The weather systems responsible for this type of situation are well documented (Gigliotti and Blake 1994), and occasionally experienced during the warmer months in southern Australia.

Therfore fire controllers should be aware of the increased weather and ignition source risks at this time of the year and plan accordingly. Spring fuel reduction burns in or adjacent to ***Very High*** to ***Extreme*** Overall Fuel Hazards can be a recipe for disaster.

b) Late Season First Attack Failures

Late season first attack failures, particularly in the West of the State, were also associated with the occurrence of one or two days of *"blow-up" Autumn weather* - i.e. high temperatures, low humidities and strong N-NW winds - which occurred in the normally stable months of March and April. One particular April "blow-up" day, the 26th April 1994, caused the escape of at least seven prescribed burns in the Grampians, Portland and the Otways (Wouters, pers. comm.). The worst of these resulted in the Moora Moora fire in the Grampians which eventually burnt 6500 hectares and cost $152,000 to control.

DNRE carries out the bulk of its Public Land fuel reduction, regeneration and habitat management burning during the Autumn (DNRE 1989, 1990) and hence there are a proliferation of *ignition sources* on public land at this time of year.

In addition, private landholders, CFA brigades and Shires often make use of the lifting of fire restrictions in March or April to carry out various hazard reduction operations on private property, often in close proximity to adjoining public land.

Fine and coarse *fuels are often at their driest in the Autumn*, having dried out substantially over the Summer period. This then means more available fuel and higher fire intensities once ignition occurs, thereby increasing the difficulties of suppression.

Fire-fighting resources are often more widely spread at this time of the year. This differs from the height of the fire season when more resources are kept in close proximity to central dispatch points. This spread of resources is determined by the requirements of, in the Orbost Forest District for example, having to complete approximately 30 regeneration burns and 20,000 hectares (over 15 burning units) of fuel reduction burning annually (DNRE 1989). This spread of resources can reduce the ability of crews to respond to either wildfires or escaped prescribed burns. The data indicated that often crews of six men or less and either no dozer, or only a D3-sized machine, were involved in the first attack effort on fires where first attack failure occurred from an already-lit prescribed burn.

Fuel Hazard

Category 3 fires (where first attack efforts failed) always occurred in or adjacent to areas of ***Very High*** to ***Extreme*** Overall Fuel Hazard (after Wilson 1993). This meant that wildfire outbreaks or prescribed burn escapes were very difficult to deal with when the FDI was higher than 8. Wilson (1993) proposed that the Reference First Attack (defined in the Elevated Fuel Guide) will fail for a site of overall ***Extreme*** fuel hazard at an FDI range of 8-12.

This proposition has been supported by first attack failures (although not necessarily the Reference First Attack) at Reedy Creek (Cann River 004), Chinaman Long Beach (Yarram 016) and a number of other Category 3 fires (some of which were prescribed burn escapes) where this same ***Very High*** to ***Extreme*** Overall Fuel Hazard existed.

The higher mean spotting distances and forward rates of spread for Category 3 fires indicated that these were the significant fire behaviour contributors to first attack failure. ***Very High*** to ***Extreme*** bark and elevated fuel hazards contributed to these greater spotting distances. Some fire controllers reported that if it hadn't been for massive short distance spotting, and some long distance spotting, it would have been possible to contain some Category 3 fires at a much smaller size.

Because Overall Fuel Hazard, and particularly the **Bark** and **Elevated** components of this hazard, was found to be so important in influencing first attack outcome, there is a clear need for fire managers to be more aware of fuel hazards when considering both wildfire suppression and prescribed burning. *Tolhurst et al. (1992) reported that the greatest benefits of Fuel Reduction Burning, in terms of reducing fuel hazard, are that elevated and bark fuel levels can be significantly reduced for up to 10 years following the burn.*

Although the Elevated Fuel Guide and the Bark Hazard Guide have been available to fire mangers for a number of years, the concept of assessing Overall Fuel Hazard did not seem to have become well established or accepted. This was particularly evident when fire controllers interviewed for this study were asked to use the two Guides to assess fuel hazard levels present on fire sites.

