Paper 6B

HOUSE LOSS RATE IN A SEVERE BUSHFIRE
Part 2 Duffy bushfire attack category
The influence of distance from ember source

Abstract

This study re-examines the bank of knowledge about the correlation between distance from ember source and house loss rate in a severe bushfire attack. It limits itself to the "Duffy bushfire category", which attacks by embers only, the moving flame having been stopped at a flame free barrier.

The study seeks to correct a misunderstanding that house loss rate is correlated with distance from vegetation. It finds that evidence given to the Royal Commission has perpetuated this misunderstanding and government policy has been based on it. It shows that regulations based on the vegetation myth have proven to be ineffective on Black Saturday. It provides a vegetation guilt test to be proven before vegetation per se can be convicted of fault.

The study finds good support for the theory that house loss rate declines as distance from ember source increases, and presents three equations that may prove to be useful in explanation, diagnosis or prediction. The study also finds good support for the sub theory that ember intensity reduces with distance from ember source and circumstantial support for the sub theory that chance of ignition of a house is correlated with ember intensity.

This study also asks - what new information did the 2009 Black Saturday fires reveal that requires pre 2009 knowledge to be revised? The answer is little new information was added by the Royal Commission and its associated studies, and that no findings disprove prior knowledge.

This is a companion to Paper 6A: **House loss rate in a severe bushfire**
Part 1 Ash Wednesday bushfire attack category
- The influence of house occupation rate

INTRODUCTION

This is the second part of a study that reviews pre 2009 knowledge about the influence of ember source on house loss rate against new information added by the Royal Commission and its associated studies. It asks - what new information did the 2009 Black Saturday fires reveal that requires pre 2009 knowledge to be revised? The first part of the study reviews pre and post 2009 knowledge about the influence of house occupation rate on house loss rate (Paper 6A).

Ahern and Chladil's paper in 1999 documented a dubious finding that vegetation proximity was the cause of house loss. Fire authorities have since accepted this belief as fact. For example, the regulatory environment for new houses in Victoria - BMO (Bushfire Management Overlay) and its predecessor WMO (Wildfire Management Overlay), Australian Standard AS3959 and mapped Bushfire Prone areas. Both the WMO and AS3959 calculations applied to vegetation within 100m of the house site. They both assume the forest and shrub vegetation within 100m of the proposed house site is the only source of damage by radiation, flame contact and embers. WMO creators believed setbacks protect dwelling from wildfire's ember attack zone (Buxton et al 2009). The WMO was recently replaced by BMO, and its calculations (Table 1 Clause 52.47, Victorian Planning Scheme) do not apply to vegetation beyond 113m. Presumably, government believes these regulations will reduce house loss rate. This paper points out that if vegetation proximity is not the cause of house loss, the Regulations can have no ameliorating effect, and the real culprit remains diagnosed and untreated.

This study seeks to re-identify and reinstate the real culprit in house loss, which is ember attack, and to encourage researchers and governments to avoid false accusations against vegetation per se so that regulations target the real causes of house loss.

THEORY

The errant theory

This theory is also addressed in Paper 3B.

A belief has existed for several years that house loss is inversely correlated with distance to vegetation. It was first documented by Ahern and Chladil (1999) and has been perpetuated since. It relies on their stated belief that the closest shrub and tree vegetation is the ember source. Their concept is as follows: The major cause of house loss is embers. Shrubs and trees are the source of embers. Therefore, closeness to vegetation increases house loss rate. Despite the flawed logic of this argument, their concept has been accepted by authorities, and now vegetation (ie, shrub and tree) is regarded as a causal agent.

The Royal Commission believed it was using it to recommended policy. It published this quote - "a 1999 study by Ahern and Chladil (1999) found that **85 per cent of houses were destroyed** within 100 metres of vegetation", and it therefore urged a greater separation gap – "something beyond 100 metres would be a more conservative choice from the perspective of safety" (VBRC, 2010). But the VBRC advisers failed to identify this as a misquote. The Ahern and Chladil study found that **85% of burnt houses** were within 100m of vegetation. But **85% of burnt houses** has a very different meaning to **85 per cent of houses were burnt.**

The Ahern and Chladil chart is reproduced in Figure 1. It is a cumulative chart. It simply means that as distance from burnt vegetation increases, more and more burnt houses are counted. Figure 1 clearly shows that 85% of burnt houses were within 100m of vegetation but it also shows that 20% of burnt houses were within 10m of vegetation. If the same Royal Commission misquote is applied to this finding, it would read - **20% of houses are destroyed within 10m of vegetation**. Using the same logic, the Royal Commission could then have said that a 20% loss rate is more acceptable than 85%, therefore it is better to build closer to vegetation. It is unfortunate when Government policy relies on a misquote.

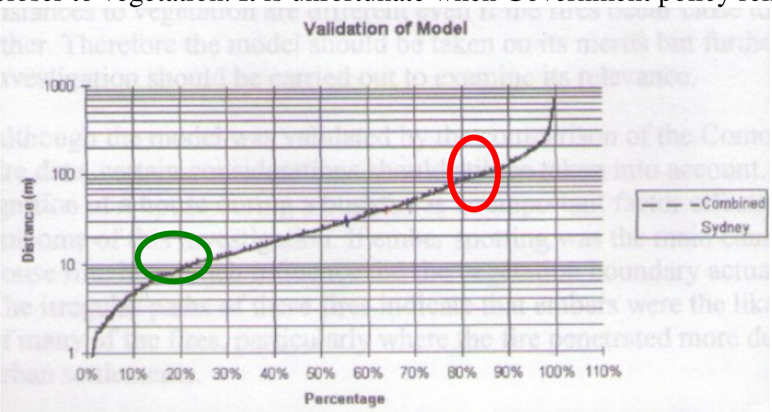


Figure 1 Reproduction of the Ahern and Chladil cumulative loss chart
Red circle shows 85% of burnt houses were within 100m of vegetation
Green circle shows 20% of burnt houses were within 10m of vegetation
Note: This chart is unusual because the dependent variable is on the x-axis is "% burnt houses". Distance to vegetation should be on the x-axis because it is the independent variable.

Sadly, not only did the Ahern and Chladil study not make this finding, but also their study failed establish any evidence that distance to vegetation was a significant causal factor in house loss. Consider these points:
- The Ahern and Chladil study counted all the burnt houses and measured distance from each house to nearest vegetation to the NW. There were also unburnt houses, but they did not count them nor measure their distances to vegetation. This is critical missing evidence and proves the study should never be quoted as a valid reference for house loss ratio or for proximity to vegetation as a causal factor. This means they were unable to exclude vegetation proximity as a coincidental factor, ie, an innocent bystander. Were 85% of burnt houses within 100m of vegetation because 85% of all houses were within 100m of vegetation?
- The Ahern and Chladil study does not identify the causes of house loss, ie, radiation, flame contact and ember attack, nor link them to the presence of vegetation.
- Their study defined vegetation as trees and shrubs. Why trees and shrubs? "The primary source of ignition of many houses in Hobart and Otway ranges is likely to have been from air-borne embers. Grassland burns intensely in bushfires but does not produce much flying debris, which would cause a house fire. Therefore trees and shrubs are more likely to have been the source of ignition." Moreover, they sought no evidence to identify if the embers that ignited the houses came from closest vegetation or from further away.

In conclusion, the Ahern and Chladil concept has neither scientific validity nor veracity. The Ahern and Chladil study should be perhaps be classified as dilettante, and the subsequent maligning of vegetation by authorities be revisited, and force research studies to seek the real causes of house loss. To counter the maligning of vegetation, this study proposes the following vegetation guilt test:
A given plant or patch of vegetation is guilty of house loss if and only if, it passes four proofs:

- It can ignite and burn
- When burning, its radiation, or flame contact
- When burning, its embers are upwind of the nominated house
- The resulting spot fire continues to burn unchecked until the house burns down
- No other causal agent ignited the house.

