Fire behaviour, suppression and lessons from the Berwick Forest Fire of 26 February 1995

L.G. Fogarty
A.F. Jackson and
W. T. Lindsay

FRI Bulletin No. 197
Forest and Rural Fire Scientific and Technical Series
Report No. 3

NEW ZEALAND
FOREST RESEARCH INSTITUTE

Wildfire Case Study

Fire behaviour, suppression and lessons from the Berwick Forest Fire of 26 February 1995*

L.G. Fogarty (New Zealand Forest Research Institute),
A.F. Jackson (National Rural Fire Authority) and
W.T. Lindsay (Wenita Forest Products Ltd.)

This research report is a product of the NZ FRI forest and rural fire research programme. Funding and "in kind" support for this project is jointly provided by the following organisations:

- **National Rural Fire Authority.**
- **New Zealand Forest Owners Association.**
- **Foundation for Research, Science and Technology.**
- **Department of Conservation.**
- **Members of the Local Government Association.**
- **New Zealand Defence Force.**

*Correct citation: Fogarty, L.G.; Jackson, A.F. and Lindsay, W.T. 1996. Fire behaviour, suppression and lessons from the Berwick Forest Fire of 26 February 1995. New Zealand Forest Research Institute, Rotorua, in association with the National Rural Fire Authority, Wellington. FRI Bulletin No. 197, Forest and Rural Fire Scientific and Technical Series, Report No. 3. 38 p. + Appendices.

Published with the assistance of:

The National Rural Fire Authority

The Forest and Rural Fire Association of New Zealand

Wenita Forest Products Ltd.

New Zealand Forest Owners Association

Disclaimer:

The contents of this publication are not intended to be a substitute for specific specialist advice on any matter and should not be relied on for that purpose. The New Zealand Forest Research Institute and the authors of this publication shall not be liable for any loss, damage or liability incurred as a direct or indirect result of reliance by any person upon information contained, or opinions expressed in this work.

Additional copies of this publication are available from:

Publications Officer
New Zealand Forest Research Institute
Private Bag 3020
Rotorua
New Zealand

National Rural Fire Authority
PO Box 2133
Wellington
New Zealand

ISSN: 0111-8129

ODC: 431.5/6 (931)

Contents

Figures

Tables

Photographs

Appendices

Executive Summary and Abstract

On 26 February 1995, a fire at Berwick Forest burnt 181 hectares of stocked plantation forest under extreme fire danger conditions. During the initial stages of the fire there was a "window of opportunity" in which better preparedness and earlier rapid initial attack may have contained the fire before it dramatically escalated. A comparison of observed head fire rate of spread with values predicted by the Canadian Forest Fire Behaviour Prediction System suggests that a combination of the coniferous plantation (C-6) and logging slash models (S-1) could provide reasonable estimates of fire rates of spread in New Zealand plantation forests. The case study shows that the use of fire weather and fire behaviour information to support fire management decision-making could have resulted in improved fire preparedness.

Although, the fire control team successfully contained the fire without injury or near miss to fire-fighters or the public, a review of incident management procedures suggests that many important aspects of fire command and control were not carried out. The reason for this was a lack of personnel trained in incident management techniques. Benchmarking of some of the current prevention, presuppression and suppression practices and procedures against those used overseas has highlighted areas in which modification could minimise the chance of future fire disasters in New Zealand. The fire protection practices and procedures that warrant consideration by New Zealand fire managers are listed in the recommendations section.

Keywords: Forest fire; Berwick Forest; fire behaviour; fire prevention, presuppression, initial attack; fire preparedness; suppression, incident management; benchmarking; disaster management.

Introduction

The coastal and foothill zones of the Otago region experience extreme fire danger conditions in most seasons, but when compared with other regions, such as Canterbury and Hawkes Bay, they do not have the worst fire climate in New Zealand. The climate of the Berwick area is characterised by warm summers and cool winters (NZMS 1983a), with an average rainfall of 734 mm (NZMS 1983b), evenly distributed throughout the year.

Few fires in the coastal and foothill areas of Otago are greater than 10 ha in size, and up until 1995, the 1972 Allanton Forest Fire[1] was the largest plantation forest fire experienced in the Otago region. The situation is similar to Australia where Cheney (1976) found that less than 10% of the fires do more than 90% of the damage. On 26 February 1995, one of these more major fires occurred. The Berwick Fire burnt a total area of 255 hectares, including 181 ha of stocked plantation forest and 74 hectares of scrub and recent cutover, in the Berwick Forest 36 km west of Dunedin (see Figure 1).

This is not a large area when compared with the area affected in some other plantation forest fires, such as the South Australian 3 500 ha 1979 Caroline Fire (Geddes and Pfeiffer 1981), the 21 000 ha 1983 Ash Wednesday fires (Keeves and Douglas 1983), and the 3 152 ha 1955 Balmoral Fire in New Zealand (Prior 1958). However, New Zealand commercial forest plantations are often subject to intensive silvicultural treatments and considerable costs are carried throughout the length of a rotation. The Berwick Fire cost approximately $250 000 to contain, control and make safe. Total losses were significant for the owners of the forest, Wenita Forests Products Ltd.

[1] The Allanton Forest Fire (6/9/1972) was caused by an adjacent land owner burning an area of gorse and burnt 139 ha of *Pinus radiata*. The noon weather and daily Fire Weather Index System values recorded at Dunedin Airport (7.3 km north-west of the fire site) were: temperature 21°C, relative humidity 28%, wind speed 46.3 km/h, FFMC 91.5, DMC 12, DC 24, ISI 54.7, BUI 11.4, FWI 37.0.

Figure 1. The location of the Berwick Fire, near Dunedin, Otago.

New practices are often adopted as a result of the analysis of fire disasters in which accepted procedures were used, but failed to prevent threat or damage to people and their property (Turner 1977, Mutch 1995). An example of how a disaster can dramatically change fire management practices and procedures is provided by the 1983 Ash Wednesday Fires in Australia, which burnt a total area of 350 000 ha, destroyed 2463 houses and caused the loss of 75 lives (Alexander 1985a). The many reviews of emergency services and community response to the 22 major fires resulted in the definition of new principles and standards. These included:

- Use of house design and fuel reduction to increase the chances of home survival (Wilson 1984).
- Promotion of effective survival strategies, such as use of the home as a refuge when extreme fire threatens (Wilson and Ferguson 1984, Krusel and Petris 1993).
- Reduction of *ad-hoc* evacuations through better use of weather and fire behaviour information and public warnings (Wilson and Ferguson 1984, Krusel and Petris 1993).
- Increased community preparedness for wildfires through involvement in group learning and decision making (Krusel and Petris 1993, Beckingsale 1994).
- Improvement of fire suppression planning and firefighting operations through use of current and predicted weather and fire behaviour information (Bartlett 1994).
- Coordination of all fire authorities and emergency services involved through a multi-agency incident management system (Bartlett 1994).

Fire incidents and disasters are a painful and expensive way to learn about the inadequacy of accepted practices and procedures. Case studies allow fire managers to measure or benchmark their current prevention, presuppression and suppression practices and procedures against those refined and used internationally. Principles derived from the Ash Wednesday fires mentioned

mentioned above have been discussed and compared with New Zealand fire suppression and evacuation strategies employed at two rural/urban interface fires (Fogarty 1996). No comparison has been made with forest fire management practices. This report provides a case study of the Berwick Fire and aims to highlight lessons by benchmarking significant aspects against New Zealand and overseas experience. It also describes the use of Berwick Fire information in the evaluation of existing fire behaviour models.

Fire Chronology

Ignition and Initial Attack

The suspected cause of the Berwick Fire was ignition of logging slash by the focussing of the suns rays through a lemonade bottle (see Photograph 1), exposed during logging (Corry *unpub*[2].). The summer had been dry and, on the day of the fire, high temperatures and low relative humidities would have lowered the moisture content of the logging slash to a level at which it would easily ignite. Figure 2 shows the approximate location of the original ignition (indicated as point 1), 10 to 15 m from the gully that divides Prentice and Longspur Roads. Photograph 2 (which was taken from the location marked as point "P" on Figure 2) shows the view east down the spur that intersects the gully where the fire started and the Prentice Road ridge line (on the left side of the picture). The ignition point is not visible in this view.

The observation of wispy smoke by residents at Waihola and Berwick Forest suggests ignition at (or before) 1130 hours on Sunday 26 February 1995, although a group of trampers walking a track 10 to 15 m from the ignition point around that time did not see the fire. The Wenita Forest Products Ltd (Wenita) duty officer received the first report at 1155 hours[3] on Sunday 26 February 1995. Subsequent reports "jammed" the duty officer's cell phone and delayed him from initiating a response by Wenita personnel. A 111 emergency system report at 1157 hours was diverted to the police instead of the New Zealand Fire Service, and delayed the initial response.

At approximately 1200 hours, a Berwick Forest resident alerted a Wenita employee who lives near the fire site. The employee made a quick inspection of the fire and used a cellular telephone to make a 111 call to the New Zealand Fire Service at 1213 hours. A crew from the Milton Volunteer Fire Brigade, located 24 kilometres from the fire, turned out immediately and was the first crew and fire appliance to arrive at the fire, at 1237 hours.

The bonnet of a truck parked near the woolshed (see Figure 2) was used as the initial fire headquarters (HQ). Wenita staff with appropriate knowledge and experience were contacted by pager, but most were unable to get to Berwick during the initial attack phase. A fire officer from the Dunedin City Council was the best qualified person present and it was agreed that he should be the fire boss[4]. A simple incident management team was established, but this did not include formal operations, planning and logistics sections. Suppression strategies and tactics were developed by this team, but comments made at debriefing suggest that fire authorities and crews arriving at the scene were not given adequate information about suppression strategies or maps of the area.

---

[2] Corry, W.E. 1995. Fire Investigation, Wenita Forestry, Berwick. 4 pages (unpublished report by the New Zealand Fire Service.).

[3] All times used in this report are given as NZ Daylight Saving Time (NZDT).

[4] In New Zealand the fire boss usually assumes overall command and control responsibilities of a fire, as well as the management of ground and air operations.

Photograph 1. The focussing of the sun's rays through an old lemonade bottle was the suspected cause of ignition for the Berwick Fire.

The fire was visible throughout the district, and more than one hundred fire fighters turned out to assist with suppression. Some volunteers did not arrive with designated crews from other fire authorities. Lack of knowledge about their levels of training, skills and experience made deployment of these fire fighters difficult. Some untrained firefighters did not register at fire headquarters and entered the fire ground on their own initiative.

Fire Behaviour and Suppression

Even though initial attack did not begin until 1237 hours, the Wenita staff member who lived nearby was able to assess the fire situation at 1215 hours (the approximate perimeter is shown in Figure 2). At this time, the fire was spreading uphill against the strong south westerly wind. Flame lengths in the *Pinus radiata* logging slash were 1 to 1.5 m, suggesting that the fireline intensity[5] was somewhere between 250 kW/m and 650 kW/m (see Photograph 3). The rear of the fire spread no further than 15 m in 55 minutes, backing downhill and crossing the gully at 1220 hours. It is probable that the rate of spread (ROS) of this section of the fire was no more than 17 m/h. Even assuming heavy fuel loads in the gully (say 100 t/ha), the fire intensity would have been less than 800 kW/m. The two estimates of fireline intensity between the time of ignition and when the fire crossed the gully at 1220 hours, indicate that the fire was controllable. After crossing the gully, the fire spread up a steep spur (30° to 40° slope) through a small patch of indigenous scrub and into a stand of mature *Pinus radiata*. The combined effects of increased slope and exposure to a 25 - 35 km/h west-southwest wind caused dramatic escalation of the fire's forward movement and, in turn, its head fire intensity. The new head fire was now heading up-hill toward Prentice Road.

[5] This figure is derived using the relationship defined by Byram (1959) and converted to SI units by Alexander (1982) for predicting the intensity of surface fires using observations of flame length. The equation is:

$I = 259.83\ (L)^{2.174}$, where I is fireline intensity (kW/m) and L is flame length (m).

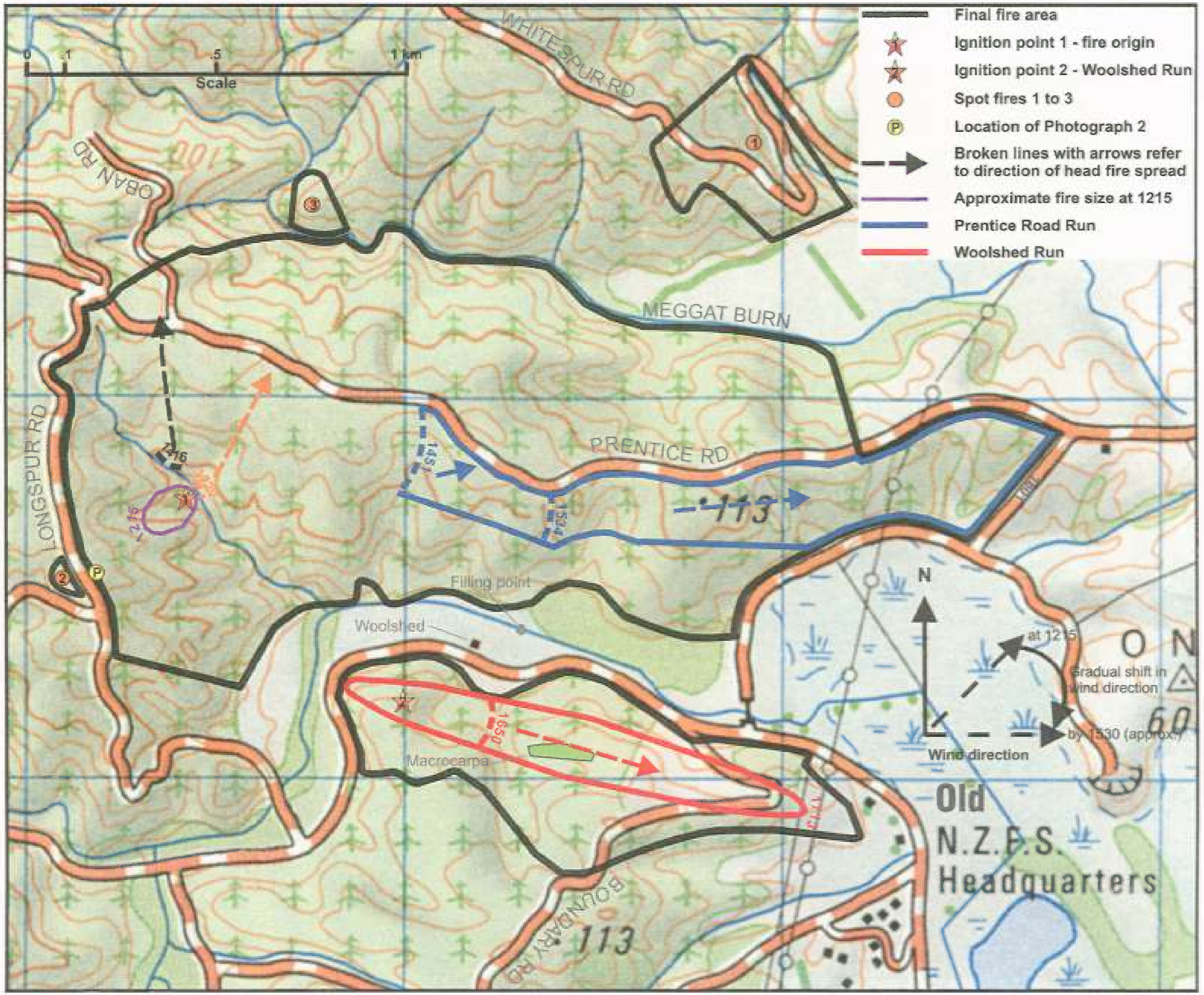


Figure 2. Map of the final area burnt and major runs in the Berwick Fire (a removable copy of this map is attached at the end of the document to assist the reader).