Forward Rate of Spread

Temperatures and *winds* appeared to be the principal contributors to higher mean FDIs for Category 3 fires, and in combination with the ***Extreme*** Overall Hazard fuels, were proposed as the principal causes for higher forward rates of spread. However at least two Category 3 fires had very high rates of spread in the absence of much wind effect. It is suspected that ***Extreme*** Fuel Hazards together with unusual convective and/or spotting activity were the most likely explanations for these results.

The rate at which a fire "accelerates" has been studied by a number of researchers and has been found to be dependent on weather, fuel, topography and ignition characteristics. Weather factors have been combined to give predictions of various stages of fire danger - the most commonly used in Victoria is McArthur's Forest Fire Danger Index (Forest FDI) 1973 Version and is calculated using the accompanying Forest Fire Danger Meter Mark V. The back of this meter also gives predictions of fire behaviour based on various levels of available fuel. These predictions can also be adjusted to account for variations in topography. As the FDI increases the rate at which a fire accelerates also increases. Luke and McArthur (1979) found that the acceleration phase of a major fire (i.e. the time between ignition and the time at which the fire reached its maximum posssible rate of spread) can take as little as 20-30 minutes, although the rate of increase in rate of spread varied considerably with the changes in fuel moisture content at different times of the day. These authors also found that wildfire acceleration could occur in a series of "steps" as various factors such as elevated fuels, spotting and the convection process began to affect fire behaviour as the fire increased in size and intensity. Cheney (1981) reported that while low intensity fires could reach their maximum rate of spread in a few minutes, a very large fire in Tasmania had been observed to continue to accelerate for nearly three hours. In relation to first attack, the implication of these findings is that there will always be a period of time when any fire can be controlled, but this period may only be very short in the case of fires with the potential to reach very high intensities, and which are accelerating rapidly.

In conjunction with a significantly higher initial mean fire size for Category 3 fires, *increased wind speeds* contributed to early rates of spread which made the *suppression problem one of perimeter containment* as well as one of *fireline intensity*.

Using a model to predict fire perimeter size and growth (Wallace 1993) the mean initial fire perimeter for Category 3 fires was 4460 metres. The mean rate of spread for these fires was 963 metres per hour, or nearly 1 kilometre per hour. For a fire of initial perimeter of 120 metres (area 0.1 hectare), this would produce a perimeter of approximately 2700 metres to deal with after the first hour. If however this initial perimeter was 4460 metres, as was the mean for Category 3 fires *at the time of first arrival at the fire,*, with no suppression action on the headfire for an additional hour there would be approximately 6-7000 metres of perimeter to deal with. This gives a measure of the resources needed to check a fires spread. Buckley (1994) found fireline construction rates in an elevated fuel type in East Gippsland to be 150 metres per hour for a D3 (75kW) bulldozer and 675 metres per hour for a D6 (130kW) bulldozer. These figures were obtained in a real fire suppression situation and therefore represent achievable line construction rates in the type of elevated fuel present at Category 3 fires.

From the predictions of perimeter growth above, even a D6-sized dozer would not have coped with the line construction task if it had taken an hour to reach the fire. That is, for first attack with a D6 to be successful, the total perimeter growth within the first hour could not exceed 675 metres - and yet it has already been calculated that even for a fire of initial size of only 0.1 ha., under the conditions prevailing for most Category 3 fires, there would have been an average of 2700 metres of perimeter to deal with after the first hour. Clearly a single D6 would be inadequate for this task, and it would certainly be inadequate to cope with a perimeter of 4460 metres - which was the mean perimeter facing arriving crews at Category 3 fires. A single D6-sized dozer, with a line construction rate of 675 metres/hour, would need to arrive at the fire when it was between 0.5 hectares (predicted perimeter 330 metres) and 1.0 hectares (predicted perimeter 500 metres) to have any chance of success under the forward rate of spread conditions which prevailed at most fires where first attack efforts did not succeed.

A summary of the mean response times recorded for Category 3 fires poses some important questions in relation to this problem of mean rates of spread and perimeter growth.

