaluate tools that use satellite imagery for the assessment of grassland curing, an important input to a GIS-assisted NZ Fire Danger Rating System. To assess the applicability of this tool to New Zealand, the objective will:

(a) Test the applicability of the NOAA weather satellite for estimating the degree of grassland curing.
(b) Identify the most appropriate Normalised Difference Vegetation Index (NDVI) for the estimation of grassland curing.
(c) Develop a conversion methodology between the most appropriate NDVI and the degree of grassland curing, including tussock grasslands.
(d) Estimate the cost of producing regular composite grassland curing maps for New Zealand.

Background:
Most pasture species undergo an annual curing process, in which the plant progressively dies and loses moisture (Luke and McArthur 1978, Garvey 1992). During this period the ignitability of the grass increases. The fine fuel moisture content of grassland fuels effects the rate of spread and intensity of fires in grass because, as the fuel dries, the heat transfer processes which enable a fire to propagate become more efficient. Grassland curing is therefore an essential input in the successful prediction of grassland fire behaviour.

Grassland curing can be estimated by field inspection using a photo guide (e.g., Garvey 1992) and more accurately measured by field sampling (Cheney *et al.* 1989), but these techniques are time consuming and expensive because in complex terrain, grassland curing may vary significantly over short distances. Remotely sensed information can average these site effects and has been used effectively to monitor grassland curing in Australia (Barber 1992). Remotely sensed data can be used to produce maps for rural fire managers, or as an input into a more sophisticated GIS-assisted fire danger rating system which is a longer term objective of this project.

The Normalised Difference Vegetation Index (NDVI) is a widely used measure which calculates the difference between two spectral bands (one in the visible and one in the infra-red range). When grass is green there is a high infra-red and low visible reflectance resulting in high NDVI values, and when it is dry the opposite occurs. Previous Australian work in this application (Barber and Partridge 1986) uses a modified measure NDVI (1.2). It would be cheaper and more convenient to use the standard NDVI measure currently produced by Landcare Research.
Future plans:
The first stage of the satellite assessment of grassland curing programme is being conducted in pasture grass and if the approach proves to be successful, then the technique will be applied to native tussock grasslands.

Modelling wind and weather inputs for the NZFDRS

Aims:
To determine techniques for modelling the meteorological processes which influence the initiation and behaviour of rural fires, in order to minimise the economic and environmental damage: To achieve this objective the programme will:
(a) Test a modelling procedures that describe the wind-field between remote automatic weather stations for rural fire danger rating.
(b) Investigating the applicability of two models to two regions in New Zealand and undertaking a brief validation study.

Background:
Fire behaviour is strongly affected by current and cumulative weather factors. A number of weather elements are important as inputs into the FWI System of the NZFDRS, including temperature, rainfall, humidity, and wind speed. Wind speed and direction strongly influence the rate and pattern of fire spread, but these are difficult to predict in complex terrain.

It is impractical to have a remote automatic weather station (RAWS) network monitoring conditions in all areas of New Zealand, so modelling between RAWS sites is required to make best use of the available information. There have been many models developed for this task and these include ones that use simple geographic multipliers (Booth 1977), numeric models that aim to conserve both the mass and momentum of air as it moves over topography (e.g., Flowstar (Hunt *et al.* 1988)), through to complex meso-scale models capable of applying hydrostatic principles to model three dimensional wind fields (e.g., RAMS (Pielke *et al.* 1992)) and other meteorological parameters. This programme aims to test some available models and assess their utility for forest and rural fire danger rating.

Future plans:
The programme will extend to the modelling of other weather parameters that effect fire behaviour, and the integration of these using the NZFMIS so that national and regional fire danger conditions can be accurately monitored.

Vegetation Fire Management Information System (NZFMIS)

Aims:
The factors that effect fire behaviour and subsequent fire danger ratings vary temporally and spatially. This programme aims to assimilate the many sources of information so that up-to-date fire danger rating maps can be produced. This objective will be achieved by:

a) Initiating a pilot programme for the development of a GIS-assisted NZFMIS.
b) Cooperating with NZ FRI's Resource Monitoring Unit staff, to initiate a GIS sensitivity analysis to assess the affects of generalising data from 3 minimum mapping units on fire danger rating.
c) Identifying existing information sources (especially digital) for the compilation of data schema for fire danger, especially *benchmark fuel types*.

Background:
Many areas of New Zealand have complex terrain, edaphic, climatic and vegetation characteristics, and the level of fire danger can vary over short distances as a result of this complexity. Geographical Information Systems (GIS) enable the rapid assimilation of the many different data sources that are temporally and spatially dynamic (Salazar and Nilsson 1989), including data from RAWS, so that fire danger maps and expected fire spread and loss maps can be produced (Buckley and Lee 1993, Beer 1989). Figure 8 illustrates the use of GIS in models for interpolating meteorological conditions between RAWS, and predicting fire behaviour with terrain and fuel information (including remotely sensed grassland curing levels), so that fire danger ratings can be spatially displayed using the NZFMIS.

