INVESTIGATION OF BUSHFIRE ATTACK MECHANISMS RESULTING IN HOUSE LOSS IN THE ACT BUSHFIRE 2003

Bushfire CRC Report

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CONTENT

1. Objectives of the study (scope of work)

This report has been prepared for the inquiry conducted by the ACT Coroner to understand the property damage resulting from the bushfire in the Canberra region on 18 January 2003.

In order to understand the unusual aspects of this catastrophic fire, an investigation was performed by CSIRO Manufacturing and Infrastructure Technology (CMIT) on affected areas of Canberra's urban interface. CMIT's involvement in bushfire building surveys began following the 'Ash Wednesday' fires of 1983 (Ramsey *et al.* 1986). Since that time, CMIT has surveyed every bushfire involving significant house loss (Leonard & McArthur 1999; Leonard 2003a).

The intent of each survey was to clarify the mechanisms of ignition and propagation of the fire in these urban areas, and to identify the bushfire attack mechanisms that played a part in the unprecedented structural loss deep within the urban environment.

2. Comparison of the ACT bushfire's consequences with previous bushfires

Preliminary studies of the damaged area around Canberra revealed unusually high impact levels of both wind and fire attack, with a significant loss of houses. It appears that most houses were ignited by either ember attack or house-to-house ignition. These ignitions were exacerbated by high localised winds that damaged houses in some parts of Canberra during the fire event, thus making them more vulnerable to ember attack.

The insured losses in the Canberra fires were comparable to the losses on Ash Wednesday with inflation taken into account, even though the number of houses lost was much less.

In terms of insured losses, Ash Wednesday stands as Australia's largest bushfire event and sixth largest natural disaster. If the Ash Wednesday losses are indexed to inflation to today's prices, it represents a total insured loss of $300–350m (Walker 2002), with 1511 houses lost (Leonard & McArthur 1999). Canberra's total insurance loss approaches this level, with approximately 516 houses destroyed.

There is a considerable increase in the asset value at the urban interface that needs to be considered during future policy development. Thankfully, life loss has not followed the same trend, with 75 lives lost in the Ash Wednesday fires compared to 4 lives lost in the ACT fires.

However, structural loss so deep into the urban area interface has not been observed since the Hobart fires of 1967 (Leonard & McArthur 1999), which resulted in 62 deaths, and destroyed 1300 homes and 128 major buildings, and was the seventeenth largest insurance loss in Australia's history (IDRA) (McArthur 1968; Walker 2002).

Previous catastrophic fire events noted in Table 1 have shown that major fires occur during extreme drought conditions with the presence of strong wind. For example:

- The first record of bushfire impact in white man's history was in 1851. The bushfire occurred in Port Philip on 6 February (Black Thursday), a day when the temperature in Melbourne rose to 47°C at 11 am. The Melbourne Town was in grave danger of destruction by the encircling bushfire. Approximately 12 lives, 1,000,000 sheep and thousands of cattle were lost.
- The 'Black Friday' bushfires of 13 January 1939 were the result of a long drought and a severe, hot and dry summer. Blown by extremely strong winds, these fires swept across large areas of Victoria. These bushfires were responsible for 71 fatalities and destroyed 1300 buildings.
- The weather conditions leading up to Ash Wednesday were extreme – by 16 February 1983, most of Victoria had experienced a drought that had lasted 10 months or more; rain over winter and spring was very low, and the summer rainfall for Victoria was approximately 75% less than in other years (refer http://www.dse.vic.gov.au/dse/nrenfoe.nsf).

The context of the meteorological condition prior to and during the ACT fire represented very dry hot conditions. These conditions not only contribute to the overall fire intensity, but also to the susceptibility of urban assets.

Table 1. Australian bushfires involving major house loss since 1939 (Leonard & McArthur 1999)

Date	Location	House loss	Research into building loss
January 1939	Victoria	1300*	Nil
January 1944	Victoria (Beaumaris)	927 (58)	 G. Barrow, CSIR, selective survey
December 1957	Leura, NSW	123	Nil
January 1961	Dwellingup, WA	132	A. G. McArthur, general survey
January 1962	Dandenong Ranges, Victoria	454	Nil
February 1967	Hobart, Tasmania	1300+	CEBS/CSIRO, questionnaire
1967/68	Dandenong Ranges, Victoria	53	Nil
November 1968	Blue Mountains, NSW	Some	R. Cole, CEBS, selective survey
January 1969	Lara	251*	Nil
February 1977	Western District, Victoria	116	CSIRO/CFA, rate of spread only
January 1983	Victoria, SA (Mount Macedon, Victoria) (Otway Ranges, Victoria)	1511 (234) (729)	 A. Wilson, in-depth survey CSIRO, in-depth survey
January 1985	Avoca/Maryborough	61	CSIRO, general survey
January 1994	Sydney and surrounds	202	CSIRO, in-depth survey
January 1997	Dandenong Ranges, Victoria	40	CFA, in-depth survey

* 'Structures', not necessarily houses.

3. Environmental conditions – context of the ACT fire

Phil Cheney, in his report to the Coroner (see 'Origin and Development of the Bushfires that Spread Into the ACT, 8–18 January 2003' by N.P. Cheney, Principal Research Scientist, CSIRO Forestry & Forest Products), mentioned that 'four fires started and burnt forests in both ACT and NSW. On 18 January, under extreme fire weather conditions, these fires made intense runs towards the east, joined together and burnt into the suburbs on the western urban edge of southern Canberra'.

The unusual severity of the fire was generated by extreme weather conditions (a combination of particularly strong wind and drought conditions). Rick McRae from the ACT Emergency Service Bureau mentioned that the weather during the event had many unusual features: very high to extreme fire danger indices on 8, 17, 18, 21, 26 and 30 January; temperatures to near 40°C; relative humidity to 6%; wind speeds to near gale strength; fuel moisture content to 2%; alpine conditions at least as serious as those in the lowlands (see http://www.esb.act.gov.au/text/riskanalysis/2003fires/weather.html).

Some particular weather conditions on 18 January 2003 are important to mention to explain the high risk of bushfire in these areas. Figures 1–3 present graphs showing the temperature, humidity, wind speed and wind direction at Canberra Airport (Bureau of Meteorology data on request). According to Phil Cheney, this station (at Canberra Airport) was the closest to the urban area affected by the fire and could give a good indication of the weather conditions and the fire propagation in the area. The wind was reported to be gusting from the north-west at about 40 km/h on 18 January until 2000 hours. A change of wind direction and speed was then observed during 19 January.

The fire reached the western part of the ACT, and several areas were affected by the bushfires: Curtin, Weston, Holder, Duffy, Rivett, Chapman, Kambah, Lyons and Torrens. Duffy was one of the areas most heavily impacted.

The weather condition from days prior to the impact coupled with the conditions shown in Figure 1–3 and extensive water restrictions, left materials on, within and around urban assets with particularly low moisture contents. This would have had the effect of raising the likelihood of ignition and the intensity of flame spread on and within these structures.

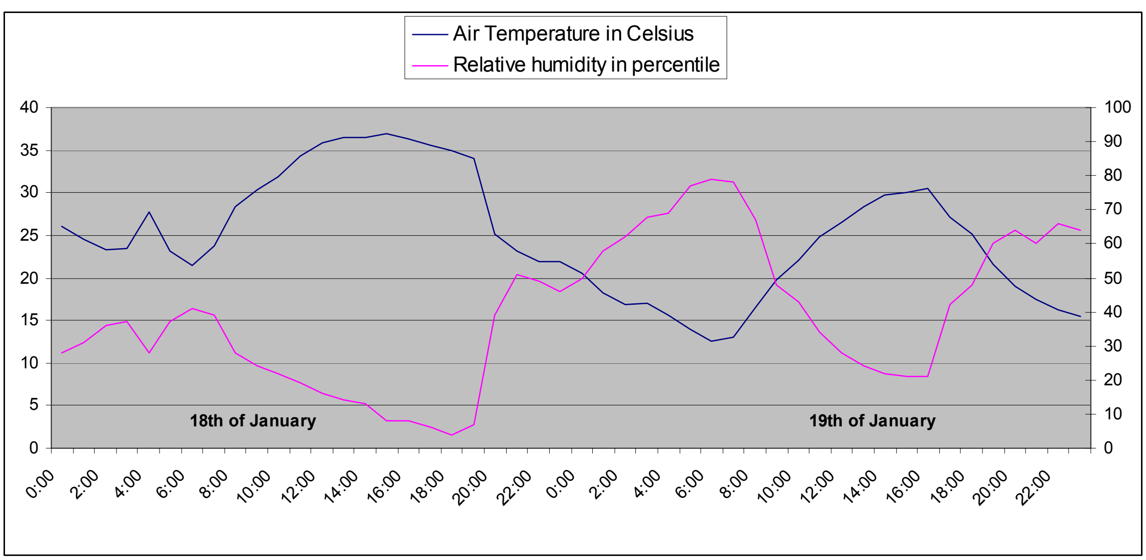

Figure 1. Air temperature and relative humidity every hour at Canberra Airport on 18 and 19 January 2003

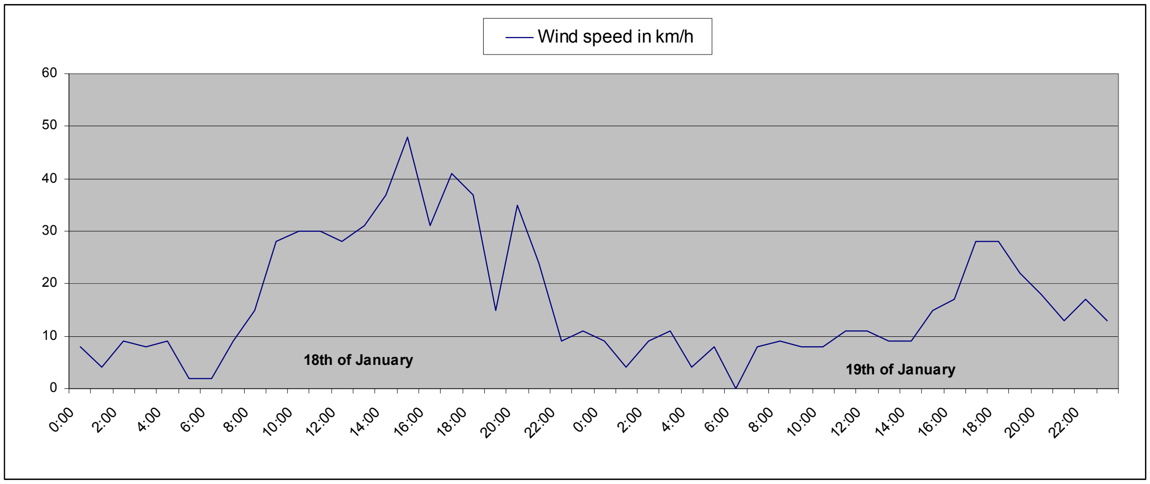

Figure 2. Wind speed every hour at Canberra Airport on 18 and 19 January 2003

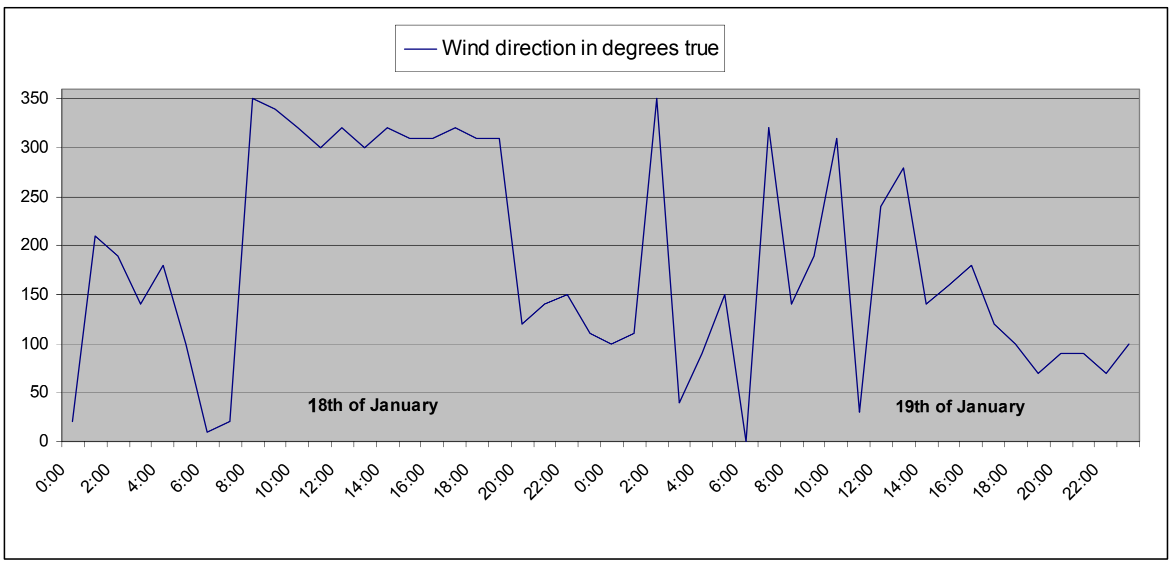

Figure 3. Wind directions every hour at Canberra Airport on 18 and 19 January 2003

4. Investigation in Duffy area

In order to understand the unusual aspect of this catastrophic fire, an investigation was performed in the area damaged by the ACT fire. Several suburbs were affected by the fire: in Curtin 3 houses were destroyed, Weston 5, Holder 31, Duffy 219, Rivett 13, Chapman 88, Kambah 35, Lyons 3, Torrens 1, and Giralong 2 (see Figure 4).

Duffy was selected after a familiarisation tour, as it presented the highest density of damage and destruction following the Canberra fire (see Figure 5). All houses within the area identified in Figure 6 were fully surveyed. This area was the first reached by the fire on 18 January, and presented more damage than in the other parts of Canberra. According to Phil Cheney, the main head fire (the leading point of the fire front) burnt across onto the eastern side of Mount Stromlo by 1500 hours, and was approaching Cotter Road north-west of Duffy.

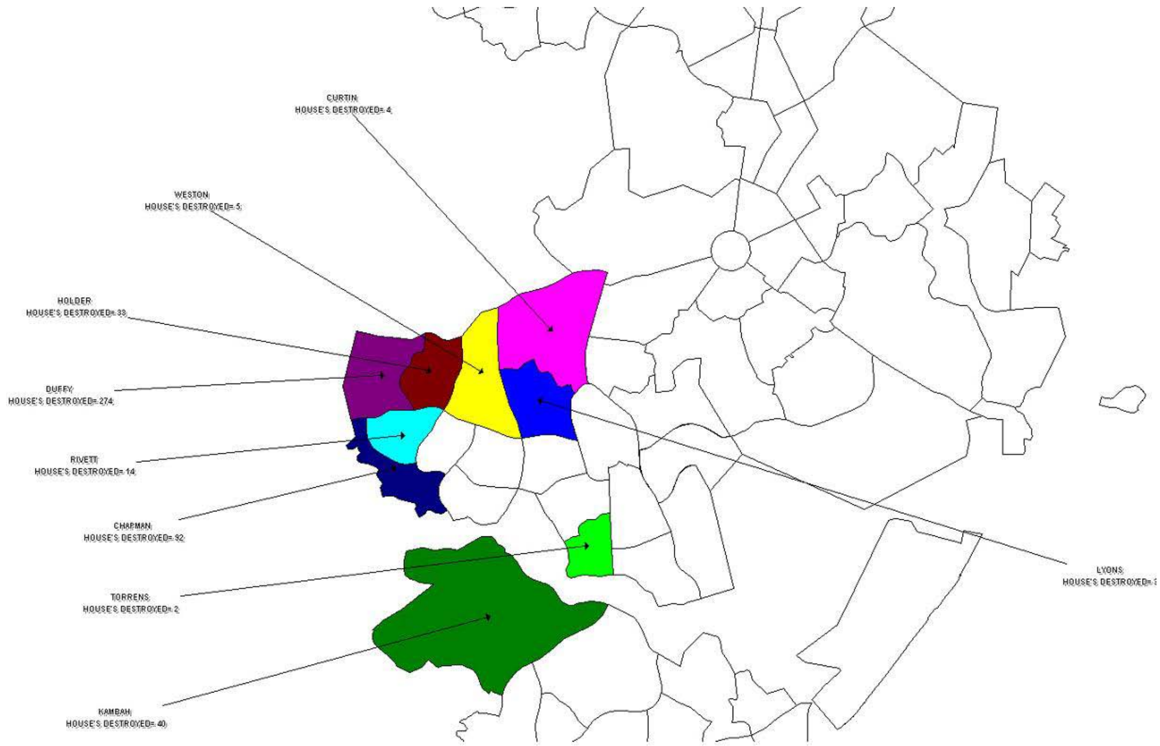

Figure 4. Destroyed house incidents, all Canberra
(produced by S/Constable Paul N. Turk Actomis, 20 January 2003)

The head of the fire burnt through the Mount Stromlo forestry settlement soon after 1500 hours and first crossed into Duffy just east of the intersection of Warragamba and Eucumbene Drive at 1505 hours (see Figures 5 and 6). By 1545 hours, the fire had entered the suburb of Duffy between Dixon Drive and Hindmarsh Drive (refer to 'Origin and Development of the Bushfires that Spread Into the ACT, 8–18 January 2003' by N.P. Cheney, Principal Research Scientist, CSIRO Forestry & Forest Products). Detailed surveys were not conducted by CMIT in other damaged areas.