The overall time delay for the average Category 3 fire appears as follows:

Time Period	Category 3 Average/mean (minutes)
Ignition (or SOAP) to Detection	40
Detection to Reporting	5
Reporting to Despatch	13
Despatch to First Suppression Work	52
	----
	110 (1hr 50 min)

This average total time is the best of the three categories, and it therefore probably represents the best possible performance which was available from the current DNRE detection, reporting and response systems/mechanisms. Therefore the question has to be asked - is this average response time unacceptable, given that the average FROS (963 m/hr) and Fire Size on Arrival for

Category 3 fires (130 ha) mean that first attack crews will already have an average of between 1 and 4.4 kilometres of perimeter to deal with, and up to 7 kilometres in the following hour if suppression action fails to slow the headfire ?

This then poses some further questions:

- are there any cost effective ways of improving this average response time from the current average 110 minutes down to the 20 - 30 minutes which would have been required to catch some of the Category 3 fires?
- would such expenditure be justified for the 1% of fires overall which become Category 3 fires?

This final question would have to be balanced against FIRES data for 1994/95 which indicated that fires where first attack efforts failed accounted for 70% of the total area burnt, and 35% of the total expenditure on fire suppression.

Fire Intensities

A further implication of the combined significance of Overall Fuel Hazard and FROS is that Category 3 fires were of a significantly higher intensity than fires in the other two categories.

Both the range and the mean intensity levels for each category suggest a number of likely outcomes in terms of suppression performance. Loane and Gould (1985) suggested that a fireline intensity of 3000 kW/m is about the upper limit for any sort of direct suppression action to succeed, and Buckley (1994) suggested that 2000 kW/m may be the upper limit for direct suppression where substantial elevated fuels are present. Burrows (1984) proposed that fires in the range 2000 - 5000 kW/m could only be controlled by indirect methods, and that 2000 kW/m was the limit for direct headfire attack using bulldozers and tankers, with the limit for direct attack with handtools being substantially lower.

It appeared that, for the highest intensity fires in Category 1 and Category 2, suppression crews were able to achieve success under quite marginal conditions and probably did so by both using indirect attack methods, as well as containing the headfire by "pinching off" the less intense flank fires on either side of the headfire. The upper level intensities of 3500 kW/m for First Attack Success, Category 1, and 6000 kW/m for Extended First Attack, Category 2, were both associated with fire situations where there were only Low to ***Moderate*** bark hazards, very good access for large tankers, and large numbers of CFA tankers arriving within the first 30 - 45 minutes.

The mean intensity of First Attack Success fires of 1247 kW/m indicates that they were generally within the limits for successful direct attack as suggested above. The mean intensity of Extended First Attack Success fires of 3066 kW/m suggests that these fires were often close to, or above, these suggested direct attack limits, and that success was only achieved by the use of both indirect attack methods, as well a concerted effort of men and machinery into the later daylight and night hours when intensity levels reduced.

The mean intensity of Category 3 fires of 11000 kW/m indicates that, for most of these fires, intensity levels were such that even indirect attack and a concerted effort could not contain the headfire, and there was little that suppression crews could do until intensity levels reduced.

Fire Size and Backburning

The finding that the average final fire size for Category 1 fires was 10 ha could be used as a guide to setting target levels for first attack. In the past a target of 5 ha has been set,although the basis for this figure was not clear. It was thought to be based on propositions from work in the USA and Canada. The figures obtained in this study indicate that fires of up to 10 ha in size, which generally means perimeters of less than 1500 m, are able to be contained with normal first attack forces. This also gives an indication that if fires progress much beyond this 10 ha level, that additional forces will be required for suppression, and that the sort of suppression effort forces common to Category 2 fires - such as large tankers, large dozers, aircraft and >10 men - will be required if suppression is to be achieved within the first work period.

Two of the fires in Category 3, Moora Moora and Black Range, had their final fire sizes increased by backburning operations. These backburning operations did not assist with reducing the progress of the headfire in the first attack phase. Backburning is only likely to be successful in halting the forward rate of spread of fires when the FDI is less than 20 and wind speeds are less than 10 km/hr. The backburns were lit to take the fire out to safe and defendable suppression boundaries such as roads, tracks or grassed private property edges. This is a relatively common practice in fuels where direct tracking of the headfire or flankfires is difficult and unsafe.

