



**Victorian 2009 Bushfire  
Research Response**

**Final Report**

**October 2009**



## Bushfire CRC

### Building and land-use planning research after the 7<sup>th</sup> February 2009 Victorian bushfires Preliminary findings

Kilmore East – Murrindindi – Churchill – Bunyip –  
Maiden Gully

Justin Leonard, Raphaele Bianchi, Felix Lipkin, Glenn Newnham,  
Anders Siggins, Kimberley Opie, Darius Culvenor  
CSIRO Sustainable Ecosystems, Bushfire CRC

and

Bob Cechet, Neil Corby, Chris Thomas, Nariman Habili,  
Matthew Jakab, Rohan Coghlan, Giovanna Lorenzin,  
David Campbell and Matthew Barwick  
Geoscience Australia

**USP2008/018**  
**CAF122-2-12**

**Final Report – October 2009**

**In confidence**

Enquiries should be addressed to:  
Justin Leonard  
CSIRO Sustainable Ecosystems  
PO Box 56, Highett 3190, Victoria

### **Important disclaimer**

CSIRO advises that the information contained in this publication comprises general statements based on scientific research. The reader is advised and needs to be aware that such information may be incomplete or unable to be used in any specific situation. No reliance or actions must therefore be made on that information without seeking prior expert professional, scientific and technical advice. To the extent permitted by law, CSIRO (including its employees and consultants) excludes all liability to any person for any consequences, including but not limited to all losses, damages, costs, expenses and any other compensation, arising directly or indirectly from using this publication (in part or in whole) and any information or material contained in it.

# Contents

<b>1.</b>	<b>Introduction – Context .....</b>	<b>9</b>
<b>2.</b>	<b>Summary of Fires .....</b>	<b>10</b>
<b>3.</b>	<b>Objectives .....</b>	<b>12</b>
<b>4.</b>	<b>Background .....</b>	<b>13</b>
4.1	Historic house loss in bushfires .....	13
4.1.1	Previous post-bushfire survey efforts .....	13
4.1.2	Definition of risk-based approach to bushfire house loss .....	14
4.1.3	Key findings from past bushfire surveys .....	14
4.2	Land-use planning in Victoria .....	16
4.2.1	Victorian legislation .....	16
4.2.2	Development controls in bushfire-prone areas .....	16
4.2.3	Planning system .....	16
4.2.4	Building system .....	17
<b>5.</b>	<b>Methodology .....</b>	<b>19</b>
5.1	Field data collection .....	19
5.1.1	Objective .....	19
5.1.2	Field site selection .....	20
5.1.3	Data-capture kit design .....	21
5.1.4	Kit usage description .....	22
5.1.5	Customised ArcPad software description and use .....	22
5.1.6	Data management .....	24
5.1.7	Post-processing data .....	25
5.2	Remote sensing demonstration study – data and analysis .....	25
5.2.1	Summary of data source .....	28
5.2.2	Airborne LiDAR data (Digital Elevation Model, vegetation structure) .....	28
5.2.3	Pre and post-fire imagery (burnt severity of forest area) .....	35
5.2.4	Structure locations and attributes .....	38
5.3	Other spatial datasets .....	41
5.3.1	Human behaviour .....	41
5.3.2	Weather conditions .....	41
5.3.3	Fire behaviour .....	42
<b>6.</b>	<b>Data analysis .....</b>	<b>43</b>
6.1	Statistical analysis on field data .....	43
6.2	Calculation of local statistics using remote sensing .....	45
<b>7.</b>	<b>Results .....</b>	<b>47</b>
7.1	Dataset description .....	47
7.2	Summary of house damage for all the fires .....	48
•	Degree of damage to the house .....	49
7.2.1	Likely cause of damage .....	50
7.2.2	Identified mechanism of bushfire attack .....	53
7.2.3	Human accounts of fire effects on houses .....	55
7.2.4	Human accounts of house ignition after the fire front has passed .....	56
7.2.5	Human accounts of house tenability .....	57
7.3	Characteristics of house design and material .....	58
7.3.1	Number of storeys .....	58
7.3.2	Flooring system .....	60



7.3.3	External wall material .....	61
7.3.4	Roof .....	63
7.3.5	Window .....	64
7.3.6	Deck and veranda.....	65
7.4	Damage to outbuildings (type and material).....	67
7.5	Vegetation around the house.....	69
7.6	Protection measures – Water supply.....	73
7.6.1	Type of water supply.....	74
7.6.2	Water storage (material degree of damage) .....	76
7.6.3	Evidence of water supply failure (i.e. pump and pipe).....	77
7.6.4	Sprinkler system .....	79
7.7	Accessibility .....	81
7.8	Land-use planning .....	82
7.8.1	Pattern of house loss .....	82
7.8.2	Density of urban area.....	82
7.8.3	Wildfire Management Overlay (WMO) .....	82
7.8.4	House loss as a function of distance from vegetation .....	83
7.9	Remote sensing results: spatial analysis on house distance to vegetation and vegetation covers.....	84
7.9.1	Mean distance from house to forest (trees taller than 8 m).....	84
7.9.2	Detailed localised analysis (Pine Ridge Road).....	92
7.9.3	Proportion of houses lost and distance to forest – Pine Ridge Road .....	94
7.9.4	Proportion of houses lost and cover in surrounding forest – Pine Ridge Road ...	95
7.9.5	Summary of remote sensing study.....	96
<b>8.</b>	<b>Discussion.....</b>	<b>97</b>
8.1	Exposure on structure.....	97
8.1.1	Ember spread distance .....	97
8.1.2	Surface fuel spread.....	98
8.1.3	Combustible elements within the urban environment.....	98
8.2	Wind-related structural compromise .....	98
8.3	House vulnerability .....	99
8.3.1	Cladding material .....	99
8.3.2	Window glass type .....	100
8.3.3	Prevalence of attached combustible elements.....	100
8.3.4	House tenability .....	100
8.4	Prevention measures – example of water defence system reliability.....	101
8.5	Impact of land-use planning and building controls .....	101
8.6	Concept of defendable house and defendable space .....	102
8.6.1	Defendable house concept .....	102
8.6.2	Defendable space.....	103
<b>9.</b>	<b>Future work and Arising questions .....</b>	<b>104</b>
9.1	Assessment of house vulnerability with different types of fire intensity.....	104
9.1.1	House vulnerability (from house design and construction material).....	104
9.1.2	Estimating exposure at house level from forest and surrounding objects .....	105
9.1.3	Crossing house vulnerability and exposure .....	106
9.2	Building controls .....	106
9.3	Arising questions .....	106
<b>10.</b>	<b>conclusion .....</b>	<b>108</b>
	<b>References.....</b>	<b>109</b>

<b>Appendix A – Paper questionnaire .....</b>	<b>111</b>
<b>Appendix B – Arc Pad survey questions .....</b>	<b>122</b>
<b>Appendix C – Data management and rectification.....</b>	<b>140</b>
<b>Appendix D – Data description.....</b>	<b>142</b>
<b>Appendix F - Kilmore East Fire (Wondong, Kinglake, Strathewen, Clonbinane, Flowerdale) .....</b>	<b>145</b>
<b>Appendix G - Murrindidi Fire (Marysville, Naberthong, Buxton, Taggerty) .....</b>	<b>157</b>
<b>Appendix H – Churchill Fire .....</b>	<b>164</b>
<b>Appendix I – Bunyip Fire .....</b>	<b>169</b>
<b>Appendix J – Maiden Gully (Bendigo) Fire .....</b>	<b>174</b>

## List of figures

Figure 1 Map of Victoria and fires perimeters (source Country Fire Authority – CFA)	10
Figure 2 Victorian Planning & Building Legislation in relation to wildfire	16
Figure 3 Example of land parcel with aerial picture and the virtual elements created during the field survey	24
Figure 4 Naming convention	25
Figure 5 Naming convention (detail)	25
Figure 6 Map of the broad study regions in the West and East of the Murrindindi shire; location of three study areas	27
Figure 7 Distribution of LiDAR points in a sample transect. Lower points lie on or close to the ground; higher points are located within vegetation.	29
Figure 8 LiDAR data extent showing derived Digital Elevation Model, and corresponding field survey data locations (yellow dots)	30
Figure 9 LiDAR extent for Murrindindi study areas – legend as for Figure 8	31
Figure 10 Canopy Height (a) is shown as a grey scale where the brightness of the image is related to the height of the highest return detected by the airborne LiDAR instrument. The derived Forest/non-forest layer (b) is simply a threshold of the canopy height layer, where image pixels with heights detected above 8 m are assigned as forest and shown in green. The remaining non-forest areas are shown in black.	32
Figure 11 Percentage of cover by strata for Kinglake study region with (a) over-storey cover 8 m and above; (b) mid-storey cover (3–8 m); (c) understorey cover (50 cm–3 m); and (d) a false-colour image where the colours are mapped as follows: red (mid-storey), green (canopy) and blue (understorey).	34
Figure 12 Pine Ridge Road subset of the pre-fire imagery provided by the DSE	35
Figure 13 Extent of the post-fire colour infrared data commissioned by the DSE	36
Figure 14 Pine Ridge Road subset of the post-fire imagery commissioned by the Victorian Police and provided by the DSE	37
Figure 15 Burn severity classification of the Pine Ridge Road subset. Burn is shown in black, scorched in brown and unburnt in green. Burnt residential structures are shown in red and unburnt residential structures in blue (as described in Section 5.2.4). Areas in white are non-forest.	38
Figure 16 Distribution of burnt and unburnt structures in the Pine Ridge Road case study site area (red: burnt structures, and blue: unburnt structures)	39
Figure 17 Residential structure footprints (red) with surveyed residential structure centroids (blue crosses) within an area of the Pine Ridge Road study case area	40
Figure 18: Sectors for distance calculations (a) and segments for area and spatial averages (b). Blue, green and red circles represent ranges of 50, 100 and 200 m, respectively.	45
Figure 19 Likely cause of damage across all fire areas	51
Figure 20 Example of house affected by wind only (Humevale, Kinglake West)	51
Figure 21 Likely cause of damage in Murrindindi and Kilmore East fire (percentage of houses surveyed)	52
Figure 22 Example of observed wind influence in Marysville	52

Figure 23 Example of wind impact in Marysville (tree blown down during the fire – comment from resident account)	53
Figure 24 Example of ignition into roof noticed by the occupant several hours after fire front had passed	57
Figure 25 Example of deck ignition, spread and suppression	66
Figure 26 Example of vegetation heavily burnt close to structure (Pine Ridge Road, Kinglake)	72
Figure 27 Example of polyethylene tank damage	77
Figure 28 Example of damaged pump	79
Figure 29 Distribution of minimum, mean, median and maximum distance (metres) to forest for residential structures in the West region (Murrindindi West) for the four residential structure damage classes	85
Figure 30 Percentage of residential structures burnt (damaged and destroyed) as a function of the distance to forest from house centroids in the Kilmore East area (Murrindindi West region). Red curve: unmasked data represent the original data extracted (forest with trees > 8m); the green curve is the forest layer with small areas of 0.5 ha subtracted; the blue curve is the forest layer with small areas of 1 ha subtracted.	87
Figure 31 Percentage of residential structures lost (damaged and destroyed) as a function of the distance to forest from house centroids in the Murrindindi area (East region). Red curve: unmasked data represent the original data extracted (forest with trees > 8m); the green curve is the forest layer with small areas of 0.5 ha subtracted; the blue curve is the forest layer with small areas of 1 ha subtracted.	88
Figure 32 Percentage of residential structures lost (damaged and destroyed) as a function of the mean distance to forest from house centroids in the Pine Ridge Road area. Red curve: unmasked data represent the original data extracted (forest with trees > 8m); the green curve is the forest layer with small areas of 0.5 ha subtracted; the blue curve is the forest layer with small areas of 1 ha subtracted.	89
Figure 33 Percentile of damaged residential structures (damaged and destroyed) as a function of the distance to forest from house centroids for the Kilmore East area (West region). Red curve: unmasked data represent the original data extracted (forest with trees > 8m); the green curve is the forest layer with small areas of 0.5 ha subtracted, the blue curve is the forest layer with small areas of 1 ha subtracted.	90
Figure 34 Percentile of damaged residential structures (damaged and destroyed) as a function of the distance to forest from house centroids for the Murrindindi area (East region). Red curve: unmasked data represent the original data extracted (forest with trees > 8m); the green curve is the forest layer with small areas of 0.5 ha subtracted, the blue curve is the forest layer with small areas of 1 ha subtracted.	90
Figure 35 Percentile of damaged residential structures (damaged and destroyed) as a function of the mean distance to forest from house centroids for the Pine Ridge Rd area. Red curve: unmasked data represent the original data extracted (forest with trees > 8m); the green curve is the forest layer with small areas of 0.5 ha subtracted, the blue curve is the forest layer with small areas of 1 ha subtracted.	91
Figure 36 Spatial distribution of residential structures	92
Figure 37 Proportion of house loss by distance to forest (Pine Ridge Road region)	94
Figure 38 Houses lost and forest cover for three radial zones around the house (0–50 m, 0–100 m and 0–200 m) for the Pine Ridge Road region	95
Figure 39 Classification process for radiation threshold of houses surveyed (NC = non-combustible)	105

## List of tables

Table 1 Summary of damages and houses surveyed during 7 <sup>th</sup> February bushfires .....	11
Table 2 Summary of in-depth bushfires surveys on house loss (from Leonard & McArthur 1999, Blanchi & Leonard 2006) .....	13
Table 3 Summary of elements studied and number of questions .....	23
Table 4 Coordinates, areas and number of surveyed houses within each study region .....	26
Table 5 Summary of remote sensing data used to derive local statistics for residential structures in each of the three study regions .....	28
Table 6 Numbers of residential structures considered within each region and their level of damage .....	40
Table 7 Weather conditions .....	41
Table 8 Description of dataset (example) .....	47
Table 9 Summary of houses surveyed and degree of damage of the houses across all areas .	48
Table 10 Percentage of houses which survived (corresponds to liveable houses, including untouched and damaged houses) and destroyed houses, for collected dataset .....	49
Table 11 Degree of damage to the surveyed houses (expressed as number of houses and percentage per row) .....	50
Table 12 Likely cause of fire (expressed as number of houses and percentage per row) .....	50
Table 13 Main bushfire attack mechanisms recorded for the ground cover, outbuildings and structures within all fire perimeters, where response was recorded .....	54
Table 14 Main bushfire mechanisms recorded in the Eyre Peninsula bushfire – comparison with Canberra bushfire and Victorian fires (from Blanchi & Leonard 2006) .....	54
Table 15 Number of functional levels (expressed as number of houses and percentage per row) .....	58
Table 16 Number of storeys and house damage across all fires .....	59
Table 17 Main material supporting floors (expressed as numbers of houses and percentage per row) .....	60
Table 18 Main material supporting floors and house damage (see footnote 6) .....	61
Table 19 Predominant external wall material (expressed as numbers of houses and percentage per row) .....	62
Table 20 Predominant wall material and house damage (see footnote 6) .....	62
Table 21 Roof profile and house damage (expressed as number of houses and percentage per row) .....	63
Table 22 Predominant roof material (expressed as number of house and percentage per row)	63
Table 23 Predominant roof material and house damage across all fires (see footnote 6) .....	63
Table 24 Type of glass (expressed as numbers of houses and percentage per row) .....	65
Table 25 Type of glass and degree of damage to the house (expressed as number of houses and percentage per column and percentage per row) .....	65
Table 26 Type of attachment (expressed as number of attachments and percentage per row)	66
Table 27 Principal decking material (expressed as numbers of decks and percentage per row) .....	67

Table 28 Degree of damage of deck (expressed as numbers of decks and percentage per row)	67
Table 29 Function of outbuilding	68
Table 30 Outbuilding type of material	68
Table 31 Degree of damage of the outbuilding	69
Table 32 Overhanging foliage in proximity to houses from Q12 of structure survey (expressed as numbers of houses and percentage per row)	69
Table 33 Overhanging tree and house damage (see footnote 6)	70
Table 34 Indication of elevated fuels 0.5 to 3-m high linking the house to wider vegetation within 50 m of the property boundary (question Q27 of the structure survey)	71
Table 35 Comparison of house condition and combustible ground cover adjacent to structure	71
Table 36 Evidence of defence using water (expressed as numbers of houses and percentage per row)	73
Table 37 Relationship between evidence of defence using water and house damage (see footnote 6)	74
Table 38 Water provision (expressed as number of houses and percentage per row)	74
Table 39 Water provision and house damage (see footnote 6)	75
Table 40 Tank material and degree of damage of the tank	76
Table 41 Number of houses with sprinklers per fire region	80
Table 42 level of damage for those houses with sprinklers	80
Table 43 Type of sprinklers identified for each of the houses surveyed	80
Table 44 Main direction of sprinklers	80
Table 45 Most appropriate access for fire vehicles	81
Table 46 Most appropriate access for fire vehicles across all fire areas (see footnote 6)	81
Table 47 Wildfire Management Overlays (WMO) per fire area	83
Table 48 Wildfire Management Overlays (WMO) and house damage (across all fires)	83
Table 49 Minimum, mean, median and maximum distances from structure to forest	85
Table 50 Paired t-tests results for structure damage classes and distance to forest	86
Table 51 Median distance to forest and damage to houses in Pine Ridge Road	93
Table 52 Percentage of over-storey, mid-storey and understorey cover and damage to the house (house untouched and burnt) in Pine Ridge Road	93
Table 53 Minimum distance to unburnt and burnt forest and damage to the house (house untouched and burnt) in Pine Ridge Road	93
Table 54 Minimum distance to unburnt and burnt structure (including other houses, sheds and tanks) and damage to the house (house untouched and burnt) in Pine Ridge Road	94
Table 55 Summary of surveyed houses per locality for the Kilmore East fire	143
Table 56 Summary of surveyed houses per locality in the Murrindindi fire	144
Table 57 Summary of surveyed houses per locality in the Churchill fire	144
Table 58 Summary of surveyed houses per localities in the Maiden Gully fire	144

## List of acronyms

AS	Australian Standard
BAL	Bushfire attack level
BCRC	Bushfire Cooperative Research Centre
CFA	Country Fire Authority
CSIR	Commonwealth Scientific and Industrial Research
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DEM	Digital Elevation Model
DSE	Department of Sustainability and Environment
FFDI	Forest Fire Danger Index
GA	Geoscience Australia
G-NAF®	Geocoded National Address File
LiDAR	Light Detection and Ranging
NEXIS	National EXposure Information System
WMO	Wildfire Management Overlay

## Acknowledgement

We would like to acknowledge the numerous participants of this project. We would like to thank the Bushfire CRC, AFAC, Country Fire Authority, Metropolitan Fire Brigade, NSW Rural Fire Service, NSW Fire Brigades, Tasmania Fire Service, SA Country Fire Service, RMIT, La Trobe Universities and all participating fire and land-use agencies for their help in the data collection and analysis. Thanks to Jenny Jones for providing the background on planning and building control.

We would like to thank the communities that have so generously given their time to contribute to this research effort.

## 1. INTRODUCTION – CONTEXT

The scale of the Victorian bushfires of 7<sup>th</sup> February 2009 in terms of the loss of life and assets is unprecedented. This presented challenges to agencies tasked with providing recommendations for changes to building design, planning and management regulations. These recommendations will certainly take into consideration the impact of fire at a range of spatial scales, from broad regional assessments of fire extent and severity, to detailed assessments of the incidents related to single properties.

In response to the fires, the Bushfire CRC assembled a group of researchers from various states, fire agencies and research organisations to provide the Australian fire and land management agencies with an objective scientific analysis and dataset of the factors surrounding these series of fires. The following three areas were considered:

- Fire behaviour, focussing on the fire behaviour across different landscapes
- Human behaviour, focussing on decision-making and actions of residents
- Building and land-use planning, examining patterns of loss and survival of buildings, and planning and building controls and their impact on patterns of building losses

This report presents the information on the building and land-use planning survey and related datasets that has been conducted and aggregated following the 7<sup>th</sup> February 2009 bushfires. It includes a description of the data-capture methodology, the data base description, preliminary analysis methodologies and preliminary results. Of particular note is the fact that this dataset has been collected with full geospatial referencing, allowing the opportunity to perform geospatial analysis, combining fire, impact, socioeconomic and demographic data to paint a picture of what happened on February 7<sup>th</sup> 2009.

The authors would like to highlight that the primary role of this report is to describe the dataset and data development methodology. The secondary role of the report is to describe the potential analysis options and provide some examples of these preliminary analyses and observations. Extensive efforts have been made to check and rectify the dataset. With additional time and effort, further dataset compilation would yield a larger number of definitive records with a greater degree of confidence. At the time of compiling this report, datasets from other efforts such as fire behaviour and human behaviour investigations were only partially available. Future data analysis will benefit greatly from the integration of information, and a discussion on future data rectification, integration and analysis has been provided in this report.



## 2. SUMMARY OF FIRES

A large number of fires were reported on 7<sup>th</sup> February (Appendix F - Map of fires perimeters in Victoria). Out of the many fires, five fires are studied in this report: Kilmore East, Murrindindi, Churchill, Maiden Gully – Bendigo, and Bunyip (see Figure 1).

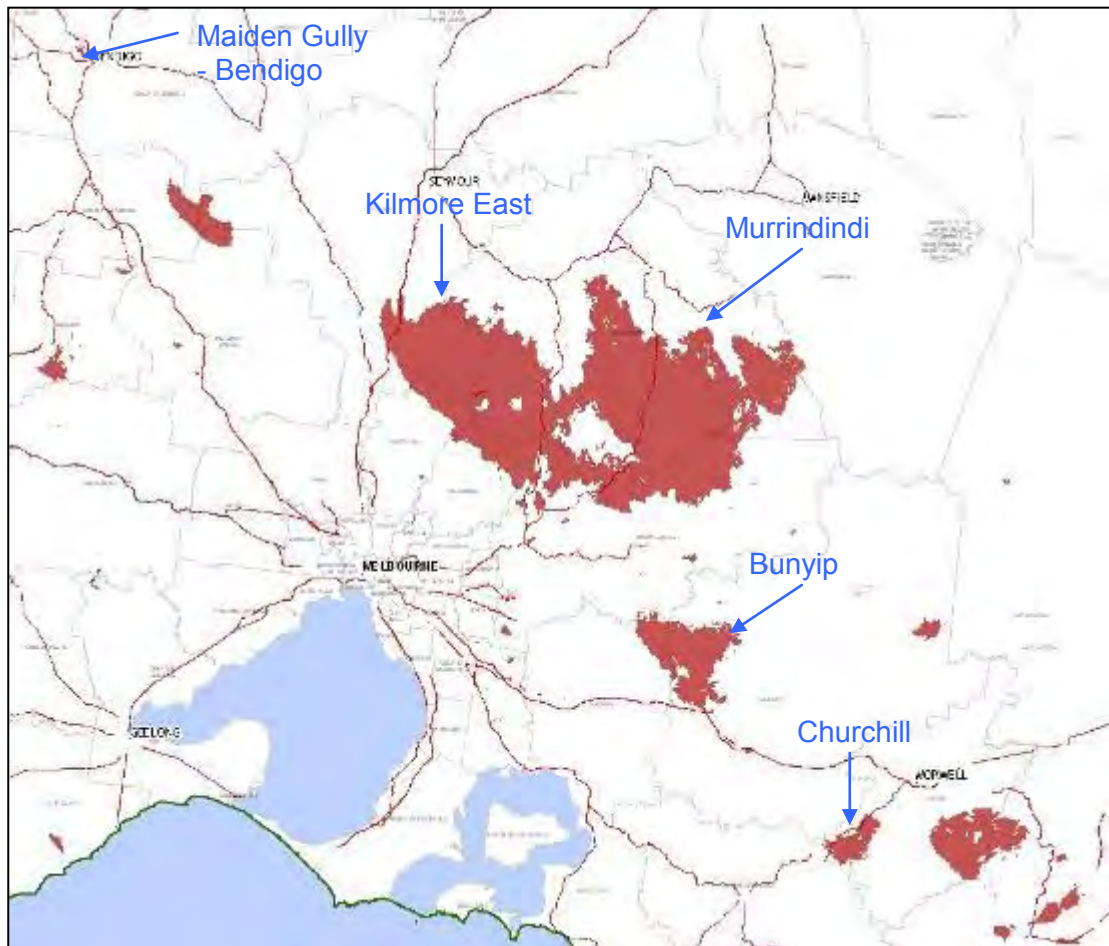


Figure 1 Map of Victoria and fires perimeters (source Country Fire Authority – CFA)

Table 1 Summary of damages and houses surveyed during 7<sup>th</sup> February bushfires

Fires	Estimated no. of houses within fire perimeter*	Houses destroyed**	Houses with minor damage**	Houses with no damage**	Houses surveyed***	Fatalities (source Victoria Police)	Forest area burnt (source DSE)
Bunyip	240	35	21	184	14	0	180,000+ ha
Churchill	359	133	86	140	140	11	150,000+ ha
Kilmore East	3540	1244	530	1766	705	121	32,800+ ha
Maiden Gully	172	48	21	103	56	1	500+ ha
Murrindindi	1064	590	74	400	150	38	24,500+ha
Total	5375	2118	832	2593	1065	171	390,000+ ha

\* Based on National Exposure Information System (NEXIS) (G-NAF®) address identifiers, assuming one residence per address<sup>1</sup>, and some extra added points identified from aerial imagery without address.

\*\* Assessment from aerial imagery and RiCS<sup>2</sup> by Geoscience Australia. (preliminary assessment at the time of writing this report; only “residential structures” have been assessed. Structures (houses) that were ruins prior to the fire have been removed from the database. GNAF and NatMap structures that were not identified on either before/after imagery or RICS photos have been removed from the database. **It is possible that some houses have been classified as sheds (in general corrugated shell construction) and some sheds as houses (old houses being used as storage facilities).**

\*\*\* Temporary number of houses surveyed and used in this analysis (subject to change when data rectification is completed)

<sup>1</sup> G-NAF® (Geocoded National Address File) is Australia’s first authoritative geocoded address index for the whole country, listing all valid physical addresses in Australia. It contains approximately 12.6 million physical addresses, each linked to its unique geocode (that is, the specific latitude and longitude of the address). Data used to build G-NAF® comes from contributors that include the Australian Electoral Commission, Australia Post, state, territory and Australian Government mapping agencies and land registries.

<sup>2</sup> RICS (Rapid Inventory Collection System) has been developed by Geoscience Australia to compliment post disaster surveys. RICS consists of four 5-Megapixel Ethernet cameras (recording at about 4 frames per second) attached to a tripod mounted on a vehicle, a GPS device. The images are compressed in jpeg format “on-the-fly” and displayed in a Graphical User Interface (GUI) along with GPS location, bearing and speed. An additional display window shows the street-directory (UBD) roadmap and a GPS tracklog. All images are geo-referenced and stored in a database..

### 3. OBJECTIVES

To understand the magnitude and nature of the impact of the February 7<sup>th</sup> bushfires, a physical survey was performed on five areas affected by fire.

The survey had several objectives:

- To provide a dataset that facilitates ongoing reform of policies, regulation and education initiatives.
- More specifically, to provide a dataset and data assessment methodology to address the following questions:
  - House vulnerability in relation to observed intensity of the fire attack mechanisms and related winds,
  - Effectiveness of various prevention measures such as
    - o Defendable space,
    - o Sprinkler systems,
    - o Other relevant measures that are identified during analysis of the data,
  - Impact of land-use planning and building controls,
  - Other emerging issues arising from the analysis.

## 4. BACKGROUND

### 4.1 Historic house loss in bushfires

This section presents an overview of approaches and findings from past bushfires survey efforts.

#### 4.1.1 Previous post-bushfire survey efforts

Several surveys following large bushfire events that resulted in significant house loss have been conducted in the past (see Table 2).

Table 2 Summary of in-depth bushfires surveys on house loss (from Leonard & McArthur 1999, Blanche & Leonard 2006)

Fire	Number of houses lost	Number of houses surveyed	Fatalities	State	Location	References
14/01/1944	58	100		VIC	Beaumaris	CSIR; Barrow, 1945
7/02/1967	1293	502	62	TAS	Hobart and south-east	CEBS/CSIRO; Cole 1983
28/11/1968	120	53	14	NSW	Sydney, Blue Mountains, Illawarra	CEBS; Coles 1983
16/02/1983	1511	1153	47	VIC	Western district	CSIRO; Ramsey et al. 1987 Wilson et al 1984
7/01/1994	202	491	4	NSW	Eastern seaboard	CSIRO; Ramsay & McArthur 1995
21/01/1997	43		3	VIC	Dandenong Ranges, Wilson's Promontory	CFA
25/12/2001	109	59		NSW	(Helensburgh)	CSIRO
18/01/2003	519	226	4	ACT	Canberra	CSIRO; Leonard & Blanche 2005
10/01/2005	76	67	9	SA	Eyre Peninsula	CSIRO, SA CFS, GA; Blanche & Leonard 2006
7/02/2009	2000	1100	173	VIC	Victoria	

Note: in addition some surveys have been conducted by the Country Fire Authority and New South Wales Fire Services (since 2000).

From 1983 onwards, a specific focus on building and landscaping issues occurred (Leonard 1999). Each survey conducted by CSIRO listed in the table above used a common approach, which has undergone a process of continual evolution since then, with aspects of some standard questions being maintained to provide statistical

continuity. The survey form focussed on assessing building design and site details that contribute to the probability of house survival (McArthur 1997). In addition, the survey includes information on site details (e.g. slope of the land); description of surroundings; and details of the actions of residents and fire-fighters during and after the event. Attention is given to each of these elements and how they interact and contribute to the risk posed by bushfire to the community (Blanchi 2008). A copy of the survey form used for these investigations is provided as Appendix A.

#### **4.1.2 Definition of risk-based approach to bushfire house loss**

The causes of house losses are complex and involve many aspects (Blanchi et al. 2006b) such as:

- weather conditions
- forest fuels
- local topography
- house design
- house materials
- landscape objects
- brigade and occupant behaviour before, during and after a bushfire event

For the purpose of discussing the mechanisms of bushfire attack on structures, it is important to first define a framework in which risk can be considered. In this case, it is the risk of building damage to a point where it no longer provides a safe haven for occupants. The Australian Standard for risk management defines the risk as „the chance of something happening that will have an impact upon objectives“ (Australian Standard for Risk Management 2004). The standard then clearly outlines two main aspects required to define an event. These are the likelihood and the consequence. Likelihood refers to the nature, magnitude or persistence of the attack mechanism (measured in terms of the intensity of the flame front and the mass of embers carried in front of the fire), and the chance of an event occurring. Consequence is a measure of impact or outcome in relation to the objective, which is determined by the effect the bushfire event has on urban assets. This is highly dependent on the level of vulnerability a property has to the mechanisms of bushfire attack.

#### **4.1.3 Key findings from past bushfire surveys**

Past bushfire surveys have provided information on different aspects including bushfire arrival intensity, house vulnerability to attack by ember, radiant heat and flame, and the influence of people's behaviour.

Severe weather conditions play an important role in house loss potential. These weather conditions can be considered as influencing the magnitude of a bushfire impact and also the vulnerability of a structure and surrounding elements (e.g. materials becoming drier

and more flammable; strong wind can damage part of the building envelope and can carry burning debris (Ramsey 1986, Bianchi & Leonard 2008)).

The Wangary bushfire in South Australia in 2005 provided a significant reminder that severe fire weather conditions can provide support for bushfire spread across rural or agricultural landscapes and present significant risk to life and property. This fire highlighted the specific risk to life that fast-moving grass fires pose to communities (Bianchi & Leonard 2006).

Previous research conducted by CSIRO has shown that the predominant causes of ignition are from ember attack, or as a result of radiant heat or flames from surrounding burning objects and/or surface fuels leading to house ignition (Ramsay et al 1987, 1995, Leonard & McArthur 1999, Leonard & Bianchi 2005). House vulnerability is defined in terms of the susceptibility to the bushfire attack mechanisms: ember entry, ember accumulation, radiant heat and flame. As an example, a survey conducted after the 2003 Canberra fire identified a high percentage (>90%) of houses as being damaged or destroyed in the absence of direct radiant heat and flames from the main fire front (Leonard & Bianchi 2005).

Radiant heat and flames present a risk based on both the level of radiant heat exposure, as well as the time over which this exposure occurs (Leonard et al. 2004). Certain levels of radiant heat can ignite combustible material (e.g. timbers from approximately 12.5 kW/m<sup>2</sup>; Babrauskas 2001), and is responsible for window breakage (e.g. plain window glass will break at a level of 12.5 kW/m<sup>2</sup>; Bowditch et al. 2006).

Different parts of the building have been identified as vulnerable: gaps in the building envelope, glazing systems (window and frame), external doors, timber decks, roof cavities, eaves, fascias, subfloor, etc. (Ramsey 1994).

The surrounding objects in the landscape, such as vegetation, fences and outbuildings (type, materials of construction, proximity to houses, etc.) play an important role as protection, or as a source of heat and ember hazard, and so can either increase or reduce the risk of house loss (Ramsay et al. 1994, Leonard & Bianchi 2005).

The results of post-bushfire surveys have also shown the importance of human behaviour before, during and after the bushfire. Staying with a house has been shown to increase the house's chance of survival when the occupant remains active in and around the house when it is safe to do so. Based on past post-bushfire surveys, if houses are attended, house losses are reduced by a factor of between 3 to 6 (Bianchi & Leonard 2008b). After the passage of the fire front, able residents can monitor and may be able to suppress small ignitions in or around the house before these become uncontrollable. Previous research has shown that active defence of houses by residents or brigade members significantly increases the chances of house survival (Wilson & Ferguson 1984; Ramsey et al. 1986; Leonard and Bowditch 2003; Bianchi et al. 2006b).

The integration of community education, planning, building construction initiatives and suppression strategies is essential in achieving effective risk mitigation in future events (Bianchi & Leonard 2006). Policy can play a key role in promoting harmony between these strategies that are understood and maintained by the community members they are designed to protect (Bianchi & Leonard 2006, 2008).

## 4.2 Land-use planning in Victoria

### 4.2.1 Victorian legislation

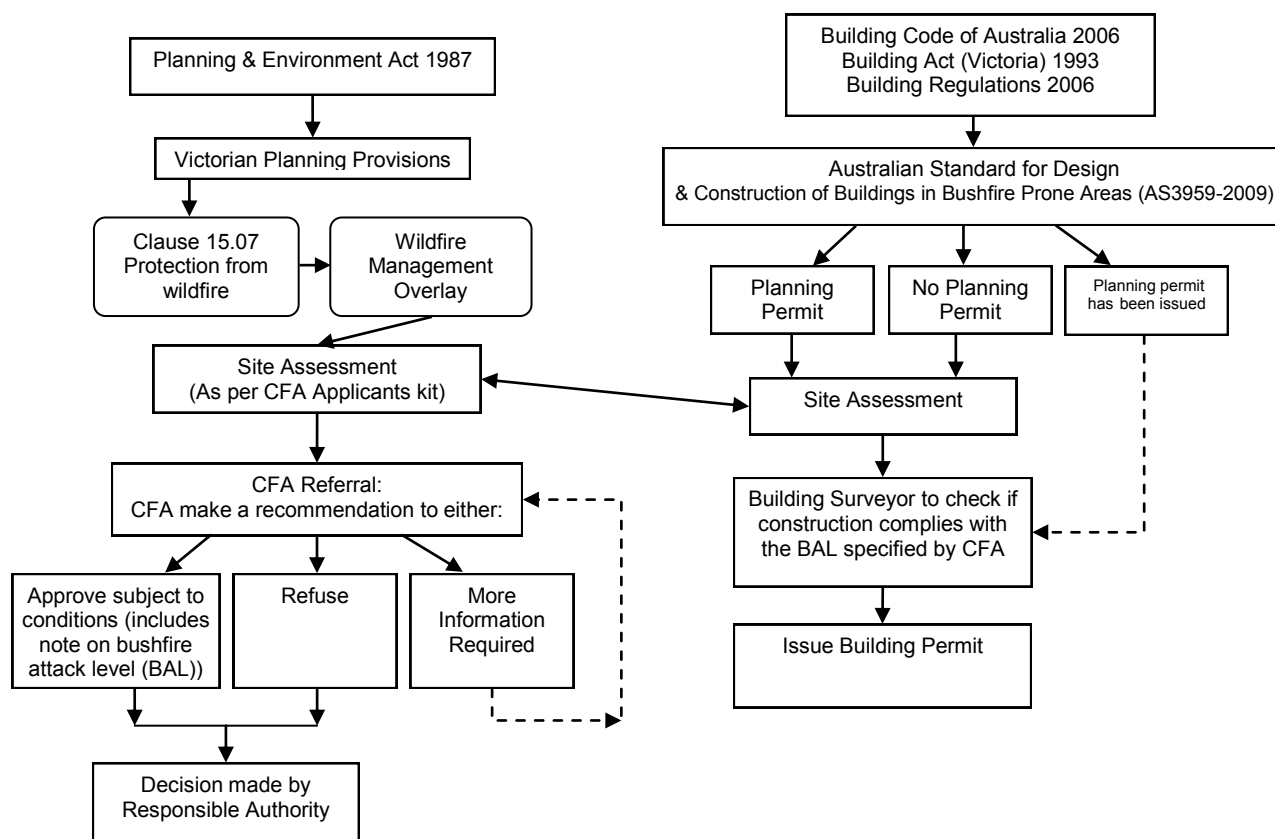


Figure 2 Victorian Planning & Building Legislation in relation to wildfire

### 4.2.2 Development controls in bushfire-prone areas

Development in areas where people and property may be at risk from wildfire is regulated in two ways within Victoria: (1) in the planning system; and (2) in the building system. The discussion below outlines how each respective system operates.

### 4.2.3 Planning system

The **Planning and Environment Act 1987 (P&E Act)** heads the legislative framework in Victoria covering planning controls. The **Victorian Planning Provisions (VPP)** enacted under the P&E Act outline the broad objectives for land use and development within Victoria. The state-based objective for wildfire protection, which is set out in Clause 15.07 of the **State Planning Policy Framework (SPPF)**, is to assist the minimisation of risk to life, property, the natural environment and community infrastructure from wildfire.

The Country Fire Authority (CFA) is responsible for identifying a **Wildfire Management Overlay (WMO)** area, in collaboration with the applicable Council; the affected area is mapped for its wildfire risk within the Council's Planning Scheme.

The WMO is a planning control that is designed to provide development that satisfies fire protection objectives and does not increase the threat to life and surrounding property from wildfire.

The most appropriate fire protection measures for a specific site are best determined at the planning permit stage when the development can be assessed comprehensively. For this reason, where a planning permit is required under the WMO, applicants are required to undertake a single-site assessment process as part of the planning permit application assessment stage. The process is set out in the *Building in a Wildfire Management Overlay Applicant's Kit*<sup>3</sup> and is designed to simplify the process of preparing and assessing an application for a dwelling or dwelling extension in a WMO and designated bushfire-prone area. As this site assessment is commonly completed at the planning permit stage, it eliminates the requirement for a further site assessment at the building permit stage.

The WMO site assessment process includes an assessment of the site including determination of: slope; fire vehicular access availability; water supply availability; orientation, and vegetation (fuel) within 100 metres of the proposed dwelling. These factors combine to determine the level of fire risk and appropriate development standards. These standards form the planning permit conditions and may include: building construction level; vegetation (fuel) management; fire vehicle access; water supply for fire-fighting purposes, and appropriate signage to identify water supply location, specific for each site. Where vegetation management is not able to be achieved either because of environmental significance or lot size, other design features are employed to reduce the likelihood of dwellings igniting by flame contact or radiant heat. These measures may include: fire retardant construction materials; radiant heat barrier walls; landscape design features; hard surface (paved) areas, and pools or the like as appropriate for the site.

#### 4.2.4 Building system

New regulations that adopt the Australian Standard for Design and Construction of Buildings in Bushfire-Prone Areas (**AS 3959-2009**) became effective in Victoria on 11 March 2009. The new regulations stipulate that every new home built in Victoria will undergo a Bushfire Attack Level (BAL) site assessment as part of the application for a building permit, to determine which method of construction is to be used. There are six Bushfire Attack Levels, which replace the four levels in the 1999 version of AS 3959.

The new regulations will guide the rebuilding process for communities affected by the 2009 bushfires. Where there is no rebuilding as a result of the recent fires („business as usual“), WMO requirements apply as usual; however, construction must be in accordance with AS 3959-2009 or as directed by the CFA as a note on the relevant planning permit.

The introduction of AS 3959-2009 will require an amendment to the WMO Applicant's Kit to reflect the revised construction requirements. To date, this has not yet been completed.

---

<sup>3</sup> <http://www.cfa.vic.gov.au/publications/policy.htm>



Notwithstanding the above, the site assessment process set out in the kit meets the requirements of a site bushfire attack assessment required under AS 3959-1999 (and it will also meet AS3950-2009 once the amendments are made). As this site assessment is commonly completed at the planning permit stage, the relevant building surveyor does not need to re-assess the BAL or the appropriateness of the site for the development during the building permit stage if the planning permit issued for the site stipulated the building construction level.

In situations where the WMO is not applicable, but the site is within a bushfire-prone area, the site assessment process is completed as part of the building permit stage, and reviewed by the building surveyor.

## 5. METHODOLOGY

Two concurrent approaches have been used to assemble a dataset of building- and planning-related parameters with respect to the 7<sup>th</sup> February 2009 fires. The two approaches were:

- a field data collection effort based on detailed surveys of individual properties by geo-referencing and attributing relevant elements of a structure, surrounding objects and other observations,
- the use of LiDAR<sup>4</sup> data and remote sensing imagery taken prior to and after the fire to generate information over a larger sample of impacted structures.

Further details of these two approaches are provided in the following sections.

Additional spatial information on weather conditions, and human and fire behaviour are important also to gain a better understanding of structural design and planning issues. Data on these aspects are being provided by other researchers and organisations that investigated the event. Much of this information is not available for integration within the time frame of this report.

### 5.1 Field data collection

This section describes the field data capture approach and sampling methods; it then describes the actions that have been taken to manage this data and produce a dataset ready for analysis.

#### 5.1.1 Objective

As there are many elements in an urban interface that contribute to the risk of house loss, this survey logs these elements in terms of their properties, spatial location and status. The survey is based on previous survey forms and strategies; however, for the first time, the objects' specific location is now recorded as a geospatial reference. Various factors were taken into consideration in order to assess the impact and consequences of the bushfire attack on a house. Questions covered the degree and cause of damage, as well as a house's design and the construction materials. Questions also covered outbuildings, details of the surroundings, site details, description of garden and foliage, and information on combustible elements stored in or near houses.

Human behaviour before, during and after the fire event has a profound influence on life and property risk; a separate survey effort run in parallel has captured people's accounts of the event (this aspect of the research will not be detailed here – please refer to the report on human behaviour for details and to Section 5.3.1 in the present report for the necessary description and use in the analysis).

---

<sup>4</sup> LiDAR (Light Detection and Ranging) instruments collect data by emitting, and receiving the reflected pulses of laser light to measure distance to targets. LiDAR data provide a structural assessment of the terrain, and can provide information on the ground surface beneath the vegetation, and information on the structure of the vegetation itself.

More than 110 questions are recorded in the survey on 11 different aspects:

- house structure (detail of material and design of wall, roof, accessibility),
- structural openings of the house (window, door and vents),
- attachments to the house (deck, veranda and stairs),
- fence and retaining wall,
- outbuildings (type and material),
- combustible elements,
- ground cover,
- vegetation,
- water supply,
- spray systems,
- observed wind directions at time of fire (see Table 3).

For a complete set of survey questions and elements recorded, see Appendix B.

Each of these aspects refers to a specific location or spatially referenced object; hence, the spatial relationship between each of these objects is able to be analysed. The information collected then provides the greatest opportunity for later analysis with regard to the potential interaction between these objects under the given conditions.

### **5.1.2 Field site selection**

Surveys were carried out from 12<sup>th</sup> February until 24<sup>th</sup> April 2009 to examine the remains of the destroyed, partially damaged and unaffected houses as well as their surroundings.

The houses surveyed are those within or close to the fire perimeter that have clearly received some level of exposure to bushfire effects. The objective was to collect a sample from destroyed, damaged and untouched houses from affected areas that have received various levels of impact.

Teams were instructed to survey houses within defined areas in an attempt to collect data on a wide range of representative clusters of houses. These clusters varied from tight urban enclaves to dispersed rural areas. They also varied in the potential exposure, from likely direct flame impact to likely impact from ember attack only. In each case, there was an attempt to comprehensively survey houses within the defined areas. An advantage of this approach is that interactions of objects located between land parcels can be analysed in addition to the interaction of objects within those land parcels (thereby facilitating analysis of structure-to-structure fire spread and other matters).

The approach to the selection of appropriate survey regions varied from clearly defined areas where a specific level of exposure was apparent, to in-field assessments of suitable regions. The range of selection approaches was necessary as for many regions, there was little to no information on the location and extent of damaged and destroyed houses at the time of the survey.

### 5.1.3 Data-capture kit design

The data-capture kit is a combination of technologies that allow accurate geo-referencing and attribution of elements belonging to a structure or its surroundings. The kit also facilitates the acquisition of geo-referenced photos. The kit comprises the following elements:

- C-19 Panasonic Toughbook computer with:
  - USB GPS receiver
  - Body support harness
  - Secondary battery
  - AC and DC power supply
  - Customised ArcPad software enabled with:
    - Pre-fire aerial imagery
    - Land parcel cadastre with:
      - Local address identifiers
      - Land parcel IDs
    - Identification of surveyed land parcels from previous survey crews
    - Roads layer
- Ricoh Caplio 500SE digital camera with either an integrated GPS and digital compass module or a Bluetooth-linked GPS module
- Standard issue log books
- Victoria map books
- Digital voice recorders (used by human behaviour survey team)
- Handheld GPS units for voice recorder operators (used by human behaviour survey team)

#### 5.1.4 Kit usage description

Field crews were deployed in teams of two (with a third crew member participating as a human behaviour surveyor); one crew member operated the Panasonic Toughbook while the other operated the digital camera and liaised with the Toughbook operator regarding observations.

After assessing a site for safe access, the crew member using the Toughbook systematically audited the elements on the site, while the camera operator captured images of the range of standard and unusual elements on the site. The photos are a vital method of recording and storing information on each surveyed house for later analysis. The photos are a useful reference for 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 useful reference information on the nature of the bushfire attack and house-to-house fire spread scenarios. These photos will become part of the dataset available for future research purposes.

#### 5.1.5 Customised ArcPad software description and use

The software used for this work was an ArcPad interface customised by CSIRO with the assistance of Geoscience Australia. A description of the ESRI software can be obtained from the following source: <http://www.esri.com/software/arcgis/arcpad/index.html>

ArcPad is designed for GIS professionals who require GIS capabilities in the field. It provides field-based personnel with the ability to capture, edit, analyse, and display geographic information easily and efficiently.

With ArcPad, you can:

- \* Perform reliable, accurate, and validated field data collection,
- \* Integrate GPS, rangefinders, and digital cameras into GIS data collection,
- \* Share enterprise data with field-workers for updating and decision making,
- \* Improve the productivity of GIS data collection,
- \* Increase the accuracy of the GIS database, and readily update it.

For this survey, a customised applet for ArcPad called the „site sketcher“ has been developed, including a map document loaded with pre-fire aerial images (that provide the users with a bird's-eye view of the area they are surveying) and a cadastre layer (parcel boundaries). The software maintains a live GPS data feed that determines a user's location on the map document. The user can then reconcile the objects they can see around them with the object recognisable in the aerial image.

The customised ArcPad software has a broad suite of virtual elements that can be selected and placed over the aerial image. For each virtual element placed in ArcPad, there are a series of questions asked of the user, which are saved in a local spatial database within the Toughbook (see Section 5.1.6 for database description). Table 3

below provides a summary of standard elements along with a description of how each element is displayed. The result is a comprehensive audit of the relevant element's spatial location, properties and condition. A comprehensive list of virtual elements and attributes is provided in Appendix B. Figure 3 below shows a land parcel with and without the virtual elements created during a field survey.

Table 3 Summary of elements studied and number of questions

<b>Elements surveyed</b>	<b>Description</b>	<b>Number of questions</b>
attachment	A series of question are used to describe all the attachments on a house: deck, veranda, and stairs, with a detailed description of the type of material, degree of damage and their spatial location on the house	15
barrier	This element provides information on fences, retaining walls or other types of barrier. This includes their spatial location, size, material and degree of damage	4
combustible	Refers to all the combustible elements in the property, such as gas bottle, wood heap, building material, dustbin, car. The location and status of these elements are recorded	7
ground cover	Ground cover is spatially registered with information on combustibility, type (grasslands, garden mulch, bark, short heath, tall heath) and status (burnt or not)	5
outbuilding	This element refers to the description of the type of outbuilding on the property (such as shed, garage), the material they are made of, their location and status (damaged or not)	12
sprinkler	A series of question detailing the location of sprinklers, the material and status (damaged or not)	3
structure	Information on the degree of damage of the house and the cause of damage. Information on different parts of the house (type and material, e.g. of roof, wall, underfloor enclosure) is recorded	27
structure opening	The location, type, material and status (degree of damage) of doors, windows and vents on the houses are recorded	19
vegetation	The type of vegetation (tree, bush, other) is spatially registered, and information is collected on the damage and mechanism of attack	6
water supplies	Information is collected on the types of water supply (water tank, dam, swimming pool, hydrant), their location and if they were used to defend the property. More detailed information is collected on the water tank (material, status)	12
wind direction	Leaf freeze direction is used to record wind direction at the house	
<b>Total</b>		<b>110</b>



Figure 3 Example of land parcel with aerial picture and the virtual elements created during the field survey

### 5.1.6 Data management

The following section describes the spatial data management system underpinning information collected using the „site sketcher“ applet.

During a debrief session following the survey, a member of the CSIRO team copied the data from the Toughbooks and loaded it on the Bushfire CRC server. A file containing all previously surveyed structure locations was then loaded onto the Toughbook, so new deployments would not accidentally re-survey an already surveyed structure.

The spatial datasets collected in the field are stored on the Bushfire CRC server and are categorised with a file structure reflecting the naming convention of „CRC + team“; see below, Figure 4 and Figure 5.

FID	Shape	ST001	ST001C	ST001A1
12	Point	a) Window		a) Aluminium
13	Point	a) Window		a) Aluminium
14	Point	b) Door		
15	Point	a) Window		b) Timber
16	Point	a) Window		b) Timber
17	Point	a) Window		b) Timber
18	Point	a) Window		b) Timber
19	Point	a) Window		b) Timber
20	Point	a) Window		a) Aluminium
21	Point	a) Window		b) Timber
22	Point	b) Door		
23	Point	a) Window		a) Aluminium
24	Point	a) Window		a) Aluminium
25	Point	a) Window		a) Aluminium
26	Point	b) Door		
27	Point	a) Window		a) Aluminium
28	Point	a) Window		a) Aluminium
29	Point	a) Window		a) Aluminium
30	Point	b) Door		
31	Point	b) Door		
32	Point	b) Door		
33	Point	b) Door		
34	Point	b) Door		

Figure 4 Naming convention

File Name	Timestamp	File Type
CRC 1.1	24/02/2009 9:15 AM	File Folder
CRC 1.2	24/02/2009 9:13 AM	File Folder
CRC 1.3	25/02/2009 2:26 PM	File Folder
CRC 1.4	27/02/2009 1:55 PM	File Folder
CRC 1.5	11/03/2009 4:39 PM	File Folder

Figure 5 Naming convention (detail)

The spatial datasets are stored in ESRI shape-file format, which describe collected data using a combination of points, lines and polygon geometries. Each item contains a corresponding record in a .dbf file with the collected attributes.

### 5.1.7 Post-processing data

A large number of post-processing tasks had to be performed on original source datasets before the data could be used for analysis. Each post-processing task has been documented in detail and can be reviewed in Appendix C (track log).

## 5.2 Remote sensing demonstration study – data and analysis

The power of remote sensing as a tool for assessing fire risk, detecting active fires and post-fire burnt area analysis is well established (see the many examples in Chuvienco 1999). Examples of these applications exist in both research and fully operational domains. In all such applications, the strength of remote sensing is the ability to make objective and repeatable assessments over the large areas relevant to fire managers.

This section demonstrates the use of remote sensing methods to generate data at both the community (or the order of hundreds of hectares) and regional (tens of thousands of hectares) scales. The data are designed to characterise the region immediately surrounding residential structures (out to a maximum range of 200 metres) that were impacted by the fire. The key aim is that these data can be readily integrated with other data sources, such as on-site surveys and the assessment of building design and materials, in order to determine the key factors that influenced the survival of structures.



Owing to the time constraints around the completion of this report, and because this specific methodology had not previously been applied in this context, a demonstration or pilot of this approach was considered appropriate. Three regions were considered during this demonstration study, as detailed in Table 4; two broad-scale regions cover the areas in the West and East of the Murrindindi Shire, and the third is a subset of the West region at Pine Ridge Road, Kinglake West. This smaller region at Pine Ridge Road in Kinglake West has been identified as a „integrative study site“ by the Bushfire CRC, where a combination of other detailed studies were combined to tell a detailed story of events on this day. The location of the three areas considered in this work is shown in Figure 6.

Table 4 Coordinates, areas and number of surveyed houses within each study region

Region	Easting range	Northing range	Area (ha)	Houses surveyed
<b>Murrindindi West</b>	335682–358959	5834622–5866652	74,556	588
<b>Murrindindi East</b>	380847–390787	5840906–5854981	13,990	196
<b>Pine Ridge Rd (Kinglake)</b>	345309–346913	5846572–5848566	320	44

The approach used in this demonstration study extracts local statistics for each residential structure from remotely sensed imagery. The resulting tabulated data can be readily analysed using standard (non-spatial) statistics. The data maintain some of the directional and range information relative to each of the structures but each structure is considered statistically as a discrete entity.

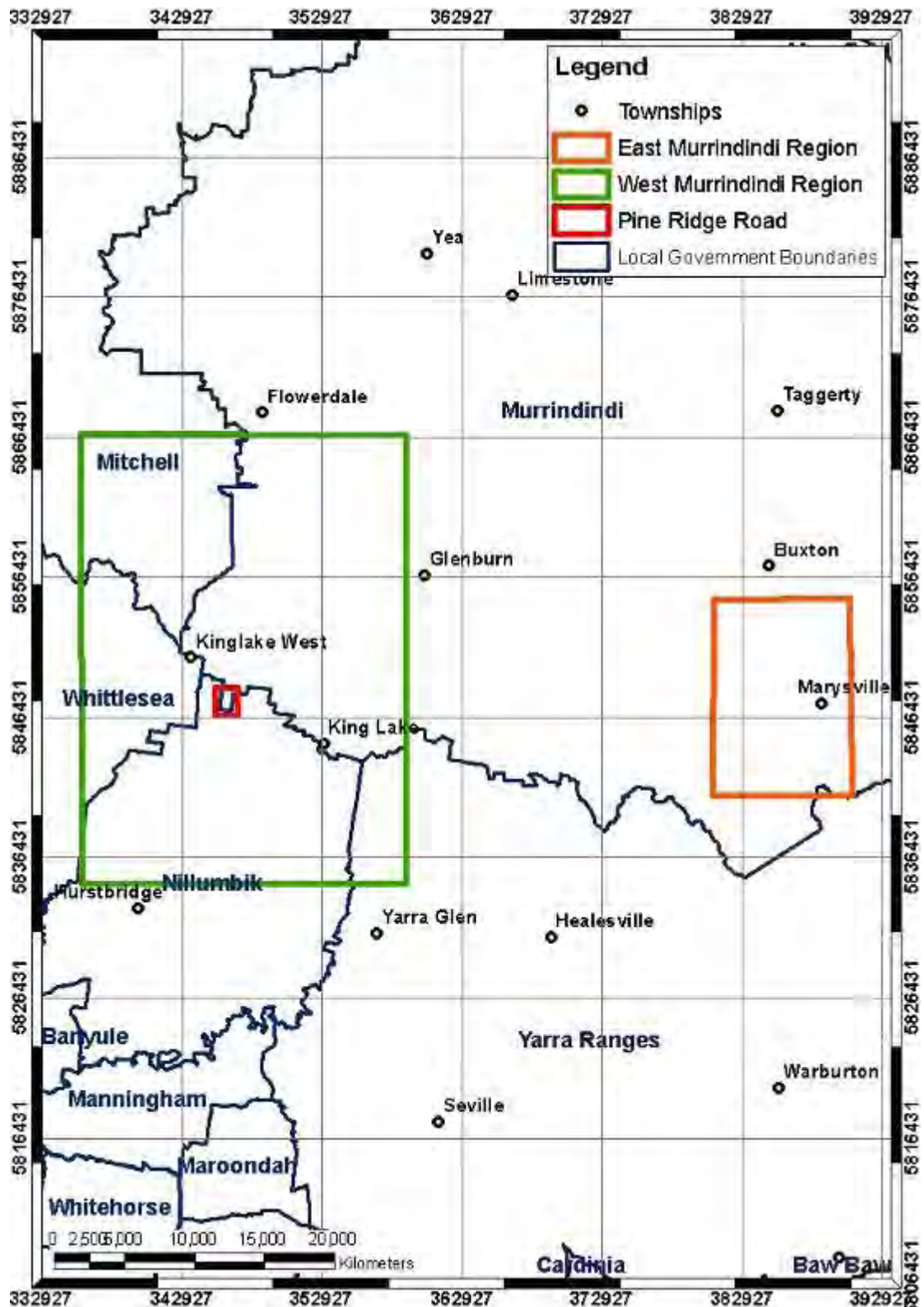


Figure 6 Map of the broad study regions in the West and East of the Murrindindi shire; location of three study areas

### 5.2.1 Summary of data source

The remotely sensed data used in the study include airborne LiDAR, visible and infrared imagery. These raw image data layers and the derived surface from which the statistics are derived are listed in Table 5 and described in the following section.

Table 5 Summary of remote sensing data used to derive local statistics for residential structures in each of the three study regions

Dataset	Murrindindi West	Murrindindi East	Pine Ridge Rd
<b>LiDAR</b>			
- DEM	✓	✓	✓
- Forest/non-forest	✓	✓	✓
- Cover by strata			✓
<b>Pre-fire imagery</b>			
- Visible	✓	✓	✓
<b>Post-fire imagery</b>			
- Visible	✓	✓	✓
- Colour infrared (not included in analysis)	✓	✓	✓
<b>Buildings vectors</b>			
- Centroids	✓	✓	✓
- Footprints			✓
- Building type			✓
- Damage level	✓	✓	✓
- Destroyed/not destroyed	✓	✓	✓
- Residential buildings	✓	✓	✓
- Outbuilding			✓
- Water tanks			✓

### 5.2.2 Airborne LiDAR data (Digital Elevation Model, vegetation structure)

LiDAR (Light Detection and Ranging) instruments collect data by emitting, and receiving the reflected pulses, of laser light to measure distance to targets. LiDAR systems that operate in commercial terrain mapping environments are typically operated from aircraft, and are capable of recording multiple discrete targets hits for each pulse, with modern systems able to emit 50,000–100,000 pulses per second. Each pulse has an associated GPS location and time associated with it. Data is collected for each flight overpass of the target area, and then flight passes are registered to GPS data and combined into a complete LiDAR dataset. LiDAR data provide a structural assessment of the terrain, as they are able to exploit gaps in vegetation cover to provide information on the ground surface beneath the vegetation, and information on the structure of the vegetation itself.