Over 229 Duffy houses were surveyed and were categorised as untouched, damaged or destroyed houses. During the course of the data collection, particular attention was given to gathering information on how the houses might have been ignited, and thus ultimately destroyed. This was done by examining each house, with particular attention given to those that had been damaged but not destroyed, and/or had occupants present.

A survey was carried out from 21 January to 4 February 2003 to examine the remains of the destroyed houses, study damage on surviving houses, and to talk with the occupants of these houses. Extensive aerial survey photos were taken on 22 January 2003.

The investigation was based on three main sources of information: data collection on houses, ground photos and high resolution aerial photos, plus additional information to understand fire behaviour.

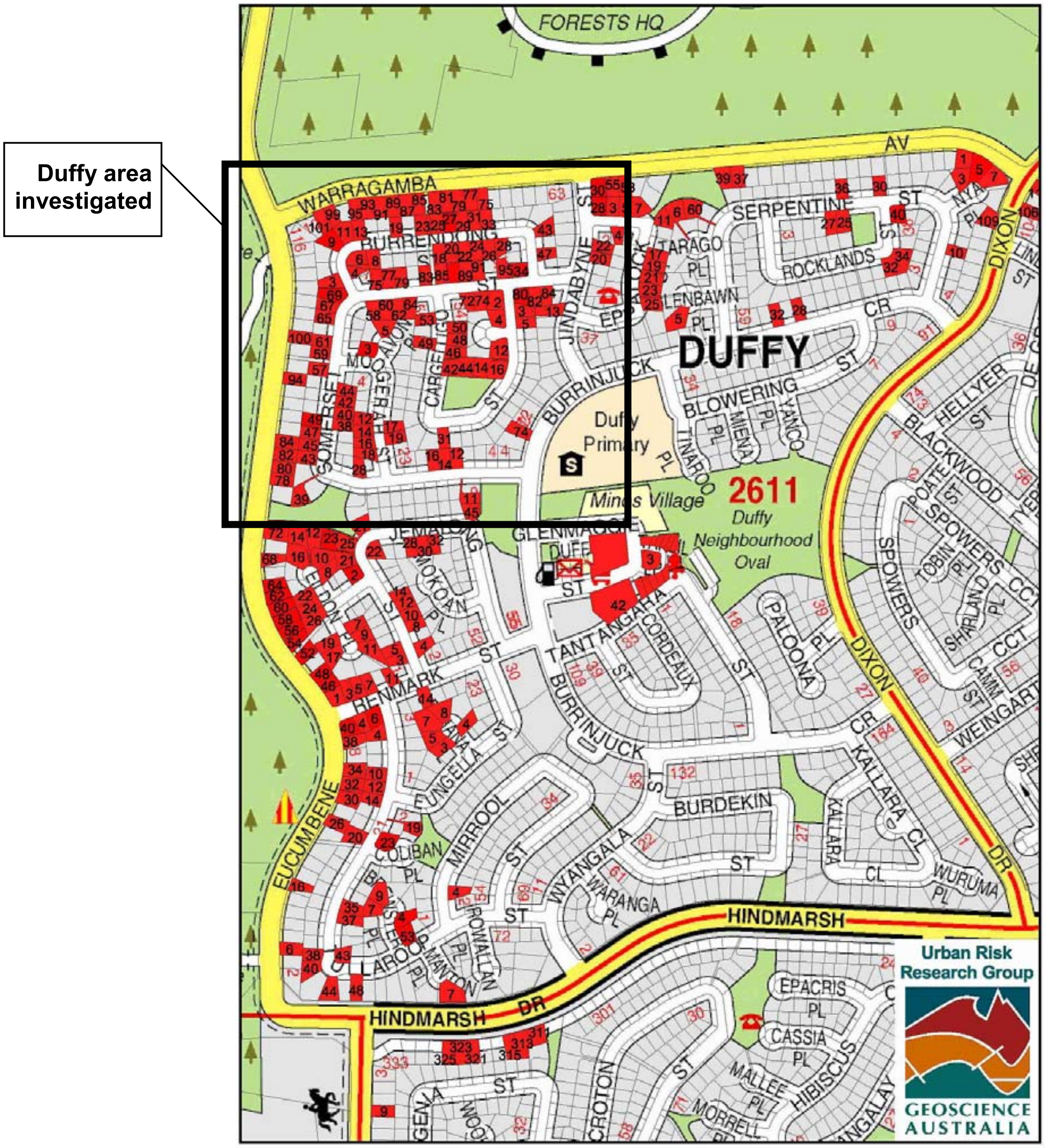

Figure 5. Map showing the area covered in survey (map provided by Geo-science Australia)

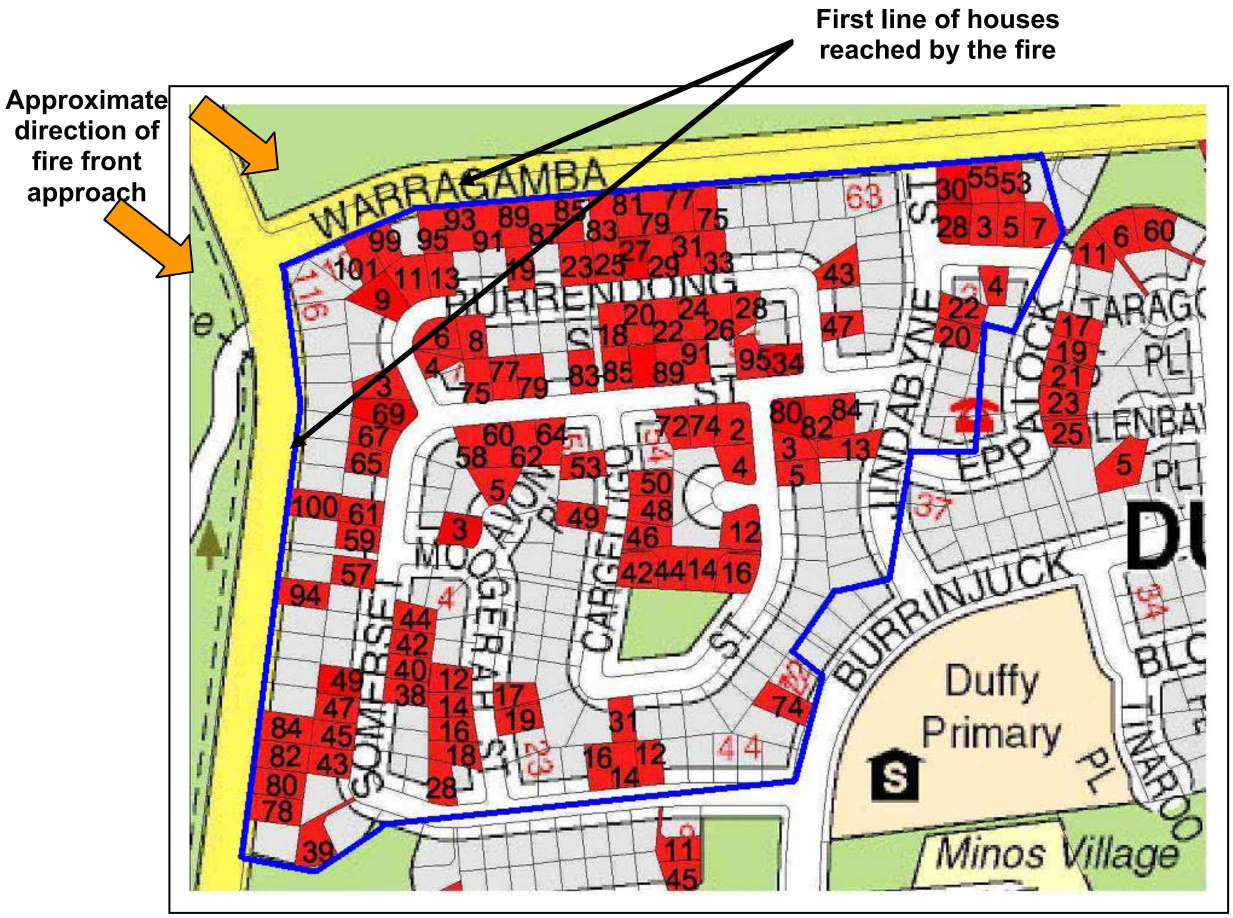

Figure 6. Houses surveyed in Duffy (inside the blue boundary)

4.1. Data collection of the houses exposed to the ACT bushfire

Various factors were taken into consideration to assess the impact and consequences of the bushfire attack on a house. More than 70 questions are recorded in the survey. The information deals with the identification, location and ownership details for each house. Questions cover the degree and causes of damage, and closely record a house's design and the materials of construction. Questions cover outbuildings and details of the surroundings. Final questions look at the activities of occupants, neighbours and firefighters around the house before, during and after the passage of the fire front. For further information on the questionnaire used, please refer to Annexe 2.

Our main objective in this work was to use a social investigation method such as a survey to obtain information that could be useful to describe the degree of damage to houses reached by the effects of the bushfire event, and also to explain population behaviour and mechanisms of attack. The enquiry tries to explain the relationships between a number of variables recorded and to extract the main tendencies from a sample of houses surveyed.

All the information collected in the questionnaire has been entered into a database program (Access database) and studied with a specific data analysis and survey processing software (Question data 2002 – Grimmersoft). Simple analyses were used such as frequency and cross-tabulation. The results are presented in various charts within this report. To supplement this statistical analysis, a number of case studies are also presented to highlight various human behaviours, structural susceptibility and bushfire attack mechanisms.

4.2. Photos on the ground and high-resolution aerial photography of the affected area

Additional information was obtained from photographs taken both on the ground and via high-resolution aerial photography of the affected area. The photos are a vital method of recording and storing information on each surveyed house for later analysis. The photos reveal information on each house's characteristics (the entire house and its surroundings), the ignition point(s), a profile of the burnt area, and the damage sustained by the house. They also provide information on the nature of the bushfire attack and house-to-house fire spread.

4.3. Additional information

Additional information on weather conditions, vegetation, slopes, prevention and suppression activities are important to gain a better understanding of the fires impact on Duffy. These weather conditions play an important role in determining the risk of house destruction in all fires as commented previously (see section 3).

The collective information has been integrated into a large database specifically designed for easy navigation and analysis. As time is made available these data sets are analysed and compared to help answer questions relevant to mitigate the risk of people living in bushfire prone areas. The reference list provided shows many examples of reports based on observations made from this dataset.

5. General discussion of mechanisms of bushfire impact on urban assets

For the purpose of discussing mechanisms of bushfire attack on structures, it is important to first define a framework in which risk can be considered. The risk needs to be clearly defined. In this case, it is the risk of building damage to a point were it no longer provides a safe haven for occupants. The most appropriate approach is to divide the risk event into two categories: impact and susceptibility. Impact defines the parameters that can describe the magnitude or persistence of the attack mechanism. Susceptibility is a measure of how well the structure is able to resist the mechanisms of attack.

Environmental conditions play an important role – the high degree of damage within urban areas is related in part to the extreme weather conditions (combination of particularly strong winds and drought conditions). Low rainfall, low humidity and water restrictions can lead to the vegetation around buildings and building elements themselves becoming very dry and flammable (see Section 7). These meteorological conditions can be considered as both influencing the magnitude of the bushfire impact and also the susceptibility of structure and surrounding elements.

The principal mechanisms of bushfire attack can be categorised into direct flame, radiant heat and embers. Previous CSIRO research has shown that the majority of houses destroyed in bushfires usually survived the passage of a fire front, but burned down during the following few hours due to fire spreading from small ignitions caused by burning debris (Leonard 2003b).

5.1. Ember attack

It has been found that burning debris can ignite buildings in a number of ways:

- With other windborne combustible debris, it can pile up against combustible materials used at or near ground level, such as facades, stumps, posts, subfloor enclosures and steps.
- It can accumulate on combustible materials used for decks, verandas and pergolas.
- It can lodge in gaps in and around combustible materials used for exterior wall cladding, windows and door frames.
- It can gain entry to the interior of a building through widows broken by radiant heat or flying debris. Once inside the building, the burning debris might possibly ignite furniture, fittings and other contents.
- It can ignite adjacent structures, which then threaten the structure of concern.

Survey work has revealed that many houses are ignited from radiation and flame contact from adjacent burning buildings or features such as timber fences. The duration of the radiation and flame exposure from adjacent burning structures may be for a significantly longer period (an hour or more) compared to the exposure to the fire front itself (a few minutes) (Leonard 2003b).

Embers are the major cause of ignition, as they can attack a building for some time before a fire front arrives, during the passage of the fire front and for many hours after the fire has passed. The burning structures themselves become significant ember sources under appropriate wind conditions. Two types of windborne debris need to be considered: burning debris that could enter into or directly ignite part of a building or its surroundings, and unburnt or partly burnt debris that could facilitate ignition when it accumulates in or on specific parts of a house (Leonard 2003b).

The risk from ember attack is complex and related to different factors, i.e. impact and susceptibility. Impact relates to the quality of the embers, the amount of ember present, and the amount and type of windborne combustible debris associated with the ember attack. The building and/or its surrounds have a susceptibility which is a measure of how likely the ember and associated debris is to create a localised flame. The susceptibility can be described through the following range of properties:

- Openings – opportunities for embers to enter the structure and access combustible furnishings.
- Configuration – a measure of the structure's susceptibility for embers and debris to accumulate on horizontal projections, and in corners or crevices where localised flame attack is then likely to result.

- Combustibility – the material's (on or adjacent to the structure) ability to support localised flame development. This property is linked to environmental factors such as temperature and humidity.
- Human activity plays an important role to mitigate this risk (prevention and suppression activities, before, during and after the ember attack).

5.2. Flame front radiation attack

As no evidence was found in the Duffy survey of direct radiation attack, this subject needs no further qualification. It is noted that without the perimeter roads surrounding the Duffy area, urban assets may have been sufficiently close to the flame front for radiation to play a role.

5.3. Flame front contact

As no direct flame attack from the actual bushfire front was observed in the Duffy Survey area. It is also noted that without the perimeter roads surrounding the Duffy area urban assets may have been sufficiently close to the flame front for direct flame impingement to play a role.