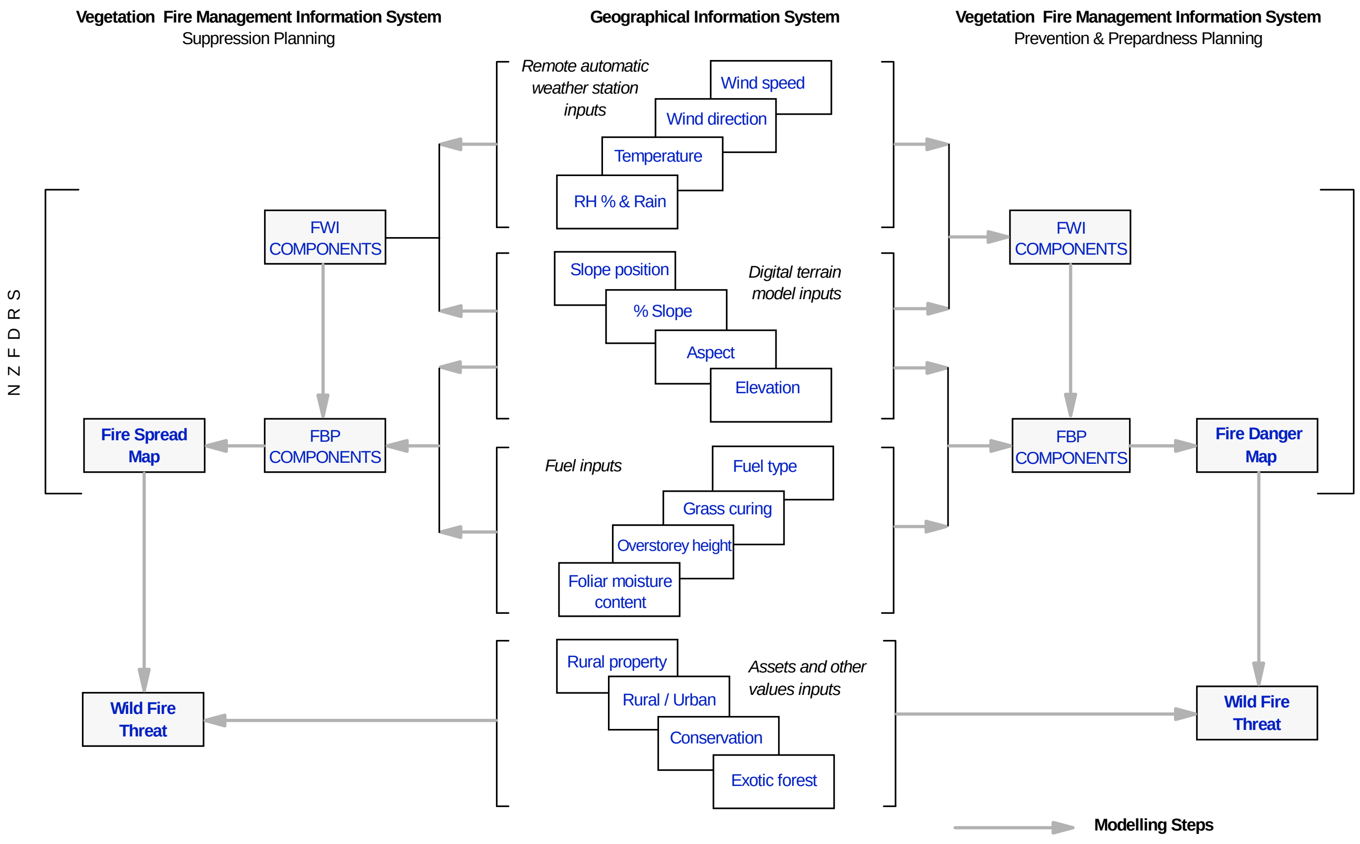


Figure 8. A wildfire threat analysis system for fire management planning.

At all levels of the fire management organisation, accurate maps of fire danger are important for fire protection decision making. The end use of these maps will determine the most appropriate resolution; for example, the district level may require detailed information for the issue and revocation of burning permits, whereas at the national level a reduction in detail may be useful for public awareness programs and the determination of priorities for resource allocation. However, the generalisation of spatial information needs to be assessed so that the robustness of model outputs and the compatibility of hierachial information can be determined (Stoms 1992). Figure 9 illustrates how data compression may result when fire danger information from the district scales is used to produce a national fire danger map. The example is based on a raster GIS, but similar problems arise if vector systems are used, or when vector and raster methods are used in conjunction.