Figure 7 shows a transect of LiDAR data, and the distribution of the points in an example area.

### Example LiDAR Transect

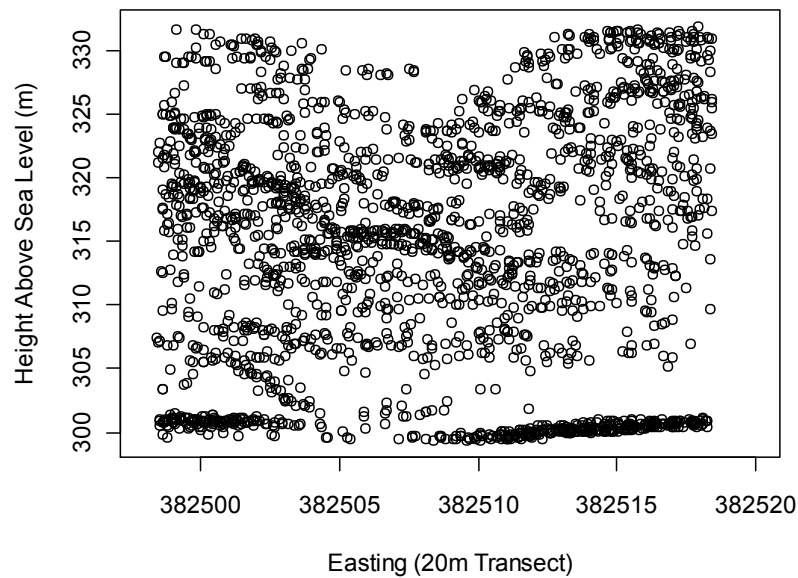


Figure 7 Distribution of LiDAR points in a sample transect. Lower points lie on or close to the ground; higher points are located within vegetation.

The points that lie on the lower envelope of the LiDAR data can be used to generate ground surfaces for terrain properties such as Digital Elevation Models (DEMs) and slope maps. By taking the highest points above the ground, surfaces representing the maximum height of the vegetation can be derived. By analysing the points between these two envelopes, details of the structure of the vegetation may be derived.

LiDAR (raw point) data were obtained from the Department of Sustainability and Environment (DSE) that were collected in late 2007, and coincided with a number of fire regions for the 2009 fires. Figure 8 shows the extents of the LiDAR data coverage with respect to Local Government Areas and the fire survey data currently available.

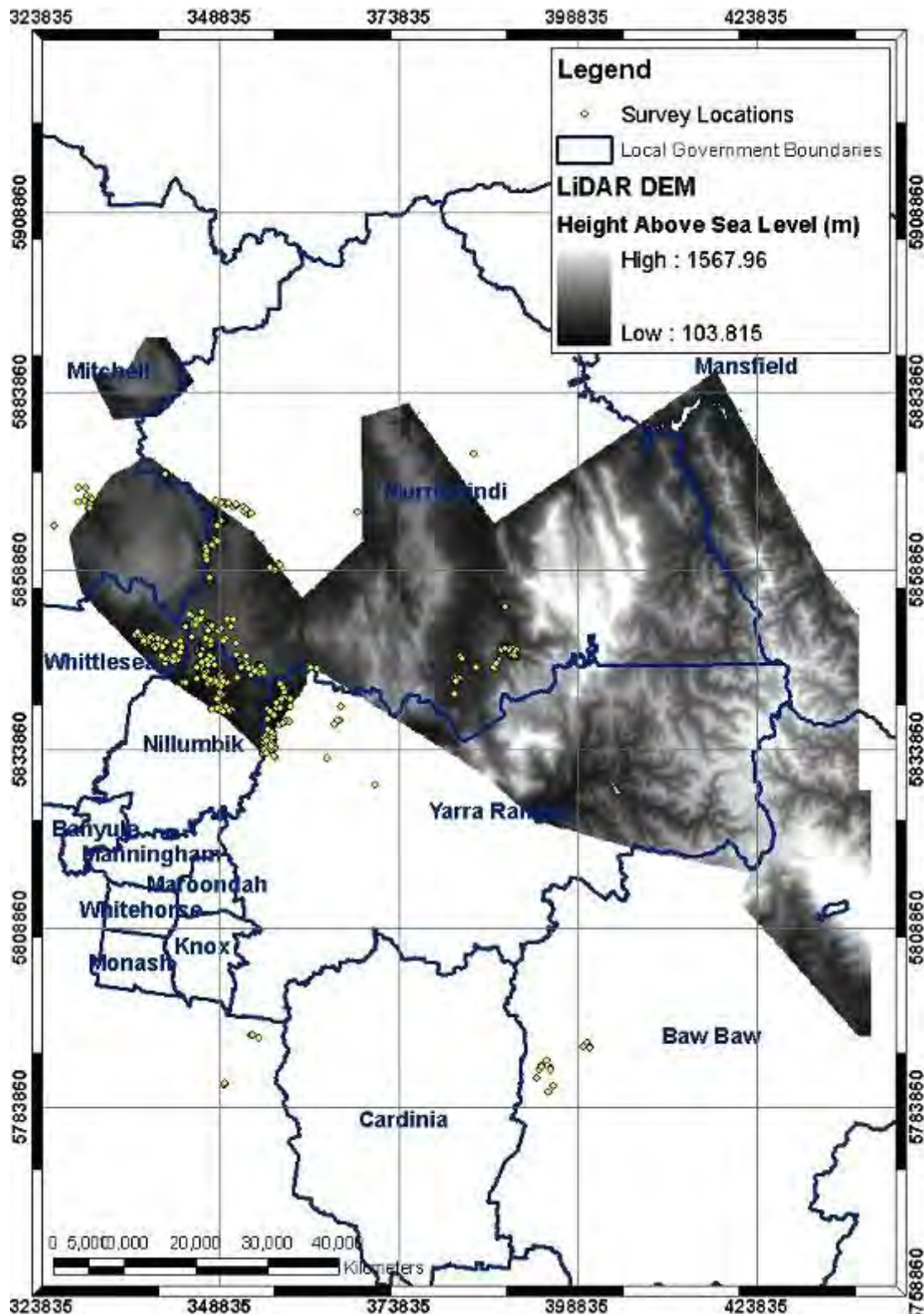


Figure 8 LiDAR data extent showing derived Digital Elevation Model, and corresponding field survey data locations (yellow dots)



The LiDAR data cover numerous fire regions, and three subsets of the data were extracted for analysis in regions. A broad-scale analysis was taken for Murrindindi East and West areas. The Pine Ridge Road study case area is smaller in extent and allowed a more detailed analysis to be performed.

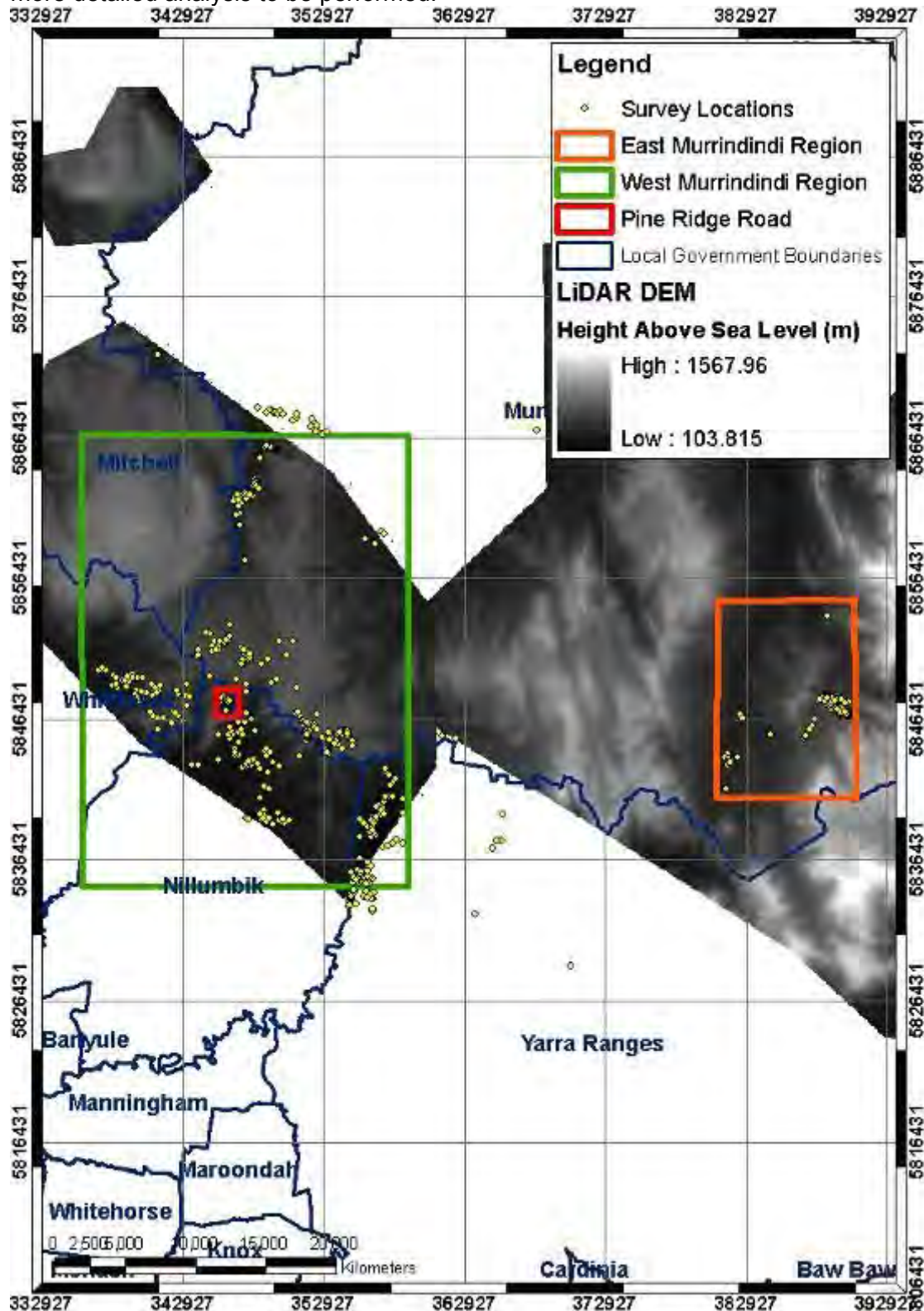


Figure 9 LiDAR extent for Murrindindi study areas – legend as for Figure 8

### *Digital Elevation Model (DEM)*

A digital elevation model (DEM) was generated for the entire area covered by the LiDAR data (Figure 8). The surface was generated at 10-m resolution, where each 10 m pixel is calculated from the ground-classified LiDAR points that fell within that pixel. This resolution was chosen as a compromise between achieving minimal smoothing of ground features and minimal gaps in the resultant surface (where dense canopy and/or data density inconsistencies may contribute to lower density of ground data available). An inverse distance weighting was applied to the points within the cells, such that points further away from the centre of each cell contributed less than points closer to the centre of the cell.

### *Forest/non-forest*

The Forest/non-forest layers were produced at 2-m resolution for all three study areas. Each output cell was considered to contain forest if there were vegetation-classified points more than 8 m above the ground within the cell. This conforms to the Specht (1970) classification of non-shrub and grass strata. Figure 10 shows sample images for West Murrindindi showing (a) the canopy height surface, and (b) the resulting forest/non-forest layer. See the caption of this image for a description of the derivation of the forest/non-forest layer.

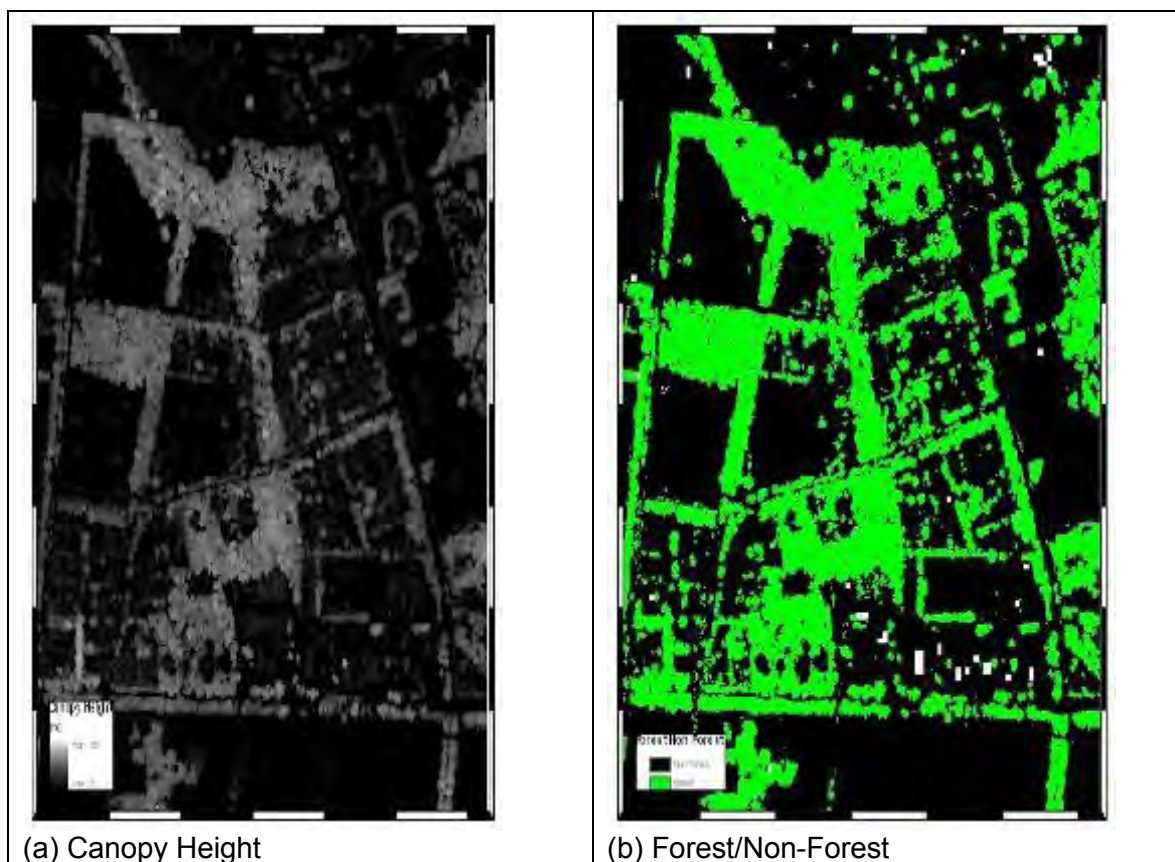


Figure 10 Canopy Height (a) is shown as a grey scale where the brightness of the image is related to the height of the highest return detected by the airborne LiDAR instrument. The derived Forest/non-forest layer (b) is simply a threshold of the canopy height layer, where image pixels with heights detected above 8 m are assigned as forest and shown in green. The remaining non-forest areas are shown in black.

### *Vegetation cover by strata*

Studies such as that of Lovell et al. (2003) have shown that there is a relationship between the distribution of LiDAR points in the forest canopy and leaf area index as measured from ground-based methodologies. These methods use a measure of gap probability ( $P_{gap}$ ) or its complement, hit probability, ( $P_{hit} = 1 - P_{gap}$ ), as an indicator of the density of leaves in a canopy. Since airborne LiDAR does not distinguish between structural forms such as leaves, branches and stems,  $P_{hit}$  can also be used as an indication of the vertical distribution of forest fuel loads. In an effort to capture this vertical distribution of fuel loads, three additional cover layers were derived from the LiDAR data. These layers represent the  $P_{hit}$  within three vertical strata (above 8 m, 3 to 8m, and 50 cm to 3 m) for each 2-m pixel on the landscape and are derived using the equations:

$$P_{hit}(z > 8) = \frac{n(z > 8)}{n(z > 0)} \quad (1)$$

$$P_{hit}(3 < z < 8) = \frac{n(3 < z < 8)}{n(z < 8)} \quad (2)$$

$$P_{hit}(0.5 < z < 3) = \frac{n(0.5 < z < 3)}{n(z < 3)} \quad (3)$$

where:

$z$  is the height above the ground

$n(z)$  is the total number of LiDAR returns in the height layer  $z$

$P_{hit}(z)$  is the hit probability at layer  $z$  in the canopy.

The resulting cover by strata surfaces using these techniques for the Kinglake region (Pine Ridge Road study case) are shown in Figure 11.



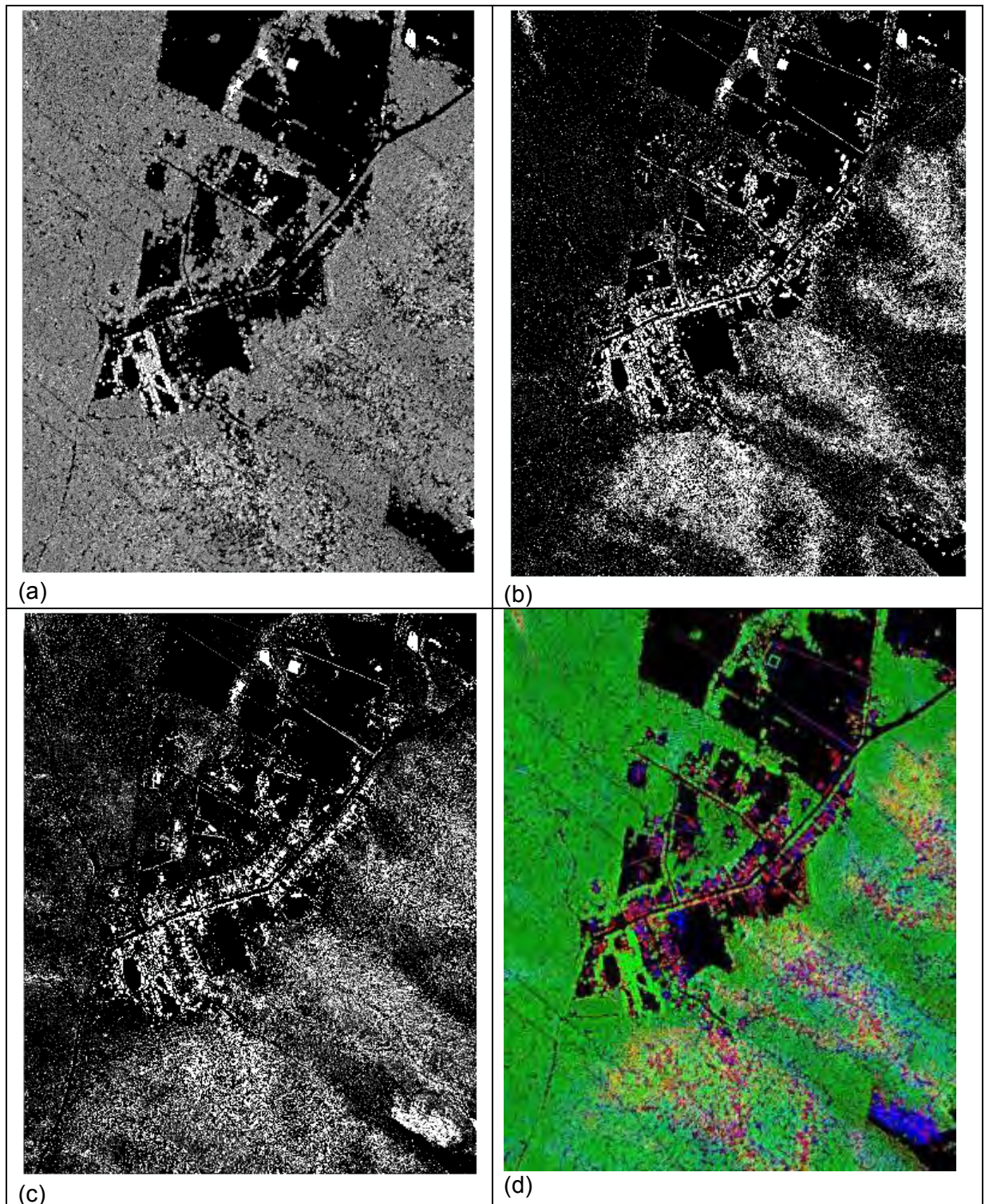


Figure 11 Percentage of cover by strata for Kinglake study region with (a) over-storey cover 8 m and above; (b) mid-storey cover (3–8 m); (c) understorey cover (50 cm–3 m); and (d) a false-colour image where the colours are mapped as follows: red (mid-storey), green (canopy) and blue (understorey).

### 5.2.3 Pre and post-fire imagery (burnt severity of forest area)

High-resolution visible multispectral (blue, green, red) airborne imagery for the Shire of Murrindindi was made available through DSE. The data were acquired during 2006 and 2007 by United Photo & Graphics. The imagery includes three visible bands at a spatial resolution of 15 cm, and has been fully ortho-rectified and tiled into 1-km tiles. A subset of these data for the Pine Ridge Road study site is shown in Figure 12.



Figure 12 Pine Ridge Road subset of the pre-fire imagery provided by the DSE

Post-fire visible airborne imagery was commissioned by the Victorian Police immediately following the February fires over key areas where human impact was greatest. The DSE also commissioned colour infrared data (blue, green, red, near-infrared) to be collected over all fire-affected areas and these data were acquired during the months following the fires. All post-fire imagery was recorded at a spatial resolution of 15 cm, and was fully ortho-rectified. The extent of the data commissioned for the Murrindindi shire by the DSE is shown Figure 13.



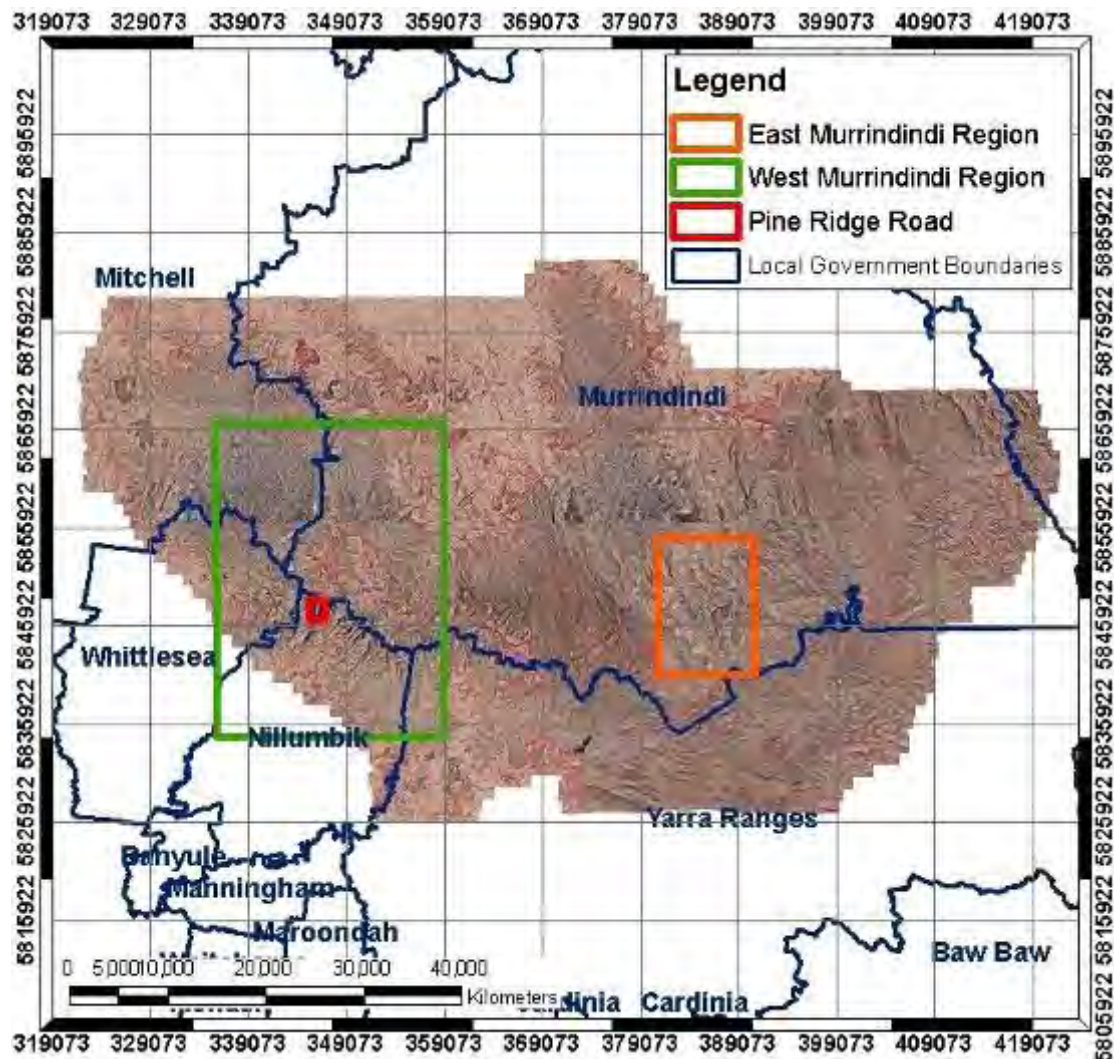


Figure 13 Extent of the post-fire colour infrared data commissioned by the DSE

Although the near-infrared data commissioned by the DSE should provide significant advantages in post-fire analysis over basic visible imagery, only the data commissioned by Victorian Police was available at the time this study was performed, and only over the Pine Ridge Road study site. Within this region, the data were used to determine the extent of structure footprints and whether structures had been destroyed during the fire.

The Pine Ridge Road subset of the post-fire imagery was also used to derive an indication of burn severity within the region (see Figure 14). Areas of forest, as defined by the LiDAR forest layer, were classified into broad severity classes:

- burnt – complete absence of foliage or undergrowth;
- scorched – scorched crowns, scorched foliage still connected;
- unburnt – green crown.



Figure 14 Pine Ridge Road subset of the post-fire imagery commissioned by the Victorian Police and provided by the DSE

Classification was performed using a minimum-distance supervised classification of the imagery, using areas of the Pine Ridge Road subset image as training data. Significant confusion was apparent between unburnt and burnt classes, and a large number of unburnt polygons in the classified image were manually reassigned to the burnt class. Future work will logically utilise airborne near-infrared data that has recently become available and is expected to greatly reduce misclassification errors. The final burn severity classification is shown in Figure 15.

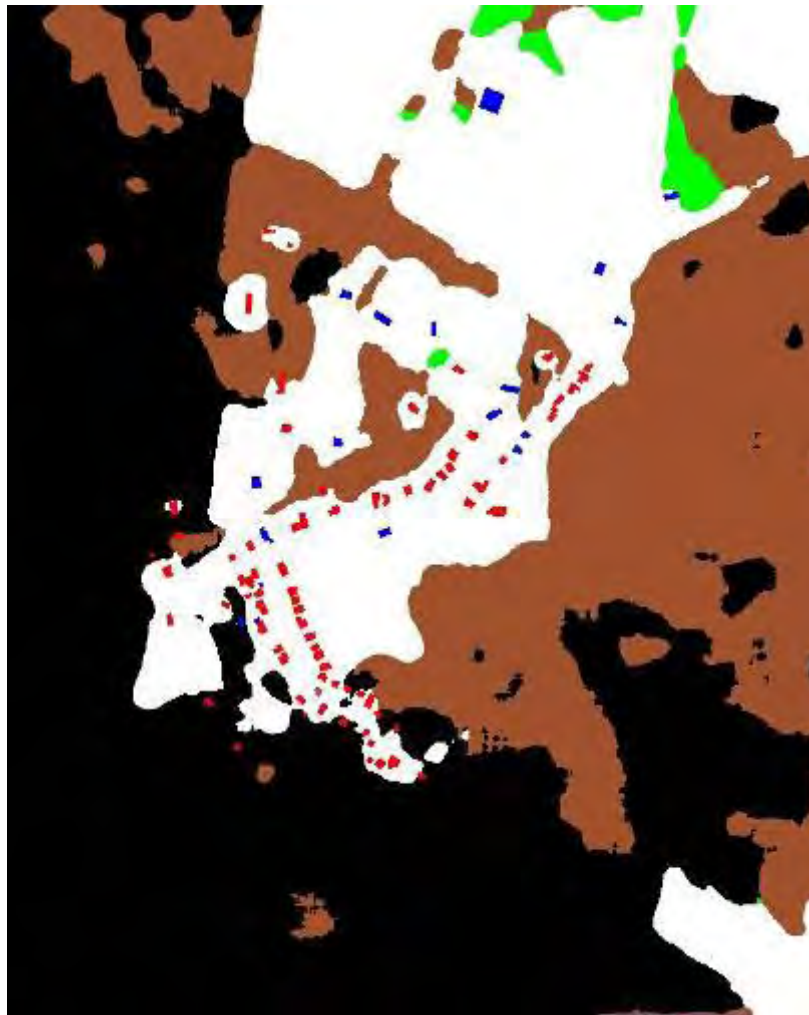


Figure 15 Burn severity classification of the Pine Ridge Road subset. Burn is shown in black, scorched in brown and unburnt in green. Burnt residential structures are shown in red and unburnt residential structures in blue (as described in Section 5.2.4). Areas in white are non-forest.

#### 5.2.4 Structure locations and attributes

Surveys have been conducted by field teams to record detailed aspects of structures within all fire-affected areas. This includes the geographic coordinates of residential structure centroids and observations of the level of damage, the structure type and building materials (see Section 5.1 Field data). Subsets of these data were extracted for both the Murrindindi West and Murrindindi East regions. These data are yet to be checked for both location and attribute errors. To ensure a higher degree of accuracy for data associated with the Pine Ridge Road integrative study area, GIS vector files describing the structure footprints (the bounding box that defines the spatial extent of structures) were also defined manually using both the pre-fire and post-fire imagery.

Structures could generally be clearly seen and delineated in the pre-fire airborne images. However, where overhanging trees existed, it was occasionally easier to delineate the structure or the burnt remains in the post-fire image. Cross-checking between the two images was performed to ensure that no errors or omissions were present.



Each structure was attributed with a structure type (residential, outbuilding or water tank) and a damage class (burnt, not burnt). This was done through subjective assessment of the pre-fire and post-fire imagery (see Figure 16). A single building was generally selected per property as the likely residential building. Factors influencing the decision included the size, location and roof type (gable, etc.). Other buildings within the property were assigned as outbuildings and circular shapes were attributed as water tanks. Burnt buildings were generally obvious through analysis of their change in appearance between the pre- and post-fire imagery.

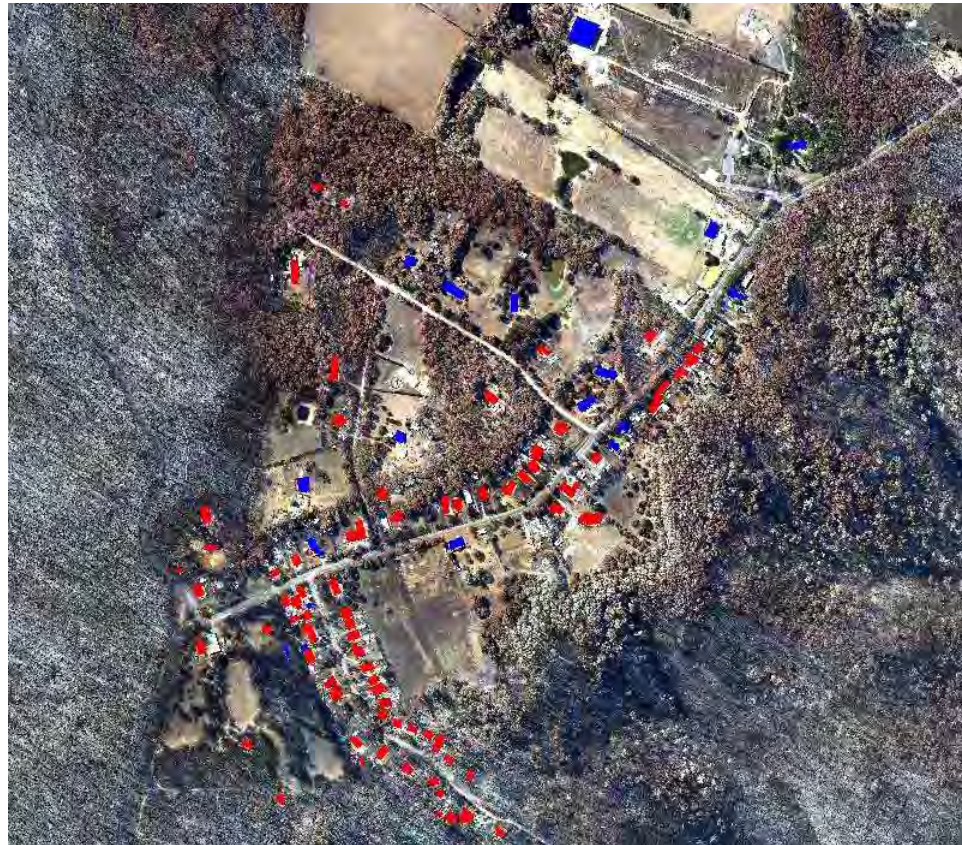


Figure 16 Distribution of burnt and unburnt structures in the Pine Ridge Road case study site area (red: burnt structures, and blue: unburnt structures)

In general, the location of field-surveyed residential structure centroids and the delineated housing footprints within the Pine Ridge Road study area aligned well (see Figure 17). The number of housing footprints delineated using the imagery (95 residential structures) was roughly twice that surveyed (44 residential structures). This can be attributed to the selective nature of the field survey. It is also possible that some commission error<sup>5</sup> has occurred in the subjective assessment made from the imagery.

Table 6 shows the numbers of residential structures considered within each region and their level of damage. Note that structures within the broader West and East regions were assessed during field surveys but structures within the Pine Ridge Road study case area were manually delineated and assigned either unburnt or destroyed based on interpretation of post-fire imagery.

<sup>5</sup> Non-residential buildings assigned as being residential using the imagery

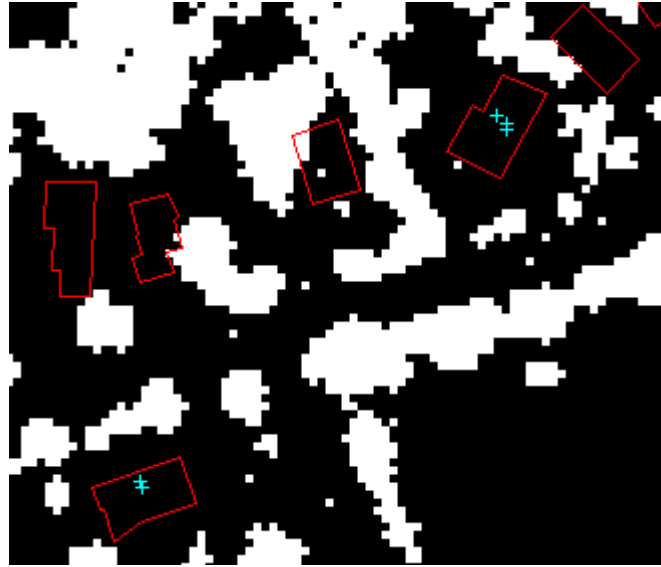


Figure 17 Residential structure footprints (red) with surveyed residential structure centroids (blue crosses) within an area of the Pine Ridge Road study case area

Table 6 Numbers of residential structures considered within each region and their level of damage

Region	Area (ha)	Unburnt	Superficial	Light	Destroyed	Total survey points
<b>West Murrindindi</b>	74,556	19	54	43	342	588
<b>East Murrindindi</b>	13,990	8	21	17	150	149
<b>Pine Ridge Rd</b>	320	2	0	0	42	77

Note that structures within the broader West and East regions were assessed during field surveys but structures within the Pine Ridge Road study case area were manually delineated and assigned either unburnt or destroyed based on interpretation of post fire imagery.

It is likely that any future work will make use of data recently assembled by GA describing the exact footprints of all structures within all fire-affected regions. It is intended that these data will be integrated with site surveys to provide detailed and spatially accurate datasets on which more comprehensive analysis can be performed over a greater number of fire-affected regions.

## 5.3 Other spatial datasets

Spatial information datasets describing human behaviour, weather conditions and fire behaviour are important synergistic datasets to be considered in the analysis. In addition, a better understanding of the urban layout, building footprints, and the age of the houses is necessary to perform certain types of useful analysis. Datasets detailing residential housing centroids and footprints were becoming available as the report was being completed. In addition, information on damage levels, replacement costs and actual value including fences and outbuildings may become available.

### 5.3.1 Human behaviour

A detailed interview-based survey effort has been conducted by the Human Behaviour Team members. Details are provided in the report from the Human Behaviour Team. Approximately 200 transcribed interviews (out of 600) were partially analysed and made available for integration with the dataset described in Section 6.1 at the time of writing the current report. There is significant future opportunity for further analysis of transcripts once they are made available. The transcripts are provided with useful summaries such as: impact on life, impact on house, intended action, action taken, planning and preparedness.

Future analysis of the full set of human behaviour interviews will allow a detailed analysis of relationships between human actions and likelihood of structural survival. In this report, we have used a limited number of interviews to identify a number of observed structural ignitions, house tenability, house defence strategies and near-structure fire behaviour.

Beyond the time frame of this report, additional information will become available from postal surveys and additional interview transcripts, providing a much broader suite of parameters for further data analysis.

### 5.3.2 Weather conditions

The data recorded on the closest meteorological station have been used to produce information on weather conditions during the fire event (see Table 7). For more details, see the fire behaviour part of this report and the Bureau of Meteorology report on the Victorian bushfires (2009).

Table 7 Weather conditions

<b>Fires</b>	<b>Weather conditions* ( maximum Forest Fire Danger Index (FFDI), maximum temperature and minimum relative humidity (RH) recorded on 7<sup>th</sup> February)</b>
<b>Bunyip</b>	130 FFDI, 42°C, 5% RH (Dunns Hill Automatic Weather Station AWS))
<b>Churchill</b>	120 FFDI, 46°C, 8% RH (Morwell AWS) 46°C, 7% RH (Melbourne Airport AWS)
<b>Kilmore East</b>	180 FFDI 43°C, 5% RH (Kilmore Gap AWS)
<b>Maiden Gully</b>	120 FFDI, 45°C, 6%RH (Bendigo Airport AWS)
<b>Murrindindi</b>	100 FFDI, 41°C, 10% RH (Eildon Fire Tower AWS)

\* From fire behaviour report



The spatial locations of the weather stations in relation to the fire perimeter can be found in the Bureau of Meteorology report on Victorian bushfires (2009).

The week leading up to February 7<sup>th</sup> was a week of above-average maximum and minimum temperatures and was preceded by approximately one month of zero rainfall<sup>6</sup>. These conditions would have been effective in reducing the moisture content of combustible elements around, on and within structures (MacIndoe & Bowditch 2007). This reduced moisture content would have led to a great propensity for ignition and support of the spread of flame. In addition, the day of the 7<sup>th</sup> was particularly hot, dry and windy, and this would have caused significant additional moisture loss from these elements, in particular at their surface (see Table 7). These are the same surfaces that define the likelihood of ignition and flame spread. It is clear that when the fire was active in the landscape, houses and surrounding elements were at their most vulnerable stage.

### 5.3.3 Fire behaviour

The map of main wind and fire direction will be provided by the Fire Behaviour Team. Spatial information on fire spread and fire intensity were not available for consideration and integration in the time frame of this report. During the course of surveying properties, field teams also observed local wind direction indicators such as leaf freeze and burn markings on vegetation. When these were observed, field teams recorded the location and direction the wind was likely to have been travelling while fire was active.

Significant insights are likely to be made when other formal datasets are made available for integration and analysis.

---

<sup>6</sup> Monthly statistical summary (<http://www.bom.gov.au/climate/averages/>)

## 6. DATA ANALYSIS

A preliminary data analysis has been detailed in the following section to demonstrate two potential approaches that can be taken. Two main approaches were used to extract relevant information to address the research questions presented in Section 3:

- Query the data to extract specific information on data elements and their relationship to other objects that they either belong to or are closely associated with.
- Spatial analysis is used to derive proximity-based information between objects, often using a combination of field and remote sensing data.

A range of statistical analyses was then performed using the data from the field surveys as well as a wide range of general variables extracted from the field survey data and other sources such as pre- and post-fire remote sensing datasets. The results of these analyses were used to provide a preliminary perspective of the relationships between one or more variables, and they were used to identify the role a variable or a group of variables may have played in determining and influencing house loss or survival.

The following data were not available at the time of writing this report but would be very useful in future analysis:

- A definitive identification of which houses were lost in the fires and their spatial location (partially done)
- a dataset of life loss with location and circumstance for each
- a model output indicating local wind speed potential due to topographical effects
- a complete set of transcribed interviews from the Human Behaviour Team (201 interviews were available)
- results from the postal survey effort conducted by the human behaviour study group
- a dataset of the build date of structures affected by the fires
- a dataset of structures that were built to various regulatory controls
- a photo archive of building wreckage taken prior to Victorian Police investigation modifying the location of building debris
- a dataset of building footprints within the fire-affected areas.

### 6.1 Statistical analysis on field data

Frequency analysis is used to describe the data collected for each fire. In addition, cross-tabulation analysis (or contingency table analysis) has been used to understand the relationship between two (or more) questions in the surveys. A cross-tabulation is a two- (or more) dimensional table that records the number (frequency) of responses that have the specific characteristics described in the cells of the table.

For this study, cross-tabulation of degree of damage to the house (corresponding to Q3 in the structure questionnaire) and a range of other queries has been performed. The frequency and cross-tabulation analysis were obtained using either Statpac or Questiondata statistical packages.

Cross-tabulations of damage to the house (Q3 in the structure questionnaire) and answers from structure, structure opening and outbuilding questions have been combined for all fires and are presented in the results section. Data analysis of this type has also been performed for each individual fire and is provided in Appendix K. Note: Appendix K does not include the Bunyip fire as the field survey sample was too small.

Question 3, for which most correlations were performed, relates to the degree of damage to the house, and has eight possible answers:

- (a) Untouched,
- (b) Superficial,
- (c) Light damage,
- (d) Medium damage,
- (e) Heavy damage,
- (f) Destroyed,
- (g) Other,
- (i) Unknown.

The question answers have been combined as follows: response (a) is labelled untouched; responses (b), (c), (d) are combined and are labelled damaged; responses (e) and (f) are combined and labelled destroyed. Further details of this are provided in Section 7.2.1.

The key to the four entries in each cell of the cross tabulation tables is:

- Count:            number of entry
- Row%            means the percentage of the row total in that cell
- Col%            means the percentage of the column total in that cell
- Tot%            means the percentage of the table total in that cell

For each cross-tabulation, a Chi-square value is provided with a significance level. Extreme caution must be exercised in drawing inferences from simple cross-tabulations such as these. An association between house damage and any factor tabulated may be due to an association of that factor with some other factors (closely related) that increases the risk of damage.

## 6.2 Calculation of local statistics using remote sensing

Local statistics were calculated from the remote sensing data around the centroid of each identified structure of interest. Three key statistics were calculated:

- (i) minimum distance, e.g. minimum distance to another structure;
- (ii) total area, e.g. total area of forest cover;
- (iii) spatial average, e.g. average cover.

Distances from a structure to nearest features were derived for each of twelve 30° sectors beginning from true North; see Figure 18(a). Area-based statistics and spatial averages were calculated within 36 segments defined by 12 directions (30°-sectors) and three ranges (0–50, 50–100 and 100–200 m); see Figure 18(b).

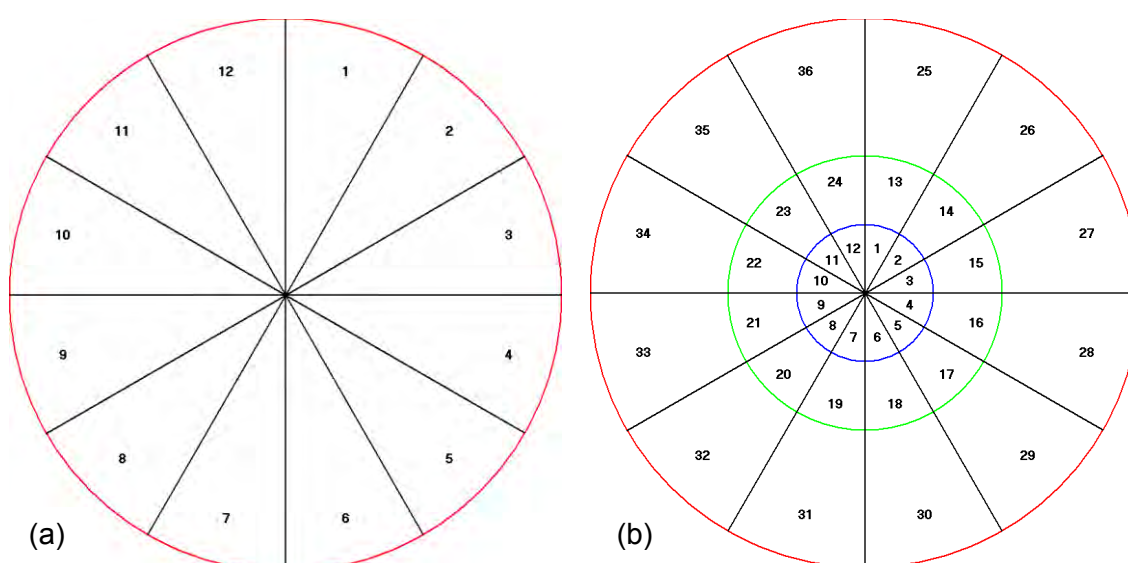


Figure 18: Sectors for distance calculations (a) and segments for area and spatial averages (b). Blue, green and red circles represent ranges of 50, 100 and 200 m, respectively.

Distances were calculated from the centroid of a structure (not the outer wall or edge) to the nearest feature of interest in each sector. Centroids were defined as integer Easting And Northing coordinates and features of interest were defined in raster (grid) form with a spatial resolution of 2 m.

Calculation of area and spatial averages in each segment was performed using raster (grid) data at a spatial resolution of 2 m. Each cell (pixel) in a raster layer was assigned a unique identifier. Area-based statistics were defined as fractional proportions of the segment area.

The tabulated data extracted from each of the data layers takes a consistent form as shown below:

ID	Burnt	Type	Cover1	.....	Cover36	Dist1	.....	Dist12
1	1	0	x		0.325813	0.32543		0.06496

A new tabulated file was generated for each layer produced from the remote sensing data. The ID for each record within the files is the unique identifier for the structure, derived from either the survey data in the case of the West Murrindindi and East Murrindindi regions, or through sequential numbering of the footprints in the case of the Pine Ridge Road site. „Burnt“ refers to the damage severity associated with that structure and „Type“ refers to the nature of the structure, specifically whether the building is residential, an outbuilding or a water tank.

The spatial average statistics for each structure in each of the 36 sectors are recorded in fields „Cover1“ to „Cover36“. Corresponding distances to the nearest pixel for each of the 12 segments is recorded in the fields „Dist1“ to „Dist12“. The summary of these data using standard non-spatial statistics is reported in Section 7.

## 7. RESULTS

### 7.1 Dataset description

The dataset used for this analysis involves 989 cadastral parcels (properties) recorded with a unique parcel ID. A number of objects are recorded as belonging to each of these properties, the term belonging refers to the object being positioned within or on the border of the property. These are detailed in the following Table 8. Some cadastral parcels contain two or more houses (structures), which explains the difference between the number of surveyed parcels and the number of surveyed houses (see also Table 3 for a detailed description of each of these elements).

Table 8 Description of dataset (example)

	Number of objects recorded in one example	Total number of records in dataset
Parcel ID	1	989
Structure	1	1065
Structure opening	8	6560
Attachment	2	767
Outbuilding	3	11,706
Combustible	5	1439
Barrier	3	451
Vegetation	15	10,195
Cover	2	1693
Sprinkler	0	344
Water supply	3	1872
Wind direction	2	626
Interviews	1	650
Photo	20	22,000
Score	78%	N/A

Please note that in subsequent sections, not all questions were answered in relation to all objects. Rather than include a lack of an answer, we have instead analysed the dataset using the answered questions and simply reported the total number of answers and the number of unanswered questions on which the comparison was based. At the time of writing the report, we had not undertaken a detailed analysis as to why questions varied in the extent to which they were answered.

## 7.2 Summary of house damage for all the fires

This section presents a general overview of the number of surveyed houses damaged and surveyed houses lost across all fire regions and the cause of loss when known (Table 9). The analysis was performed on 1065 surveyed houses (approximately 50 houses that need further processing as well as 90 paper-based surveys have been excluded from this analysis). A detailed breakdown of the houses surveyed by locality is presented in Appendix E.

Table 9 Summary of houses surveyed and degree of damage of the houses across all areas

<b>Fire</b>	<b>Surveyed houses</b>	<b>% Houses surveyed houses in fire perimeter</b>	<b>Surveyed houses destroyed</b>	<b>Surveyed houses damaged</b>	<b>Surveyed houses untouched</b>
<b>Bunyip</b>	14	6%	29%	14%	57%
<b>Churchill</b>	140	41%	51%	18%	31%
<b>Kilmore East</b>	705	18%	58%	15%	27%
<b>Maiden Gully</b>	56	26%	41%	25%	34%
<b>Murrindindi</b>	150	13%	75%	23%	3%
<b>Total</b>	1065	18%	58%	17%	25%

Across all fires, 58% of houses surveyed were classed as destroyed (see Table 10).

Within the fire perimeter of Kilmore East, Table 9 shows that 705 houses were surveyed, and Appendix E provides additional detail on the 21 localities this involved. It was noted in the fire behaviour report (see fire behaviour part of this report) that the fire burnt with very high intensity in forested areas during the day.

A total of 150 houses were surveyed in the Murrindindi fire (covering both the areas of Marysville and Narbethong). Of these, 75% were destroyed, which is a higher figure than in other survey areas but indicative of the extent of damage in the Marysville township.

In total, 56 houses were surveyed within the fire perimeter of Maiden Gully (Bendigo), in which 41% of houses were destroyed. The fire has been identified as having a moderate rate of spread in light to moderate fuels (see fire behaviour part of this report).

A total of 140 houses were studied in various locations within the Churchill fire perimeter, mainly in Callignee, Hazelwood South and Koornalla. Half of the houses were destroyed. The fire is likely to have involved substantial spotting (see fire behaviour part of this report).

Fourteen houses were surveyed in the Bunyip area. Six houses were affected by the fire, two by wind and fire and six were untouched. The Council performed a survey of each house destroyed in the fire; however, the information was not available at the time of writing this report.

One of the aims of the rapid research response to the fires of 7<sup>th</sup> February 2009 was to collect information that would be lost in time owing to human activity. Table 10 shows this was achieved, with surveyors able to collect data from a large proportion of houses that

had been destroyed but had not yet been disturbed by site clearance. The 5% of surveys involving site clearance occurred later in the survey effort, and these surveys do not contain details of house design and extent of damage. However, the context provided by the location and surrounding elements is still useful.

Table 10 Percentage of houses which survived (corresponds to liveable houses, including untouched and damaged houses) and destroyed houses, for collected dataset

<b>House survived</b>	444	42%
<b>House destroyed, site not cleared</b>	567	53%
<b>House destroyed, site cleared</b>	54	5%
<b>Total</b>	1065	100%

- **Degree of damage to the house**

Six main levels of damage were used to describe the state of structures in the survey, according to the following descriptions:

Untouched: no fire-related impact to the houses, e.g. scorching, charring, ignitions (a smoke-damaged house may still be untouched).

Superficial: damage to the house that does not require rectification for normal house function, e.g. discoloration, paint blistering, small scorch marks, small burn marks.

Light damage: localised combustion of an element on the house that has not spread to other elements, or localised damage that requires rectification for normal house function, e.g. cracked or broken window, burnt window frame, burnt area on eaves.

Medium damage: combustion that has spread to secondary elements, or extensive radiation impact, e.g. flame spread involving a large area of façade, flame entry into building or building cavities, or majority of windows cracked on at least one side of the house.

Heavy damage: flames have entered the house and engulfed at least one room in the house, or sufficient external combustion to compromise the structural integrity of the house.

Destroyed: more than 50% of the floor area of the house is burnt. House is typically un-occupiable.



Table 11 gives a breakdown of the degree of house damage of surveyed structures for each fire and a total for all fires.

Table 11 Degree of damage to the surveyed houses (expressed as number of houses and percentage per row)

% Row	Untouched	Superficial	Light damage	Heavy damage	Medium damage	Destroyed	Total	% Total
<b>Bunyip</b>	8	2	0	0	0	4	14	1%
	57%	14%	0%	0%	0%	29%		
<b>Churchill</b>	44	20	3	0	3	70	140	13%
	31%	14%	2%	0%	2%	50%		
<b>Kilmore East</b>	190	71	33	14	0	397	705	66%
	27%	10%	5%	2%	0%	56%		
<b>Maiden Valley</b>	19	1	1	0	12	23	56	5%
	34%	2%	2%	0%	21%	41%		
<b>Murrindindi</b>	4	17	16	3	1	109	150	14%
	3%	11%	11%	2%	1%	73%		
<b>Total</b>	265	111	53	17	16	603	1065	100%
<b>%</b>	25%	10%	5%	2%	2%	57%		

In addition, see maps of degree of damage to houses per fires in Appendices F, G, H, I, J.

### 7.2.1 Likely cause of damage

The causes of damage to houses are dominated by fire-related effects. However, 13% of damage or destroyed houses have been identified as being impacted by a combination of both fire and wind (see Table 12, Figure 19 and maps of likely cause of damage in Appendices F, G, H, I, J). Some wind effects have been recorded in the Marysville region, such as trees and branches broken, and some localised cases of trees being uprooted (as example see Figure 22 and Figure 23). The survey team also identified strong wind effects in other area such as the Kilmore East region; for details on each fire, see Appendices F, G, H, I, J). A very small number of surveyed houses were identified as having wind-related damage only. These occurred within 8 km of each other on the border of Humevale and Kinglake West (see Figure 20). Wind-related impact was also identified in a number of interviews.

Table 12 Likely cause of fire (expressed as number of houses and percentage per row)

% Row	Fire only	Wind only	Fire & wind	Fire damage, wind unknown	Other	Untouched, no damage	Unknown	Total	% Total
<b>Bunyip</b>	6	0	2	0	0	6	0	14	1%
	43%	0%	14%	0%	0%	43%	0%		
<b>Churchill</b>	35	0	6	39	0	46	12	138	14%
	25%	0%	4%	28%	0%	33%	9%		
<b>Kilmore East</b>	183	4	81	217	3	127	40	655	65%
	28%	1%	12%	33%	0%	19%	6%		
<b>Maiden Valley</b>	8	0	4	14	2	9	19	56	6%
	14%	0%	7%	25%	4%	16%	34%		
<b>Murrindindi</b>	7	0	42	62	2	5	31	149	15%
	5%	0%	28%	42%	1%	3%	21%		
<b>Total</b>	239	4	135	332	7	193	102	1012	100%
<b>%</b>	24%	0%	13%	33%	1%	19%	10%		100%

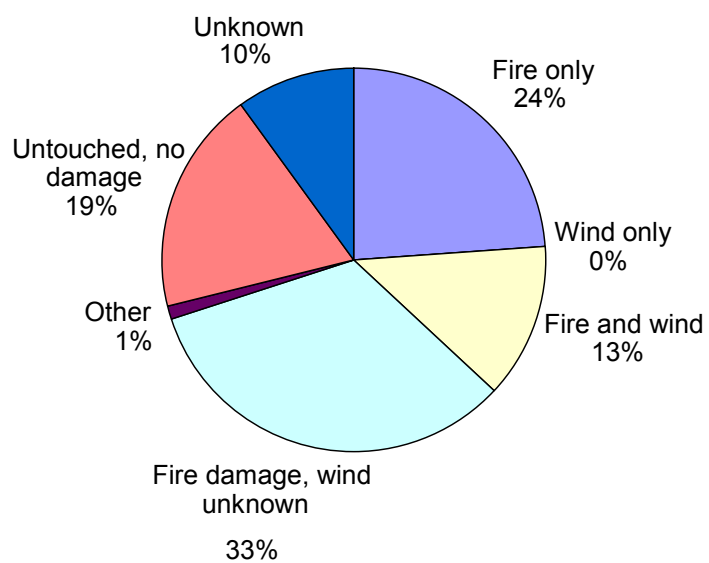


Figure 19 Likely cause of damage across all fire areas



Figure 20 Example of house affected by wind only (Humevale, Kinglake West)

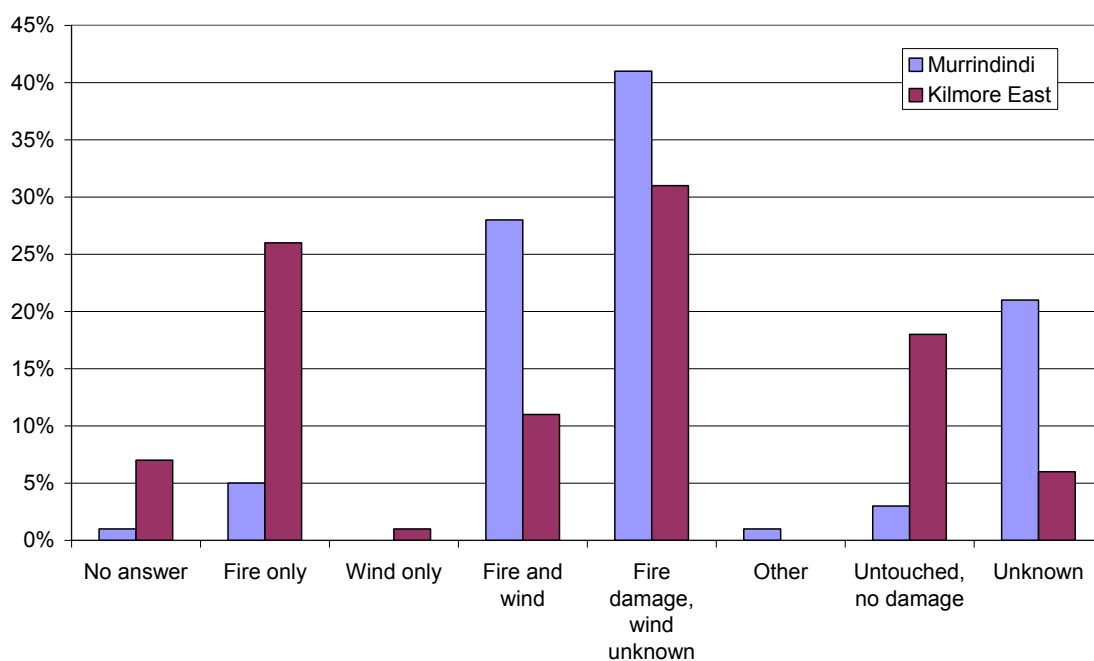


Figure 21 Likely cause of damage in Murrindindi and Kilmore East fire (percentage of houses surveyed)



Figure 22 Example of observed wind influence in Marysville



Figure 23 Example of wind impact in Marysville (tree blown down during the fire – comment from resident account)

## 7.2.2 Identified mechanism of bushfire attack

This section presents a summary of identified mechanisms of bushfire attack (embers, radiant heat and flame) using two approaches:

- an analysis of the information recorded in the building survey,
- an extraction of information from human account (interviews from Human Behaviour Team).