Probability of First Attack Success

The probabilities of success of first attack (at a given FDI and Overall Fuel Hazard rating) derived from the actual fire situations investigated in this study serve to generally confirm the suggestions outlined by Wilson (1993) in the Elevated Fuel Guide. The probabilities derived indicate that the ranges for possible first attack failure are slightly different than those suggested by Wilson. A comparison of the two appears in Table 6 below. Data is also shown for Fuel Hazard and FDI situations where Extended First Attack may be required.

Table 6 Comparison of the FDI and Overall Fuel Hazard ranges/limits for which first attack may fail between Wilson (1993) and this study. Range of FDI and Overall Fuel Hazard for which Extended First Attack may be required - data from this study.

Overall Fuel Hazard Rating		Range of FDI for which first attack can fail. Wilson - Elev. Fuel Guide	Lowest FDI for which (normal) first attack may fail (only 90% probability of success). Logit prediction from model.	Lowest FDI for which Extended First Attack may be required. (95% probability of success). Actual data from this study.
Extreme -	5	8-12	1 or more	2 or more
Very High -	4	12-24	20 or more	6 or more
High -	3	24-50	70 or more*	25 or more
Moderate -	2	50+	Normal First Attack should succeed	Normal First Attack should succeed
Low -	1	Normal First Attack should succeed	Normal First Attack should succeed	Normal First Attack should succeed

* note prediction only - no (normal) first attack failure on ***High*** Overall Fuel Hazard sites in collected data.

Perhaps the most important aspect of this comparison is that a model prediction from this study indicates that first attack failure can occur on a site with an Overall Fuel Hazard Rating of ***Extreme*** from an FDI of as low as 1, and also that actual data showed that Extended First Attack was required on an ***Extreme*** site at FDI 2.

The relationship and graphs (Figure 7) derived using FDI and Overall Fuel Hazard as predictors of first attack outcome could be used in the fire protection planning process by assisting with establishing acceptable levels of risk for the various Fuel Management (Priority) Zones (for strategic FRB planning).

That is, for a "reference" FDI of 50 the Overall Fuel Hazard levels may be modified to achieve a specified probability of first attack success:

eg. **Fuel Management Zone 1- 100% chance of first attack success desirable.**
- therefore need to maintain Overall Fuel Hazard at ***Moderate*** (Fuel Hazard level 2 - 2.5 on the graph - see Figure 7)

Fuel Management Zone 2 - 80% chance of first attack success desirable.
- therefore need to maintain Overall Fuel Hazard at ***High*** (Fuel Hazard level 3 - 3.5 on the graph)

Fuel Management Zone 3 - 50% chance of first attack success desirable.
- therefore need to maintain Overall Fuel Hazard at ***Very High*** (Fuel Hazard level 3.5 - 4.5 on the graph)

The main operational requirement from this is that an assessment of Overall Fuel Hazard would have to be made for all FMZ 1, FMZ 2 and FMZ 3 Fuel Management Zones, and a map of this Overall Fuel Hazard maintained in conjunction with the other fire protection planning maps.

Assessments of surface fine fuel, elevated and bark fuel hazards can readily be done using the Overall Fuel Hazard Guide (McCarthy, Tolhurst and Chatto 1998).

Weather, Fire Behaviour and Fuel Hazard thresholds as indicators for possible first attack failure

The following figures were obtained by calculating the lower 95% confidence limits from the means of Category 3 fires. They could constitute a "watchout" situation for fire managers. That is, first attack failure is more likely to occur when:

Wind speed is greater than 20 km/hr, with:
- an FDI greater than 22;
- a forward rate of spread greater than 600 m/hr;
- spotting distances of more than 50 m;
- Overall Fuel Hazard is in the upper ***Very High*** to ***Extreme*** range (4.5 - 5.0).

Variables assessed which did not infuence first attack outcome

Comments on some of the variables which did not have a (statistically) significant influence on first attack outcome in this study are presented in Appendix 3. Some of this information comes from fire controllers interviewed during the data collection process, while other information in regard to these variables comes from both the fire experience of the authors and also other experienced fire control staff.

The following is a short resume of these variables.

Wind Direction

There were no significant differences in mean wind direction values for the three first attack outcome categories. All the Wind Direction data show a tendency for the predominant wind direction to be a north or north-westerly which, as would be expected, indicates more fires with the potential to become large when winds were north to north-westerly with accompanying higher temperatures and lower relative humidities.