GIS functions can be combined with other models or expert opinion to produce some of the data schema, including a map of *benchmark fuel types*, which are unique fuel types or clusters of vegetation types with similar floristic and structural characteristics. The programme will assess the appropriateness of existing information for the derivation of these and the production of maps using GIS.

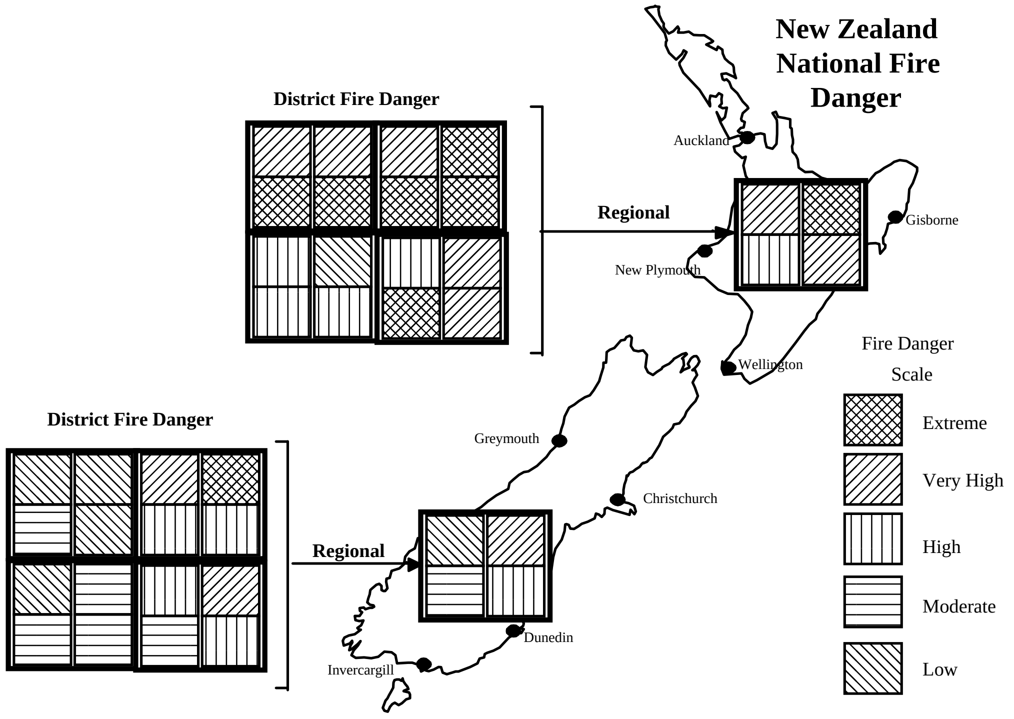


Figure 9. The effect of data compression when composite maps are produced.

Future plans:
Once a core NZFMIS has been developed for the purposes of fire danger rating, the programme aims to integrate additional data schema that reflect environmental damage (e.g., maps of soil erodibilty), and techniques for the mapping of wildfire spread so that more detailed *wild fire threat analysis* can be conducted (Beck and Muller 1989, Garvey *et al.* 1993). This will involve integration of all four objectives in this bid, where fire behaviour models form the basis of the fire spread and danger prediction system, and the interpolation of meteorological parameters (including a fire spread vector from wind research) and satellite grassland curing rates are temporally dynamic inputs superimposed onto fuel and terrain parameters. By integrating the NZFDRS with other biophysical data (including environmental management information), fire managers can conduct a number of "what if" scenarios for planning prior to or during wildfire events to develop contingency plans should a worst case situation arise.

Technology transfer:

Aims:
This programme aims to support and promote the application of up-to-date science and technology by fire protection personnel and fire researchers in New Zealand, and to promote the NZ FRI fire research program among the international fire research community to foster an environment for technology transfer.

Background:
New Zealand fire managers and fire fighters need to be exposed to the results of local and overseas research and technology development. The strategy devised is to target at all levels through published reports, the Fire Technology Transfer Note, conferences, advanced fire training programmes and workshops. Most importantly, the information developed by the NZ FRI fire research programme will be used to illustrate the use of fire danger rating and behaviour prediction for prevention, pre-suppression and suppression planning and operations, so that damaging wildfires can be prevented and if prevention fails, their negative impacts minimised.

Figure 10 is a representation of the use of the VFMIS for day-to-day and longer term strategic fire protection planning by national, regional and district fire authorities. The major inputs are based on the NZFDRS, and Geographical Information Systems (GIS) technology is needed to collate and display information from a number of different sources. The system must be built from the ground up, so that fuel type and weather parameters can be used to establish district, regional and national fire danger conditions, and resources can be directed to minimise fire occurrence and impact in areas where they are most likely to occur and cause damage. The technology transfer component of this programme aims to produce training courses and guidelines so that fire managers are able to use the information from this research project and implement a scientifically based fire management system.