In the building survey, the mechanisms of bushfire attack were recorded for:

- ground cover
- outbuildings
- houses.

In some cases, the main mechanism of bushfire attack was difficult to identify. This explains the large proportion of unknown survey answers (22%) with regard to the nature of bushfire attack the structure may have experienced (see Table 13). Ground cover, outbuildings and structures tended to experience similar proportions of attack mechanism when aggregated across all Victorian fires considered in this study.

Table 13 Main bushfire attack mechanisms recorded for the ground cover, outbuildings and structures within all fire perimeters, where response was recorded

	Damage on ground cover		Damage on outbuilding		Damage on structure	
<b>Embers only</b>	64	15%	94	12%	95	19%
<b>Ember and some radiant heat</b>	150	35%	262	34%	168	33%
<b>Predominant radiant heat</b>	18	4%	76	10%	24	5%
<b>Flame contact from bush</b>	82	19%	103	13%	67	13%
<b>Other (please comment)</b>	3	1%	5	1%	11	2%
<b>No direct bushfire attack</b>	34	8%	62	8%	36	7%
<b>Unknown</b>	76	18%	172	22%	111	22%
<b>Total</b>	427	100	774	100	512*	100%

\* Note 553 surveys contained no answer to this question

Table 14 shows a comparison with the Eyre Peninsula and Canberra fires. For those fires, the main mechanism of attack was by embers and radiant heat. The Victorian bushfires show a much lower proportion of „embers only“ (19%) compared with the other fires.

If we combine all categories involving flame, we see the Victorian fires and the Eyre Peninsula fire are similar while the Canberra fire is much lower. The combination of embers and radiant heat is roughly comparable across all fires.

It should be noted that this is a difficult question to answer as some evidence disappeared, as elements around the house ignite and spread to other elements. Hence questions such as these may be interpreted differently owing to the different background of the survey staff. This influence is likely to have been expressed in percentage of unknown reports in the survey.

Table 14 Main bushfire mechanisms recorded in the Eyre Peninsula bushfire – comparison with Canberra bushfire and Victorian fires (from Blanche & Leonard 2006)

	Eyre Peninsula 2005		Canberra Bushfire 2003		Victorian fires 2009	
	No of houses	%	No of houses	%	No of houses	%
<b>Embers, radiant heat and flame contact</b>	9	11%	0	0%	*	*
<b>Embers and flame</b>	2	3%	1	0%	*	*
<b>Embers and some radiant heat</b>	7	9%	74	34%	168	33%
<b>Embers only</b>	45	56%	107	49%	95	19%
<b>Predominantly radiant heat</b>	2	3%	11	5%	24	5%
<b>Flame contact from bush vegetation</b>	1	1%	4	2%	67	13%
<b>Other</b>	1	1%	2	1%	11	2%
<b>No direct bushfire attack</b>	5	6%	15	7%	36	7%
<b>Unknown</b>	8	10%	5	2%	111	22%
<b>Total</b>	80	100%	219	100%	512	100%

\* question not asked in survey

### 7.2.3 Human accounts of fire effects on houses

In addition to the survey of structures, occupant accounts were used to identify the main ignition points on the structures, by ember and/or radiant heat. This approach is essential to increase our knowledge of house vulnerability. The observations identifying mechanisms of attack are readily drawn from eyewitness accounts and surviving house case studies, as this provides the most definitive identification of house loss mechanisms. The ignition points were preserved owing to occupant and/or brigade activities, or were identified by the occupant before developing into an extensive house fire.

In this example, we used the occupant accounts from the interviews conducted by the human behaviour team. Owing to the short time frame for the completion of this report, only 40 out of the 201 interviews available were studied (interviews of occupants who stayed and defended were selected in priority). Twenty-three of these interviews provided interesting observations on the mechanism of attack and are presented here. It is anticipated that a much greater sample will be analysed in future efforts. Extracted quotes involving the following specific structural features (and the number of separate interviews they appear in) are provided below:

#### Window (2 cases)

*“My hot-house had caught fire in two places on the windows, so I put that out with buckets”*

#### Roof, ceiling, eaves (11 cases), see also Figure 24 as an example of roof ignition

*“The eaves caught on fire and even with pump and hose...I could not stop it”*

*“Yes, the embers somehow got under the tiles even with the sprinklers on. I don't know how they did but yes, and it was burning underneath” (could not reach from outside).*

*“When the main embers had passed, and the house had caught in four different spots, all at the roof line, and we put those out”*

*“It was the roof beam that went (rough-sawn Oregon), could not reach with buckets”*

*“There's big embers everywhere up in there (roof)”*

#### Inside house (4 cases)

*“Embers on carpet” (house not well sealed)*

*“House full of smoke and embers ...came through the door”*

#### Veranda and other house attachments (2 cases)

*“On the other side of the house, the fire picks up the veranda beams”*



In addition, some interviews provided information on the type of mechanisms of bushfire attack. For instance, some occupants, mainly in the Marysville and Kinglake regions, have commented on the magnitude and ferocity of ember attack; further analysis of interviews will give an insight on these and other regions. The following comments are indicative:

### **Marysville**

*“It was just all over the place and the embers were just rocketing in, big, big stuff. Not an ember attack I was thinking was leaves and ferns and shit, but this was incoming branches, burning branches, it was quite large. And they were coming out of the gloom just like red rockets. And like they were just streaking in and hitting the roof, the ground, and when they hit the ground, they would just ignite.”*

*“We had a horizontal hailstorm of burning embers, some the size of golf balls, accompanied by a thick smoke cloud and gigantic flames leaping over the back fence towards our house”*

### **St Andrews**

*“Hailed embers, like I say or more, for an hour – or more”*

### **Kinglake**

*“It was more a hail of fire spots. And it was as though the air was alight”*

These accounts are particularly insightful for consideration by the researchers, as much of this evidence is not observable from surveying the building remains after the bushfire.

## **7.2.4 Human accounts of house ignition after the fire front has passed**

Occupant interviews have also provided evidence of houses lost after the fire front had passed, usually from small ignitions that were unattended (an example is shown in Figure 24).

*“It took half an hour, and we watched a little fire start at a post out the front of the house (neighbouring house). There was nothing we could do from here. So it got lost. The one next to the tennis court was an hour later before it actually lit up”*

*“Three houses on the block, the second house rented went around midnight from embers”*

*“Come back one o’clock if we weren’t here, this could have taken alight after”*

*“This house here, I thought – I thought at about 10.30 (pm), that it had actually gone. This one didn’t start until 12.30. I remember the time. It was 12.30. I came out and I just – the front porch started to catch. Just a little fire, just started, and that was it. Two hours later, the whole house was on fire”*

From the small interview sample, there were 10 interview cases where the occupant either stayed and defended, or left and returned soon after the fire. Nine of these mentioned they had saved their houses from certain loss.



Figure 24 Example of ignition into roof noticed by the occupant several hours after fire front had passed

### 7.2.5 Human accounts of house tenability

There is evidence provided by occupants that the heat was too intense to be able to survive outside, owing to several fire fronts impacting on the house (or surrounding elements burning).

*“And the fire front – I’ve always been told a fire front will take you five or seven minutes to go through. Well, I’ve got to say it was at least half an hour, you couldn’t come... venture outside... Yep. And I’ve heard other people say 30 to 45 minutes.” (Kinglake)*

*“And how long did you stay inside for?” “At least 40 minutes” (Strathewen)*

There are some examples of house ignitions forcing people to carefully move through the house as it became involved until they could make an exit when the house became untenable. This example in St Andrews describes the case of a house where the roof caught alight; the occupant closed this part of the house and sheltered in another part of the house while the fire was progressing. The occupant defended himself inside as the house gradually became more involved.



*“An hour, maybe an hour and a quarter since the fire first hit”* (answering a question how long they stayed in the house)

Another example of occupants having to shelter in a burning house and work their way out of the house was found in Kinglake (Pine Ridge Road).

### 7.3 Characteristics of house design and material

The characteristics of house design and material play an important role in the house loss process. The vulnerability of a house depends on three aspects:

- the probability of embers entering in the structure through gaps
- the probability of ember ignition against the envelope and sustaining the ignition, leading to a breach in the structure
- the probability of ignition from radiant heat and flame due to the combustion of external combustible material (e.g. vegetation and surrounding objects).

Different parts of the house will present vulnerabilities to these attack mechanisms, such as wall material, roof, subfloor space, windows, decks and verandas. Each aspect is studied for each fire, as well as being compared across all fires.

#### 7.3.1 Number of storeys

It is interesting to consider whether the number of storeys of a house may have bearing on the likelihood of structural impact. The majority of houses in all fire areas are single storeys, although the proportion varies across areas as follow: Kilmore East fire area (79%); Murrindindi fire (61%); Churchill fire (80%), Maiden Gully (63%); and Bunyip fire area (79%) (see Table 15).

Table 15 Number of functional levels (expressed as number of houses and percentage per row)

% Row	One level	Split single level	Two levels	More than two full levels	Other	Unknown	Total	% Total
<b>Bunyip</b>	11 79%	1 7%	2 14%	0 0%	0 0%	0 0%	14	1%
<b>Churchill</b>	116 85%	7 5%	10 7%	1 1%	0 0%	2 1%	136	14%
<b>Kilmore East</b>	506 78%	34 5%	80 12%	3 0%	5 1%	18 3%	646	65%
<b>Maiden Gully</b>	35 63%	1 2%	2 4%	0 0%	0 0%	18 32%	56	6%
<b>Murrindindi</b>	89 61%	10 7%	27 18%	2 1%	4 3%	15 10%	147	15%
<b>Total</b>	757	53	121	6	9	53	999*	100%
<b>%</b>	76%	5%	12%	1%	1%	5%		100%

\* 66 no answer or missing cases

It is unclear why there are a large number of unknowns for Maiden Gully at this point. This is possibly due to local site clearing or the survey team finding it difficult to identify structural wreckage.

Table 16 shows the cross-tabulation analysis between the number of storeys and house damage on all the fires. This shows a higher proportion of houses with one storey are destroyed (61%) compared with the two storey-houses (44%); this may be an expression of house age rather than the number of storeys, as it would be fair to suggest that older houses in the region are more likely to be single-storey. Further investigation of this issue is required.

Table 16 Number of storeys and house damage across all fires<sup>7</sup>

House damage	One level	Split single level	Two levels	More than two full levels	Other	Unknown	Totals
<b>Untouched</b>	168	12	31	1	1	10	
	75.3%	5.4%	13.9%	0.4%	0.4%	4.5%	223
	22.2%	22.6%	25.6%	16.7%	11.1%	18.9%	22.3%
	16.8%	1.2%	3.1%	0.1%	0.1%	1.0%	
<b>Damaged</b>	123	10	37	1	2	0	
	71.1%	5.8%	21.4%	0.6%	1.2%	0.0%	173
	16.2%	18.9%	30.6%	16.7%	22.2%	0.0%	17.3%
	12.3%	1.0%	3.7%	0.1%	0.2%	0.0%	
<b>Destroyed</b>	466	31	53	4	6	43	
	77.3%	5.1%	8.8%	0.7%	1.0%	7.1%	603
	61.6%	58.5%	43.8%	66.7%	66.7%	81.1%	60.4%
	46.6%	3.1%	5.3%	0.4%	0.6%	4.3%	
<b>Totals</b>	757	53	121	6	9	53	999
	75.8%	5.3%	12.1%	0.6%	0.9%	5.3%	100.0%

Chi-Square = 33.23  
 Caution: 5 cells (28%) E < 5  
 Probability (df = 10) = 0.000

Valid cases = 999  
 Missing cases = 66  
 Response rate = 93.8%

<sup>7</sup> The key to the four entries in each cell is given as follows:

- number of houses
- percentage of the row total in that cell
- percentage of the column total in that cell
- percentage of the total entry in that cell

### 7.3.2 Flooring system

The survey and resulting study of flooring systems sought to verify whether these areas were vulnerable to ember entry, accumulation, and/or direct ignition. Across all the houses surveyed, 35% were slab-on-ground construction, 30% of the floors were supported by concrete stumps and 12% by timber stumps (see Table 17).

Table 18 suggests that house construction types involving raised flooring is more likely to be destroyed than slab-on-ground construction. Slab-on-ground construction had a similar distribution of undamaged to damaged houses. Houses with raised floors supported by stumps had a far greater proportion of destroyed houses compared with undamaged. The type of stump material does not seem to influence the likelihood of loss. Treated pine stumps had a significantly different distribution; this may be due to the fact that treated pine elements tend to burn to completion once ignited, leaving little evidence of their existence, and this may have led to a poor detection rate of this stump type in destroyed house wreckage.

Table 17 Main material supporting floors (expressed as numbers of houses and percentage per row)

% Row	Treated pine	Other timbers	Concrete stumps,	Steel posts	Brick piers	Other	Slab on ground	Unknown	Total	%
<b>Bunyip</b>	3	1	1	0	1	0	0	2	8	1%
	38%	13%	13%	0%	13%	0%	0%	25%		
<b>Churchill</b>	6	7	51	6	2	1	29	7	109	15%
	6%	6%	47%	6%	2%	1%	27%	6%		
<b>Kilmore East</b>	19	86	199	21	42	5	59	38	469	63%
	4%	18%	42%	4%	9%	1%	13%	8%		
<b>Maiden Gully</b>	0	10	7	1	5	0	9	15	47	6%
	0%	21%	15%	2%	11%	0%	19%	32%		
<b>Murrindindi</b>	8	20	59	0	8	2	3	12	112	15%
	7%	18%	53%	0%	7%	2%	3%	11%		
<b>Total</b>	36	124	317	28	58	8	100	74	745*	100%
<b>%</b>	5%	17%	43%	4%	8%	1%	13%	10%		100%

\* no answer or missing cases = 320

Table 18 Main material supporting floors and house damage (see footnote 6)

House damage	Treated pine	Other timbers	Concrete stumps, etc.	Steel posts	Brick piers, walls	Other	Slab on ground	Unknown	Totals
<b>Untouched</b>	14	20	43	4	15	1	41	24	
	8.6%	12.3%	26.5%	2.5%	9.3%	0.6%	25.3%	14.8%	162
	38.9%	16.1%	13.6%	14.3%	25.9%	12.5%	41.0%	32.4%	21.7%
	1.9%	2.7%	5.8%	0.5%	2.0%	0.1%	5.5%	3.2%	
<b>Damaged</b>	11	20	36	5	15	0	18	6	
	9.9%	18.0%	32.4%	4.5%	13.5%	0.0%	16.2%	5.4%	111
	30.6%	16.1%	11.4%	17.9%	25.9%	0.0%	18.0%	8.1%	14.9%
	1.5%	2.7%	4.8%	0.7%	2.0%	0.0%	2.4%	0.8%	
<b>Destroyed</b>	11	84	238	19	28	7	41	44	
	2.3%	17.8%	50.4%	4.0%	5.9%	1.5%	8.7%	9.3%	472
	30.6%	67.7%	75.1%	67.9%	48.3%	87.5%	41.0%	59.5%	63.4%
	1.5%	11.3%	31.9%	2.6%	3.8%	0.9%	5.5%	5.9%	
<b>Totals</b>	36	124	317	28	58	8	100	74	745
	4.8%	16.6%	42.6%	3.8%	7.8%	1.1%	13.4%	9.9%	100.0%

Chi-Square = 80.87

Caution: 3 cells (13%) E &lt; 5

Probability (df = 14) = 0.000

Valid cases = 745

Missing cases = 320

Response rate = 70.0%

### 7.3.3 External wall material

The predominant external wall material of the surveyed houses is brick (37 %; see Table 19). Other cladding materials and their respective proportions are cellulose cement (18%) and timber (18%); half of the timber-clad houses are smooth weatherboard (painted) and a quarter of them are rough-sawn weatherboard. Table 20 shows a cross-tabulation of the house damage and the main construction material. It appears that the brick structures (43.8% destroyed) performed significantly better than other classes such as cellulose cement, timber and mud brick. The worst performer was cellulose cement (75.1% destroyed), indicating either higher vulnerability or poor building integrity associated with this cladding type, or the associated light construction approach for these dwellings. Mud brick (65.2% destroyed) has not performed similarly to brick; it is also a heavy non-combustible wall material, and its poor performance may be due to the other structural design details associated with mud brick constructions.

Table 19 Predominant external wall material (expressed as numbers of houses and percentage per row)

% Row	Timber	Cellulose cement	Brick (not mud brick)	Mud brick	Aluminium siding	PVC siding	Other	Unknown	Total	% Total
<b>Bunyip</b>	2	3	7	0	0	0	1	1	14	1%
	14%	21%	50%	0%	0%	0%	7%	7%		
<b>Churchill</b>	7	26	56	3	4	0	10	15	121	13%
	6%	21%	46%	2%	3%	0%	8%	12%		
<b>Kilmore East</b>	112	100	227	58	2	1	63	51	614	65%
	18%	16%	37%	9%	0%	≈0%	10%	8%		
<b>Maiden Gully</b>	1	8	16	4	0	1	1	21	52	6%
	2%	15%	31%	8%	0%	2%	2%	40%		
<b>Murrindindi</b>	44	32	43	4	0	1	7	13	144	15%
	31%	22%	30%	3%	0%	1%	5%	9%		
<b>Total</b>	166	169	349	69	6	3	82	101	945*	100%
<b>%</b>	18%	18%	37%	7%	1%	0%	9%	11%		100%

\* no answer or missing cases = 120

Table 20 Predominant wall material and house damage (see footnote 6)

House damage	Timber	Cellulose cement	Brick (not mudbrick)	Mud brick	Aluminium siding	PVC siding	Other	Unknown	Totals
Untouched	25	24	114	9	2	0	19	10	
	12.3%	11.8%	56.2%	4.4%	1.0%	0.0%	9.4%	4.9%	203
	15.1%	14.2%	32.7%	13.0%	33.3%	0.0%	23.2%	9.9%	21.5%
	2.6%	2.5%	12.1%	1.0%	0.2%	0.0%	2.0%	1.1%	
Damaged	33	18	82	15	0	1	13	4	
	19.9%	10.8%	49.4%	9.0%	0.0%	0.6%	7.8%	2.4%	166
	19.9%	10.7%	23.5%	21.7%	0.0%	33.3%	15.9%	4.0%	17.6%
	3.5%	1.9%	8.7%	1.6%	0.0%	0.1%	1.4%	0.4%	
Destroyed	108	127	153	45	4	2	50	87	
	18.8%	22.0%	26.6%	7.8%	0.7%	0.3%	8.7%	15.1%	576
	65.1%	75.1%	43.8%	65.2%	66.7%	66.7%	61.0%	86.1%	61.0%
	11.4%	13.4%	16.2%	4.8%	0.4%	0.2%	5.3%	9.2%	
<b>Totals</b>	166	169	349	69	6	3	82	101	945
	17.6%	17.9%	36.9%	7.3%	0.6%	0.3%	8.7%	10.7%	100.0%

Chi-Square = 96.03  
 Caution: 6 cells (25%) E < 5  
 Probability (df = 14) = 0.000

Valid cases = 945  
 Missing cases = 120  
 Response rate = 88.7%

### 7.3.4 Roof

Two types of roof profile are dominant in the survey dataset: a simple roof with one ridge and no valleys (40%), and complex ridge (27%) (see Table 21). The presence of complex ridges means that valleys exist. These valleys are areas where accumulation of embers and windborne debris can occur and will increase the likelihood of roof ignition during ember attack. However, there appears to be no statistical significance when correlating house loss to the degree of roof complexity.

The predominant roof material is corrugated iron (75%) and metal deck (metal roof profile other than the wave-profile corrugated iron) (10%) (see Table 22). Table 23 indicates that there is no statistical significance between house loss and roof material type.

Table 21 Roof profile and house damage (expressed as number of houses and percentage per row)

Row	One slope, no ridge or valley	One ridge, no valley	One valley, no ridge	Complex ridge	Other	Unknown	Total	%
<b>Bunyip</b>	0	7	0	7	0	0	14	1%
	0%	50%	0%	50%	0%	0%		
<b>Churchill</b>	10	44	1	47	3	29	134	13%
	7%	33%	1%	35%	2%	22%		
<b>Kilmore East</b>	63	284	1	168	16	116	648	65%
	9%	44%	0%	26%	2%	18%		
<b>Maiden Gully</b>	3	15	1	13	0	24	56	6%
	6%	27%	2%	23%	0%	43%		
<b>Murrindindi</b>	10	45	2	37	3	49	146	15%
	7%	31%	1%	25%	2%	34%		
<b>Total</b>	86	395	5	272	22	218	998*	100%
<b>%</b>	9%	40%	1%	27%	2%	22%		100%

\* 67 missing or no answer

Table 22 Predominant roof material (expressed as number of house and percentage per row)

% Row	Metal deck	Corrugated iron	Corrugated cement sheet	Tiles (terracotta, concrete)	Metal pseudo tiles	Other	Unknown	Total	% Total
<b>Bunyip</b>	0	13	0	1	0	0	0	14	1%
	0%	93%	0%	7%	0%	0%	0%		
<b>Churchill</b>	13	98	0	14	4	2	4	135	14%
	10%	73%	0%	10%	3%	1%	3%		
<b>Kilmore East</b>	72	496	3	55	2	13	9	650	65%
	11%	76%	0%	8%	0%	2%	1%		
<b>Maiden</b>	1	32	0	6	1	0	15	55	6%
	2%	58%	0%	11%	2%	0%	27%		
<b>Murrindindi Valley</b>	14	109	0	12	0	3	8	146	15%
	10%	75%	0%	8%	0%	2%	5%		
<b>Total</b>	100	748	3	88	7	18	36	1000*	100%
<b>%</b>	10%	75%	0%	9%	1%	2%	4%		100%

\* 65 missing or no answer

Table 23 Predominant roof material and house damage across all fires (see footnote 6)

House damage	Metal deck	Corrugated iron	Corrugated cement sheet	Tiles (terracotta concrete)	Metal pseudo tiles	Other	Unknown	Totals
<b>Untouched</b>	29	156	0	28	0	4	8	
	12.9%	69.3%	0.0%	12.4%	0.0%	1.8%	3.6%	225
	29.0%	20.9%	0.0%	31.8%	0.0%	22.2%	22.2%	22.5%
	2.9%	15.6%	0.0%	2.8%	0.0%	0.4%	0.8%	
<b>Damaged</b>	18	127	0	19	2	4	3	
	10.4%	73.4%	0.0%	11.0%	1.2%	2.3%	1.7%	173
	18.0%	17.0%	0.0%	21.6%	28.6%	22.2%	8.3%	17.3%
	1.8%	12.7%	0.0%	1.9%	0.2%	0.4%	0.3%	
<b>Destroyed</b>	53	465	3	41	5	10	25	
	8.8%	77.2%	0.5%	6.8%	0.8%	1.7%	4.2%	602
	53.0%	62.2%	100.0%	46.6%	71.4%	55.6%	69.4%	60.2%
	5.3%	46.5%	0.3%	4.1%	0.5%	1.0%	2.5%	
<b>Totals</b>	100	748	3	88	7	18	36	1000
	10.0%	74.8%	0.3%	8.8%	0.7%	1.8%	3.6%	100.0%

Chi-Square = 17.95

Caution: 8 cells (38%) E &lt; 5

Probability (df = 12) = 0.117

Valid cases = 1000

Missing cases = 65

Response rate = 93.9%

### 7.3.5 Window

Where possible, the survey recorded the location of windows for each house, as well as their different material types. For this report, preliminary information has been used from 657 houses (additional window details from other houses will be provided with further data analysis). The information on window glass type has been aggregated per house taking into account the most vulnerable type of glass present if different types of glass were recorded (plain is considered as the most vulnerable glass type). As shown in Table 24, the large majority of houses have plain glass (67%). The low number of houses that were identified as having all toughened or laminated glass make it unsuitable to compare their relative contribution to house survival compared with plain glass.

Information on window frame material, type of protection of window, protection material and presence of shutters and how these may affect house damage needs further processing and will be presented in the second phase of the research.

Table 24 Type of glass (expressed as numbers of houses and percentage per row)

% Row	Toughened	Laminated	Plain	Other	Unknown	Total	% Total
<b>Bunyip</b>	0	0	9	0	0	9	1%
	0%	0%	100%	0%	0%		
<b>Churchill</b>	5	1	56	1	19	82	14%
	5%	1%	62%	1%	21%		
<b>Kilmore East</b>	12	11	291	12	85	411	66%
	3%	3%	67%	3%	20%		
<b>Maiden Gully</b>	2	0	10	1	4	17	3%
	12%	0%	59%	6%	24%		
<b>Murrindindi</b>	2	0	76	2	23	103	16%
	2%	0%	72%	2%	22%		
<b>Total</b>	21	12	442	16	131	622*	100%
<b>%</b>	3%	2%	71%	3%	21%		100%

\* No answer or missing case or window elements not considered for 443 houses

Table 25 Type of glass and degree of damage to the house (expressed as number of houses and percentage per column and percentage per row)

% Column							%
% Row	Toughened	Laminated	Plain	Other	Unknown	Total	Total
<b>Untouched</b>	6	6	130	3	19	164	27%
	29%	50%	30%	19%	15%		
	3%	3%	73%	2%	11%		
<b>Damaged</b>	8	3	119	7	8	145	23%
	38%	25%	27%	44%	6%		
	5%	2%	80%	5%	5%		
<b>Destroyed</b>	7	3	188	6	101	305	50%
	33%	25%	43%	38%	79%		
	2%	1%	58%	2%	31%		
<b>Total</b>	21	12	437	16	128	614	100%
<b>%</b>	3%	2%	71%	3%	21%		100%

\* 451 missing or no answer

### 7.3.6 Deck and veranda

Different types of attachments have been recorded on some of the houses surveyed (such as deck, stairs). Some houses have more than one attachment, and some have no attachments recorded (these mainly relate to the destroyed houses). Of those with attachments, 75% are decks (and 45% of those decks have a roof covering), 5% are stairs, and 20% other attachments have been specified in the comment field, such as veranda (around 30%) (see Table 26). Of the deck attachments, 87% have been identified as combustible. Across the fires, the decking material varies as follow: 5% are tongue board, 18% gapped board treated pine, and 17% gapped board other timber (see Table 27). Of the deck attachments, 46 % are undamaged and 35% are completely burnt (see Table 28).



Cross tabulation of the presence of combustible decking and house loss could be undertaken as future work.

Table 26 Type of attachment (expressed as number of attachments and percentage per row)

% Row	Deck	Stairs	Other	Total	% Total
<b>Bunyip</b>	1	0	0	1	0%
	100%	0%	0%		
<b>Churchill</b>	130	3	25	158	22%
	82%	2%	16%		
<b>Kilmore East</b>	332	26	85	443	62%
	75%	6%	19%		
<b>Maiden Valley</b>	16	1	3	20	3%
	80%	5%	15%		
<b>Murrindindi</b>	57	9	31	97	13%
	59%	9%	32%		
<b>Total</b>	536	39	144	719	100%
<b>%</b>	75%	5%	20%		100%



Figure 25 Example of deck ignition, spread and suppression

Table 27 Principal decking material (expressed as numbers of decks and percentage per row)

% Row	Tongue and groove boards	Gapped boards – treated pine	Gapped boards – other timber	Gapped boards – timber unknown	Other	Unknown	Total	% Total
<b>Bunyip</b>	0 0%	0 0%	1 100%	0 0%	0 0%	0 0%	1	~0%
<b>Churchill</b>	5 4%	32 26%	3 2%	29 24%	33 27%	20 16%	122	22%
<b>Kilmore East</b>	11 3%	51 15%	78 22%	55 16%	84 24%	69 20%	348	64%
<b>Maiden Valley</b>	3 17%	3 17%	0 0%	1 6%	8 44%	3 17%	18	3%
<b>Murrindindi</b>	7 12%	14 24%	11 19%	4 7%	2 3%	20 34%	58	11%
<b>Total</b>	26	100	93	89	127	112	547	100%
<b>%</b>	5%	18%	17%	16%	23%	20%		100%

Table 28 Degree of damage of deck (expressed as numbers of decks and percentage per row)

% Row	Undamaged	Some isolated scorching	Partially burnt	Mostly burnt	Other	Total	% Total
<b>Bunyip</b>	0 0%	1 100%	0 0%	0 0%	0 0%	1	~0%
<b>Churchill</b>	34 53%	2 3%	0 0%	13 20%	15 23%	64	17%
<b>Kilmore East</b>	124 51%	14 6%	15 6%	86 35%	4 2%	243	66%
<b>Maiden Valley</b>	3 100%	0 0%	0 0%	0 0%	0 0%	3	1%
<b>Murrindindi</b>	10 18%	13 23%	4 7%	29 51%	1 2%	57	15%
<b>Total</b>	171	30	19	128	20	368*	100%
<b>%</b>	46%	8%	5%	35%	5%		100%

\* 179 missing or no answer

## 7.4 Damage to outbuildings (type and material)

In total, 1740 outbuildings have been surveyed. Of these outbuildings, the closest to the house (with outbuilding information recorded) have been extracted, which represents a total of 795 outbuildings. The closest outbuildings are likely to cause the greatest risk of impact on the house compared with more distant outbuildings. The closest outbuildings are located at an average distance of 22 m from the house (0.3 m is the minimum distance and 155 m the furthest distance). Of these outbuildings, 44% are sheds, 22% are garages and 16% are carports (see Table 29). The predominant material used for the outbuildings is iron (54%; see Table 30).

The outbuildings had a greater likelihood of destruction in the Murrindindi and Maiden Gully fire, with respectively 69% destroyed and 65% destroyed compared with 55% in Kilmore fire (Table 31). With a destroyed house percentage of 58% over all fires, it appears that sheds have a slightly higher likelihood of loss compared with houses. Table 31 shows a breakdown of degree of damage of outbuildings for each fire. As outbuildings are rarely designed to resist bushfire, it may be possible to use them as an indicator of fire exposure intensity. If this were the case, then the results indicate that the Bunyip fire was the least severe, followed by Churchill, with the Murrindindi fire representing the most severe structural exposure.

Table 29 Function of outbuilding

% Row	Garage	Carport	Laundry, toilet	Storage shed, garden shed, workshop	Barn, dairy, chook-shed, other	Other	Total	% Total
<b>Bunyip</b>	2	2	0	4	3	3	14	2%
	14%	14%	0%	29%	21%	21%		
<b>Churchill</b>	39	26	3	37	6	12	123	15%
	32%	21%	2%	30%	5%	10%		
<b>Kilmore East</b>	106	73	7	251	24	58	519	65%
	20%	14%	1%	48%	5%	11%		
<b>Maiden Gully</b>	7	5	0	16	0	6	34	4%
	21%	15%	0%	47%	0%	18%		
<b>Murrindindi</b>	22	25	3	45	2	8	105	13%
	21%	24%	3%	43%	2%	8%		
<b>Total</b>	176	131	13	353	35	87	795	100%
<b>%</b>	22%	16%	2%	44%	4%	11%		100%

Table 30 Outbuilding type of material

% Row	Timber	Iron, steel	Aluminium	Cement fibre	Brick	Other	Not applicable	Unknown	Total	% Total
<b>Bunyip</b>	3	4	4	0	0	1	1	1	14	2%
	21%	29%	29%	0%	0%	7%	7%	7%		
<b>Churchill</b>	12	72	3	6	11	3	7	5	119	15%
	10%	61%	3%	5%	9%	3%	6%	4%		
<b>Kilmore East</b>	41	296	36	17	20	34	48	18	510	65%
	8%	58%	7%	3%	4%	7%	9%	4%		
<b>Maiden Gully</b>	3	14	2	1	4	0	3	8	35	4%
	9%	40%	6%	3%	11%	0%	9%	23%		
<b>Murrindindi</b>	21	34	6	6	6	6	14	12	105	13%
	20%	32%	6%	6%	6%	6%	13%	11%		
<b>Total</b>	80	420	51	30	41	44	73	44	783	100%
<b>%</b>	10%	54%	7%	4%	5%	6%	9%	6%		100%

Table 31 Degree of damage of the outbuilding

% Row	Untouched	Superficial	Light damage	Medium damage	Heavy damage	Destroyed	Other	Unknown	Total	% Total
<b>Bunyip</b>	7	2	0	0	0	5	0	0	14	2%
	50%	14%	0%	0%	0%	36%	0%	0%		
<b>Churchill</b>	35	10	5	4	5	63	0	1	123	15%
	28%	8%	4%	3%	4%	51%	0%	1%		
<b>Kilmore East</b>	94	45	23	19	50	287	1	0	519	65%
	18%	9%	4%	4%	10%	55%	0%	0%		
<b>Maiden Gully</b>	5	1	0	2	4	22	0	0	34	4%
	15%	3%	0%	6%	12%	65%	0%	0%		
<b>Murrindindi</b>	11	8	5	2	7	72	0	0	105	13%
	10%	8%	5%	2%	7%	69%	0%	0%		
<b>Total</b>	152	66	33	27	66	449	1	1	795	100%
<b>%</b>	19%	8%	4%	3%	8%	56%	0%	0%		100%

## 7.5 Vegetation around the house

A key question was asked in the survey with regard to overhanging trees (Q12 of structure survey – see appendix B). This question provides an indication of the proximity of vegetation to the house. The answer to this question suggests that overhanging trees are common in all regions but comparatively less prevalent in Churchill.

Table 32 Overhanging foliage in proximity to houses from Q12 of structure survey (expressed as numbers of houses and percentage per row)

% Row	Many overhanging trees	Some overhanging trees	Trees against house	Bushes against house	Trees and/or bushes against house	No predominant vegetation adjacent to house	Unknown	Total	% Total
<b>Bunyip</b>	0	6	0	1	1	6	0	14	2%
	0%	43%	0%	7%	7%	43%	0%		
<b>Churchill</b>	9	11	2	7	2	27	1	59	8%
	15%	19%	3%	12%	3%	46%	2%		
<b>Kilmore East</b>	50	176	24	69	39	140	10	508	67%
	10%	35%	5%	14%	8%	28%	2%		
<b>Maiden Gully</b>	0	9	0	2	0	9	8	28	4%
	0%	32%	0%	7%	0%	32%	29%		
<b>Murrindindi</b>	14	45	15	22	36	15	0	147	19%
	10%	31%	10%	15%	24%	10%	0%		
<b>Total</b>	73	247	41	101	78	197	19	756*	100%
<b>%</b>	10%	33%	5%	13%	10%	26%	3%		100%

\* 309 missing or no answer

There is a strong correlation between the observation of overhanging trees and house loss (see Table 33). Both trees overhanging and/or against the house correlated with house destruction, suggesting that these are a significant risk indicator or exposure element. Another possible factor may be the way overhanging trees contribute to the deposition of fine debris on, around and under the house. Further analysis of the field survey and the remote sensing dataset will further qualify these observations.

Table 33 Overhanging tree and house damage (see footnote 6)

Number Row% Col% Total%	Many overhanging trees	Some overhanging trees	Trees against house	Bushes against house	Trees and/or bushes against house	No predominant vegetation adjacent to house	Unknown	Totals
Untouched	2 1.4% 2.7% 0.3%	41 28.5% 16.6% 5.4%	3 2.1% 7.3% 0.4%	23 16.0% 22.8% 3.0%	12 8.3% 15.4% 1.6%	62 43.1% 31.5% 8.2%	1 0.7% 5.3% 0.1%	144 19.0%
Damaged	5 3.7% 6.8% 0.7%	47 34.6% 19.0% 6.2%	4 2.9% 9.8% 0.5%	28 20.6% 27.7% 3.7%	12 8.8% 15.4% 1.6%	40 29.4% 20.3% 5.3%	0 0.0% 0.0% 0.0%	136 18.0%
Destroyed	66 13.9% 90.4% 8.7%	159 33.4% 64.4% 21.0%	34 7.1% 82.9% 4.5%	50 10.5% 49.5% 6.6%	54 11.3% 69.2% 7.1%	95 20.0% 48.2% 12.6%	18 3.8% 94.7% 2.4%	476 63.0%
Totals	73 9.7%	247 32.7%	41 5.4%	101 13.4%	78 10.3%	197 26.1%	19 2.5%	756 100.0%

Chi-Square = 74.07  
Caution: 2 cells (10%)  $E < 5$   
Probability (df = 12) = 0.000

Valid cases = 756  
Missing cases = 309  
Response rate = 71.0%

Another question has the objective to evaluate the presence of elevated fuel linking the house to wider vegetation (with regard to 0.5 to 3-m-high vegetation linking the house to wider vegetation within 50 m; see Table 34). Although the sample collected is too small to be effectively compared with house damage, the answers do indicate that there is a relatively high proportion of observed elevated fuels in the Murrindindi fire compared with Kilmore East and Bunyip. These results are based on a small sample and should be considered with caution.

Table 34 Indication of elevated fuels 0.5 to 3-m high linking the house to wider vegetation within 50 m of the property boundary (question Q27 of the structure survey)

% Row	Elevated fuel present	Elevated fuel not present	Unknown/Vegetation Burnt	Total	% Total
<b>Bunyip</b>	5 36%	9 64%	0 0%	14	7%
<b>Kilmore East</b>	49 49%	38 38%	14 14%	101	54%
<b>Murrindindi</b>	55 76%	12 17%	5 7%	72	39%
<b>Total</b>	109	59	19	187	100%
<b>%</b>	58%	32%	10%		100%

To better understand the role of combustible ground cover such as grassland, a question was asked (for cases where grasslands were present) to evaluate whether these grassland fuels were adjacent to the structure or not (see Table 35). The destroyed category has the highest proportion of houses with adjacent combustible ground cover, the damaged category having a slightly lower proportion of houses with adjacent ground cover and the untouched category having the lowest proportion. Although these proportional differences are small, further analysis may highlight the relevance of this effect by removing other forms of loss influence from the sample dataset.

Table 35 Comparison of house condition and combustible ground cover adjacent to structure

% Column % Row	Combustible cover adjacent to the house	Combustible cover not adjacent to the house	Total	% Total
<b>Untouched</b>	63 20% 82%	14 30% 18%	77	21%
<b>Damaged</b>	58 18% 85%	10 21% 15%	68	19%
<b>Destroyed</b>	196 62% 89%	23 49% 11%	219	60%
<b>Total</b>	317	47	364	100%
<b>%</b>	87%	13%		100%

Certain types of vegetation are particularly susceptible to fire. For example, cypress trees produce large quantities of fine dead material, which becomes very dry at times of high fire danger, and the intensity at which they burn may adversely impact structures in the vicinity. This was noted in the Canberra 2003 and Eyre Peninsula 2005 fires (Leonard & Bianchi 2005, 2006). Figure 26 shows an example of this from the Victorian fires.



Figure 26 Example of vegetation heavily burnt close to structure (Pine Ridge Road, Kinglake)

In addition, some comments were made by occupants that highlight the role of grassland. Some examples are listed below:

*“It was leap-frogging all the way down the paddock. It wasn’t sort of just – and whether that was a series of embers all coming at once”*

*“Well, the grass had been mowed two days before. So it was basically just burning organic matter and it was moving so fast that it was just – I mean if it had stood still, it would have gone out because there was no fuel to sustain it. But because it was travelling so fast, there was always something there just to sustain it long enough to get to the next bit of grass. It hit that fence and the fence just exploded”*

*“In this paddock it was just, I don’t know, probably a foot high but around the house it was probably about two inches high, you know, and so you’d think you are safe, like you’ve got many trees and what not, but the way it come through, it didn’t matter what’s in its way”*

*“We weren’t hit with a big front of all the trees, but we were hit with more of a grass front”*

## 7.6 Protection measures – Water supply

The water supply was one of the key protection measures studied in detail in this report. Other prevention measures could be analysed in future phases of this research.

Evidence was found of water defence in 33% of the surveyed properties (see Table 36). The table also indicates that the houses studied in the Churchill fire had the highest percentage of evidence of defence using water (48%), while Murrindindi had the lowest (28%), which may be an indicator of the level of human activity in these regions. Further analysis may reveal the relevance of this correlation. There is a strong correlation between house destruction and the lack of active water defence (78%; see Table 37), thus confirming the influence of human defence in these circumstances. Past bushfire studies also confirm a strong correlation between active human defence and house survival (Ramsey 1994, Blanchi & Leonard 2008).

Table 36 Evidence of defence using water (expressed as numbers of houses and percentage per row)

% Row	Evidence of using water	No evidence of using water	Total	% Total
<b>Bunyip</b>	6 43%	8 57%	14	2%
<b>Churchill</b>	28 48%	30 52%	58	8%
<b>Kilmore East</b>	164 33%	334 67%	498	67%
<b>Maiden Valley</b>	10 36%	18 64%	28	4%
<b>Murrindindi</b>	40 28%	105 72%	145	20%
<b>Total</b>	248	495	743*	100%
<b>%</b>	33%	67%		100%

\*322 missing or no answer



Table 37 Relationship between evidence of defence using water and house damage (see footnote 6)

House damage	Evidence of using water	No evidence of using water	Totals
<b>Untouched</b>	81 57.0% 32.7% 10.9%	61 43.0% 12.3% 8.2%	142 19.1%
<b>Damaged</b>	85 63.4% 34.3% 11.4%	49 36.6% 9.9% 6.6%	134 18.0%
<b>Destroyed</b>	82 17.6% 33.1% 11.0%	385 82.4% 77.8% 51.8%	467 62.9%
<b>Totals</b>	248 33.4%	495 66.6%	743 100.0%

Chi-Square = 142.75  
 Degrees of Freedom = 2  
 Probability of Chance = 0.000

Valid cases = 743  
 Missing cases = 322  
 Response rate = 69.8%

### 7.6.1 Type of water supply

A concurrent question was asked regarding the type of water provision used for defence only if active defence was indicated in the previous question (see Table 38).

Table 38 Water provision (expressed as number of houses and percentage per row)

% Row	Mains only	Pump and secondary water source	Secondary water source – gravity-fed	Total	% Total
<b>Bunyip</b>	0 0%	6 100%	0 0%	6	2%
<b>Churchill</b>	1 4%	27 96%	0 0%	28	11%
<b>Kilmore East</b>	9 6%	139 85%	15 9%	163	67%
<b>Maiden Valley</b>	8 89%	1 11%	0 0%	9	4%
<b>Murrindindi</b>	24 62%	13 33%	2 5%	39	16%
<b>Total</b>	42	186	17	245	100%
<b>%</b>	17%	76%	7%		100%

The table highlights certain areas, such as Kilmore East, as having few houses with mains supply, where the dominant type of water supply is via pump and secondary water supply. It is interesting to note that main water supply systems often lost pressure or stopped during these fire events. There were also many accounts of pump-related failures (see Section 7.6.3).

Although the sample is very small, there were a higher proportion of surviving houses where the water supply was sourced on the property and gravity-fed (see Table 39), suggesting that this is the most reliable water supply configuration for structural defence.

Table 39 Water provision and house damage (see footnote 6)

	<b>Mains only</b>	<b>Pump and secondary water source</b>	<b>Secondary water source – gravity-fed</b>	<b>Totals</b>
<b>Untouched</b>	8 9.8% 19.0% 3.3%	69 84.1% 37.1% 28.2%	5 6.1% 29.4% 2.0%	82 33.5%
<b>Damaged</b>	16 19.3% 38.1% 6.5%	58 69.9% 31.2% 23.7%	9 10.8% 52.9% 3.7%	83 33.9%
<b>Destroyed</b>	18 22.5% 42.9% 7.3%	59 73.8% 31.7% 24.1%	3 3.8% 17.6% 1.2%	80 32.7%
<b>Totals</b>	42 17.1%	186 75.9%	17 6.9%	245 100.0%

Chi-Square = 8.43  
Degrees of Freedom = 4  
Probability of Chance = 0.077

Valid cases = 245  
Missing cases = 820  
Response rate = 23. .0%

### 7.6.2 Water storage (material degree of damage)

In all survey areas, the water supply was predominantly identified as water tanks (81%), dam or similar water-body (12%), swimming pool (12%) and hydrant (5%). These water supplies appear to have been actively used to protect structures in 30% of the cases; in 40% of the cases, water was not utilised and 30% of cases were unknown. Concrete, polyethylene and steel were the dominant tank material types.

Table 40 indicates that in 20% of all cases, tanks were either ruptured (6%) or were identified as mostly burnt (14%) during the fire event. It can be assumed that in these cases, they would then no longer be an effective water source.

Fibreglass tanks were not common but out of the 14 tanks identified in the survey, over half were identified as failing. For polyethylene tanks, 37% failed (see Figure 27), steel tanks failed in 16% of cases, and concrete tanks failed in 5% of cases. The tanks appeared to all be above ground and hence would tend to have similar exposure to bushfire and structural effects. Further analysis of the data will clarify the degree of functionality tanks had when partially or mostly burnt, as these categories of condition may vary depending on tank material type.

Table 40 Tank material and degree of damage of the tank

Number % Column % Row	Concrete	Fibreglass	Polyethylene	Steel	Other	Total %
<b>Undamaged</b>	179 50% 45%	2 14% 0%	136 37% 34%	82 31% 20%	2 25% 0%	401 40%
<b>Some isolated scorching</b>	106 30% 45%	1 7% 0%	37 10% 16%	90 34% 38%	2 25% 1%	236 24%
<b>Partially burnt</b>	44 12% 37%	1 7% 1%	40 11% 34%	32 12% 27%	2 25% 2%	119 12%
<b>Mostly burnt</b>	9 3% 6%	7 50% 5%	99 27% 71%	23 9% 16%	2 25% 1%	140 14%
<b>Ruptured</b>	9 3% 14%	2 14% 3%	35 10% 55%	18 7% 28%	0 0% 0%	64 6%
<b>Other</b>	10 3% 23%	1 7% 2%	16 4% 36%	17 6% 39%	0 0% 0%	44 4%
<b>Total</b>	357 36%	14 1%	363 36%	262 26%	8 1%	1004 100%



Figure 27 Example of polyethylene tank damage

### 7.6.3 Evidence of water supply failure (i.e. pump and pipe)

There is evidence from human accounts of water supply failure due to pump or pipe failure; this failure may have contributed to the house loss, but not in every case. This varies according to the intensity of the fire at the house (from bush or surrounding elements) and to the ignition of different elements on the house due to embers (ignition in the roof, as described previously, is difficult to extinguish with little or no water or reduced water pressure).

These preliminary qualitative results were extracted from a sample of 20 interviews from people who stayed to defend their house. This analysis will be conducted on all interviews for the second phase of the project.

The following cases have been described by residents:

#### Loss of electric pump with electricity failure

*“But the pumps were gone and the electricity was out and the new petrol pumps were both gone”*

*“Lost electric pump from electricity failure”*

**The fire pumps were not protected and caught fire** (seven occupants have described the failure of pumps – three described success with pumps protected)

*“There must have been a couple of leaves that caught fire. And the pump shed caught fire. Went in the pipe, which’s burst off. Took the pipe out. So, I actually – I thought this is too serious, I’m not going to hang around”*

*“As I said, the last sprinkler system I did was for me father-in-law... And it worked. Because the fire pump, once again, was under the sprinklers”*

*“And then our pump, when the fire came, all the hoses burned. And the pump burned”*

*“Petrol fire-fighting pump... too far away and next to a structure, so it all burnt”*

*“And we looked down and saw the generator on fire. Put out spot fire with Pepsi”*

### **Petrol in pump vaporised**

*“Fire pump vaporised. We were down to buckets”*

*“Lost fire pump because petrol vaporised”*

### **Pump is too far away and the occupant does not have the time to start it**

*“Did not have the time to start the pump or open gravity-fed tank (too far and fire came too fast).”*

### **Evidence of pipe or fittings melting**

*“Pipe from creek failed”*

*“We couldn’t use the tap on the outside because that was burnt off”*

### **The loss of pressure from mains**

*“I thought we would have water. Because our town supply is not fed by a pump, it’s gravity feed from the dam up on the hill. And I thought, well, if the power goes out, we’ve always got water. So therefore if the power gets knocked out and we’ve got fire, we will have water. What I didn’t understand was that, as each house disappears, the water’s running free... The pipes burst... The pressure’s gone” (Marysville occupant)*

*“We had hoses on every tap... but the water went off at any rate”*



Figure 28 Example of damaged pump

#### 7.6.4 Sprinkler system

Sprinkler systems were identified on 82 houses of the 1065 houses surveyed Table 41 identifies 60 spray systems in the Kilmore East survey area, 12 in the Churchill area and 7 in Murrindindi. The percentage of houses destroyed with spray systems fitted is 37%, compared with 58% of the total sample of houses lost. However, these results should be used with caution as the number of spray systems that were effectively activated are not identified in these statistics. This should also be put in perspective with the exposure received at the house and the other preparation measures set up by the occupant, which could be the subject of future analysis.

Only one sprinkler identified in the survey was internal (in a commercial building destroyed in Marysville), and all other sprinklers were external. Most of the sprinklers were directed both away from the house and on the house. The most common sprinkler types were choppers, and the second most common were the spraying type (see

Table 43).

Table 41 Number of houses with sprinklers per fire region

<b>Fire region</b>	<b>Number of houses with sprinkler</b>	<b>%</b>
<b>Bunyip</b>	2	2%
<b>Churchill</b>	12	15%
<b>Kilmore East</b>	60	73%
<b>Maiden Valley</b>	1	1%
<b>Murrindindi</b>	7	9%
<b>Total</b>	82	100%

Table 42 level of damage for those houses with sprinklers

<b>House status</b>	<b>Number of houses with sprinkler</b>	<b>%</b>
<b>Untouched</b>	30	37%
<b>Damaged</b>	30	37%
<b>Destroyed</b>	22	27%
<b>Total</b>	82	100%

Table 43 Type of sprinklers identified for each of the houses surveyed

<b>Type of sprinkler</b>		
<b>No answer</b>	9	
<b>Chopper</b>	31	42%
<b>Misting</b>	2	3%
<b>Spraying</b>	25	34%
<b>Chopper and spraying</b>	5	7%
<b>Other</b>	3	4%
<b>Unknown</b>	6	8%
<b>Misting and chopper</b>	1	1%
<b>Total</b>	73	100%

Table 44 Main direction of sprinklers

<b>Direction of sprinkler</b>		
<b>No answer</b>	11	
<b>Towards house</b>	11	15%
<b>Away from house</b>	10	14%
<b>Both</b>	41	58%
<b>Unknown</b>	9	13%
<b>Total</b>	71	100%

## 7.7 Accessibility

The survey included a question on fire vehicle access to the property. The most common path was via a perimeter road (78%), followed by battleaxe lot (9%; see Table 45). Kilmore East appeared to have the highest prevalence of access via fire trails, although only 5% of all access was via this path. There appears to be no correlation between the house accessibility and the likelihood of house damage based on the data provided (see Table 46).

Table 45 Most appropriate access for fire vehicles

% Row	Perimeter road	Perimeter fire trail	Perimeter fire break	Battleaxe lot	Other	Unknown	Total %
<b>Bunyip</b>	5 38%	0 0%	0 0%	8 62%	0 0%	0 0%	13 2%
<b>Churchill</b>	45 92%	0 0%	1 2%	0 0%	3 6%	0 0%	49 7%
<b>Kilmore East</b>	364 70%	26 5%	2 0%	52 10%	71 14%	2 ~0%	517 69%
<b>Maiden Gully</b>	5 24%	0 0%	0 0%	5 24%	11 52%	0 0%	21 3%
<b>Murrindindi</b>	135 92%	3 2%	1 1%	5 3%	2 1%	0 0%	146 20%
<b>Total</b>	554	29	4	70	87	2	746
<b>%</b>	74%	4%	1%	9%	12%	~0%	100%

Table 46 Most appropriate access for fire vehicles across all fire areas (see footnote 6)

	Perimeter road	Perimeter fire trail	Perimeter fire break	Battleaxe lot	Other	Unknown	Totals
<b>Untouched</b>	101 69.2% 18.2% 13.5%	6 4.1% 20.7% 0.8%	2 1.4% 50.0% 0.3%	18 12.3% 25.7% 2.4%	19 13.0% 21.8% 2.5%	0 0.0% 0.0% 0.0%	146 19.6%
<b>Damaged</b>	103 75.7% 18.6% 13.8%	6 4.4% 20.7% 0.8%	0 0.0% 0.0% 0.0%	17 12.5% 24.3% 2.3%	10 7.4% 11.5% 1.3%	0 0.0% 0.0% 0.0%	136 18.2%
<b>Destroyed</b>	350 75.4% 63.2% 46.9%	17 3.7% 58.6% 2.3%	2 0.4% 50.0% 0.3%	35 7.5% 50.0% 4.7%	58 12.5% 66.7% 7.8%	2 0.4% 100.0% 0.3%	464 62.2%
<b>Totals</b>	554 74.3%	29 3.9%	4 0.5%	70 9.4%	87 11.7%	2 0.3%	746 100.0%

Chi-Square = 11.85  
Caution: 6 cells (33%) E < 5  
Probability (df = 10) = 0.295

Valid cases = 746  
Missing cases = 319  
Response rate = 70.0%



## **7.8 Land-use planning**

### **7.8.1 Pattern of house loss**

At the time of compiling this report a definitive map of house loss was not available. A study of the patterns of house loss is best performed on a comprehensively large set of lost houses. The survey dataset collected here represents a small sample of the total houses lost. A study of house loss patterns could be pursued in future work.

Aerial imagery was used to produce some maps of preliminary house status (including destroyed, minor damage, no damage and unclassified), which are shown in Appendices F, G, H, I, J.

### **7.8.2 Density of urban area**

The density of urban development plays an important role in influencing the propagation of the fire within the region as well as influencing the potential for structures to be impacted by various fire mechanisms. In future work, the distance between structures could be compared with house loss, and a study of house loss patterns in urbanised areas compared with areas of lesser urbanisation could also be pursued.

### **7.8.3 Wildfire Management Overlay (WMO)**

At the time of compiling this report, a definitive dataset on which structures were intentionally built to be compliant with WMO requirements. Using survey data analysis and remote sensing techniques, it is feasible to identify which houses are likely to be compliant and which are not. However, this was not possible within the time frame of compiling this report.

A simple analysis of which surveyed structures were in a currently defined WMO was performed. Table 47 shows that 58% of all surveyed structures were not within a currently defined WMO. Churchill had the highest proportion (99%) of surveyed structures within the WMO, while Murrindindi had the lowest (15%).

Table 48 indicates a small correlation in the likelihood of structures lost in an area that was not defined as a WMO. It also indicates that 59% of all surveyed structures that were either damaged or destroyed were not in a region that was subject to WMO requirements at the time of the fire.

Analysis of the statistical correlation between WMO-compliant structures and house survival could be the subject of future analysis.

Table 47 Wildfire Management Overlays (WMO) per fire area

% Row	No WMO	WMO present	Total %
<b>Bunyip</b>	10	4	14
	71%	29%	1%
<b>Churchill</b>	1	139	140
	1%	99%	13%
<b>Kilmore East</b>	436	269	705
	62%	38%	66%
<b>Maiden Valley</b>	38	18	56
	68%	32%	5%
<b>Murrindindi</b>	128	22	150
	85%	15%	14%
<b>Total</b>	613	452	1065
<b>%</b>	58%	42%	100%

Table 48 Wildfire Management Overlays (WMO) and house damage (across all fires)

% Column	No WMO	WMO present	Total %
<b>% Row</b>			
<b>Untouched</b>	144	121	265
	23%	27%	25%
	54%	46%	
<b>Damaged</b>	92	87	179
	15%	19%	17%
	51%	49%	
<b>Destroyed</b>	377	244	621
	62%	54%	58%
	61%	39%	
<b>Total</b>	613	452	1065
<b>%</b>	58%	42%	100%

#### 7.8.4 House loss as a function of distance from vegetation

Building and planning regulations often identify a distance from continuous vegetation at which building or planning prevention measures are required (AS3959-2009). This is 100 m in Victoria (see Section 4.2). Ahern and Chladil have studied the penetration of bushfires into urban areas from the Otways 1983 and Hobart 1967 fires (Ahern & Chladil 1999). These studies revealed that the furthest distance from the forest a house was lost was 680 m in the Hobart fire, and 430 m in the Otways fire. This study showed that 70% of burnt houses were within 50 m from the vegetation boundary and 85% of houses were within 100 m from the vegetation boundary (Ahern & Chladil 1999). Following this analysis, Chen and McAneney assessed the penetration of bushfire in the Canberra 2003 fire, and found a case of house loss at 670 m from vegetation (Chen & McAneney 2004).

Preliminary analysis of the Marysville region indicates that approximately 40% of destroyed surveyed structures occurred within 10 m of continuous forest fuels. However, extensive loss of structures throughout Marysville suggests that the urban context that Marysville provided did not limit the extent of fire spread. The observation that houses in Marysville were up to 375 m from continuous vegetation is probably more a function of urban extent than a measure of the reach of fire effects.

## 7.9 Remote sensing results: spatial analysis on house distance to vegetation and vegetation covers

Three regions were considered during this demonstration study, as detailed in section 5.2; two broad-scale regions cover the areas in the West and East of the Murrindindi Shire, and the third is a subset of the West region at Pine Ridge Road, Kinglake West.

### 7.9.1 Mean distance from house to forest (trees taller than 8 m)

The proximity and density of fire fuel, in the form of forest vegetation, is an obvious factor influencing the destruction of residential and non-residential structures (Ramsay et al. 1986). This is the basis of „defendable space“, as outlined in numerous fire agency publications. Despite the clear dangers posed by forest fuel, it may often be difficult to assess at what proximity and vegetation density this risk becomes unacceptable for a specific structure.