Photograph 2. Prentice Road ridgeline viewed from Longspur Road (source: Michael Olsen).

Photograph 3. Fire burning in logging slash and backing into the wind and uphill. Observations of flame length and subsequent discussion with fire personnel suggest that flank and back fire suppression would have been possible.

Conditions worsened throughout the afternoon as temperature and wind speed increased and relative humidity fell. Observations suggest that the wind moved gradually from the south-west to the west during the afternoon. At around 1530 hours, the wind was driving the fire directly along the Prentice Road ridgeline. Figure 2 shows that in the period between 1451 and 1534 hours, the Prentice Road Run travelled 390 m (±100 m) at a rate of spread of 545 m/h (±140 m/h). From 1534 to 1601 hours the fire spread more rapidly, covering a further 1250 m (±50 m) at 2780 m/h (± 110 m/h). The Prentice Road Run threw numerous spots ahead of the fire front and easily surmounted undulations in the terrain. At approximately 1530 hours, a spot fire also started on a spur leading into the Meggat Burn, south of Whitespur Road (Spot fire 1). Photograph 4 shows an extreme intensity crown fire that burnt a swath through many fuel types. The fire was halted only when it reached green pasture on the eastern boundary of the forest. Even though the spot fire spread over Whitespur Road, it was easily contained because head fire spread stopped when it reached pasture along the eastern boundary.

The first stage of the Prentice Road Run spread through 290 m of three-year-old pine (*Pinus radiata*) and Yorkshire fog grass (*Holcus lanatus*) and then through 100 m of 48-year-old western red cedar (*Thuja plicata*) (Table 1). The second stage spread through stands of mid-rotation pine, larch (*Larix decidua*), western red cedar, Douglas-fir (*Pseudotsuga menziesii*) and an area of gorse (*Ulex europaeus*) under the powerlines. The pine and Douglas-fir stands had a dense understorey of 3 to 5 m tall gorse. In the western red cedar stands, the crown fire was described as an "explosion", and the level of crown foliage consumption was greater than that observed for other species. Using a conservative fuel load estimate of 30 t/ha and the average ROS, the intensity of the Prentice Road Run was estimated to be between 8000 and 42 000 kW/m.

Table 1. Distance burnt (m) by species type and age class during the Prentice Road and Woolshed Fire Runs.

Prentice Road Run	Distance burnt (m) by species and age					
	Pine (1992)	Larch (1982)	*Thuja* (1947)	Douglas-fir (1981)	Gorse	Total
1451 - 1534 hours	290	0	100	0	0	390
1534 - 1601 hours	510	280	100	220	140	1250

Woolshed Run	Distance burnt (m) by species and age						
	Pine (1948)	Pine (1973)	Pine (1980)	Pine (1982)	Eucalypts	Gorse / kanuka	Total
1626 - 1650 hours			340				340
1650 - 1713 hours	120	370		150	200	50	890

Descriptions:

- Pine (1948 - 1973): mature and maturing *Pinus radiata* forest with generally light understorey and deep duff layer. In some lower stocked areas the understorey was dense scrub. The 1973 stand had been pruned to 6 m.
- Pine (1980 - 1982): mid-rotation pine forest pruned to 4.5 m to 6.4 m and characterised by dense understorey fuels, especially gorse.
- Douglas-fir (1981): *Psuedotsuga menziesii* with a dense understorey of 3 to 5 m gorse.
- Pine (1992): three-year-old *Pinus radiata* with logging slash, grasses and lighter scrub fuels.
- 48-year-old *Thuja* with high stocking (up to 2500 stems per hectare), light understorey and persistent low branches.
- 16-year-old eucalypts.

Photograph 4. The fire burning towards the eastern boundary of Berwick Forest.

During and after the Prentice Road Run, the flank fire spread down the south-facing slope in an uneven pattern, exhibited occasional torching, and made crown fire runs back up into the burn area. This behaviour made flank fire suppression on this face dangerous, and perhaps impossible. The flank and back fires behaved as a vigorous surface fire in all fuel types except mature macrocarpa (*Cupressus macrocarpa*) which had insufficient surface litter to carry a fire. The fire also backed down to the Meggat Burn outside of the influence of the prevailing wind, occasionally torching in mature pine trees that had not been high pruned (i.e., pruned to 6 m). The Meggat Burn contained dense riparian vegetation, and by the time that the fire reached the gully, the wind had slowed after the passage of a cold front, preventing further spread.

The fire suppression strategy concentrated on minimising the spread of the rear and flank fires. The original fire, burning in logging slash, was left to spread slowly up slope and into the wind toward Longspur Road, while the road was being widened by a grader. The Milton Brigade attempted to contain the right flank of this section of the fire, and the Longspur/Prentice Road intersection was widened with a D7 bulldozer. Efforts to keep the fire from igniting "birds nests" (i.e., large piles of logging slash on skid sites) were only partially successful because the crew responsible for this sector had no maps and got lost when trying to locate water. The "birds nest" debris burned vigorously after the fire front had passed.

Burning conditions remained extreme even after the head fire had reached the pasture on the eastern boundary of Berwick Forest. By 1416 hours, the western flank of the original fire in logging slash had spread west from the ignition point, up the gully, and into a stand of tall dense kanuka (*Kunzea ericoides*). From here, a finger of fire, no more than 50 to 60 m wide, exhibited extreme fire behaviour as it ran towards the Prentice Road/Oban Road ridge top intersection, and the newly widened break was breached near the intersection (see Figure 2). After the fire crossed Prentice Road and spread down hill, it was partially sheltered from the wind. Fire intensity decreased, and only occasional torching and low level (3 to 4 m) crown scorch occurred. Between the west side of Oban Road and Prentice Road the fire was flanked by fire crews, supported by one appliance, the bulldozer, and one helicopter. Although these resources contained this sector, water shortages hindered their effectiveness. The fire also crossed onto the slope north of Prentice Road at an unknown number of locations. Suppression efforts were concentrated only on the western flank near Oban Road. By this time the total resources at the fire included 85 firefighters, one bulldozer, one helicopter, one grader, four fire appliances and one water tanker. These assisted at the helibase and secured the Longspur Road sector once the fire had reached the ridgeline road.

At 1626 hours, a spot fire started in continuous fuels to the south west of the Woolshed HQ (see ignition point 2 on Figure 2). Embers from the original fire were blown down hill after the back fire had reached the ridge at Longspur Road approximately 700 m away. The spot fire grew rapidly in spite of aerial attack by two helicopters within minutes of ignition. Driven by the westerly winds blowing down the gully, it spread 340 m (±100 m) in 24 minutes, at a head fire ROS of 850 m/h (±250 m/h). Between 1650 and 1713 hours (when the fire crossed Boundary Road) the estimated ROS was 2325 m/h (±130 m/h). Assuming a conservative fuel load of 30 t/ha, the fire intensity during the Woolshed Run was estimated to be between 12 750 and 30 100 kW/m. Heavy smoke made the Woolshed HQ inoperable, so the Command Centre was shifted to a bulk store near the old NZ Forest Service HQ. At this time, an employee of Wenita assumed control of the fire.

The Woolshed Run spread mainly through pine (980 m), eucalypt (200 m) and some gorse and kanuka (50 m). Although the rate of spread was lower than in the second stage of the Prentice Road Run, a crown fire occurred throughout most of the run. The head fire did not burn through a dense macrocarpa stand that had very low levels of surface litter, but it was able to burn around and spot over this stand with no observable effect on fire behaviour. The dimensions of this stand were 30 m by 150 m with the long axis aligned in the direction of fire spread. Even at the western end where the trees were subject to an intense head fire the edge trees were only scorched. Head fire suppression was impossible, and it stopped only after reaching an area of green pasture east of the power line easement.

By 1640 hours, resources on site included 100 firefighters, two bulldozers, three helicopters, one grader, four fire appliances and one water tanker. Efforts to contain and secure sectors along Longspur Road and down toward the Meggat Burn continued. Crews were also deployed near the old NZ Forest Service HQ to protect houses and other buildings.

Variable and gusty winds, that were probably associated with an approaching cold front, began to occur over the fire site at around 1700 hours. A full 180° wind shift caused the fire to breach Longspur Road (see spot fire 2, on Figure 2) and at some time before 1630 hours a spot started on the unburnt side of the riparian vegetation in the Meggat Burn (see spot fire 3, on Figure 2). A notable weather change occurred at the fire site sometime around 1830 hours. By 1900 hours, smoke was hanging over the fire site because the wind had changed to a light north easterly breeze. Spot fire 3 did not spread vigorously under these conditions and was easily contained by ground crews using hand tools. Following the passage of a cold front between 1800 and 1900 hours, the temperature, relative humidity and wind speed at Dunedin Airport changed from 32°C, 18% and 19 km/h to 21°C, 58% and 15 km/h respectively. Under these mild conditions, the fire was contained at about midnight.

Public Safety and Evacuations

Assets other than those owned by Wenita were threatened by the Berwick Fire. These included stock, houses, and a small privately owned woodlot. The fire control team evacuated four homes threatened by the fire. Visitors staying at the Otago Youth Adventure Trust Lodge (not directly threatened, but within the forest) were moved to a safe area. A lessee with grazing rights to the area adjacent to the Woolshed HQ was allowed to remove his stock when it was considered safe to do so.

Roads were closed to prevent the public entering the fire area. The woodlot owner attempted to protect his trees, but, after consultation with the fire control team, police denied entry, since the highest edge of the stand, and access to it, were in the direct path of the Prentice Road Run at that time.

Aerial Suppression

Although three helicopters used for aerial suppression provided support for ground crews, their operations were considered to be only partially successful. Non availability of aircraft was a major problem and the first helicopter did not arrive until approximately 1330 hours. Many aerial drops were ineffective, and a major reason for this was thought to be use of inadequate concentrations of retardant and suppressant. Such failures were more noticeable in the areas with dense canopies (J. Kerr[6] *pers. comm.*). Some drops were made from hovering helicopters, spreading the load over too small an area.

Mop up

The conditions experienced at Berwick on 26 February were not the driest recorded for the Otago Region, but they were considered to be unusually dry[7]. As expected, the mop-up was a long and arduous process involving the digging and wetting of all hotspots. Although firefighters systematically worked away from the perimeter through the burnt area, many hotspots were missed and the risk of escapes remained high.

Aerial surveys using an infra-red detector (PYR-OLEX CORP hand held type) assisted the later location of hotspots. Early morning surveys when the ground surface was coolest partially overcame the difficulty of differentiating between deep hotspots and heated surface rocks, but there were still problems, especially when trying to scan through standing trees. Better results were achieved when night ground survey parties marked hotspots for action the following day. Without an integrated infra-red scanner and global positioning system, it was not practical to systematically cover a large area from the air. The hand held infra-red camera was most effective when used on the ground in areas where hotspots were likely to occur. Surveys concentrated on the fire perimeter and areas where harvesting and roading operations had buried logs and other organic matter.

The burnt area was finally declared safe after three weeks of intensive mop-up. No significant rain fell during this period, so the location and extinguishing of all hotspots was essential. Deep seated fires smouldering in "birds nests" around old skid sites needed to be dug up back to the original soil profile using an excavator, and extinguished with water (see Photograph 5).

---

[6] J. Kerr is a forestry superintendent with Wenita Forests Products Ltd.

[7] The Duff Moisture Code (DMC) and Drought Code (DC) values on the day of the fire were 37 and 535 respectively. These are lower than the driest values at Dunedin Airport where a DMC of 92 and a DC of 730 were recorded in April 1976, but they are higher than the long term averages for February of 20 and 332 for DMC and DC respectively (Pearce, H.G. 1996. An initial assessment of fire danger in New Zealand's climatic regions. Fire Technology Transfer Note 10 (October 1996) (Unpublished)).

Photograph 5. Excavator digging up smouldering slash in "birds nests".

Damages/Costs

As well as burning a large area of forest, the fire incurred suppression costs totalling $250 000. Initial fire suppression costs were in excess of $60 000 ($235/ha), and ongoing mop up operations cost approximately $190 000 ($745/ha). The fire burnt recently logged areas and trees aged 3 to 48 years. A wide range of species was involved because the area had been used for trial and amenity plantings close to the former New Zealand Forest Service headquarters.

With the exception of the *Thuja*, all stands of 13 years or over were salvage logged. Aggressive marketing minimised losses that would have been incurred if burnt stands needed to be cleared for waste. Wenita was able to use the export sawlog market, the local sawlog market, the local chip market and its own sawmill. Losses included a discount for heavily charred logs (Photograph 6) and the non-realisation of growth potential.

Harvesting costs were increased because charcoal caused greater wear on chainsaw chains and machine filters needed to be changed more frequently. Charcoal dust also caused a health and safety problem, with harvesting personnel having to wear filter masks. Re-establishment costs were greater because the dense regeneration of gorse and pine that occurred after the fire needed chemical control. Stands less than 13 years old were not commercially harvested and heavy slash made re-stocking difficult. The weight of burnt trees was found to be 10–15% greater than that of unburnt trees, possibly due to water absorption by charred wood. This resulted in increased transport costs.

Forest health was monitored by Ministry of Forestry Forest Health Officers on a monthly basis. No insects affected harvesting and re-establishment of the site. Wood quality remained relatively high while the trees were standing, but staining occurred rapidly after felling.

Photograph 6. Trees defoliated by crown fire during the Prentice Road Run.

Fire Environment Factors

The fire environment is defined as "the surrounding conditions, influences, and modifying forces of topography, fuel and fire weather that determine fire behaviour" (Countryman 1972). Assessment of the fire environment factors influencing the spread of the Berwick Fire was assisted by the use of the New Zealand Fire Danger Rating System (NZFDRS)[8] which is based on the Canadian Forest Fire Danger Rating System (CFFDRS) (Stocks *et al.* 1989, Forestry Canada Fire Danger Group 1992).