Evidence for the correlation between house loss and distance to vegetation

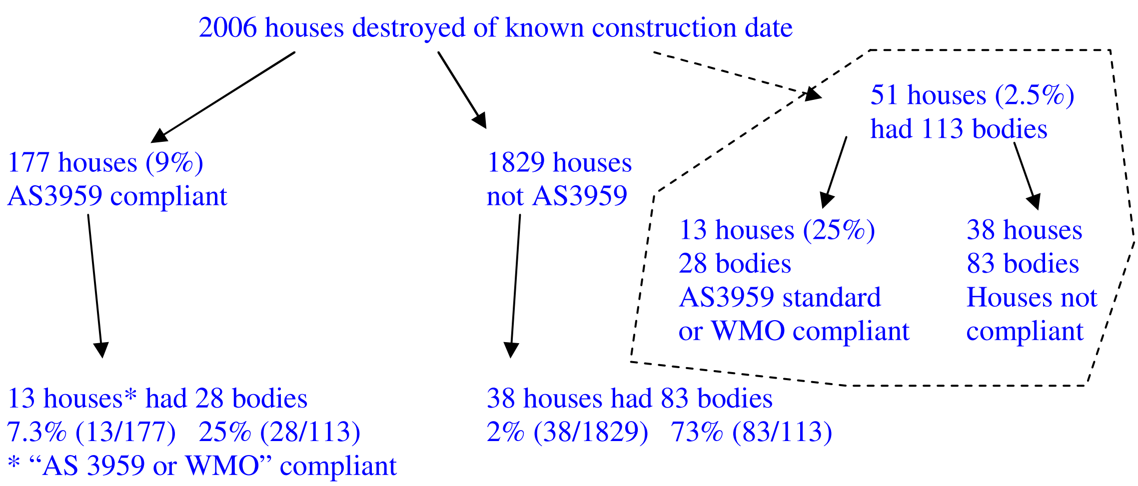
If vegetation proximity was a cause of house loss, there should be evidence of its effectiveness in the government's tools for house protection, the WMO and AS3959. The Royal Commission asked for evidence that the WMO and AS3959 reduced house loss, and was told there was none (VBRC, 2010). However, other evidence was presented that indicated very clearly that neither had any impact on saving houses or lives:

Saving houses:
Influence of WMO compliance: Marysville town data (provided by the Shire) showed the total house loss rate was 90%, and the house loss rate for constructed houses with WMO approval was 85%. This suggests WMO compliance gave no significant extra protection.

Using CFA figures, a report by Holland et al (2009) CFA.600.003.0001 suggested that WMO compliance reduced house loss to one third. They found that only six WMO compliant houses were destroyed in the Black Saturday fires. We can only suggest their figures and findings are inaccurate when compared with references given to and by the Royal Commission, because they alone add up to more than six destroyed WMO houses. For example, "The Commission heard that 24 houses that were destroyed by fire on 7 February had been built in Marysville, Pine Ridge Road and Grandview Crescent after the introduction of the WMO in 2004." Furthermore, Shire data for Marysville showed that 26 dwellings were built with WMO permits, and 22 of them were destroyed and 4 were not destroyed.

Influence of AS3959 compliance: Building Commission figures found that 2006 destroyed houses had known construction dates. After removing unknowns, they found 177 destroyed houses were built under AS3959. Thus, 9% of destroyed houses were AS3959 compliant. We estimate from Buxton et al (2009) and (Leonard et al, 2009) that, of total houses exposed to the fires, the likely proportion of AS3959 compliant houses was 8 – 12%. This suggests that AS3959 compliance made no significant difference to house loss rate.

Saving lives:
Influence of AS3959 compliance:
Building Commission provided the following data:
113 bodies were found in 51 houses, 7 bodies were in sheds or garages.
83 bodies were in 38 houses that were neither AS3959 nor WMO compliant
28 bodies were in 13 houses that were either AS3959 or WMO compliant
Note: Building Commission used the joint term "AS3959 or WMO compliant" in their report, but in reality, very few houses were WMO compliant.



Of destroyed houses with known construction date, 2.5% had dead bodies inside
Of destroyed houses built to AS3959 or WMO compliance, 7.3% had bodies inside.
(Comment: If AS3959 or WMO was effective, the percentage would be much less, not **triple** the rate.)
In addition, AS3959 compliant houses averaged just over two bodies per house, which is very close to non AS3959 houses. Again, AS3959 provides no evidence of improvement in protection level.

AS3959 seems to have serious self doubts. Despite the fact that AS3959 assumes nearby vegetation is unmanaged (and therefore generates maximum flame height), despite the fact that AS3959 uses worst case fire behaviour data in its fire behaviour equations, and despite the fact that AS3959 does calculations for worst case weather conditions, AS3959-2009includes this extraordinary disclaimer: "It should be borne in mind that the measures contained in this Standard cannot guarantee that a building will survive a bushfire event on every occasion. This is substantially due to the degree of vegetation management, the unpredictable nature and behaviour of fire, and extreme weather conditions."

In summary, WMO and AS3959 rely wholly on distance to vegetation for the effectiveness of their fortification specifications. But the above data provides no evidence of an effective house saving strategy. We suggest they have blamed the wrong culprit. Similar to the wrongly accused murderer, if he is not the perpetrator, the real killer is still free.

Specific surveys regarding proximity to vegetation and house loss

Ahern and Chladil (1999) painted proximity of vegetation as the cause of house loss rate. They said the major cause of house loss was embers and that shrubs and trees were the source of embers. Therefore, closeness to vegetation increases house loss.

Researchers continued this theme when they advised the Bushfire Royal Commission the survey results (see Section 7.5) "show a clear correlation between house loss and proximity to trees and bushes" (Leonard et al, 2009). The following analysis shows that this finding totally misrepresents the results and proves only that proximity to vegetation is an innocent bystander. Their findings fail the vegetation guilt test.

Influence of vegetation proximity:
Vegetation was defined in the survey as overhanging trees (some or many), adjacent trees and adjacent bushes.
"The influence of trees close to the house is strongly expressed in Table 33, with a strong correlation between houses with overhanging or adjacent trees and house loss. To a lesser extent, bushes immediately adjacent to houses correlated well with observed house loss."
Their leading evidence said:
Of 756 surveyed houses, 63% were destroyed. Of 540 houses with bushes or trees adjacent to house, 67% (363) were destroyed. Of the 197 houses with no bushes or trees adjacent to house, 48% (95) were destroyed (Leonard et al, 2009).

A closer look shows that their research does not specify if the vegetation was burnt. It simply notes presence or absence of vegetation. The survey asked two independent questions per house – what are the adjacent vegetation types and what is the level of house damage. This means the adjacent vegetation type is not linked in any way to the house loss or the cause of the loss.

Furthermore, the survey questions do not ask if vegetation proximity was a cause of house loss. Therefore, at best they have found a coincidental correlation, ie, that most houses have vegetation close by. This can be demonstrated with data from their Table 33.
Of all 756 surveyed houses, 71% have trees and bushes close to the house.
Of 476 destroyed houses, 76% have trees and bushes close to the house.
Of 136 damaged houses, 71% have trees and bushes close to the house.
Of 144 untouched houses, 56% have trees and bushes close to the house.

The logic is as follows. In round figures, if 3/4 of houses have vegetation close to the house, and if vegetation proximity has no causal impact on damage, 3/4 of damaged houses will also have vegetation close to the house. They could have surveyed the colour of gutters and found a similar correlation. If ¾ of all houses have green gutters and if gutters have no causal impact on damage, ¾ of damaged houses will also have green gutters.

Thus, they really discovered that approx 2/3 of destroyed houses had bushes or trees close to the house because approx 2/3 of all houses had bushes or trees close to the house. This does not pass the vegetation guilt test.

Influence of combustible material
"Table 35 indicates a possible correlation between house loss potential and proximity to combustible ground cover" (Leonard et al, 2009).
Combustible cover is defined as grasslands, garden mulch, bark, short heath, tall heath. However, their reported finding is misleading like the previous finding. It does not identify combustible fuel proximity as a cause of house loss, nor do they specify if the combustible fuel was burnt.
The researchers' data reveals that of all 364 surveyed houses, 87% have combustibles close to the house. But, they also found that:
Of 219 destroyed houses, 89% have combustibles close to the house.
Of 219 damaged houses, 85% have combustibles close to the house.
Of 63 untouched houses, 82% have combustibles close to the house.