The initial ignition of these structures can be caused by a number of factors including:

- Direct flame contact
- Direct exposure to radiant heat from burning forest fuel
- Attack from burning forest fuel embers
- Indirect ignition via other structures

These multiple ignition mechanisms further complicate decisions regarding the degree of fuel removal required around a property. Empirical evidence regarding the relationship between vegetation proximity and the probability of structure loss is one approach to assist in making objective decisions about the recommendations for the scale of defendable space. The following section provides an analysis of this relationship, as defined by the LiDAR-derived forest/non-forest layer, for each of the three study regions described in Section 5.2.

#### General statistics for all regions

The proximity to forest within each angular segment around each of the structures was extracted using the method described previously. The mean value for these statistics across all residential structures shown in the following tables indicates the trend across each region for a given structure damage class.

A total of 588 residential properties were considered in the Murrindindi West region, of which 451 (76%) sustained some form of fire damage. The proportion of houses affected in the eastern region was more severe, where of the 149 houses surveyed, 145 (97%) sustained some damage. At the Pine Ridge Road site, 77 residential structures were burnt of the 95 delineated in the imagery, representing a loss of 81%.

Statistics on distances (minimum, mean, median and maximum) were derived for each residential structure using the individual distance measurements within the 12 angular segments around each structure. The mean of these statistics for all structures is shown in Table 49.

Table 49 Minimum, mean, median and maximum distances from structure to forest

New dataset	<i>P</i> (> <i>F</i> )	Untouched	Superficial	Damaged	Destroyed
<i>n</i>		137	61	29	361
Minimum	$2.50 \times 10^{-6}$	12.8	10.6	6.72	7.27
Mean	$2.18 \times 10^{-9}$	30.2	23.9	15.4	17.8
Median	$5.50 \times 10^{-8}$	26	21.3	13.1	15.6
Maximum	$2.57 \times 10^{-8}$	64.1	48.5	36.5	38.7

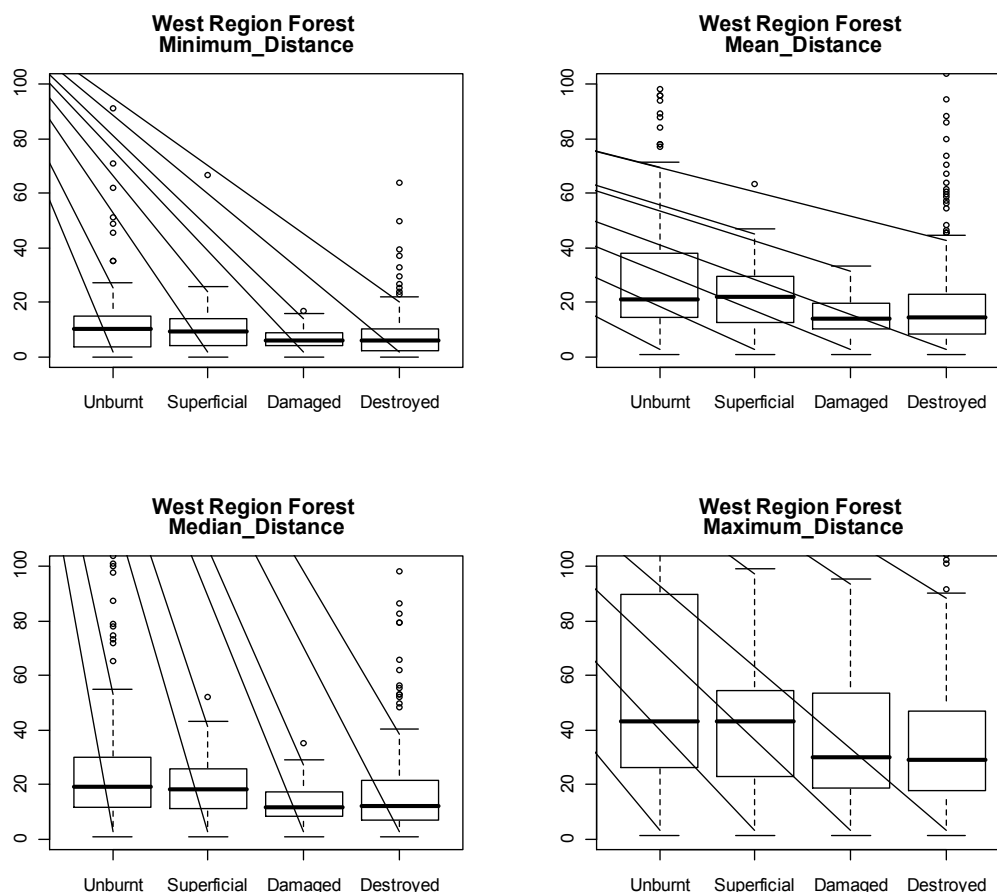


Figure 29 Distribution of minimum, mean, median and maximum distance (metres) to forest for residential structures in the West region (Murrindindi West) for the four residential structure damage classes

Distances to forest from all residential structures are heavily skewed towards the zero as shown in Figure 29 for the West region (Murrindindi West). This indicates a large number of properties within or adjacent to forest. Some distinction can be seen between the distribution of burnt and unburnt structures with the skew towards zero for unburnt structures being slightly less than that of the burnt structures.

The distinction between individual structure damage class groups can also be tested using paired t-tests. Table 50 shows the significance of the difference between structure damage classes for each distance to forest statistic. Lower values indicate a lower probability that the mean of the distances statistics for both of the damage classes is the same. These show that for the West region, there is a statistically significant difference between the distances to untouched structures and damaged and destroyed houses. However, there is not a statistically significant difference (at the 99% confidence level) between distance to forest from superficially damaged, damaged and destroyed properties (Table 50). Hence, the distance to forest appears to be a good indicator of likelihood of damage rather than the degree of damage a structure may experience.

Table 50 Paired t-tests results for structure damage classes and distance to forest

<b>Class separability</b>	<b>Minimum</b>	<b>Mean</b>	<b>Median</b>	<b>Maximum</b>
<b>Untouched–Superficial</b>	0.534	0.145	0.311	0.067
<b>Untouched–Damaged</b>	0.028	0.001	0.002	0.006
<b>Untouched–Destroyed</b>	0.000	0.000	0.000	0.000
<b>Superficial–Damaged</b>	0.376	0.209	0.178	0.568
<b>Superficial–Destroyed</b>	0.112	0.105	0.102	0.317
<b>Damaged–Destroyed</b>	0.994	0.917	0.884	0.992

### **Residential structure burn probability**

The LiDAR-based forest/non-forest layer used for this analysis has a strict and rather simplistic definition of forest. This definition assumes that any LiDAR return within a 2 by 2-m area that is greater than 8 m above the modelled ground surface indicates the presence of forest. It specifies no minimum cover of vegetation within the 2 by 2-m area and no measure of continuity of the forest relative to adjoining pixels. In theory, such a return could emanate from a single tree standing alone in the centre of a bare paddock, which would not under normal circumstances be regarded as forest. Statistics based on these data potentially include measures to such discrete objects, although the use of the mean distance statistic removes the bias of such cases to some degree.

In recognition of the disparity between the LiDAR definition of forest and that which would be considered continuous forest in the sense of forest fire propagation, contiguous pixels classified as forest within the LiDAR-derived layer that were less than 0.5 ha were removed. A corresponding new layer with forest areas less than 1 ha removed was also produced. These new layers with small areas of isolated trees removed are an attempt to distinguish the difference in impact a fire may have on structures when emerging from small numbers of isolated trees and large, more continuous forest.

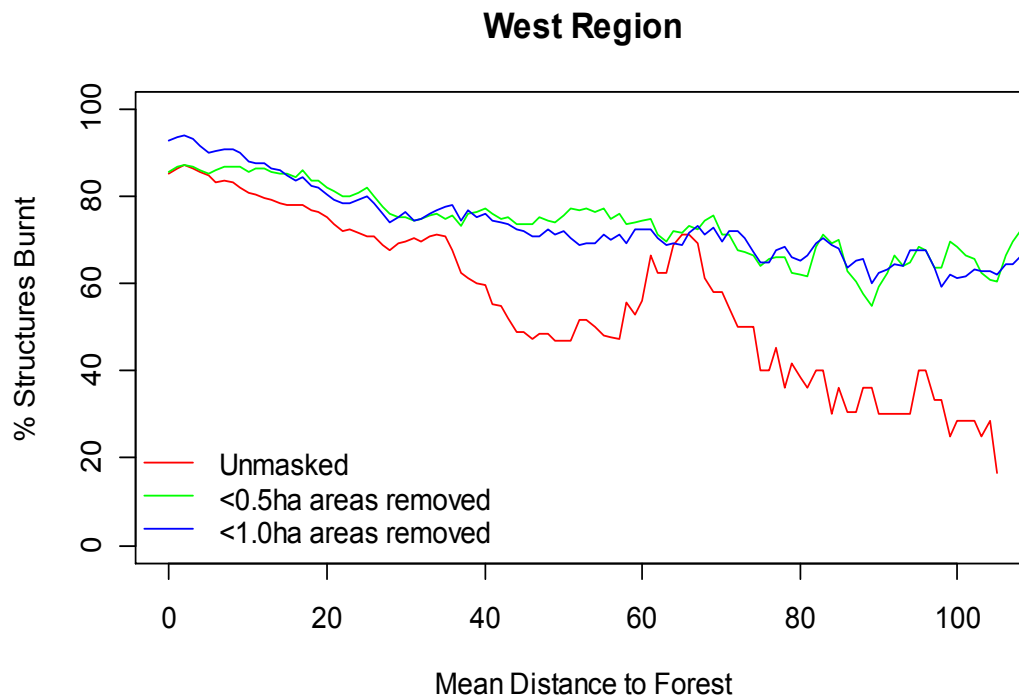


Figure 30 Percentage of residential structures burnt (damaged and destroyed) as a function of the distance to forest from house centroids in the Kilmore East area (Murrindindi West region). Red curve: unmasked data represent the original data extracted (forest with trees > 8m); the green curve is the forest layer with small areas of 0.5 ha subtracted; the blue curve is the forest layer with small areas of 1 ha subtracted.

The Murrindindi West region containing the greatest sample of structures provides the most effective opportunity to study any statistical expression of likelihood of structural loss as a function of distance from forest (see Figure 30). The vertical axis defines the percentage of structures lost compared with total houses surveyed in the region. The horizontal axis describes distance between the house centroid and the forest edge. There is a clear trend towards total loss as the distance approaches zero, which can be expected given the extent of the influence of forest fuels for this event. This appears to be true whether the structures are adjacent to small isolated clumps of trees, or larger aggregations. The graph suggests that clumps of trees of the order of 0.5 ha or more may affect structures at greater distances when with to the unmasked curve, which considers all trees including those in small clumps.

Beyond 50–60 m, the immediate effects of forest would be expected to become less significant as other landscape features and vegetation classes closer to structures become dominant. Of note is the peculiar kick in the curve just prior to 100 m; this may in fact be an expression of the point at which building and planning requirements are relaxed, where buildings that are greater than 100 m from forest are subject to no specific building requirements. These buildings outside the 100-m threshold suffered a slightly greater loss compared with houses that fall within the 100-m threshold. Note: this could also be an expression of structure-to-structure spread in urban clusters that would tend to be more than 100 m from bushland or forest.

Further investigation may reveal the reason for the hump in the red curve around 60 to 70m.

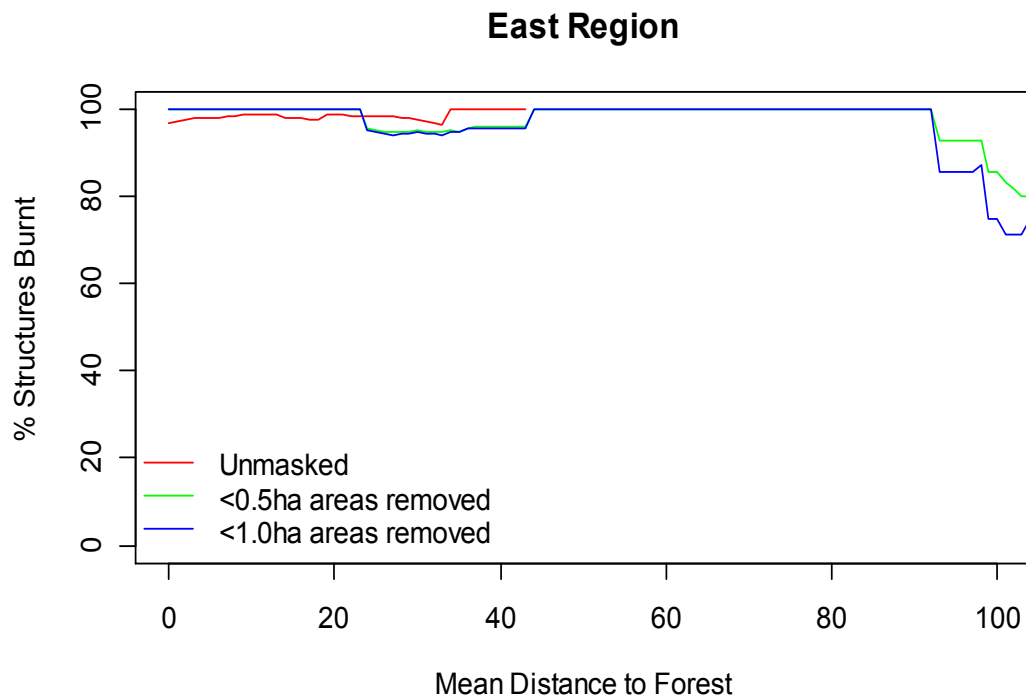


Figure 31 Percentage of residential structures lost (damaged and destroyed) as a function of the distance to forest from house centroids in the Murrindindi area (East region). Red curve: unmasked data represent the original data extracted (forest with trees > 8m); the green curve is the forest layer with small areas of 0.5 ha subtracted; the blue curve is the forest layer with small areas of 1 ha subtracted.

The same graphical plot for Murrindindi (East region) shows little correlation, mainly owing to the extensive urban spread of fire (structure to structure) within the township. There is a peculiar dip around the 100-m point similar to the Kilmore East (West region) in the previous graph (see Figure 30).

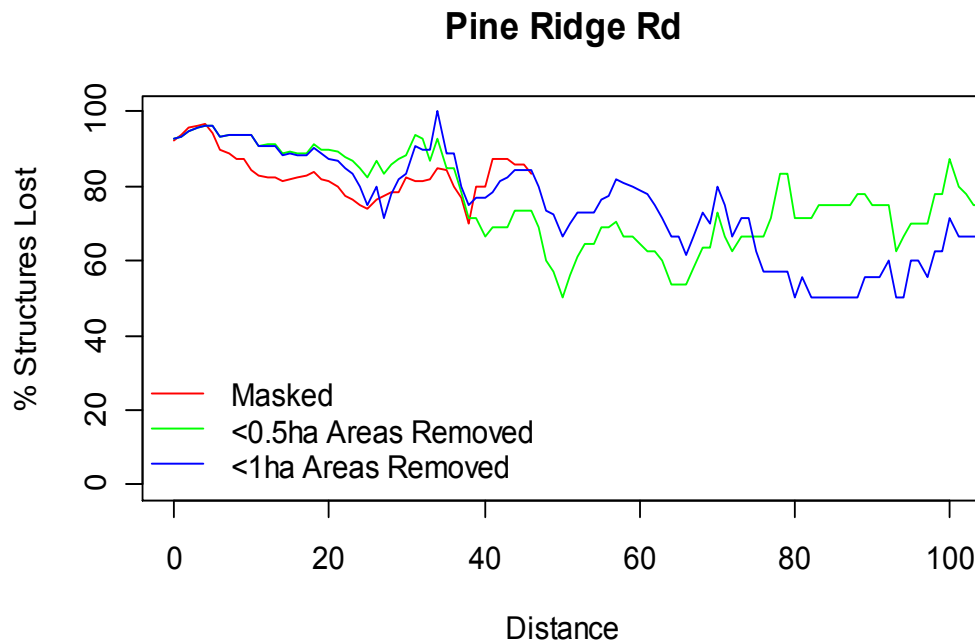


Figure 32 Percentage of residential structures lost (damaged and destroyed) as a function of the mean distance to forest from house centroids in the Pine Ridge Road area. Red curve: unmasked data represent the original data extracted (forest with trees > 8m); the green curve is the forest layer with small areas of 0.5 ha subtracted; the blue curve is the forest layer with small areas of 1 ha subtracted.

This approach shows variation of the proportion of all structures at a particular distance that are damaged. Another approach to consider the loss statistics is to compare the percentile of structures lost as a function of distance from forest. This approach shows how the proportion of damaged structures varies with distance.

Figure 33, Figure 34 and Figure 35 show that there are significant numbers of dispersed trees among the structures sampled that may or may not present a significant risk to structures. Further data analysis would be required to isolate these effects. The graphs also shows that 0.5-ha and 1-ha filters produce very similar results, suggesting that either clumps of trees within the 0.5- to 1-ha range are not prevalent or clumps of this size present fire behaviours indicative of continuous forest.



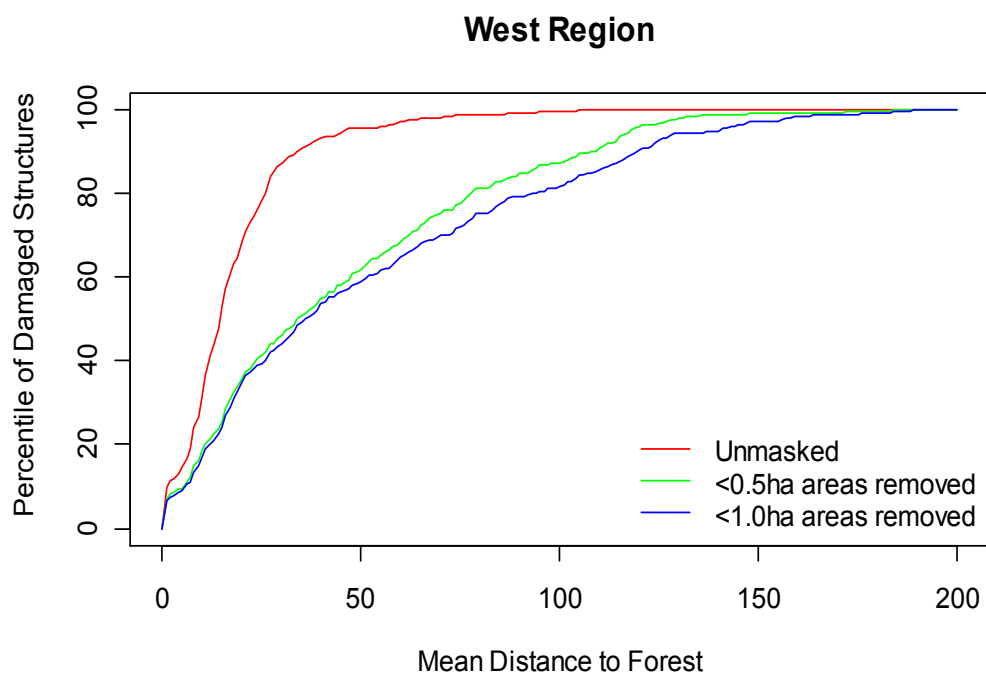


Figure 33 Percentile of damaged residential structures (damaged and destroyed) as a function of the distance to forest from house centroids for the Kilmore East area (West region). Red curve: unmasked data represent the original data extracted (forest with trees > 8m); the green curve is the forest layer with small areas of 0.5 ha subtracted, the blue curve is the forest layer with small areas of 1 ha subtracted.

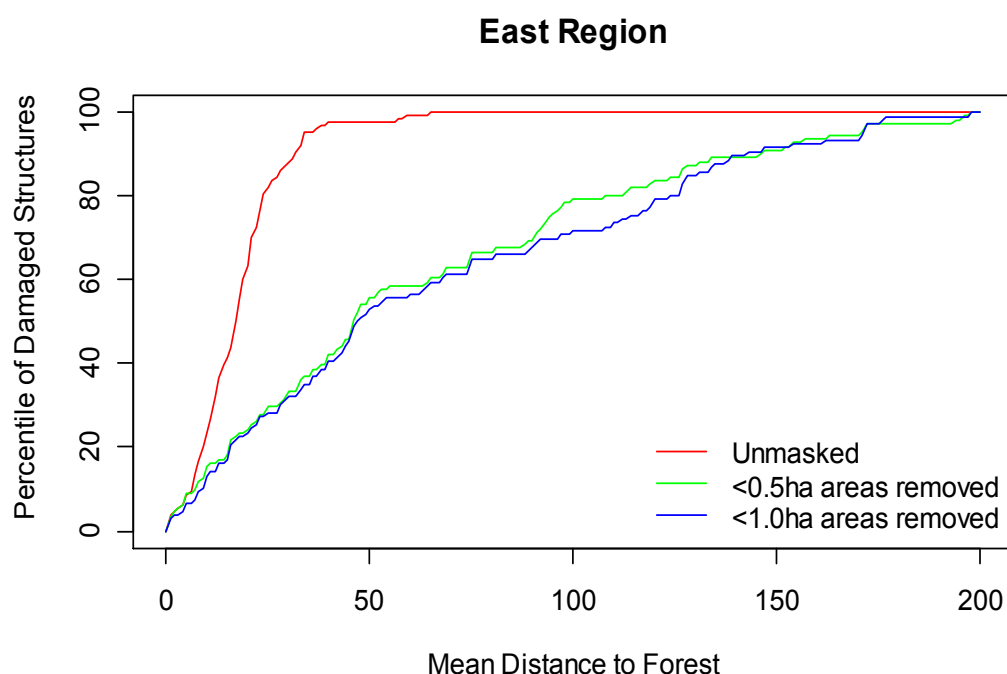


Figure 34 Percentile of damaged residential structures (damaged and destroyed) as a function of the distance to forest from house centroids for the Murrindindi area (East region). Red curve: unmasked data represent the original data extracted (forest with trees > 8m); the green curve is the forest layer with small areas of 0.5 ha subtracted, the blue curve is the forest layer with small areas of 1 ha subtracted.

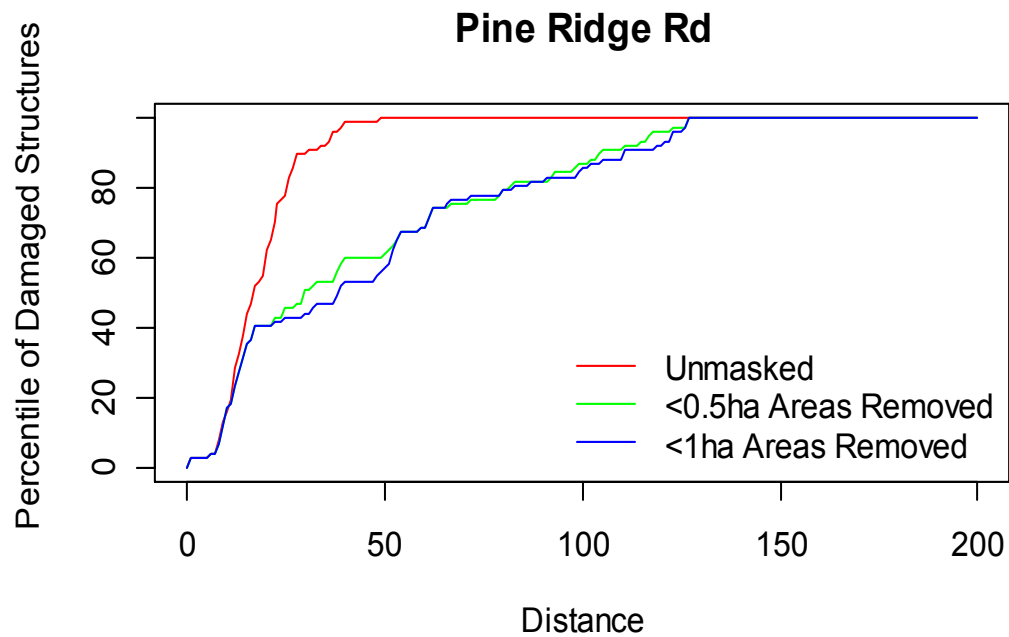


Figure 35 Percentile of damaged residential structures (damaged and destroyed) as a function of the mean distance to forest from house centroids for the Pine Ridge Rd area. Red curve: unmasked data represent the original data extracted (forest with trees > 8m); the green curve is the forest layer with small areas of 0.5 ha subtracted, the blue curve is the forest layer with small areas of 1 ha subtracted.

Figure 36 shows the spatial distribution of residential structures that fall within 100 m of nearest forest, and those that do not.

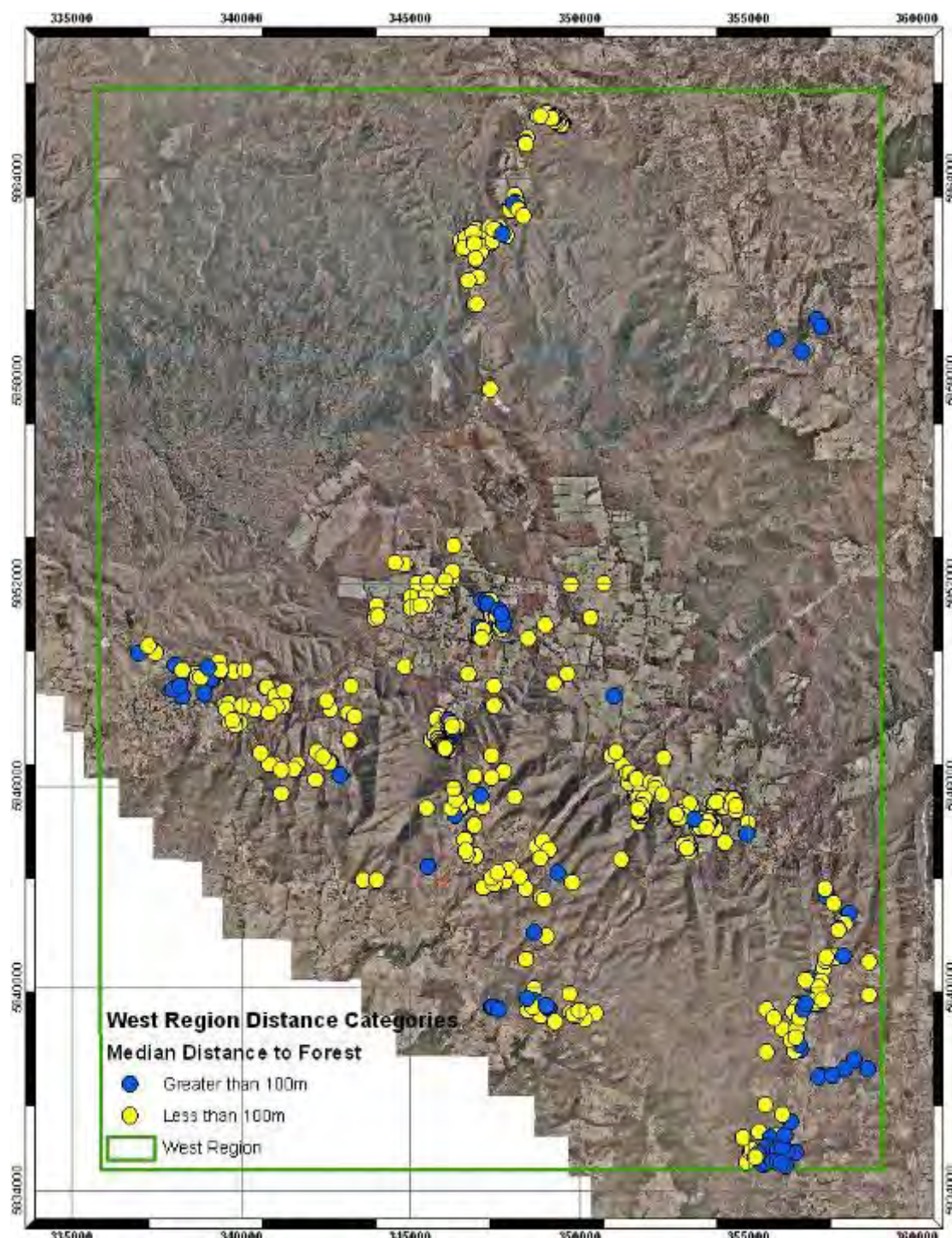


Figure 36 Spatial distribution of residential structures

### 7.9.2 Detailed localised analysis (Pine Ridge Road)

The following tables show the ability of a variety of forest cover-derived (from LiDAR data) and structural-derived (from aerial photography) layers to differentiate between burnt and untouched houses (see Table 51 to 54). A test of significance ( $P$  value) is then performed to determine correlation between the variable and the house status (house burnt or untouched); very low  $P$  values indicate some correlation.

Table 51 Median distance to forest and damage to houses in Pine Ridge Road

Variable	House untouched	House burnt	Test of significance ( <i>P</i> value)
Median distance to forest (m)	19.55	13.45	0.06063

Table 52 shows the percentage of cover in the over-storey (8 m and above), mid-storey (3–8 m), and understorey (50 cm–3 m) for three radial zones around the burnt and untouched houses (0–50 m, 0–100 m and 0–200 m).

Table 52 Percentage of over-storey, mid-storey and understorey cover and damage to the house (house untouched and burnt) in Pine Ridge Road

Variable	House untouched	House burnt	Test of significance ( <i>P</i> value)
Over-storey cover (0–50 m)	20%	27%	0.03056
Over-storey cover (0–100 m)	22%	39%	0.005365
Over-storey cover (0–200 m)	24%	31%	0.001287
Mid-storey cover (0–50 m)	12%	11%	0.7813
Mid-storey cover (0–100 m)	11%	11%	0.5713
Mid-storey cover (0–200 m)	10%	12%	0.1257
Understorey cover (0–50 m)	7%	8%	0.2059
Understorey cover (0–100 m)	6%	8%	0.00721
Understorey cover (0–200 m)	6%	9%	0.008505

Table 53 Minimum distance to unburnt and burnt forest and damage to the house (house untouched and burnt) in Pine Ridge Road

Variable	House untouched	House burnt	Test of significance ( <i>P</i> value)
Min. distance to unburnt forest (m)	83.21	96.31	0.3905
Min. distance to scorched forest (m)	64.42	64.15	0.9819
Min. distance to burnt forest (m)	91.24	43.69	0.004827

Of particular interest in Table 53 is the correlation between burnt forest, compared with scorched forest, with a much stronger correlation with the burnt houses. This may be a good indicator of scenarios where high-intensity forest combustion has contributed to the likelihood of house loss.

Table 54 Minimum distance to unburnt and burnt structure (including other houses, sheds and tanks) and damage to the house (house untouched and burnt) in Pine Ridge Road

Variable	House untouched	House burnt	Test of significance ( <i>P</i> value)
Min Distance to burnt structure (m)	32.96	13.07	0.01486
Min Distance to unburnt structure (m)	17.59	48.39	0.00000006466

### 7.9.3 Proportion of houses lost and distance to forest – Pine Ridge Road

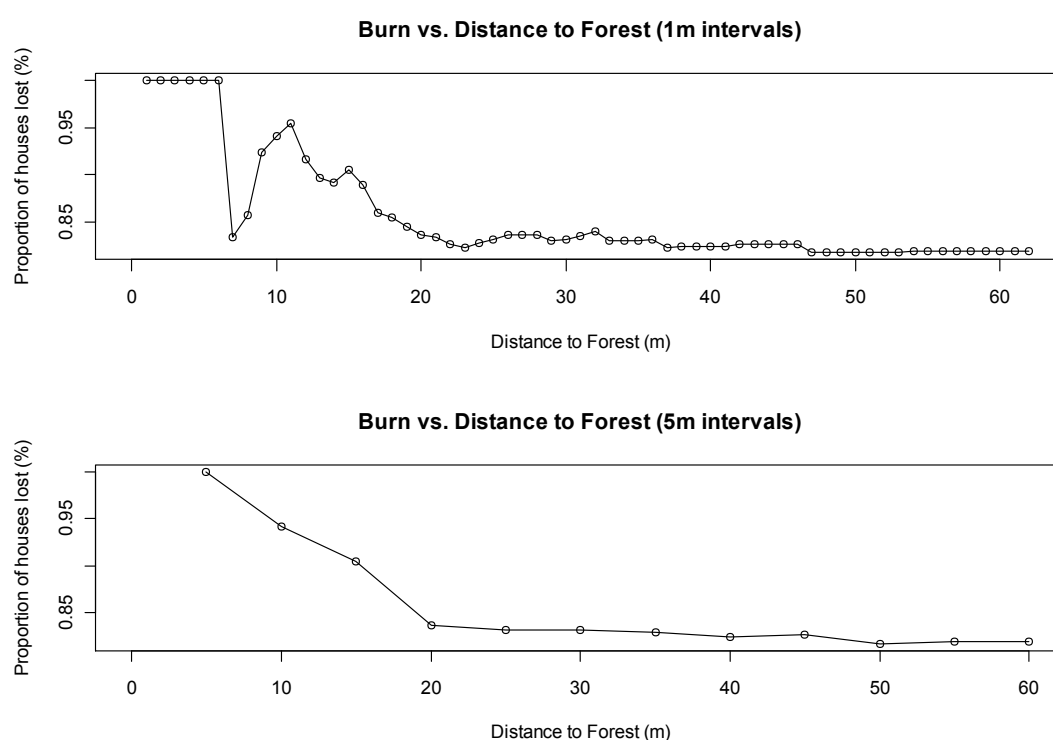


Figure 37 Proportion of house loss by distance to forest (Pine Ridge Road region)

Figure 37 shows the proportion of houses lost in the Pine Ridge Road region compared with the total number of houses, plotted against distance to forest from the house. The first graph shows this for 1-m intervals (i.e. proportion of houses lost between 0–1 m, 1–2 m, etc.) from the minimum distance to forest, to the recorded maximum distance. The second is smoothed by changing the intervals to 5 m (i.e. proportion of houses lost between 0–5 m, 5–10 m, etc.), and shows a clearer overview of how distance to forest affected the likelihood that residential structures were lost. The distance to forest results imply that there is an increase in risk of a residential structure being destroyed as it is located closer to forest, but the results do not include any information about the amount of forest in the vicinity of the structure, which is covered in the next section.

### 7.9.4 Proportion of houses lost and cover in surrounding forest – Pine Ridge Road

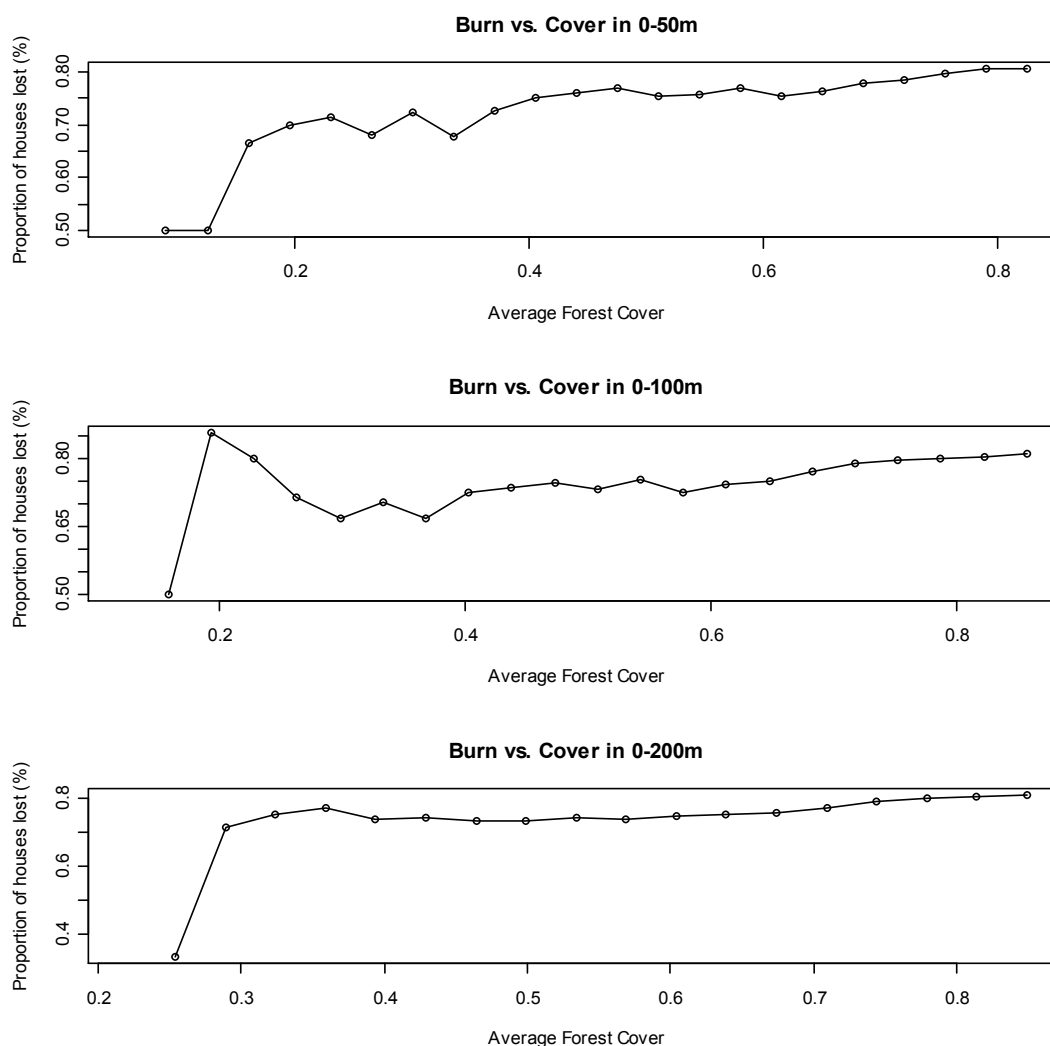


Figure 38 Houses lost and forest cover for three radial zones around the house (0–50 m, 0–100 m and 0–200 m) for the Pine Ridge Road region

As the distance from the house to forest increases, the variation in cover in the region immediately around the house has less effect on the likelihood of house loss (see Figure 38). The 0–50 m cover may explain burn behaviour due to vegetation in the immediate location of the house, showing that there is a definite increase in the probability of house loss as cover increases, and a threshold value of around 15% cover below which the chance of burning decreases dramatically. The 0–200 m range may indicate that the characteristics of the forest in the greater surrounding area also play a role in determining house loss likelihood. All ranges show an increase in the probability of house loss as the forest cover increases, with a marked increase when cover exceeds 15% (for 0–50 m and 0–100 m).

The graph demonstrates that small amounts (less than 10%) of forest within 50 m of a structure is a strong indicator of house exposure compared with higher percentage of

forest cover. This may be an expression of both a forest's potential to produce embers and produce radiant heat.

#### **7.9.5 Summary of remote sensing study**

- The results of this preliminary study show that the distance to the forest may be capable of explaining roughly 20% of the variation between surviving and destroyed houses.
- The results indicate that there is a correlation between the percentage of forest cover in the vicinity of a house and the likelihood of it being burnt.
- The results from further detailed Pine Ridge Road study region show that there is a significant difference between the distance from a burnt property to the nearest burnt property, and from a burnt property to the nearest unburnt property. This indicates that proximity to other houses may be a strong driver in fire risk.
- The East Murrindindi region showed little dependence on forest cover or forest distance from the burnt and unburnt residential structures. This may indicate different dominant fire spread mechanisms such as structure-to-structure spread. The West and Pine Ridge Road regions show roughly the same trends in both distance and cover statistics.
- Caveats:
  - At the time of writing, the survey data for the burnt and unburnt residential structures from all the fire data are still being finalised and validated.

## 8. DISCUSSION

The key role of this report is to present a dataset of post-bushfire surveys and some preliminary analyses of this dataset. For this reason, a focus on factual presentation of the preliminary analysis of these results is the key point, rather than a detailed discussion on the relevance of this analysis. There is a significant amount of additional work required to provide a definitive interpretation of this dataset and its relationship to other datasets.

### 8.1 Exposure on structure

The key categories of structural exposure are flame, radiation and embers.

The factors that may influence the degree of exposure a house experiences are as follows:

- Distance from continuous vegetation
- Ember reach driven by high winds
- Drier (more ignitable) vegetation
- Ground cover and its proximity to structures
- Proximity to adjacent structures
- Proximity to other combustible elements

Combined together, those factors increase the likelihood of loss beyond those observed in bushfire events of lower fire-weather severity. Flame contact from surrounding bushland appears to be more prevalent in this study compared with previously surveyed areas. This appears to be in part due to a higher prevalence of structures with close proximity to bushland.

In comparison, the analysis of the bushfires of Ash Wednesday 1983, Sydney 1994, Canberra 2003 and the Eyre Peninsula 2005 identified ember attack as the predominant ignition mechanism. The significance of ember-based attack and its interaction with surrounding combustible elements is a clear theme throughout all fires. Direct flame and radiation attack from the flame front itself played a much less significant role in these previous fires, either because the flame front was not of sufficient strength when reaching the structure or because it was unable to approach sufficiently close to the structures.

The Canberra fires highlight the significance of unchecked house-to-house fire transfer, a fire spread mechanism that is exacerbated by close proximity of structures (Blanchi & Leonard 2005).

#### 8.1.1 Ember spread distance

Structural losses have been observed at least 350 m into urbanised regions of Marysville and are comparable with losses in the fires of Hobart 1969 (680 m), Otways 1983 (430m) and Canberra 2003 (670 m) (Ahern & Chladil 1999). The role of ember reach from continuous vegetation to structures needs due consideration. It is understood that embers can travel many kilometres under these conditions; however, it requires a substantial number of embers in the vicinity of a house to make it statistically likely to cause house ignition, either directly or indirectly.



It is not yet clear from this study whether embers travelled substantial distances and caused structural loss or whether vegetative and non-vegetative elements between continuous vegetation and the structure produced sufficient embers to cause structural loss at such distances.

In either case, there may be substantial risk mitigation benefits in considering structural design for ember mitigation at far greater distances than are currently considered in building regulations, which provide a regulatory zone of 100 m from forest. In addition, a broader range of vegetation classes could be considered as ember sources for which building regulation for ember ignition mitigation could be considered.

Figure 33 demonstrates that for the largest detailed sample region (Murrindindi West region), house loss was occurring at distances out to 150 m, with over 20% of house loss occurring at greater than 100 m. The distances refer to the separation distance from forest greater than 8 m in height that are in clumps larger than 0.5 hectares. Note: more extensive analysis on other relevant fuel classes (such as 3–8 m vegetation and 0.5–3 m vegetation) and their spatial orientation may identify ember reach trends of shorter distances. This could be the subject of further analysis and debate as to sources of embers from these vegetation class types (e.g. bark is a key source, which is more prevalent from tall forest than low shrubs). It is difficult to confidently link observed loss patterns to ember reach based solely on this dataset. The integration of human accounts and the detailed descriptions of fire spread under these weather conditions will be very useful in determining the confidence of this conclusion.

### **8.1.2 Surface fuel spread**

Table 35 indicates a possible correlation between house loss potential and proximity to combustible ground cover, which has also been inferred by occupant accounts.

As in other fires (Eyre Peninsula and Canberra, for instance), grassland fuels have been observed to support rapid fire spread and have the capability to bring fire effects to other combustible elements (Leonard & Blanche 2005, 2006).

Surface fuels (e.g. mulch bed, dry grass) also are likely to support fire spread to other combustible elements and structures at and within the urban interface.

### **8.1.3 Combustible elements within the urban environment**

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. Other combustible elements are yet to be analysed but are expected to have similar correlations. Further analysis may also reveal the specific differences between the influence of isolated trees or small groups of trees compared with continuous forest.

## **8.2 Wind-related structural compromise**

In 13% of the surveyed houses (135 houses), wind was identified as a mechanism that contributed to compromising the structure as well as fire. In at least two confirmed cases, wind alone was identified as seriously affecting the structure with no associated fire damage. Wind-related damage is highly likely to compromise the integrity of the building

envelope, allowing ember entry into occupied areas of the house or confined spaces where combustible building elements or stored material may reside. The potentially compromised structures identified in the survey may or may not have been adequately built and maintained to withstand wind strengths potentially associated with fire. As the evidence of wind-related effects is difficult to identify from burnt house wreckage, the proportion of houses affected by wind is likely to be substantially greater than is represented in the sample. Structures suffering little or no fire damage and minor wind damage (missing roof tiles, lifted roof sheeting or missing eaves sheeting) provide an indication of how wind effects may have aided fire impact. A study of human accounts relating to this effect in future research efforts would add significant detail to this analysis.

It is well known that large fires can increase the local winds experienced and that there is a strong association between fire events such as 7<sup>th</sup> February fires and the potential for damaging winds (Bureau of Meteorology 2009). If this is found to be the case, then there is a strong case for the review of wind loading specifications approaches in bushfire-prone areas. The survey data emphasises the interdependency between wind loading-related building design and house vulnerability.

The Canberra 2003 survey showed that wind played only a minor role in the direct impact of the structures in the Duffy suburb. However, this is in contrast to the impact on the suburb of Chapman, where more houses were affected by fire-generated wind effects than the fire itself (Leonard & Blanchi 2005).

Further data analysis will endeavour to determine whether age of structure, building type, local topography, etc., are statistically relevant factors to further inform the discussion on wind-related damage.

### **8.3 House vulnerability**

House vulnerability can be influenced by a wide range of design elements. The following section discusses a number of key elements.

#### **8.3.1 Cladding material**

Section 7.3.3 details the breakdown of house survival and external wall material. Brick construction performed well compared with all other forms of construction. Mud brick, cellulose cement and timber-clad structures all performed similarly to each other. It could be expected that light-weight construction, such as timber and cellulose cement, would fare poorly under the given conditions; however, the reasons for mud brick performing poorly are not so clear. There is a statistically small sample of mud brick structures in the survey. Further analysis may either verify or dispel this observation. Further correlations of house survival with respect to building age, cladding type, and proximity to bush in future research will also provide significant guidance as to the appropriate use of each construction type in given circumstances.

Further analysis as to how these cladding materials are associated with other vulnerable construction styles may also provide further insights. For example; brick and mud brick

construction is more likely to be associated with slab-on-ground constructions than timber or cellulose cement-clad houses.

### **8.3.2 Window glass type**

The survey dataset contains only a small sample of houses identified as having all toughened glass windows (21). This is not a sufficient sample to demonstrate a correlation between house survival and glass type. However, the physical characteristics of glass and framing performance are well understood in the study of glazing performance (Bowditch and al. 2006).

### **8.3.3 Prevalence of attached combustible elements**

In order to effectively assess house vulnerability and the performance of the weakest aspects of its design, we need to compare these weak points and an estimation of the intensity of exposure the structure is likely to have experienced against house loss. This comparison could be the subject of future work.

### **8.3.4 House tenability**

Another aspect to consider is the tenability of the house during the fire event. The survey dataset does indicate that a number of structures were subjected to multiple wind directions during the peak of the fire event. This suggests that multiple fire fronts may have approached these houses. This observation appears to be consistent with human accounts recorded in interviews during the survey (see human behaviour part of this report). This raises the question of the adequacy of the house to provide shelter over the time period for which multiple fire fronts may be active around the house.

It is reasonable to suggest that increasing extreme fire behaviour caused by more extreme weather in the future could lead to a greater exposure of structures. The greater the fire exposure, the more readily a structure may be ignited. In addition to this, the higher level of house exposure may cause a more rapid rate of loss of tenability of the structure. This could occur for a number of reasons:

- prevalence of window failure due to higher exposure
- rate of fire development in roof and wall cavities due to lower moisture content of combustible elements (MacIndoe 2007) (combined with potential for wind to compromise the integrity of the cladding in these areas)
- higher propensity for combustible cladding elements to ignite and support rapid flame spread
- compromises to structural envelope due to wind effects
- high wind speeds causing a greater rate of air exchange between outside and inside the house

Further work could involve reviewing human accounts of the issues around ignition, spread and the rate at which houses become untenable. Preliminary reviews of these

accounts suggest that roof ignition and rapid spread occurred in a number of cases, which led to the house becoming untenable.

#### **8.4 Prevention measures – example of water defence system reliability**

Different prevention measures can be taken by the occupant prior to the fire event and on the day of the fire. A wealth of information is available from the occupant interviews regarding their preparations and actions on the day. Out of this information, the example of water supply was analysed.

Of the houses surveyed, 82 had sprinkler systems fitted, and only one of these cases involved an internal system. In addition, a number of different types of pumps were used for active defence through ad-hoc or hand-held spray systems.

Preliminary reviews of human accounts identified mechanical (petrol- and diesel-driven) pump reliability as a major issue during the more intense period of fire exposure, with the majority of pumps being rendered inoperable owing to thermal exposure. In many cases, the defence capability was severely hampered by the lack of water, although in a lot of these cases, defence continued using other means.

Section 7.6 highlights the prevalence of water use as a key mechanism for house defence, and shows a strong correlation between house survival and evidence of the use of water to defend the structure. Previous bushfire investigations have shown the strong correlation between active human defence of houses and house survival.

Further data analysis as to the effectiveness of various water defence strategies could be carried out, when confirmation (from occupant interviews) of the use of various systems and behaviours will be related to house survivability.

#### **8.5 Impact of land-use planning and building controls**

Survey data and remote sensing-based analysis have both shown that proximity to vegetation, in particular forest, is strongly correlated with house loss potential. This agrees with the underlying principles of existing building and planning controls. The specific distances between various house design features and vegetation types have been accurately mapped and recorded in this survey effort. In order to unravel the many ways vegetation can influence structural survival and its surrounding features to express any statistical correlations, a range of data sampling techniques need to be applied. This process requires a detailed definition of building footprint location and its relationship to vegetation classification and extent. At the time of finalising this report, these datasets are well developed but not complete. Future analysis could provide a detailed insight into the spatial interaction of these features to underpin future planning and building codes reform.

Owing to the lack of house age data and building compliance data at the time of writing this report, it was not possible to draw direct statistical correlations between the effectiveness of the Wildfire Management Overlay (WMO) or the implementation of

AS3959 (Building in Bushfire-Prone Areas Construction Standard). However, the underlying assumptions on which these controls are based are expressed in the various examples throughout the Results section of the report. Future analysis of these data could make statistical correlations possible.

## 8.6 Concept of defensible house and defensible space

### 8.6.1 Defensible house concept

A defensible house is one that can withstand fire effects that may arise in a given location. Hence the location, surrounding elements and design all contribute to the defensibility of a house. For a detailed discussion of house design and landscaping for bushfire risk mitigation, refer to Blanchi & Leonard (2008).

The word defensible automatically infers the interaction of people with the structure. They may be fire agency personnel, house owners or others. It could be assumed that a house may survive with a small or large amount of attention provided by the human element, and this attention could be provided immediately before the fire event, immediately after or both. It could infer that the house will or should survive throughout the course of the fire or for a short period in which the most intense part of the fire event passes the house. Each of these contexts would have a major bearing on the appropriate design and siting of a house that is considered defensible.

In order to simplify the discussion, we need to define the specific context for which we define the defensible house by answering the following questions:

- Should the house be expected to survive without human intervention immediately before and after the passage of the main fire front?
- Should the house defensibility be sensitive to vegetation growth and other common combustible elements around the house (e.g. the construction of a neighbouring house), hence requiring ongoing detailed assessment of its defensibility?
- Should the house be expected to survive all likely fire arrival events under all likely weather conditions? If so, what is an acceptable likelihood of exceedance of these conditions, and what is the consequence of an exceedance event? For example; will the house rapidly lose tenability once its threshold is exceeded, or has it been specifically designed to provide shelter for a limited time even if its design threshold is exceeded?

Irrespective of how these questions are answered, the most ideal situation for life safety is to have a house design that will survive under all circumstances. In reality, cost and functionality of the design open up the debate as to which compromises can or should be made. In many cases, few compromises need to be made with risk mitigation methods being simple, and synergistic with other objectives such as durability.

A discussion of a methodology of assessing house defensibility is provided in Section 9 below.

It is necessary to consider the constraints of the house location. This will clarify what „distance from various vegetation types“ will be recommended. These distances may be fixed, negotiable or preferred (see Section 4.2). These distances immediately define the context for what a building may be subject to and can range from light ember attack to heavy flame contact.

### 8.6.2 Defendable space

Defendable space is a common concept used by many fire agencies. It is a region of reduced fuel immediately around a house that reduces the maximum impact the house may receive; it should also increase the opportunity for occupants to defend their structure after the fire has passed, or to flee the structure if it becomes untenable.

#### Definition from Country Fire Authority (from WMO Kit)

*“Defendable space is several zones of managed vegetation surrounding the building. ...This provides an area of protection from radiant heat, direct flame contact and ember attack.”*

#### Definition from Tasmanian Fire Service

*“A defendable space is an area around your home where you have modified the vegetation and removed most of the other flammable materials to reduce the fire’s intensity. Removing flammable materials will mean sparks and embers will have less fuel to ignite when they land, and any spot fires will be easier to put out. Also, the impact of the flames and radiant heat from an approaching bushfire will be reduced.”*

#### Definition from NSW Rural Fire Service (from Planning for Bushfire Protection)

*“An asset protection zone (APZ) is also known as a fire protection zone and aims to protect human life, property and highly valued assets. It is a buffer zone between a bush fire hazard and buildings, which is managed progressively to minimise fuel loads and reduce the potential radiant heat levels, flame contact, ember and smoke attack on life and property.”*

The concept of a fuel-reduced zone immediately around a house is sound. The survey results show a clear correlation between house loss and proximity to trees and bushes (see Section 7.5). Even well-designed and prepared houses will benefit from the reduced exposure by providing an increased safety margin as well as improving the likelihood of effective defence by occupants once the peak in fire activity has passed. A defendable space also improves the likelihood of safe egress from a house that may have ignited and is becoming untenable. This space would need to provide a sufficient buffer from surrounding heavy fuel elements that remain burning long after the fire front has passed. Further analysis of surveyed structures and surroundings will provide an insight into the distances and configurations that were effective in reducing house damage.

## 9. FUTURE WORK AND ARISING QUESTIONS

Future work is related to the assessment of house vulnerability under different types of fire exposure.

### 9.1 Assessment of house vulnerability with different types of fire intensity

The characteristics of house design and construction materials play an important role in the house loss process. The vulnerability of a structure can be evaluated by taking into account its resistance to embers, flame and radiant heat attack, and is described in this section.

#### 9.1.1 House vulnerability (from house design and construction material)

The assessment of house vulnerability can be based on a combination of factors. In future work, these factors (extracted from the survey) will be aggregated to estimate a house's vulnerability to various levels of exposure. These include:

- likelihood of ember entry in the structure through gaps
- ignitability from low-level flame
- ignitability from accumulated fine debris
- ignition or loss of integrity of materials due to different radiant heat levels

The ember entry vulnerability is estimated from: the presence of screen protection on vents and doors, the presence of a floor with a minimum height above the ground less than 600 mm from the ground that is either fully enclosed (with non-combustible material) or slab on the ground.

The low-level flame ignition is based on the presence of combustible fascia material within 400 mm of the ground or other horizontal projections, and exposed combustible floor material within 600 mm of the ground or other horizontal projections. The classification is determined from the ground cover or deck material and from the wall material (major and minor portion). In the event of the presence of different material combustibility for those two aspects, it will be necessary to check a photo of the house to estimate the type of material.

The radiant heat classes are defined by taking into account the radiant heat level that a house should be able to sustain. The defined classes are: all radiant heat levels up to 12.5 kW/m<sup>2</sup>; all radiant heat levels up to 19 kW/m<sup>2</sup>; and all radiant heat levels up to 40 kW/m<sup>2</sup>. The classification is based on the type of glass material, the presence of shutters and screen on all glazing elements, the wall material, the eaves material, the doors material, the subfloor enclosure material.

The following decision tree summarises a classification process for the radiation threshold of houses that have been previously surveyed (see Figure 39). This would effectively create a new data attribute for this structure that could be assessed for its statistical correlation to factors such as distance to vegetation.

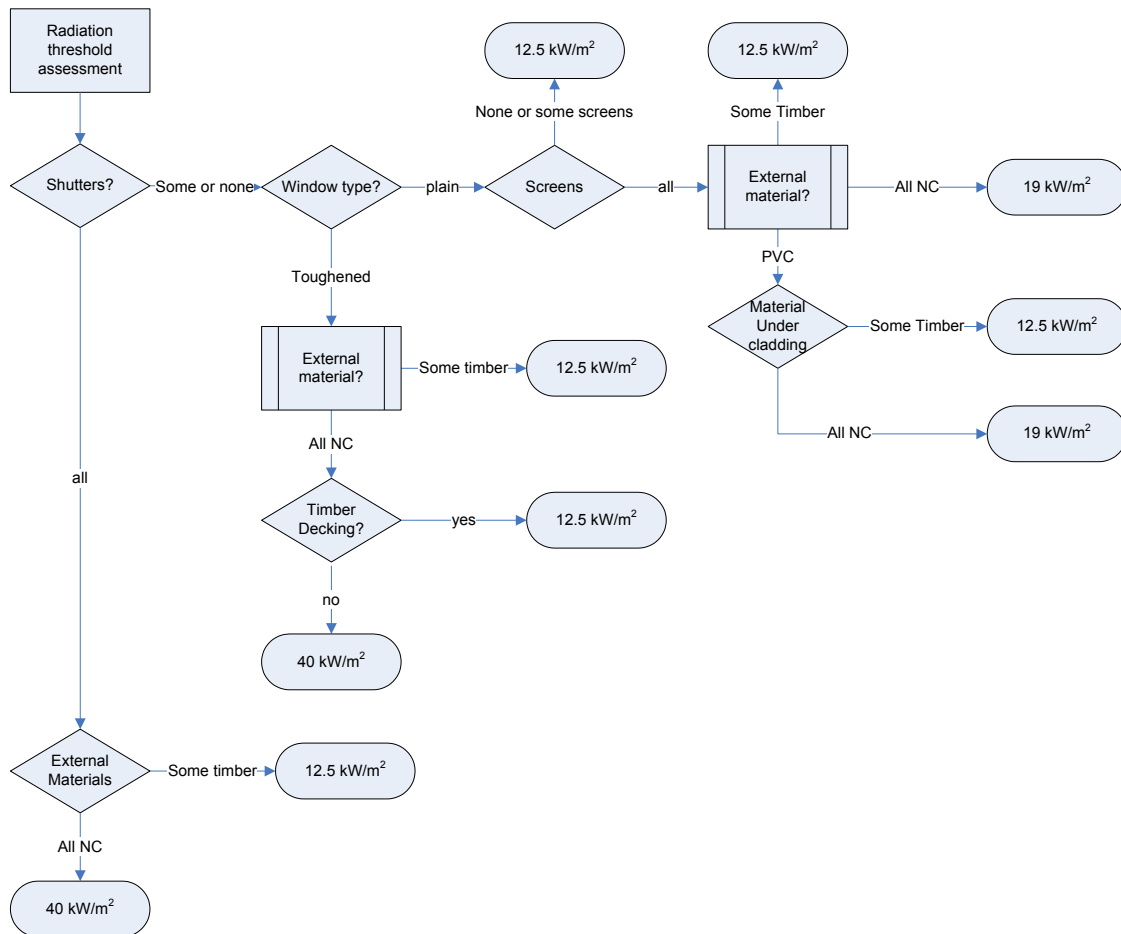


Figure 39 Classification process for radiation threshold of houses surveyed (NC = non-combustible)

### 9.1.2 Estimating exposure at house level from forest and surrounding objects

The exposure received at the house level could result from the fire front, the surrounding elements burning or a combination of both. The exposure received from these elements is a function of distance and the amount of other element(s) the house is exposed to. We used this as a variable to statistically relate house loss to exposure. Other approaches to define the exposure are used as well in certain specific areas, for instance proximity from burnt, scorched or unburnt vegetation, from the remote sensing analysis (see Section 5.2.3) and from human account when available.