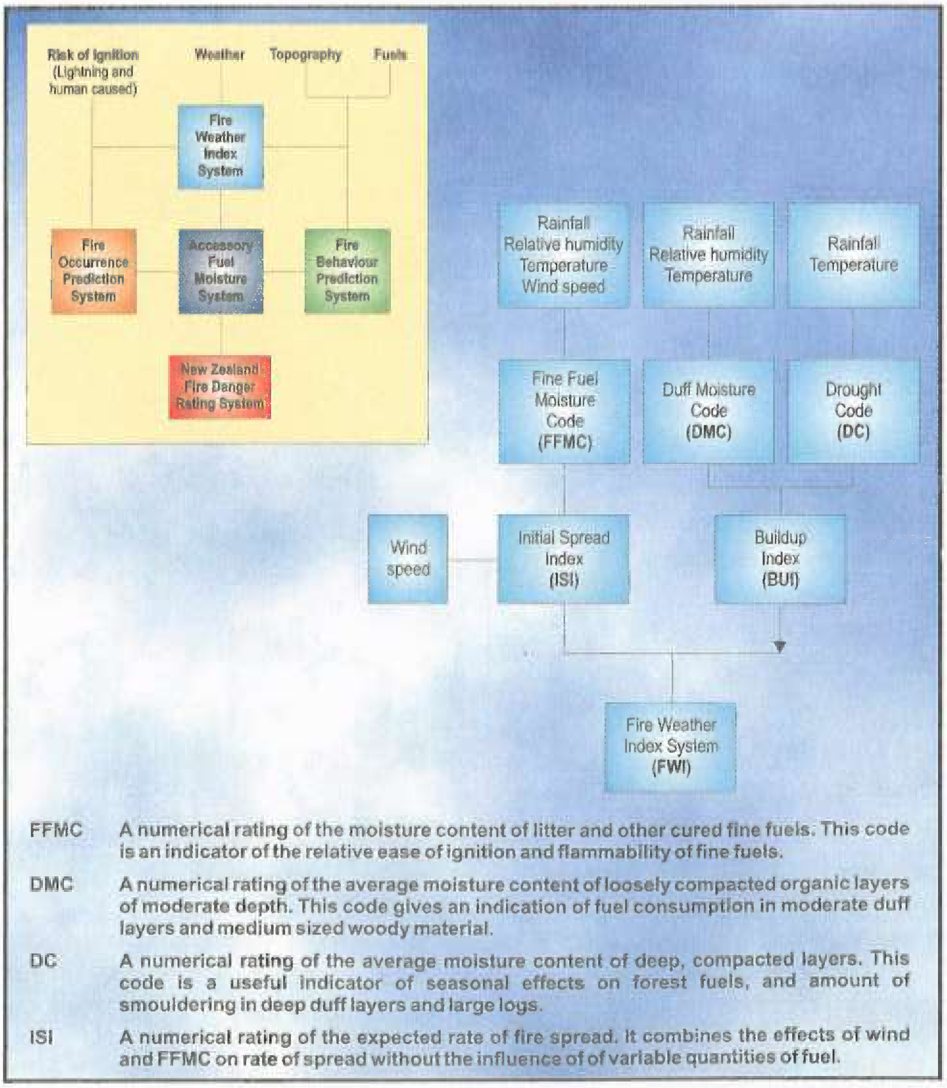
[8] New Zealand adopted the Canadian FWI System for fire danger rating in coniferous plantation forests in 1980 (Valentine, J.M. 1978. Fire Danger Rating in New Zealand - review and evaluation. New Zealand Forest Service, Forest Research Institute, Forest Establishment Report No. 123 (unpublished)). This was the precursor to the later adoption of the CFFDRS for use throughout New Zealand.

The NZFDRS is used by New Zealand fire authorities to assess the probability of a fire starting, spreading and doing damage. Figure 3 shows the submodels of the NZFDRS. These include:

- The Fire Occurrence Prediction System: An incomplete module predicting the probability of fire ignition from natural or human causes.
- The Fire Weather Index (FWI) System: This module produces a set of codes and indices which estimate the relative flammability and availability of fuel, based on the current and preceding weather conditions, and the effect that this is likely to have on rate of head fire spread and intensity.
- The Accessory Fuel Moisture System: An incomplete system being developed to allow the estimation of fuel moisture content for a range of fuel components (e.g., elevated scrub, twigs, grass, forest litter) and larger woody material. Factors taken into account include the effects of temperature, relative humidity, time, topography, latitude and season.
- The Fire Behaviour Prediction (FBP) System: This module combines the FWI spread indicators with data on fuel type and topography to make quantitative predictions of fire behaviour (e.g., head, flank and back fire rate of spread and fireline intensity).

As well as showing the broad structure of the NZFDRS, Figure 3 also lists the components of the Fire Weather Index (FWI) System. Values from the FWI System were used to describe the short and long term weather factors influencing the Berwick Fire

Figure 3. Structure of the New Zealand Fire Danger Rating System (adapted from Canadian Forest Service 1984 and Stocks *et al.* 1989).



Fuels

The Berwick Fire burnt through a number of crop or fuel types that can be broadly categorised as mature, mid-rotation and cutover forest. The length of the fire run through each fuel type is shown in Table 1. Pine stands planted in 1992 were oversown with Yorkshire fog grass and had only lightly distributed fuels. Pine and Douglas-fir stands planted after the late 1970s often had a dense gorse understorey. Fuel loads were not measured, but an estimate of 30 t/ha, considered to be conservative for all the stands burnt, has been used for fire intensity calculations.

Weather

The 3 months prior to the Berwick Fire were characterised by general drying, interrupted by occasional rainfall. Figure 4 shows the weather records from Dunedin Airport[9], which is 11.5 km northeast of the forest. In the six weeks before the fire, the Buildup Index (BUI) fluctuated between 35 and 65 and Fine Fuel Moisture Code (FFMC) values in the high eighties and low nineties were recorded. At Dunedin Airport 18 days of Very High to Extreme Fire Danger had been recorded since 1 November 1994 (Fig 5).

Figure 4. Wetting and drying cycle leading up to and during the Berwick Fire, calculated from Dunedin Airport weather data.

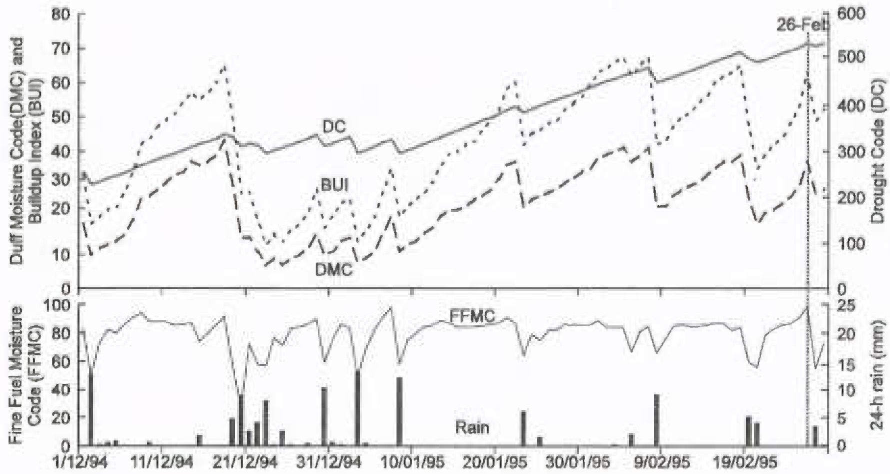
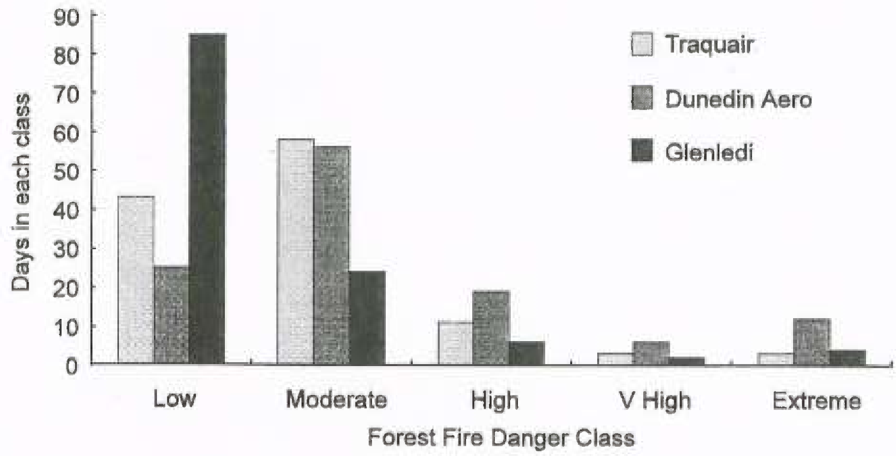


Figure 5. Number of days in each forest fire danger class between November 1 1994 and February 26 1995, for the Traquair, Glenledi and Dunedin Airport weather stations.



[9] Dunedin Airport was considered to be the most relevant weather station for the fire location. Unless it is stated otherwise, all temperature and FWI values are based on records from Dunedin Airport.

On the day before the fire, warm south to south-westerly winds were experienced at Berwick during the afternoon. Maximum daytime temperature and minimum relative humidity were 28°C and 32% respectively (Figure 6). The surface weather chart (Figure 7a), was characterised by the progression of a low pressure system across northern New Zealand, followed by an anticyclone situated in the Tasman Sea. At midday, Initial Spread Index (ISI) and BUI values of 9 and 53 respectively, gave a Fire Weather Index (FWI) value of 21.3 and the fire danger class for forest areas was High. The wind speed increased from 13 km/h to greater than 30 km/h during Saturday afternoon. At 1600 hours on Saturday, the maximum daily values were recorded when the ISI reached 23.1 and the FWI was 40.4. Extreme fire behaviour would have been expected from any ignition in Berwick Forest between 1400 to 1600 hours on Saturday.

By midday on Sunday 26 February, weather conditions in the South Island were dominated by a high pressure system moving off the Australian continent, and a trough lay to the south (Figure 7b). Surface isobars for midday on Sunday show that the pressure gradient was generating west to south-westerly winds which were likely to become more westerly during the afternoon as the trough approached.

At 1300 hours, the temperature was 33°C, relative humidity was 6%, and wind speeds reached a maximum of 33 km/h, providing daily fire danger values of FFMC 98.6, ISI 73.1 and FWI 87.9. These values indicate that the moisture content of fine fuels would have dropped below 3% by mid-afternoon and there was a high probability of extreme fire behaviour. Table 2 and Figure 8 show hourly fire weather and FWI codes and indices recorded at Dunedin Airport on the day of the fire. The peak burning period occurred at 1700 hours when the FFMC reached 98.7, the ISI was 74.4 and the FWI was 88.8. When the cold front arrived on Sunday evening, weather conditions changed dramatically. Cool, moist air was channelled over Otago by light southerly winds (Figure 7c). Light rain fell over the fire area on Monday, restricting aerial operations.

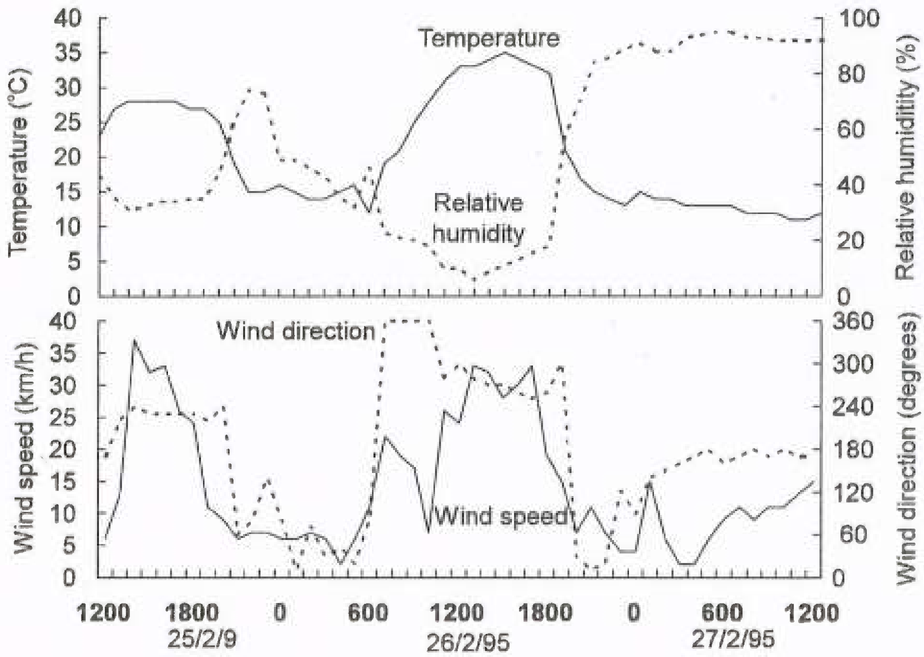
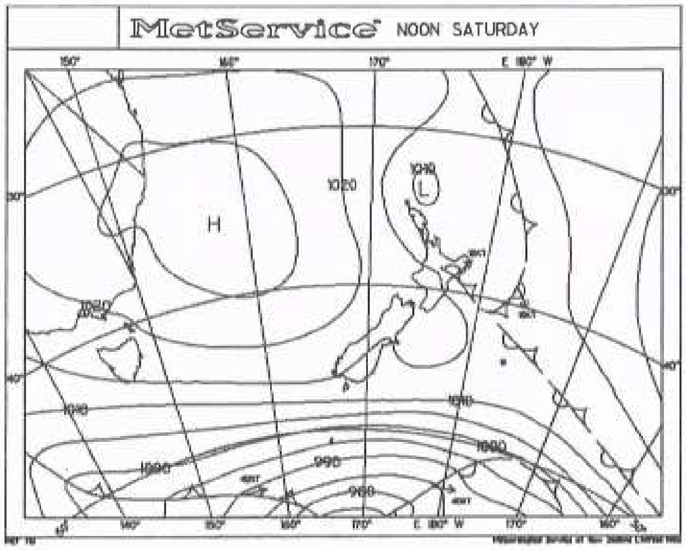


Figure 6. Diurnal weather patterns recorded at Dunedin Airport before, during, and after the Berwick Fire.

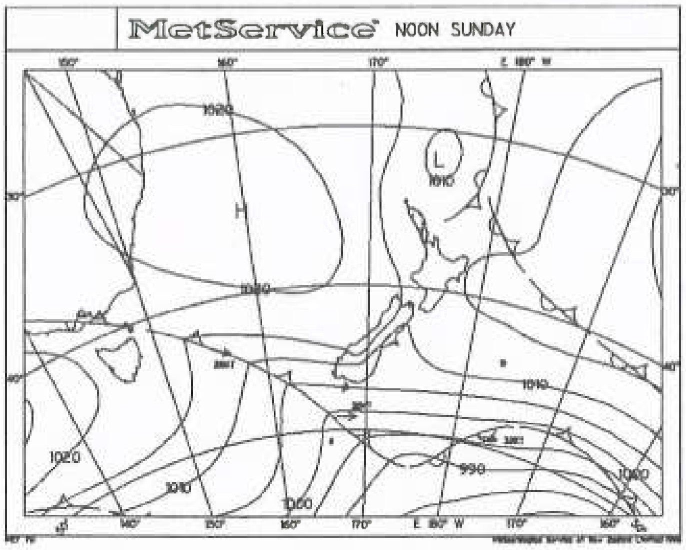
Topography

The topography of the area burnt is characterised by long east-west aligned ridges with steep spur/gully systems that fall to the north and south. The average slope from the start to finish of the Prentice Road and Woolshed Runs is less than 5°, but the terrain is divided by a succession of ridges with slopes that range from 10° to 40° and 200 to 500 m in length.



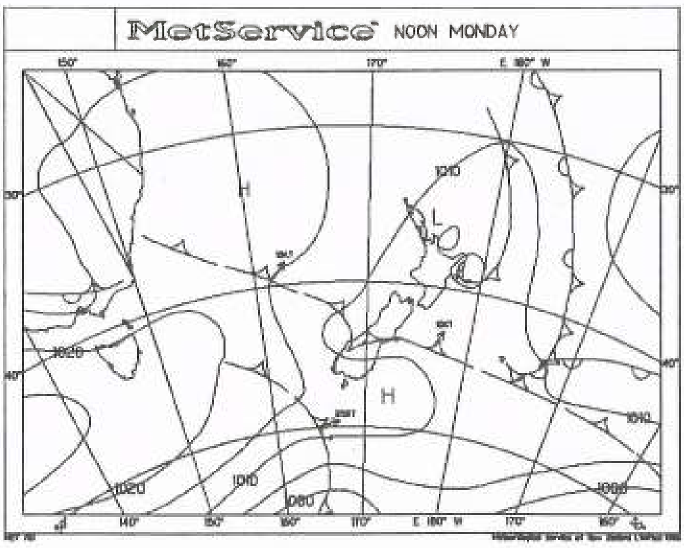
Situation:
A ridge over central New Zealand is weakening, and a disturbed southwest flow is expected to affect the country for the next few days. A cold front in this flow should move over much of the South Island tomorrow, and then cross the North Island on Tuesday, followed by a cool southerly change. On Wednesday and Thursday, weaker disturbances are likely to brush over the country, while a broad ridge in the Tasman Sea spreads higher pressures towards the North Island.