5.4. Other factors influencing susceptibility of structures

Despite the ever-increasing desire to be close to nature, many people are unaware of the risks and responsibilities associated with living in bushfire-prone areas. Research has shown that human activity plays an important role in mitigating the risks (prevention and suppression activities, before, during and after ember attack) (Ramsay 1996). If the small ignitions made by embers are not extinguished, they can grow to involve the whole building. The CFA (1999) notes that people who are well prepared and who return to their houses after the passage of the fire front can, in many cases, successfully save their houses without endangering their lives.

Building design also plays an important part in the survivability of a structure. Any part of a building where burning debris can accumulate (or enter) is susceptible to ignition. The accumulation of burning and non-burning debris can occur before, during and after a fire front has passed. Some researchers have already studied the mechanisms of bushfire attack on houses, and their findings have been integrated into AS 3959 *Construction of Buildings in Bushfire Prone Areas* (Standards Australia 1999), to improve the performance of buildings in bushfire-prone areas (Ramsay & McArthur 1995). The measures set out in the Standard have the objectives to improve construction, and thus better equip a building to withstand the effects from bushfire. The Standard may also be used as a guide for those who wish to voluntarily adopt such measures, in situations where regulatory compliance is not mandated. The measures required in AS 3959 are presented for each specific part of the building in Section 7.

All these factors played a significant role in the damage caused to the houses in Duffy.

6. The degree and causes of damage in the surveyed Duffy area

This section first presents a brief analysis of the degree of damage and house loss. The causes of these losses, and how the siting of homes and other structures contributed to house loss is then presented. General statistics are followed by individual case studies to emphasise particular mechanisms of attack.

Four main levels of damage were used for the investigation (see Figure 7):

- Untouched – directly threatened by the bushfire but no house damage.
- Superficial – small ignitions that were, in almost all cases, extinguished before they entered the structure.
- Light damage –some penetration before extinguishment, confined to item first ignited and immediate surroundings.
- Destroyed – total structure loss.

The proportion of houses destroyed in the surveyed region is very high given the shape of the surveyed area (refer to Figure 6). Loss so far into an urban environment is rarely observed.

6.1. Identified mechanisms of bushfire front attack in surveyed area

Analysis of the data indicates that no houses in Duffy were directly impacted by flames from the fire front itself. In 50% of cases, the bushfire attack mechanisms were via embers only, and 35% were via ember and some radiant heat from surrounding isolated vegetation or other structures (see Figure 8). The houses that survived included all those superficially or lightly damaged, and those that were untouched. Radiation from the main fire front was not sufficient to cause ignition or direct damage to the structures; however, it is likely to have played a role in increasing the likelihood of flame propagation as a result of ember attack. Convective heat (hot gases from the flame front) is also likely to have contributed to increased risk in a similar way.

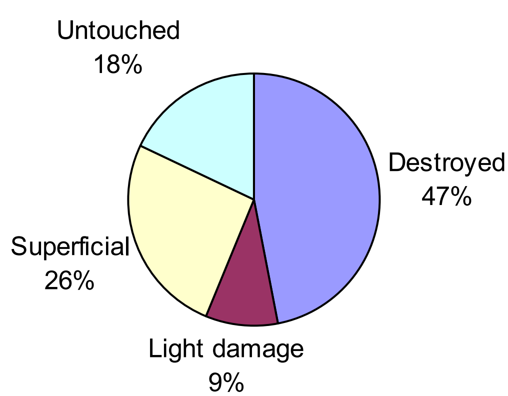

Figure 7. Degree of house damage

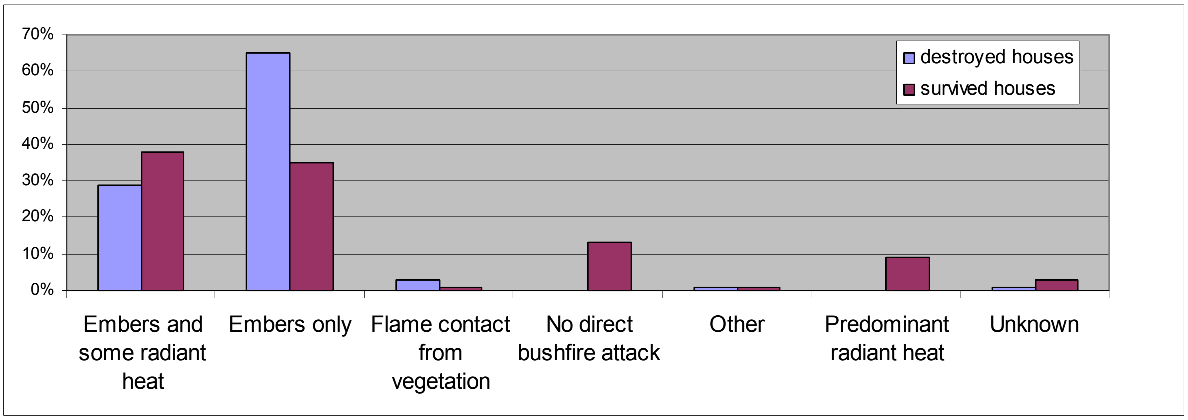

Figure 8. Mechanisms of bushfire attack

The following case study for 73 Somerset St provides an example of how a building's envelope can be breached during a bushfire (see Figure 16, aerial picture of the house). The occupant of this house elected to stay. Inside the house he found that windows on the north-facing wall were broken or cracked from radiant heat from a neighbouring house (main structure and fences) (Figures 9–10 and 12–13), curtains were heat affected, embers entering through broken windows had caused burn marks on carpet (Figure 12). During and after the fire event, he moved inside and outside to check for spot fires and extinguished various ignition points.

Figure 9. Broken and cracked windows from radiant heat from neighbouring house and fences (73 Somerset St)

Figure 10. Radiant heat impacts on eaves from surrounding vegetation (73 Somerset St)

Figure 11. Other example of radiant heat impact due to vegetation and car fire (86 Somerset St)

Figure 12. Ember attack on carpet
(73 Somerset St)

Figure 13. Ember attack on chair on deck (73 Somerset St)

The impact of radiant heat on a house not only supports the ignition of flammable material on the structure, but may also create openings by broking windows, which facilitates the entry of embers into the structure. The synergistic effect of these two mechanisms of attack increases the potential of house loss, especially if the ignited points are not extinguished quickly.

6.2. House-to-house fire spread

House-to-house ignition played an important role after the passage of the fire front in Canberra; the ignitions were due to burning debris from house on fire, direct flame contact or radiant heat (see Figure 14).

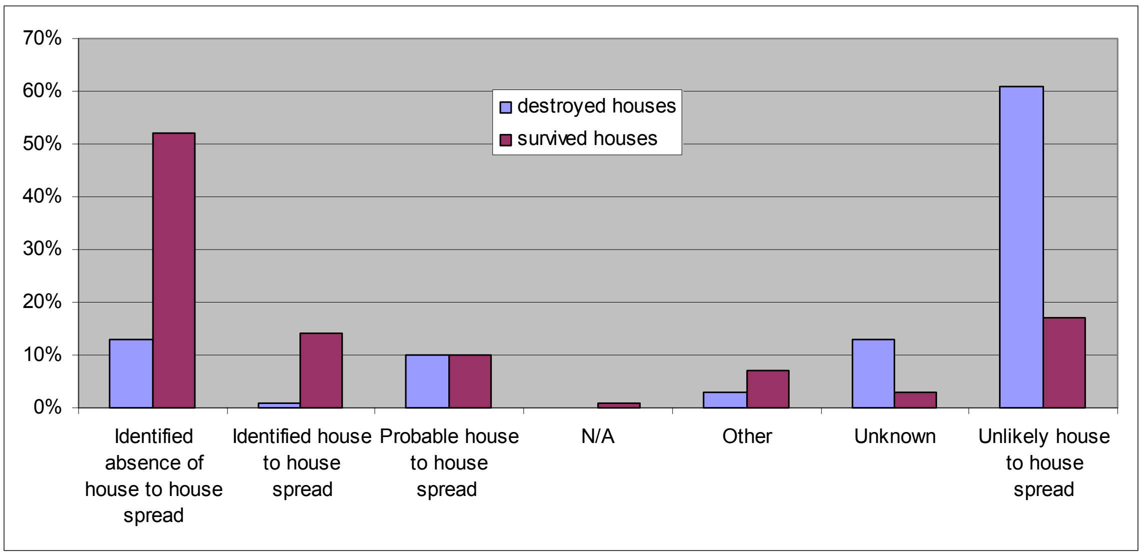

Figure 14. Identification of house-to-house fire spread in Duffy

The initial vegetation and structural fires in Duffy created an even more concentrated and enduring ember attack for those homes further downwind. Some of the structural fires provided direct flame attack and radiation impact on adjacent structures also. These impacts persisted for hours rather than the few minutes it takes for a flame front to pass. This effect was exacerbated by the placement of relatively large houses on medium sized blocks, and the presence of timber fences and vegetation between the closely orientated structures (see Figure 16). For further detail on vegetation and other structure impact, see Section 8.

These impacts endured throughout the afternoon and well into the night. We found many examples of community and agency suppression activities during this time, and examples of many houses being saved. It was highly likely that if no suppression activity occurred during this time, the house loss would have approached 100% in the surveyed area.

The following case studies identify house-to-house ignitions that resulted in house loss in the surveyed area (see Figure 15).

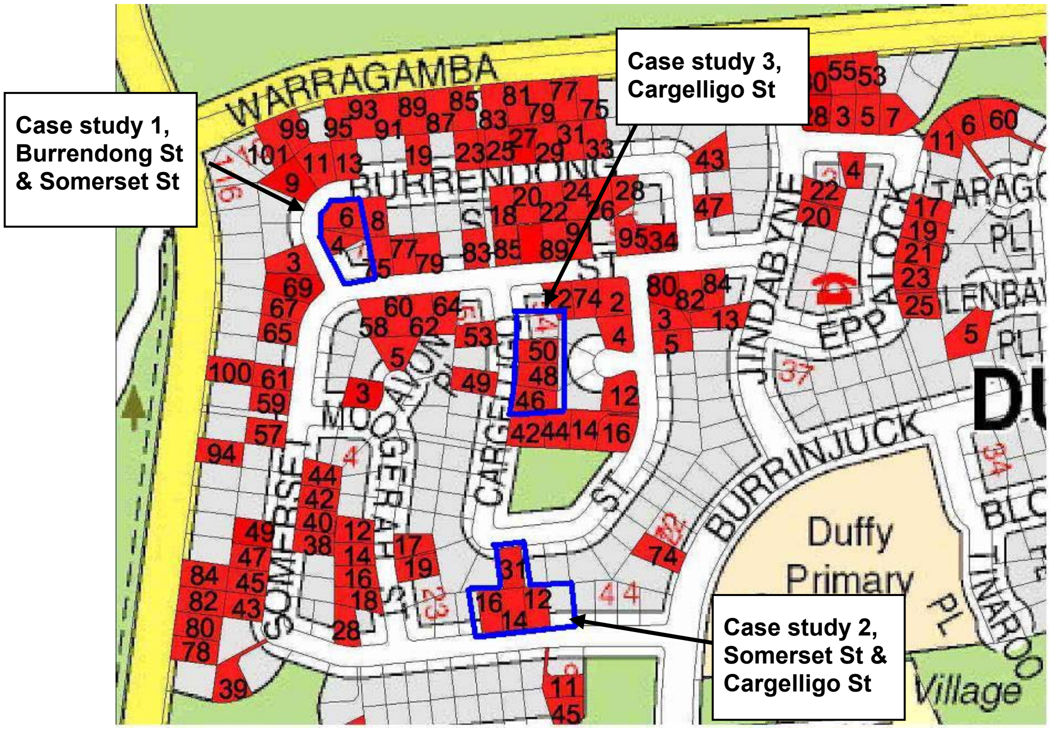

Figure 15. Location of case study houses

6.2.1. Impact of surrounding vegetation, case study 1

4 and 6 Burrendong St, and 73 Somerset St (see Figure 16 and 17).

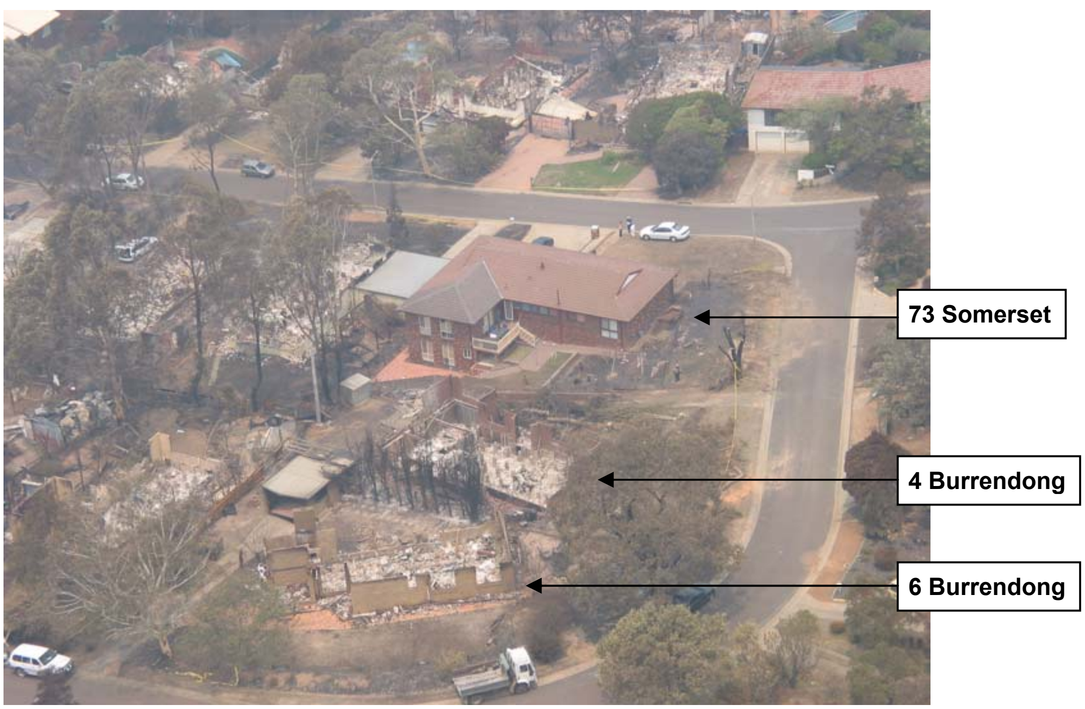

Figure 16. House-to-house fire spread involving cypress trees

Figure 17. Detail of pencil pine burn between 4 and 6 Burrendong St

An occupant of 73 Somerset St reported that, at a neighbouring house (4 Burrendong St), 'embers igniting pencil pines and ignition started at the east back corner of the house, embers "plastering" under eaves, along fences, garden, mulch, bark all alight from embers, strong wind'.

6.2.2. Impact of fire deeply in the suburb, case study 2:

10, 12 and 14 Somerset St, and 31 Cargelligo St (see Figure 18).