### 9.1.3 Crossing house vulnerability and exposure

This will be demonstrated on specific areas with a multivariable analysis on the following parameters:

- The vulnerability of the house (see Section 9.1.1)
- The exposure: from proximity to continuous vegetation (distance from building footprint to continuous vegetation type) and comments on status of vegetation if available (burnt, scorched)
- The exposure from surrounding vegetation elements and combustible objects (and available comments on status of elements)
- Slope
- Weather context

## 9.2 Building controls

To better understand the role of building controls, a study of a compliant house will be necessary. Additional information is required on house age to determine structures that might be compliant, or information from councils on house compliancy. The assessment of house vulnerability described in Section 9.1.1 could be used to determine the types of houses that appear to be compliant with the building controls.

## 9.3 Arising questions

- Evaluate house loss probability based on multivariable analysis and comparison with Wilson model of house survival (Wilson and Ferguson 1986).
- Better understanding of the influence of slope. This could be done by combining slope with fire direction to determine the impact of slope. The objective is to define slope classes, taking into account the slope, aspect and fire direction to determine what type of slope (up slope and down slope) have led the fire to the house and influenced its intensity.
- Wind modelling to better understand the impact of topography and terrain on the house vulnerability (identification of ridges and valleys). It has been shown in tropical cyclone damage assessments that topographically assisted winds where terrain roughness due to vegetation influences wind speed correlates highly with damage (Walker et al. 1988).
- Severity of fire weather may indicate an exceedance of threshold limits in building design, e.g. wind loading, moisture-driven shrinkage allowing ember access. Rather than extrapolating likely house loss as a function of fire weather or fire severity and observed loss to date, it may be more appropriate to consider what

aspects of house design may pass a critical design threshold and contribute to a major escalation of structural loss.

- The prevalence of houses lost and apparent rapid loss of tenability raises the question of whether house design to limit the rate at which a house becomes untenable be also considered along with the conventional approach of considering house ignition potential.

## 10. CONCLUSION

A detailed dataset has been established that can assist further analysis for future planning and building codes reform. The opportunities of spatial data capture have only begun to be explored in the analysis of this dataset. From the preliminary analysis performed, the following conclusions can be made:

- Over 1000 houses have been surveyed to form a representative sample of houses lost in these fires.
- Active defence of structures has a major influence on house survival.
- Building quality, detail and possibly house age appear to be factors influencing the likelihood of house loss.
- Brick houses performed significantly better than mud brick and light-weight constructions clad with timber and cellulose cement sheet.
- The potential for wind damage of structures should be a key factor in future building consideration in bushfire-prone areas.
- Approximately 20% of house loss in the chosen study areas appears to be directly related to their immediate proximity to adjacent forest fuels.
- House loss has occurred at distances greater than 380 m from continuous forest, and this figure may be substantially greater once a broader set of houses is analysed.
- Over half of the surveyed houses lost in the February 7<sup>th</sup> fires were not in regions classified by a Wildfire Management Overlay.
- Metal and concrete water tanks are more likely to maintain an effective water supply for house defence than polyethylene and fibreglass tanks.
- Design, location and degree of protection of water pump and pipe-work are important factors in maintaining an effective water supply throughout the fire event.
- Mains water pressure and mains electricity cannot be relied upon during the fire event.
- Vegetation overhanging or immediately adjacent to houses, whether it is isolated or continuous, is a key factor influencing the likelihood of house loss.

## REFERENCES

- Ahern A, and Chladil M (1999) How far do bushfires penetrate urban areas?  
Australian Bushfire Conference, Albury, July 1999.
- Barrow GJ (1945) A survey of houses affected in the Beaumaris fire, January 14, 1944. *Journal of the Council for Scientific and Industrial Research* **18**(1)
- Blanchi R, Leonard J (2008) Property safety: judging structural safety. In „Community Bushfire Safety.“ (Eds J Handmer, K Haynes) (CSIRO Publishing: Melbourne)
- Blanchi R, Leonard J (2008b) The influence of human behaviour on house loss.  
Bushfire CRC conference, Adelaide.
- Blanchi R, and Leonard J (2006) A study of the interaction between bushfire and community in the south Australian Wangary fire 2006. Bushfire CRC report – Confidential, submitted to coroner.
- Blanchi R, Leonard J, Leicester RH (2006b) Bushfire risk at the rural–urban interface.  
Australasian Bushfire Conference, 6–9 June, Brisbane, Queensland
- Bowditch PA, Sargeant A, Leonard J, Macindoe L (2006). Window and glazing exposure to laboratory-simulated bushfires. Bushfire CRC report CMIT(C)-2006-205
- Babrauskas V (2001) Ignition of wood: a review of the state of the art, pp. 71–88 in „Interflam 2001“. Interscience Communications Ltd., London.
- Bureau of Meteorology (2009) Meteorological aspects of the 7 February 2009 Victorian fires, an overview. Report for the 2009 Victorian Bushfires Royal Commission
- Chen K, and McAneney J (2004) Quantifying bushfire penetration into urban areas in Australia. *Geophysical Research Letters*, **31**, L12212,
- Chuvieco E (1999) „Remote sensing of large wildfires.“ Springer-Verlag
- Cole RE (1983) Houses exposed to bushfires: a survey of the effects of the Hobart Fire of 1967 and the Blue Mountains Fire of 1968. Department of Housing and Construction, Experimental Building Station Technical Record 390(L)
- Country Fire Authority (1983) „The Major Fires Originating 16th February, 1983.“ (CFA: Victoria)
- Country Fire Authority (1990) „Investigation into Major Fires of 27th December 1990.“ (CFA: Victoria)
- Leonard JE, Blanchi R (2005) Investigation of bushfire attack mechanisms involved in house loss in the ACT Bushfire 2003. Report CMIT(C)-2005-377. (Bushfire CRC: Victoria)
- Leonard J, Blanchi R, and Bowditch P (2004) Bushfire impact from a house's perspective. Earth Wind and Fire – Bushfire 2004 Conference, Adelaide.

- Leonard J, Bowditch P (2003) Findings of studies of houses damaged by bushfire in Australia. Presented to 3rd International Wildland Fire Conference, Sydney, 3–6 October
- Leonard JE, McArthur NA (1999) A history of research into building performance in Australian bushfires. Proceedings of Bushfire 99: Australian Bushfire Conference, Albury, Australia, 7–9 July 1999. pp. 219–225. (School of Environmental and Information Sciences, Charles Sturt University: Albury)
- Lovell JL, Jupp DLB, Culvenor DS and Coops NC (2003). Using airborne and ground-based ranging lidar to measure canopy structure in Australian forests. *Canadian Journal of Remote Sensing*. **29**(5), 607-622.
- MacIndoe L, Bowditch PA (2007) Measurements of moisture content in decking timbers exposed to bushfire weather conditions. Report CMMT(C)-2007-141. (Bushfire CRC: Victoria)
- McArthur NA (1997). A protocol for surveying bushfire building damage. CSIRO BCE Reprint 8-7-1997.
- Ramsay GC, McArthur, NA, and Dowling, VP (1994). Bushfires : lessons for planners. Queensland Planners Conference.
- Ramsay GC, McArthur NA (1995) Building in the urban interface: lessons from the January 1994 Sydney bushfires. Presented to Bushfire '95 Conference, Hobart, Tasmania
- Ramsay GC, McArthur NA, Dowling VP (1987) Preliminary results from an examination of house survival in the 16 February 1983 bushfires in Australia. *Fire and Materials* **11**, 49–51
- Ramsay GC, McArthur NA, Dowling VP (1986). Building survival in bushfires. Fire Science '86: 4th Australian National Biennial Conference, 21–24 October, The Institution of Fire Engineers.
- Specht RL (1970). Vegetation. In 'Australian Environment'. 4th Edn. (Ed. G. W. Leeper.) pp. 44–67. (Melbourne University Press: Melbourne.)
- Standards Australia. Risk Management AS/NZS 4360:2004.
- Standards Australia. Design and Construction of Buildings in Bushfire-Prone Areas AS 3959: 2009
- Victoria Police [http://www.police.vic.gov.au/content.asp?Document\\_ID=20350](http://www.police.vic.gov.au/content.asp?Document_ID=20350)
- Wilson AAG, Ferguson IS (1984) Fight or flee? – a case study of the Mount Macedon bushfire. *Australian Forestry* **47**(4), 203–236
- Wilson AAG and Ferguson IS (1986). Predicting the probability of house survival during bushfires. *J. Environmental Management* **23**, 259–270

## APPENDIX A – PAPER QUESTIONNAIRE



### 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)

- |                            |  |
|----------------------------|--|
| <input type="checkbox"/> 1 | <input type="checkbox"/> Contacting ground, slab |
| <input type="checkbox"/> 2 | <input type="checkbox"/> <600 mm                 |
| <input type="checkbox"/> 3 | <input type="checkbox"/> 600 mm to 1.6 m         |
| <input type="checkbox"/> 4 | <input type="checkbox"/> >1.6 m                  |
| <input type="checkbox"/> 9 | <input type="checkbox"/> Unknown                 |
- 

## 5 Major material supporting floors

- |  |   |
|--|---|
| 1 <input type="checkbox"/> Treated pine          | 5 <input type="checkbox"/> Brick piers, walls |
| 2 <input type="checkbox"/> Other timbers         | 6 <input type="checkbox"/> Other .....        |
| 3 <input type="checkbox"/> Concrete stumps, etc. | 7 <input type="checkbox"/> Slab on ground     |
| 4 <input type="checkbox"/> Steel posts           | 9 <input type="checkbox"/> Unknown            |

**6-9 Predominant external wall material****6,7 Major portion of house****6 Broad classification**

- 1 ☐ Timber
- 2 ☐ Cellulose cement
- 3 ☐ Brick (other than mud brick)
- 4 ☐ Mud brick
- 5 ☐ Aluminium siding
- 6 ☐ PVC siding
- 7 ☐ Other .....
- 9 ☐ Unknown

**7 Narrower classification**

- 1 ☐ Smooth weatherboard (painted)
- 2 ☐ Rough-sawn weatherboard
- 3 ☐ Treated pine logs
- 4 ☐ Other timber .....
- 5 ☐ Cellulose cement flat sheets
- 6 ☐ Cement planks, profiles
- 8 ☐ Not applicable (brick, etc.)
- 9 ☐ Unknown

**8,9 Minor portion of house****8 Broad classification**

- 1 ☐ Timber
- 2 ☐ Cellulose cement
- 3 ☐ Brick (other than mud brick)
- 4 ☐ Mud brick
- 5 ☐ Aluminium siding
- 6 ☐ PVC siding
- 7 ☐ Other .....
- 9 ☐ Unknown

**9 Narrower classification**

- 1 ☐ Smooth weatherboard (painted)
- 2 ☐ Rough-sawn weatherboard
- 3 ☐ Treated pine logs
- 4 ☐ Other timber .....
- 5 ☐ Cellulose cement flat sheets
- 6 ☐ Cement planks, profiles
- 8 ☐ Not applicable (brick, etc.)
- 9 ☐ Unknown

**10 Underfloor enclosure**

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

**11 Predominant roof material**

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



**12 Size of house**

- |  |   |
|--|---|
| 1 <input type="checkbox"/> Small, <80 m <sup>2</sup>     | 5 <input type="checkbox"/> Large, >150 m <sup>2</sup> |
| 2 <input type="checkbox"/> Medium, 80–150 m <sup>2</sup> | 9 <input type="checkbox"/> Unknown                    |

**13 Roof profile**

- |  |  |
|--|--|
| 1 <input type="checkbox"/> One slope, no ridge or valley | 4 <input type="checkbox"/> Complex ridge |
| 2 <input type="checkbox"/> One ridge, no valley          | 7 <input type="checkbox"/> Other .....   |
| 3 <input type="checkbox"/> One valley, no ridge          | 9 <input type="checkbox"/> Unknown       |

**14 Window frame materials**

- |   |  |
|---|--|
| 1 <input type="checkbox"/> Aluminium              | 5 <input type="checkbox"/> Other mixed |
| 2 <input type="checkbox"/> Timber                 | 7 <input type="checkbox"/> Other ..... |
| 3 <input type="checkbox"/> Steel                  | 9 <input type="checkbox"/> Unknown     |
| 4 <input type="checkbox"/> Mixed aluminium/timber |  |

**15–20 Protection of openings****15–17 Protection extent**

- |   |
|---|
| 1 <input type="checkbox"/> Each one protected fully     |
| 2 <input type="checkbox"/> All opening sashes protected |
| 3 <input type="checkbox"/> Some protected, some not     |
| 4 <input type="checkbox"/> None to protect              |
| 8 <input type="checkbox"/> None protected               |
| 9 <input type="checkbox"/> Unknown                      |

**15 Windows**

- |                            |
|----------------------------|
| 1 <input type="checkbox"/> |
| 2 <input type="checkbox"/> |
| 3 <input type="checkbox"/> |
| 4 <input type="checkbox"/> |
| 8 <input type="checkbox"/> |
| 9 <input type="checkbox"/> |

**16 Doors**

- |                          |
|--------------------------|
| <input type="checkbox"/> |
| <input type="checkbox"/> |
| <input type="checkbox"/> |
| <input type="checkbox"/> |
| <input type="checkbox"/> |
| <input type="checkbox"/> |

**7 Vents**

- |                          |
|--------------------------|
| <input type="checkbox"/> |
| <input type="checkbox"/> |
| <input type="checkbox"/> |
| <input type="checkbox"/> |
| <input type="checkbox"/> |
| <input type="checkbox"/> |

**18–20 Protection material**

- |   |
|---|
| 1 <input type="checkbox"/> Metal flywire      |
| 2 <input type="checkbox"/> Fibreglass flywire |
| 3 <input type="checkbox"/> Flywire (unknown)  |
| 4 <input type="checkbox"/> Metal grid, etc.   |
| 5 <input type="checkbox"/> Mixed              |
| 7 <input type="checkbox"/> Other .....        |
| 8 <input type="checkbox"/> None               |
| 9 <input type="checkbox"/> Unknown            |

**18 Windows**

- |                            |
|----------------------------|
| 1 <input type="checkbox"/> |
| 2 <input type="checkbox"/> |
| 3 <input type="checkbox"/> |
| 4 <input type="checkbox"/> |
| 5 <input type="checkbox"/> |
| 7 <input type="checkbox"/> |
| 8 <input type="checkbox"/> |
| 9 <input type="checkbox"/> |

**19 Doors**

- |                          |
|--------------------------|
| <input type="checkbox"/> |
| <input type="checkbox"/> |
| <input type="checkbox"/> |
| <input type="checkbox"/> |
| <input type="checkbox"/> |
| <input type="checkbox"/> |
| <input type="checkbox"/> |
| <input type="checkbox"/> |

**20 Vents**

- |                          |
|--------------------------|
| <input type="checkbox"/> |
| <input type="checkbox"/> |
| <input type="checkbox"/> |
| <input type="checkbox"/> |
| <input type="checkbox"/> |
| <input type="checkbox"/> |
| <input type="checkbox"/> |
| <input type="checkbox"/> |

**21 Window screen position**

- |   |                                    |
|---|------------------------------------|
| 1 <input type="checkbox"/> Outside            | 8 <input type="checkbox"/> None    |
| 2 <input type="checkbox"/> Inside             | 9 <input type="checkbox"/> Unknown |
| 3 <input type="checkbox"/> Outside and inside |                                    |

## 22 Window shutters

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

## 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
- 

### 26 Timber support poles – material

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

### 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**

<input type="checkbox"/>	1	<input type="checkbox"/>	Treated pine
<input type="checkbox"/>	2	<input type="checkbox"/>	Red gum
<input type="checkbox"/>	3	<input type="checkbox"/>	Other timber
<input type="checkbox"/>	4	<input type="checkbox"/>	Timber (unknown)
<input type="checkbox"/>	5	<input type="checkbox"/>	Metal
<input type="checkbox"/>	6	<input type="checkbox"/>	Other non-combustible
<input type="checkbox"/>	7	<input type="checkbox"/>	Other .....
<input type="checkbox"/>	8	<input type="checkbox"/>	No external stairs
<input type="checkbox"/>	9	<input type="checkbox"/>	Unknown

---

**30–41 Detached outbuildings within 20 m of house (largest first)****30–32 Function of detached outbuilding**

	<b>1st</b>	<b>2nd</b>	<b>3rd</b>	
1	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	Garage
2	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	Carport
3	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	Bungalow, flat
4	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	Laundry, toilet
5	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	Storage shed, garden shed, workshop
6	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	Barn, dairy, chookshed, etc.
7	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	Other .....
8	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	Not applicable
9	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	Unknown

---

**33–35 Degree of damage – detached outbuildings**

	<b>1st</b>	<b>2nd</b>	<b>3rd</b>	
1	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	Untouched
2	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	Superficial
3	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	Light damage
4	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	Medium damage
5	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	Heavy damage
6	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	Destroyed
7	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	Other .....
8	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	Not applicable
9	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	Unknown

### 36–41 Materials – detached outbuildings

#### 36–38 External walls

	1st	2nd	3rd	
1	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	Timber
2	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	Iron, steel
3	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	Aluminium
4	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	Cement fibre
5	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	Brick
7	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	Other .....
8	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	Not applicable
9	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	Unknown

---

#### 39–41 Roof

	1st	2nd	3rd	
1	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	Steel
2	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	Aluminium
3	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	Cement fibre
7	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	Other .....
8	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	Not applicable
9	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	Unknown

---

### 42,43 Combustibles

#### 42 Gas bottles (other than household supply)

1 <input type="checkbox"/> Inside house	6 <input type="checkbox"/> Under, outside
2 <input type="checkbox"/> Under house	7 <input type="checkbox"/> Other (including all) .....
3 <input type="checkbox"/> Outside house	8 <input type="checkbox"/> None
4 <input type="checkbox"/> Inside, under	9 <input type="checkbox"/> Unknown
5 <input type="checkbox"/> Inside, outside	

---

#### 43 Building materials, wood heaps

1 <input type="checkbox"/> Under house	6 <input type="checkbox"/> Outside, outbuilding
2 <input type="checkbox"/> Outside house	7 <input type="checkbox"/> Other (including all) .....
3 <input type="checkbox"/> Outbuilding	8 <input type="checkbox"/> None
4 <input type="checkbox"/> Under, outside	9 <input type="checkbox"/> Unknown
5 <input type="checkbox"/> Under, outbuilding	

#### **44–48 External LPG cylinders (household supply)**

##### **44 Position**

- |  |   |
|--|---|
| 1 <input type="checkbox"/> Against external wall   | 7 <input type="checkbox"/> Other .....              |
| 2 <input type="checkbox"/> Under verandah, etc.    | 8 <input type="checkbox"/> No bottled gas installed |
| 3 <input type="checkbox"/> Remote from house, <6 m | 9 <input type="checkbox"/> Unknown                  |
| 4 <input type="checkbox"/> Remote from house, >6 m |   |
- 

##### **45 Security**

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

##### **46 Behaviour**

- |  |   |
|--|---|
| 1 <input type="checkbox"/> Undamaged                       | 6 <input type="checkbox"/> Bottle condition unknown |
| 2 <input type="checkbox"/> Heat affected – not vented      | 7 <input type="checkbox"/> Other .....              |
| 3 <input type="checkbox"/> Heat affected – vented          | 8 <input type="checkbox"/> Not applicable           |
| 4 <input type="checkbox"/> Heat affected – venting unknown | 9 <input type="checkbox"/> Unknown                  |
| 5 <input type="checkbox"/> Split, ruptured                 |   |
- 

##### **47 Preserved ignition point evidence**

- |   |  |
|---|--|
| 1 <input type="checkbox"/> Windowsill, door frame | 6 <input type="checkbox"/> Timber deck |
| 2 <input type="checkbox"/> Wall cladding          | 7 <input type="checkbox"/> Other ..... |
| 3 <input type="checkbox"/> Stump battens          | 8 <input type="checkbox"/> None        |
| 4 <input type="checkbox"/> Fascia board           | 9 <input type="checkbox"/> Unknown     |
| 5 <input type="checkbox"/> External stairs        |  |
- 

##### **48 Solid fences (in direction of fire approach)**

- |  |  |
|--|--|
| 1 <input type="checkbox"/> Brick, stone              | 5 <input type="checkbox"/> Timber, ignited |
| 2 <input type="checkbox"/> Metal panel               | 7 <input type="checkbox"/> Other .....     |
| 3 <input type="checkbox"/> Cement sheet profile etc. | 8 <input type="checkbox"/> None            |
| 4 <input type="checkbox"/> Timber, not ignited       | 9 <input type="checkbox"/> 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
- 

### **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
- 

### **51 Evacuation behaviour**

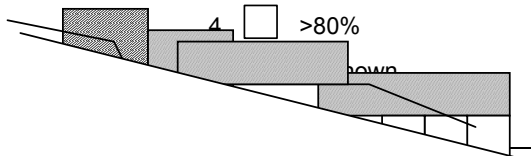
- 1 ☐ Forced to leave by emergency services
  - 2 ☐ Given the option to leave by emergency services
  - 3 ☐ Left by own decision
  - 4 ☐ Elected to stay
  - 5 ☐ Unable to leave due to fire
  - 6 ☐ Unable to leave – other reason .....
  - 7 ☐ Other action .....
  - 8 ☐ House not occupied on day
  - 9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

**54 Largest single pane of glass (including sliding doors)**

- 1 ☐ <1.5m<sup>2</sup>  
 2 ☐ 1.5–2m<sup>2</sup>  
 3 ☐ 2.5–4m<sup>2</sup>  
 4 ☐ >4m<sup>2</sup>  
 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
- 

### 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



## Appendix B – Arc Pad Survey questions

Layer type of attachment detailed

Layer	Caption	Question	Field	Answer
Attachment.shp	Q1	Attachment Type	ATTQ1	a) Deck
Attachment.shp	Q1	Attachment Type	ATTQ1	b) Stairs
Attachment.shp	Q1	Attachment Type	ATTQ1	c) Other
Attachment.shp	Q2	Does it have a roof?	ATTQ1A1	a) Yes
Attachment.shp	Q2	Does it have a roof?	ATTQ1A1	b) No
Attachment.shp	Q2	Does it have a roof?	ATTQ1A1	c) Unknown
Attachment.shp	Q3	Is it combustible (including deck boards or support structure)?	ATTQ1A2	a) Decking boards only
Attachment.shp	Q3	Is it combustible (including deck boards or support structure)?	ATTQ1A2	b) Support structure only
Attachment.shp	Q3	Is it combustible (including deck boards or support structure)?	ATTQ1A2	c) Decking boards and support structure
Attachment.shp	Q3	Is it combustible (including deck boards or support structure)?	ATTQ1A2	d) No
Attachment.shp	Q4	Combustible description	ATTQ1A3	a) Tongue and groove boards
Attachment.shp	Q4	Combustible description	ATTQ1A3	b) Gapped boards - treated pine
Attachment.shp	Q4	Combustible description	ATTQ1A3	c) Gapped boards - other timber
Attachment.shp	Q4	Combustible description	ATTQ1A3	d) Gapped boards - timber unknown
Attachment.shp	Q4	Combustible description	ATTQ1A3	e) Bituminous membrane
Attachment.shp	Q4	Combustible description	ATTQ1A3	f) Other
Attachment.shp	Q4	Combustible description	ATTQ1A3	g) Unknown
Attachment.shp	Q5	Support material (poles)	ATTQ1A4	a) Treated pine
Attachment.shp	Q5	Support material (poles)	ATTQ1A4	b) Red gum
Attachment.shp	Q5	Support material (poles)	ATTQ1A4	c) Other timber
Attachment.shp	Q5	Support material (poles)	ATTQ1A4	d) Timber (unknown)
Attachment.shp	Q5	Support material (poles)	ATTQ1A4	e) No timber support poles
Attachment.shp	Q5	Support material (poles)	ATTQ1A4	f) Unknown
Attachment.shp	Q5	Support material (poles)	ATTQ1A4	g) Steel
Attachment.shp	Q5	Support material (poles)	ATTQ1A4	h) Concrete
Attachment.shp	Q6	Timber Support Poles Ground Interface	ATTQ1A5	a) Ground contact
Attachment.shp	Q6	Timber Support Poles Ground Interface	ATTQ1A5	b) Ground contact

Layer	Caption	Question	Field	Answer
Attachment.shp	Q6	Timber Support Poles Ground Interface	ATTQ1A5	c) No ground contact
Attachment.shp	Q6	Timber Support Poles Ground Interface	ATTQ1A5	d) No timber support poles
Attachment.shp	Q6	Timber Support Poles Ground Interface	ATTQ1A5	e) Unknown
Attachment.shp	Q7	Supporting beams material	ATTQ1A6	a) Treated pine
Attachment.shp	Q7	Supporting beams material	ATTQ1A6	b) Red gum
Attachment.shp	Q7	Supporting beams material	ATTQ1A6	c) Other timber
Attachment.shp	Q7	Supporting beams material	ATTQ1A6	d) Timber (unknown)
Attachment.shp	Q7	Supporting beams material	ATTQ1A6	e) No timber support poles
Attachment.shp	Q7	Supporting beams material	ATTQ1A6	f) Unknown
Attachment.shp	Q7	Supporting beams material	ATTQ1A6	g) Steel
Attachment.shp	Q7	Supporting beams material	ATTQ1A6	h) Concrete
Attachment.shp	Q8	Smallest distance from edge of deck to ground	ATTQ1A7	a) Less than 0.6m
Attachment.shp	Q8	Smallest distance from edge of deck to ground	ATTQ1A7	b) 0.6m to 1.6m
Attachment.shp	Q8	Smallest distance from edge of deck to ground	ATTQ1A7	c) Greater than 1.6m
Attachment.shp	Q8	Smallest distance from edge of deck to ground	ATTQ1A7	d) Unknown
Attachment.shp	Q9	Damage description	ATTQ1A8	a) Undamaged
Attachment.shp	Q9	Damage description	ATTQ1A8	b) Some isolated scorching
Attachment.shp	Q9	Damage description	ATTQ1A8	c) Partially burnt
Attachment.shp	Q9	Damage description	ATTQ1A8	d) Mostly burnt
Attachment.shp	Q9	Damage description	ATTQ1A8	e) Other
Attachment.shp	Q10	Are stairs(more then 3 stairs) attached to the deck?	ATTQ1A9	a) Yes
Attachment.shp	Q10	Are stairs(more then 3 stairs) attached to the deck?	ATTQ1A9	b) No
Attachment.shp	Q10	Are stairs(more then 3 stairs) attached to the deck?	ATTQ1A9	c) Unknown
Attachment.shp	Q12	Material of treads (What you stand on)	ATTQ1B2	a) Treated Pine
Attachment.shp	Q12	Material of treads (What you stand on)	ATTQ1B2	b) Red Gum
Attachment.shp	Q12	Material of treads (What you stand on)	ATTQ1B2	c) Other (please comment)
Attachment.shp	Q12	Material of treads (What you stand on)	ATTQ1B2	d) Unknown
Attachment.shp	Q12	Material of treads (What you stand on)	ATTQ1B2	e) Non-Cumbustible
Attachment.shp	Q14	Material of strings?	ATTQ1B4	a) Treated Pine
Attachment.shp	Q14	Material of strings?	ATTQ1B4	b) Red Gum
Attachment.shp	Q14	Material of strings?	ATTQ1B4	c) Other (please comment)

Layer	Caption	Question	Field	Answer
Attachment.shp	Q14	Material of strings?	ATTQ1B4	d) Unknown
Attachment.shp	Q14	Material of strings?	ATTQ1B4	e) Non-Cumbustible
Attachment.shp	Q15	Damage description	ATTQ1B5	a) Undamaged
Attachment.shp	Q15	Damage description	ATTQ1B5	b) Some isolated scorching
Attachment.shp	Q15	Damage description	ATTQ1B5	c) Partially burnt
Attachment.shp	Q15	Damage description	ATTQ1B5	d) Mostly burnt
Attachment.shp	Q15	Damage description	ATTQ1B5	e) Other

#### Layer type of barrier detailed

Layer	Caption	Question	Field	Answer
Barrier.shp	Q1	Barrier type	BARQ1	a) Solid fence
Barrier.shp	Q1	Barrier type	BARQ1	b) Slatted fence
Barrier.shp	Q1	Barrier type	BARQ1	c) Retaining wall
Barrier.shp	Q2	Approximate height in metres	No Field	No Answer
Barrier.shp	Q3	Material	BARQ3	a) Brick
Barrier.shp	Q3	Material	BARQ3	b) Metal panel
Barrier.shp	Q3	Material	BARQ3	c) Cement sheet profile
Barrier.shp	Q3	Material	BARQ3	d) Treated pine
Barrier.shp	Q3	Material	BARQ3	e) Timber – other
Barrier.shp	Q3	Material	BARQ3	f) Other
Barrier.shp	Q3	Material	BARQ3	g) None
Barrier.shp	Q3	Material	BARQ3	h) Unknown
Barrier.shp	Q4	Damage	BARQ3D1	a) Undamaged
Barrier.shp	Q4	Damage	BARQ3D1	b) Some isolated scorching
Barrier.shp	Q4	Damage	BARQ3D1	c) Partially burnt
Barrier.shp	Q4	Damage	BARQ3D1	d) Mostly burnt
Barrier.shp	Q4	Damage	BARQ3D1	e) Other

## Layer type of combustible detailed

Layer	Caption	Question	Field	Answer
Combustible.shp	Q1	Type of combustible	COMQ1	a) Gas Bottle
Combustible.shp	Q1	Type of combustible	COMQ1	b) Wood Heap
Combustible.shp	Q1	Type of combustible	COMQ1	c) Building Material
Combustible.shp	Q1	Type of combustible	COMQ1	d) Dustbin
Combustible.shp	Q1	Type of combustible	COMQ1	e) External LPG Cylinder
Combustible.shp	Q1	Type of combustible	COMQ1	f) Car
Combustible.shp	Q1	Type of combustible	COMQ1	g) Boat
Combustible.shp	Q1	Type of combustible	COMQ1	h) Stock feed
Combustible.shp	Q1	Type of combustible	COMQ1	i) Other
Combustible.shp	Q2	Support description	COMQ1A1	a) Freestanding
Combustible.shp	Q2	Support description	COMQ1A1	b) Secured
Combustible.shp	Q2	Support description	COMQ1A1	c) Unknown
Combustible.shp	Q3	Damaged?	COMQ2	a)Yes
Combustible.shp	Q3	Damaged?	COMQ2	b)No
Combustible.shp	Q4	Behaviour	COMQ3	a) Undamaged
Combustible.shp	Q4	Behaviour	COMQ3	b) Heat Affected – venting unknown
Combustible.shp	Q4	Behaviour	COMQ3	c) Heat Affected – vented
Combustible.shp	Q4	Behaviour	COMQ3	d) Heat Affected – not vented
Combustible.shp	Q4	Behaviour	COMQ3	e) Split
Combustible.shp	Q4	Behaviour	COMQ3	f) Bottle Condition Unknown
Combustible.shp	Q4	Behaviour	COMQ3	g) Other
Combustible.shp	Q4	Behaviour	COMQ3	h) Not Applicable
Combustible.shp	Q4	Behaviour	COMQ3	i) Unknown
Combustible.shp	Q5	Location description	COMQ4	a) Beside structure
Combustible.shp	Q5	Location description	COMQ4	b) Under structure
Combustible.shp	Q5	Location description	COMQ4	c) Within carport
Combustible.shp	Q5	Location description	COMQ4	d) Within garage
Combustible.shp	Q5	Location description	COMQ4	e) Remote from structure (less than 6m)
Combustible.shp	Q5	Location description	COMQ4	f) Remote from structure (greater than 6m)
Combustible.shp	Q5	Location description	COMQ4	g) Other (please comment)
Combustible.shp	Q5	Location description	COMQ4	h) Unknown
Combustible.shp	Q6	Damage description	COMQ5	a) Undamaged
Combustible.shp	Q6	Damage description	COMQ5	b) Some isolated scorching

Layer	Caption	Question	Field	Answer
Combustible.shp	Q6	Damage description	COMQ5	c) Partially burnt
Combustible.shp	Q6	Damage description	COMQ5	d) Mostly burnt
Combustible.shp	Q6	Damage description	COMQ5	e) Unknown
Combustible.shp	Q7	Damage description	COMQ1G1	a) Plastic
Combustible.shp	Q7	Damage description	COMQ1G1	b) Fibreglass
Combustible.shp	Q7	Damage description	COMQ1G1	c) Timber

#### Layer Type of ground cover detailed

Layer	Caption	Question	Field	Answer
Combustible.shp	Finish	null	No Field	No Answer
GroundCover.shp	Q1	Is the ground cover combustible?	GNDQ1	a) Yes
GroundCover.shp	Q1	Is the ground cover combustible?	GNDQ1	b) No
GroundCover.shp	Q2	Type of ground cover	GNDQ2	a) Grasslands
GroundCover.shp	Q2	Type of ground cover	GNDQ2	b) Garden mulch
GroundCover.shp	Q2	Type of ground cover	GNDQ2	c) Bark
GroundCover.shp	Q2	Type of ground cover	GNDQ2	d) Short heath
GroundCover.shp	Q2	Type of ground cover	GNDQ2	e) Tall heath
GroundCover.shp	Q2	Type of ground cover	GNDQ2	f) Other
GroundCover.shp	Q2	Type of ground cover	GNDQ2	g) Unknown
GroundCover.shp	Q3	Attack Mechanism	GNDQ3	a) Embers only
GroundCover.shp	Q3	Attack Mechanism	GNDQ3	b) Embers and some radiant heat
GroundCover.shp	Q3	Attack Mechanism	GNDQ3	c) Predominant radiant heat
GroundCover.shp	Q3	Attack Mechanism	GNDQ3	d) Flame contact from bush
GroundCover.shp	Q3	Attack Mechanism	GNDQ3	e) Other (please comment)
GroundCover.shp	Q3	Attack Mechanism	GNDQ3	f) No direct bushfire attack
GroundCover.shp	Q3	Attack Mechanism	GNDQ3	g) Unknown
GroundCover.shp	Q4	Damage	GNDQ4	a) Undamaged
GroundCover.shp	Q4	Damage	GNDQ4	b) Some isolated burnt patches
GroundCover.shp	Q4	Damage	GNDQ4	c) Partially burnt
GroundCover.shp	Q4	Damage	GNDQ4	d) Mostly burnt
GroundCover.shp	Q4	Damage	GNDQ4	e) Other
GroundCover.shp	Q5	Is this fuel layer immediately adjacent to a habitable dwelling?	GNDQ5	a) Yes
GroundCover.shp	Q5	Is this fuel layer immediately adjacent to a habitable dwelling?	GNDQ5	b) No

### Layer type of outbuilding detailed

Layer	Caption	Question	Field	Answer
Outbuilding.shp	Q1	Is the outbuilding attached to a habitable structure (not sharing common roof)	OUTQ1	a) Yes
Outbuilding.shp	Q1	Is the outbuilding attached to a habitable structure (not sharing common roof)	OUTQ1	b) No
Outbuilding.shp	Q2	Function of Outbuilding	OUTQ2	a) Garage
Outbuilding.shp	Q2	Function of Outbuilding	OUTQ2	b) Carport
Outbuilding.shp	Q2	Function of Outbuilding	OUTQ2	c) Laundry
Outbuilding.shp	Q2	Function of Outbuilding	OUTQ2	d) Storage shed
Outbuilding.shp	Q2	Function of Outbuilding	OUTQ2	e) Barn
Outbuilding.shp	Q2	Function of Outbuilding	OUTQ2	f) Other
Outbuilding.shp	Q3	Damage	OUTQ3	a) Untouched
Outbuilding.shp	Q3	Damage	OUTQ3	b) Superficial
Outbuilding.shp	Q3	Damage	OUTQ3	c) Light damage
Outbuilding.shp	Q3	Damage	OUTQ3	d) Medium damage
Outbuilding.shp	Q3	Damage	OUTQ3	e) Heavy damage
Outbuilding.shp	Q3	Damage	OUTQ3	f) Destroyed
Outbuilding.shp	Q3	Damage	OUTQ3	g) Other
Outbuilding.shp	Q3	Damage	OUTQ3	h) Unknown
Outbuilding.shp	Q4	External Wall Material	OUTQ4	a) Timber
Outbuilding.shp	Q4	External Wall Material	OUTQ4	b) Iron
Outbuilding.shp	Q4	External Wall Material	OUTQ4	c) Aluminium
Outbuilding.shp	Q4	External Wall Material	OUTQ4	d) Cement fibre
Outbuilding.shp	Q4	External Wall Material	OUTQ4	e) Brick
Outbuilding.shp	Q4	External Wall Material	OUTQ4	f) Other
Outbuilding.shp	Q4	External Wall Material	OUTQ4	g) Not applicable
Outbuilding.shp	Q4	External Wall Material	OUTQ4	h) Unknown
Outbuilding.shp	Q5	Material of Roof	OUTQ5	a) Steel
Outbuilding.shp	Q5	Material of Roof	OUTQ5	b) Aluminium
Outbuilding.shp	Q5	Material of Roof	OUTQ5	c) Cement fibre
Outbuilding.shp	Q5	Material of Roof	OUTQ5	d) Other
Outbuilding.shp	Q5	Material of Roof	OUTQ5	e) Not applicable
Outbuilding.shp	Q5	Material of Roof	OUTQ5	f) Unknown
Outbuilding.shp	Q6	Bushfire Attack Mechanism	OUTQ6	a) Embers only

Layer	Caption	Question	Field	Answer
Outbuilding.shp	Q6	Bushfire Attack Mechanism	OUTQ6	b) Embers and some radiant heat
Outbuilding.shp	Q6	Bushfire Attack Mechanism	OUTQ6	c) Predominant radiant heat
Outbuilding.shp	Q6	Bushfire Attack Mechanism	OUTQ6	d) Flame contact from bush
Outbuilding.shp	Q6	Bushfire Attack Mechanism	OUTQ6	e) Other
Outbuilding.shp	Q6	Bushfire Attack Mechanism	OUTQ6	f) No direct bushfire attack
Outbuilding.shp	Q6	Bushfire Attack Mechanism	OUTQ6	g) Unknown
Outbuilding.shp	Q7	Is there any evidence of outbuilding defence using water?	OUTQ7	a) Yes
Outbuilding.shp	Q7	Is there any evidence of outbuilding defence using water?	OUTQ7	b) No
Outbuilding.shp	Q8	Was water provided by:	OUTQ7B1	a) Mains only
Outbuilding.shp	Q8	Was water provided by:	OUTQ7B1	b) Pump and secondary water source
Outbuilding.shp	Q8	Was water provided by:	OUTQ7B1	c) Secondary water source – gravity (no pump)
Outbuilding.shp	Q9	Water apparatus used	OUTQ7B2	a) Hoses only
Outbuilding.shp	Q9	Water apparatus used	OUTQ7B2	b) Formal spray system
Outbuilding.shp	Q9	Water apparatus used	OUTQ7B2	c) Other (please comment)
Outbuilding.shp	Q10	Formal spray system location	OUTQ7B3	a) Internal
Outbuilding.shp	Q10	Formal spray system location	OUTQ7B3	b) External
Outbuilding.shp	Q10	Formal spray system location	OUTQ7B3	c) Both
Outbuilding.shp	Q11	Spray location details	OUTQ7B4	a) On outbuilding
Outbuilding.shp	Q11	Spray location details	OUTQ7B4	b) In garden
Outbuilding.shp	Q11	Spray location details	OUTQ7B4	c) Both
Outbuilding.shp	Q12	Outbuilding spray location details	OUTQ7B5	a) On roof
Outbuilding.shp	Q12	Outbuilding spray location details	OUTQ7B5	b) On walls
Outbuilding.shp	Q12	Outbuilding spray location details	OUTQ7B5	c) Both

#### Layer Type of sprinkler detailed

Layer	Caption	Question	Field	Answer
Sprinkler.shp	Q1	What is the direction of the sprinkler spray?	SPRQ1	a) Towards house
Sprinkler.shp	Q1	What is the direction of the sprinkler spray?	SPRQ1	b) Away from house
Sprinkler.shp	Q1	What is the direction of the sprinkler spray?	SPRQ1	c) Both
Sprinkler.shp	Q1	What is the direction of the sprinkler spray?	SPRQ1	d) Unknown
Sprinkler.shp	Q2	What is the type of sprinkler spray?	SPRQ2	a) Chopper
Sprinkler.shp	Q2	What is the type of sprinkler spray?	SPRQ2	b) Misting
Sprinkler.shp	Q2	What is the type of sprinkler spray?	SPRQ2	c) Spraying
Sprinkler.shp	Q2	What is the type of sprinkler spray?	SPRQ2	d) Mixed

Layer	Caption	Question	Field	Answer
Sprinkler.shp	Q2	What is the type of sprinkler spray?	SPRQ2	e) Other
Sprinkler.shp	Q2	What is the type of sprinkler spray?	SPRQ2	f) Unknown
Sprinkler.shp	Q3	Is the sprinkler thermally activated?	SPRQ3	a) All
Sprinkler.shp	Q3	Is the sprinkler thermally activated?	SPRQ3	b) None
Sprinkler.shp	Q3	Is the sprinkler thermally activated?	SPRQ3	c) Some
Sprinkler.shp	Q3	Is the sprinkler thermally activated?	SPRQ3	d) Unknown

#### Layer structure detailed

Layer	Caption	Question	Field	Answer
Structure.shp	Q1	Most appropriate access for fire vehicles via ...	Q1	a)Perimeter Road
Structure.shp	Q1	Most appropriate access for fire vehicles via ...	Q1	b)Perimeter Fire Trial
Structure.shp	Q1	Most appropriate access for fire vehicles via ...	Q1	c)Perimeter Fire Break
Structure.shp	Q1	Most appropriate access for fire vehicles via ...	Q1	d)Battleaxe Lot
Structure.shp	Q1	Most appropriate access for fire vehicles via ...	Q1	e)Other
Structure.shp	Q1	Most appropriate access for fire vehicles via ...	Q1	f)Unknown
Structure.shp	Q2	House Condition	Q2	a)House survived
Structure.shp	Q2	House Condition	Q2	b)House destroyed
Structure.shp	Q2	House Condition	Q2	c)House destroyed
Structure.shp	Q3	Degree of Damage	Q3	a)Untouched
Structure.shp	Q3	Degree of Damage	Q3	b)Superficial
Structure.shp	Q3	Degree of Damage	Q3	c)Light Damage
Structure.shp	Q3	Degree of Damage	Q3	d)Medium Damage
Structure.shp	Q3	Degree of Damage	Q3	d)Heavy Damage
Structure.shp	Q3	Degree of Damage	Q3	d)Destroyed
Structure.shp	Q3	Degree of Damage	Q3	e)Other
Structure.shp	Q3	Degree of Damage	Q3	f)Untouched
Structure.shp	Q3	Degree of Damage	Q3	g)Unknown
Structure.shp	Q4	Cause of damage to house - Please select unknown if at all uncertain	Q4	a)Fire only
Structure.shp	Q4	Cause of damage to house - Please select unknown if at all uncertain	Q4	b)Wind only
Structure.shp	Q4	Cause of damage to house - Please select unknown if at all uncertain	Q4	c)Fire and wind
Structure.shp	Q4	Cause of damage to house - Please select unknown if at all uncertain	Q4	d)Fire damage



Layer	Caption	Question	Field	Answer
Structure.shp	Q4	Cause of damage to house - Please select unknown if at all uncertain	Q4	e)Other
Structure.shp	Q4	Cause of damage to house - Please select unknown if at all uncertain	Q4	f)Untouched
Structure.shp	Q4	Cause of damage to house - Please select unknown if at all uncertain	Q4	g)Unknown
Structure.shp	Q5	Greatest distance from edge of floor to ground	Q5	a)0m (Slab on ground)
Structure.shp	Q5	Greatest distance from edge of floor to ground	Q5	b)< 0.6m
Structure.shp	Q5	Greatest distance from edge of floor to ground	Q5	c)0.6m to 1.6m
Structure.shp	Q5	Greatest distance from edge of floor to ground	Q5	d)> 1.6m
Structure.shp	Q5	Greatest distance from edge of floor to ground	Q5	e)Unknown
Structure.shp	Q6	Smallest distance from edge of floor to ground	Q6	a)Contacting ground
Structure.shp	Q6	Smallest distance from edge of floor to ground	Q6	b)Less then 600 mm
Structure.shp	Q6	Smallest distance from edge of floor to ground	Q6	c)600 mm to 1.6 m
Structure.shp	Q6	Smallest distance from edge of floor to ground	Q6	d)Greater then 1.6 m
Structure.shp	Q6	Smallest distance from edge of floor to ground	Q6	e)Unknown
Structure.shp	Q7	Main material of posts supporting floors	Q7	a)Treated pine
Structure.shp	Q7	Main material of posts supporting floors	Q7	b)Other timbers
Structure.shp	Q7	Main material of posts supporting floors	Q7	c)Concrete stumps
Structure.shp	Q7	Main material of posts supporting floors	Q7	d)Steel posts
Structure.shp	Q7	Main material of posts supporting floors	Q7	e)Brick piers
Structure.shp	Q7	Main material of posts supporting floors	Q7	f)Other
Structure.shp	Q7	Main material of posts supporting floors	Q7	g)Slab on ground
Structure.shp	Q7	Main material of posts supporting floors	Q7	h)Unknown
Structure.shp	Q8	Material used to enclose underfloor	Q8	a)Stump battens
Structure.shp	Q8	Material used to enclose underfloor	Q8	b)Cement sheet
Structure.shp	Q8	Material used to enclose underfloor	Q8	c)Brick
Structure.shp	Q8	Material used to enclose underfloor	Q8	d)Concrete
Structure.shp	Q8	Material used to enclose underfloor	Q8	e)Not enclosed
Structure.shp	Q8	Material used to enclose underfloor	Q8	f)Other
Structure.shp	Q8	Material used to enclose underfloor	Q8	g)Slab
Structure.shp	Q8	Material used to enclose underfloor	Q8	h)Unknown
Structure.shp	Q9	Accessibility for fire crews during fire	Q9	a)Accessible
Structure.shp	Q9	Accessibility for fire crews during fire	Q9	b)Cut off
Structure.shp	Q9	Accessibility for fire crews during fire	Q9	c)Unknown

Layer	Caption	Question	Field	Answer
Structure.shp	Q9	Accessibility for fire crews during fire	Q9	d)Other
Structure.shp	Q10	Standard of maintenance	Q10	a)Well Maintained
Structure.shp	Q10	Standard of maintenance	Q10	b)Poorly Maintained
Structure.shp	Q10	Standard of maintenance	Q10	c)Other
Structure.shp	Q10	Standard of maintenance	Q10	d)Unknown
Structure.shp	Q11	Provision of electrical services	Q11	a)Above Ground
Structure.shp	Q11	Provision of electrical services	Q11	b)Below Ground
Structure.shp	Q11	Provision of electrical services	Q11	c)Other
Structure.shp	Q11	Provision of electrical services	Q11	d)Unknown
Structure.shp	Q12	Is there Overhanging Foliage	Q12	a)Many overhanging trees
Structure.shp	Q12	Is there Overhanging Foliage	Q12	b)Some overhanging trees
Structure.shp	Q12	Is there Overhanging Foliage	Q12	c)Trees against house
Structure.shp	Q12	Is there Overhanging Foliage	Q12	d)Bushes against house
Structure.shp	Q12	Is there Overhanging Foliage	Q12	e)Trees and/or bushes against house
Structure.shp	Q12	Is there Overhanging Foliage	Q12	f)No predominant vegetation adjacent to house
Structure.shp	Q12	Is there Overhanging Foliage	Q12	g)Unknown
Structure.shp	Q13	Is there a garage under the common roof of the structure?	Q13	a) Yes
Structure.shp	Q13	Is there a garage under the common roof of the structure?	Q13	b) No
Structure.shp	Q13	Is there a garage under the common roof of the structure?	Q13	c) Unknown
Structure.shp	Q13_1	Is the garage ember proof gaps (greater than 2mm)?	Q13_1	a) Yes
Structure.shp	Q13_1	Is the garage ember proof gaps (greater than 2mm)?	Q13_1	b) No
Structure.shp	Q13_1	Is the garage ember proof gaps (greater than 2mm)?	Q13_1	c) Unknown
Structure.shp	Q14	Is there a carport under the common roof of the structure?	Q14	a) Yes
Structure.shp	Q14	Is there a carport under the common roof of the structure?	Q14	b) No
Structure.shp	Q14	Is there a carport under the common roof of the structure?	Q14	c) Unknown
Structure.shp	Q15	Is there any evidence of structure defence using water?	Q15	a) Yes
Structure.shp	Q15	Is there any evidence of structure defence using water?	Q15	b) No
Structure.shp	Q15_1	Water provision	Q15_1	a) Mains only
Structure.shp	Q15_1	Water provision	Q15_1	b) Pump and secondary water source

Layer	Caption	Question	Field	Answer
Structure.shp	Q15_1	Water provision	Q15_1	c) Secondary water source - gravity
Structure.shp	Q15_2	Type of apparatus	Q15_2	a) Hoses only
Structure.shp	Q15_2	Type of apparatus	Q15_2	b) Formal spray system
Structure.shp	Q15_2	Type of apparatus	Q15_2	c) Other
Structure.shp	Q15_2_1	Location of the formal spray system	Q15_2_1	a) Internal
Structure.shp	Q15_2_1	Location of the formal spray system	Q15_2_1	b) External
Structure.shp	Q15_2_1	Location of the formal spray system	Q15_2_1	c) Both
Structure.shp	Q15_2_1_1	Spray location	Q15_2_1_1	a) On house
Structure.shp	Q15_2_1_1	Spray location	Q15_2_1_1	b) In garden
Structure.shp	Q15_2_1_1	Spray location	Q15_2_1_1	c) Both
Structure.shp	Q15_2_1_1_1	Spray location	Q15_2111	a) On roof
Structure.shp	Q15_2_1_1_1	Spray location	Q15_2111	b) On walls
Structure.shp	Q15_2_1_1_1	Spray location	Q15_2111	c) Both
Structure.shp	Q15_2_1_2	Spray type	Q15_2_1_2	a) Chopper
Structure.shp	Q15_2_1_2	Spray type	Q15_2_1_2	b) Misting
Structure.shp	Q15_2_1_2	Spray type	Q15_2_1_2	c) Spraying
Structure.shp	Q15_2_1_2	Spray type	Q15_2_1_2	d) Mixed
Structure.shp	Q15_2_1_2	Spray type	Q15_2_1_2	e) Other
Structure.shp	Q15_2_1_2	Spray type	Q15_2_1_2	f) Unknown
Structure.shp	Q15_2_2	Thermally activated	Q15_2_2	a) All
Structure.shp	Q15_2_2	Thermally activated	Q15_2_2	b) None
Structure.shp	Q15_2_2	Thermally activated	Q15_2_2	c) Some
Structure.shp	Q16	Occupant account of house design provided?	Q16	a) Yes
Structure.shp	Q16	Occupant account of house design provided?	Q16	b) No
Structure.shp	Q17	Number of functional levels	Q17	a)One level
Structure.shp	Q17	Number of functional levels	Q17	b)Split single level
Structure.shp	Q17	Number of functional levels	Q17	c)Two levels
Structure.shp	Q17	Number of functional levels	Q17	d)More than two full levels
Structure.shp	Q17	Number of functional levels	Q17	e)Other
Structure.shp	Q17	Number of functional levels	Q17	f)Unknown
Structure.shp	Q18	Predominant roof material	Q18	a)Metal deck
Structure.shp	Q18	Predominant roof material	Q18	b)Corrugated iron
Structure.shp	Q18	Predominant roof material	Q18	c)Corrugated cement sheet

Layer	Caption	Question	Field	Answer
Structure.shp	Q18	Predominant roof material	Q18	d) Tiles (terracotta
Structure.shp	Q18	Predominant roof material	Q18	e) Metal pseudo tiles
Structure.shp	Q18	Predominant roof material	Q18	f) Other
Structure.shp	Q18	Predominant roof material	Q18	g) Unknown
Structure.shp	Q19	Roof Profile	Q19	a) One slope
Structure.shp	Q19	Roof Profile	Q19	b) One ridge
Structure.shp	Q19	Roof Profile	Q19	c) One valley
Structure.shp	Q19	Roof Profile	Q19	d) Complex ridge
Structure.shp	Q19	Roof Profile	Q19	e) Other
Structure.shp	Q19	Roof Profile	Q19	f) Unknown
Structure.shp	Q20	External wall material (Major Portion of House-Broad Classification)	Q20	a) Timber
Structure.shp	Q20	External wall material (Major Portion of House-Broad Classification)	Q20	b) Cellulose cement
Structure.shp	Q20	External wall material (Major Portion of House-Broad Classification)	Q20	c) Brick (other than mud brick)
Structure.shp	Q20	External wall material (Major Portion of House-Broad Classification)	Q20	d) Mud brick
Structure.shp	Q20	External wall material (Major Portion of House-Broad Classification)	Q20	e) Aluminium siding
Structure.shp	Q20	External wall material (Major Portion of House-Broad Classification)	Q20	f) PVC siding
Structure.shp	Q20	External wall material (Major Portion of House-Broad Classification)	Q20	g) Other
Structure.shp	Q20	External wall material (Major Portion of House-Broad Classification)	Q20	h) Unknown
Structure.shp	Q21	External wall material (Major Portion of House-Narrow Classification)	Q21	i) Smooth weatherboard (painted)
Structure.shp	Q21	External wall material (Major Portion of House-Narrow Classification)	Q21	ii) Rough-sawn weatherboard
Structure.shp	Q21	External wall material (Major Portion of House-Narrow Classification)	Q21	iii) Treated pine logs
Structure.shp	Q21	External wall material (Major Portion of House-Narrow Classification)	Q21	iv) Other timber
Structure.shp	Q22	External wall material (Major Portion of House-Narrower Classification)	Q22	i) Cellulose cement flat sheets
Structure.shp	Q22	External wall material (Major Portion of House-Narrower Classification)	Q22	ii) Cement planks
Structure.shp	Q22	External wall material (Major Portion of House-Narrower Classification)	Q22	iii) Other
Structure.shp	Q22	External wall material (Major Portion of House-Narrower Classification)	Q22	iv) Unknown
Structure.shp	Q23	External wall material (Minor Portion of House-Broad Classification)	Q23	a) Timber
Structure.shp	Q23	External wall material (Minor Portion of House-Broad Classification)	Q23	b) Cellulose cement
Structure.shp	Q23	External wall material (Minor Portion of House-Broad Classification)	Q23	c) Brick (other than mud brick)
Structure.shp	Q23	External wall material (Minor Portion of House-Broad Classification)	Q23	d) Mud brick
Structure.shp	Q23	External wall material (Minor Portion of House-Broad Classification)	Q23	e) Aluminium siding

Layer	Caption	Question	Field	Answer
Structure.shp	Q23	External wall material (Minor Portion of House-Broad Classification)	Q23	f)PVC siding
Structure.shp	Q23	External wall material (Minor Portion of House-Broad Classification)	Q23	g) Other
Structure.shp	Q23	External wall material (Minor Portion of House-Broad Classification)	Q23	h)Unknown
Structure.shp	Q24	External wall material (Minor Portion of House- Narrower Classification)	Q24	i)Smooth weatherboard (painted)
Structure.shp	Q24	External wall material (Minor Portion of House- Narrower Classification)	Q24	ii)Rough-sawn weatherboard
Structure.shp	Q24	External wall material (Minor Portion of House- Narrower Classification)	Q24	iii)Treated pine logs
Structure.shp	Q24	External wall material (Minor Portion of House- Narrower Classification)	Q24	iv)Other timber
Structure.shp	Q25	External wall material (Minor Portion of House- Narrower Classification)	Q25	i)Cellulose cement flat sheets
Structure.shp	Q25	External wall material (Minor Portion of House- Narrower Classification)	Q25	ii)Cement planks
Structure.shp	Q25	External wall material (Minor Portion of House- Narrower Classification)	Q25	iii) Other
Structure.shp	Q25	External wall material (Minor Portion of House- Narrower Classification)	Q25	iv)Unknown
Structure.shp	Q26	Is there evidence of a bushfire attack mechanism	Q26	a) Embers only
Structure.shp	Q26	Is there evidence of a bushfire attack mechanism	Q26	b) Embers and some radiant heat
Structure.shp	Q26	Is there evidence of a bushfire attack mechanism	Q26	c) Predominant radiant heat
Structure.shp	Q26	Is there evidence of a bushfire attack mechanism	Q26	d) Flame contact from bush
Structure.shp	Q26	Is there evidence of a bushfire attack mechanism	Q26	e) Other (please comment)
Structure.shp	Q26	Is there evidence of a bushfire attack mechanism	Q26	f) No direct bushfire attack
Structure.shp	Q26	Is there evidence of a bushfire attack mechanism	Q26	g) Unknown
Structure.shp	Q27	Is there any indication of elevated fuels 0.5 to 3m high linking the house to wider vegetation within 50m of the property boundary	Q27	a) Yes
Structure.shp	Q27	Is there any indication of elevated fuels 0.5 to 3m high linking the house to wider vegetation within 50m of the property boundary	Q27	b) No
Structure.shp	Q27	Is there any indication of elevated fuels 0.5 to 3m high linking the house to wider vegetation within 50m of the property boundary	Q27	c) Unknown/Vegetation Burnt