Figure 7a. Surface weather chart and situation on 25 February 1995 (day before the Berwick Fire)



Situation:
A low near northern New Zealand should drift south east and lie east of Gisborne tonight and east of the Chatham Islands Tuesday night. Meanwhile southerlies should prevail over the country. On Wednesday, a front should bring south westerlies to the South Island, followed by a ridge on Thursday and another front on Friday. A ridge is expected to remain slow moving over the North Island from Wednesday to Friday.

Figure 7b. Surface weather chart and situation on 26 February 1995 (day of the Berwick Fire)



Situation:
A trough over northern New Zealand is expected to move off to the east on Thursday, leaving a southerly flow over the North Island through Friday. A ridge should move onto the North Island on Saturday. Over the South Island, a ridge dominates, although fronts are expected to affect the island on Wednesday and again on Friday.

Figure 7c. Surface weather chart and situation on 27 February 1995 (day after the Berwick Fire)

Figure 7. Surface weather charts and situation in the lead up to, during, and following the Berwick Fire (source: NZ MetService).

Table 2. Hourly weather observations and selected Fire Weather Index System values recorded at Dunedin Airport before and during the Berwick Fire.

Time (NZDT)	Dry bulb. temp (°C)	RH (%)	10 m open wind direction (degree)	speed (km/h)	Rain (mm)	FWI System values* Hourly FFMC	Hourly ISI	Hourly FWI
0900	25	20	360	17	0	87.3	6.8	19.0
1000	28	18	360	7	0	89.8	5.9	17.1
1100	31	10	280	26	0	92.4	22.2	42.5
1200	33	10	300	24	0	92.9	21.5	41.6
1300	33	6	280	33	0	96.6	56.3	75.4
1400	34	9	270	32	0	97.2	58.1	76.8
1500	35	11	270	28	0	97.7	50.7	70.9
1600	34	13	260	30	0	98.2	59.9	78.2
1700	33	16	250	33	0	98.7	74.4	88.8
1800	32	18	260	19	0	98.2	34.4	56.0
1900	21	58	300	15	0	88.3	7.1	19.6
2000	17	70	30	7	0	86.4	3.6	11.6
2100	15	84	10	11	0	83.3	2.9	9.7

* The other FWI System values on 26 February 1995 were: DMC 35, DC 534 and BUI 63.

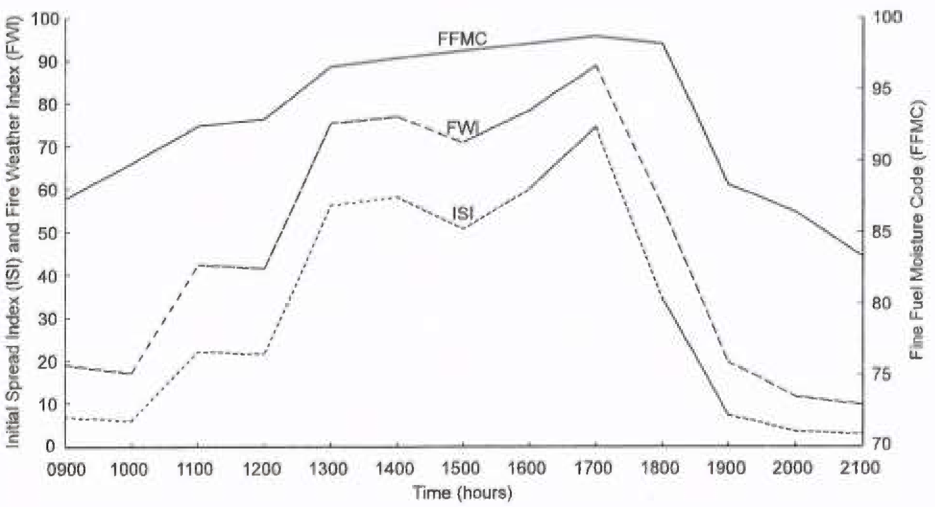


Figure 8. Fine Fuel Moisture Code, Initial Spread Index and Fire Weather Index values recorded at Dunedin Airport on the day of the Berwick Fire.

Weather Forecasts

At the time of the Berwick Fire, no weather forecasts were being issued specifically for forest and rural fire danger rating. Public forecasts issued for Otago by the MetService (at 1220 hours on Radio National) and Blue Skies (Appendix 1) indicated that westerly or north westerly winds were expected on Saturday. A change to cooler south westerlies was expected on Sunday, and the westerlies were expected to increase as the front approached New Zealand. The expected time of the change was not given. High temperatures and low relative humidities were not forecast for Sunday.

Fire Behaviour Prediction

Observations at wildfires provide valuable information for the evaluation of theories and predictive models of fire behaviour (Alexander and Pearce 1992, Alexander 1985b, Rothermel 1991, Forestry Canada Fire Danger Group 1992). They also assist in the assessment of the productivity and effectiveness of fire suppression resources (Alexander and Pearce 1992, Rothermel 1991, Buckley 1994). Fire behaviour observations made at the Berwick Fire lack the detail required for the development of new models for fire behaviour prediction. However, the usefulness of existing models from the Canadian Forest Fire Behaviour Prediction (FBP) System (Forestry Canada Fire Danger Group 1992) in the management of fire in New Zealand plantation forests can be retrospectively tested through comparison of actual and predicted fire spread rates. Table 3 compares the actual spread rates of the head fire in two major runs with values predicted from the FBP System. Average values derived from a combination of the two most relevant models (logging slash (S-1) and standing plantation forest (C-6)) are also presented for the Prentice Road Run. For FBP System calculations, wind speed and FFMC values used were an average of the nearest hourly records from Dunedin Airport.

The estimated actual ROS during the second stage of the Prentice Road Run (2780 ±110 m/h) was greater than the predicted rate for standing coniferous forest (2466 m/h) (see Table 3) but was fairly close to the weighted average of predicted values for plantation and logging slash (2949). The estimated ROS of the second stage of the Woolshed Run (2325 ±130 m/h) compared well with the predicted value of 2526 m/h for standing plantation forest. An over-prediction of the rate of spread during the initial phase of the Woolshed Run (850 ±250 m/h compared with 2502 m/h) was possibly due to firebombing by two helicopters from filling points less than 400 m away while the fire was accelerating. Although attempts at containment were unsuccessful, the rate of acceleration could have been decreased.

During the initial phase of the Prentice Road Run the observed ROS was much lower than that predicted by the FBP System. The wind was swinging from south west to west-south-west when the run started. It was thus blowing across Prentice Road and down into the Meggat Burn. The fire spread along the top of the ridge through logging slash was therefore probably a flank fire rather than a head fire at this time. The observed ROS of 545 (±140) m/h through logging slash and *Thuja* between 1451 and 1534 hours, is similar to a predicted rate for a flank fire (655 m/h), derived as a weighted average of values from the C-6 and S-1 models.

Because species other than *Pinus radiata* were involved in each of the fire runs, the maximum foliar moisture content value from the FBP System (120%) (Forestry Canada Fire Danger Group 1992) was used to derive the ROS predictions shown by Table 3 – rather than 145% suggested by Alexander (1994) for use in *Pinus radiata* plantations. When compared with the predicted values shown in Table 3, head fire ROS predictions made using the C-6 (coniferous plantation) model and a foliar moisture content of 145% were 38% less. Predictions made using 145% foliar moisture content were also less than the estimated ROS values during each of the wildfire runs. For example, the estimated ROS of the second stage of the Woolshed Run (2325 ±130 m/h) compared well with the predicted value of 2526 m/h for standing plantation forest when 120% foliar moisture content was used. Using a foliar moisture content of 145%, the predicted value (1577 m/h) was much lower.

Table 3. Comparison of predicted and actual fire spread for the Prentice Road and Woolshed Runs using four fire behaviour models from the Canadian Fire Behaviour Prediction System.

Fire run	Observed head fire spread rate (m/h)	Predicted head fire spread rate[a](m/h)			
		C-6 Coniferous Plantation	C-7 Ponderosa Pine and Douglas-fir	S-1 Jack or Lodgepole Pine logging slash	Average for C-6 and S-1[b]
Prentice Road[c] (1451 - 1534 hours)	545 (±140)	2430	1704	3960	3410
Prentice Road (1534 - 1601 hours)	2780 (± 110)	2466	1812	4122	2949
Woolshed[d] (1626 - 1650 hours)	850 (±250)	2502	1944	Not applicable	Not applicable
Woolshed (1650 - 1713 hours)	2325 (±130)	2526	2064	Not applicable	Not applicable

[a] Predicted rates are for fire spread on flat terrain, The height to green crown break used for C-6 fire behaviour predictions was 4 m for the first phase of the Woolshed Run and 6 m for the second. The foliar moisture content used for all standing forest fire behaviour predictions was 120%.

[b] The weighted average (ROS_{av}) takes into account the length of run through different fuel types (see Table 1) and was calculated as follows:

$$ROS_{av} = \frac{(D_1 + D_2)}{\left(\frac{D_1}{ROS_1} + \frac{D_2}{ROS_2}\right)}$$

where

ROS_{av} = average rate of spread predicted for the two fuel types (m/h)

D_1, D_2 = length of run through Fuel Type 1, Fuel Type 2 etc (m)

ROS_1, ROS_2 = predicted rate of spread through each fuel type (m/h).

[c] Prentice Road Run spread rates were predicted using average values from 1500 and 1600 hours for phase 1 and the 1600 hour values for phase 2.

[d] Woolshed Run spread rates were predicted using average values from 1600 and 1700 hours for phase 1 and the 1700 hour values for phase 2.

Discussion

Fire Danger Rating and Fire Behaviour

The Berwick Fire exhibited extreme and uncontrollable behaviour, with frontal spread being halted only when the fire reached green pasture. Figure 9 shows that fire danger conditions were as bad as or worse than those encountered in many other New Zealand and overseas wildfires. Spread rates of the major fire runs were 850–2780 m/h and fire intensities ranged between 12 750 and 41 650 kW/m. Changes in wind direction, fuel type and terrain significantly altered fire behaviour, making suppression difficult and dangerous.

Extreme burning conditions prevailed from 1100 to 1830 hours. Within 6 hours a theoretical *free burning* fire on flat ground, in a continuous plantation of mature and mid-rotation conifers, would be expected to spread more than 17 km, have a perimeter length exceeding 30 km, and burn an area greater than 4500 hectares[10]. The Berwick Fire burnt a much smaller area (255 ha). This is mostly due to the head fire running out of continuous fuels when it reached green pasture and, to a lesser extent, the adoption of a conservative suppression strategy by which flank and back fire spread was contained when burning conditions allowed.

Based on this study, and a single experimental burn in logging slash[11], the logging slash and coniferous plantation models provide reasonable estimates of fire spread rates, particularly in severe weather conditions. However, the Fire Behaviour Prediction (FBP) System component of the New Zealand Fire Danger Rating System (NZFDRS) has not yet been adequately validated and interpreted for New Zealand conditions. The Berwick Fire spread through several stands with different species and silvicultural histories, and insufficient fire behaviour information was recorded to evaluate whether the FBP System could provide a reasonable estimate of fire behaviour in each stand. Possible explanations for over-predictions have been provided, but these cannot be fully substantiated. Rate of spread predictions made using foliar moisture content values typically recorded in New Zealand *Pinus radiata* (145%) are very different from those made using the maximum value from the FBP System (120%), but the latter foliar moisture content value provided a better estimate of crown fire rate of spread during the Berwick Fire. A relationship between foliar moisture content and crown fire rate of spread has not been statistically proven, but the effect was intuitively built into the FBP System using physical models that account for the influence of moisture content on the ignition of crown foliage and the transfer of energy through the canopy (Forestry Canada Fire Danger Group 1992). The effect of foliar moisture content on the ROS of crown fires in *Pinus radiata* stands requires further investigation.

Predictions made with the FBP System are undoubtably better than most fire managers could make without a decision support system. But fire behaviour prediction is both an art and a science and the use of the FBP System requires a knowledge of how to assess and interpret the values that it gives. For example, use of the predicted head fire ROS for the Prentice Road Run between 1451 and 1534 hours would have overestimated fire behaviour because the wind was blowing across ridge line and the fire spread at rates closer to those predicted for a flank fire. The analysis

---

[10]Predicted values from the C-6 fire spread and growth models from the FBP System using the same values used to predict head fire spread for phase 1 of the Prentice Road Run (i.e., average values from 1500 and 1600 hours).

[11]The experimental burn conducted in Kinleith Forest on 9 March 1993. The observed rate of forward spread (144 m/h) was nearly identical to the rate predicted by the logging slash model of the FBP System (Alexander, M.E; Pearce H.G; Farrow R.G; Smart P.N. 1993. Experimental fire in radiata logging slash within Kinleith Forest during early 1993. In: Proceedings, Forest and Rural Fire Association of New Zealand (FRFANZ) 3rd Annual Conference, 4-6 August, 1993, Wellington, pp. 40-41. (Unpublished).

of this case study suggests that the FBP System can provide information that would be of value in fire prevention, presuppression, and suppression activities.

More detailed observations of fire spread and related weather conditions are needed before it will be possible to develop specific fire behaviour models for New Zealand fuel types. Accurate observations are difficult during major fire runs, and trained people, appointed specifically as fire behaviour observers, are needed on site (Alexander and Pearce 1992). Fire behaviour models can be used to support many aspects of fire management decision making. To ensure that the costs of actions such as forest closure and the placement of crews or aircraft on standby are warranted, continued evaluation and development using experimental fires and wildfire case studies, must remain a priority for fire researchers and fire managers.