Again, they have found a coincidental correlation, ie, that most destroyed houses had combustible cover close to the house because most houses had combustible cover close to the house. Again, this does not pass the vegetation guilt test.

Presence of trees
The researchers said the results show the distance to tree or trees appears to be a good indicator of likelihood of damage to a house but not the degree of damage (Leonard et al, 2009).. But again, their research does not support this conclusion.

Forest was defined as any vegetation detected by remote sensing more than 8m above ground. It could be one tree or a forest. The survey measured presence only, not noting if the tree was burnt or not, if the bark was flammable or non flammable, or if the forest had dense undergrowth or short grass. This means the survey has no relevance to flame behaviour. Furthermore, they measured the distance from the house to the closest forest or tree, regardless of its direction from the structure. Yet it is well accepted that in a severe bushfire attack, direction is critical.

They sampled 588 residential properties in the Murrindindi West region, of which 451 (76%) sustained some form of fire damage, 149 houses in East Murrindindi where 145 or 97% were damaged, and 95 at Pine Ridge Road where 77 were damaged, a loss of 81%. This means almost all the houses they surveyed were damaged in some way.

These results are gleaned from Tables in Section 7.9:

For all 588 surveyed houses, the average distance to a tree or forest is 21.1m
For the 137 untouched houses, the average distance to a tree or forest is 30.3m
For 61 superficial damaged houses, the average distance to a tree or forest is 23.9m
For 29 damaged houses, the average distance to a tree or forest is 15.4m
For 361 destroyed houses, the average distance to a tree or forest is 17.6m
These results do not support a causal correlation between proximity to tree and house loss.

The researchers said the closer a tree or forest is to a house, the greater chance of some form of damage. How close? Their table says the minimum distance from a tree or forest to a damaged house is 6.7m and to a destroyed house is 7.3m. The minimum distance from a tree or forest to an untouched house is 12.8m.
Is the tree or trees to blame for the damage to the house? The researchers have not established this.
What causal element (radiant heat, flame contact or ember attack) is indicated by the proximity to tree or trees? The researchers have not established this.

Again, they have found nothing more than a coincidental correlation, ie, that most damaged houses had tree cover close to the house because most houses had tree cover close to the house. Again, this does not pass the vegetation guilt test.

Thus, although vegetation type, combustible material and trees continue to be widely regarded as a risk factor, this research does not provide any supporting evidence that they were a cause of house loss. This lack of integrity in reporting to a Royal Commission is troublesome because it adds nothing to the bank of knowledge and it perpetuates a myth.

It of concern that the authorities blame the closest vegetation, particularly forest or trees, as the source of embers, but it is more concerning they omit attention to simple but well known fire behaviour facts (eg, Luke and McArthur, 1978) as follows:

- The actual condition of the forest is not identified, yet flame height and ember production from a given site is very individual, very site specific.
- The condition of the forest is assumed to be the highest fuel load on record, yet it has been long known that the forest can be treated to reduce flame height and ember production.
- The source of the embers is assumed to be the closest forest, yet it has long been known (eg, Luke and McArthur, 1978), that three types of ember cohort can be identified, short distance (up to 0.5 – 1km), medium distance (1 – 10 km) and long distance (> 10 km).
- The direction of the vegetation from the house site is disregarded, yet it has been long known that embers travel downwind only.

The correct theory

A more meaningful and accurate causal theory is now stated as follows:
House loss rate is inversely correlated with distance from upwind ember source.

This theory relies on two sub-theories:
Ember intensity reduces with distance from upwind ember source
Chance of ignition of a house is correlated with ember intensity

This is the implicit theory underlying the work of researchers where they attempt to show that house loss rate rises with proximity to vegetation. It adds the following rigour to the analysis:

It requires the ember source to be identified, and clearly, vegetation that cannot generate embers should be excluded.
It requires evidence that supply or intensity of ember attack increases as separation distance reduces.
It requires evidence that ignition is more likely if an area is more heavily bombarded by embers, or conversely, and less likely at lower ember intensity. Whilst this may be appear a reasonable expectation, it does not exclude the possibility that the source is one rogue ember from the medium distance cohort or that there may be a specific ember intensity at which house loss rate peaks, and that additional ember intensity has no further impact.

METHOD

This study re-examines a collection of pre-2009 data about house loss rate in several recent severe bushfires where embers are the cause of house loss. It compares it with data from Royal Commission sources about Black Saturday. Data is standardised to enable comparisons and analysis. Care is taken to verify ember sources before analyses are done.

This Paper deals with the "Duffy bushfire category" and a companion study deals with the "Ash Wednesday bushfire category" (Paper 6A).

Pre 2009 data and the Black Saturday data is screened by bushfire attack category. The author agrees with the Chen and McAneney (2004) distinction of two different bushfire attack types, one where homes and bushland were intermixed (as the Ash Wednesday fires were) and one where bushland was separated from houses by a distinct distance (as the Duffy fire was). Two categories of bushfire attack are defined as follows:

The first category (called the Ash Wednesday bushfire attack category) features a moving flame that runs largely unrestricted through continuous fuel bed (eg, extensive areas of forested rural, semi rural and residential land) and any house in its path is exposed to full scale attack by moving flame and associated short distance embers.

The second category (called the Duffy bushfire attack category) sees the moving flame stop at the boundary of a residential area and short distance embers thrown downwind into it. Upwind of the firebreak, the continuous fuel bed allows running flame to occur, whereas downwind of the firebreak the highly discontinuous fuel bed in the residential area allows only stationary flames to occur. Thus, the Duffy bushfire attack is an ember attack which generates stationary flames in flammable fuel beds.

The Duffy study area has the following similarities with Paper 6A to enable reasonable comparisons.

- All areas that were hit by a severe bushfire at the peak of its severity
- All areas had substantial urban residential areas and featured substantial house losses.
- Surveys of survivors were conducted in all areas.
- All days were similar - very hot (40^0C or more), very dry (RH 10% or less) and very strong winds (40 kph or more).
- All areas were examined by the author, either during the bushfire attack or soon after.

In addition, the author has closely inspected unedited video footage of the bushfire attack, taken by a professional cameraman.

This analysis is supplemented with data from a severe bushfire in native forest vegetation, the Como Jannali fire, Sydney suburbs 1994.

RESULTS

Pre 2009 studies - Duffy surveys

A number of surveys in the Duffy area were reported after the Canberra fires. The results are of interest because the firebreak gap that bordered Duffy ensured that houses were protected from the advancing flame and its radiation, which meant the houses were attacked by embers only (Chen and McAneney, 2004).

Duffy Survey 1

Blanchi et al, (2004) reported a survey of over 229 houses at Duffy (Fig 2) in the area with most damage. Summary house fate findings were 47% destroyed, 18% untouched, 26% superficial damage, 9% light damage, ie, houses destroyed 47% and houses survived 53%.

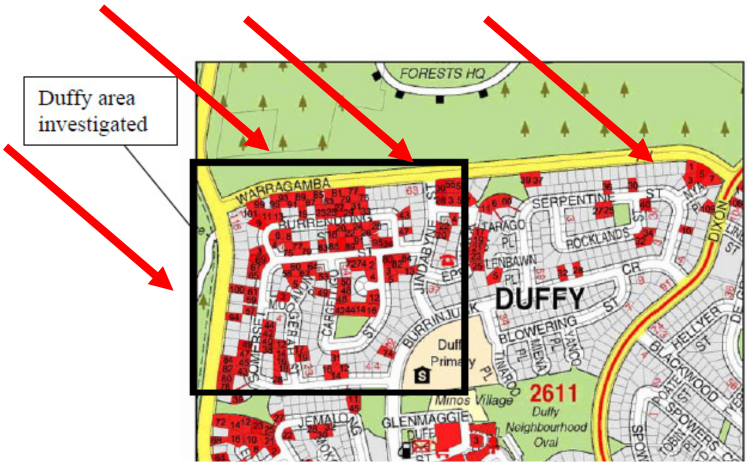


Figure 2 this part of Duffy was investigated by Blanchi et al (2004)
Red arrows show approx direction and approximate location of fire fronts attacks observed by author on video footage.