### Layer type of structure opening detailed

Layer	Caption	Question	Field	Answer
StructureOpening.shp	Q1	Opening Type	STOQ1	a) Window
StructureOpening.shp	Q1	Opening Type	STOQ1	b) Door
StructureOpening.shp	Q1	Opening Type	STOQ1	c) Vent
StructureOpening.shp	Q1	Opening Type	STOQ1	d) Skylight
StructureOpening.shp	Q2	Window frame materials	STOQ1A1	a) Aluminium
StructureOpening.shp	Q2	Window frame materials	STOQ1A1	b) Timber
StructureOpening.shp	Q2	Window frame materials	STOQ1A1	c) Steel
StructureOpening.shp	Q2	Window frame materials	STOQ1A1	d) Mixed aluminium/timber
StructureOpening.shp	Q2	Window frame materials	STOQ1A1	e) Other mixed
StructureOpening.shp	Q2	Window frame materials	STOQ1A1	f) Other
StructureOpening.shp	Q2	Window frame materials	STOQ1A1	g) Unknown
StructureOpening.shp	Q3	Type of Glass	STOQ1A2	a) Toughened
StructureOpening.shp	Q3	Type of Glass	STOQ1A2	b) Laminated
StructureOpening.shp	Q3	Type of Glass	STOQ1A2	c) Plain
StructureOpening.shp	Q3	Type of Glass	STOQ1A2	d) Other (please comment)
StructureOpening.shp	Q3	Type of Glass	STOQ1A2	e) Unknown
StructureOpening.shp	Q4	Double Glazing?	STOQ1A3	a) Yes
StructureOpening.shp	Q4	Double Glazing?	STOQ1A3	b) No
StructureOpening.shp	Q4	Double Glazing?	STOQ1A3	c) Unknown
StructureOpening.shp	Q5	Glazing damage	STOQ1A4	a) Glass cracked in place
StructureOpening.shp	Q5	Glazing damage	STOQ1A4	b) Glass fallen mainly inside
StructureOpening.shp	Q5	Glazing damage	STOQ1A4	c) Glass fallen mainly outside
StructureOpening.shp	Q5	Glazing damage	STOQ1A4	d) Glass fallen mainly inside
StructureOpening.shp	Q5	Glazing damage	STOQ1A4	e) Glass fallen mainly outside
StructureOpening.shp	Q5	Glazing damage	STOQ1A4	f) Glass intact
StructureOpening.shp	Q5	Glazing damage	STOQ1A4	g) Other (Please comment)
StructureOpening.shp	Q5	Glazing damage	STOQ1A4	h) Unknown
StructureOpening.shp	Q6	Bushfire attack mechanism on window system	STOQ1A5	a)Embers only
StructureOpening.shp	Q6	Bushfire attack mechanism on window system	STOQ1A5	b)Embers and some radiant heat
StructureOpening.shp	Q6	Bushfire attack mechanism on window system	STOQ1A5	c)Predominant radiant heat
StructureOpening.shp	Q6	Bushfire attack mechanism on window system	STOQ1A5	d)Flame contact from bush
StructureOpening.shp	Q6	Bushfire attack mechanism on window system	STOQ1A5	e)Other

Layer	Caption	Question	Field	Answer
StructureOpening.shp	Q6	Bushfire attack mechanism on window system	STOQ1A5	f) No direct bushfire attack
StructureOpening.shp	Q6	Bushfire attack mechanism on window system	STOQ1A5	g)Unknown
StructureOpening.shp	Q7	Protection of window panes	STOQ1A6	a) Protected fully
StructureOpening.shp	Q7	Protection of window panes	STOQ1A6	b) Opening sash protected only
StructureOpening.shp	Q7	Protection of window panes	STOQ1A6	c) Not Protected
StructureOpening.shp	Q8	Protection of Openings - Protection Material	STOQ1A7	a) Metal flywire (less than 2mm aperture)
StructureOpening.shp	Q8	Protection of Openings - Protection Material	STOQ1A7	b) Fibreglass flywire (less than 2mm aperture)
StructureOpening.shp	Q8	Protection of Openings - Protection Material	STOQ1A7	c) Flywire (unknown
StructureOpening.shp	Q8	Protection of Openings - Protection Material	STOQ1A7	d) Metal grid (greater than 2mm aperture)
StructureOpening.shp	Q8	Protection of Openings - Protection Material	STOQ1A7	c) No Flywire/Grid Panels
StructureOpening.shp	Q9	Window screen position	STOQ1A8	a) Outside
StructureOpening.shp	Q9	Window screen position	STOQ1A8	b) Inside
StructureOpening.shp	Q9	Window screen position	STOQ1A8	c) Outside and inside
StructureOpening.shp	Q9	Window screen position	STOQ1A8	d) Unknown
StructureOpening.shp	Q10	Window shutters	STOQ1A9	a) Roller shutters
StructureOpening.shp	Q10	Window shutters	STOQ1A9	b) Aluminium awnings
StructureOpening.shp	Q10	Window shutters	STOQ1A9	c) Other
StructureOpening.shp	Q10	Window shutters	STOQ1A9	d) None
StructureOpening.shp	Q10	Window shutters	STOQ1A9	e) Unknown
StructureOpening.shp	Q11	Door frame material	STOQ1B1	a) Aluminium
StructureOpening.shp	Q11	Door frame material	STOQ1B1	b) Timber
StructureOpening.shp	Q11	Door frame material	STOQ1B1	c) Steel
StructureOpening.shp	Q11	Door frame material	STOQ1B1	d) Mixed aluminium/timber
StructureOpening.shp	Q11	Door frame material	STOQ1B1	e) Other mixed
StructureOpening.shp	Q11	Door frame material	STOQ1B1	f) Other (please comment)
StructureOpening.shp	Q11	Door frame material	STOQ1B1	g) Unknown
StructureOpening.shp	Q12	Door material	STOQ1B2	a) Solid timber
StructureOpening.shp	Q12	Door material	STOQ1B2	b) Timber veneer
StructureOpening.shp	Q12	Door material	STOQ1B2	c) Metal
StructureOpening.shp	Q12	Door material	STOQ1B2	d) Other (please comment)
StructureOpening.shp	Q12	Door material	STOQ1B2	e) Unknown
StructureOpening.shp	Q13	Protection of Openings - Protection Material	STOQ1B3	a) Metal flywire (less than 2mm aperture)
StructureOpening.shp	Q13	Protection of Openings - Protection Material	STOQ1B3	b) Fibreglass flywire (less than 2mm aperture)
StructureOpening.shp	Q13	Protection of Openings - Protection Material	STOQ1B3	c) Flywire (unknown
StructureOpening.shp	Q13	Protection of Openings - Protection Material	STOQ1B3	d) Metal grid (greater than 2mm aperture)

Layer	Caption	Question	Field	Answer
StructureOpening.shp	Q14	Does the door contain a glazing element?	STOQ1B4	a)Yes
StructureOpening.shp	Q14	Does the door contain a glazing element?	STOQ1B4	b)No
StructureOpening.shp	Q15	Protection of Vents - Protection Material	STOQ1C1	a) Metal flywire (less than 2mm aperture)
StructureOpening.shp	Q15	Protection of Vents - Protection Material	STOQ1C1	b) Fibreglass flywire (less than 2mm aperture)
StructureOpening.shp	Q15	Protection of Vents - Protection Material	STOQ1C1	c) Flywire (unknown)
StructureOpening.shp	Q15	Protection of Vents - Protection Material	STOQ1C1	d) Metal grid (greater than 2mm aperture)
StructureOpening.shp	Q16	External covering material (skylight)	STOQ1D1	a) Plastic
StructureOpening.shp	Q16	External covering material (skylight)	STOQ1D1	b) Glass
StructureOpening.shp	Q16	External covering material (skylight)	STOQ1D1	c) Other
StructureOpening.shp	Q16	External covering material (skylight)	STOQ1D1	d) Unknown
StructureOpening.shp	Q17	Type of plastic	STOQ1D2	a) Acrylic
StructureOpening.shp	Q17	Type of plastic	STOQ1D2	b) Polycarbonate
StructureOpening.shp	Q17	Type of plastic	STOQ1D2	c) Other (please comment)
StructureOpening.shp	Q18	Plastic damage	STOQ1D3	a) Melted
StructureOpening.shp	Q18	Plastic damage	STOQ1D3	b) Melted
StructureOpening.shp	Q18	Plastic damage	STOQ1D3	c) Cracked
StructureOpening.shp	Q18	Plastic damage	STOQ1D3	d) Cracked
StructureOpening.shp	Q18	Plastic damage	STOQ1D3	e) None
StructureOpening.shp	Q18	Plastic damage	STOQ1D3	f) Other (please comment)
StructureOpening.shp	Q19	Glass type	STOQ1D4	a) Plain
StructureOpening.shp	Q19	Glass type	STOQ1D4	b) Laminated
StructureOpening.shp	Q19	Glass type	STOQ1D4	c) Toughened
StructureOpening.shp	Q19	Glass type	STOQ1D4	d) Wired
StructureOpening.shp	Finish	null	No Field	No Answer

#### Layer type of vegetation detailed

Layer	Caption	Question	Field	Answer
Vegetation.shp	Q1	Vegetation type	VEGQ1	a) Tree
Vegetation.shp	Q1	Vegetation type	VEGQ1	b) Bush
Vegetation.shp	Q1	Vegetation type	VEGQ1	c) Other (please comment)
Vegetation.shp	Q1	Vegetation type	VEGQ1	d) Unknown
Vegetation.shp	Q2	Tree type	VEGQ2	a) Eucalypt (rough bark)
Vegetation.shp	Q2	Tree type	VEGQ2	b) Eucalypt (stringy bark)
Vegetation.shp	Q2	Tree type	VEGQ2	c) Eucalypt (smooth bark)
Vegetation.shp	Q2	Tree type	VEGQ2	d) Pine



Layer	Caption	Question	Field	Answer
Vegetation.shp	Q2	Tree type	VEGQ2	e) Other
Vegetation.shp	Q2	Tree type	VEGQ2	f) Unknown
Vegetation.shp	Q3	How damaged is the vegetation?	VEGQ3	a) Mainly Untouched
Vegetation.shp	Q3	How damaged is the vegetation?	VEGQ3	b) Canopy Scorched
Vegetation.shp	Q3	How damaged is the vegetation?	VEGQ3	c) Most of canopy scorched
Vegetation.shp	Q3	How damaged is the vegetation?	VEGQ3	d) Some Crown involvement
Vegetation.shp	Q3	How damaged is the vegetation?	VEGQ3	e) Most burnt
Vegetation.shp	Q4	Approximate foliage scorch height	No Field	No Answer
Vegetation.shp	Q5	Which side is damaged?	VEGQ5	a) House side
Vegetation.shp	Q5	Which side is damaged?	VEGQ5	b) Non-house side
Vegetation.shp	Q5	Which side is damaged?	VEGQ5	c) Both
Vegetation.shp	Q6	Attack mechanism on this vegetation	VEGQ6	a) Embers only
Vegetation.shp	Q6	Attack mechanism on this vegetation	VEGQ6	b) Embers and some radiant heat
Vegetation.shp	Q6	Attack mechanism on this vegetation	VEGQ6	c) Predominant radiant heat
Vegetation.shp	Q6	Attack mechanism on this vegetation	VEGQ6	d) Flame contact from bush
Vegetation.shp	Q6	Attack mechanism on this vegetation	VEGQ6	e) Other (please comment)
Vegetation.shp	Q6	Attack mechanism on this vegetation	VEGQ6	f) No direct bushfire attack
Vegetation.shp	Q6	Attack mechanism on this vegetation	VEGQ6	g) Unknown

#### Layer type of water supplies detailed

Layer	Caption	Question	Field	Answer
WaterSupplies.shp	Q1	Was this water supply actively used to protect structures?	WATQ1	a) Yes
WaterSupplies.shp	Q1	Was this water supply actively used to protect structures?	WATQ1	b) No
WaterSupplies.shp	Q1	Was this water supply actively used to protect structures?	WATQ1	c) Unknown
WaterSupplies.shp	Q2	Type of water supply	WATQ2	a) Water tank
WaterSupplies.shp	Q2	Type of water supply	WATQ2	b) Dam or Waterbody
WaterSupplies.shp	Q2	Type of water supply	WATQ2	c) Swimming Pool
WaterSupplies.shp	Q2	Type of water supply	WATQ2	d) Hydrant
WaterSupplies.shp	Q3	Is there a standardised fire agency approved attachment?	WATQ2A1	a) Yes
WaterSupplies.shp	Q3	Is there a standardised fire agency approved attachment?	WATQ2A1	b) No
WaterSupplies.shp	Q3	Is there a standardised fire agency approved attachment?	WATQ2A1	c) Unknown
WaterSupplies.shp	Q4	Nature of other fittings	WATQ2A2	a) Plastic
WaterSupplies.shp	Q4	Nature of other fittings	WATQ2A2	b) Metal

Layer	Caption	Question	Field	Answer
WaterSupplies.shp	Q4	Nature of other fittings	WATQ2A2	c) Unknown
WaterSupplies.shp	Q4	Nature of other fittings	WATQ2A2	d) None
WaterSupplies.shp	Q5	Nature of pipework attached to tank	WATQ2A3	a) Plastic
WaterSupplies.shp	Q5	Nature of pipework attached to tank	WATQ2A3	b) Metal
WaterSupplies.shp	Q5	Nature of pipework attached to tank	WATQ2A3	c) Unknown
WaterSupplies.shp	Q5	Nature of pipework attached to tank	WATQ2A3	d) None
WaterSupplies.shp	Q6	Tank Support	WATQ2A4	a) Tank on ground
WaterSupplies.shp	Q6	Tank Support	WATQ2A4	b) Tank fully buried
WaterSupplies.shp	Q6	Tank Support	WATQ2A4	c) Tank partially buried
WaterSupplies.shp	Q6	Tank Support	WATQ2A4	d) Tank on stand
WaterSupplies.shp	Q7	Height of tank stand	No Field	No Answer
WaterSupplies.shp	Q8	Tank stand material	WATQ2A6	a) Treated pine
WaterSupplies.shp	Q8	Tank stand material	WATQ2A6	b) Other timbers
WaterSupplies.shp	Q8	Tank stand material	WATQ2A6	c) Concrete
WaterSupplies.shp	Q8	Tank stand material	WATQ2A6	d) Steel
WaterSupplies.shp	Q8	Tank stand material	WATQ2A6	e) Brick
WaterSupplies.shp	Q8	Tank stand material	WATQ2A6	f) Other
WaterSupplies.shp	Q8	Tank stand material	WATQ2A6	g) Unknown
WaterSupplies.shp	Q9	Material of water tank	WATQ2A7	a) Concrete
WaterSupplies.shp	Q9	Material of water tank	WATQ2A7	b) Fibreglass
WaterSupplies.shp	Q9	Material of water tank	WATQ2A7	c) Polyethelyne
WaterSupplies.shp	Q9	Material of water tank	WATQ2A7	d) Steel
WaterSupplies.shp	Q9	Material of water tank	WATQ2A7	e) Other
WaterSupplies.shp	Q10	Damage description	WATQ2A8	a) Undamaged
WaterSupplies.shp	Q10	Damage description	WATQ2A8	b) Some isolated scorching
WaterSupplies.shp	Q10	Damage description	WATQ2A8	c) Partially burnt
WaterSupplies.shp	Q10	Damage description	WATQ2A8	d) Mostly burnt
WaterSupplies.shp	Q10	Damage description	WATQ2A8	e) Ruptured
WaterSupplies.shp	Q10	Damage description	WATQ2A8	f) Other
WaterSupplies.shp	Q11	Current level of water supply	WATQ3	a) Full
WaterSupplies.shp	Q11	Current level of water supply	WATQ3	b) Partial
WaterSupplies.shp	Q11	Current level of water supply	WATQ3	c) Empty
WaterSupplies.shp	Q11	Current level of water supply	WATQ3	d) Unknown
WaterSupplies.shp	Q12	Specify capacity in litres	No Field	No Answer
WaterSupplies.shp	Finish	null	No Field	No Answer

## APPENDIX C – DATA MANAGEMENT AND RECTIFICATION

### Post-processing tasks include:

#### Adding attributed tracking information

For the purpose of being able to track each data record from the final database to the „source“ dataset (as downloaded from the Toughbooks), we have added three extra fields to all dataset.

- Team

The team corresponds to a team number as specified by the Bushfire CRC in their deployment log (see attached).

- Rotation

The rotation field corresponds to a deployment as specified by the Bushfire CRC in their deployment log (see attached).

- ORIG\_FID

ORIG\_FID refer to the FID (Feature ID) from the original dataset as is in Toughbook and source (Bushfire CRC Server).

#### Merging datasets

There were 59 separate databases at the completion of the survey, each database corresponding to a team within a crew rotation. Databases underwent a process of merging that involved combining datasets of a particular type into a single dataset.

#### Mapping versions of datasets

By rotation 4, we had developed a new version of the „site sketcher“ that included additional questions to the original survey and was based on feedback that we received from crew members and items we identified as crucial information for specific fires.

The databases derived during deployment 2 and 3 underwent a process of remapping, which is documented in Appendix C and involved populating the newer database structure using the database derived during deployment 2 and 3.

#### Rectification of observed data deficiencies:

- Copy function failure

Certain layers such as Vegetation, Structure Opening, Combustible, required a user to enter the same answers for multiple items. To streamline this process, we created a Copy Function, which allowed the user to enter attributes for an item and then copy those attributes along multiple locations of the map.

As users had to undertake a very specific procedure (after attributes entered), at times users would follow an unexpected procedure and spatial features would be entered without attributes. These records were manually identified (see track log) and by using the tracking information, we were able to rectify the problem and populate the necessary fields.

- Duplicate records

Occasionally, equipment errors led to data files being corrupted – these files were recovered using the ShapeFile Corrector Utility. When such an error occurred, crews were asked to copy a previous team's database that was available locally and continue collecting data into this database.

- Extracting test and training records

Test and training records were extracted from the main database and copied to a separate layer. Data were extracted based on the date and location of the training. The process below describes the exact procedure.

- Extract by date

Bushfire CRC logs contain information regarding the date each team was deployed. The merged database was queried by these dates and the relevant records extracted from the database. Training normally occurred between 11am–2pm on deployment days; the identified records reflect these times.

- Extract by training location

Areas where we conducted field training were identified and extent polygon boundaries drawn. All items falling within these polygons were extracted from the final database and copied into a separate database representing the deleted records; see track log.

### Re-editing function failure

If a crew member saved a data record that he or she later decided to change, they would insert a new record in the same location and comment in changes to the previous data record. These records were identified using a systematic query that searched through the database and identified records that were populated with only comments. The identified records were then audited and rectified.

### Comments made by users

Large numbers of comments have been made by surveyors and need to be addressed case by case.

## Appendix D – Data description

All information was captured in ESRI Shapefile format; please find below an extract from the Shapefile Whitepaper describing the format.

„A shapefile stores non-topological geometry and attribute information for the spatial features in a dataset. The geometry for a feature is stored as a shape comprising a set of vector coordinates... Shapefiles can support point, line, and area features. Area features are represented as closed loop, double-digitized polygons. Attributes are held in a dBASE® format file. Each attribute record has a one-to-one relationship with the associated shape record.”

<http://www.esri.com/library/whitepapers/pdfs/shapefile.pdf>

Data captured during the surveys included all three vector formats – point, polyline and polygon. Each set of vectors contains a corresponding record in a DBF table which is described in the table below.

All captured vector data was digitised from pre-bushfire aerial imagery that had been spatially referenced to the GCS coordinate system in the GDA94\_Zone 55 grid. The process of digitising from the map involved sketching on the Toughbook touch screen the geometry that was automatically captured within the above-mentioned coordinate system.

### Point

Points are a single set of x and y coordinates representing the centroid of an object. Points were captured by placing a point over an object.

### Polyline

Polylines are a set of x and y coordinates representing the vertices of a polyline. Polylines were captured by marking vertices of an object.

### Polygon

Polygons are a set of x and y coordinates representing the vertices of a polygon boundary. Polygons were captured by marking vertices of an object.

Name	Type	Capture method
Structure	Point	Centroid of buildings
Structure opening	Point	Approx. locations of openings
Attachment	Point	Approx. location of attachments
Outbuilding	Point	Centroid of outbuildings
Combustible	Point	Centroid of combustible objects
Barrier	Polyline	Line representing the bird's-eye view of a barrier
Vegetation	Point	Centroid of tree
Groundcover	Polygon	Polygon representing the bird's-eye view of a groundcover
Sprinklers	Point	Centroids of sprinklers
Water supplies	Point	Centroids of water supplies
Wind direction	Line	Line representing a direction, as a vector.

## Appendix E – Survey house per locality

This information was extracted from a dataset prior to data rectification (hence some errors or duplicates may be included)

Table 55 Summary of surveyed houses per locality for the Kilmore East fire

Locality	% Houses surveyed/houses in fire perimeter	Number of houses surveyed	Total houses in fire perimeter (NEXIS)*	Fatalities (Victorian Police)
<b>Arthurs Creek</b>	29%	2	7	2
<b>Castella</b>	2%	2	108	
<b>Christmas Hills</b>	62%	13	21	
<b>Chum Creek</b>	2%	4	232	
<b>Clonbinane</b>	8%	12	157	1
<b>Dixons Creek</b>	1%	1	90	
<b>Flowerdale</b>	30%	36	119	2
<b>Glenburn</b>	3%	4	123	
<b>Hazeldene</b>	29%	116	395	10
<b>Humevale</b>	84%	51	61	6
<b>Kinglake</b>	18%	135	744	38
<b>Kinglake Central</b>	26%	53	205	
<b>Kinglake West</b>	29%	144	490	4
<b>Pheasant Creek</b>	11%	15	132	
<b>St Andrews</b>	23%	26	111	12
<b>Steels Creek</b>	51%	65	128	10
<b>Strath Creek</b>	2%	1	44	1
<b>Strathewen</b>	60%	48	80	27
<b>Tarrowarra</b>	6%	1	16	
<b>Whittlesea</b>	15%	3	20	2
<b>Yarra Glen</b>	61%	51	83	1
<b>Other localities</b>	0%	0	583	5
<b>Total</b>	20%	783	3949	121

\* Based on NEXIS database (total houses by locality, in the fire perimeter)

Table 56 Summary of surveyed houses per locality in the Murrindindi fire

Locality	% Houses surveyed/houses in fire perimeter	Number of houses surveyed	Total houses in fire perimeter (NEXIS)*	Fatalities (Victorian Police)
Buxton	0%	0	358	
Limestone	0%	0	1	
Marysville	35%	162	464	34
Murrindindi	0%	0	16	
Narbethong	20%	27	135	4
Taggerty	0%	0	142	
Whanregarwen	0%	0	1	
<b>Total</b>	<b>17%</b>	<b>189</b>	<b>1117</b>	<b>38</b>

\* Based on NEXIS database (total houses by locality, in the fire perimeter)

Table 57 Summary of surveyed houses per locality in the Churchill fire

Locality	% Houses surveyed/houses in fire perimeter	Number of houses surveyed	Total houses in fire perimeter (NEXIS)*	Fatalities
Callignee	65%	83	128	
Churchill	100%	1	1	11
Hazelwood South	65%	22	34	
Jeeralang	57%	8	14	
Koornalla	81%	25	31	
Traralgon South	10%	5	50	
Other localities	0%	0	86	

\* Based on NEXIS database (total houses by locality, in the fire perimeter)

Table 58 Summary of surveyed houses per localities in the Maiden Gully fire

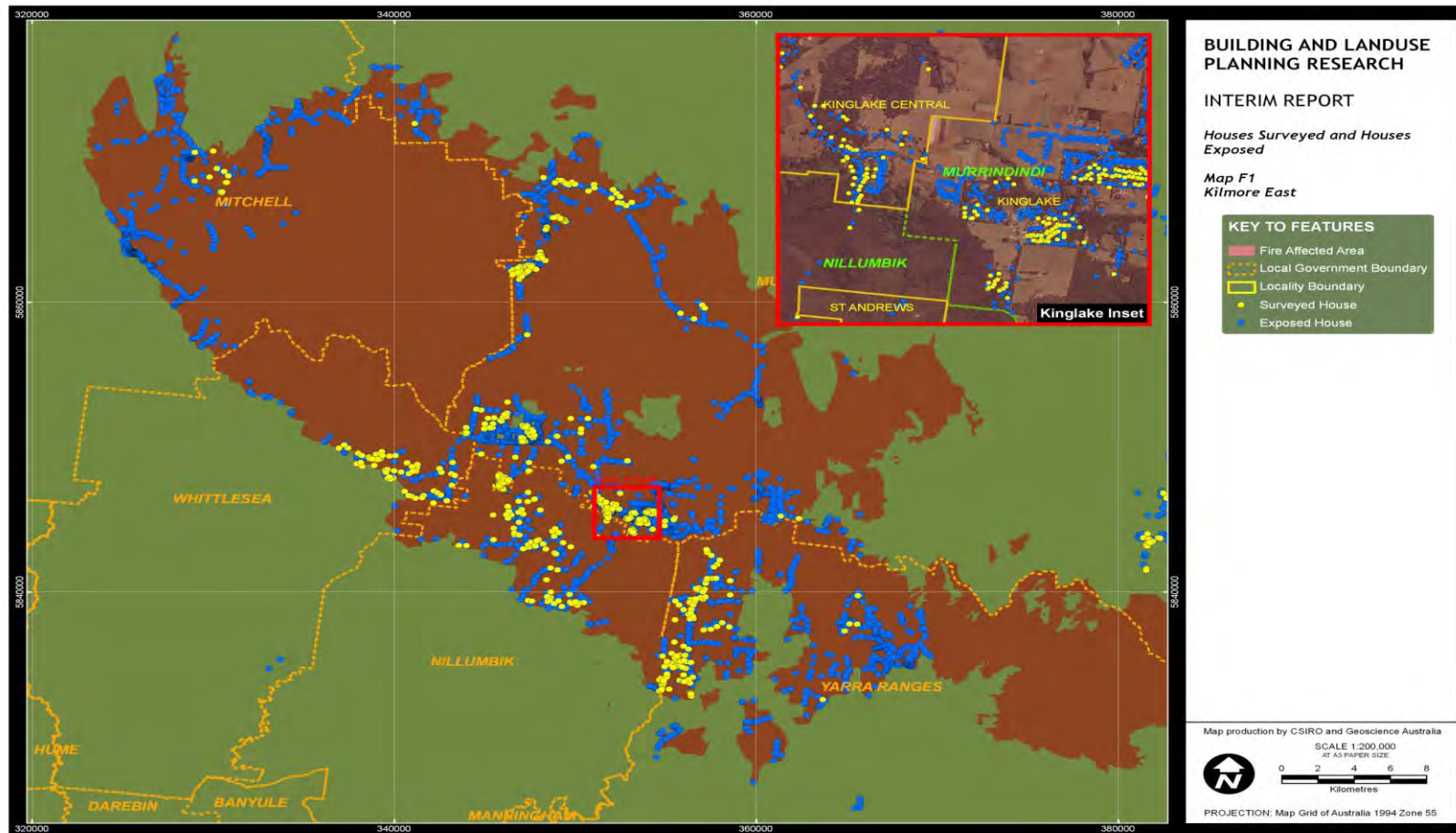
Locality	% Houses surveyed/houses in fire perimeter	Number of houses surveyed	Total houses in fire perimeter (NEXIS)*	Fatalities
California Gully	4%	1	26	
Golden Square	0%	0	1	
Ironbark	20%	1	5	
Long Gully	56%	45	81	1
Maiden Gully	71%	24	34	
West Bendigo	25%	17	68	
<b>Total</b>	<b>41%</b>	<b>88</b>		

\* 14 houses were surveyed in the Bunyip area out of 231 houses in the fire perimeter (NEXIS).

## APPENDIX F - KILMORE EAST FIRE (WONDONG, KINGLAKE, STRATHEWEN, CLONBINANE, FLOWERDALE)

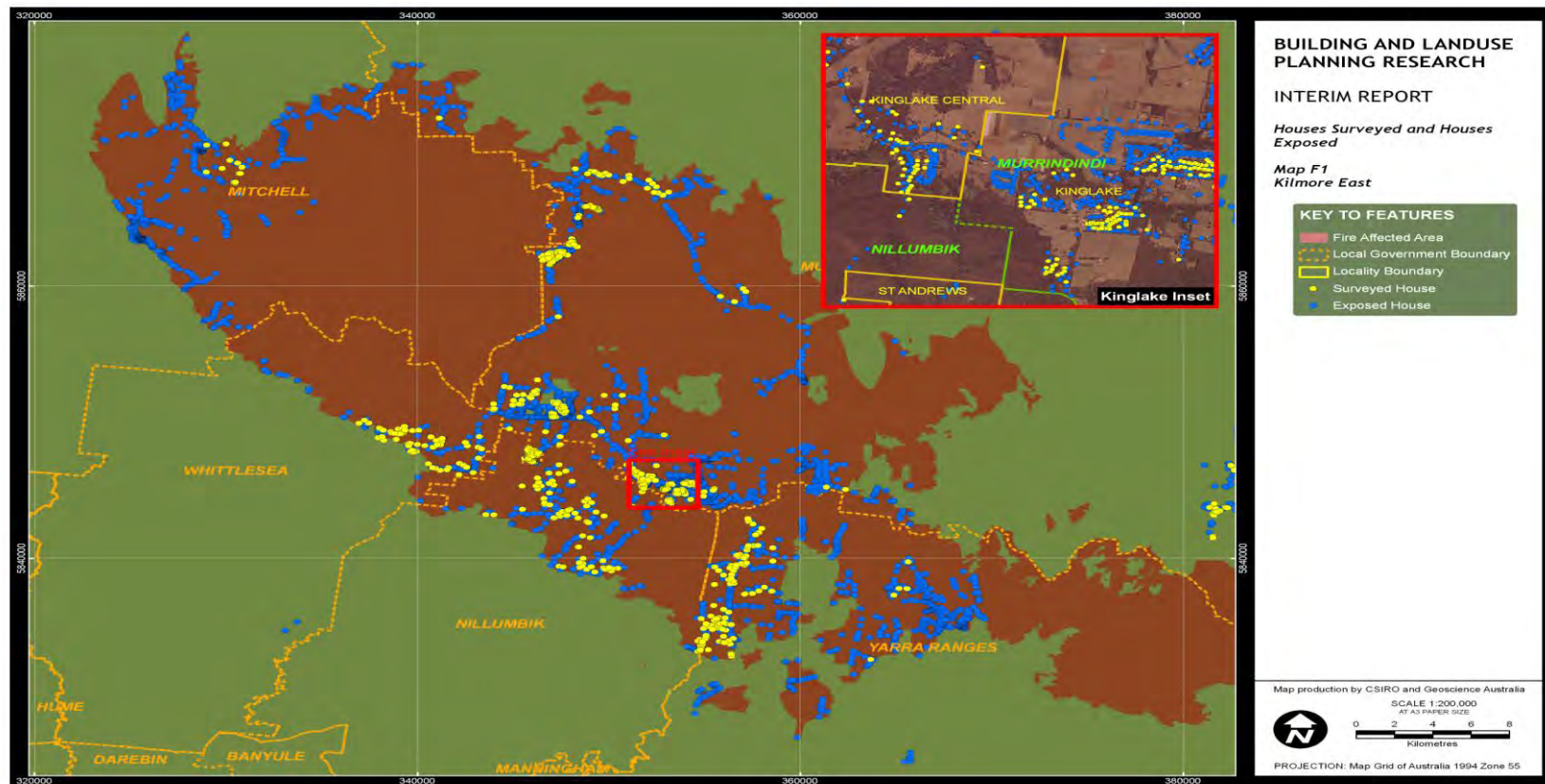
Summary of map provided:

Map 1 Fire Perimeter





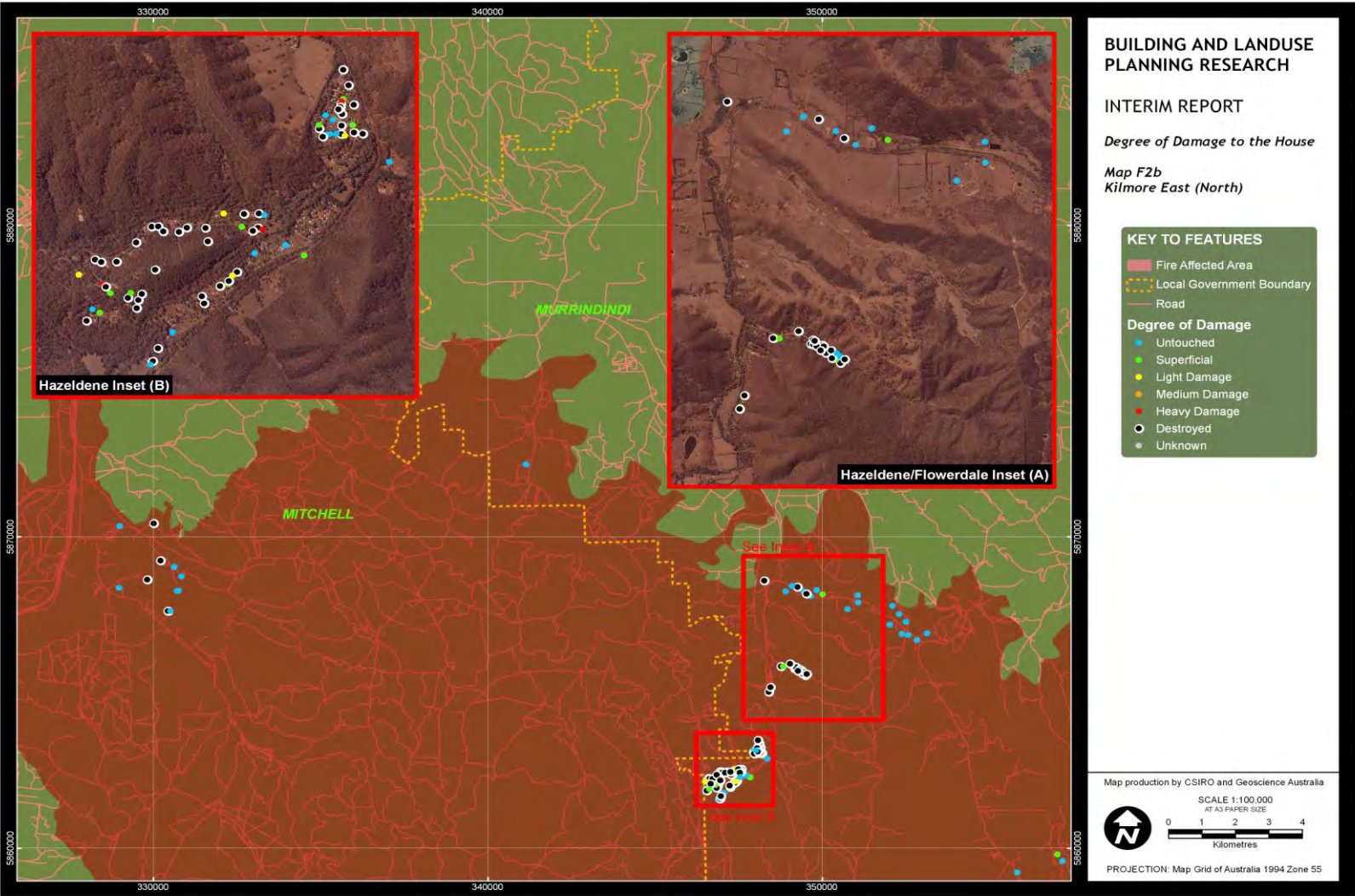
Map F1 Houses surveyed and houses exposed (NEXIS)



Map F2a Degree of damage to the house Kilmore East (north region)

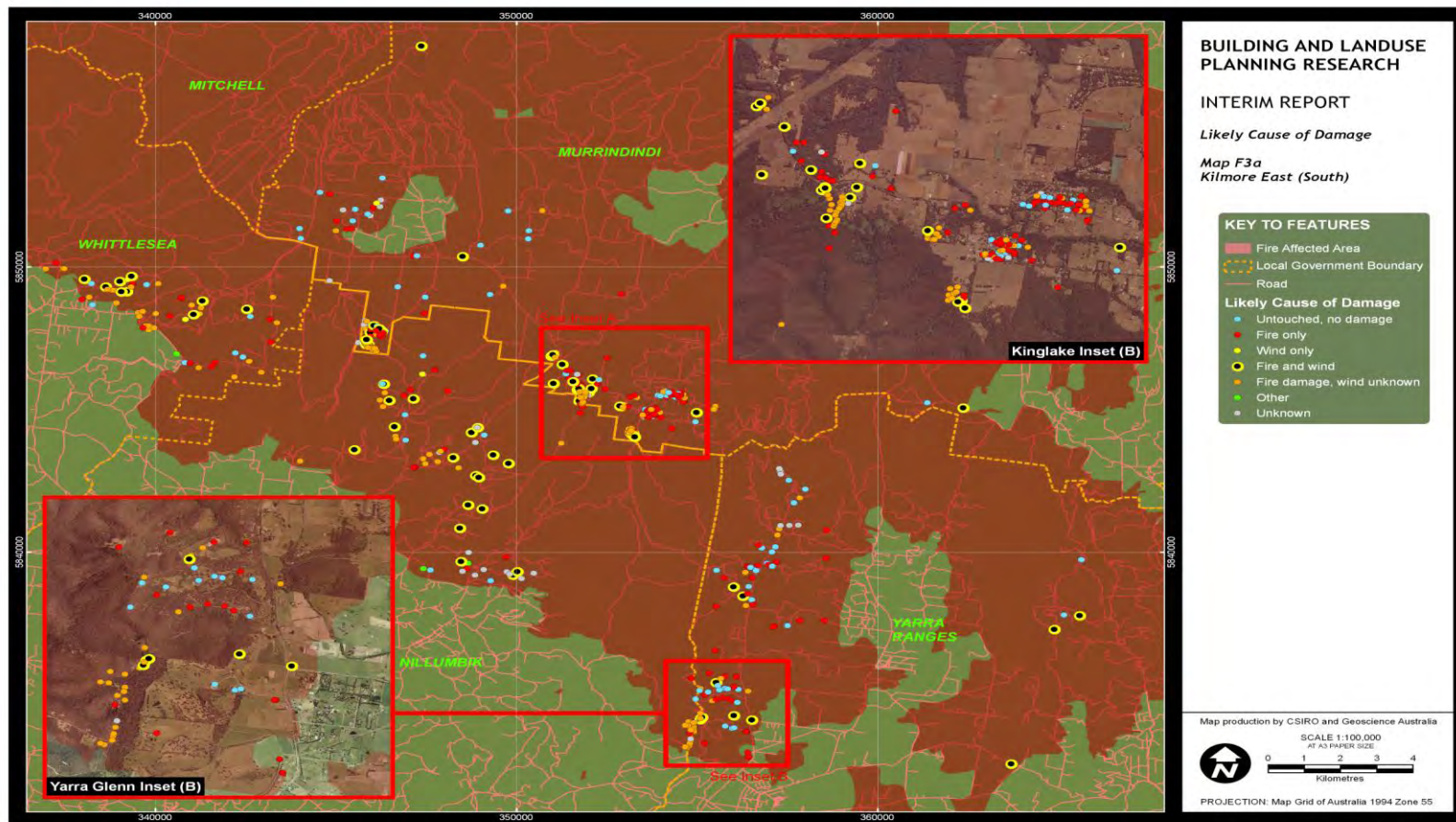
(Map not available)

Map F2b Degree of damage to the house Kilmore East (south region)

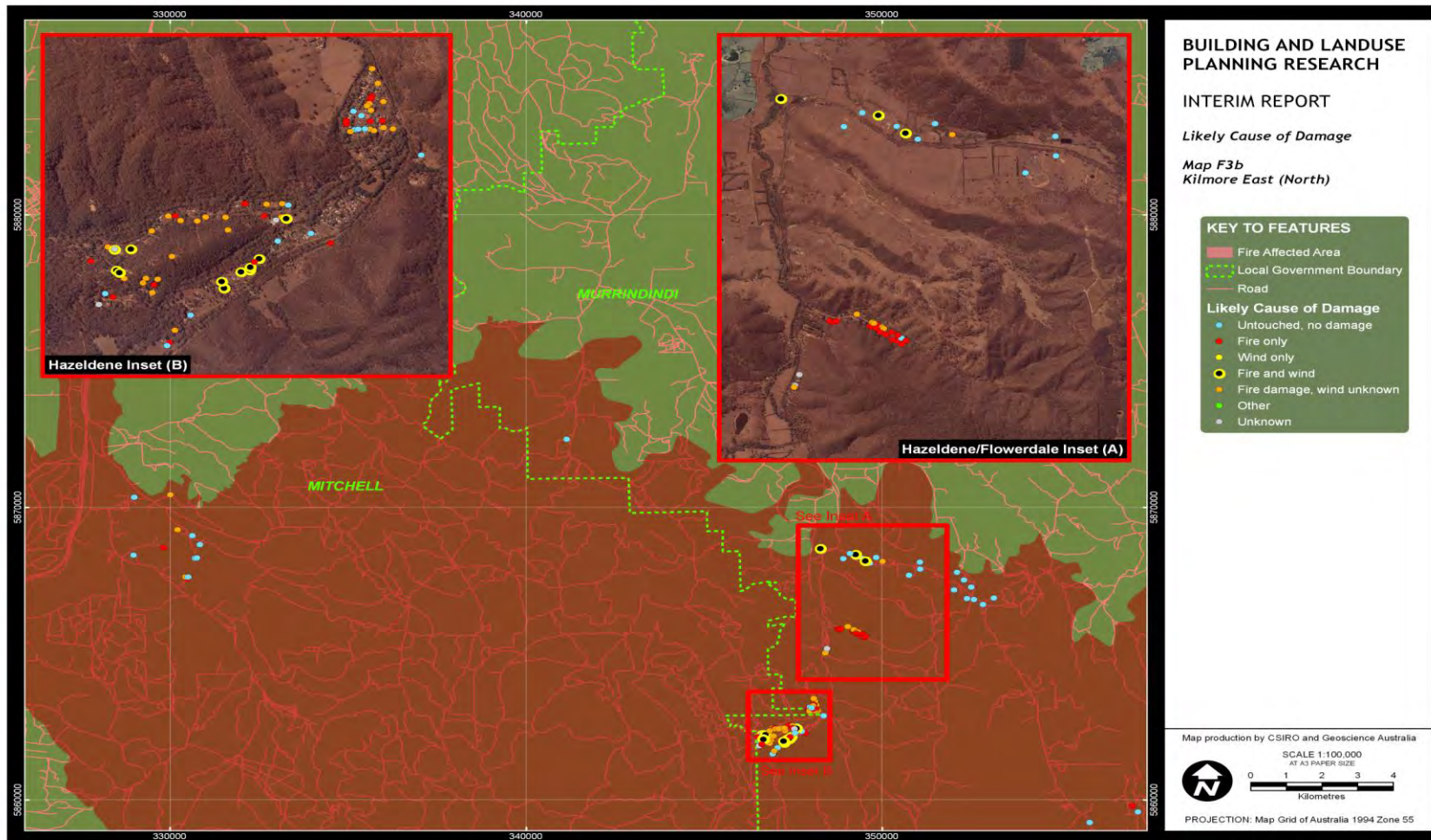




Map F3a Likely cause of damage to the house (fire and wind) Kilmore East (south region)

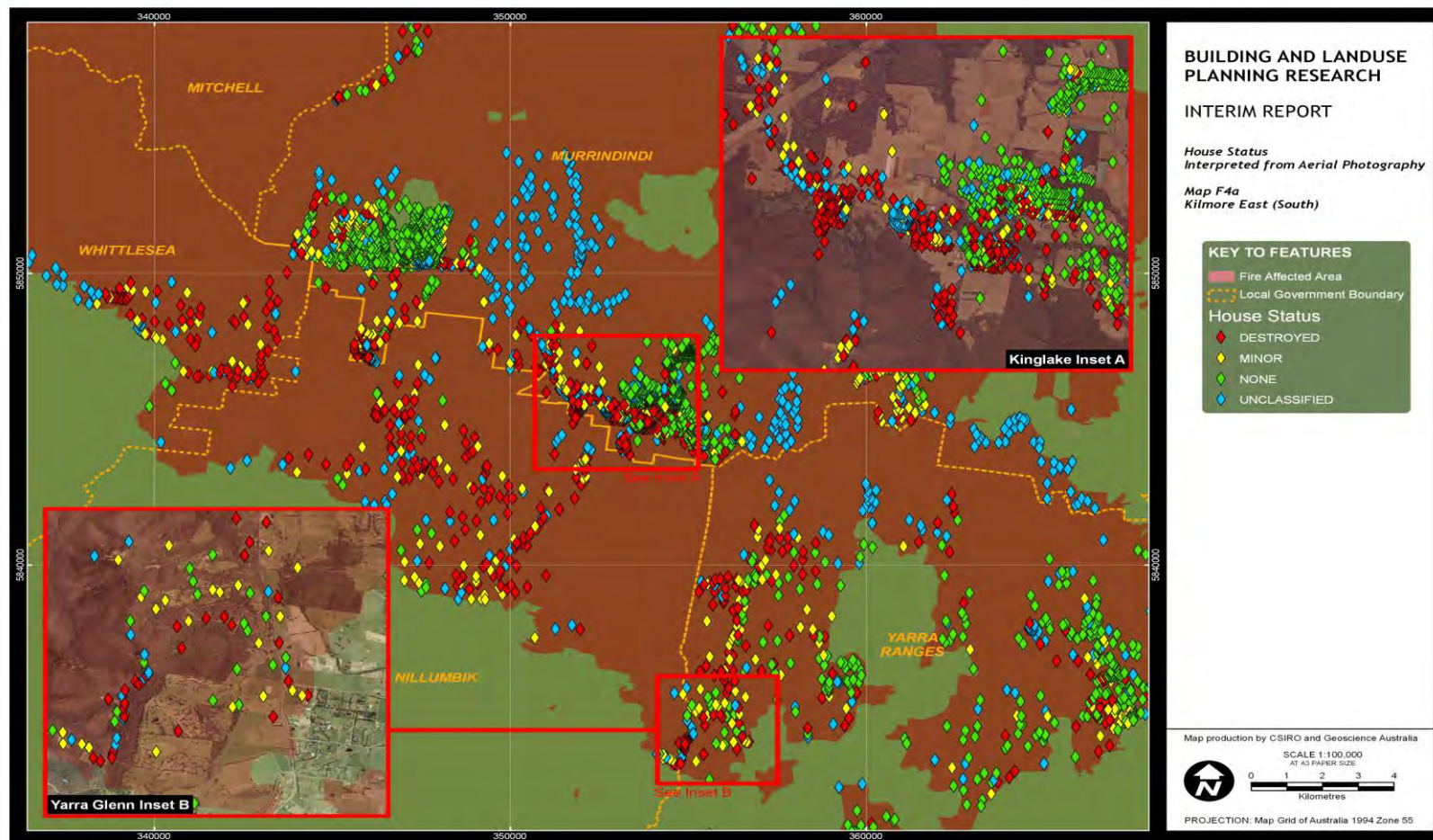


Map F3b Likely cause of damage to the house (fire and wind) Kilmore East (south region)

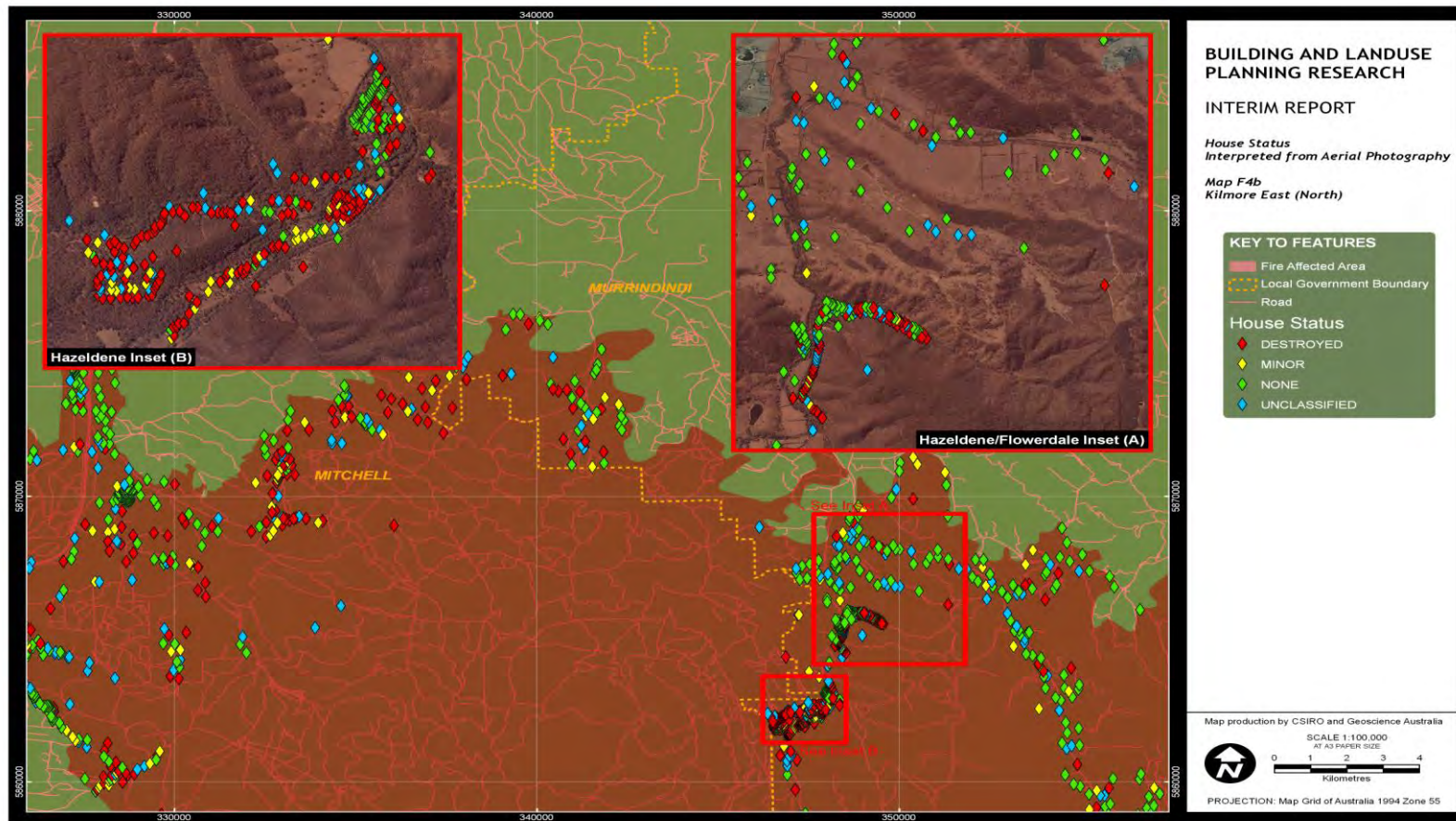




Map F4a House status interpreted from aerial picture Kilmore East (north region)

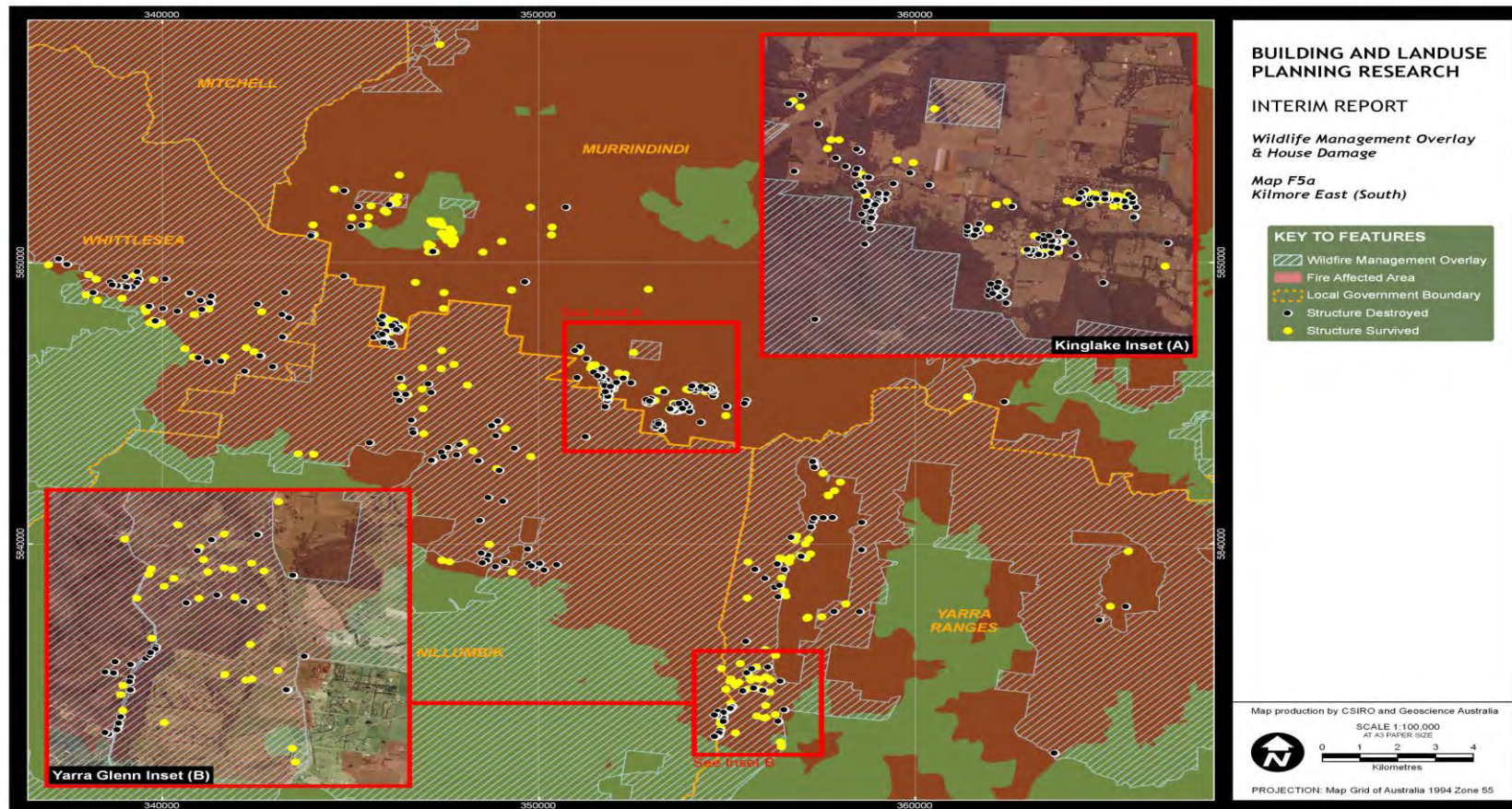


Map F4b House status interpreted from aerial picture Kilmore East (south region)



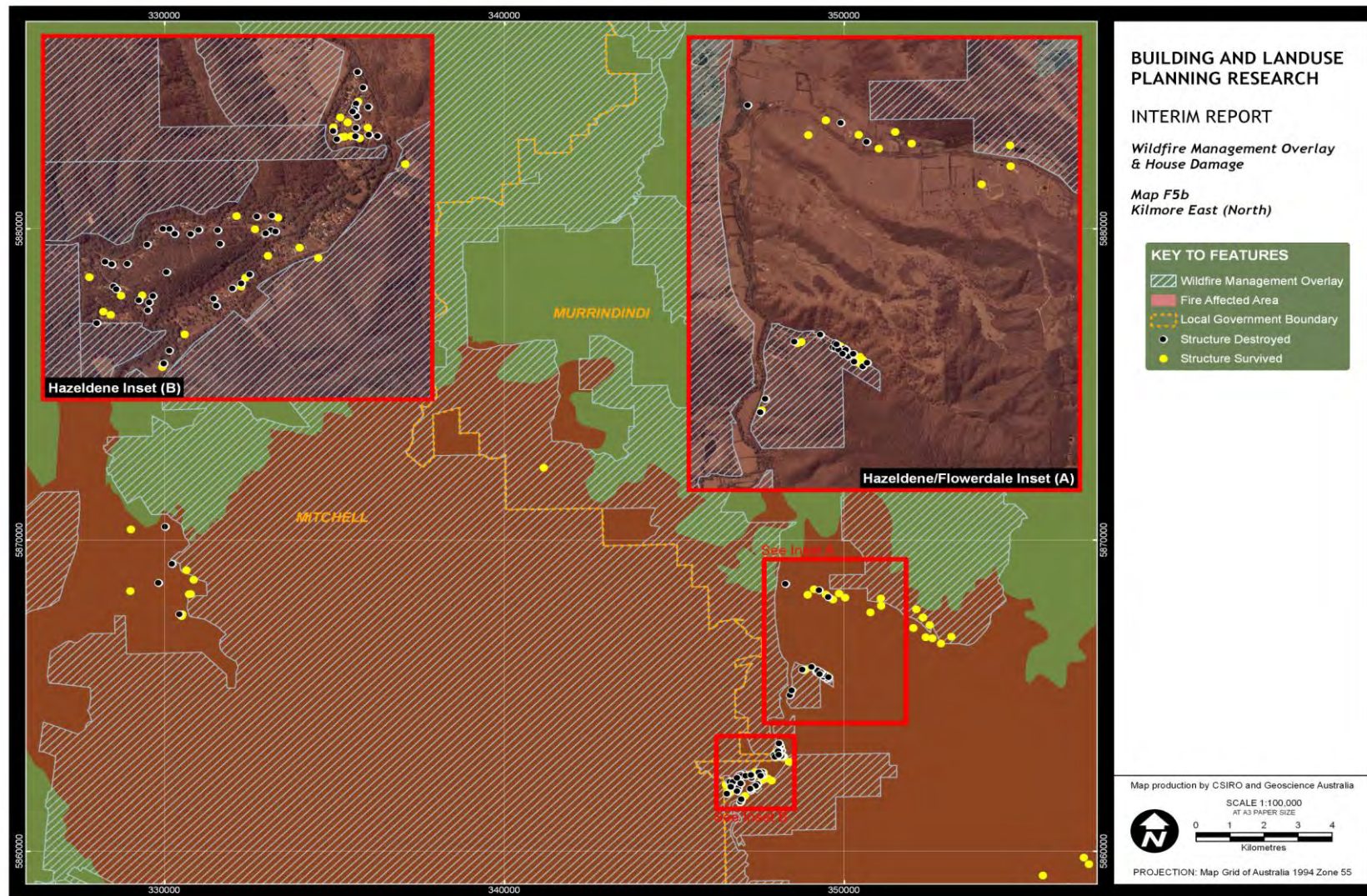


Map F5a Wildfire management overlays and house damaged Kilmore East (north region)