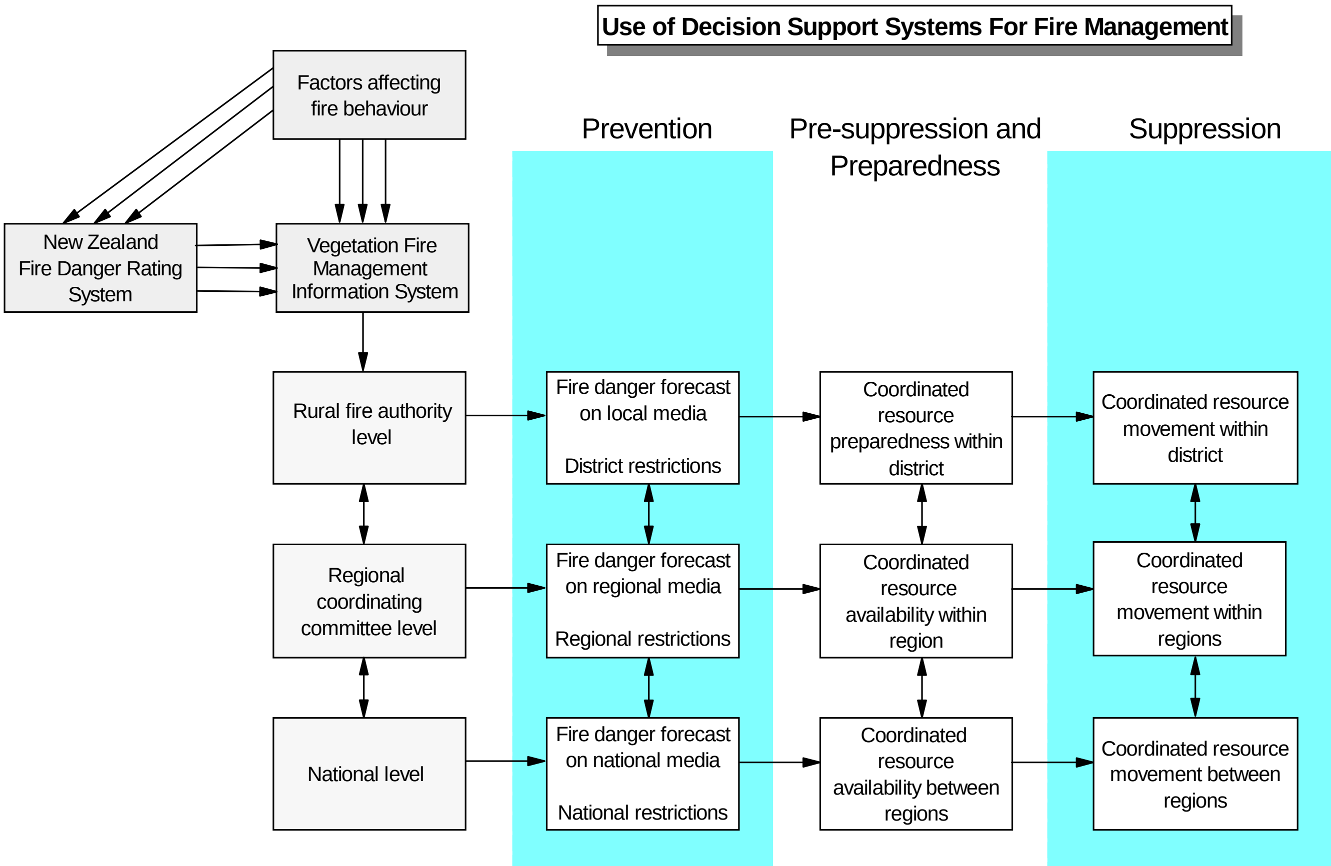


Figure 10. Example of the use of the Vegetation Fire Management System for New Zealand.

Summary and conclusion

The NZ FRI fire research programme covers a wide range of topics, and involves cooperation from a number of fire authorities and other researchers. Appendix 1 shows that to-date, significant efforts been spent on technology transfer aimed at meeting the needs of this wide industry base, with fire behaviour training courses being the major technology transfer effort. This needs to continue so that fire managers can better apply the NZFDRS to their own fire environment, which will ultimately improve the standards of fire management decision making in New Zealand. Fire behaviour research in New Zealand fuel types must continue as a high priority because it forms the core of the NZFDRS which is used to assist fire prevention, preparedness and suppression decision making.

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