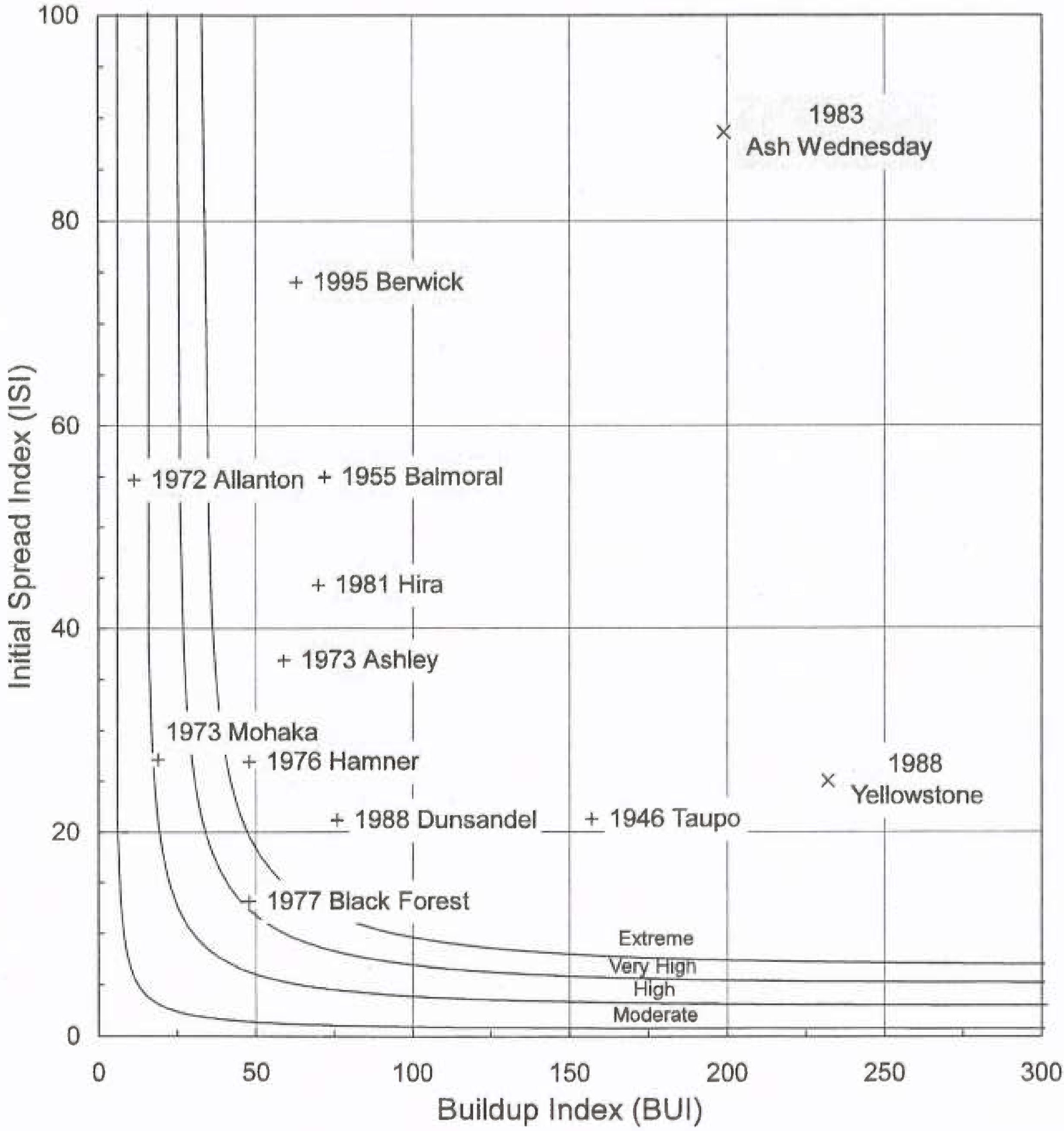


Figure 9. The fire danger conditions associated with the Berwick Fire compared with other New Zealand and overseas forest fires (adapted from Pearce and Alexander 1994).

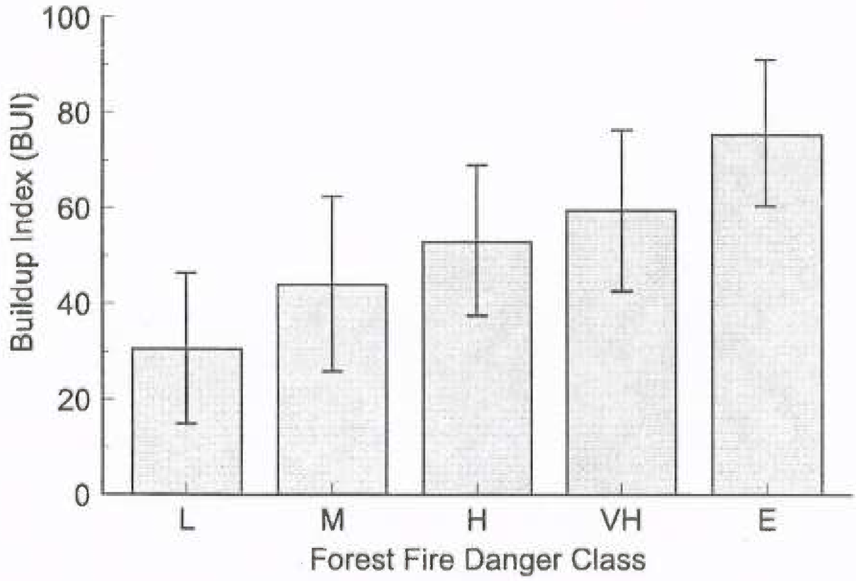
Fire Prevention[12]

Given the suspected ignition source, it would have been difficult to prevent the start of the Berwick Fire. The concave bases of aerosol cans and glass bottles containing clear liquid are known to focus the sun's rays sufficiently to ignite forest fuel (MacTavish 1960, Fuquay and Baughman 1965). Safe disposal of these items by contractors and forest users is one method whereby future fires can be prevented.

A prohibited fire season was not in place when the Berwick Fire occurred, but the experiences of this fire can be used to test the approach proposed by Alexander (1994) for the initiation of a prohibited period in forested areas. Using fire behaviour information, he suggested that when the BUI reaches 53 in forests there is a high probability that Very High or Extreme fire behaviour will occur under "average" summer weather conditions. Alexander (1994) recommended that a BUI of 40 should be the trigger point for the implementation of a prohibited period in forested areas because it is likely that the BUI will increase from 40 to 53 after a week of average drying.

Figure 10 shows average BUI values associated with the occurrence of different fire danger classes in the four months before the Berwick Fire. The average values on days when Very High and Extreme fire danger conditions occurred were 59 and 76 respectively. The range bounded by one standard deviation below Very High and above Extreme (which indicates that at least two out of three of days in these classes are likely to fall within these limits) was 42 to 93. This suggests that most days with a BUI of 42 to 93 would be in the Very High and Extreme fire danger classes, and supports the use of BUI trigger levels for declaring a prohibited fire season in forested areas. Alexander's analysis used general average summer weather conditions; better thresholds can be developed for each region by following the "trigger point" approach and using local weather conditions (Alexander 1994).

Figure 10. Average Buildup Index value (and variation shown to one standard deviation) associated with the occurrence of different fire danger classes recorded at the Dunedin Airport (for the period 1 October 1994 to 26 February 1995).



For the Berwick Fire to have been suppressed without substantial losses, the time period between ignition and initial attack would have had to be shorter. It is often suggested that systematic surveillance (e.g., fire towers or aerial patrol) is not necessary in forested and rural areas of New Zealand, because reporting by local residents and aircraft pilots is sufficiently effective. However,

[12] Fire prevention is defined by Merrill and Alexander (1987) as all "activities directed at reducing fire occurrence; it includes public education (e.g., the fire danger class criteria signs), law enforcement, personal contact and reductions of fire hazards (e.g., prescribed burning) and risks".

although this fire was seen by many neighbours soon after ignition, it took at least 27 minutes for the report to be made through the 111 emergency reporting system. Another 16 minutes passed before the nearest fire brigade was dispatched due to a failure in the 111 System and the blockage of the Wenita Duty Officer cell phone[13]. In order to reduce the chances that systems or equipment failure will slow reporting and dispatch, fire authorities need to consider the following actions:

- Use systematic methods of fire detection during Very High or Extreme Fire Danger conditions.
- Assess detection, reporting and dispatch performance at all fires and rectify problems, thus minimising the chances of a system failure when Very High or Extreme Fire Danger conditions occur.
- Continue to promote the 111 System as the preferred method of fire reporting.
- Ensure literature promoting the 111 system for rural fire reporting (particularly telephone stickers and refrigerator magnets) does not list fire authority contact numbers; and
- Use automatic pagers to activate initial attack resources, including personnel to manage command and control, dispatch and support functions.

Fire Presuppression[14]

Initial Attack

Initial attack, by a single fire appliance, was not made until 42 minutes after the first fire report to the Wenita Duty Officer, and 67 minutes after the probable ignition time of 1130 hours. Wenita, a small company with limited resources, considered that with the elimination of prescribed burning (historically a major source of wildfires) in their forests, the fire preparedness standards existing before the fire were adequate. Similarly, many fire managers argue that more effort in this area is not warranted because large forest fires are not common in New Zealand, most being "one-day-wonders". The Berwick Fire and other case studies (Prior 1958, Pearce and Alexander 1994) show clearly that wildfires with extremely dangerous behaviour do occur in New Zealand. Better fire preparedness, allowing an earlier and more substantial initial attack, could have significantly reduced the size of the area burnt at Berwick. Fire managers need systems and competence to respond appropriately to any fire, and not only those that are small and short lived.

Fires originating from point source ignition, spreading on flat terrain, and under the influence of wind coming from a constant direction, will accelerate to reach their steady state rate of spread and intensity; this is the point at which the head fire is sufficiently large to respond to the combined influences of fuel, weather and topography (Cheney 1981, Alexander 1992). Forest fires spreading in severe burning conditions may take more than 30 minutes to reach a steady state rate of spread (Brown and Davis 1973), and the acceleration phase will approximate the typical curves shown by Figures 11a and 11b. In broken terrain, topographical position may enhance or impede the effect of other factors on fire growth. At the time of initial attack, the Berwick Fire was burning in a deep gully, and was not subject to the full effect of the wind. The intensity of the backfire is unlikely to have been greater than 800 kW/m. After crossing the gully, the slow-moving backfire became an extreme head fire as it ran up a 40° slope and became fully exposed to the effects of the gradient wind.

---

[13]The Milton Volunteer Fire Brigade at 1223. They arrived on site by 1237, only 14 minutes after notification.

[14]Presuppression refers to "those activities in advance of a fire concerned with the organisation (e.g., initial attack guidelines and the location of crews in areas with a high fire danger), training and management of a fire fighting force and the procurement, maintenance, and inspection of improvements, equipment and supplies to ensure effective fire suppression" (Merrill and Alexander 1987).

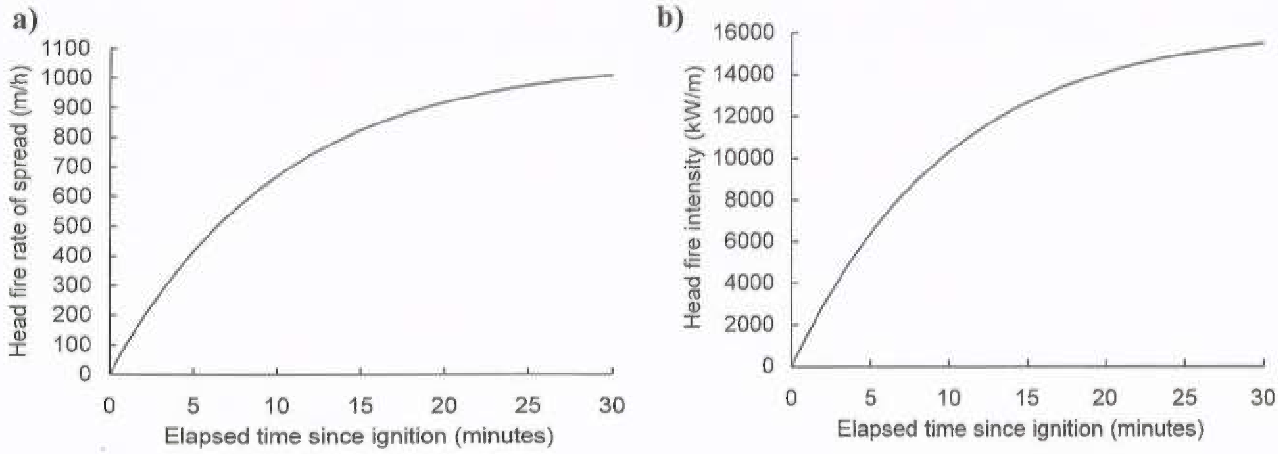


Figure 11. a) Rate of head fire spread, and **b)** head fire intensity of a fire during a thirty minute period after ignition. The curves were derived for a fire burning on flat terrain under the influence of a unidirectional wind and conditions similar to those recorded at Dunedin airport at the time that the Berwick Fire was ignited (i.e., the average of the values recorded at 1100 and 1200 hours).

On the day of the Berwick Fire the FFMC value was 98.6, indicating that extreme fire behaviour was likely to occur with only minor changes in wind or terrain. Ground-based containment in the gully area was therefore risky. Given the low to moderate intensity of the fire observed at 1215 hours, it is possible that rapid initial attack using aircraft, long term retardants and follow-up by ground crews would have prevented the escalation. By contrast, an immediate initial attack on the spot fire by two helicopters failed to prevent the Woolshed Run during peak Fire Danger conditions.

The Berwick Fire thus demonstrates both the potential and limits of rapid initial attack. Timing and the immediate fire environment can determine the success or failure of suppression operations in Very High or Extreme fire danger conditions. Fire managers have no control over these elements of chance and can only aim to make the best use of any opportunities by being ready to mount a rapid Initial Attack (IA). One way to achieve this is through the development of initial attack plans[15] to establish appropriate responses on the basis of:

- The likely effect of the fire environment factors on fire behaviour characteristics (i.e., fire intensity, head fire rate of spread, rate of perimeter growth).
- Estimated time of detection, reporting, dispatch and travel and probable fire growth during this time.
- An estimate of fireline intensity and the ability of available resources to halt back, flank and head fire spread.
- The effect of fire behaviour and environmental factors (e.g., topography, vegetation and soil type) on the ability of available resources to construct firebreaks.

The aim is to deploy sufficient resources to construct effective firebreaks at a rate that is greater than the rate of perimeter growth, thus ensuring that the fire is suppressed while small (Lanoville and Mawdsley 1990, De Groot 1990, Hirsch 1991, Alexander 1992).

When the intensity of a head fire exceeds 4000 kW/m direct attack on the head fire is generally considered to be difficult and unsafe (Appendix 2). At the 1979 Caroline Forest Fire (Geddes and Pfeiffer 1981) which burnt in similar weather conditions to the Berwick Fire and exhibited

[15]For a detailed discussion on initial attack planning, "Fire behaviour as a factor in forest and rural fire suppression" by Alexander (1992) is recommended reading.

exhibited extreme behaviour, suppression crews using 38 mm canvas hose lay were able to control more than 12 km of fire perimeter along less intensely burning back and flanks. This example shows that even if an initial attack fails, a well organised ongoing response is often able to restrict spread of a fire on the less intensely burning sections of the fire when head fire attack is impossible.

Initial Attack Using Aircraft

In the initial attack stage of the Berwick Fire there were no readily available aircraft. Given the initial low intensity of the fire, and the potential for extreme fire behaviour, air support could have made a large contribution to its early containment. The experience of the Berwick Fire suggests that having aircraft and filling crew on standby may be warranted when Very High or Extreme fire danger conditions are forecast. In reviewing aircraft needs and cost effectiveness, factors that should be considered include:

- The size and value of the forest.
- The effect of fire environment factors on expected fire behaviour.
- Distance between the forest and airport, and the probable effect on fire growth before IA.
- The distribution of airstrips, helibases and water points within the forest.
- Effect of fuel type characteristics (e.g., height, cover, density, form) on penetration of suppressants or retardants to surface fuels.
- The effect of aircraft flying speed and payload on the rate of construction of fire line.
- Running and standby costs.
- The influence of wind speed and terrain on aircraft performance and access.

Fire Weather and Fire Danger

From the outset, a lack of preparedness made the suppression of the Berwick Fire difficult. Specific fire weather forecasts and information from the fire weather station network were not used before or during the Berwick Fire because:

- The rain gauge at the nearest fire authority weather station (i.e., Glenledi) was inoperable.
- Cost of weather forecasts and Dunedin Airport data from the New Zealand Meteorological Service was considered to be too high.
- The use of remote automatic weather stations (RAWS) has removed the need for personnel to take manual weather readings and to calculate the fire danger using the "Fire Weather Index System Tables for New Zealand" (Anon. 1993), thereby reducing the need to monitor fire danger conditions each day. Consequently there is less understanding of how the FWI System values fluctuate with changing weather conditions.

To ensure adequate preparation for fire incidents, continuous review, interpretation and awareness of local fire weather information is essential.

The Berwick Fire case study shows that fire weather and fire danger conditions can change rapidly and need to be monitored daily as shown by Figure 12. Weather forecasts issued in the afternoon (1600 hours) can be used to predict fire danger conditions for the next day. This information allows forest and rural fire managers to improve fire prevention through forest and park closures and the notification of staff and the public of expected fire danger conditions. Information and planned action can be refined from the next morning forecast's and the monitoring of actual weather conditions at (say) 1000 hours. Duty personnel can then initiate a review of the morning forecast if required.