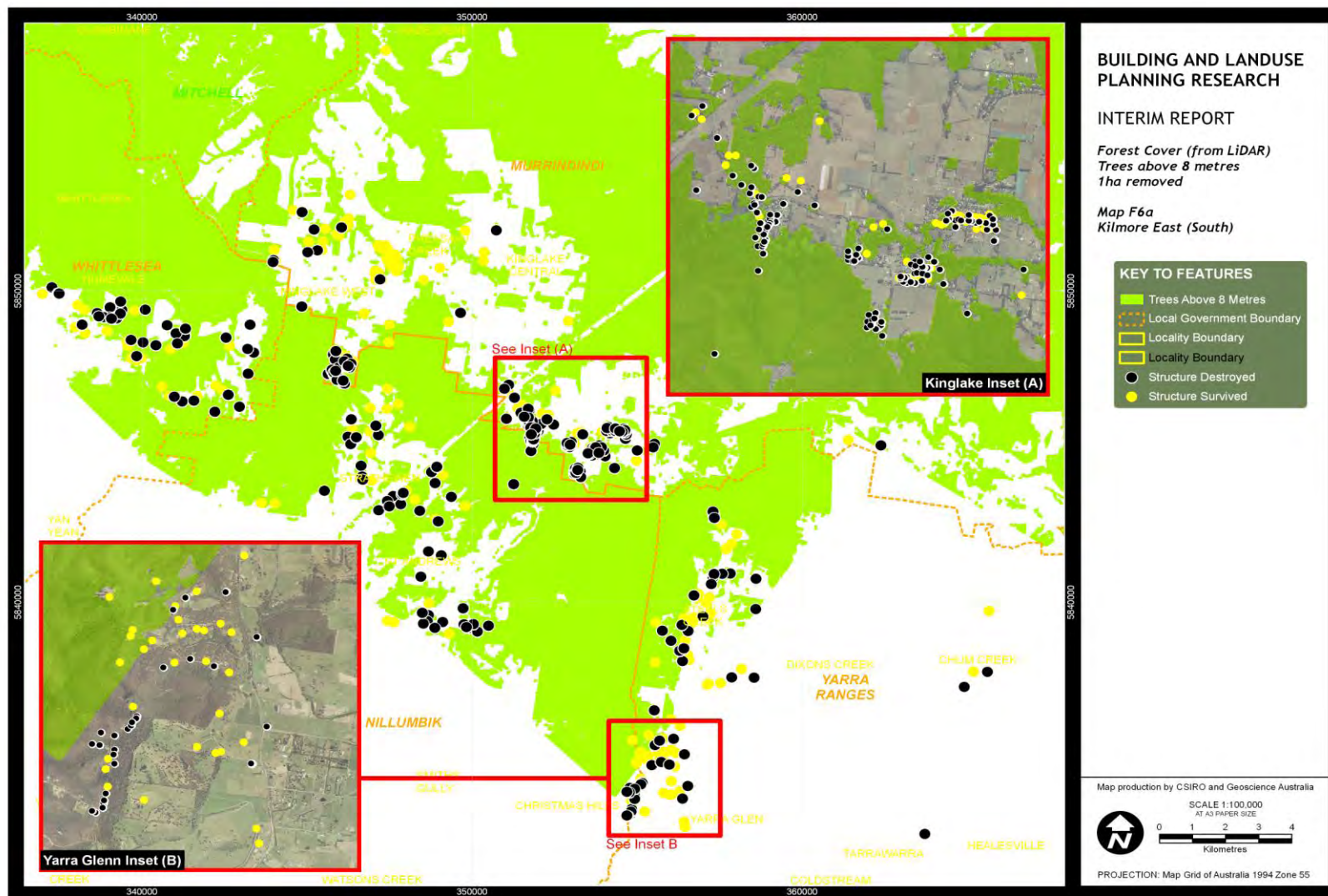


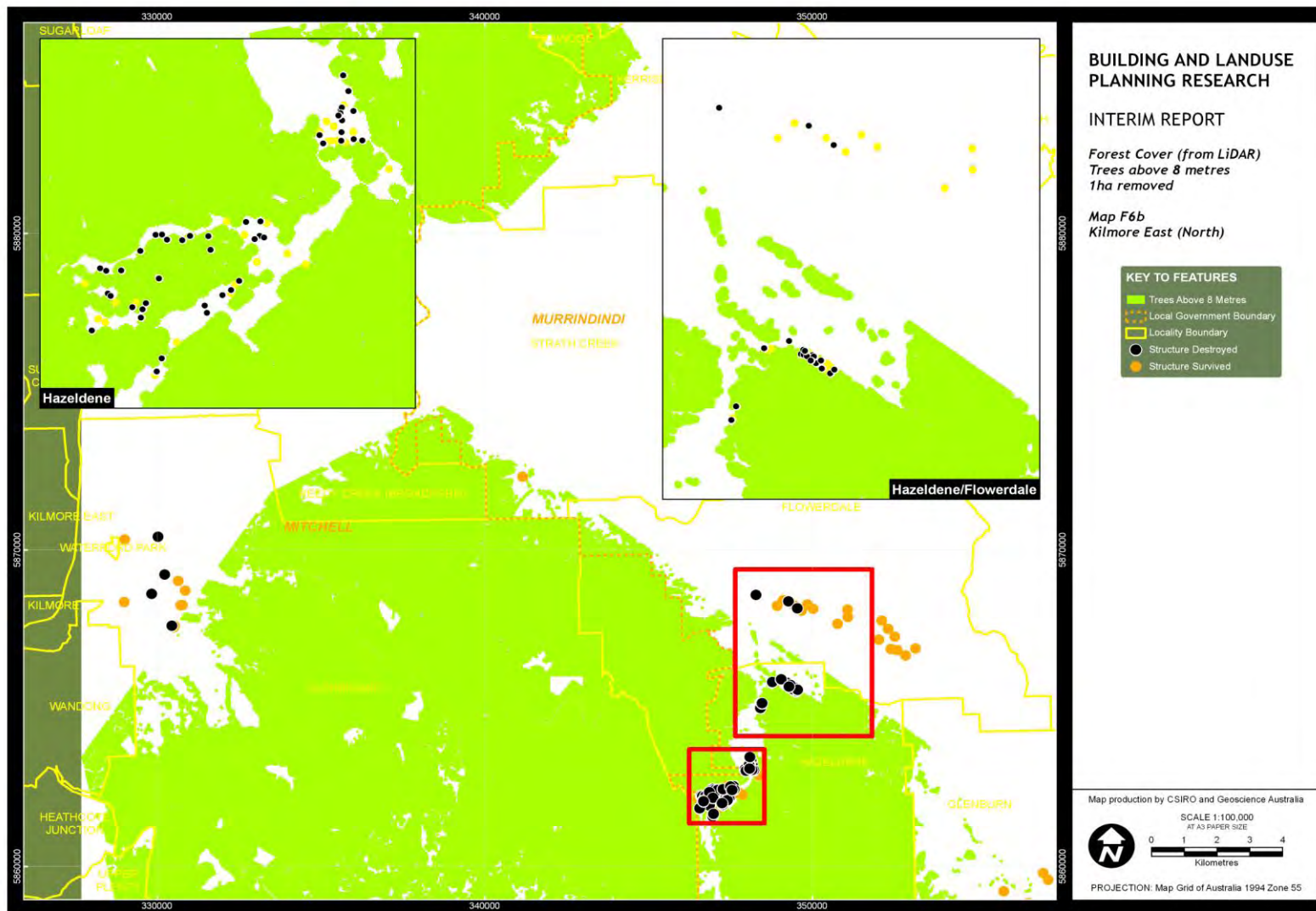
Map F5b Wildfire management overlays and house damaged Kilmore East (south region)





Map F6 Forest cover ( from LiDAR )

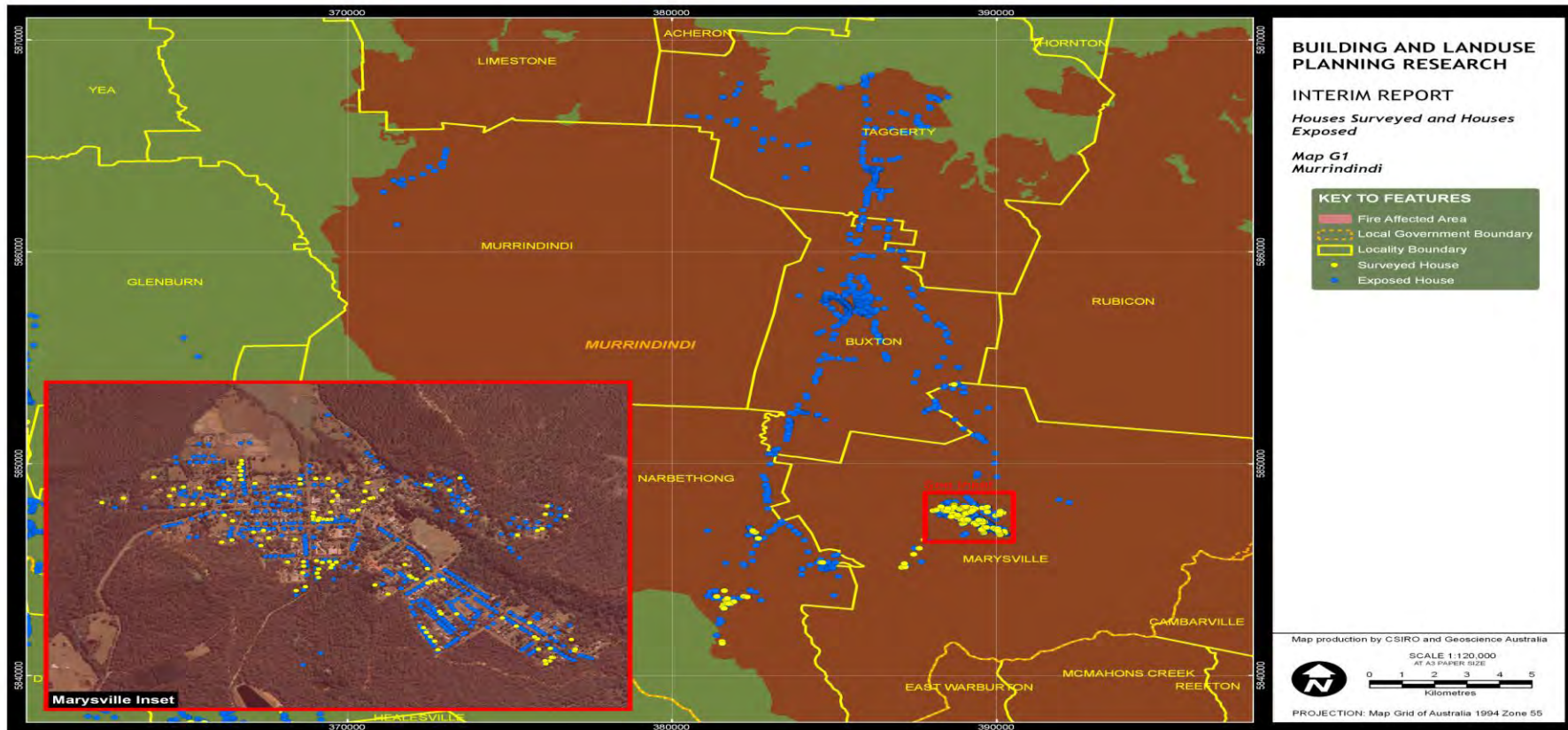




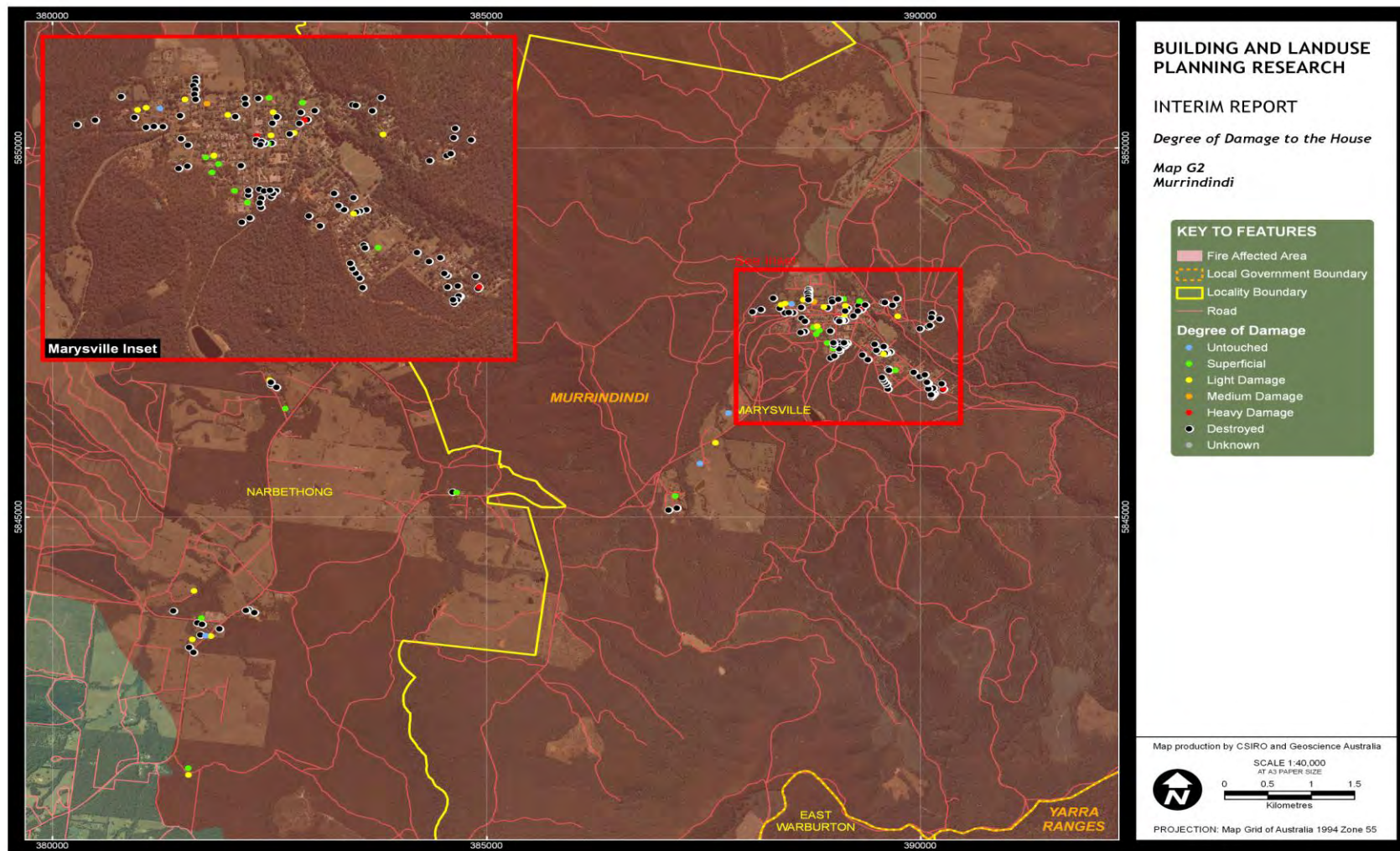


## APPENDIX G - MURRINDIDI FIRE (MARYSVILLE, NARBETHONG, BUXTON, TAGGERTY)

Map G1 Houses surveyed and houses exposed (NEXIS)

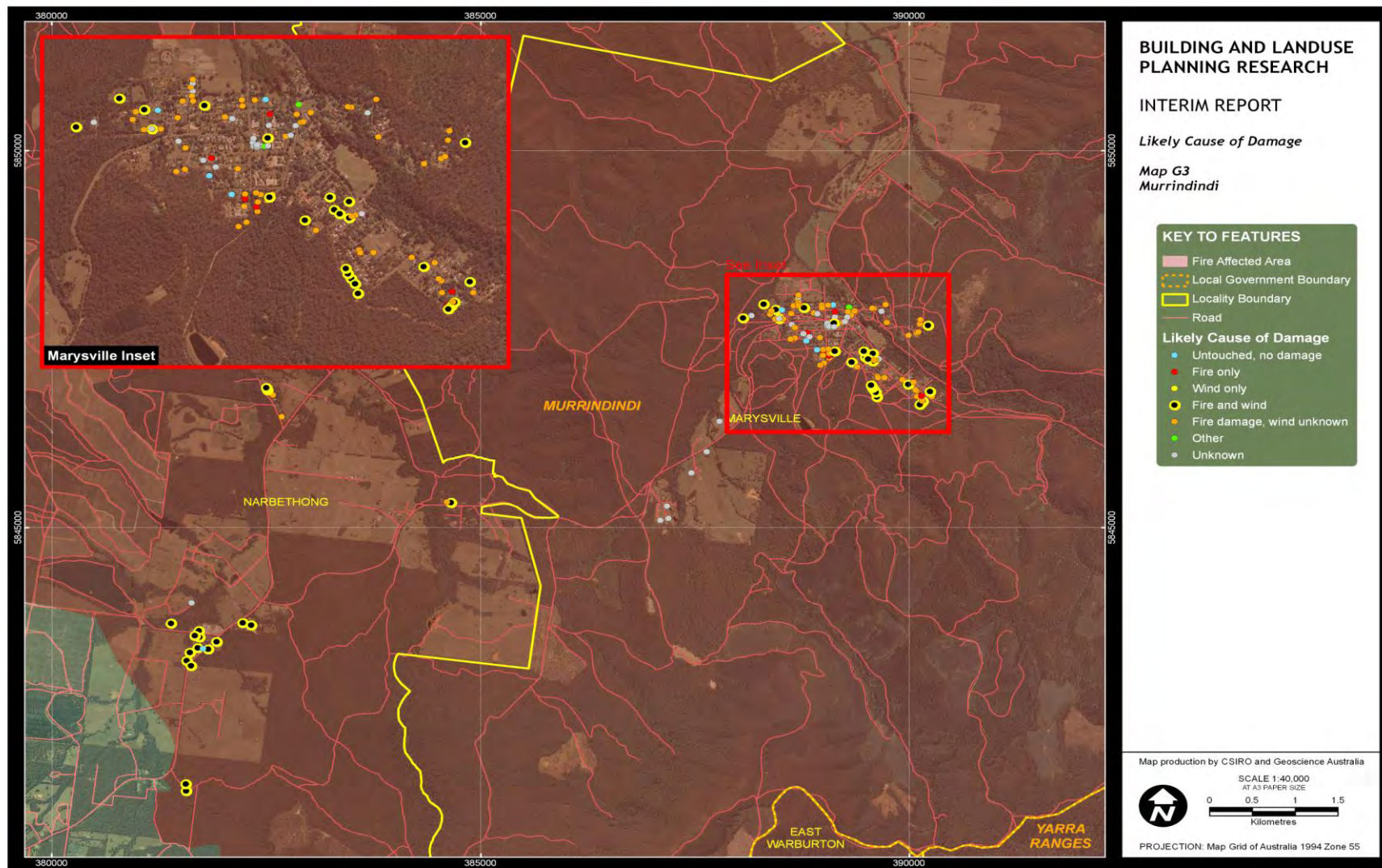


Map G2 Degree of damage to the house Murrundindi



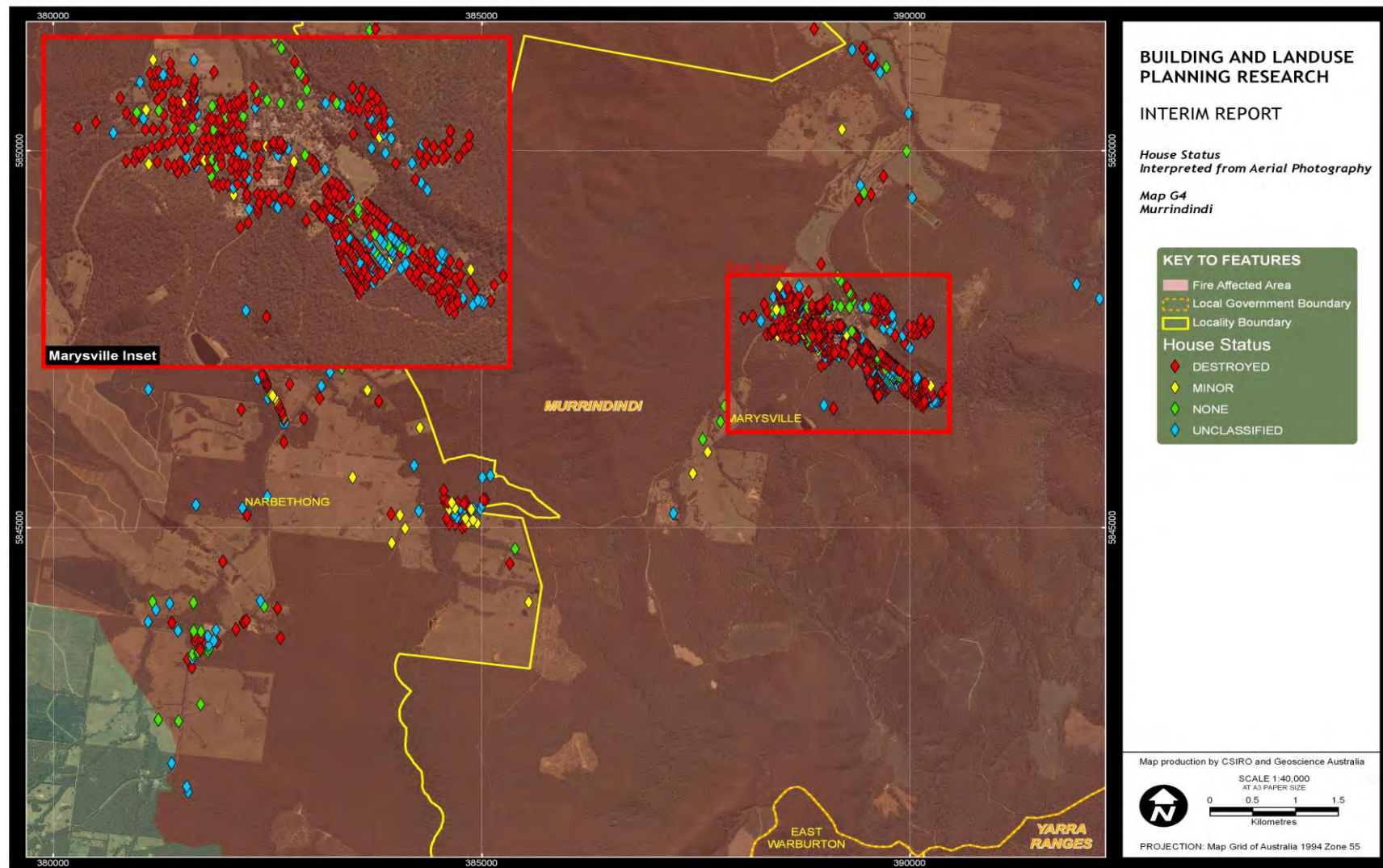


Map G3 Likely cause of damage to the house (fire and wind) Murrindindi Region



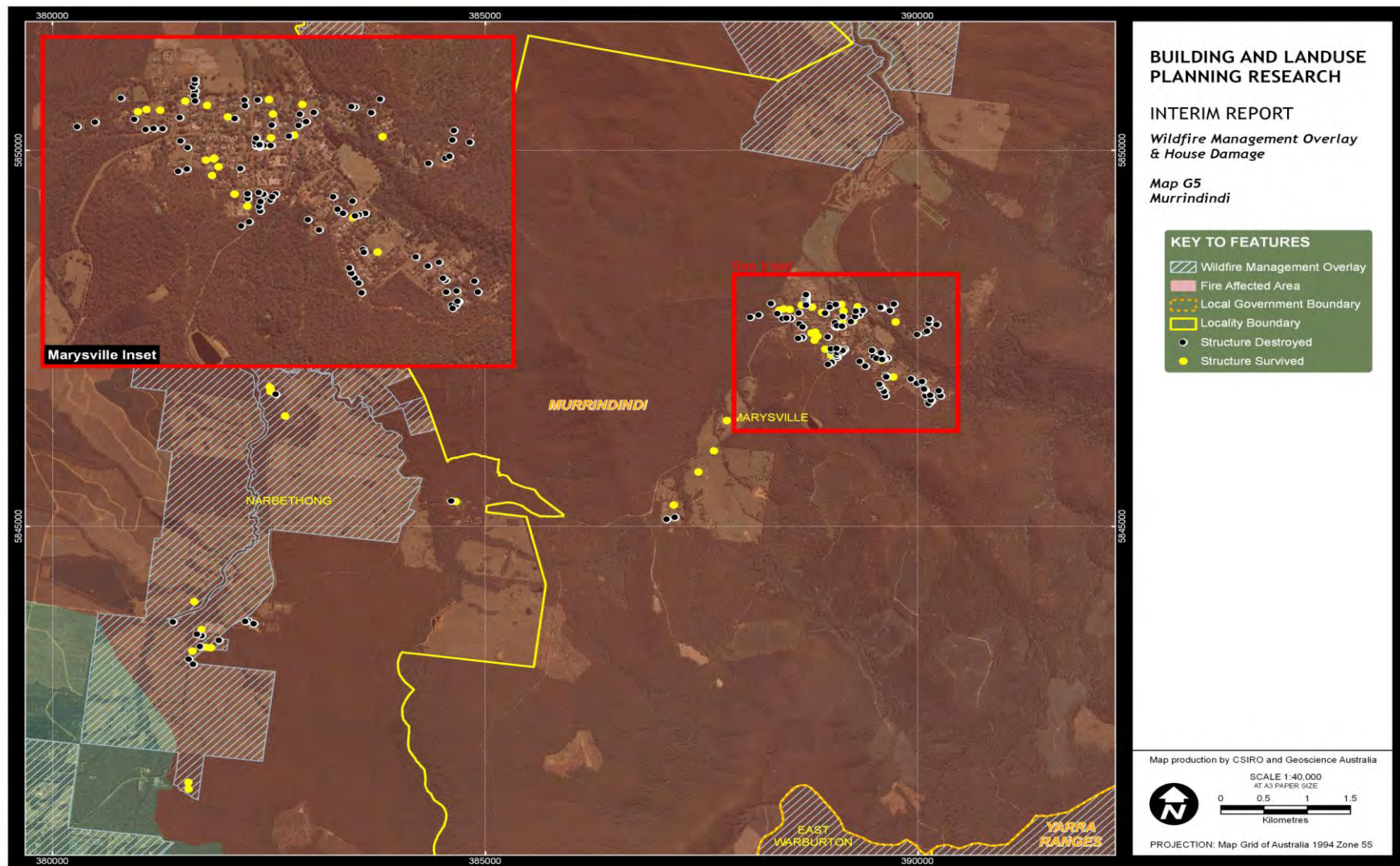


Map G4 House status interpreted from aerial picture Murrindindi Region



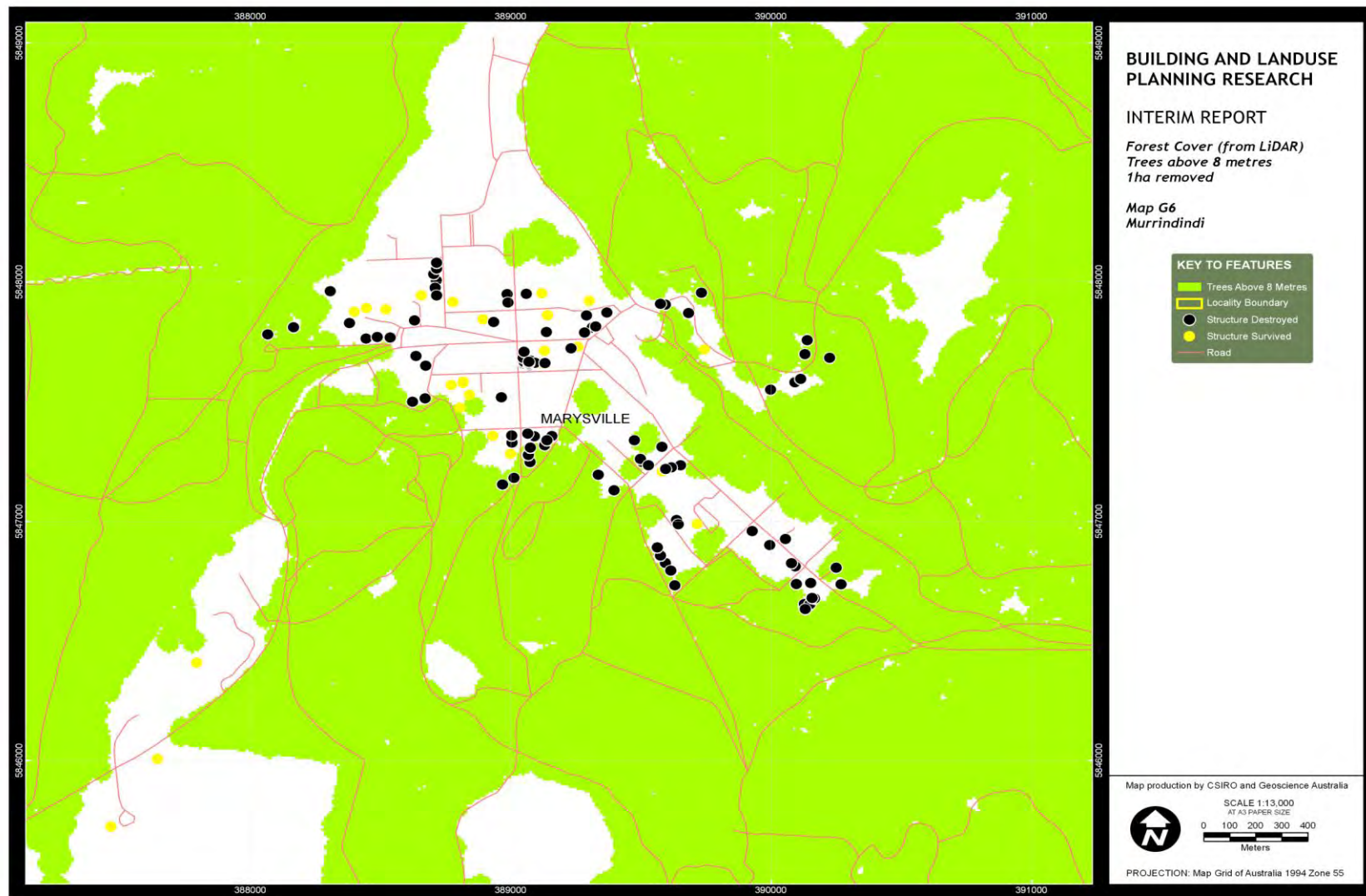


Map G5 Wildfire management overlays and house damaged Murrindindi Region





Map G6 Forest cover ( from LiDAR ) Murrindindi



Map G7 Example of outbuilding Murrindindi Region (Marysville)

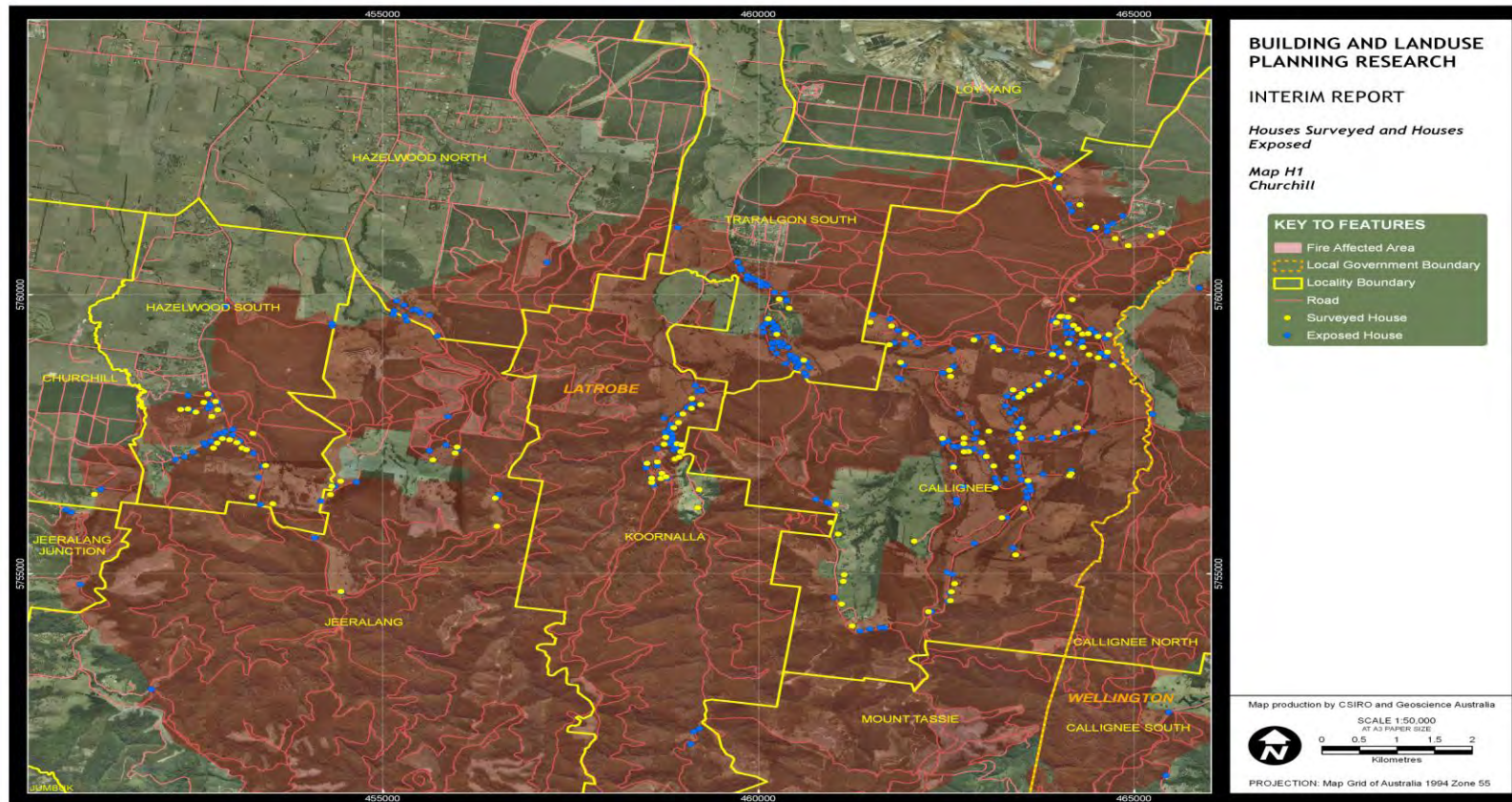




## APPENDIX H – CHURCHILL FIRE

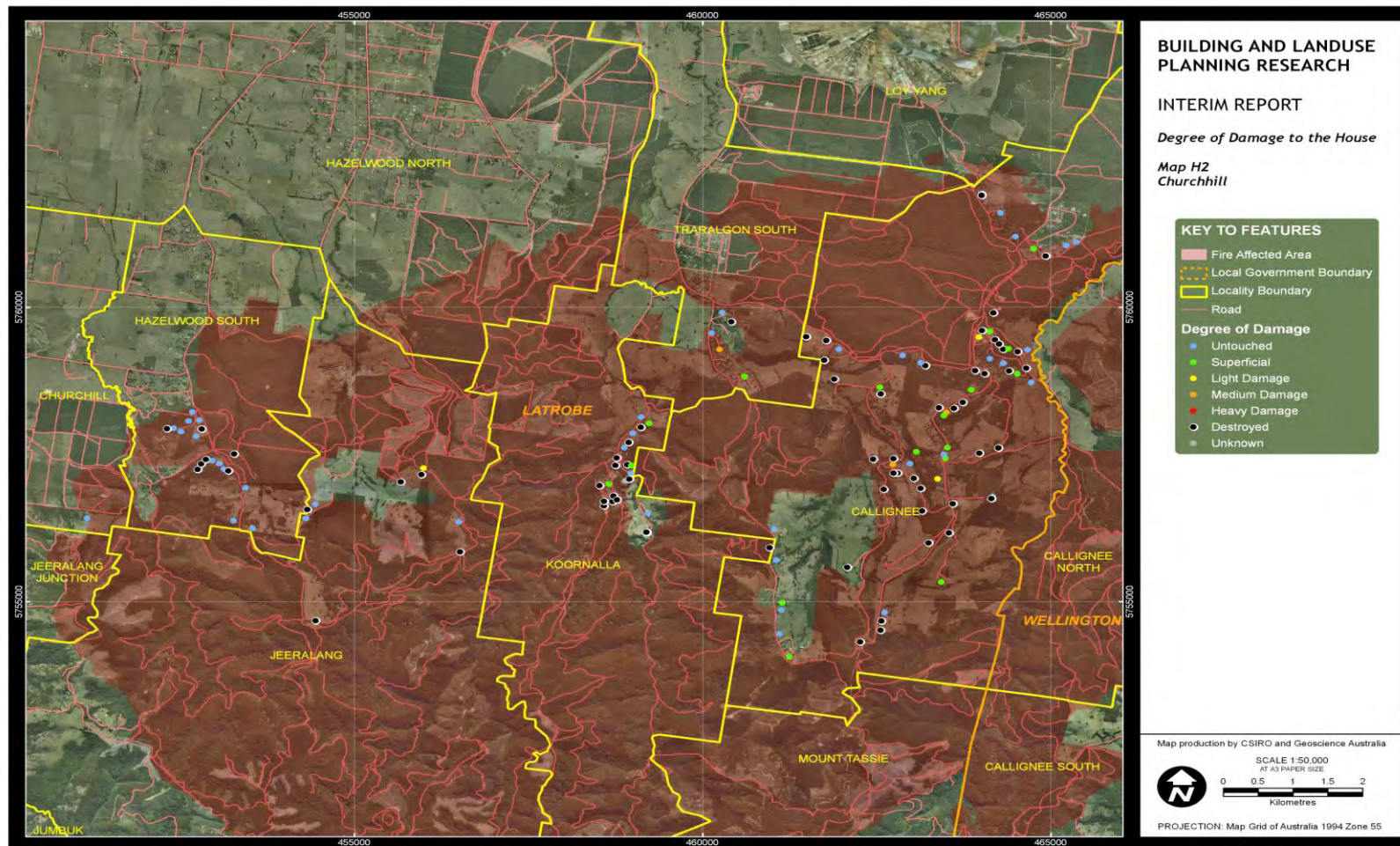
Summary of maps provided:

Map H1 Houses surveyed and houses exposed (NEXIS)



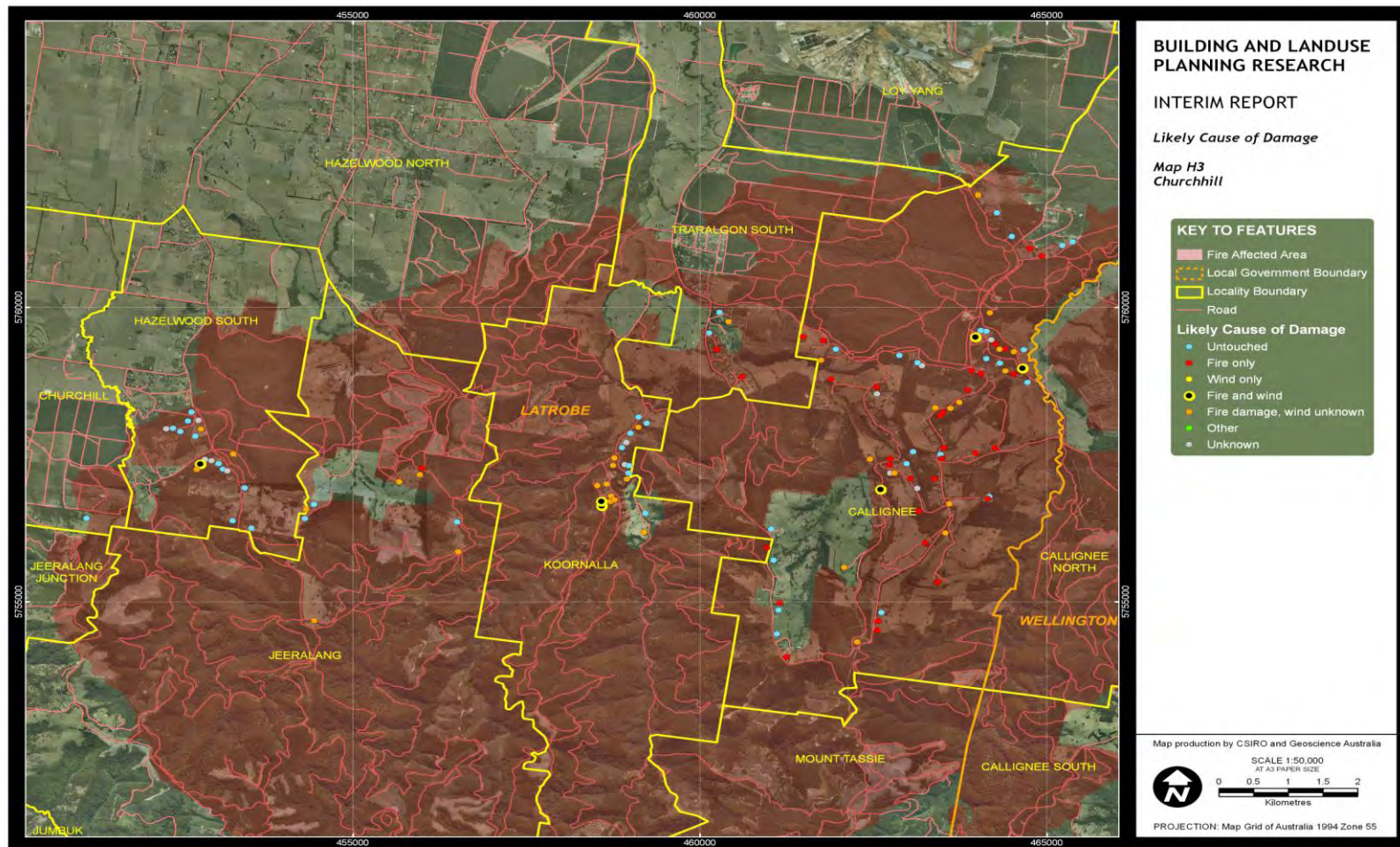


Map H2 Degree of damage to the house Churchill



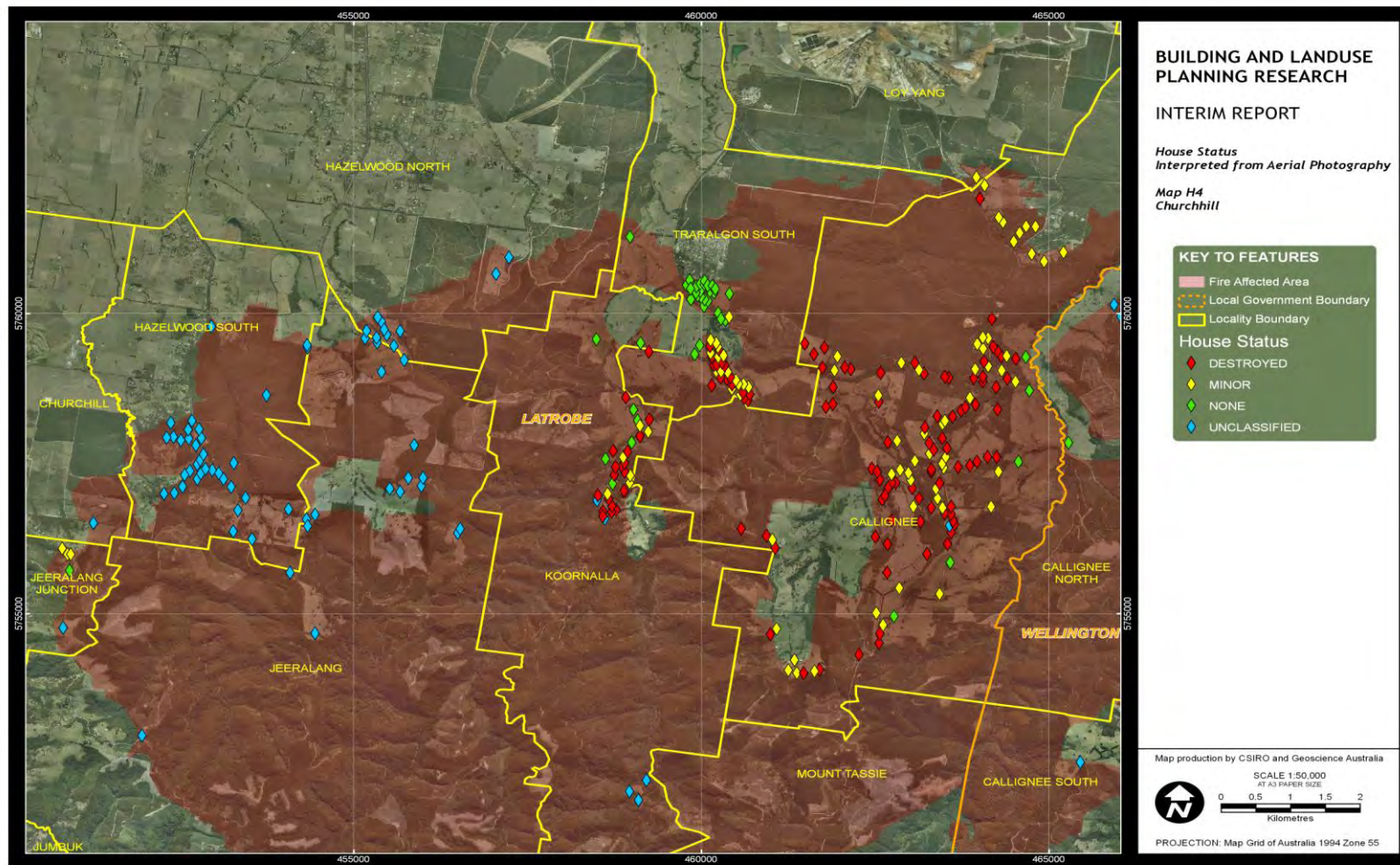


Map H3 Likely cause of damage to the house (fire and wind) Churchill



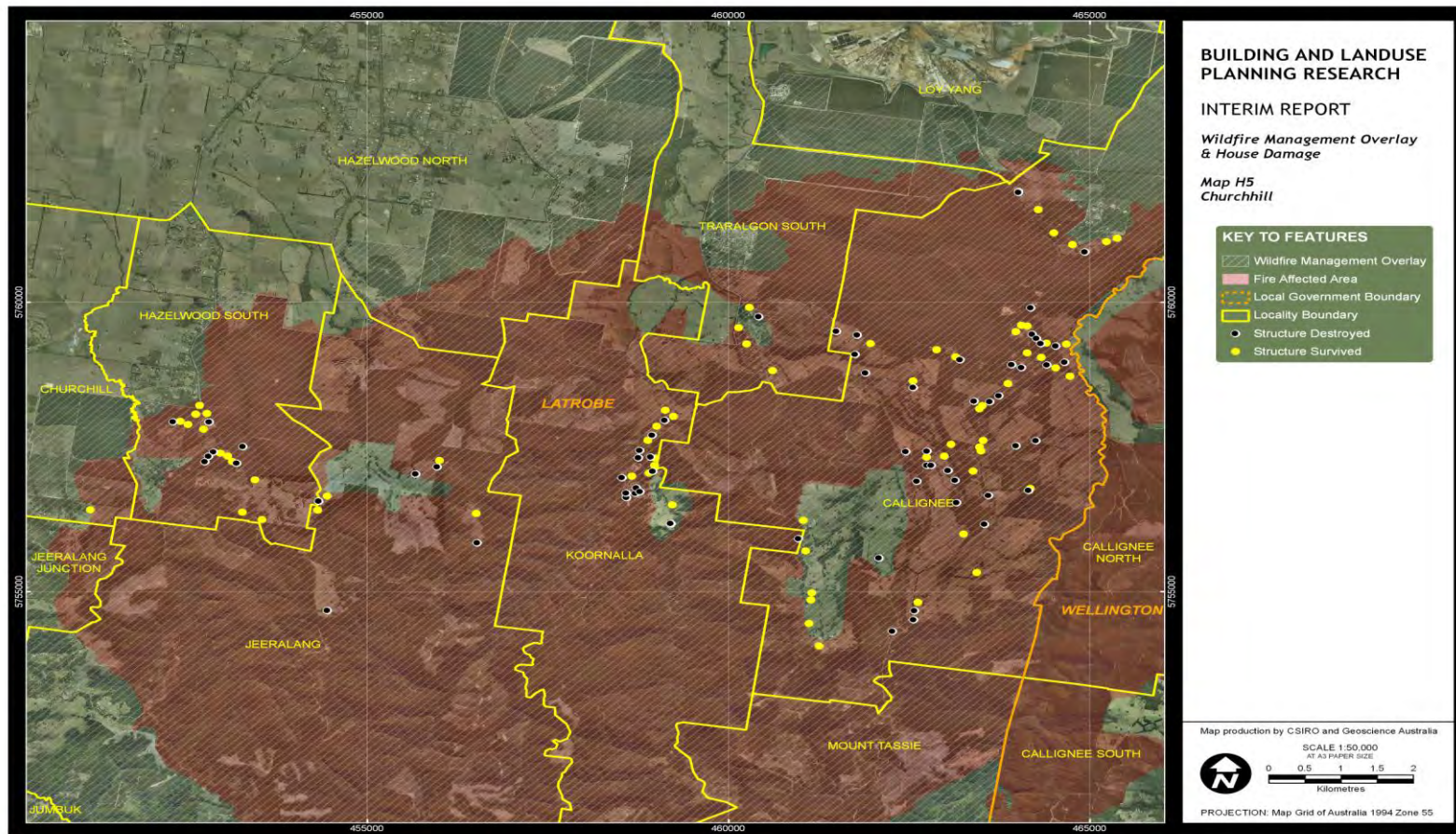


Map H4 House status interpreted from aerial picture Churchill





## Map H5 Wildfire management overlays and house damaged Churchill

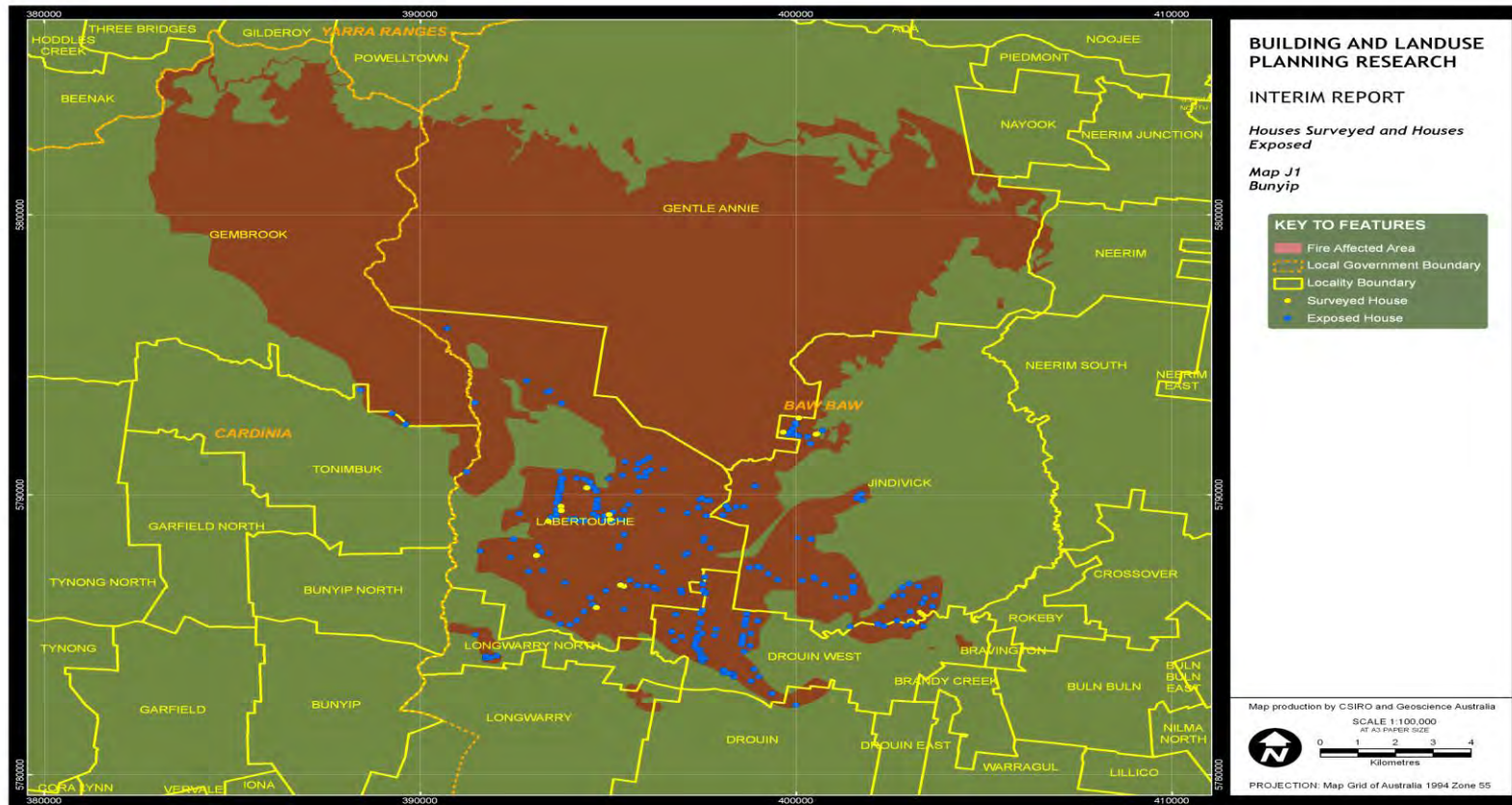




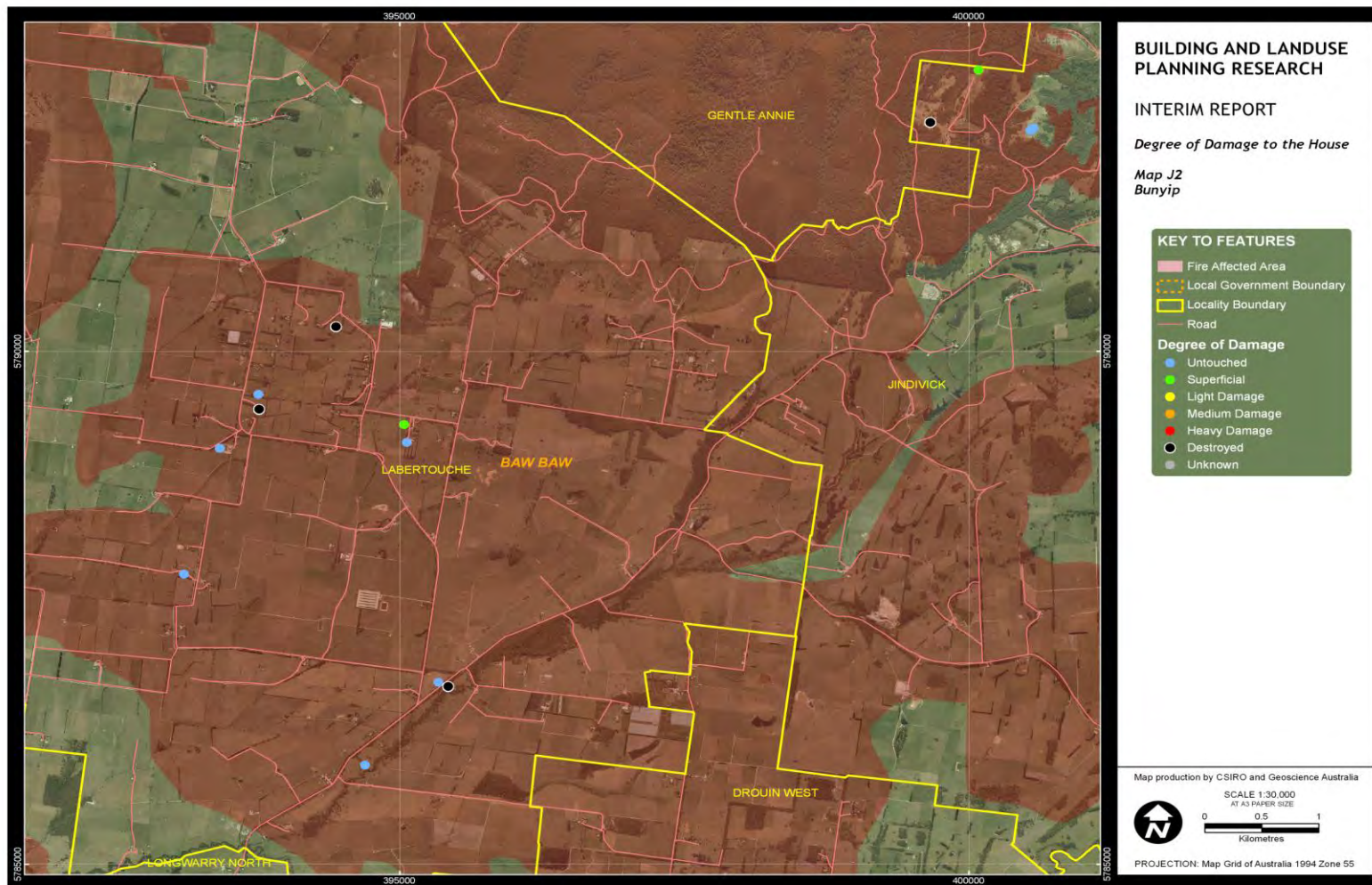
## APPENDIX I – BUNYIP FIRE

Summary of maps provided:

Map I1 Houses surveyed and houses exposed (NEXIS)