Blanchi and Leonard (2008) re-presented some fire suppression data - during and after the fire attack (Fig 3). Table 1 shows data extracted from Fig 3.

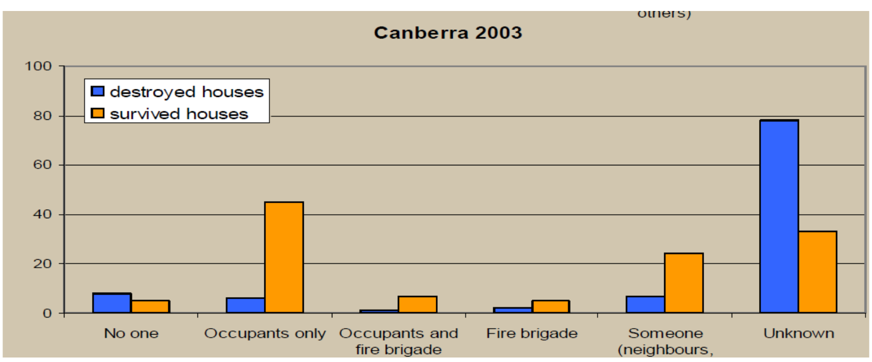


Figure 3 Duffy data reworked by Blanchi and Leonard (2008)

These houses extend from very close to a few hundred metres from the plantation fire fronts. Table 1 has a very large number of unknowns. The known data shows that the house loss rate for vacant, undefended houses is 64%, which is close to the averages found in the Part 1 study. The survival rate for defended houses is 14% (= 10+5 / 45+49)

Table 1 House loss rate Duffy, human activity during and after bushfire attack

	Houses destroyed		Houses survived	Total	
House vacant, undefended	7	(64% of 11)	4	11	(10% of 105)
House vacant, but defended by someone eg, neighbours, fire brigade	10	(22% of 45)	35	45	
House occupied and defended by occupants	5	(10 % of 49)	44	49	
Sub total	**22**	**(21% of 104)**	**83**	**105**	
Unknown	78		34	112	
Total	**100**	**46%**	**117**	**217**	

Duffy Survey 2

Blanchi et al (2004) reported results for the first two rows of houses closest to the pine plantation. The findings are presented in Table 2.

Table 2 Fate of 76 houses Canberra fires, 2003, Duffy area within first 2 rows of houses, based on house occupation

	Houses destroyed		Houses survived		Total	
Houses vacant	12	(60% of 20)	8		20	(41% of 49)
Houses occupied	4	(14% of 29)	25		29	(59% of 49)
Sub total houses	16	(32% of 49)	33		**49**	
unknown	25		2		27	
Total houses	41	(54% of 76)	35	(46%)	**76**	

These houses are closest to the pine plantation fire fronts. The known data shows that the house loss rate for vacant, undefended houses is 60%, which again is close to the averages found in the Part 1 study. In the Part 1 study, the houses were engulfed by the running flame and associated embers.

Table 3 now combines known data from the above studies. By ignoring the unknowns, the implicit assumption is that the unknown data can be distributed in proportion to known data.

Table 3 Tables 1 and 2 combined

Probability of destruction for:			**D1 Duffy Table 1**	**D2 Duffy Table 2**
All houses within sample			46%	54%
Vacant and undefended houses within sample			64%	60%
Occupied and defended houses within sample			10%	14%

Table 3 shows the loss rate of vacant undefended houses is between 60 and 64%. It also shows the loss rate for occupied and defended houses is between 10 and 14%. These figures are very similar to the findings in Part 1.

Duffy Survey 3

Chen and McAneney (2004) examined an area of Duffy within which 206 houses were destroyed. They later published the location of this area (Chen and McAneney, 2010), now shown in Fig 4. Their sample size was approx 1200 houses. The house loss rate within this area is approx 16% (206/1200). They did not record house occupation figures.

To interpret their work, there is a need to reconcile distances and distinguish between their terminology - "% of houses destroyed" and "% of destroyed houses"

Distances Chen and McAneney (2004) related house loss to distance from the edge of the pine plantation. The author inspected the Duffy fire break within a few days of the bushfire and can confirm that the firebreak was short grass, 30 – 40m wide. The bitumen road added another 10m, which adds up to 40 - 50m separation between the plantation edge and the front boundary of houses. From a fire behaviour perspective, the implicit intention of a grassy firebreak is to reduce flame height and of a fuel free barrier is to prevent flame occurrence. The fuel free barrier is effective against a moving flame when it is wide enough to prevent flame rollover or stretch. Byram (1959) suggested 1.5 x flame length was adequate. Film footage during the bushfire attack shows the flame height in the plantation was up to 20 – 30m and on the grass was 20 - 30 cm. Therefore, the 10m fuel free break comfortably stopped the firebreak flame.

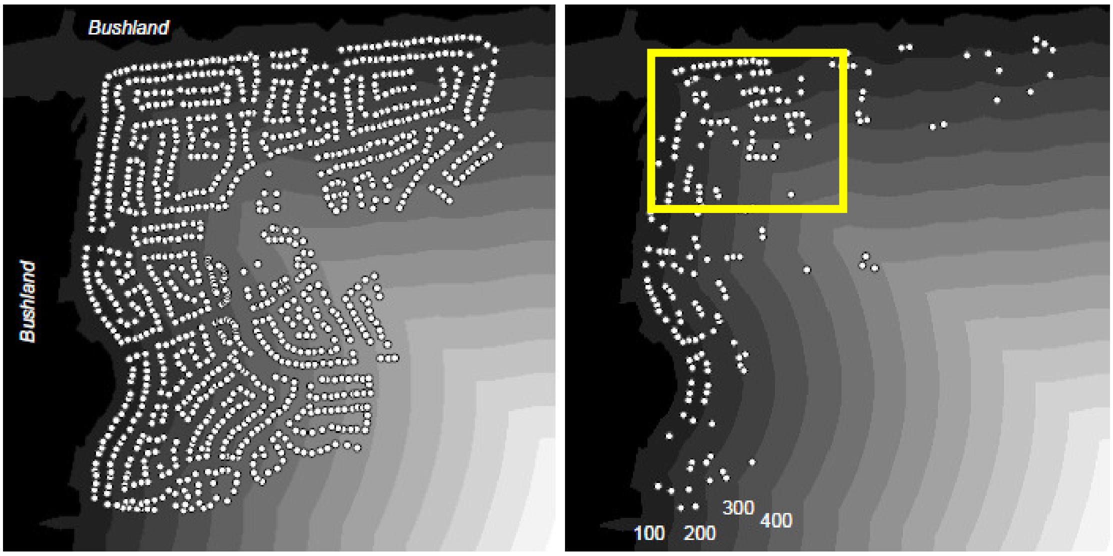


Figure 4
Left hand side Location of approx 1200 houses before the fire attack
Right hand side Location of 206 destroyed houses.
Yellow square corresponds with previous Duffy study area, shown in Fig 2.

Chen and McAneney (2004) plotted percentage of homes destroyed at different distance ranges (50m intervals), plotting house loss rate at the mid point, ie, for 0-50m interval, they plotted 58% house loss rate at 25m. Their chart is reproduced in Fig 5.