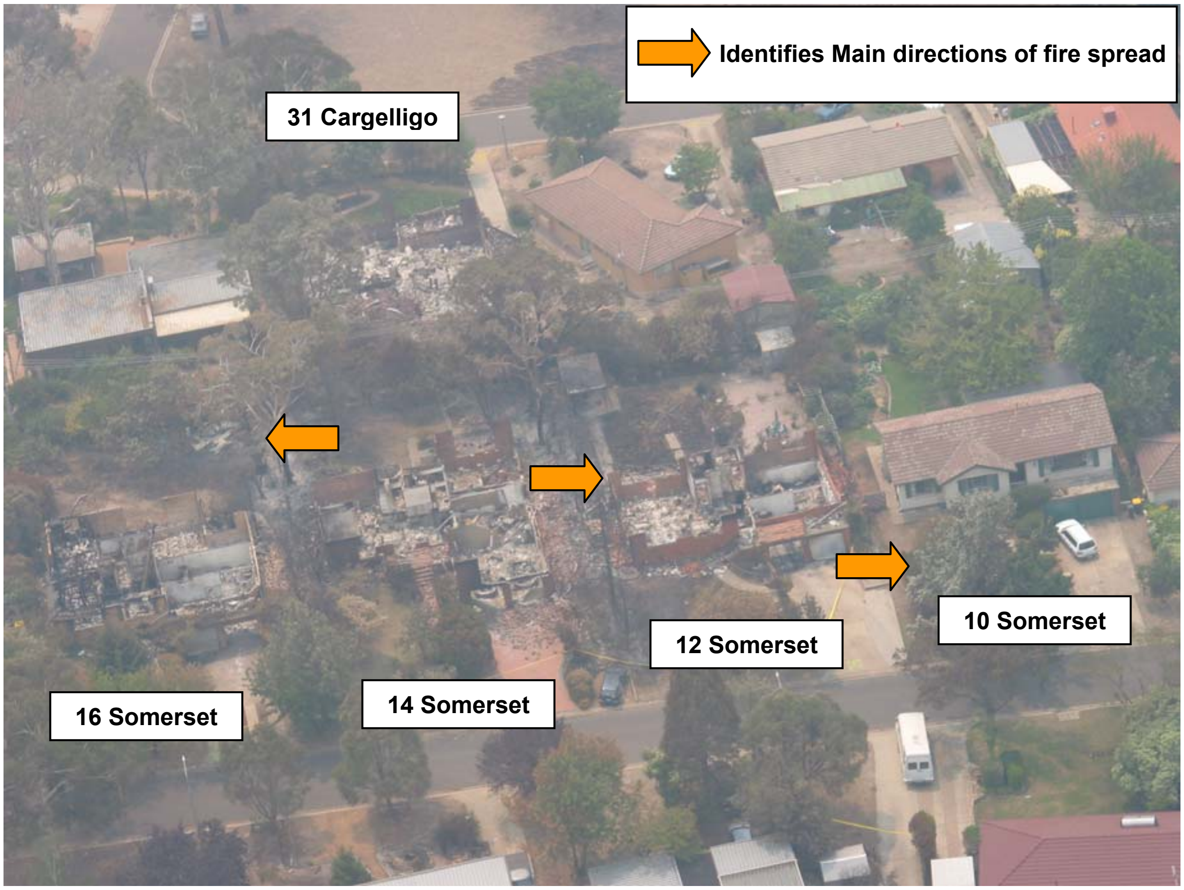

Figure 18 Aerial photo of 12, 14, 16 Somerset St and 31 Cargelligo St (destroyed houses)

These four destroyed houses were deep within the suburb and surrounded by surviving houses. It is highly likely that an ember attack ignited 31 Cargelligo St, which then become the predominant source of fire attack on the area of 14 Somerset St. House-to-house fire spread from 14 to 12 Somerset was reported during the survey, and ground-based photo evidence identifies that fire spread involving ground fuels and secondary elements between 14 to 16 Somerset, as well as from 31 Cargelligo to 16 Somerset. Figures 19 and 20 provide further visual evidence of these mechanisms. The occupant of 10 Somerset elected to stay, he mentioned that he was involved in extinguishment activities from ember attack and burning fences associated with the structural fire at 12 Somerset, these activities may have reduced the risk of further house ignitions.

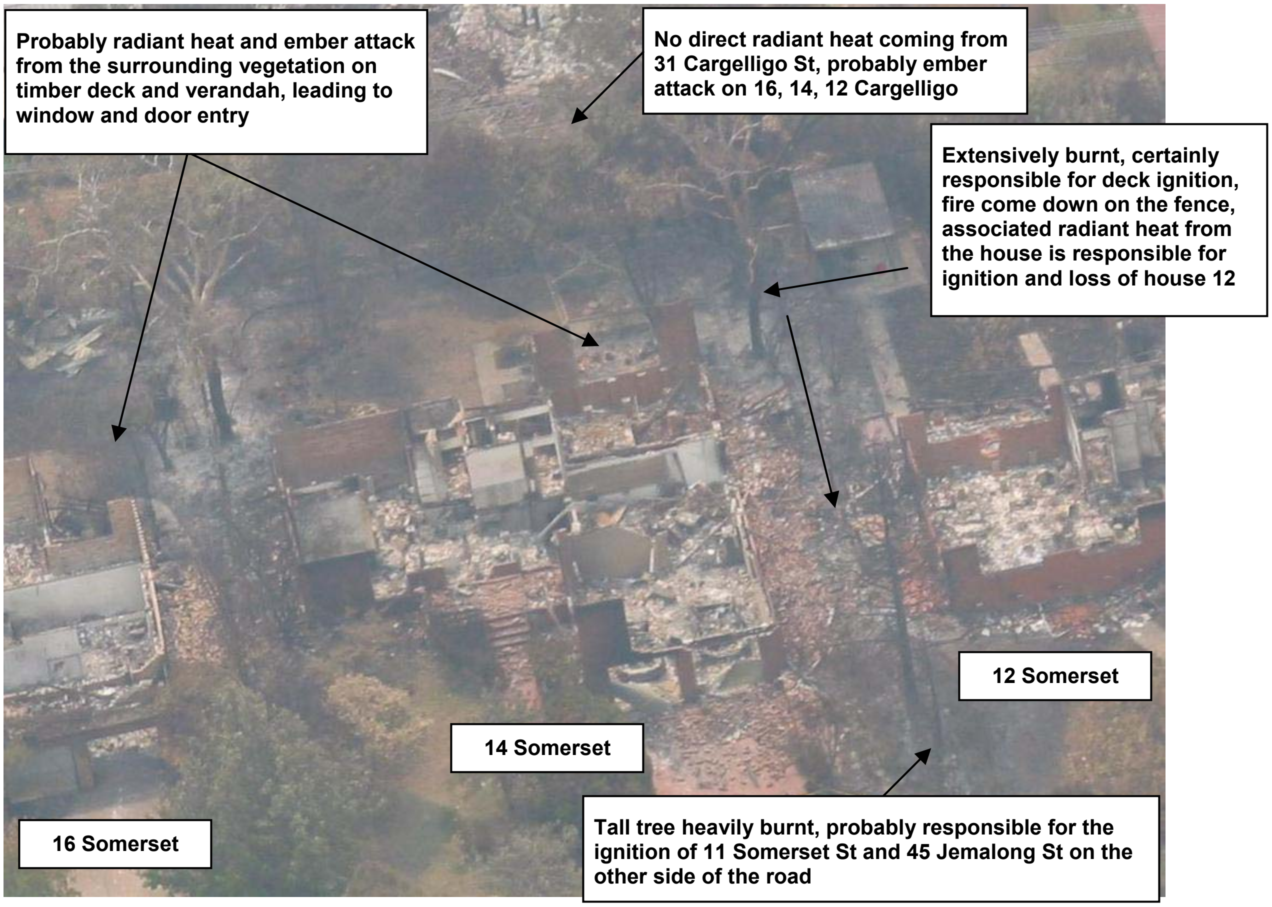

Figure 19. Detail of 14 Somerset St

Figure 20. 12 Somerset St

6.2.3. House-to-house fire spread , study case 3

42, 46, 48 and 50 Cargelligo St (see Figure 15).

These four brick houses were destroyed by a fire that probably resulted from embers ignition. The occupant of 52 Cargelligo St identified that the fire started at 42 Cargelligo St and spread against the predominant wind direction to 46 then 48 then 50 until reached the house he was occupying at 52 Cargelligo St. Most other observed spread mechanisms are driven or heavily influenced by the prevailing wind direction.

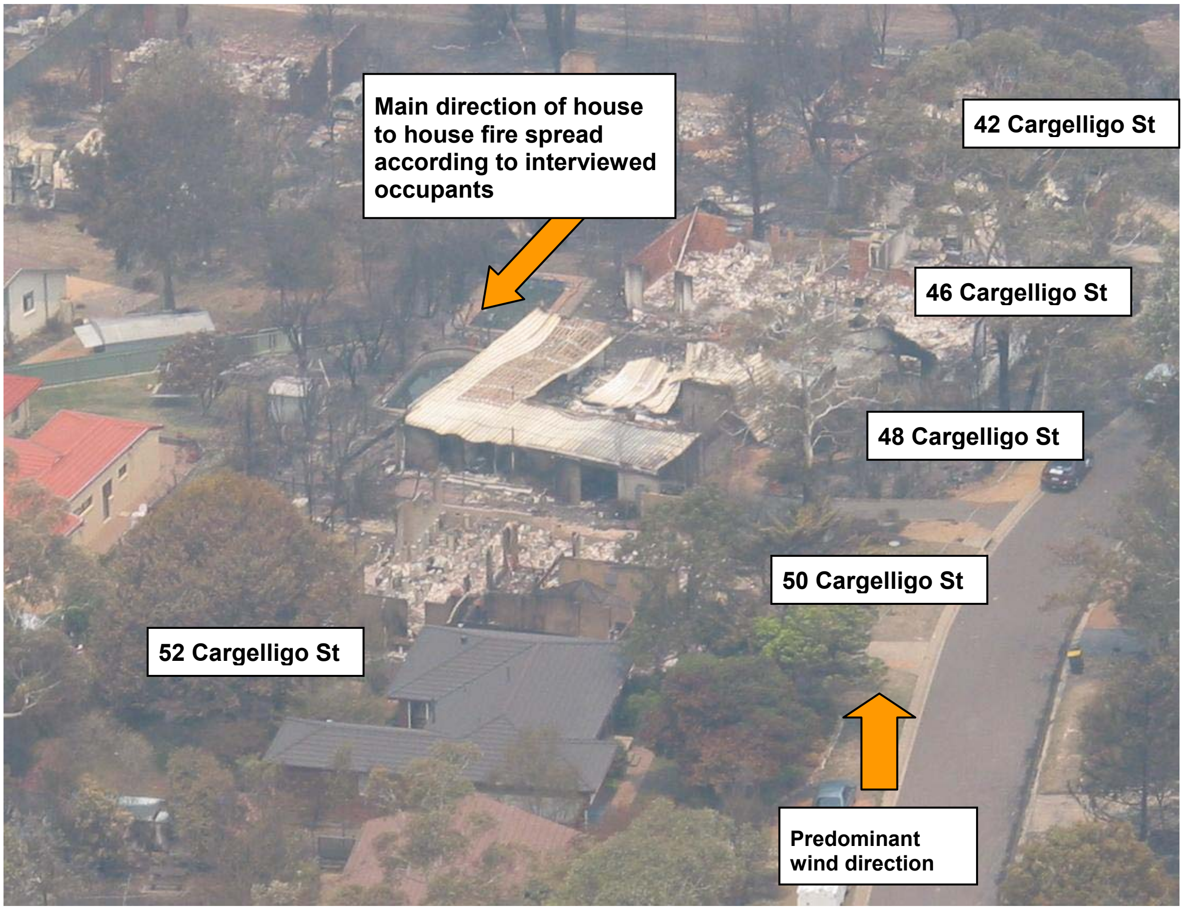

Figure 21. Aerial photo of 46, 48, 50 and 52 Cargelligo St

6.3. Susceptibility due to urban design in surveyed area

The general town planning design of providing perimeter roads as a buffer zone between houses and forest fuels is considered to be a very effective measure to prevent direct flame and radiation impact. The configuration of Duffy indicated that the houses were far enough from the forest not to be impacted directly by flames from the fire front. However, the particular conditions of wind and burning vegetation combined to generate a large amount of burning debris. The houses in Duffy were particularly vulnerable to this ember attack as they had no specific design requirements to mitigate the entry of embers into the structure.

Due to the fact that AS 3959 is not applied retrospectively, there were no houses in the Duffy area that had prescribed mitigation measures. The average age of houses in the Duffy area was approximately 30 years. AS 3959 recommends that buildings within 100 m of contiguous forest fuels require specific measures to mitigate ember attack. This requirement would have significantly reduced the levels of house loss in Duffy, but would not have prevented loss altogether. It would also not have prevented loss once a significant number of houses were alight beyond the 100 m perimeter.

The characteristics of a house design, and materials used in construction, influenced house survivability. The investigation of damaged houses provided a large amount of information on the mechanisms of the Duffy bushfire attack, and increased our knowledge of the parameters that could have influenced house survivability.

7. Characteristics of house design and material

In Duffy, 229 houses were surveyed, taking into account house design, materials of construction and the proximity to other features.

General characteristics of the houses showed that they were principally built in 1970 (85%), with 73% of the houses having one functional level, and 22% having two functional levels. Building type is mainly brick veneer (82%).

In order to reduce the risk of house loss, the shapes of buildings should incorporate the minimum number of re-entrant corners or roof valleys where burning debris may accumulate and ignite the building.

The following sections present and discuss the design features that significantly contributed to the vulnerability to ember attack of houses in the surveyed Duffy area.

7.1. Flooring system and external walls

The survey and resulting study of flooring systems and external walls sought to ascertain whether these areas were resistant to ember entry, accumulation, and/or direct ignition.

AS 3959 gives some basic guidelines for the design of flooring systems and external walls in areas likely to be subject to ember attack or low level flame contact (from combustible ground litter). The general rule is to protect combustible wall cladding, and post and poles above a horizontal or near-horizontal surface where debris and embers can accumulate (see Figure 22). Wall vents should be screened with metal mesh (bronze flywire is suitable) to prevent embers from entering underfloor areas.

The schematic in Figure 22 presents an example of the protection that is required in AS 3959, these requirements are prescribed according to the level of bushfire attack the house may receive.

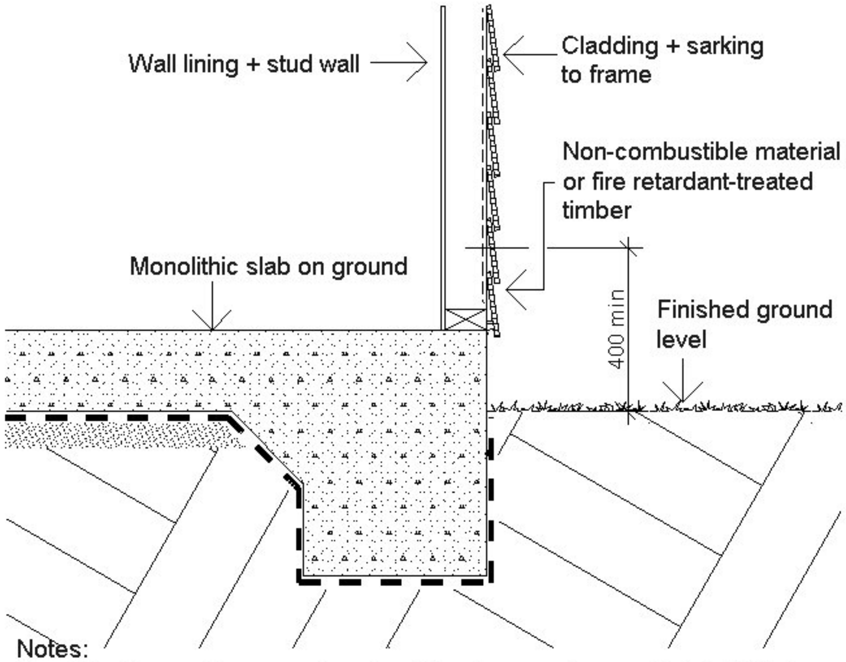

Figure 22. Wall cladding covering a slab-on-ground (extract for AS 3959-1999)

In the houses surveyed, 84% of floors were supported by brick piers, 99% of house external wall materials were brick, and 92% of underfloor enclosures were brick.

Brick construction in this area provides a non-combustible façade. However, these enclosed areas commonly have a large number of vents and gaps that allow ember entry. This point is further discussed in the following section.