Few fire authorities in New Zealand could individually respond to an incident with a similar magnitude to the Berwick Fire, and a large proportion of immediately-available vegetation fire fighting expertise and resources were committed to the fire. A second fire in the region would have caused a dilemma. Some form of regional coordination is clearly needed to maximise the effectiveness of fire suppression resources during periods of Very High and Extreme Fire Danger. Figure 12 shows some criteria that might be used to implement a regional fire preparedness plan. The appointment of a regional fire duty officer, and the establishment of a multi-agency incident management team before the fire would have greatly improved the response to the Berwick Fire.

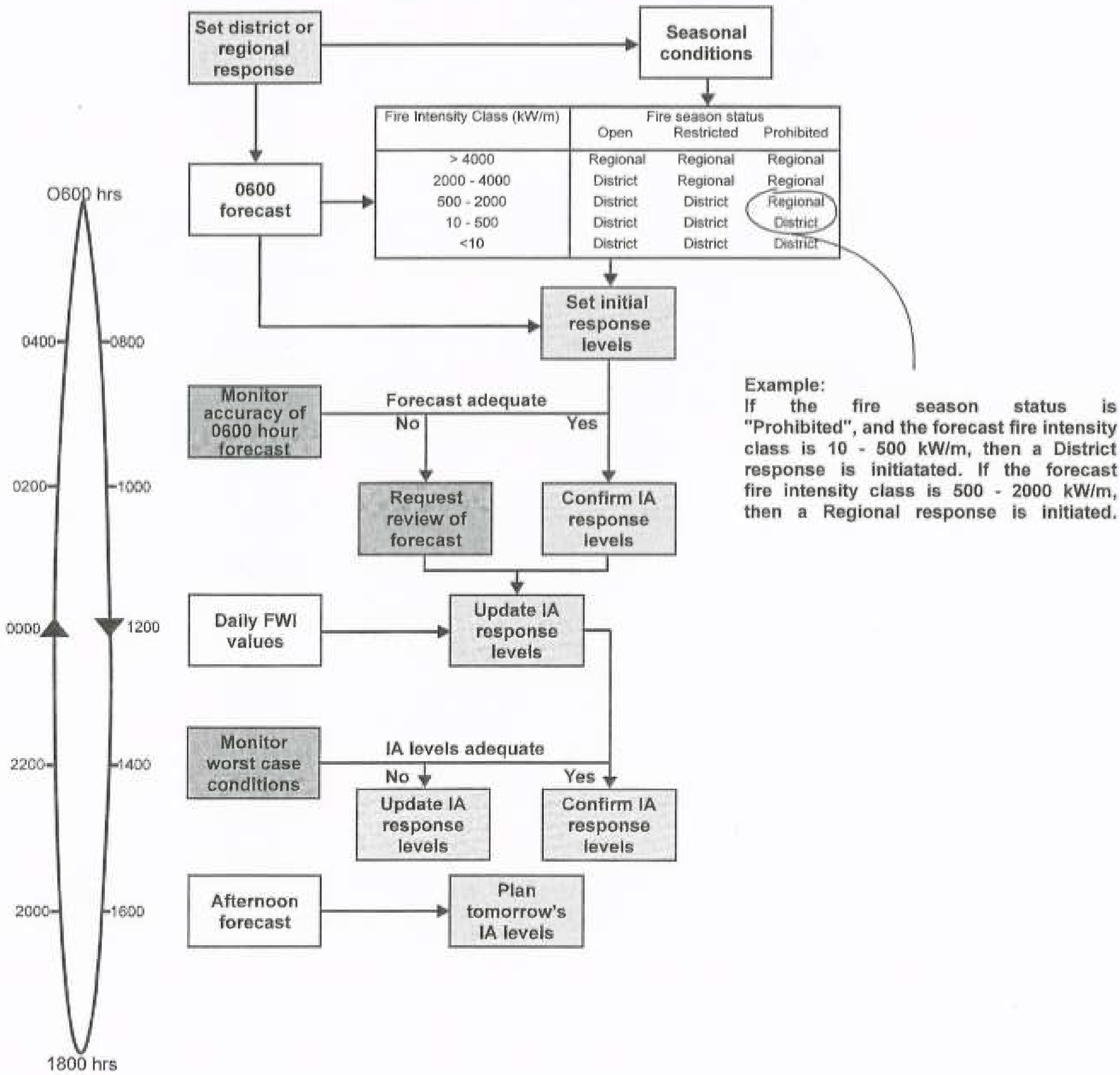


Figure 12. The preparedness planning cycle for the establishment of initial attack levels[16].

[16]The initiation of a regional response is triggered by situations when extreme and uncontrollable fire behaviour is possible. The influence of seasonal factors and daily fire danger conditions are used to determine this. It is assumed that Regional Rural Fire Committees will have a system for initiating prohibited and restricted fire seasons following guidelines similar to those defined by Alexander (1994). In forests, Alexander concluded that in summer, there is a high probability that Very High or Extreme fire behaviour will occur when the BUI reaches a value of 53. In pasture, the degree of grassland curing strongly influences the ability of a fire to spread over a broad area. When the average degree of curing has reached 80%, continuous fire spread is likely.

Although public weather forecasts issued before the Berwick Fire (Appendix 1) correctly predicted the surface weather conditions before and during the Berwick Fire, they underestimated the extremes of temperature reached and lacked detail on important factors that influence fire behaviour such as relative humidity and the expected time of arrival of frontal systems. These forecasts provide insufficient detail for fire preparedness and suppression planning.

Communications Technology

While providing many benefits, the adoption of new technologies can also have unforseen and sometimes negative consequences. For example, the availability of pagers and cell phones provided Wenita staff with the illusion of being easy to contact when and if they were required. However, because the fire occurred on a weekend, most staff were away from their homes enjoying one of the "best days of the summer". Consequently, they were not able to get to the fire site rapidly and fire preparedness standards (e.g., minimum acceptable response times and levels) were compromised.

Clearly, the adoption of new technologies needs to be planned and its effects reviewed so that any negative consequences can be identified and minimised. For example, cell phones are increasingly being used instead of a radio channel designated for command and control communications. While cell phones may be useful for external contact and internal communications over sensitive issues (e.g., the emergency evacuation of an injured firefighter), there are some drawbacks which should be considered before they become the standard tool for fire ground command and control communications:

- Cell phones provide discrete contact between individuals which reduces the ability of other fire line management staff to passively monitor the status of the fire and suppression operations, and to assess any impacts on their own operations or the safety of their crews.
- They increase the time taken to initiate communications, thus reducing the ability of the fire organisation to respond to critical situations such as a major fire escape or a potential blow up.

Fire Suppression[17]

Fire Suppression Operations

Despite head fire intensities in excess of 10 000 kW/m, flank fire spread was successfully contained between the west side of Oban Road and Prentice Road. However, progress by ground crews along this sector was hindered because the tanker fleet was unable to meet their demand for water. Furthermore, a decision was made to not contain the initial back fire burning in logging slash because it was not considered to be an immediate threat and there was a shortage of heavy machinery and trained crews. This section of the fire was the source of the spot that started the Woolshed Run and thus illustrates the importance of having sufficient personnel and machinery to contain fire spread wherever possible. As with the initial attack phase, insufficient resources were available to contain the spread of the less intensely burning back and flanks of the Berwick Fire. Better forecasting of the potential for fire spread and of resource requirements would have alleviated this problem.

[17] Suppression is all "activities concerned with the control and extinguishment of a fire following its detection, this includes the establishment of a fire management team, the determination of strategies and tactics given current and expected fire weather and fire behaviour, and the management of fire suppression resources" (Merrill and Alexander 1987).

During the suppression of the Berwick Fire there was confusion and uncertainty about application and effectiveness of retardants. Retardants were applied at the wrong concentrations, and some drops were delivered while hovering rather than attempting to lay a continuous firebreak from higher speeds. Some drops did not appear to penetrate the forest canopy and had little or no effect on fire spread. In spite of similar experiences during the 1976 Hanmer Forest Fire (Anon no date-a), no tested guidelines exist to inform fire fighters about the most appropriate chemical concentrations, flying speeds, drop heights, productivity rates and effectiveness for aerial fire suppression in New Zealand fuel types. This information is essential for pilot training and for fire presuppression and suppression planning. Further investigations into aircraft effectiveness through wildfire case studies, field trials (also recommended after the Hanmer Forest Fire) and economic analysis (e.g., Loane and Gould 1986) are needed to ensure that the maximum benefit is obtained from expenditure on aircraft at wildfires.

Firebombing will only be effective if "drops" are able to prevent the fire from burning either through a firebreak, by combustion of fuels immediately ahead of the flames, or over it by flame contact or spotting. At the Berwick Fire, some loads targeted to knockdown sections of the fire were wasted by being dropped from a hover indicating that not all pilots had appropriate knowledge of aerial suppression techniques. Where a number of aircraft are operating, the appointment of an air-attack supervisor would lead to better management of aircraft by:

- ensuring that pilots implement the fire control strategy; and
- monitoring the effectiveness of drops so that adjustments can be made to bombing tactics and technique.

Incident Management

The lack of fire preparedness at Berwick almost guaranteed that the incident management team would be caught on the "back foot" in dealing with extreme fire behaviour in a valuable plantation forest. As has happened at other fire incidents, concerned neighbours, the media, other emergency services and an influx of firefighters often of unknown training and capability added to their workload. Key members of the fire control team had a fire suppression strategy marked on a rudimentary map, but a detailed suppression plan had not been outlined. The lack of a detailed plan, combined with a shortage of maps and photocopying equipment, resulted in inadequate crew briefings. Ongoing implementation of the suppression strategy was difficult to monitor because fire intelligence (i.e., current and expected fire weather and fire behaviour) and resource allocation information was not systematically recorded or displayed. Absence of this information meant that hazardous situations and resource requirements could not be immediately identified. Despite the problems, the fire was successfully contained and no injuries occurred.

The Berwick Fire underlines the fact that to achieve better preparedness and improve the standards of incident management, fire officers need to do more than train firefighters and maintain equipment. Not only do initial attack and suppression plans have to include competent management personnel, but also the necessary administration and communications infrastructure required to support management activities. This includes the prior identification of appropriate fire headquarters, and availability of equipment and personnel to assist with internal and external communications, and intelligence gathering and recording.

Commissions of Inquiry set up after the 1955 Balmoral Forest Fire (Anon. undated-b) and the 1976 Hanmer Forest Fire (Anon. undated-a) stated that training in fire control techniques would have prepared the fire control teams to deal more effectively with the stressful and difficult situations that confronted them. No detailed fire control training has been organised since these fires. Difficulties in management of the Berwick Fire show that the need still exists.

Although not yet adopted in New Zealand, Incident Management System(s) (IMS) have been developed and used overseas to provide fire managers with processes and procedures to deal with the command, control, planning, logistical and operational demands of fire or other emergency events. IMS training provides a mechanism for fire officers to become more competent incident managers. These systems go beyond the current loose approach employed at most New Zealand wildfires. They ensure that "important tasks such as weather intelligence, strategic planning and aircraft management are not overlooked" (Bartlett 1994) and have been developed and refined by experiences at many types of fire and other emergencies. A symptom of inadequate incident management is the loss of *operational coherency*[18] (Miller *et al.* 1984, Bartlett 1994). This loss occurs as a result of one or more of the following (adapted from Bartlett 1994):

- An effective and identifiable command and control system has not been established.
- The fire exhibits severe and dynamic fire behaviour.
- There is an absence of accurate information on weather and fire development.
- The communications system is inadequate.
- Management personnel are unable to deal with the flow of information about the fire situation and resource deployment and availability.
- Communication and coordination between multiple emergency service agencies attending the fire is inadequate.

Incident management principles should not only be used at significant events such as the Berwick Fire. Regardless of the fire size and intensity, from the time that ignition occurs to the time when the area is declared safe, there is the potential for damage and danger (Wilson 1977, Millman 1993). The transition from initial to ongoing attack is usually the busiest time for the fire control team, and the elements of incident management (e.g., well defined command and control, information gathering and planning, briefings on strategies and tactics, and logistical support) must be considered as a continuum during this time. Having essential structures, systems and procedures in place at all fires will help to ensure that from the very outset:

- The most effective incident management team is established.
- Safe and effective suppression strategies are developed.
- A smooth transition in personnel will occur if the fire has escalated beyond the capabilities of the original team.

Like the Wenita fire staff, many New Zealand fire managers predominantly have duties that are unrelated to fire and they don't have experience in all aspects of incident management. Training in incident management techniques would increase their chance of maintaining operational coherency at future wildfires.

Safety

Even though no injury or near miss incidents occurred at the Berwick Fire, similarities exist between the management of this fire and other New Zealand wildfires where firefighters have been injured or threatened by fire burnovers during initial or ongoing attack (Fogarty 1996, Rasmussen and Fogarty 1997). Many firefighters attending the Berwick Fire received no initial and ongoing briefings on the state of the fire and expected developments, and of how these factors

---

[18] Bartlett (1994) did not define the term *operational coherency*, however it can considered to be exemplified by a situation where there is effective control and coordination of all resources employed on a fire; suppression tactics (including public warning and evacuations) are implemented by all fire fighters from a number of agencies in the full knowledge of the control strategy in respect to the current and expected fire situation; and all logistical and information requirements of firefighters and managers are met.

had been accounted for in the suppression strategy. Although the Berwick Fire Control Team used weather and fire behaviour information to determine strategies and tactics, site-specific fire weather forecasts had been considered unnecessary (a standard situation in New Zealand) and like many wildfires where incidents have occurred, margins of safety for worst-case conditions were not assessed.

The 1994 "South Canyon" or "Storm King Mountain" Fire, in which 14 American fire fighters died after a wind change associated with a predicted dry cold front caused the fire to escalate and entrap them (Anon. 1994, Anon. 1995), illustrates the potential danger of fire suppression operations. The firefighters, in taking what they considered to be calculated risks to get the job done (Rhoades 1994), broke a number of safety rules. While these actions contributed to the final outcome (Anon. 1994), the "blow up" should have been predicted by the fire control team and the suppression plan altered to avoid the hazards faced by the firefighters (Anon. 1995).

As a result of the Storm King Mountain disaster, a new imperative for encouraging a "passion" for safety has been proposed (Anon. 1994, Saveland 1995). The aim is to promote a situation where firefighters will (from Gleason 1994, Saveland 1995):

- Eagerly follow the safety rules.
- Refuse to enter the fire ground until they are adequately briefed with their duties.
- Expect the unexpected at all times.

While this is a worthwhile initiative, and new training procedures targeting psychological and sociological processes (Putnam 1995a, Putnam 1995b) need to be reviewed by New Zealand fire managers, it is essential that a passion for safety does not stop on the fireline. Fire managers shouldn't assume that providing firefighters with the latest gear and training them to recite safety rules will ensure their safety. At each of the levels in the command chain, people must feel motivated to follow well-established procedures for recognising, eliminating and minimising hazards. Fire managers rely on firefighters to safely implement strategies. A two-way relationship must be developed where firefighters can rely on the following support from management staff:

- Provision of a minimum standard of training that is appropriate and necessary rather than cheap.
- Provision of a safe and effective fire suppression plan based on consideration of the influences of the broader fire environment on fire behaviour.
- Provision, through initial and ongoing briefings, of information about the broader environment of the operation. Firefighters can then make objective judgements about the effect of behaviour on their own safety, and the best way to achieve their goals.