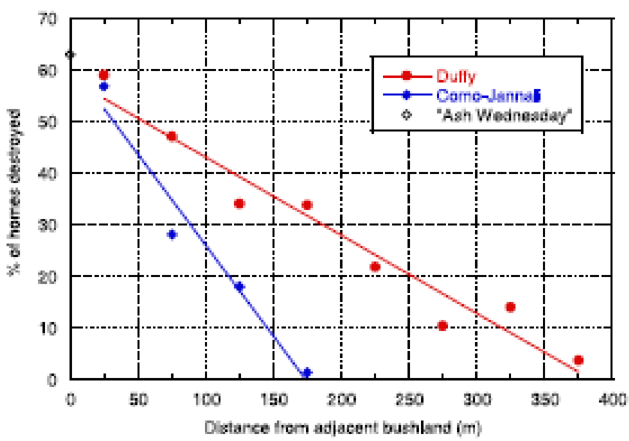


Figure 5 reproduction of Fig 2 in Chen and McAneney (2004)

Chen and McAneney (2004) said the closest house was 37 m to the edge of the pine plantation. This means the x axis points should be read with caution. For example, the 0-50m interval was plotted at 25m showing 58% house loss rate. They stated that "nearly 60% of all homes within the first 50 m were laid waste". The key question is this – what is the total house population of the sample? Numbers were not specified in their text, but they can be deduced (see below).

Terminology % of houses destroyed

Figure 5 is a copy of Fig 2 in Chen and McAneney (2004). It shows that 28% of houses were destroyed within 200m of the plantation edge.
But what is the total house population of the sample?
They have advised that a total of 206 were destroyed in their sample, therefore, 70% of 206 = 144 were destroyed within 200m.
If 28% of all houses = 144, therefore total number of houses within 200m of the pine plantation edge is 515.
"Percentage of houses destroyed" is the true house loss rate.

Terminology % of destroyed houses

Chen and McAneney (2004) present this data in the same format as Ahern and Chladil (1999) (reproduced in Figure 1). It shows that 70% of destroyed houses were within 200m of the pine plantation edge. It also shows that 10% of destroyed houses were within 50m of the pine plantation edge.
"Percentage of destroyed houses" is a cumulative figure which has little value to the resident and the fire protection planner.

The above two somewhat confusing percentiles are listed for comparison in Table 4, but important to understand them correctly because, as explained in the Theory section, they have been misquoted in the Royal Commission Report and used by government to make policy recommendations. The Table 4 figures are derived from Figs 1 and 2 in Chen and McAneney (2004). Their Fig 1 is cumulative % of destroyed houses over distance, ie, a percentage of 206. Their Fig 2 is the % of houses destroyed within distance intervals. These charts are now used to calculate numbers which are then reapplied to 100m intervals in Table 5 for display in Figure 6. House loss rate figures for distance intervals are much more relevant to the resident and the fire protection planner.

Table 4 Data derived from Figs 1 and 2 in Chen and McAneney (2004)

	Cumulative totals, counted from plantation		**Distance Interval data**			
Distance interval from plantation edge (m)	Cumulative % of destroyed houses	Cumulative No of houses destroyed	% of houses destroyed = house loss rate	No. of houses lost	Total houses	Cumulative total no. of houses by distance interval
0 - 50	10	21	58 (= 21/36)	21	36	36
50 - 100	35	72	47	52	110	146
100 - 150	55	113	37	41	111	257
150 - 200	70	144	37	31	84	341
200 - 250	85	175	21	31	147	488
250 - 300	90	185	10	10	103	591
300 - 350	96	198	13	12	95	686
350 - 400	98	202	3	8	275	961
400 - 670	100	206				

The reason for the 100m interval choice is as follows. The average house block size in Duffy was 24 x 35m (Chen and McAneney, 2010). Assuming houses are in rows, each house is approx 10m long and the roads are also 10m, it can be calculated that the 0-100m interval includes two rows of houses and each subsequent 100m also includes 2 rows. Standardising data to 100m intervals means house loss rates can be compared per double rows of houses.

Table 5 Data for each 100m interval from plantation

Distance from plantation edge	**Total no. of houses**	**No of houses destroyed**	**% of houses destroyed (= house loss rate)**
0-100	146	73	50
100-200	195	72	37
200-300	250	41	16
300-400	370	20	6

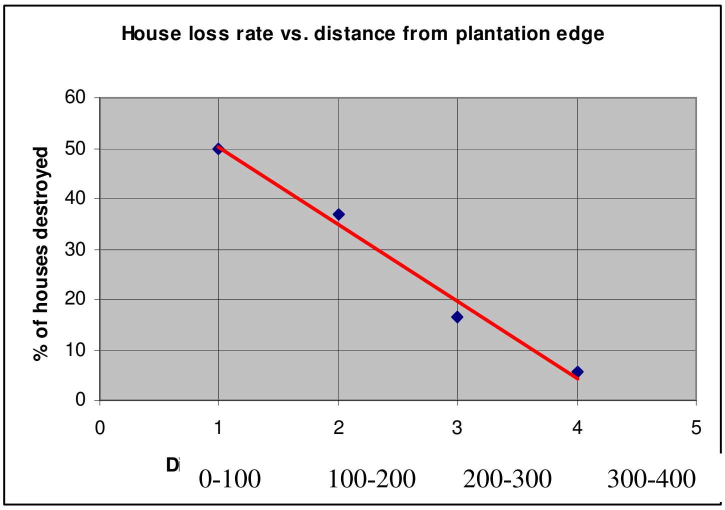


Figure 6 The source of this chart is Table 5

Fig 6 matches the linear chart of Chen and McAneney (2004) (see Fig 5). The formula is

House loss rate = 65 – 0.15 x Distance range … Equation 1

It shows the highest proportion of houses is destroyed closest to the pine plantation. If separation distance is zero, the house loss rate is 65%, which Chen and McAneney (2004) found corresponded with the house loss rate they found for Ash Wednesday fires – heavily wooded township areas - Fairhaven 71% (127 houses), Aireys Inlet 61% (98 houses), Macedon 57% (97 houses) , Mt Macedon 62% (122 houses), average 63%. They concluded that the house loss rate in the first 50m was remarkably stable.

This Paper accepts that the pine plantation is the source of the embers. Therefore, distance from pine plantation is synonymous with distance from closest ember source. Thus, figure 6 provides support for the theory that **house loss rate declines with distance from ember source**.

But this equation alone does not explain the variation seen in the two boxed areas of Figure 7. The box on the right hand side has approx 10% house loss rate, whereas the left box has approx 40% loss rate. Both areas were adjacent to a severe plantation fire. Film footage of the

Duffy fire attack examined by the author confirms that several narrow (eg, 50-100m) fire fronts hit the fire break at different times (see Figure 2).

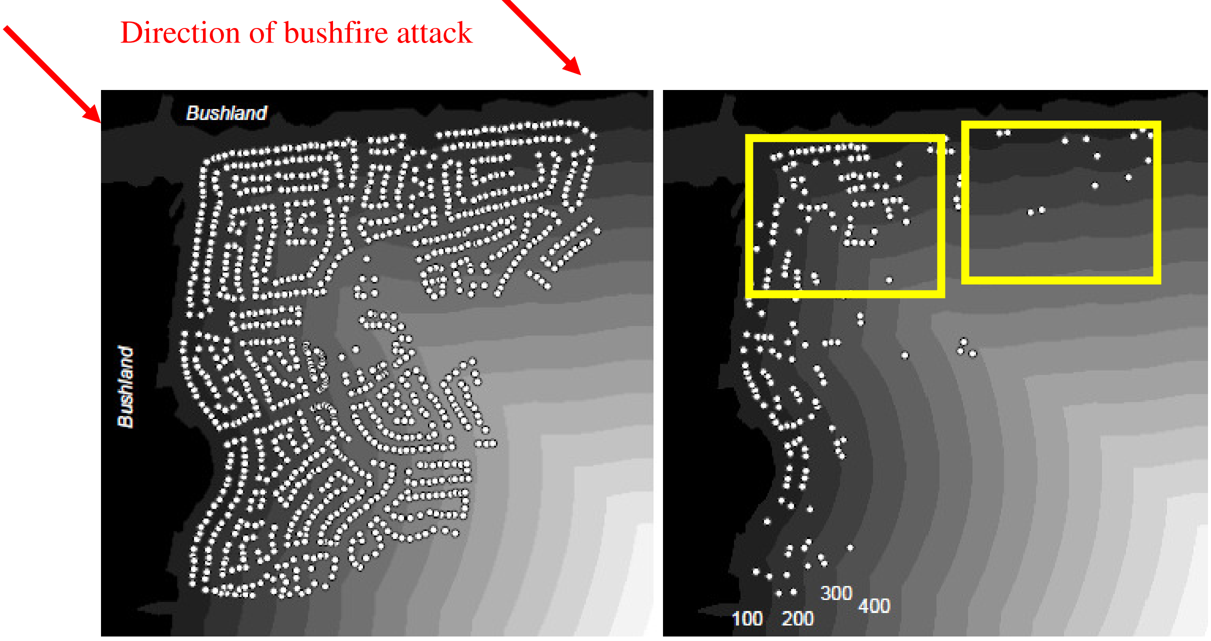


Figure 7 Distance ranges (interval 100 m) from adjacent pine plantation edge superimposed over home locations in Duffy.
Left: Pre-fire homes.
Right: Destroyed homes (206). House loss rate in left box is approx 40%, in right box is approx 10%.