7.2. Other accumulation areas – windows, and external doors

Openings present a significant opportunity for embers to penetrate the building envelope. The presence of combustible material increases the risk of ignition. The parameters of these openings were studied in detail in this investigation (frame, kind of material, type of protection, type of damage, etc.). The following subsections detail some of the most significant entry points.

7.2.1. Doors

Doors present, in most cases, a re-entrant corner with re-radiation effects (see Figure 23). An ember landing on one surface may ignite this surface and create a localised flame attack that may or may not develop. The flame impacts on the second surface which is likely to become involved, the two burning surfaces increase the radiation and provoke the ignition of the third face. This phenomenon of re-radiation between surfaces increases the opportunity for a small flame to develop into a significant flaming attack on a structure.

They also present an opportunity for ember entry. Gaps around window frames or around opening windows and doors are common entry points.

Figure 23. Ember attack on a door (re-entrant corner)

A method of reducing this effect is to either screen the door with a non-combustible screen door or use low- or non-combustible materials in the door assembly. The data collected in Duffy suggests some correlation between protected door openings and house survivability; howeverm this correlation is far from conclusive due to the large percentage of destroyed houses for which door protection was not determined (refer Figure 24). An important point to also make is that these screen doors are only effective if they are closed before, during and after the fire event.

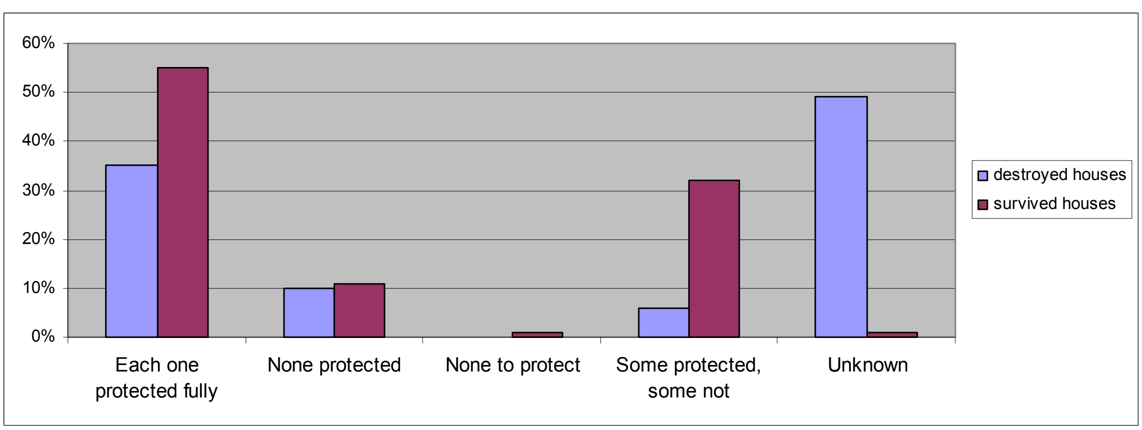

Figure 24. Survey on door protection

7.2.2. Windows Frames

Window glass is particularly vulnerable to direct flame contact, hence the ignition and propagation of a combustible window frame would provide a significant risk to maintaining an integral building envelope. AS 3959 prescribes the use of low- or non-combustible framing materials for certain categories of bushfire attack. Figure 25 provides a visual example of this. If occupant suppression did not occur in this case, the house would have been at great risk of total destruction.

Figure 25. Ember attack at a re-entrant corner

In the houses surveyed, the window framing material was predominantly aluminium.

Figure 26 shows the percentage of each window frame type. There was insufficient data to identify a correlation between window frame type and risk of house loss.

The poor condition of some timber windows could further increase ignitability (see Figure 25).

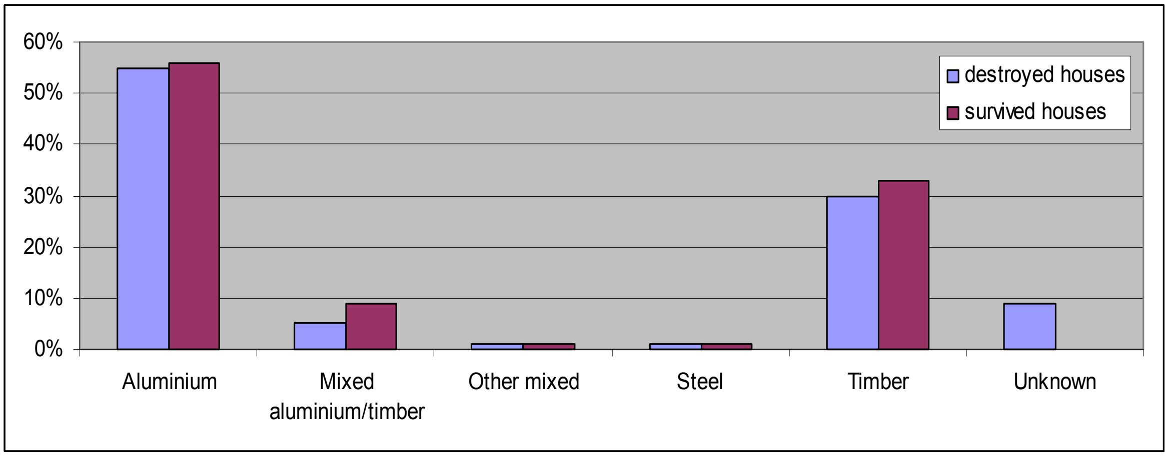

Figure 26. Window frame material

Tight-fitting shutters can provide superior protection for windows as, when closed, they reduce the horizontal projection available for debris accumulation, remove one combustible surface in a re-entrant corner, and provide a radiation and ember barrier. Shutters, however, need to be closed to be effective. Optimum protection is provided by shutters (hinged or roll-down) that are made from materials which are not combustible, such as aluminium or steel. As well as protecting the glazing, shutters usually cover and protect window sills. This is of considerable advantage in the case of timber window sills which, like all horizontal timber elements of a house, are vulnerable to ember ignition.

The houses surveyed in Duffy did not have shutters in the majority of the cases (see Figure 27).

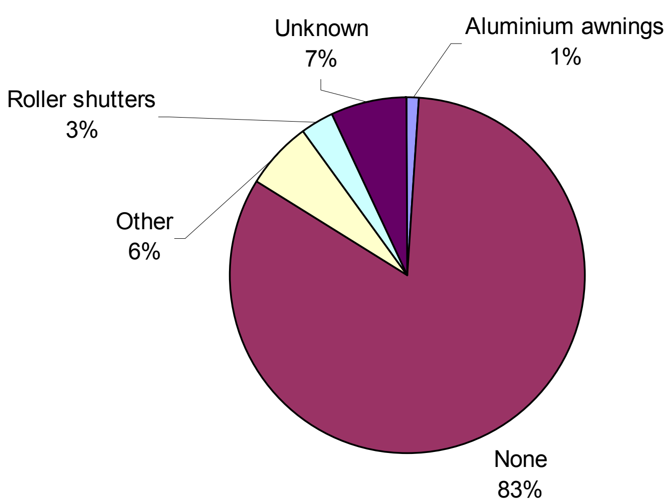

Figure 27. Presence of shutters

7.3. Common gaps and entry points

Gaps in the building envelope are a key area for ember attack. AS 3959 prescribes requirements for gaps greater than 2 mm to be protected. Metal flywire screening is an effective method of protecting these gaps.

7.3.1. Vents

AS 3959 requires that vents and weepholes shall be fitted with ember guards made from non-combustible material, corrosion-resistant steel, bronze or aluminium mesh with a maximum aperture size of 2.0 mm (see Figure 28). Note: care must be taken not to reduce the airflow potential through these vents below recommended levels.

Data collected in the investigation shows that only 31% of the destroyed houses have vents fully protected (see Figure 29).

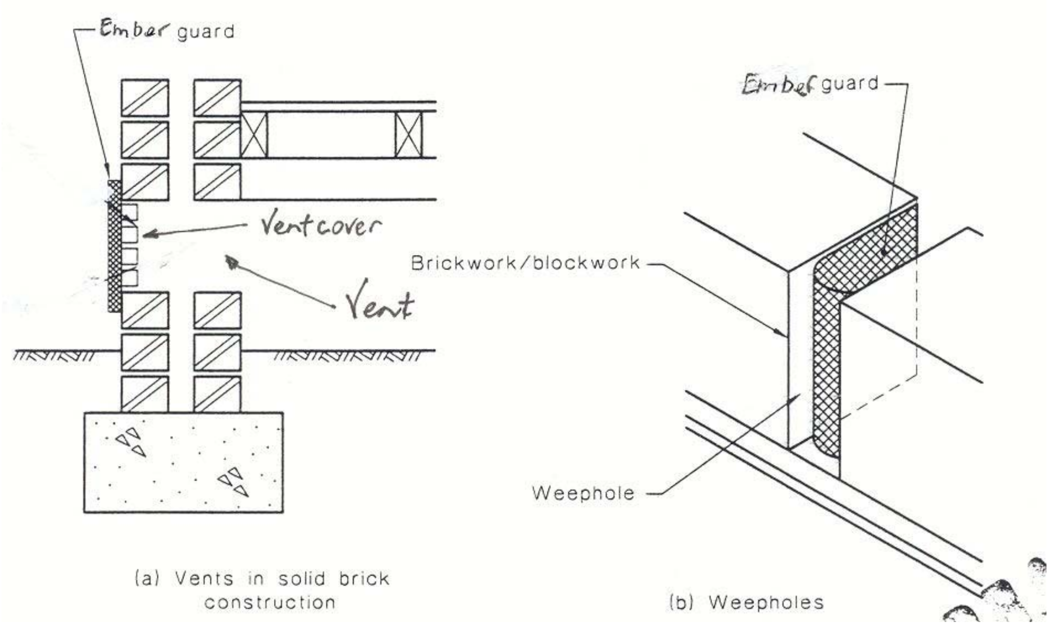

Figure 28. Protection of vents and weepholes required by AS 3959

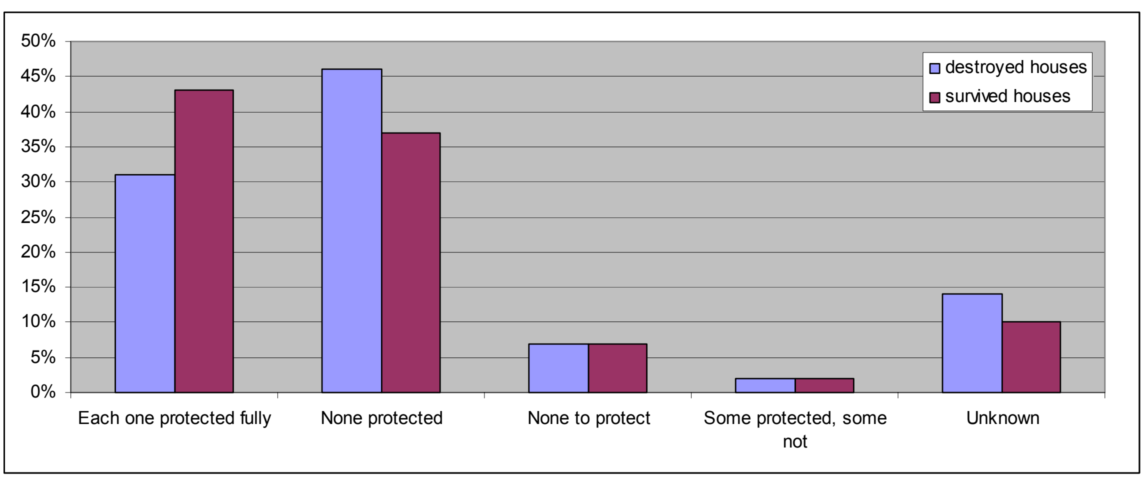

Figure 29. Protection of vents

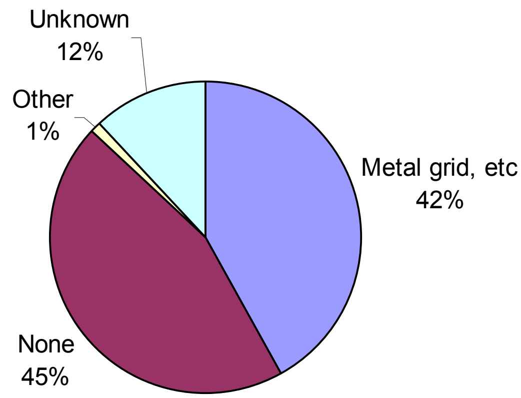

Figure 30. Vent protection material

An example of an unprotected vent in a house surveyed in Duffy is shown in Figure 31.

Figure 31. Typical unprotected vent

7.3.2. Windows

Window glass is a sensitive area of the house, but is not directly affected by ember attack. A secondary element such as a window frame or combustible material must first be ignited to produce sufficient radiant heat and flame for the window to break. Windows are damaged by radiant heat or flame contact either from the flame front itself or from the combustion of building elements or nearby fuel sources (e.g. vegetation, verandah, deck, garage, shed, car, neighbouring houses). If glazing cracks and falls away from an unprotected opening, windborne embers are highly likely to ignite internal furnishings. Passive protection can be provided by glazing options such as wired, laminated or toughened glass. Wired glass is generally confined to bathrooms, laundries and the like, on aesthetic grounds. Laminated glass generally performs better than plain glass, however its performance varies greatly between specific glass laminate formulations. Toughened glass performs better than plain glass and better than virtually all laminates. It is prescribed by AS 3959 for the more extreme categories of bushfire attack.

Double-glazing, or the use of ordinary glass thicker than is required for a particular window size and wind zone, gives little improvement in window performance against intense radiant heat.

AS 3959 specifies wire mesh screens on all opening windows including louvres. This reduces, to some extent, the levels of radiant heat impacting on the glazing and, if the glass cracks and falls away, it can help prevent windborne burning debris from entering the building. It is, however, less effective on the inside of hopper or awning windows, it is difficult to fit on non-opening sashes, especially with aluminium windows, and it impairs the view from picture windows unless special designs are adopted. Figure 32 shows that there is some indication that houses with protected opening sashes are less likely to be lost on a bushfires. However, the statistics are far from conclusive given that there is a statistical bias introduced by the large number of destroyed houses where window protection was not able to be identified.

Additional protection can be provided to window openings by flywire screens. It is important to note that the screening of all opening windows assists in reducing ember entry for partly open windows or windows that provide a greater than 2 mm gap when in a closed position. When screens are fitted to all windows, they reduce the radiation incident on the glassing and provide some ember protection in the event of the glass breaking.