Firefighter safety is not the only aspect that needs to be considered by fire managers. Conflict regarding a neighbour's right to enter the fire ground hindered the management of the Berwick Fire. After the fire, complaints were made about the decision by the fire control team and police to evacuate one resident and deny access to the woodlot owner. The estimated fireline intensity of the run threatening the woodlot, was in the order of 40 000 kW/m, or ten times the level at which conventional methods of fire control *may* be successful (Alexander and Lanoville 1989, Alexander 1992 and Alexander 1994). The fire control team's decision, which recognised that attempts to protect the woodlot would have been both futile and life threatening, is considered to be entirely justified.

Benchmarking and Critical Lessons

A *disaster* can be defined as an event that threatens "*people with major unwanted consequences as the result of the collapse of precautions which had hitherto been culturally accepted as adequate*" (Turner 1977). Many of the practices that have been discussed in relation to the management of the Berwick and Karori (Fogarty 1996) Fires were responses to *disaster* situations. The "Watchout Situations" and "10 Standard Orders" provide examples of safety rules resulting from an improved understanding of wildfire hazards after a wildfire disaster (Mutch 1995). While these rules have been adopted by most New Zealand forest and rural fire authorities, a systematic approach to the use of fire behaviour information for fire management has been largely ignored (Alexander 1992). Instead, emphasis is still placed on the use of new and better equipment rather than on how, when, and where to use resources to improve fire protection standards (Alexander 1992). Many of the issues discussed in this report, echo the findings of the 1955 Balmoral Forest Fire and 1976 Hanmer Forest Fire Commissions of Inquiry.

Benchmarking involves systematically defining the best procedures and practices for comparison with those currently used by an organisation, in order to identify ways to improve effectiveness, and adaptability (Harrington 1991). Between the late 1970's and the initiation of the current forest and rural fire research programme at the New Zealand Forest Research Institute in 1993, research and technology transfer were largely neglected. Therefore the costs of upgrading management systems to meet requirements discussed in this report may be significant. However, the adoption of these recommendations will lead to the better use of resources and has the potential to reduce the area of forest burnt.

The extent to which forest and rural fire authorities accept the need for change will depend on an assessment of the cost and benefits involved. As more information is gathered on the New Zealand fire environment, fire behaviour, resource productivity and effectiveness and the effect of these on forest losses, the benchmarking and risk management process can become less qualitative and more quantitative. In the meantime, to reduce the chances of fire disasters occurring, New Zealand fire managers should seriously consider adopting the following benchmarked practices:

1. Improved methods of detection and reporting to reduce the time between ignition and initial attack.
2. Development of initial attack plans to improve procedures for responding to wildfire situations.
3. The monitoring of appropriate weather and fire danger information to improve preparedness for wildfires and set the level of initial attack in the event of a fire.
4. Use of incident management principles to ensure effective command, control and multi-agency coordination at all wildfires regardless of size.
5. Use of fire weather and fire behaviour information to ensure safe and effective fire suppression strategies and tactics.
6. Improved communication with, and supervision of, aerial suppression operations.
7. Determination of the effectiveness of aerially applied suppressants and retardants in a range of fuel types at different fire intensities.
8. Recognition that the adoption of new or existing technology must not compromise preparedness and operational coherency.

Attention to these components of fire management before the Berwick Fire would in all likelihood have contained the fire in the small area burnt by 1215 hours (Figure 2).

Conclusions

The Berwick Fire of 26 February 1995 occurred in extreme burning conditions. The loss of 181 hectares of plantation forest was small in relation to the potential threat. This is partly attributable to the implementation of a strategy to minimise flank fire spread. However, elements of chance, such as the head fire running into green pasture, and the effect of a change to moist, cold weather conditions, significantly assisted fire containment.

Even though the Berwick fire spread through a range of species and age classes with different burning characteristics, the C-6 coniferous plantation and S-1 logging slash fire behaviour models provided reasonable estimates of observed fire behaviour. Greater attention to the measurement of on-site weather and fire spread through individual stands would have improved the testing and validation of the available fire behaviour models.

Benchmarking the Berwick Fire against international experience underlines the importance of adopting (i) presuppression planning techniques (ii) improved detection and reporting systems, and (iii) improved incident management systems to enhance New Zealand forest fire protection standards. Monitoring of fire weather and fire behaviour information is pivotal to prevention, presuppression and suppression planning. Initial attack plans should not only detail resources necessary to control a fire, but also outline an initial incident management structure that can be adapted to changing on-site conditions. The concept of a partnership between fire managers and firefighters based on the provision of two-way support mechanisms should be encouraged.
The Berwick Fire provides a timely lesson on the importance of reviewing practices and procedures developed after overseas fire disasters. By *benchmarking* these against local standards and acting on recognised deficiencies, the occurrence of fire disasters will be minimised. However, if these often hard learned lessons are ignored, New Zealand fire managers may contribute to the occurrence of a future fire disaster.

Acknowledgments

The authors thank Ruth Gadgill, Leslie Whitehouse, Ken Klitscher (FRI), Ross Hamilton (Dunedin City Council), Rodger Hancock, John Kerr and Ian Young (Wenita Forest Products Ltd) for their comments and assistance. Particular thanks are extended to Paddy Enright (Wenita Forest Products Ltd) for recording on-site fire behaviour information, Vaughan Gera for assistance in the preparation of Figure 2, and especially to Grant Pearce (FRI) and Marty Alexander (Canadian Forest Service) for many useful comments throughout this study.

Recommendations

Use Of These Recommendations

These recommendations summarise the key points to emerge from the Berwick Fire. While not every aspect of fire protection is covered, they provide fire managers with a useful checklist to assess their own ability to prevent and respond to other major wildfires.

General

Disaster Prevention

1. Most parts of New Zealand experience periods of extreme fire danger. To reduce the risk of a major fire disaster occurring, practices and procedures for fire control need regular review and updating; this would enable adoption of appropriate best practice, based on experience gained in fire incidents locally and overseas.
1. The logging slash (S-1) and coniferous plantation (C-6) models of the Fire Behaviour Prediction System are recommended as decision support tools for fire prevention, presuppression and suppression planning.

Fire Research

1. Collection of data on local weather and fire behaviour during plantation wildfires is required for validation and the further development of fire behaviour models.
2. Fire behaviour observers, whose task it is to collect this data, should be included in the standard initial response to wildfires.
3. Procedures developed by Pearce and Alexander (1992) are recommended to record fire spread rates and on-site weather conditions during wildfires.
4. Data on the productivity and effectiveness of different fire suppression resources are needed for initial attack and fire suppression planning.
5. Information from wildfire case studies and field trials is also needed to develop guidelines on the most appropriate chemical additives, flying speeds, drop heights and placement patterns for aerial fire suppression in New Zealand fuel types.
6. The comparative advantages of fixed wing aircraft and helicopters need to be investigated.

Fire Prevention

Litter removal

1. Empty cans and bottles must be removed from forests to reduce the chance of ignitions occurring.

Fire Season Status

1. New Zealand forest and rural fire managers should adopt the recommendations and approach of Alexander (1994) and develop trigger points for the implementation of prohibited fire periods in their region.

Fire Detection and Reporting

1. Systematic methods of fire detection need to be developed for use during periods of Very High and Extreme fire danger.
2. Wildfire case studies can be reviewed and simulation used to assess the effectiveness of the 111 system and of publicity campaigns by forest and rural fire authorities that promote its use.

Fire Presuppression

1. Fire authorities/regional fire committees should coordinate regional preparedness and response plans. The appointment of a regional fire duty officer, and the establishment of a multi-agency incident management team is recommended, particularly during periods of extreme fire danger.
2. Systems should be put in place and training given to enable fire managers to respond appropriately to any fire.
3. The adoption of new equipment and technologies should be planned and reviewed so that potential negative consequences on preparedness and operational coherency can be minimised.

Initial Attack Planning

1. Greater emphasis should be placed on developing initial attack plans leading to deployment of resources capable of suppressing a fire while it is still small.
2. Initial attack plans establish the response levels appropriate to:
   - the fire environment and expected fire behaviour (i.e., fire intensity, head fire rate of spread and rate of perimeter growth);
   - the time required for detection, reporting, dispatch of firefighting resources and travel (i.e., the time lapse between ignition and initial suppression action);
   - the effect of fire behaviour (e.g., fireline intensity, rate of spread and spotting) on the ability of resources to contain back, flank and head fire spread; and
   - the effect of fire behaviour and environmental factors on the line building productivity of suppression resources.
3. Where head fire containment is not possible, due to extreme fire behaviour, a rapid and well organised attack must be implemented to restrict back and flank fire spread.
4. Initial attack and suppression plans should include organising administrative and communications personnel and the infrastructure needed to support both management and operational activities. Some examples are:
   - identification of appropriate fire headquarters;
   - identification and procurement of functioning equipment to assist with communications (e.g., radios, mobile radio repeater station, faxes, phones and photocopiers); and
   - ensuring rapid availability of people and tools to support administrative demands (e.g., for mapping and the maintenance of a communications and activities log book).

Training

1. Training in the use of an incident management system is recommended for fire managers.
2. Training of fire managers and firefighters should have increased emphasis on fire behaviour and firefighter safety. The aim should be to instil a "passion for safety".
3. Pilots need to be trained in aerial suppression techniques, particularly the use of suppressants and retardants on fires burning different fuel types under a range of fire danger conditions.

Weather

1. Fire personnel need to review, interpret and act on fire weather information on a continuous cyclical basis, so that they are adequately prepared during potentially dangerous periods.
2. Fire weather and fire behaviour information should always be used to assess, set and modify initial attack levels.
3. Publicly available weather forecasts should not be used for input into the Fire Weather Index System or for fire presuppression and suppression planning.

Aircraft

1. Forest fire managers should consider having aircraft and filling crews on standby when Very High or Extreme fire danger conditions are forecast.
2. The suitability of available aircraft for specific operations should be determined and used to select aircraft.

Fire Suppression

Incident Management Systems

1. Operational coherency will be increased by the use of incident management techniques which have been developed and refined from experience at other fires and emergencies.
2. Incident management must be approached as a continuum of response from initial to ongoing attack to ensure smooth transition between these phases. This is particularly important when the fire escalates beyond capabilities of the incumbent team.
3. Current and expected weather and fire behaviour should be monitored during the implementation of the suppression strategy so that hazardous situations can be identified and resource requirements anticipated.

Weather

1. Site-specific weather data and fire behaviour should be monitored and predicted from the beginning of wildfire suppression operations so that safe and effective fire suppression strategies and tactics can be developed and implemented.

Safety

1. Fire managers need to minimise hazards at fire incidents, not only by providing firefighters with safety clothing and equipment and an understanding of safety rules, but also by :
   - providing fire behaviour training;
   - using fire environment and fire behaviour information to develop, refine and implement safe and effective fire suppression plans; and
   - providing initial and ongoing briefings to firefighters about suppression strategies and tactics, the broader fire environment and fire behaviour.

Aircraft

1. An air-attack supervisor should be appointed at fires where a number of aircraft are operating.

References

Alexander, M.E. 1982. Calculating and interpreting forest fire intensities. *Canadian Journal of Botany 60*: 349-357.

Alexander, M.E. 1985a. The Ash Wednesday bushfires of 16 February 1983 in south-eastern Australia: videotape. In: *Proceedings of the Second Western Region Fire Weather Committee Scientific and Technical Seminar*, 23-28. Canadian Forestry Service, Northern Forestry Research Centre, Edmonton, Alberta. Study NOR-5-191, File Report No. 9.

Alexander, M.E. 1985b. Estimating the length-to-breadth ratio of elliptical forest fire patterns. In: Donoghue, L.R.; Martin, R.E. (editors), *Proceedings of the Eighth Conference on Fire and Forest Meteorology, April 29-May 2, 1985, Detroit, Michigan*, 287-304. Society of American Foresters, Bethesda, Maryland. SAF Publication 85-04.

Alexander, M.E. 1992. Fire behaviour as a factor in forest and rural fire suppression. In: *Proceedings, Forest and Rural Fire Association of New Zealand (FRFANZ) 2nd Annual Conference, August 5-7, 1992, Christchurch*, 64-103.

Alexander, M.E. 1994. Proposed revision of fire danger class criteria for forest and rural areas in New Zealand. National Rural Fire Authority, Wellington. Circular 1994/2. 73 p.

Alexander, M.E.; Lanoville, R.A. 1989. Predicting fire behaviour in the black spruce-lichen woodland fuel type in western and northern Canada. Forestry Canada, Northern Forestry Centre, Edmonton, Alberta, and Government of the Northwest Territories, Department of Renewable Resources, Territorial Forest Fire Centre, Fort Smith, Northwest Territories. Poster (with text).

Alexander, M.E.; Pearce, H.G. 1992. Guidelines for investigation and documentation of wildfires in plantation pine plantations. Draft report prepared for the meeting of Australian Forestry Council Research Working Group No. 6 - Fire Management Research, December 9, 1992, Creswick, Victoria, Australia. 10 p.

Anon. No date-a. Report of the commission of inquiry into the Hanmer Fire. New Zealand Forest Service, Canterbury Conservancy. 31 pages and Appendices.

Anon. No date-b. Report of the commission of inquiry into the Balmoral Forest Fire 1955. New Zealand Forest Service. 30 pages and Appendices.

Anon. 1993. *Fire Weather Index System Tables for New Zealand.* National Rural Fire Authority in association with the New Zealand Forest Research Institute. Wellington, N.Z. 48 p.

Anon. 1994. South Canyon Fire Investigation. Report of the South Canyon Fire Accident Investigation Team. 39 pages and Appendices.

Anon. 1995. The Occupational Safety and Health Administration's investigation of the South Canyon Fire, February 8, 1995. *Wildfire 4(1)*: 1-6.

Bartlett, A.G. 1994. Managing multi-agency wildfires in south-eastern Australia. In: *Proceedings, Forest and Rural Fire Association of New Zealand (FRFANZ) 4th Annual Conference, August 3-5, 1994, Rotorua.*

Beckingsale, D. 1994. Community Fireguard. In: *Proceedings, Forest and Rural Fire Association of New Zealand (FRFANZ) 4th Annual Conference, August 3-5, 1994, Rotorua.*

Brown, A.A.; Davis, K.P. 1973. *Forest Fire: Control and Use*. 2nd edition. McGraw-Hill, New York. 686 p.

Buckley, A.J. 1994. *Fire Behaviour and Fire Suppression in an Elevated Fuel Type in East Gippsland: Patrol Track Wildfire, February 1991.* Department of Conservation and Natural Resources, Fire Management Branch. Fire Research Report No. 42. 23 pages and Appendices.

Miller, S.I.; Carter, W.; Stephens, R.G. 1984. *Report on Bushfire Disaster Preparedness and Response in Victoria, Australia, following the Ash Wednesday Fires of 16 February 1983.* Victorian Government Printer. 174 p.

Byram, G.M. 1959. Combustion of forest fuels. In: Davis, K.P. (editor), *Forest Fire: Control and Use*, 61-123. McGraw-Hill, New York.

Cheney, N.P. 1981. Fire behaviour. In: Gill, A.M.; Groves, R.H.; Noble, I.R. (editors), *Fire and the Australian Biota,*151-175. Australian Academy of Science, Canberra, Australian Capital Territory.

Cheney, 1976. Bushfire disasters in Australia, 1945 - 1975. *Australian Forestry 39(4)*: 245-268.

Countryman, C.M. 1972. *The Fire Environment Concept.* USDA Forest Service, Pacific Southwest Forest and Range Experiment Station, Berkeley, California. 12 p. [reprinted as *National Fire Equipment System (NFES) 2166* by National Wildfire Coordinating Group, Boise Interagency Fire Center., Boise, Idaho].