Pre 2009 studies - Como Jannali fire, Sydney suburbs 1994

Chen and McAneney (2004) examined this fire. They noted that that FFDI was only 50, compared to the other fires where FFDI was around or over 100. Upwind embers ignited the Glen Bushland Reserve (see Fig 8) and strong winds from the west pushed the flames up the steep slopes toward the properties at the top of the hill, showering them with embers. The spot fires ran as moving flames up slope and emerged from the forest directly into many back yards, throwing embers as they progressed. There was no fuel free barrier. It can be assumed that some properties may have had sufficient fuel bed discontinuity by landscape design to stop the moving flame, but otherwise the flames stopped at the roads along the ridgeline, Woronora and Lincoln Crescents.

Figure 8 shows that between the bush reserve and two roads, an average distance of 80m (range 10 – 120m), 33 houses were destroyed and 31 survived. This is a house loss rate of 51%. This strip ranged from 0 – 75m from the forest edge, and was very steep. There was no fuel free barrier between houses and forest then as is still the case now.
Downwind of these roads for the next 100m were two rows of houses. Figure 8 shows that some 27 houses were destroyed and 80 survived, making a loss rate of 25%. This strip was an average 75 – 175 m from the forest edge.
The remaining 16 destroyed houses were 100 - 150m downwind of the next road, or 175 - 225 m from the forest edge. The house loss rate in this zone was less than 5%.

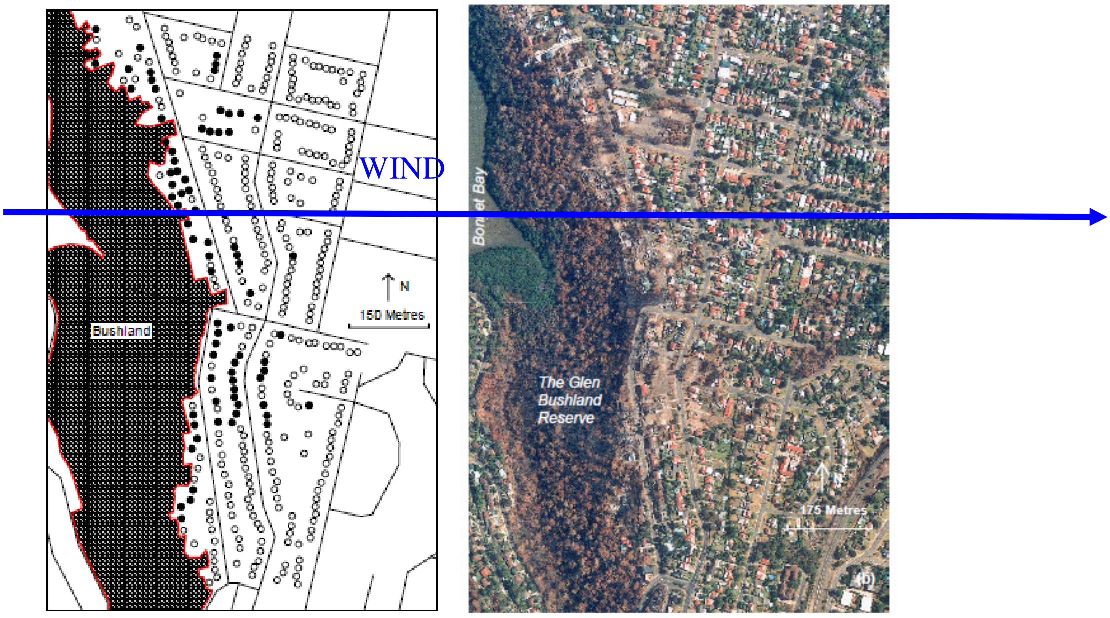


Figure 8 Como Jannali fire 1994 (from Chen and McAneney 2010)
Black dots are destroyed buildings Black circles are survived buildings
Burned vegetation (= tree cover) is shown in\\as dark grey.
Blue arrow shows direction of bushfire attack from W.
The black lines are the major roads.

Figure 5 confirms these figures, showing that 55% house loss rate occurred 0-50m from forest edge, 30% loss rate between 50 and100m and 10% between 100 and 150m.

Figure 5 generates this equation:
House loss rate = 60 – 0.3 x Distance … Equation 2

This study accepts that the eucalypt forest is the source of the embers. Therefore, distance from the bush reserve is synonymous with distance from closest ember source. Thus, Figure 5 provides support for the theory **that house loss rate declines with distance** from ember source

Specific Black Saturday fire areas

Kinglake township

Chen and McAneney (2010) surveyed the Kinglake area. They counted 616 destroyed buildings among a total of 1531, giving a 40% building loss rate. Part of their study area is shown in Figure 9. Pockets of variation in the building loss rate can be clearly seen. The red circle areas were examined in Paper 6A because they correspond to the "Ash Wednesday bushfire scenario" of simultaneous moving flame and ember attack. The residential area just north of the main road (blue circle on Fig 9) had a high building loss rate, approx 70%. This area technically corresponds with the "Duffy bushfire scenario" where moving flame stopped some distance from the houses. The blue ring residential area was more than 400m from the forest edge, which was the main source of embers during the SW wind change. The flame would have been low through the paddock and stopped at the wide main road. The residential area within green ring approximates 30% loss rate. It is more than 1.2 km from the forest edge in the SW, but Fig 9 shows that there is a partly wooded area between the two.

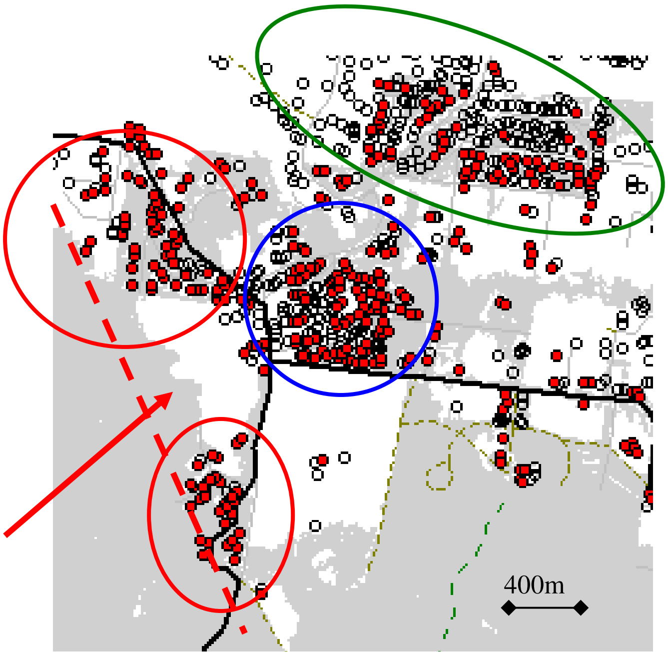


Figure 9 Kinglake township
Red dots are destroyed buildings Black circles are survived buildings
Tree cover is shown in grey.
Major ember source is west and downhill from dashed red line.
Red arrow shows direction of bushfire attack from SW.
The black lines are the major roads.
House loss rate in red rings is approx 90%, in blue ring is 70% and in green ring is 30%.