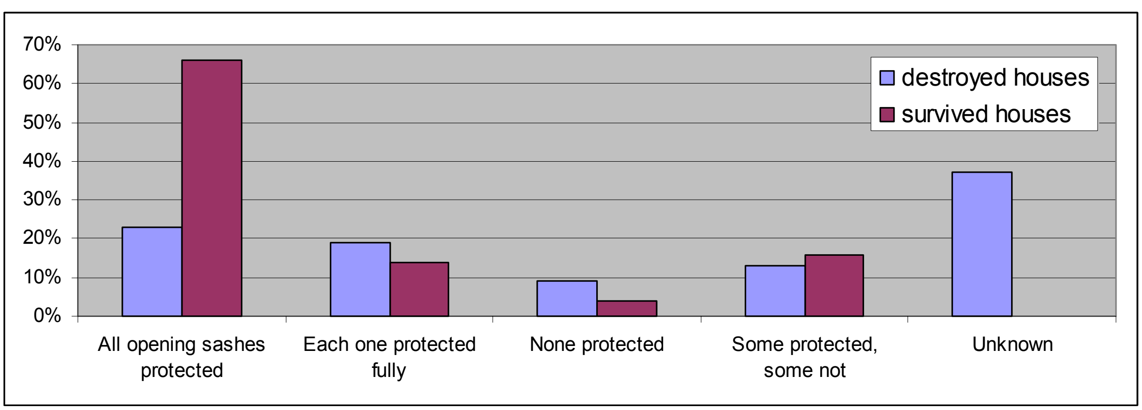

Figure 32. Protection of windows on surviving houses

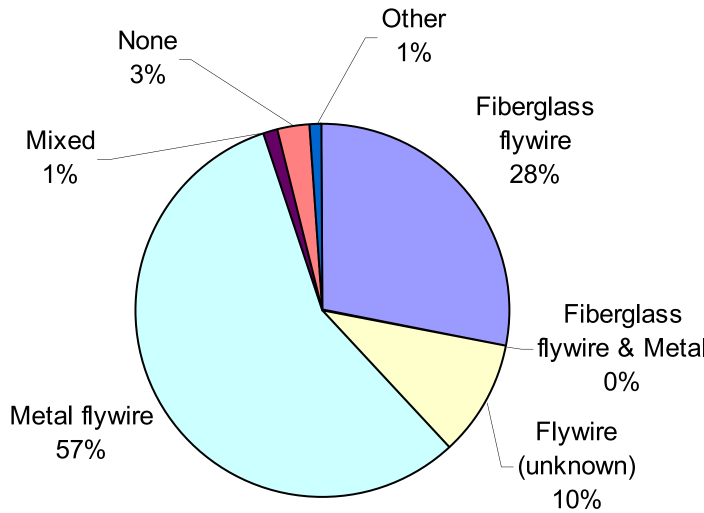

Figure 33. Window protection material for surviving houses

Figure 34. Damage to laminated glass

7.3.3. Roof – and part of the roof (eaves, gutters)

The design of the roof is a vital element in a building's resistance to bushfire attack; certain roof profiles are susceptible to debris built-up and ignition. Virtually all roofs surveyed were not tightly sealed from ember entry. This observation is typical of houses that are approximately 30 years of age.

AS 3959 requires that the roof or roofing systems present some characteristics to prevent ember entrance. Timber shakes or shingles shall not be used for the roof covering. The roof/wall junction shall be sealed either by the use of fascia and eaves linings, or by sealing between the top of the wall and the underside of the roof, and between the rafter at the line of the wall. Roof ventilation must be protected. Pipes and conduits which penetrate the roof covering shall consist of non-combustible materials, and where the gap between the pipe or conduit and the roof covering is greater than 2 mm, the material used to flash the penetration shall also be non-combustible.

The information collected in the survey shows that the predominant roof material is tiles (90%). Tiled roofs contain many gaps, as tiles rarely fit together tightly enough to maintain a less than 2 mm gap. AS 3959 provides the approach to install sarking underneath the tiles to provide an ember-tight barrier. Care must be taken in these cases to provide adequate roof ventilation. Roof ventilation can be effectively screened using metal flywire. Investigation of roof space design is difficult and was not investigated in the scope of this survey.

The roof profiles are predominantly complex in design, the presence of complex ridges mean that many valleys exist. These valleys are areas where accumulation of embers and windborne debris can occur. The fascias and eaves have also been studied to understand the possibility of ignition by embers or radiant heat. Figure 35 and Figure 36 show examples of various attack modes on different eave configurations.

The information contained in the survey shows some differentiation between destroyed and survived, however these considerations are not conclusive until further analysis can be performed to reduce the number of unknown factors. This work is currently under way at CMIT.

7.4. Decks and verandas

CMIT research has found timber decks to be particularly vulnerable to multiple ignitions from ember attack (Leonard 2003b). These small ignitions, if left unattended, can grow to a point where they threaten building elements such as facades, windows and doors, thus threatening the building envelop. In the absence of successful firefighting intervention, this can lead to total destruction of the house. Design alternatives such as suspended concrete decks or decks paved with highly compressed cellulose-cement sheet tend to be considerably more expensive and aesthetically less acceptable than timber decks. Further research is planned by CSIRO to investigate design alternatives to improve the performance of timber decks.

Figure 35. Ember attack on poor fitting capping

Figure 36. Eaves damage due to radiant heat from adjacent fence and vegetation

Of the houses in the surveyed area, 69% either had no deck or had non-combustible decks (Figure 37). A number of examples of timber deck ignitions that were suppressed by occupant activity were noted in the survey (see Figure 38).

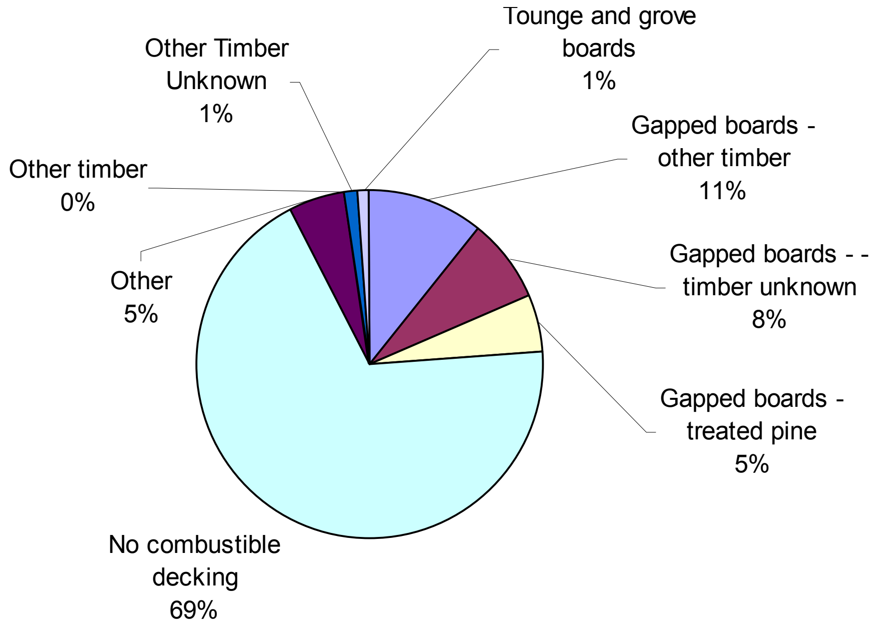

Figure 37. Principal decking material

Figure 38. Ember attack on deck (with intervention)

8. Damage to outbuildings and surroundings

Details of outbuildings (type, degree of damage, materials of construction) and the surrounding environment (type of vegetation, etc.) were also studied in the 2003 Duffy survey. This information is important when considering the risk that these elements may pose on the main residential structure.

8.1. Outbuildings

Outbuildings like garages and sheds present more openings in their structure and are more susceptible to ember-based ignition compared to conventional house design. These outbuildings provide a wide range of functions. Figure 39 shows the range of outbuilding function for the closest outbuilding to the main residential structure provided that it was less than 20 metres away.

The survey highlighted the fact that outbuildings are more readily lost compared to the main structuress and represent a significant impact mechanism for main structure loss. In the survey area, 134 outbuildings were lost, while 106 houses were destroyed. Figure 40 identifies a strong correlation between destroyed outbuildings and destroyed houses. This correlation has obvious interdependency, as a burning house has the potential to ignite an adjoining outbuilding. Also, in areas of high ember attack, house loss and outbuilding loss are going to both be influenced by the increased ember attack. It is fair to conclude that a burning outbuilding presents an increased risk to the house, and that this contributes to the correlation seen in Figure 40.

Detached outbuilding fires can provide significant risk of main structure ignition (Figure 41).

The presence of dry vegetation could increase the risk of attack by embers, flame contact and radiant heat.

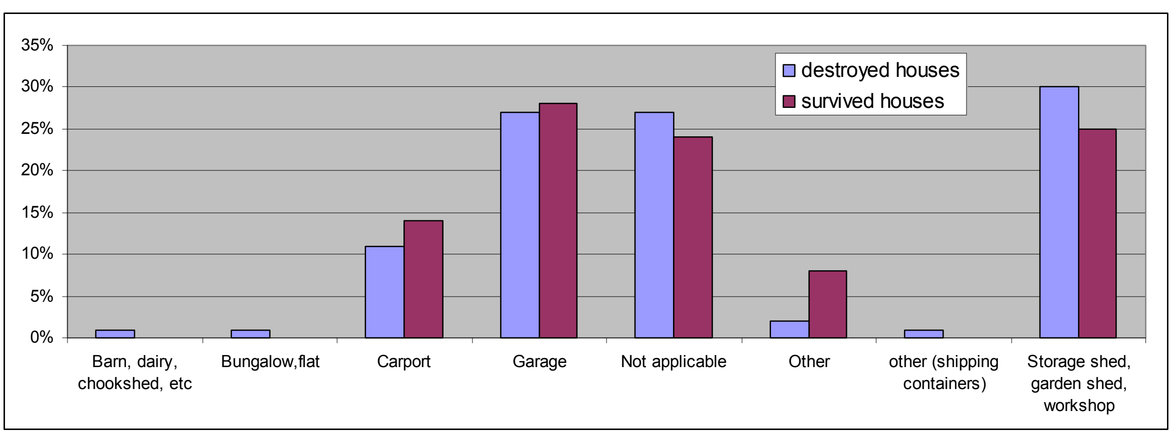

Figure 39. Main function of the first detached outbuilding

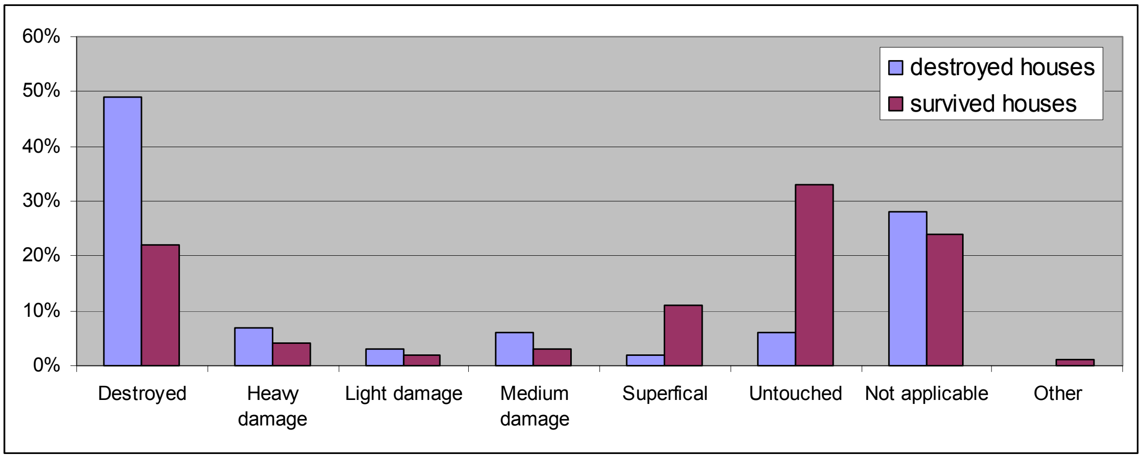

Figure 40. Degree of damage of the first detached outbuilding

Figure 41. Shed fire damage

8.2. Vegetation

The amount and type of vegetation around the house was found to be an important factor in previous bushfire survey investigations (Ramsay *et al*. 1987). Houses were more likely to be damaged or destroyed as the vegetation around them became thicker and the proportion of trees to shrub increased (Ramsay *et al*. 1987). It is desirable to have a fuel-reduced area around a building to reduce the level of hazard, in particular the risk of attack by flame contact and radiant heat (see Section 5). The practical extent of the fuel-reduced area depends on the type of vegetation, slope of the land and its aspect. Advice on the size of this area can be obtained from the appropriate fire authority. In some cases, it may include neighbouring lots or public land, necessitating approaches to owners for concerted action. The management of existing vegetation involves both selective fuel reduction (removal, thinning or pruning) and the retention of vegetation, which may have beneficial effects by acting as windbreaks and radiant heat barriers.

Certain types of vegetation are particularly susceptible to fire, for example cypress trees produce large quantities of dead material, and the intensity at which they burn may adversely impact on structures in the vicinity (see Figure 42 to Figure 44). The performance of this vegetation type is a direct observation of the survey initiative.

The following case study highlights the role that this vegetation type plays in house ignition.

Figure 42. Cypress tree (large quantities of dead material inside the tree, example not in Duffy area)

Figure 43. Pines fence responsible for ignition of 74 Somerset and 2 Cargelligo St

The extensive row of pine trees between 74 Somerset St and 2 Cargelligo St (see Figure 43) wase most likely ignited by ember attack from houses on the other side of the road. The combustion of this kind of pine tree presents a very high risk from radiant heat and embers to the adjacent houses. This situation is exacerbated by windows facing these pencil pines. This observation is emphasised by the fact that the aerial picture (Figure 43) shows no other ignition in the vegetation in front of the house (unburnt trees).

The condition and type of vegetation in Duffy significantly exacerbated the progression of structural loss deep into urban areas. Extensive water restrictions and low rainfall left vegetation immediately around the structures in a very dry and susceptible state. This also led to the ground cover having very low moisture content and a greater thickness due to the lack of natural composting. Many of the vegetation types found in Duffy were highly combustible (see Figure 44).

Figure 45 shows another example of how the proximity of vegetation provides direct flame and radiation attack on the main structure. In this case, the window was broken during the attack and a gas meter positioned at the corner of the structure provided further impact on the windows and eaves. This structure was defended by occupants during the fire event. Further discussion on gas meter performance can be found in Section 8.3.

Figure 44. Pencil pine trees heavily burnt (fence between 74 Somerset and 2 Cargelligo St)

Figure 45. Local fuel impact on a structure

8.2.1. Fences

The contribution of fencing systems to the risk to the main residential structure was observed on many cases in Duffy. As detailed in previous sections timber fencing and vegetation adjacent to houses has the potential to break windows and ignite combustible features of the home. Figure 45 also provides an example of how timber fences contribute to the overall radiation and flame attack on a structure. In a number of cases, the fence was responsible for spreading the flame up between houses.

Figure 46 shows how common fence design provides re-entrant corners ideal for ember lodgement nd transition to flaming.

In some cases, non-combustible fences provided radiation barriers, thus reducing the potential for fire attack from either the main fire front or the burning of an adjacent structure. Figure 47 shows heat-affected metal panels that have played a significant role in preventing ignition of stored material and structural elements of the house.

Additional factors influenced the damage of houses, for example the breaching of gas lines.