De Groot, W.J. 1990. Development of Saskatchewan's fire preparedness system. In: Hirsch, K.G. (compiler and editor), *Proceedings of the Sixth Central Region Fire Weather Committee Scientific and Technical Seminar, April 4, 1989, Winnipeg, Manitoba*, 23-50. Forestry Canada, Northern Forestry Centre, Edmonton, Alberta. Study NOR-36-03-1, File Report No. 5,

Fogarty, L.G. 1996. *Two Rural/urban Interface Fires in the Wellington Suburb of Karori: Assessment of Associated Burning Cnditions and Fire Control Strategies.* New Zealand Forest Research Institute, Rotorua, in association with the National Rural Fire Authority, Wellington. FRI Bulletin No. 197, Forest and Rural Fire Scientific and Technical Series, Report No. 1. 16 p.

Forestry Canada Fire Danger Group. 1992. *Development and Structure of the Canadian Forest Fire Behaviour Prediction System.* Forestry Canada, Science and Sustainable Development Directorate, Ottawa, Ontario. Information Report ST-X-3, 63 p.

Fuquay, D.M; Baughman, R.G. 1965. Can glass and metal containers start forest fires? *Fire Control Notes 26(2)*: 3-5.

Geddes, D.J.; Pfeiffer, E.R. 1981. *The Caroline Forest Fire, 2nd February, 1979.* Woods and Forests Department, Adelaide, South Australia, Bulletin 26. 52 p.

Gleason, P. 1994. Unprepared for the worst case scenario. *Wildfire 3(3)*: 23-26.

Harrington, H.J. 1991. *Business Process improvement: the Breakthrough Srategy for Total Quality, Productivity and Competitiveness.* McGraw-Hill Inc. 274 p.

Hirsch, K.G. 1991. Development of an initial attack preparedness system for Manitoba. In: Andrews, P.L.; Potts, D.F. (editors), *Proceedings of the 11th Conference on Fire and Forest Meteorology, April 16-19, 1991, Missoula, Montana,* 81-89. Society of American Foresters, Bethesda, Maryland. SAF Publication 91-04.

Keeves, A.; Douglas, D.R. 1983. Forest fires in South Australia on 16 February 1983 and consequent future forest management aims. *Australian Forestry 46*: 148-162.

Krusel, N.; Petris, S.N. 1993. A study of civilian deaths in the 1983 Ash Wednesday Bushfires Victoria, Australia. In: *Proceedings, 12th Conference on Fire and Forest Meteorology, October 25-29, 1993, Jekyll Island, Georgia*, 112-119. Society of American Foresters, Bethesda, Maryland. SAF Publication. 94-02.

Lanoville, R.A.; Mawdsley, W.M. 1990. Systematic assessment of daily fire preparedness planning. In: Alexander, M.E.; Bisgrove, G.F. (technical coordinators), *The Art and Science of Fire Management. Proceedings of the First Interior West Fire Council Annual Meeting and Workshop. October 24-27, 1988, Kananaskis, Alberta.* Forestry Canada, Northwest Region, Northern Forestry Centre, Edmonton, Alberta. Information Report NOR-X-309. pp 253-261.

Loane, I.T.; Gould, J.S. 1986. *Project Aquarius: Aerial Suppression of Bushfires - Cost-benefit Study for Victoria.* Commonwealth Scientific and Industrial Research Organisation, Division of Forest Research, National Bushfire Research Unit, Canberra, Australian Capital Territory. 213 p + Appendices.

MacTavish, J.S. 1960. A new worry for forest fire control. *Timber of Canada. 21(6)*: 56,61.

Merrill, D.F.; Alexander, M.E. (editors). 1987. *Glossary of Forest Fire Management Terms.* 4th edition. National Research Council of Canada, Canadian Committee on Forest Fire Management, Ottawa, Ontario. Publication. NRCC No. 26516. 91 p.

Millman, R.I. 1993. Firefighting tragedies and near misses. In: *Proceedings, Forest and Rural Fire Association of New Zealand (FRFANZ) 3rd Annual Conference, August 4-6, 1993, Wellington,* 84-101.

Mutch, R.W. 1995. Fireline safety: preventing accidents and disasters. In: *Proceedings, Forest and Rural Fire Association of New Zealand (FRFANZ) 5th Annual Conference, August 2-4, 1995, Nelson,* 87-102.

NZMS. 1983a. *Climatic Map Series (1:200 000). Part 2: Climate Regions.* New Zealand Meteorological Service. NZMS Miscellaneous Publication 175. 172 p.

NZMS. 1983b. *Summaries of Climatological Observations to 1980.* New Zealand Meteorological Service. NZMS Miscellaneous Publication 177. 172 p.

Pearce, H.G.; Alexander, M.E. 1994. Fire danger ratings associated with New Zealand's major pine plantation wildfires. In: *Proceedings, 12th Conference on Fire and Forest Meteorology, October 25-29, 1993, Jekyll Island, Georgia,* 534-543. Society of American Foresters, Bethesda, Maryland. SAF Publication 94-02.

Prior, K.W. 1958. The Balmoral Forest Fire. *New Zealand Journal of Forestry 7(5)*: 35-50.

Putnam, T. 1995a. The collapse of decision making and organisational structure on Storm King Mountain. *Wildfire 4(2)*: 40-45.

Putnam, T. 1995b. *Findings From the Wildland Firefighters Human Factors Workshop; 12-16 June 1995; Missoula MT*: U.S. Department of Agriculture, Forest Service, Missoula Technology Development Centre. 74 p.

Rasmussen, J.H; Fogarty, L.G. 1997. *A Case Study of Grassland Fire Behaviour and Suppression: The Tikokino Fire of 31 January 1991.* New Zealand Forest Research Institute in association with the National Rural Fire Authority, Wellington. FRI Bulletin No. 197, Forest and Rural Fire Scientific and Technical Series, Report No. 2. 18 p. + Appendices.

Rhoades, Q. 1994. Effective firefighting calls for bending the rules sometimes. *Wildfire 3(3):* 22.

Rothermel, R.C. 1991. Predicting behaviour of the 1988 Yellowstone Fires: projections versus reality. *International Journal of Wildland Fire 1(1)*: 1-10.

Saveland, J. 1995. Creating a passion for safety versus management oversight and inspection. *Wildfire 4(3):* 38-41.

Stocks, B.J.; Lawson, B.D.; Alexander, M.E.; Van Wagner, C.E.; McAlpine, R.S.; Lynham, T.J.; Dubé, D.E. 1989. The Canadian Forest Fire Danger Rating System: an overview. *Forestry Chronicle 65:* 450-457.

Turner, B.A. 1977. The development of disasters - a sequence model for the origin of disasters. *Sociological Review 24(1976)*: 753-774.

Van Wagner, C.E. 1987. *Development and structure of the Canadian Forest Fire Weather Index System.* Canadian Forestry Service, Ottawa, Ontario. Forestry Technical Report 35. 37 p.

Wilson, A.A.G. 1984. *Assessing the Bushfire Hazard of Houses: a Quantitative Approach.* National Centre for Rural Fire Research, Chisholm Institute of Technology, Melbourne. Technical Paper No. 6. 16 p.

Wilson, C.C. 1977. Fatal and near-fatal forest fires — the common denominators. *International Fire Chief 43(9)*: 9-10, 12-15.

Wilson A.A.G.; Ferguson, I.S. 1984. Fight or flee? - a case study of the Mount Macedon bushfires. *Australian Forestry 47:* 230-236.

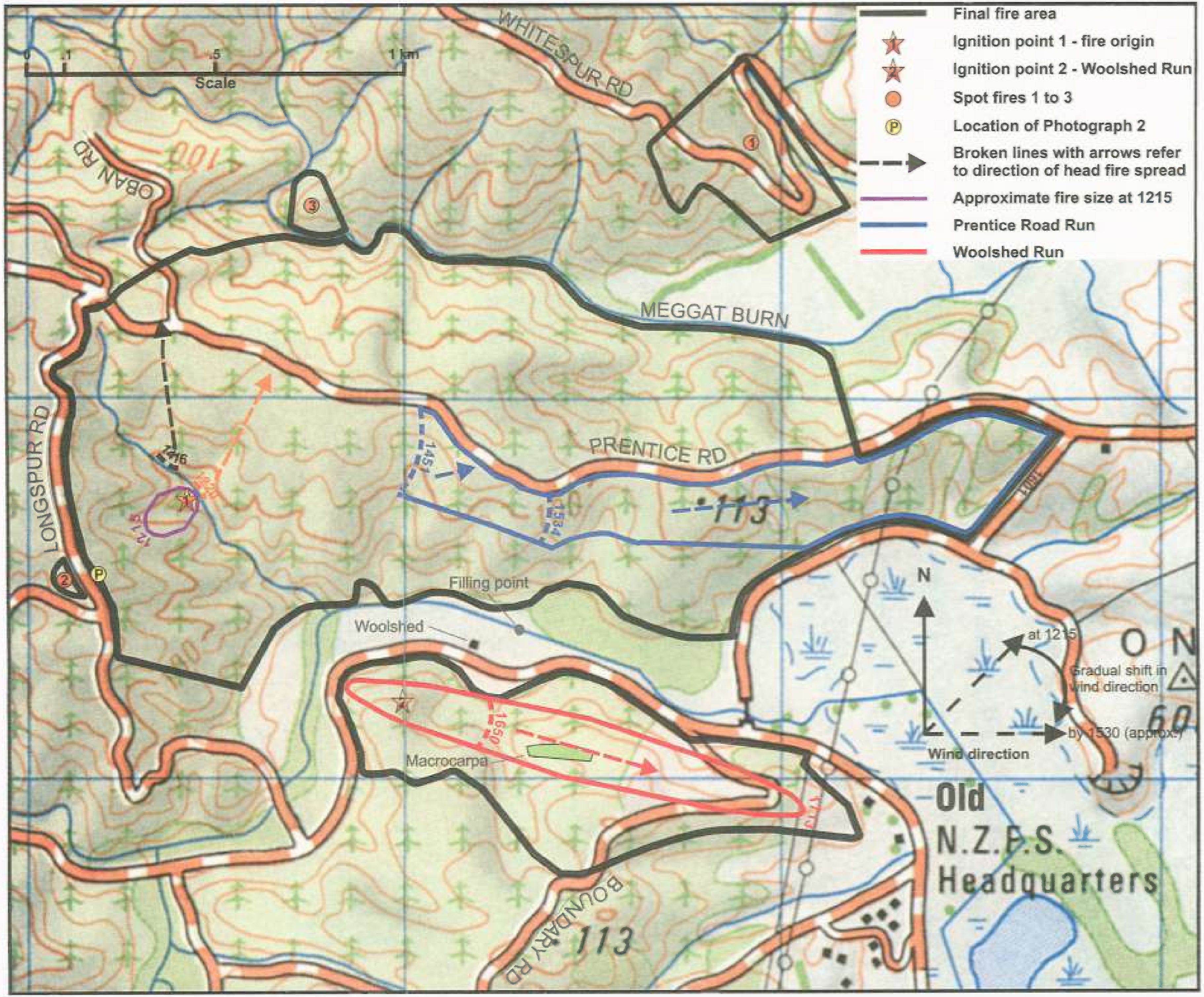
Appendix 1. Summary of *public* weather forecasts leading up to the Berwick wildfire.

Date issued	Forecast
Friday, 24/2/95	**MetService:** Mostly fine, but high cloud increasing tomorrow, and scattered rain spreading from the west late in the day or evening. Gusty north westerlies. On Monday, rain at first, then easing to showers. Cooler south westerlies. Becoming fine on Tuesday apart from showers about Foveaux Strait. On Wednesday, brief rain may spread from the west.
	Blue Skies: Cooler south easterly winds are expected over much of the South Island today. Westerlies are forecast to develop over the south of the country tomorrow and Sunday. A weakening cold front should travel over most of the country on Sunday, followed by cooler south westerly winds. Dunedin: Moderate south east winds, showers clearing; maximum temperature 16°C.
	Forecast Otago/Southland tomorrow: Mostly fine and often sunny. Expect some areas of cloud at times. Milder temperatures with fresh westerly winds.
Saturday, 25/2/95	**MetService:** Fine and warm today with gusty north westerlies in some places. Scattered rain spreading north tomorrow with a cool southerly change. Clearing on Tuesday, and southerlies dying out. On Wednesday and Thursday, mainly fine, but a few showers possible at times with south west changes.
	Blue Skies: Westerlies are forecast to develop over the South Island today. These westerlies are expected to increase in strength tomorrow. A weak cold front is also expected to move over the county tomorrow, followed by cooler south westerlies, which should persist over the South Island next week.
	Forecast Otago/Southland: Mostly fine and often sunny and often sunny today. Milder temperature with westerly winds freshening. Dunedin: Moderate westerly winds, mostly fine, maximum temperature 20°C. Outlook for tomorrow: Mostly cloudy at first with some showers likely. Showers clearing during the day and fine weather developing by the afternoon, especially in inland areas. Warmer temperatures with fresh gusty westerly winds
Sunday, 26/2/95	**MetService:** Scattered rain today, clearing from the south. Mostly fine tomorrow, then showery south westerlies developing on Wednesday. On Thursday, mostly fine except for a few showers about the Southland coast. Showers and southerlies on Friday.

Appendix 2. Fire intensities and implications for fire suppression adapted from Alexander and Lanoville (1989), Alexander (1992) and Alexander (1994).

Fire Intensity (kW/m)	Nominal maximum flame height (m)	Fire behaviour description	Fire suppression interpretation*
0 - 10	no visible flame	Smouldering or sub-surface.	Control by hand-tools is easily achieved. Mop-up or complete extinguishment of fires that are already burning may be required.
10 - 500	up to 1.3	Creeping or gentle surface.	Direct manual attack at the fire's head or flanks by firefighters with hand-tools and water is possible.
500 - 2000	1.4 - 2.5	Running or vigorous surface.	Hand constructed firelines likely to be challenged. Heavy equipment (e.g., bulldozers, helicopters) and water under pressure needed for head fire attack. Fire pumps and hose lays can work on flanks.
2000 - 4000	2.6 - 3.5	Very vigorous or extremely intense surface.	Control efforts at the fire's head may fail. Direct attack on the head fire may be possible by ground crews only in the first few minutes after ignition. Any attempt to attack the head fire should be limited to aircraft.
> 4000	3.6 +	Violent physical behaviour of fires is a certainty (e.g., rapid spread rates, crowning in forests and scrub fuel types, medium to long range mass spotting, fire whirls and towering convection columns).	Direct attack is rarely possible. Indirect attack by burning-out may be effective. Breaching of firelines will regularly occur.
> 10000	5.5 +	Very extreme fire behaviour will occur (e.g., rapid spread rates, crowning in forests or scrub, mass spotting, fire whirls, towering convection columns).	Limit of possible control using burning-out. Fires are virtually impossible to control until conditions ameliorate.

*** This table should not be used as a guide to firefighter safety, as fires can be potentially dangerous or life threatening at any fire intensity.**


Final fire area
Ignition point 1 - fire origin
Ignition point 2 - Woolshed Run
Spot fires 1 to 3
Location of Photograph 2
Broken lines with arrows refer to direction of head fire spread
Approximate fire size at 1215
Prentice Road Run
Woolshed Run
Scale
0
.1
.5
1 km
WHITESPUR RD
OBAN RD
MEGGAT BURN
PRENTICE RD
LONGSPUR RD
BOUNDARY RD
1416
1451
1534
1650
1215
113
Filling point
Woolshed
Macrocarpa
N
at 1215
Gradual shift in wind direction
by 1530 (approx.)
Wind direction
Old
N.Z.F.S.
Headquarters