Marysville township

Chen and McAneney (2010) surveyed the broader Marysville area (Fig 12). They counted 644 buildings, of which 540 were destroyed and 104 survived. This is a loss rate of 84%. Figure 10 shows the Marysville house losses in more detail. The loss rate is 90%.

The Marysville residential area is well subdivided with roads, and technically corresponds with the "Duffy bushfire scenario" where moving flame cannot proceed through township area because of discontinuous fuel bed. The forest runs downhill to the edge of the residential area and probably contributed to ember volume, although the forested slopes west of the ridge line and further south west were probably the main sources of embers, driven by the SW wind.

This example appears to be a worst case example of "Duffy bushfire category". The forest flame was immediately adjacent to the residential area. Edge houses had an inadequate separation gap, and therefore risked huge radiation and flame contact. Interior houses experienced spot fires on their blocks (confirmed by evidence to VBRC, 2010) in the same way as Duffy, but the flames would have been unable to run very far because of fuel bed discontinuity. Proximity to untreated forest would have generated huge and prolonged ember intensity.

The narrowness of the town and the closeness to the forest also means that the expected reduction with distance from the forest's embers would not have been detectable.

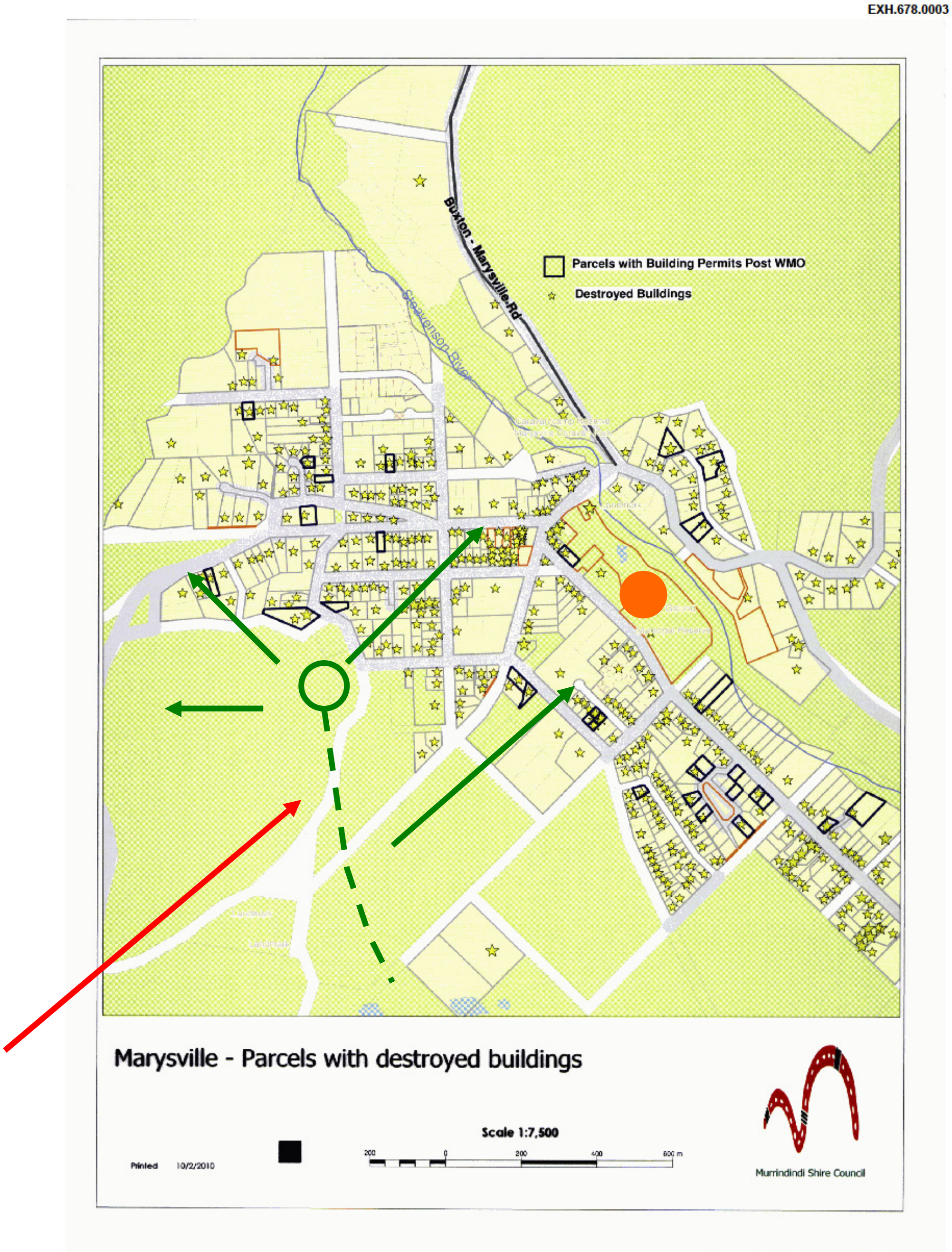


Figure 10 The town layout of Marysville, showing the destroyed houses.
Of 463 houses, 418 were destroyed. 90% house loss rate. (Figures and map provided by Murrindindi Shire to Royal Commission)
Red arrow is direction of bushfire attack (from SW)
Green circle is peak of steep hill, green dashed line is ridge line with steep slopes, green arrows are down slope directions
Orange dot is the sports ground where fire authorities and many residents evacuated to. They were showered with same ember intensity as the rest of the town.

DISCUSSION

The Duffy embers originated from a pine plantation, whereas most studies have been done on eucalypt forests. Pine plantation embers have long been known to have different characteristics, eg, pine plantation firebrands tend to be lower in quantity and shorter distance than eucalypt forests (Douglas 1964). Luke and McArthur (1978) said plantations spot up to 2km, eg, the Wandilo plantation fire, whereas, eucalypt forests can spot up to 20km of more. For this reason, the following analyses are separated by forest type.

Pine plantation fire - house loss rate

Similar to findings in Paper 6A, the overall house loss rate for a given fire varies according to size of sample, the type of sample. Eg, for the Duffy area, house loss rate for a 1200-house sample was 16%, for a 229 sample was 47% and for a sample of 76 in the two rows of houses closest to the pine plantation was 54%. Similar variations were reported above for Kinglake and Marysville, depending on the sample size and area.

These figures support the Theory 1 and 2 of Paper 6A.
Theory 1: ***House loss rate varies with house occupancy***
Theory 2 ***House loss rate for unoccupied houses is several times higher than occupied houses.***
The loss rate of vacant undefended Duffy houses is between 60 and 64% and for occupied and of defended houses is between 10 and 14% (Table 3). and in fact are very similar to the findings in Paper 6A for the "Ash Wednesday bushfire category".

Tables 1 and 2 suggest that of the "known" data, about half the houses were occupied, but Chen and McAneney (2004) noted that enforced home evacuation left most homes undefended, leading to high loss rates. They also quoted numerous studies that found suppression activity by residents during and immediately after fires is important in saving homes. The video footage examined by the author was shot along the roadways adjacent to the firebreaks. It indicated very low house occupancy by residents and insignificant defensive effort.

Equation 1 shows the highest rate of houses loss is closest to and downwind of the pine plantation and falls with distance from the edge. This supports the lead theory of this Paper:
House loss rate is inversely correlated with distance from upwind ember source.

If separation distance is zero, the house loss rate is 65%, which Chen and McAneney (2004) found corresponded with the house loss rate they found for "Ash Wednesday fires" – heavily wooded township areas - Fairhaven 71% (127 houses), Aireys Inlet 61% (98 houses), Macedon 57% (97 houses) , Mt Macedon 62% (122 houses), average 63%. They did not mention occupation rate of these houses.