Figure 46. Ember attack on fence (with intervention)

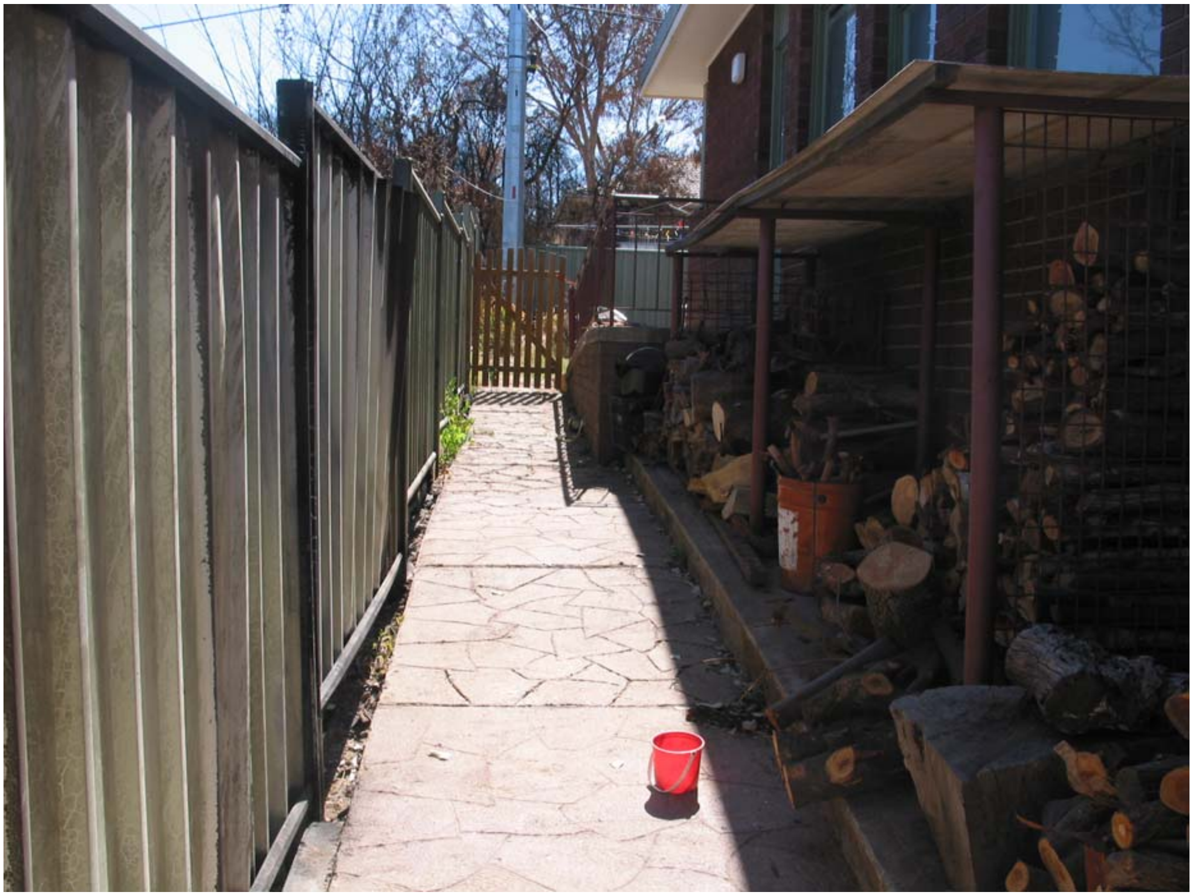

Figure 47. Benefits of non combustible fencing

8.3. Breaching of gas lines

The contribution of gas supply infrastructure to the bushfire threat on structures has traditionally been limited to liquid petroleum gas (LPG) storage vessels for either house supply or barbeque supply. The general advice as to the installation and storage or these vessels has been to store them away from the house if possible, and store them with the pressure relief valve facing away from the house. In the Duffy investigation, the presence of LPG barbeque bottles was observed, with only a small number venting during the event.

An unusual observation, however, was made in the behaviour of the mains gas supply infrastructure. The mains pressure supply lines to many of the Duffy houses was via a flexible polymer coated hose (Figure 48).

In a number of cases, these flexible lines ruptured after receiving low-level flame contact. The presence of a burning gas plume adjacent to a structure represented a significant risk to the structure. AS 3959 requires all pipe infrastructure supplying a dwelling with essential services utilise non-combustible piping. Figure 49 provides a visual example of how this mode of attack affects a residential structure.

Figure 48. Flexible gas line supply to gas meter

Figure 49. Gas meter flaring attack on eaves

The last part of the investigation deals with the role of the occupant before, during and after the fire.

9. Role of the occupant (human behaviour and evacuation issues)

Bushfire is an inevitable part of living at the urban interface and in peri-urban area. The way people deal with this risk varies greatly across the Australian demographic.

Previous research has shown that human activity can influence the survivability of structures (Leonard & Bowditch 2003). The results from the 1983 survey after the Ash Wednesday fires showed that people played an important role in house survival, by extinguishing both ignitions of a house and burning materials around a house (Ramsay *et al.* 1987).

In order to better understand the human dimension during a bushfire, the activities of occupants, neighbours and firefighters were recorded during the Duffy survey (see Figure 30).

Information on occupant behaviour was obtained for 50% of the houses in the Duffy area. The information should be used with caution as there is a bias introduced by the lower number of known occupant behaviour for destroyed houses. However, the interviews of people who had stayed with their house have broadened the general understanding of the mechanisms of bushfire attack. This information provides a framework for discussion of the problems that an occupant is likely to face.

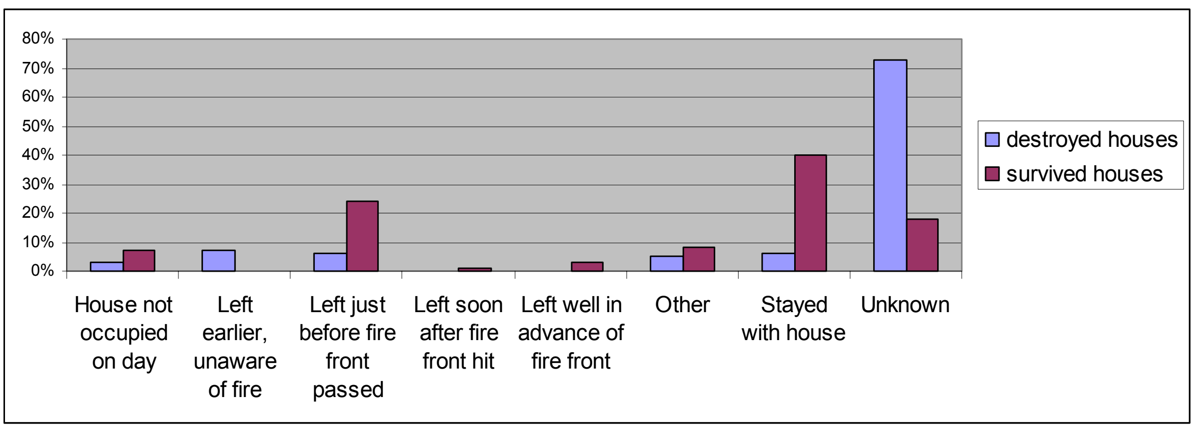

Figure 50. Action of occupants before, during and after the fire

A simple analysis of occupancy behaviour to the houses closest to the fire front have been summarised in Table 2. The occupancy of houses for the first and second rows back from Eucumbene and Warragamba Avenue reveal that, in fact, more people in the first row stayed with their house during the entire fire event.

Table 2. Occupant behaviour

Occupant behaviour	First line		Second line	
	Surviving houses (20)	Destroyed houses (22)	Surviving houses (15)	Destroyed houses (19)
Stayed with the house (before, during and after fire front passed)	14		7	2*
Left after fire front passed and returned after 12 hours		1	1	
Left after fire front passed	1	1	2	
Left before fire front passed and returned after 3 hours	1			2
Left before fire front passed and returned after 6 hours	1		1	
Left before fire front passed and returned after 12 hours	2	3	2	2
Left before fire front passed		1		
Away – left early		2	1	2
Unknown	1	14	1	11

* Of the two cases of people staying (with regrettably the death of one of the occupants

10. Time based study of house losses

As a general rule, houses are reduced to rubble within one hour of the internal furnishings becoming involved in fire. The following case study provides an example of house loss that has occurred many hours after the fire front has reached Canberra in the January 2003 fires.

Phil Cheney mentioned that the fire reach the corner of Warragamba Ave and Eucumbene St Duffy at15:05. By 15:45 the fire had entered the suburb of Duffy between Dixon Drive and Hindmarsh Drive (see ‘Origin and Development of the Bushfires that Spread Into the ACT, 8–18 January 2003’ by N.P. Cheney, Principal Research Scientist, CSIRO Forestry & Forest Products). See Figure 51 for details.

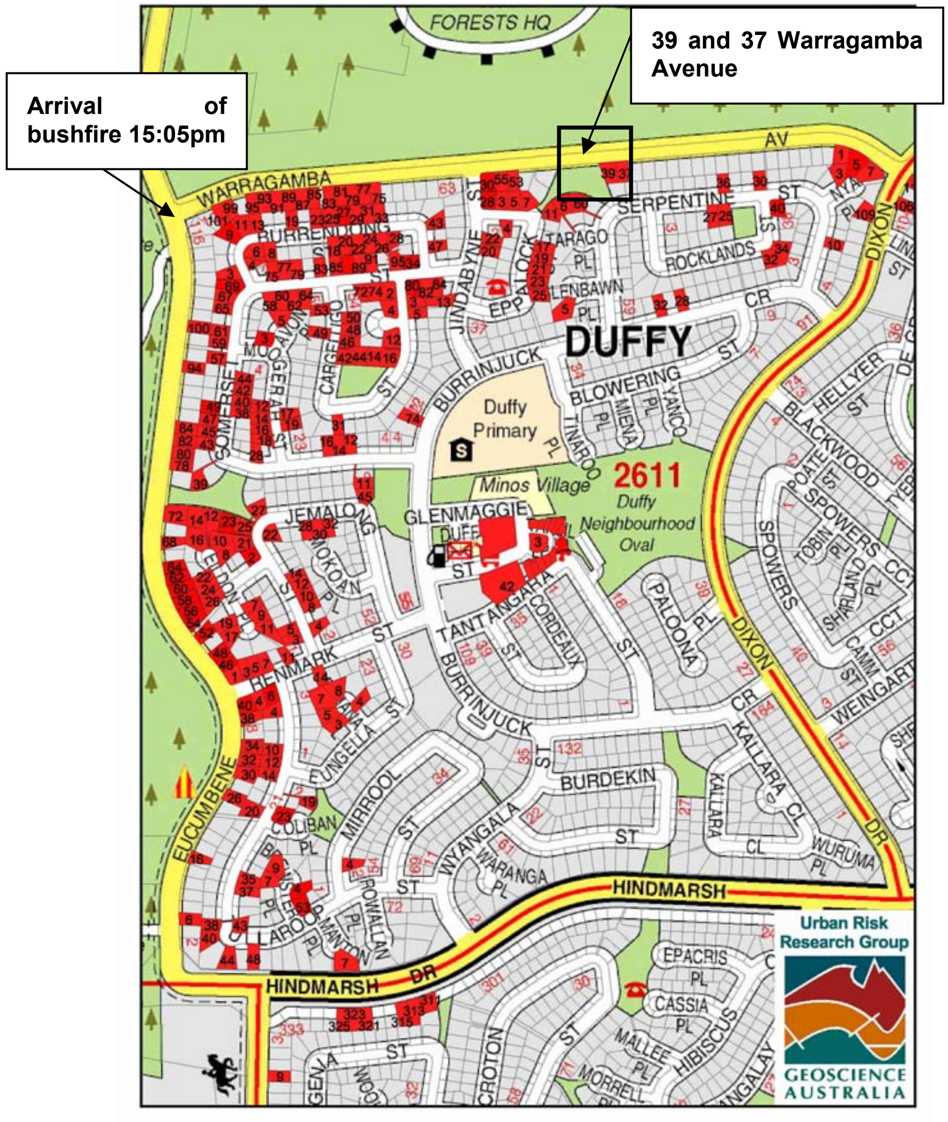

Figure 51 Fire passage in Duffy suburb

An Aerial photo showing number 37, 39 Warragamba Av was taken at 7:09 pm on the 18th of January, see Figure 52. This photo identifies that the houses at 39 Warragamba Avenue was reduced to smouldering rubble at this time, while the house at 37 Warragamba Ave was burning vigorously. This provides an important example of how 37 Warragamba Avenue burnt down well after the main fire event. 37 Warragamba Avenue was most likely ignited by radiation and flame impact from the adjacent house fire at 39 Warragamba Avenue.

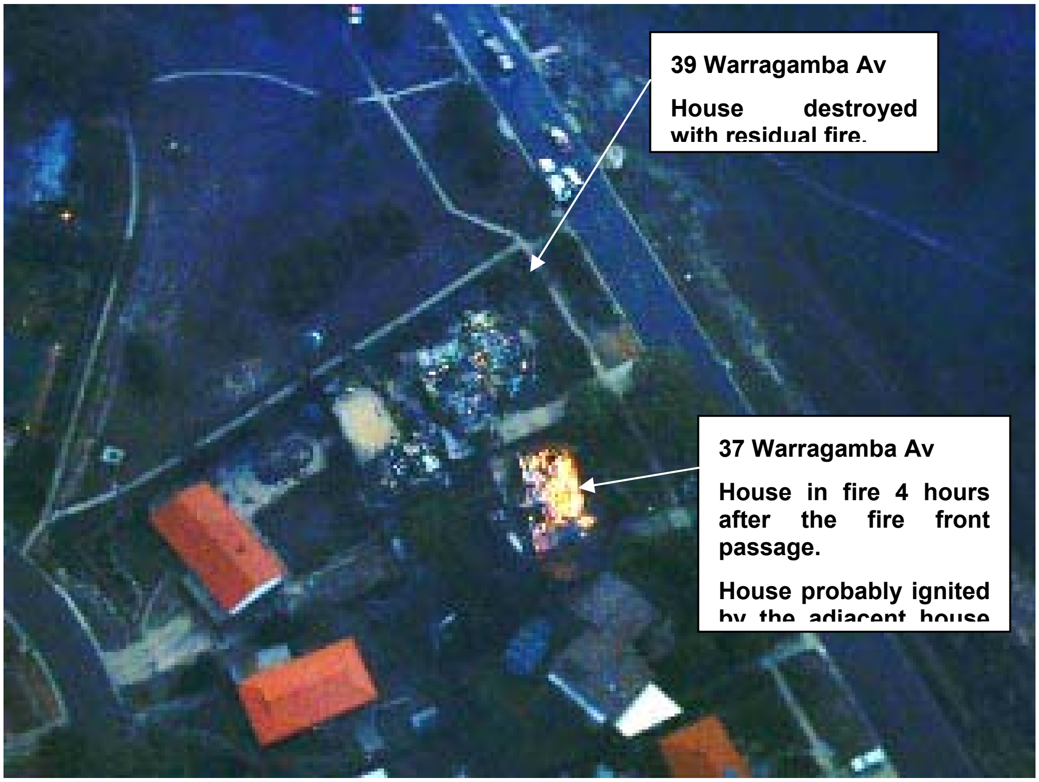

Figure 52 Aerial picture of 37 and 39 Warragamba Av taken at 7:09 pm (Photo kindly provide by Steve Wilkes)

This provides an important example of the time based nature of house lose in urban interface fires. The deployment of fire fighting resources into areas that have recently been impacted by a bushfire event may be an effective strategy for reducing house loss.

11. Key point – significant factors specific to Canberra

General observations of the losses in Canberra identified areas where high winds had damaged houses prior to the fire front reaching the area. However, in Duffy wind damage was not evident. It appears that in Duffy most houses were ignited by either ember attack or house-to-house ignition.

The initial vegetation and structural fires in Duffy created an even more concentrated and enduring ember attack for those further downwind. The ember attack caused by persistent winds blowing over structural fires played a role in the spread of fire deep into urban areas. Some of the structural fires provided direct flame attack and radiation impact on adjacent structures. This effect was exacerbated by the placement of relatively large houses on medium sized blocks, and the presence of timber fences and vegetation between the closely aligned structures.

These impacts endured throughout the afternoon and well into the night of 18 January 2003. CSIRO found many examples of community and agency suppression activities during this time, with many houses being saved. The presence of brigades and resident activity deep within the Duffy area was low compared to previous surveyed bushfires. Traditionally, it has been accepted that suppression activities by agencies and residents are sufficient to mitigate the spread of structural fires deep into urban areas. The house loss in Duffy stands as an isolated example of how this assumption is not always true.

In each major bushfire surveyed by CMIT (Leonard & McArthur 1999) ember attack has been identified as a key ignition mode for both the initial attack and through house to house transfer. The presence of very hot and dry conditions, coupled with extensive water restrictions created an urban environment that was very susceptible to ember attack and ember production.

The synergistic effect of a number of factors (as listed above) resulted in an unusually high number of houses lost deep within the urban area of Canberra – a degree of loss that had previously been considered unlikely.