Topography - Slope and Aspect

There were no significant differences in the mean aspect or slope values for the three first attack outcome categories. The analysis of aspects showed most aspects represented except for north-eastern and eastern aspects. This is a reasonable result given that easterly aspects tend to both be moister and cooler as a result of both lower solar radiation and less exposure to the influence of drying north to north-westerly winds. This indicated that fires are generally more likely to occur when the aspect is between north and west-south-west. These aspects are generally drier as a result of both wind and exposure to higher temperatures/solar radiation later in the day, and therefore fuels on these aspects are often significantly drier and hence more flammable.

The mean slope figures showed no significant difference for the three categories of first attack outcome, with the first attack failures that were recorded being on generally gentler slopes, or in fact flat ground, than fires in the other two categories. Slope was less important than fuel and weather conditions.

Ignition, Detection and Response Times

No response time variable was of sufficient significance to first attack outcome to be included in the multiple linear regression model. This may be an artifact of this particular dataset as other research indicates that faster response times and concentrated effort (particularly where large numbers of big firebombing aircraft are available) can lead to better first attack success (Quintilio and Anderson 1976, Dimitrakopolous 1987).

The data on mean response times, and mean fire size at the time of first attack, indicate that many fires had the opportunity to grow to unstoppable sizes and intensities, i.e. within the first 30 minutes after acceleration commenced (Luke and McArthur1979, Cheney 1981), before first attack forces arrived. The hypothesis that response times of 30 minutes to 1 hour could have influenced first attack outcome could not be tested, as these appeared to be unobtainable with available response systems and resources.

Suppression Effort

No suppression effort variable was significant to first attack outcome in the presence of the other variables studied. The differences in effort levels in relation to first attack outcome were not sufficient to conclude that a significantly larger effort level could make the difference between first attack failure and first attack success.

In the case of some Category 3 fires, it is unlikely increased effort levels would have made much difference given the fuel hazard and weather (particularly wind strength) conditions which prevailed at the time, *unless these increased resources could have been deployed to the fireline much quicker.* As already outlined Loane and Gould (1985) suggest that a fireline intensity of 3000 kW/m is about the upper limit for any sort of direct suppression action to succeed, and Buckley (1994) suggests that 2000 kW/m may be the upper limit for direct suppression where substantial elevated fuels are present. Some First Attack Failure fires had fireline intensities well in excess of this within the first 30-60 minutes and therefore it is unlikely that even very large amounts of suppression forces would have been able to contain the headfire. Therefore suppression would only have been possible in the first 15 to 30 minutes after ignition.

Comments were made by fire controllers that getting a larger machine, such as a D6 (130 kW), to the fire quickly allowed for much faster line construction rates than would normally be possible with the D3/D4-sized first attack machine, and consequently crews were able to achieve either first attack or extended first attack success. This was particularly the case where heavy fuels and steeper topography made the task more difficult for the smaller machines.

Aircraft

Aircraft did not play a significant role in the cases where first attack failed, with aircraft only being involved in the first attack effort for 2 out of the 15 Category 3 fires. The principal reasons for this mostly relate to the lack of availability of aircraft at the time of year when most Category 3 fires occurred. Table 4 shows that 12 out of the 15 Category 3 fires occurred outside the Requirement 1 contract period for firebombing aircraft, as compared with only 4 of the 26 Category 1 (First Attack Success) fires occurring outside this Requirement 1 period.

CONCLUSIONS

Overall First Attack Performance

DNRE successfully stopped 99% of all wildfires at the first attack stage in the period 1991/92 to 1994/95. This very high success rate is as good that reported by any other fire-fighting agency in the world. In the 6 instances where first attack efforts did not succeed during the 1994/95 season, the campaign fires which ensued accounted for 70% of the total area burnt, and 35% of the total expenditure on fire suppression for that season. The principal contributors to these few instances where first attack efforts did not succeed were :

weather (wind esp.), fuel hazard and seasonality.