Project Vesta research (2007) also found that ember density generally decreased exponentially downwind of the fire break. This provides good support for the ***sub theory that ember intensity declines with distance from upwind ember source***. Taken together, if ember intensity and house loss rate both decline with distance from firebreak (= ember source), a causal correlation between ember intensity and house loss rate seems very probable. It seems logical that for a given level of house defence, lower ember intensity results in less spot fires on the house, and therefore a lower house loss rate.

However, there are other variables to consider.

Ember intensity varies at given distance from ember source
Figure 7 shows a distinct difference in house loss rate at a given distance from ember source. Both areas are adjacent and downwind of the plantation, and the bushfire attacked both areas. The sub theory - ***Chance of ignition of a house is correlated with ember intensity -*** suggests one possible explanation. Ember intensity may have differed between the two areas. Project Vesta research (2007) showed that differences in ember intensity occurred at a given distance downwind of the fire break according to where the fire front hit it (ie, the fire front was the most intense flame, and the flanks were lower intensity). Ember density at a given distance downwind of the firebreak was higher at the fire front impact point and reduced as the flanks spread along the firebreak. Analysis of the video footage enabled the author to locate approximate points of impact of four separate fire fronts (See Figure 2), but unable to confirm whether the right hand box of Figure 7 was hit by a flank or a front.

Project Vesta research (2007) also found that for a given fire front, the plume oscillated between vertical or uplift phase and a strong lean or downdraft phase. The oscillations occurred on a 1 – 3 minute frequency as the fire front proceeded. When the plume was vertical, the flame was tall and vigorous with dense dark smoke and the rate of spread slowed. It was proposed that this phase generated longer distance spotting. When the plume was leaning over, the flame was shortest, ran fastest and generated maximum short distance spotting. When the plume in the updraft phase hit the firebreak, it usually collapsed and blew dense smoke and a concentrated shower of embers a short distance across the break. Occasionally, when the updraft phase hit the firebreak and the plume did not collapse, it was smokeless and ember attack was very low intensity. Thus, the oscillation of the plume structure provides a plausible explanation for variation in ember intensity at a given distance from the firebreak (= ember source). It is also plausible that lower ember intensity results in less spot fires at the house, and therefore lower house low rate, and thus provides some support for the sub theory that house loss rate is correlated with ember intensity.

Thus, research evidence confirms that ember intensity can vary **at a given distance** from the firebreak (= closest ember source), and provides some support for the sub theory that house loss rate is correlated with ember intensity. A redefined conclusion is this - the house loss rate is potentially higher where ember intensity is higher, reaching a maximum of over 50 - 60% within 100 m of the forest edge, but house loss rate can be mitigated by localised flame behaviour upwind of the firebreak or level of house defence activity.

Eucalypt bushfire - house loss rate

Figure 5 generated this equation for eucalypt forest fire:
House loss rate = 60 – 0.3 x Distance … Equation 2

The shorter throw distances reflect the fact that the ember attack happened on a non severe fire day, which also means lower flame height, which also means less ember generation and less carry distance for live embers. This formula could be useful as a reference to explain shorter ember throw distances for milder weather or for a low fuel load eucalypt forest on a severe day, where the shorter flame generates weaker updraft, and keeps weaker flame updraft.

Equation 2 shows the highest rate of houses loss is closest to the eucalypt forest that house loss rate falls with distance from forest edge. It is noted here that source of embers can be identified as the eucalypt forest. This supports the lead theory of this Paper:
House loss rate is inversely correlated with distance from upwind ember source.

If separation distance is zero, the house loss rate is 60%, which Chen and McAneney (2004) found corresponded with their average house loss rate of 63% for eucalypt "Ash Wednesday bushfires".

The data shows a progressive decline in house loss rate with distance from closest ember source, ie, forest edge. The combination of low fuel load and discontinuous fuel beds within the first line of properties probably acted as a de facto barrier to the moving flame, suggesting that ember attack was the predominant bushfire attack category. The fall in house loss rate with distance mirrors the Duffy house loss rate, and also corresponds with Vesta findings that ember intensity falls with distance from ember source. Unfortunately, house vacancy rates were not recorded, but it is assumed they were low because the NSW policy of compulsory evacuation would probably have been enacted.

None of the post-Black Saturday studies investigated the house loss rate gradation theory for the Royal Commission, but one of the studies provided some support for it, ie, the Kinglake area shown in Fig 9. The majority of embers arose from the grey forested slopes in the SW. The forest edge can be regarded as the closest ember source. Fig 9 shows a progressive reduction in house loss rate with distance from the SW forest edge - 95% in the red rings, to 70% in the blue ring to 30% in the green ring. The house loss rate at Kinglake was greater than Duffy or Como-Jannali for each distance interval from ember source.

The 70% house loss rate in the blue circle corresponds with 400 – 600m distance range from the ember source. The 400m wide paddock provided an ember-free gap between the forest and the houses. It is probable that the ember attack was a combination of live aerodynamic firebrands, large enough to ignite a flammable fuel bed instantly, and smaller embers which either self extinguished over such large distances or accumulated in corners and caused ignition. The 30% house loss rate area was approx 1.2 km from ember source. It is possible that some new embers generated from the vegetated areas between the blue and green rings.

The house loss rate by distance at Marysville did not show a fall because the width of the township area was narrow, approx 200m. Figure 10 shows the house loss rate adjacent to the ember source was 85 – 90%.

Combining the findings for Kinglake and Marysville, the following formula is proposed for a worst case bushfire attack in eucalypt forest. It assumes these eucalypt forests are long unburnt, and there is a high percentage of unoccupied undefended houses.

House loss rate = 80 – 0.1 x Distance (m) … Equation 3

It allows 80% house loss rate adjacent to forest for the first 100m, declining at 10% per 100m from ember source.

CONCLUSION

For the "Duffy bushfire attack category", the analysis finds that the probability of house loss of an unoccupied undefended house is around 60% and of an occupied defended house is around 14%. These figures are very similar to the findings of Part 1 for the "Ash Wednesday bushfire category".

The study finds good support for the theory that house loss rate declines as distance from ember source increases, and proposes the following three equations that may prove to be useful in explanation, diagnosis or prediction. They allow flexibility to be mixed and matched to suit the forest fuel and the weather.

For worst case bushfire attack in unthinned, unpruned pine plantation
House loss rate = 65 – 0.15 x Distance from ember source

For worst case bushfire attack in for long unburnt eucalypt forest
House loss rate = 80 – 0.1 x Distance from ember source

For medium severity bushfire attack in long unburnt eucalypt forest or worst case bushfire attack in fuel reduced eucalypt forest
House loss rate = 60 – 0.3 x Distance from ember source

INTEGRATION OF PAPERS 6A AND 6B

The first number in each equation is the house loss rate when separation distance from the ember source is zero or minimal, ie, 65, 80 and 60%. They assume the houses are predominantly vacant undefended. They correspond to the Paper 6A findings where the house is overrun by the running flame and associated ember attack. The Paper 6A house loss rate ranged up to 90% for vacant undefended houses and was reduced by increasing the percentage of occupied and defended houses. It is proposed that the same process can be used to adjust the above equations. For example,
Where
House loss rate = 65 – 0.15 x Distance range equation 1 in this Paper
Combines with
House loss rate = 0.64V + 13 equation 4 in Paper 6A
Becomes
House loss rate = (0.64V + 13) - 0.15 x Distance range
(V = house vacancy rate %)

The study also finds good support for the sub theory that ember intensity reduces with distance from ember source and circumstantial support for the sub theory that chance of ignition of a house is correlated with ember intensity.

The study hopes to dispel the myth that house loss is correlated with vegetation proximity by firstly requiring proof that the vegetation is a source of embers and secondly that those embers caused house ignition.

This study also asks - what changed during the Black Saturday fires that pre 2009 knowledge became redundant? The answer is little new information was added by the Royal Commission and its associated studies. Indeed, no information was found that disproves prior knowledge.

GLOSSARY OF ACRONYMS

BMO	Bushfire Management Overlay
WMO	Wildfire Management Overlay
AS3959	Australian Standard 3959
RFS	Rural Fire Service
BAL	Bushfire Attack Level
FDI	Fire Danger Index
CFA	Country Fire Authority

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