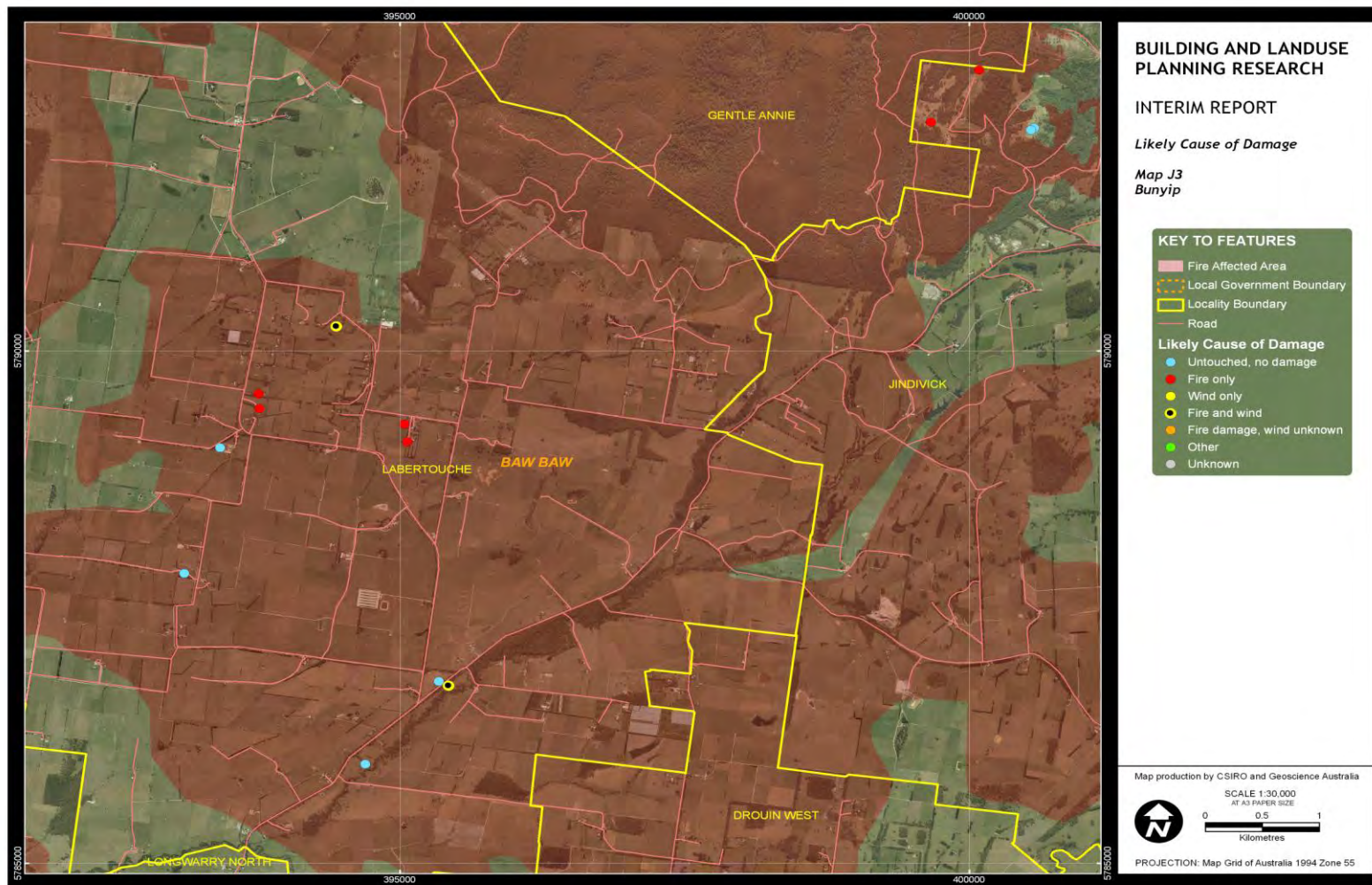


Map I2 Degree of damage to the house Bunyip

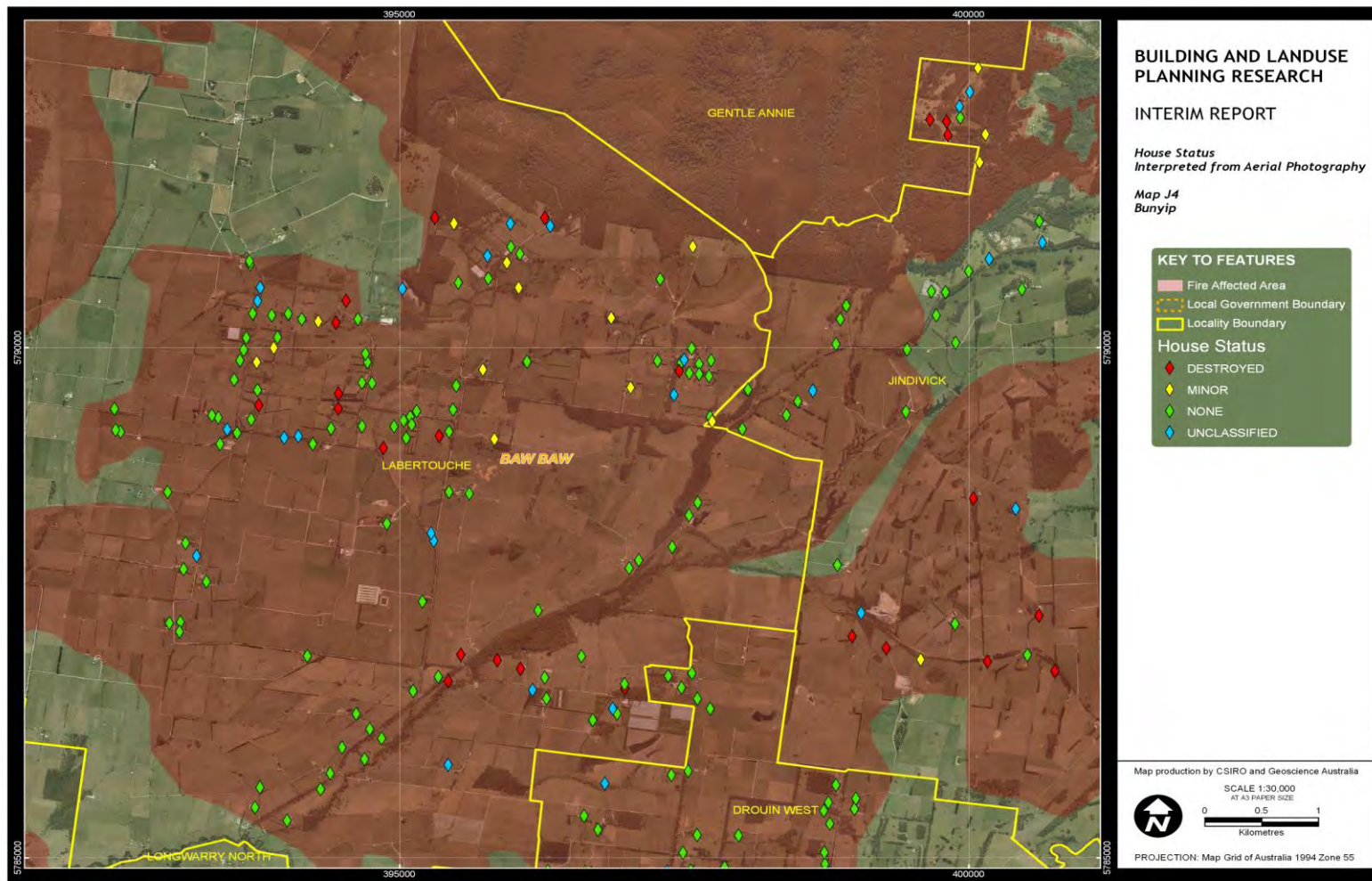




Map I3 Likely cause of damage to the house (fire and wind) Bunyip

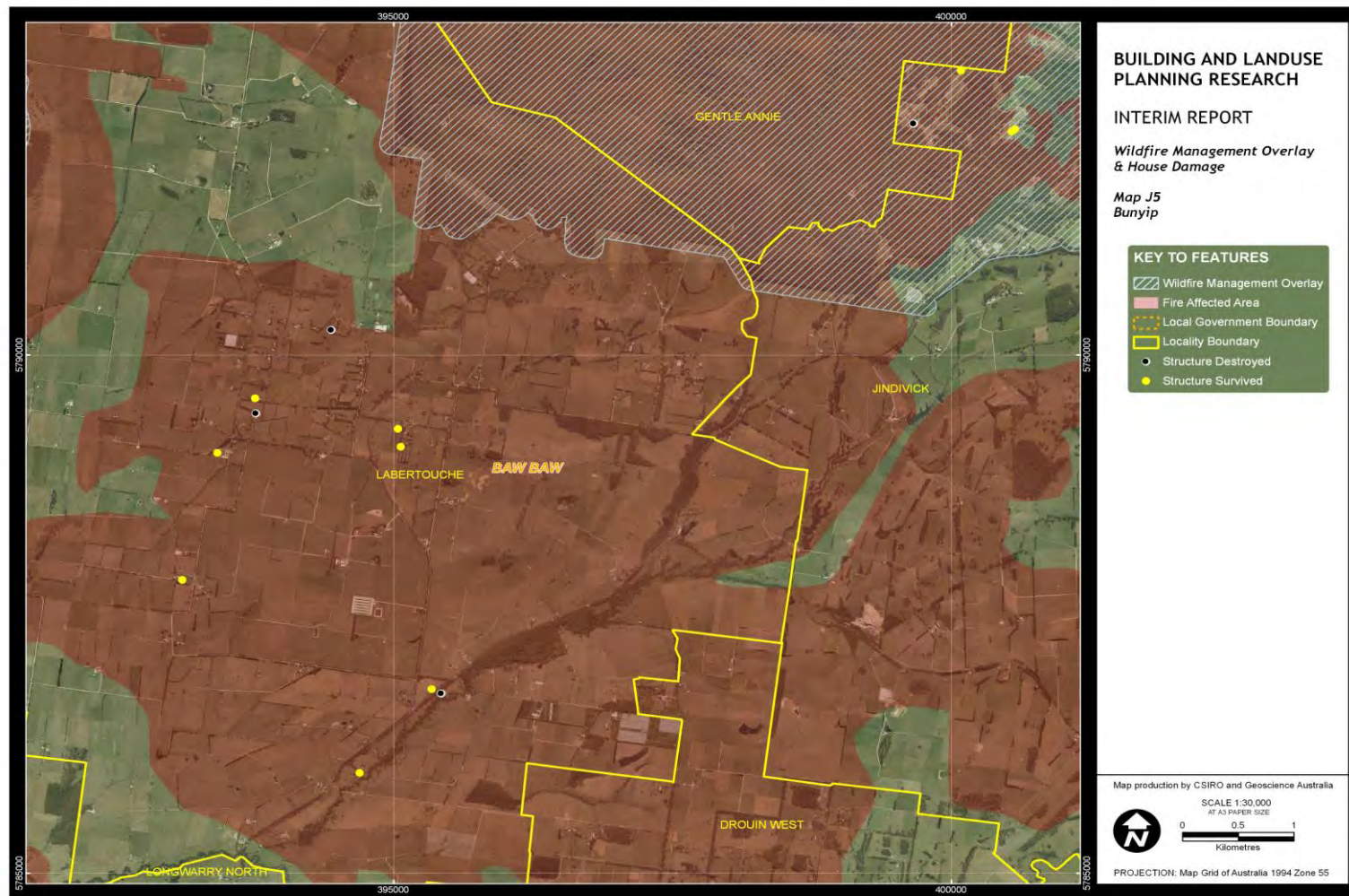


Map I4 House status interpreted from aerial photography Bunyip





Map I5 Wildfire management overlays and house damaged Bunyip

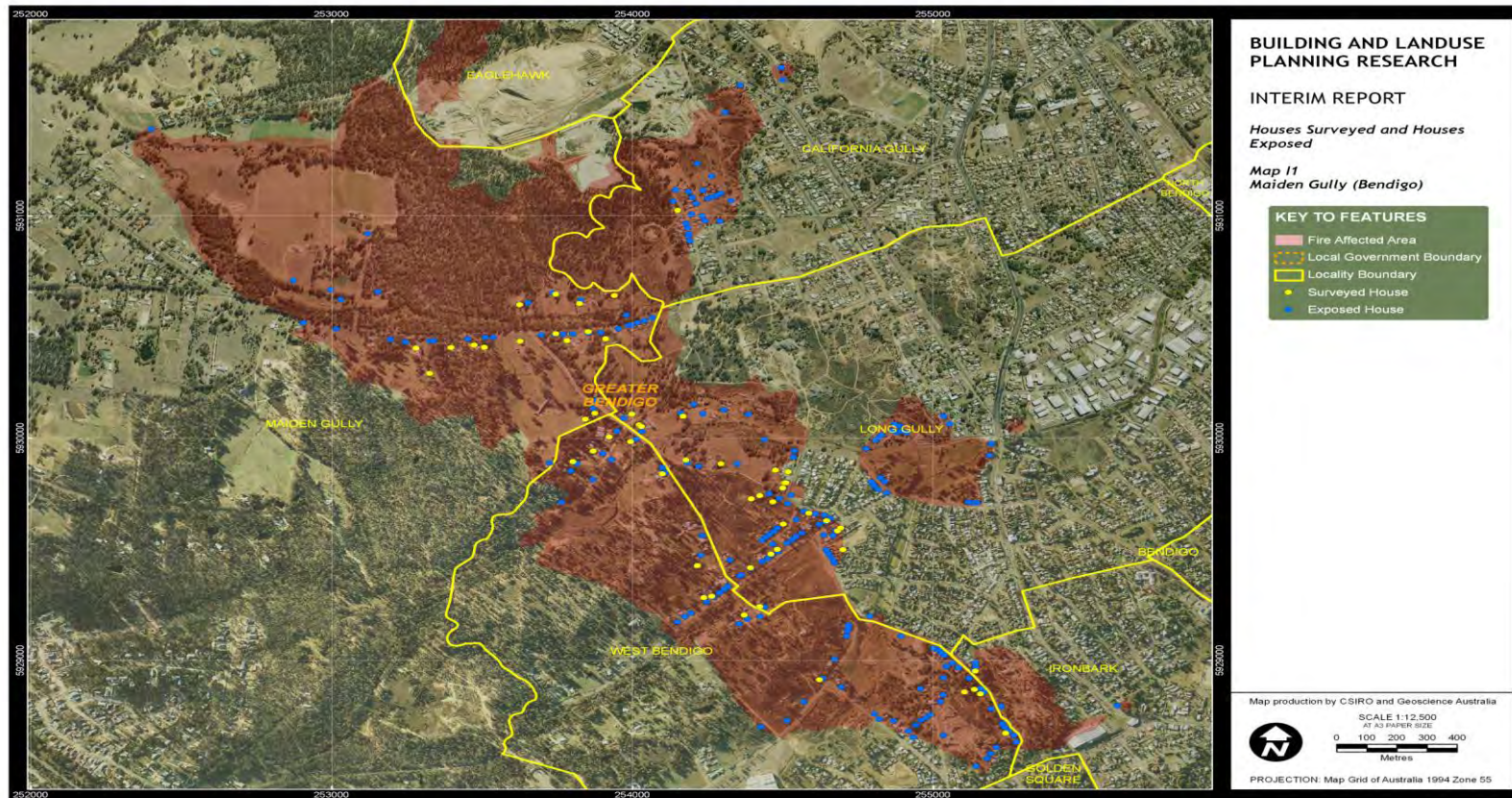




## APPENDIX J – MAIDEN GULLY (BENDIGO) FIRE

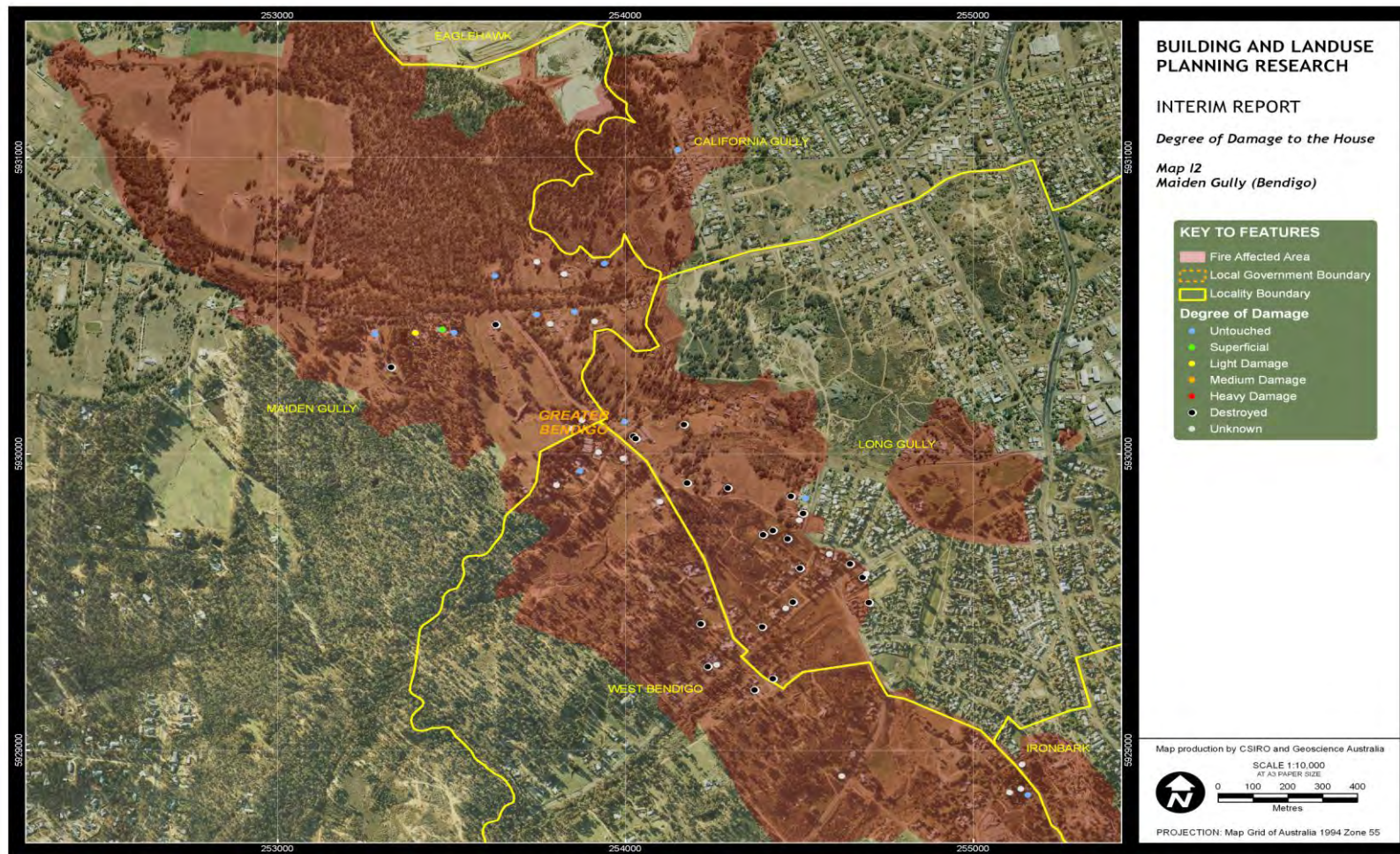
Summary of maps provided:

Map J1 Houses surveyed and houses exposed (NEXIS)



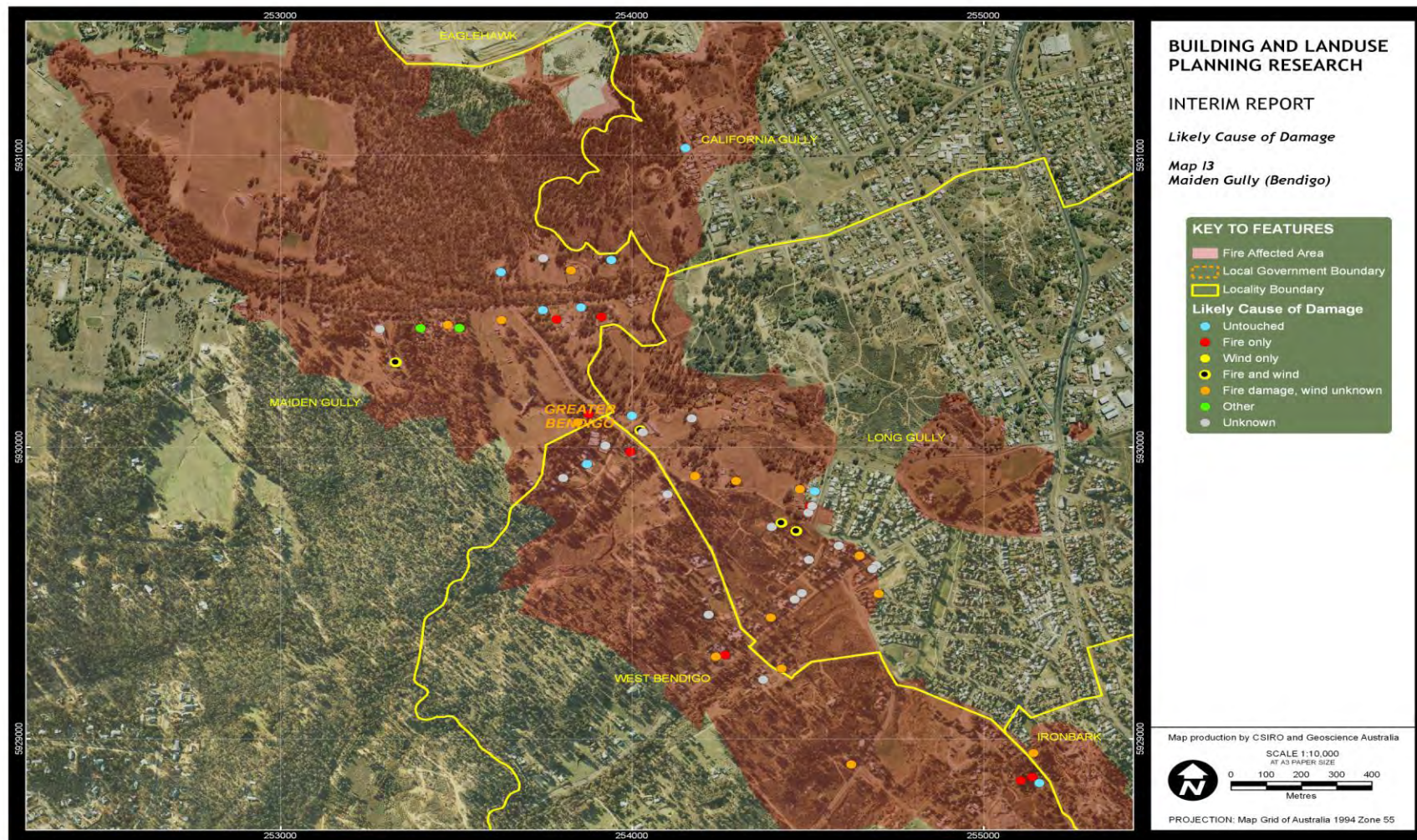


Map J2 Degree of damage to the house Maiden Gully



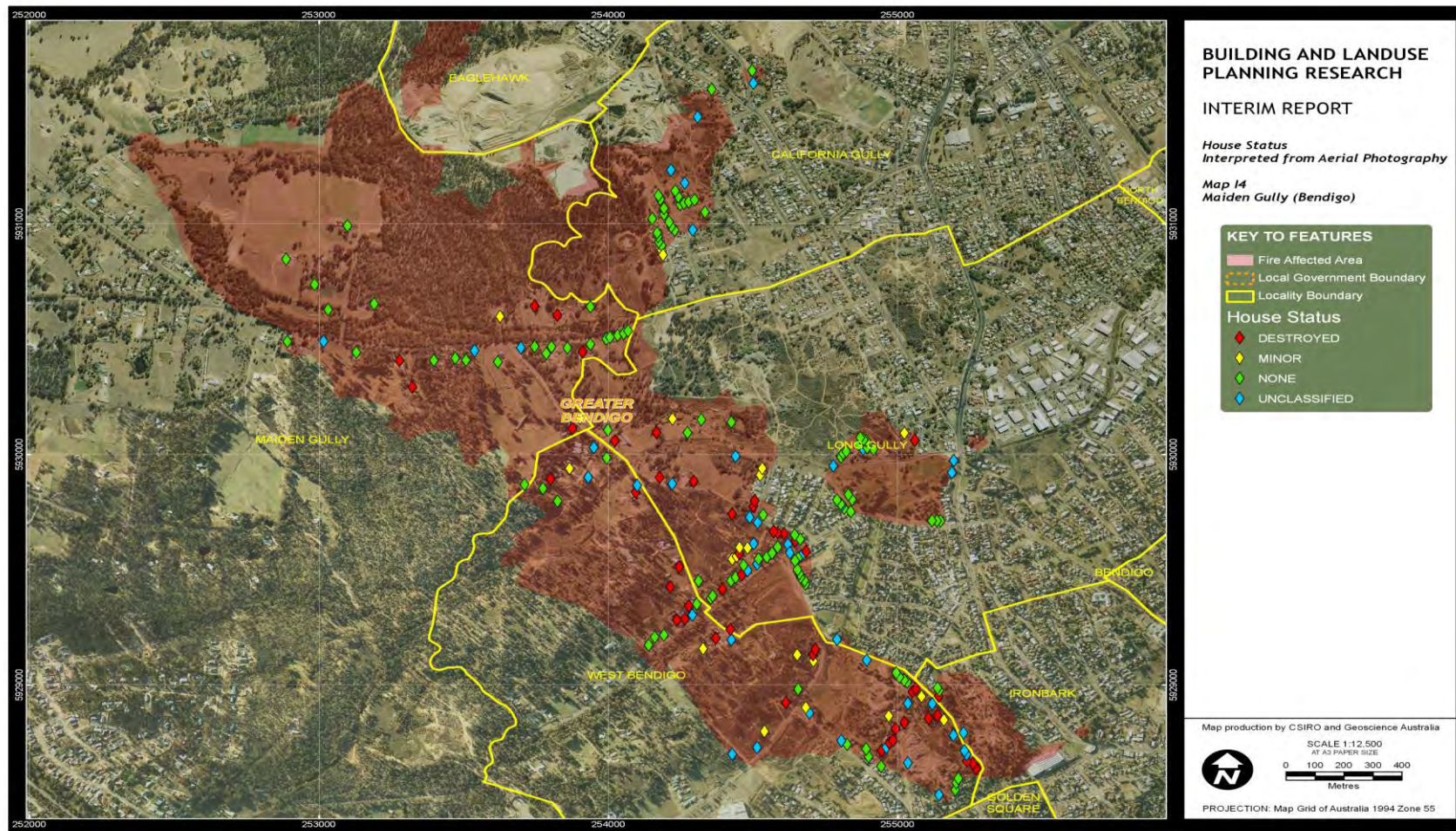


Map J3 Likely cause of damage to the house (fire and wind) Maiden Gully



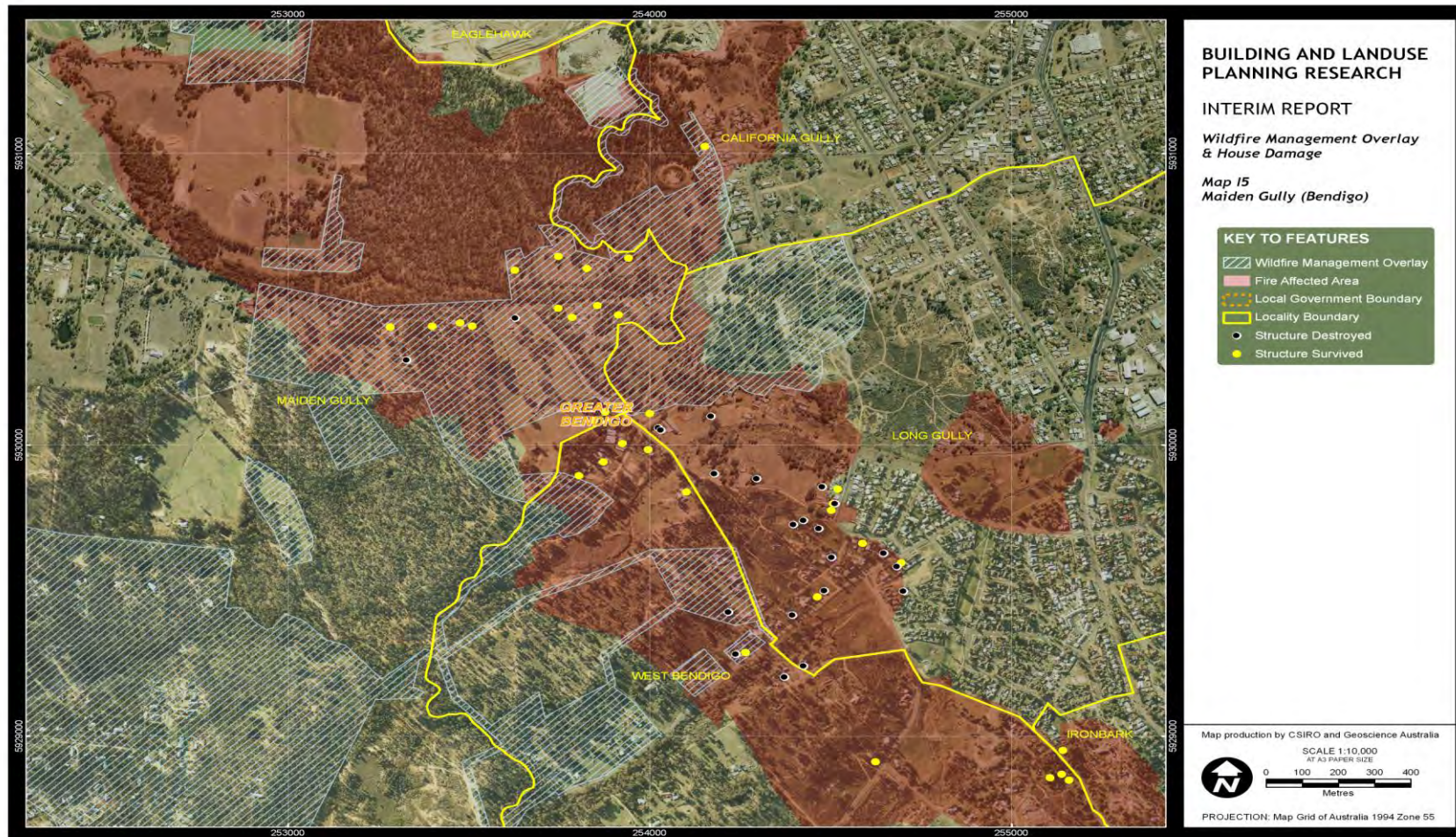


Map J4 House status interpreted from aerial picture Maiden Gully





Map J5 Wildfire management overlays and house damaged



## TRANSCRIPT OF PROCEEDINGS

*The attached transcript, while an accurate recording of evidence given in the course of the hearing day, is not proofread prior to circulation and thus may contain minor errors.*

### 2009 VICTORIAN BUSHFIRES ROYAL COMMISSION

#### MELBOURNE

TUESDAY 1 SEPTEMBER 2009 (43rd day of hearing)

BEFORE: THE HONOURABLE B. TEAGUE AO -Chairman MR R. MCLEOD AM -  
Commissioner MS S. PASCOE AM -Commissioner

[Key: **BOLD- Justin Leonard**; non-bold – Others]

MS RICHARDS: If I can move now to a different report, the interim report prepared by the Bushfire CRC which was tendered some time ago. It is exhibit 126. The document number is (CRC.300.001.0001\_R). I would like to go straight to part 3 of that report which commences at page 0117\_R, or actually 118 is probably the best page to go to. Mr Leonard, during the last hearing block the interim report of the Bushfire CRC was tendered in evidence. We have already heard from Professor Handmer, who was the lead author of the human behaviour part, although not specifically in relation to the contents of this report. Just by way of introduction, there are three major parts to the report, are there not? There's a part dealing with fire behaviour, there's a part dealing with human behaviour and there is a part dealing with building and land use planning ?

**That's correct. I think there is also a smaller part that deals with demographics and there is a reference to integrative studies that are under way?**

Yes, and each of those sections was managed by a different group that conferred in an ongoing way. You were part of the group that prepared the building and land use planning part of the report, part 3?

**That's correct.**

In fact you are identified as the lead author of that report or that part of the report?

**Yes, and I coordinated the post bushfire survey effort with respect to this area as well.**

What I would like to do with you with what remains of the morning session is to ask you to take us through part 3 of the report reasonably briskly, starting with the methodology that was adopted which we see at page 0140\_R?

**So we were tasked with collecting all the relevant time-sensitive data that was feasible with regard to building and planning related issues. So our approach was twofold. One was to quickly ascertain the degree or the range of remote sensing data that could be found pre and post bushfire. That's visual aerial imagery and LiDAR, which is like a ranging, scanning radar from the sky that finds the ground surface and also the scatter or the back scatter from vegetated environment and the built environment. So that helps us locate those types of objects and qualify the types of vegetation in**

the landscape in a broad scale sense. Combining the two together gives us visual and spatial information that helps us determine perimeters of forests, whether we have bare earth or grassland surfaces and where building envelopes may reside. In considering that type of data it makes our field data collection efforts far less onerous because we can rely on not having to collect those bodies of information in a spatial sense when we are out in the field. So our other key approach is to send surveyors out in the field and to collect spatially relevant data. So, for example, they would go out, locate individual houses, identify where they are in the landscape, attribute that house with a whole range of observed details like construction type, status of structure, whether it was burnt or damaged or untouched, all of the relevant building details, and then look at all of the other elements around the house or evidence of those other elements, reconfirming its proximity to vegetation types and bring all that back as a complete spatial dataset that can be navigated through readily when you have brought the data back to one location.

So in the field survey there was literally a survey, was there not, with a set of questions for each building you looked at?

That's right, except that rather than use the approach that's been taken in past bushfires where we actually physically go out with a set of questions that we answer through a tick box approach, we actually went out with computers, touchscreen computers in the field with spatial referencing software on them and physically added objects in the landscape; like, here is a tree, here is a house, here is a pile of wood, here is a gas bottle, and its status is this, this and this. So you actually more or less can recreate the 3D environment that the people went out and collect the data on. So it is a much higher level of data quality and thus provides a much greater capacity to review and analyse it in relation to the spatial arrangements of objects and the way that played out in the real bushfire scenario.

And clearly has the benefit of immediate data entry rather than it having to occur in an office some time later on?

Certainly. So the data capture of this magnitude involving well over a thousand houses, that dataset was able to be compiled in a much shorter timeframe because the demands for post-processing were far less. You say at 5.1.2 that the surveys were carried out between February, so at a time when the fires were still burning, through to 24 April.

What areas were surveyed?

There are a number of fire perimeters that we identify in the report later on. Can I just maybe find the relevant table. It certainly involved the Kinglake-Murrindindi complex. I should speak authoritatively off the actual --Please take your time to find the part you are looking for? So the Churchill fire complex; the Kinglake-Murrindindi, which were combined; Maiden Valley, which is in the Bendigo region; Bunyip; and Churchill.

So there was field data capture, and you describe in the report exactly how that was done. Then you have also mentioned the remote sensing. There were three specific areas that you concentrated on, were there not, that are set out in a map on page 0148 or page 31 of the chapter? The three regions? Yes? This was in reference to a more detailed study area



for which we provide examples of how remote sensing can be used in a detailed analysis approach. There was Pine Ridge Road, which was an iconic area of high loss where intimate flame attack had occurred on a number of structures and there was interesting surface topography and proximity between forest and structures in that area.

And that's the small red rectangle in the middle of the larger green one? **That's right. And then obviously the larger Kinglake region is an area of specific interest involving a significant number of house loss within that perimeter, and of course Marysville being another significant area of focus. So this approach here is more of a demonstration study to show the potential value of remote sensing data analysis and approaches and its potential integration with the types of survey data collection we also pursued.**

There were some other sources of information that you took into account which you have listed at part 5.3, other spatial datasets, so at page 44 of the report, CRC page 0161?

**So there's a whole range of spatial and non-spatial data that can also be combined. Obviously observations of human behaviour and their role around specific buildings has been demonstrated in past fire surveys, that the human behaviour or human interaction around the house has a profound influence on its survivability. Obviously the weather conditions, which in fact is a spatial variable because weather intensity varies in both time and space throughout the fire events. It would be fair to say that each of the fire perimeters experienced quite a different localised fire weather intensity within them. Obviously the resultant fire behaviour which is a combination of fire weather terrain, vegetation type et cetera that all occur in a spatial sense, and that's a key area where we can draw on other data capture and other survey efforts and combine them with these.**

As I read the report, those other spatial datasets are not really complete yet, particularly the human behaviour and the fire behaviour sets which were works in progress at the time that you were preparing this part of the report? **That's right. So in preparing this part of the report our major priority was to assemble the data in a state that was analysable, which took up most of the time period from data capture through to the time the report was finalised, and we had a very narrow window to actually perform some analyses and some demonstration, and that was of the order of two weeks, which we have provided in this report as well as the description of the data. The human behaviour, the weather conditions and the fire behaviour were also still under development. So we didn't get the opportunity to integrate in a major sense these other datasets into ours. So there are a few examples where we have taken human behaviour accounts of some 200-odd samples and shown how they can be effectively combined to reveal a lot more valuable outputs and observations.**

All right. Taking due account of the lack of technical knowledge in your audience, can you explain broadly how you set about analysing the data that you had in the time that you had available?

**So in terms of data analysis there are a number of ways that we can create comparisons. A key one is through cross-tabulation. So you can look at something as**

simple as the status of the house, whether it has burnt down, whether it is completely untouched or whether it has some degree of damage, and its correlation to another factor like the type of windows it may have, its proximity to bushland or the type of building material that's used on its facade. In a step by step you can cross-tabulate each of those events. Now, it becomes more complex to cross-tabulate three variables instead of just two. But it is really just a case of looking for statistically relevant correlations between various factors to verify either the theories we have or to reveal new correlations that are quite statistically profound that lead us in new directions in trying to understand what actually played out in these approaches.

So a high correlation between two or three different variables might highlight an area for closer inquiry because of course correlation does not equal a causal relationship?

**That's right. We have to build up a greater theory. You might have a relationship like overhanging trees and a proliferation of building loss. The specific reason why the overhanging tree caused the loss might not be immediately obvious. It might be individual trees or it might be a lot of trees overhanging. It may be something like the proliferation of leaf debris around the house is the main driver, it might be a role of the trees regularly falling on the houses or it might be the radiation or flame contact the trees produce to the house or it might be a combination of all those things. So it certainly identifies key areas to drill down and start petitioning the datasets up into finer parts. So we might then break that dataset up into trees that were in isolation and trees that were highly prolific in overhanging the house and then see if there is still a correlation or whether the correlation is predominantly in one of those datasets.**

Am I right in the conclusion I have reached in reaching your report that you are really at a very preliminary stage in identifying those interesting correlations? **Yes.** But some of them you have set out in the section headed "Results", part of this chapter? **That's right, and really the intent of producing the results section is to take the reader through a sample of the breadth of analysis that could be drawn from this dataset rather than to make clear and definitive observations as to what the dataset is revealing. In many cases we have only analysed a limited number of surveyed houses where it could be much larger, and in many cases we have only obviously compared a few isolated examples of their components rather than considering much larger datasets that would give us a far more comprehensive understanding of any of those individual factors.**

On the understanding that these are preliminary results, can you take us through them one by one, I think starting with 7.2, "Summary of house damage for all the fires"? In relation to each, if you could identify the particular finding or preliminary finding or correlation that you have identified that's worthy of comment?

**I guess the first overview is to look at each of the different fire perimeters and see whether there is a significantly different ratio of destroyed, partly damaged or untouched structures, because this provides a potentially valuable insight into the intensity of a fire in a given fire area or the vulnerability of the built assets in those areas or a combination of the two. The relative percentages are actually quite variable throughout those fire perimeters in table 9. Which I think is on the next page from the one that's on the screen? Where we can take something like the Bunyip fire where 29**

per cent of the surveyed houses were destroyed as opposed to 57 per cent that were untouched. These are a representative sample of the houses rather than all the houses that were surveyed in any of these fire scars. Because we go out and try to select a representative area, it is only attempting to mimic the overall proportions that you might find in any given fire. In fact later on there's been other attempts to understand destroyed houses versus not destroyed houses from a spatial reconciliation approach where you could actually make a determination of all the houses within these fire perimeters rather than a representative sample that this report provides. So if we take something like the Murrindindi, compare Bunyip to Murrindindi, we have 75 per cent of houses lost as compared to three houses survived. So that is suggesting a far more extensive and prolific loss in that area. That is obviously driven by the fact that we may have losses within that fire perimeter that represented something like Marysville.

Under 7.2.1 you deal with the degree of damage to the house?

Yes. In our survey approach we tried to specify specifically the degree of damage, and that can vary from obviously destroyed to heavily damaged, which is where the effects of fire have entered the structure but have managed to be stopped. So you would expect that category to be relatively low in its representation, or be in an area where there is a high degree of human activity. We are looking at table 11; is that right? That's right. Table 11. Then we have medium damage, which is more of an extensive external exposure that hasn't entered the structure; light damage; and then superficial, where you might have a few burn marks or what-not; and untouched meaning absolutely no evidence of fire effects in that area.

As I read this table, it is consistent with what you have told us earlier, that the tendency is for either a house not to catch fire or to be destroyed completely and there is very little in between?

That's right. So we tend to invariably find in fires to get a lot of untouched and superficially damaged structures, relatively few medium and heavily damaged structures and then a significant number of completely destroyed.

Then likely cause of damage over the page at 7.2.2?

Because wind has a potential to play a role in all fire events, it is very important to identify whether fire was the causal approach, whether wind on its own was a causal approach or whether it was clearly a combination of the two. What's particularly clear in this work is that 13 per cent of the surveyed structures were identified as being a combination of fire and wind. In fact we found four cases in our survey effort where a house was damaged purely by wind, like, it was compromising of its structure by wind alone, where the fire effects weren't prevalent in the area but it was within the fire perimeter; it was just that fire wasn't particularly active within that specific location. So this is unusually high. I think it appears to be typical of an event under such a high fire whether intensity where the wind effect starts to become a very dominant factor in itself.

The next, at 7.2.3 on page 56, you deal with identified mechanisms of bushfire attack. As I read this part, the significant preliminary finding is that there is a much lower proportion of

ember-only attack as compared with the other attack mechanisms that are listed there when compared with previous fires?

**Yes, that's right. So direct bushfire attack is relatively high at around 21 per cent. There appears to be a lot of interaction from secondary objects around the house through flame contact from surrounding bush or isolated features, some radiant heat and the combination of embers and radiant heat. It may also be a feature of the fact that we combine embers -the way we combine categories in the past, but it is clear that radiant heat and the interaction of other objects around the house has moved up in its dominance in what appears to be coming out in the surveys.**

If we could move to 7.3, which is on page 60 of the report, "Characteristic of house design and material". In this part of the report you go through various characteristics of house design, materials used and do some preliminary analysis of the correlation between the design feature or the material and the survival of the house?

**Sure. So what we are attempting to illuminate in this section is the probability of embers entering into the structure through gaps, the probability of ember ignition against the envelope, the probability of ignition from radiant heat and flame, those key mechanisms that we have discussed previously, and to potentially cross-correlate those with obvious and not so obvious building design features that may then reveal a susceptibility or lead us to further investigation within the dataset.**

The first one was perhaps a not very obvious one, was the correlation between the number of storeys and building survival. What did you find there?

**Because a lot of features like whether you have one, two or more storeys is a constant question to ask, it is important to either show that there is a correlation or in fact that there isn't. There's not a huge correlation. I guess a higher proportion of houses with one storey were destroyed compared to houses with two storeys. This may simply be an expression of house age rather than the number of storeys, as it would be fair to suggest that older houses in the region are more likely to be single storey. So it is sort of a case where we see correlations but in fact we have to go further to either find whether it is in fact single storeys are more susceptible than two, which we don't have many plausible theories on, and as to whether there are other features for which the number of storeys, for example, express in other areas.**

The next one you deal with at 7.3.2 is flooring systems, where I think it is fair to say the findings are very preliminary. What were you able to draw out of the correlations that you did here, or the analysis that you did here?

**So what we found that we had a reasonable representative sample of slab-on-ground versus floors that were supported by various types of stumps and timbers. In terms of the destroyed -- If you could just give us a hint which table you are referring to, that will help the operator to get the right one on screen?**

**"Main materials supporting floors", table 18. I guess because we haven't made any relevant comment as to what that correlation reveals, we haven't found there is any sort of reason to comment on that as yet.**

Next is 7.3.3, "External wall materials", and there are some interesting findings that emerge from this part of your analysis?--

Yes, I guess external wall materials are sort of one of those features of a house that people relate to and try to develop theories on whether it has or hasn't an effect. Past bushfires of some fires have inferred there isn't a great correlation between survivability and wall material type. But in this preliminary finding we are actually seeing a significant correlation where brick construction has performed significantly better than lighter-weight construction approaches like cellulose cement or timber-clad houses which also tend to be raised floor type construction style houses. So there's obviously more to -like, brick houses also tend to be slab-on-ground construction, which has less vulnerable floor systems. So there may be a reasonable correlation between the performance of the facade and its floor system combined to produce a greater outcome for that construction type.

Then 7.3.4, "Roofs", on the next page. What were the preliminary findings in relation to roofs?

Once again we haven't made any direct reference to an observed correlation from these statistics, suggesting that there isn't a strong statistical driver. I guess in the past we observed that the complexity of roofs plays a role, and there may be a correlation here but we haven't obviously had time to review the report -review the stats and write the necessary observations.

You then go on to deal with windows at part 7.3.5. I understand what you say there, that that's something that you have left for future analysis?

That's right. There's a significant number of variables because in a window system you have a combination of glass type and framing material type. Because windows break through a radiant heat threshold approach, it is important to start categorising the structures in potential or expected exposure that they would have received and then to analyse those subcategories. So you take the houses that are likely to receive flame contact or a high degree of radiant heat, review the window, whether there is a window correlation in that and then move down through the process; otherwise we would end up having a large number of houses that were subject to less than 12.5 kilowatts of radiant heat exposure in our sample simply creating noise and undue variability and making it more difficult to find any statistical significance.

Then the last one in terms of design and materials is deck and verandah. Were you able to draw any preliminary conclusions under that heading?

I guess we found a large number of combustible decks. So we had a really good sample size for those types, and we found plenty of examples of ignitions of those deck materials. Ideally it would be appropriate to look at the decking material, the decking type and the proliferation of observed ignition points on those. But, because we only correlated these between destroyed and undestroyed houses, it is not the appropriate time to draw out observed conclusions from that. Then 7.4 deals with damage to outbuildings, and there's a preliminary indication that sheds have a slightly higher likelihood of loss as compared to a house. Some possible reasons for that present themselves; that houses are more likely to be defended than sheds.



There may be other reasons?

**For instance, the degree of tightness or weather tightness a house is likely to be built with compared to a shed and the likely inference that that has for its performance against ember attack and other effects, other fire effects.**

Then part 7.5, vegetation around the house has revealed some interesting preliminary findings?—

**I guess this is where we observed correlations between overhanging trees, the presence of overhanging trees and the likelihood of loss, and that would be a key area to drill down into as to what the specific drivers are. That's a point I covered as an example a bit earlier.**

Then 7.6, protection measures, water supply. There is a finding here that there is a strong correlation between house destruction and lack of active water defence which I take it didn't challenge earlier learnings on that subject?

**You could imagine that identified use of water as a defence mechanism also infers that there was human defence active either before, during or after the fire event and, that being the single biggest influencer of house survival in past bushfires, it is no surprise to find it being a consistent driver here also.**

At 7.6.1 you deal with type of water supply. I won't take you to that. If we could go to 7.6.2, water storage, which is essentially the type of material that tanks are made of?

**Yes, we collected this type of data to start to comprehend the reliability of the water source, the size, the particular type of containment of water that may have been used to defend, and I guess some of the clear observations was the performance of different type of water tank material types. Concrete and steel proved to be relatively good performers, whereas fibreglass and polyethylene tanks readily failed in a lot of cases. I guess that correlates well with our experimental work on tank performance that we have performed in the past as well that showed that polyethylene tanks in complete isolation with no other fuel sources around them can actually hold water, but may melt or burn down to the waterline, but if any other fuel materials reside near the tank like a shed or some stored combustible material or in fact another tank, then it is likely that they will burn and fail, completely rupture and lose their ability to hold water.**

In part 7.6.4 you deal with sprinkler systems, and there is I think a potentially interesting correlation that emerges from this data?

**Yes, obviously the use of active spray systems around the house had a reasonable correlation with house survival, even despite the fact that it was observed that pump failure or a means for pressurising those systems failed at some point during the fire exposure.**

I guess it is fair to suggest that somebody that's gone to the point of installing a spray protection system or a sprinkler system is also likely to be the same type of person that has addressed many other risk mitigation features around their building. This, as you point out on page 82, is a very rough correlation. There's been no analysis of whether the sprinkler

systems were in fact activated. It is just a correlation between the presence of sprinkler systems and the survival of the house?

**That's right. So it would be really useful to segregate the ones that were effectively activated and the ones that weren't, and then to drill deeper down into that data.**

7.7, dealing with accessibility, which I understand to be accessibility for emergency vehicles, and under that heading you find no correlation between house accessibility and the likelihood of house damage?

**That's right. Given that accessibility is a potential indicator of whether fire appliances can reach the building itself, there are just not enough examples where the interaction of fire trucks and houses were to overcome the variability of the dataset.**

Then land use planning, 7.8, starting on page 85, what you have done here is look at the extent of house loss and compared where the houses are with where the wildfire management overlays are. What are your results?

**We were able to attain an understanding of where wildfire management overlay areas were declared throughout the fire-affected regions. So we were able to map the number of destroyed houses that we had surveyed in relation to whether they resided within a wildfire management overlay or did not. We found that more houses actually burnt down that were not in a wildfire management overlay compared to ones that were.**

You give a figure of 58 per cent of all surveyed structures were not within a wildfire management overlay?—

**That's right.**

59 per cent of the surveyed structures that were damaged or destroyed were not within a wildfire management overlay?

**Mm-hm. It is interesting to sort of go on to assess the observations that losses occurred. In our surveys we have a preliminary figure of something like 400 metres for which houses appeared to be lost from typical bushfire type vegetation. So that gives an inference that it is not just about an intimate relationship between sources of fuel and buildings, but in fact the effects of fire playing over a significant distance in the landscape. So this is part 7.8 that you are referring to?**

**That's right. House lost as a function of distance from vegetation. You refer in the first paragraph there to the Ahern and Chladil study that has studied the penetration of fires into urban areas and has come up with the figure of 85 per cent of house losses occur within 100 metres of continuous vegetation.**

As I read this part of the report and probably the next part, part 7.9, your preliminary results suggest that there may be a need to go back and have a another look at that figure?

**I think what appears to be occurring is the dataset that Ahern and Chladil considered was the representative dataset of fires up to that time, 1999, and their assessment appears to be quite reasonable from that dataset. Since that time there have been**

**fires of lesser severity and fires of greater severity. What appears to be the case is that, as fire severity driven by fire weather severity increases, then the distance for which the fire effects are reaching and causing loss are greater. So we might need to be considerate of the fact that, if we are planning for a higher-intensity fire event, we need to think about provisions for the performance of houses at a greater distance from conventional bush.**

So if you take 85 per cent as the acceptable level of risk, it might be that that 85 per cent figure requires a longer distance?

**That's correct.**

COMMISSIONER McLEOD: Would that be likely to be as a result of influence of fire caused by embers?

**Because the predominant amount of loss is in the absence of firefront interaction and flames and radiant heat anyway, it is given that these observations are mainly driven by the effects of embers and the follow-on effects of those. So it is reasonable to say that increased fire weather intensity or wind is one of the key drivers in defining fire weather intensity, is transporting ember attack, embers further and having them cause more damage at a greater distance from their sources under these higher-intensity conditions.**

MS RICHARDS: You have done a detailed analysis in part 7.9 of the report using the remote sensing results of the relationship between house distance to vegetation and what happened to the houses. This does appear to be a more detailed analysis than some parts of the report. Can you summarise what you have been able to draw from your analysis so far?

**Probably one of the most interesting observations is in the graph on page 90, at the top of page 90. It is actually the result of using remote sensing analysis and the physical distance between the housing envelope and a classified region of vegetation, in this case of forest, and what it shows is how the percentage of burnt structures declines as a function of distance from the forest itself. Within that graph we have looked at whether it is distance from any part of the forest or distance from forest where we have removed half a hectare isolated islands of forest or one hectare islands of forest.**

The light blue line is with the half hectare isolated areas removed and the dark blue line is with the one hectare areas removed?

**That's right. It appears to try and demonstrate whether it is large continuous forest areas that are producing the impact or whether it is a combination of small isolated forest and large pieces of forest that are causing the effect. In each case we have got a steady decline, but what is clear is that out to 100 metres we have still got a fairly high percentage of burnt structures. So these graphs are quite revealing in comparing back to the Ahern and Chladil observations to say that 85 per cent of the loss is more or less confined to the 100-metre range. This is showing that there is still a high percentage of structural failure well past the 100 metres.**

COMMISSIONER McLEOD: Any interpretation of the blip in the bottom line in the middle of the graph, why it would increase and then decrease in the middle of that profile?

**It is more of a statistical anomaly because we need to analyse a larger and larger region to get a cleaner correlation. It simply reveals that there is probably not enough data examples in that area that we get -where we have received an anomaly. It is a reasonable demonstration of the power of this type of spatial analysis, though, in informing our trends and approaches.**

CHAIRMAN: This may be an appropriate time. MS RICHARDS: Yes. I should be able to finish off Mr Leonard in about 10 minutes, if we could do that immediately after the break. I just want to ask him about future work. CHAIRMAN: Okay. We will resume with Mr Leonard, although do we know the position in relation to questioning?

MS RICHARDS: I have had no indication that anybody wants to ask him about that report. CHAIRMAN: That gives us a better idea. Thank you.

MS RICHARDS: Mr Leonard, before I take you to questions of future work, there is just one issue I would like to clear up about land use planning which is in part 7.8 of part .

You spoke about a finding that some 59 per cent of surveyed structures that were damaged or destroyed were not in a wildfire management overlay, but you do note at the commencement of that passage under the heading "Wildfire management overlay" that there was no information about which houses were built in compliance with wildfire management overlay requirements?

**That's right. That was in reference to the fact that that area had been declared a wildfire management overlay prior to February 7th.**

So indeed it is quite possible that a number of the buildings that were damaged or destroyed were built before the imposition of a wildfire management overlay on that land?

**That's right, so there would be a range of phasing in of wildfire management overlays throughout the period before February 7th, that's right.**

So these conclusions don't shed any light on the effectiveness or otherwise of the wildfire management overlay provisions?

**That's right, and I believe that even though a wildfire management overlay may be in place at a particular time, it doesn't guarantee that a particular house was built under that regime after that date also.**

COMMISSIONER McLEOD: It does raise some questions about the footprint of the overlay, though, doesn't it, if you indicated that quite a considerable number of houses burnt were outside the bushfire overlay area?

**I'm unsure of the process of deciding what is in an overlay and what isn't and also the timeframe in which it is implemented. I'm really not sure whether there was an intention to be more prolific in that description in future, or any of those points. It was**

**only simply to compare the observed loss versus the overlays that we understood it as at February 7th.**

MS RICHARDS: The conclusion that does come forth from your preliminary analysis is that the imposition of a wildfire management overlay is not a good predictor of whether there will be house loss in an area?

**Yes, that's fair.**

COMMISSIONER McLEOD: You would hope it would be a reasonable predictor of where there are likely to be severe bushfires, though.

MS RICHARDS: Indeed, Commissioner.

COMMISSIONER McLEOD: Which is what the purpose of it is, isn't it?

MS RICHARDS: And that's probably something for future examination. If I can turn to future work, you set out in part 9 of your report, starting at page 106, future work and arising questions. What future work have you and the team who have worked on this part of the interim report 16 identified and what work would you like to see given priority?

**I guess the report demonstrates a wide range of capability to drill down into any given issue and I think it is really a judgment on what the most significant or contentious issues are that require some type of immediacy in their priority. So we probably would be interested to hear what the Commission would like to set as those priorities and be happy to pursue those.**

Let's call it an iterative process, Mr Leonard. We are also interested to hear from you on what priorities you have identified?

**Certainly, and I guess I would like to flag issues like defensible space and where defensible space has appeared to play a role in improving house performance; just the relative effectiveness of the broad range of building measures that we see in the building standard; the role of what's called or referred to as managed vegetation, which is the isolated vegetation that resides in close proximity to structures but isn't observed as being one of the declared fuel types that represent a requirement for building for, so this is sort of a bit lost in the middle ground between continuous forest fuel and the structure; the specific interaction between building and people and how the survey data reveals the strength of that interaction and the context under which that interaction occurs. Because we have a much greater detailed picture of people's behaviour and accounts as well as a highly detailed picture of house performance, we can create a much more revealing account of the specific roles and inform on how much value activity prior to the event has benefited house survival and its ramifications for life safety during the fire and after the fire, which we haven't been able to tease out so accurately before. We would like to use the data to validate our urban vulnerability assessment tools which we have spoken about previously.**

At the very commencement of your evidence last week?

That's right. I think something that's really revealed itself in this dataset is the wind and the sensitivity to wind as a prolific influencer of house performance and particularly around the sensitivity of receiving localised wind effects in the landscape, going to the effort of running wind modelling over the terrain and understanding how the terrain is exacerbating local wind effects and how that may play a role in future prescription. I think the economic analysis of the impact would certainly warrant further investigation so we can look at the tangible/ intangible costs, impacts of this fire and be much more effective in providing an informed cost benefit analysis of future regulation in control and policy. I think scenario modelling around this fire. Because we have got a very good spatial understanding of what happened under this context, it would be really valuable to try some what-if scenarios, like what if this occurred on a Tuesday, what if the population was in a work mode and the non-adult population was at school, how would that play out in terms of populations in transit, the infrastructure that would be relied upon as a shelter under those circumstances, and of course the obvious one, critical infrastructure, power, water, road network-type approaches. I think the way all of that work can also lead in and inform the way we effectively define risk and vulnerability in the interface and create these tools that 16 we have spoken about earlier, maturing those tools into a way that can be used by a broad suite of practitioners and potentially community members and also broadening the application of those tools to include a broader suite of urban design considerations; for instance, energy efficiency is a key one everyone has to work towards and meet. It is quite obvious that they could in fact share a common platform for which you can perform an energy efficiency audit or a bushfire risk audit. It is the same spatial information, it could be in fact an integrated design tool. I think then to move on and use those tools to inform future decision-making processes, policy, reform and overarching urban design in that really holistic integrated way.

MS RICHARDS: Thank you, Mr Leonard. Do the Commissioners have any questions?

CHAIRMAN: Can I inquire whether you either have in the process identified houses in which people died or whether it is possible because you go back to the basics that would enable them to be linked up with other information that could be established -I suppose that's the first question?

We weren't privy to the specific data that identified which houses involved deaths and which didn't. That's a perfect example of how we could benefit from linking separate datasets together and revealing a much more relevant outcome from those integrated datasets. The starting point then is that you don't have the information and to some extent it makes it -there is the advantages of randomness. But if it was possible then to correlate the information that is available from other sources, it may then be possible to use the information you have got as to water supplies –

did you check on things like hoses as well as pumps? (**Witness nods.**) So you have a bit of an indication as to whether there were signs of an active defence of the house that might be used in relation to an investigation into the circumstances of deaths?

**Yes, definitely. So, one of the key points we reviewed in fact was evidence of suppression and evidence of use of suppression devices and the state of those**



suppression devices, so the critical link between tank supply, water pressuring infrastructure like pumps and the hoses and whether they were fixed or mobile hoses fixed to a spray system on a house or hoses that would be operated by a person. But I think, as you have revealed, a really key point, and I think this is a really important point that needs to come right at the front of the whole process. We need to combine as many of the available relevant databases together as the very first step before we begin the analysis process, because every little bit of extra piece of data that is combined before we begin the analysis gives us a huge improvement in the opportunity to reveal correlations in important features of those datasets.

MS RICHARDS: Thank you, Mr Leonard. May Mr Leonard be excused?