12. Recommendations to mitigate bushfire impact at the urban interface

1. Implement the provisions of AS 3959 to the Canberra urban interface. In virtually all cases, the exposure level will be deemed to be medium in accordance with the provisions of AS 3959 requiring the provision of basic ember protection at little additional cost to construction. This zoning may also lead to increased voluntary adoption of these mitigation measures.
2. Encourage the community to become bushfire aware and suggest the benefits of retrofitting basic ember protection provisions to their homes if they are deemed to be in a medium level zone as defined in AS 3959.
3. Continue the strategy of using perimeter roads as radiation and flame buffers for urban assets.
4. Provide an effective community education program that integrates knowledge of bushfire behaviour with knowledge of an effective warning system and an understanding of the urban design principles that contribute to a specific level of risk.
5. Utilise the knowledge collected in the Canberra fires to influence the priorities on which all regulatory reform and community education are based.
6. Provide risk assessment methodologies that identify both the risk of a bushfire attack and the susceptibility of an urban and peri-urban area.
7. Encourage the use and positioning of outbuildings around residential structures that reduce their potential ignition and impact on the main structure.
8. Ensure that house losses many hours after a bushfire front has impacted an urban area is a consideration when allocating fire fighting resources to the event.

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14. Questionnaire

CSIRO

BUSHFIRE BUILDING DAMAGE SURVEY

Fire I/D

Survey no.

Address: ....
(of surveyed building)
Town: ....

Nearest intersection: ....

Other identifier: ....
(house name, opposite fire station, etc.)

☐ House survived
☐ House destroyed, site not cleared
☐ House destroyed, site cleared

Location sketch map

Owner's name: ....

Contact address: ....

.... **Postcode:** ....

Phone numbers: BH (   ) .... AH (   ) ....

Mobile: .... **Fax:** (   ) ....

Email: ....

Surveyed by: .... and ....

Date: ....

Images/photos:

BUILDING DETAILS

1 Degree of damage – house

1 ☐ Untouched
2 ☐ Superficial
3 ☐ Light damage
4 ☐ Medium damage
5 ☐ Heavy damage
6 ☐ Destroyed
7 ☐ Other ....
9 ☐ Unknown

---

2 Number of functional levels

1 ☐ One level
2 ☐ Split single level
3 ☐ Two levels
4 ☐ More than two full levels
5 ☐ Other (illustrate) ....
9 ☐ Unknown

3,4 Distance from edge of floor to ground

3 Side nearest ground (at lowest point) **4 Side furthest from ground** (at highest point)

3		4	
☐	1	☐	Contacting ground, slab
☐	2	☐	<600 mm
☐	3	☐	600 mm to 1.6 m
☐	4	☐	>1.6 m
☐	9	☐	Unknown

---

5 Major material supporting floors

1 ☐ Treated pine
2 ☐ Other timbers
3 ☐ Concrete stumps, etc.
4 ☐ Steel posts
5 ☐ Brick piers, walls
6 ☐ Other ....
7 ☐ Slab on ground
9 ☐ Unknown

6–9 Predominant external wall material

6,7 Major portion of house

6 Broad classification		7 Narrower classification	
1	☐ Timber	1	☐ Smooth weatherboard (painted)
2	☐ Cellulose cement	2	☐ Rough-sawn weatherboard
3	☐ Brick (other than mud brick)	3	☐ Treated pine logs
4	☐ Mud brick	4	☐ Other timber ……………………………
5	☐ Aluminium siding	5	☐ Cellulose cement flat sheets
6	☐ PVC siding	6	☐ Cement planks, profiles
7	☐ Other ……………………………..	8	☐ Not applicable (brick, etc.)
9	☐ Unknown	9	☐ Unknown

8,9 Minor portion of house

8 Broad classification		9 Narrower classification	
1	☐ Timber	1	☐ Smooth weatherboard (painted)
2	☐ Cellulose cement	2	☐ Rough-sawn weatherboard
3	☐ Brick (other than mud brick)	3	☐ Treated pine logs
4	☐ Mud brick	4	☐ Other timber ……………………………
5	☐ Aluminium siding	5	☐ Cellulose cement flat sheets
6	☐ PVC siding	6	☐ Cement planks, profiles
7	☐ Other ……………………………..	8	☐ Not applicable (brick, etc.)
9	☐ Unknown	9	☐ Unknown

10 Underfloor enclosure

1	☐ Stump battens	5	☐ Not enclosed
2	☐ Cement sheet	7	☐ Other ……………………………………
3	☐ Brick	8	☐ Slab, no underfloor space
4	☐ Concrete	9	☐ Unknown

11 Predominant roof material

1	☐ Metal deck	5	☐ Metal pseudo tiles
2	☐ Corrugated iron	7	☐ Other ……………………………………
3	☐ Corrugated cement sheet	9	☐ Unknown
4	☐ Tiles (terracotta, concrete)		

12 Size of house

1	☐	Small, <80 m^2	5	☐	Large, >150 m^2
2	☐	Medium, 80–150 m^2	9	☐	Unknown

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13 Roof profile

1	☐	One slope, no ridge or valley	4	☐	Complex ridge
2	☐	One ridge, no valley	7	☐	Other ....
3	☐	One valley, no ridge	9	☐	Unknown

---

14 Window frame materials

1	☐	Aluminium	5	☐	Other mixed
2	☐	Timber	7	☐	Other ……………………………………….
3	☐	Steel	9	☐	Unknown
4	☐	Mixed aluminium/timber			

15–20 Protection of openings

15–17		**Protection extent**		**15 Windows**	**16 Doors**	**7 Vents**
1	☐	Each one protected fully	1	☐	☐	☐
2	☐	All opening sashes protected	2	☐		
3	☐	Some protected, some not	3	☐	☐	☐
4	☐	None to protect	4			☐
8	☐	None protected	8	☐	☐	☐
9	☐	Unknown	9	☐	☐	☐

18–20		**Protection material**		**18 Windows**	**19 Doors**	**20 Vents**
1	☐	Metal flywire	1	☐	☐	☐
2	☐	Fibreglass flywire	2	☐	☐	☐
3	☐	Flywire (unknown)	3	☐	☐	☐
4	☐	Metal grid, etc.	4	☐	☐	☐
5	☐	Mixed	5	☐	☐	☐
7	☐	Other …………………………	7	☐	☐	☐
8	☐	None	8	☐	☐	☐
9	☐	Unknown	9	☐	☐	☐

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21 Window screen position

1	☐	Outside	8	☐	None
2	☐	Inside	9	☐	Unknown
3	☐	Outside and inside			

22 Window shutters

1 ☐ Roller shutters
2 ☐ Aluminium awnings
7 ☐ Other ....
8 ☐ None
9 ☐ Unknown

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23 Skylights

1 ☐ Plastic
2 ☐ Plain glass
3 ☐ Wired glass
7 ☐ Other ....
8 ☐ None
9 ☐ Unknown

24–27 Decks, verandahs, balconies with combustible decking

24 Extent of combustible decking

1 ☐ Up to 1/2 side (including porch, landing)
2 ☐ 1/2 + 1/2 side
3 ☐ 1 side
4 ☐ 1 1/2 sides
5 ☐ 2 side
6 ☐ >2 sides
7 ☐ Other ....
8 ☐ No combustible decking
9 ☐ Unknown

---

25 Principal decking material

1 ☐ Tongue and groove boards
2 ☐ Gapped boards – treated pine
3 ☐ Gapped boards – other timber
4 ☐ Gapped boards – timber unknown
5 ☐ Bituminous membrane
7 ☐ Other ....
8 ☐ No combustible decking
9 ☐ Unknown

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26 Timber support poles – material

1 ☐ Treated pine
2 ☐ Red gum
3 ☐ Other timber
4 ☐ Timber (unknown)
8 ☐ No timber support poles
9 ☐ Unknown

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27 Timber support poles/ground interface

1 ☐ Ground contact, unprotected
2 ☐ Ground contact, sleeved min. 400 mm
3 ☐ No ground contact, stirruped etc.
8 ☐ No timber support poles
9 ☐ Unknown

28,29 External stairs (more than 3 steps)

28 Strings		29 Treads	
☐	1	☐	Treated pine
☐	2	☐	Red gum
☐	3	☐	Other timber
☐	4	☐	Timber (unknown)
☐	5	☐	Metal
☐	6	☐	Other non-combustible
☐	7	☐	Other ....
☐	8	☐	No external stairs
☐	9	☐	Unknown

30–41 Detached outbuildings within 20 m of house (largest first)

30–32 Function of detached outbuilding

	1st	2nd	3rd	
1	☐	☐	☐	Garage
2	☐	☐	☐	Carport
3	☐	☐	☐	Bungalow, flat
4	☐	☐	☐	Laundry, toilet
5	☐	☐	☐	Storage shed, garden shed, workshop
6	☐	☐	☐	Barn, dairy, chookshed, etc.
7	☐	☐	☐	Other ....
8	☐	☐	☐	Not applicable
9	☐	☐	☐	Unknown

33–35 Degree of damage – detached outbuildings

	1st	2nd	3rd	
1	☐	☐	☐	Untouched
2	☐	☐	☐	Superficial
3	☐	☐	☐	Light damage
4	☐	☐	☐	Medium damage
5	☐	☐	☐	Heavy damage
6	☐	☐	☐	Destroyed
7	☐	☐	☐	Other ....
8	☐	☐	☐	Not applicable
9	☐	☐	☐	Unknown

36–41 Materials – detached outbuildings

36–38 External walls

	1st	2nd	3rd	
1	☐	☐	☐	Timber
2	☐	☐	☐	Iron, steel
3	☐	☐	☐	Aluminium
4	☐	☐	☐	Cement fibre
5	☐	☐	☐	Brick
7	☐	☐	☐	Other ....
8	☐	☐	☐	Not applicable
9	☐	☐	☐	Unknown

39–41 Roof

	1st	2nd	3rd	
1	☐	☐	☐	Steel
2	☐	☐	☐	Aluminium
3	☐	☐	☐	Cement fibre
7	☐	☐	☐	Other ....
8	☐	☐	☐	Not applicable
9	☐	☐	☐	Unknown

42,43 Combustibles

42 Gas bottles (other than household supply)

1	☐	Inside house	6	☐	Under, outside
2	☐	Under house	7	☐	Other (including all) ....
3	☐	Outside house	8	☐	None
4	☐	Inside, under	9	☐	Unknown
5	☐	Inside, outside			

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43 Building materials, wood heaps

1	☐	Under house	6	☐	Outside, outbuilding
2	☐	Outside house	7	☐	Other (including all) ....
3	☐	Outbuilding	8	☐	None
4	☐	Under, outside	9	☐	Unknown
5	☐	Under, outbuilding			

44–48 External LPG cylinders (household supply)

44 Position

1 ☐ Against external wall
2 ☐ Under verandah, etc.
3 ☐ Remote from house, <6 m
4 ☐ Remote from house, >6 m
7 ☐ Other ....
8 ☐ No bottled gas installed
9 ☐ Unknown

45 Security

1 ☐ Free standing
2 ☐ Secured
7 ☐ Not applicable
9 ☐ Unknown

46 Behaviour

1 ☐ Undamaged
2 ☐ Heat affected – not vented
3 ☐ Heat affected – vented
4 ☐ Heat affected – venting unknown
5 ☐ Split, ruptured
6 ☐ Bottle condition unknown
7 ☐ Other ....
8 ☐ Not applicable
9 ☐ Unknown

47 Preserved ignition point evidence

1 ☐ Windowsill, door frame
2 ☐ Wall cladding
3 ☐ Stump battens
4 ☐ Fascia board
5 ☐ External stairs
6 ☐ Timber deck
7 ☐ Other ....
8 ☐ None
9 ☐ Unknown

48 Solid fences (in direction of fire approach)

1 ☐ Brick, stone
2 ☐ Metal panel
3 ☐ Cement sheet profile etc.
4 ☐ Timber, not ignited
5 ☐ Timber, ignited
7 ☐ Other ....
8 ☐ None
9 ☐ Unknown

49–54 Occupant action

49 Before fire front passed

1 ☐ Left earlier, unaware of fire
2 ☐ Left well in advance of fire front
3 ☐ Left just before fire front passed
4 ☐ Stayed with house
7 ☐ Other ....
8 ☐ House not occupied on day
9 ☐ Unknown

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50 After fire front passed

1 ☐ Stayed with house
2 ☐ Returned within 30 minutes
3 ☐ Returned within 3 hours
4 ☐ Returned within 6 hours
5 ☐ Returned within 12 hours
6 ☐ Returned after 12 hours
7 ☐ Other ....
8 ☐ Stayed away
9 ☐ Unknown

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51 Evacuation behaviour

1 ☐ Forced to leave by emergency services
2 ☐ Given the option to leave by emergency services
3 ☐ Left by own decision
4 ☐ Elected to stay
5 ☐ Unable to leave due to fire
6 ☐ Unable to leave – other reason ....
7 ☐ Other action ....
8 ☐ House not occupied on day
9 ☐ Unknown

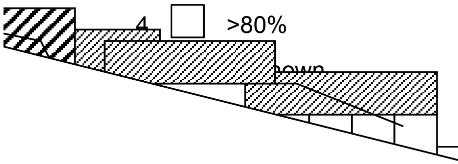
---

52 Cause of damage to house

1 ☐ Fire only
2 ☐ Wind only
3 ☐ Fire and wind
4 ☐ Fire damage, wind unknown
7 ☐ Other ....
8 ☐ Untouched, no damage
9 ☐ Unknown

53 Glassed area – worst wall

1 ☐ <30%
2 ☐ 30–50%
3 ☐ 50–80%
4 ☐ >80%
9 ☐ Unknown



54 Largest single pane of glass (including sliding doors)

1 ☐ <1.5m²
2 ☐ 1.5–2m²
3 ☐ 2.5–4m²
4 ☐ >4m²
9 ☐ Unknown

55 House site

1 ☐ 1–5° slope
2 ☐ 6–12°, house built to slope
3 ☐ 6–12°, house cut in
4 ☐ 13–30°, house built to slope
5 ☐ 13–30°, house cut in
6 ☐ >30° slope
7 ☐ Other ....
8 ☐ No slope – flat
9 ☐ Unknown

Cut in

Built to slope

56,57 Firefighting

56 Pre-fire activities (filling gutters, hosing walls, etc.) carried out by:

1 ☐ Fire brigade
2 ☐ Occupants
3 ☐ Others
4 ☐ Fire brigade, occupants
5 ☐ Fire brigade, others
6 ☐ Others, occupants
7 ☐ Someone
8 ☐ None
9 ☐ Unknown

57 Firefighting activities during and after the fire (extinguishing ignitions, etc.) carried out by:

1 ☐ Fire brigade
2 ☐ Occupants
3 ☐ Others
4 ☐ Fire brigade, occupants
5 ☐ Fire brigade, others
6 ☐ Others, occupants
7 ☐ Someone
8 ☐ None
9 ☐ Unknown

58 Bushfire attack mechanisms

1 ☐ Embers only
2 ☐ Embers and some radiant heat
3 ☐ Predominant radiant heat
4 ☐ Flame contact from bush vegetation
7 ☐ Other ....
8 ☐ No direct bushfire attack
9 ☐ Unknown

---

59 House-to-house fire spread

1 ☐ Unlikely house-to-house spread
2 ☐ Probable house-to-house spread (from house No. ....)
3 ☐ Identified house-to-house spread (from house No. ....)
7 ☐ Other ....
8 ☐ Identified absence of house-to-house spread
9 ☐ Unknown

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60 Glazing damage (to windows in the direction of fire approach)

1 ☐ Glass cracked in place
2 ☐ Glass fallen mainly inside, clean
3 ☐ Glass fallen mainly outside, clean
4 ☐ Glass fallen mainly inside, some soot-stained
5 ☐ Glass fallen mainly outside, some soot-stained
7 ☐ Glass intact
8 ☐ Other ....
9 ☐ Unknown