Model for Prediction of First Attack Success using Overall Fuel Hazard and FDI

Statistical analysis of 50 fires in the "borderline area" of first attack success and failure allowed the construction of a model for the prediction of the probability of first attack success using Overall Fuel Hazard (Wilson 1993, McCarthy *et al.* 1998) and Forest Fire Danger Index, FDI (McArthur 1975). This model can allow fire managers to set Overall Fuel Hazard levels in Fuel Management Zones which will give specific probabilities of first attack success.

Overall and Component Fuel Hazard

First attack efforts are less likely to be successful when the Overall Fuel Hazard rating for a site is in the ***Very High*** to ***Extreme*** range, with first attack failure being possible at FDIs as low as 3 on an ***Extreme*** site. At FDIs above 25, the probablity of first attack success diminishes to less than 50% on an ***Extreme*** site, thus significantly increasing the chance of first attack efforts failing. The principal contributors to ***Very High*** and ***Extreme*** Overall Fuel Hazards (where first attack efforts were unsuccessful) were *Elevated* and *Bark* fuels. *Elevated* and *Bark* fuel hazards can be significantly reduced by appropriate prescribed burning for up to ten years (Tolhurst 1992).

Weather and Fire Behaviour - "Watchouts" for first attack

There is a **significant effect of wind on rate of spread** and hence first attack outcome, with first attack failure being more likely when wind speeds average more than 20 kilometres per hour in combination with an FDI exceeding 22. First attack efforts are more likely to fail when forward rates of spread are 600 metres/hour or greater and spotting distances are 50 metres or greater.

Seasonality

A majority of the few instances where first attack did not succeed occurred on the "shoulders" of the fire season - as opposed to at its height - and included a number of instances where prescribed burns escaped into adjoining unburnt fuels. Contributing factors to this were, firstly, from the data analysis:

- Spring and Autumn weather extremes;
- Very High to Extreme Overall Fuel Hazards in adjacent fuels;
- Lack of aircraft resources for first attack -the majority of the instances where first attack did not succeed were outside of aircraft contract periods.

and secondly, from both the data analysis and the anecdotal information collected:

- Insufficient resources, often due to large prescribed burn programs, to contain prescribed burn escapes at suddenly-increased FDIs;
- Multiple ignition sources including burning on adjacent private land, deliberate malicious lighting, and already-lit prescribed burns;
- Lack of activated duty officer/detection systems;

Fire Intensities

The mean fire intensities generally confirm the propositions of Burrows (1984), Loane and Gould (1985) and Buckley (1994) in relation to the level of fire intensity for which both direct and indirect attack will succeed, with the range 2000 - 3000 kW/m being the intensity around which direct attack begins to fail and indirect methods are required. Intensities in the range 3000 - 11000 kW/m appear to create significant control problems by any method.

Response Time/Perimeter

Response times did not have a statistically significant influence on first attack outcome in this study. However average response times and rates of spread for Category 3 fires (where first attack efforts did not succeeed) were such that crews were often faced with large fire perimeters (1 to 4.4 km. on average) at the time of arrival. Such perimeters were often significantly greater than the line construction rate capability of available machinery within the first hour after arrival. Reduced response times in this situation are desirable but it may not be cost effective to be able to achieve them. First attack success fires had an initial mean fire size of less than 10 hectares, and this contributed to manageable perimeter lengths. The hypothesis that response times between 30 minutes and one hour (with more than the normal first attack resources) could have influenced first attack outcome could not be tested.

Topography

Northerly and westerly aspects were more common in conjunction with occurrence of all 50 fires studied, but aspect did not appear to significantly influence first attack outcome. Slope did not appear to have any significant influence on first attack outcome for the fires studied.

Suppression Effort

Effort levels did not appear to have a significant effect on first attack outcome in this study. Mean Effort levels were sufficient to restrict the average final fire size to less than 10 ha for Category 1 (First Attack Success) fires, and 150 ha for Category 2 (Extended First Attack Success) fires . Effort levels could not prevent first attack failure at some Category 3 fires, although failure was due to a combination of factors including weather, fuel hazard, response time and effort.

First Attack Successes under Adverse Conditions

Some first attack successes were made despite adverse weather. This was particularly the case where response times were low, fuel hazards for bark and elevated fuels were only ***Low*** to ***Moderate***, resources were sufficient and crew commitment levels were high.