Life and house loss database description and analysis

Final report

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1 Executive Summary

This report describes the development and analysis of a dataset containing bushfire related life loss in Australia over the past 110 years (1901-2011). Over this time period 260 bushfires have been associated with a total of 825 known civilian and firefighter fatalities. This dataset encompasses the spatial, temporal and localised context in which the fatalities have occurred (known as the Attorney General Department's (AGD) NFDRS Life Loss database). This database was developed to provide a firm evidence base for which an Australian National fire danger rating system can be developed. It represents the most complete set of known bushfire fatalities and the most comprehensive spatially and temporally correlated dataset of these fatalities ever assembled.

The analysis phase of the project has focused on the characterisation of the relationship between fatal exposure location, fire arrival, weather conditions (using the McArthur Forest Fire Danger Index (FFDI) and its individual components), proximity to fuel, and fatality activity and decision making leading up to the death.

From this analysis it is evident that fire weather and proximity to forest are very strong contextual drivers for defining the potential for fatalities to occur. With over 78% of all fatalities occurring within 30m of the forest and 50% of all fatalities occurring on days exceeding an FFDI of 100 (the current threshold for declaring a day as 'catastrophic'). In fact 15 major bushfire events involving 9 or more fatalities per event represent 51% of all civilian fatalities. These bushfire events occurred during 10 fire days. The total number of fatalities during those days account for 65% of all civilian fatalities. The analysis shows that the losses are dominated by a several iconic events that have occurred under very severe weather conditions (such as Ash Wednesday 1983, Black Saturday 2009)

The location of fatal exposure provides a useful context with 58% occurring out in the open and 28% occurring inside structures, of particular interest is the fact that for bushfires occurring under weather conditions exceeding an FFDI value of 100, fatalities within structures represents over 75% of all fatalities. These are associated with people dying while attempting to shelter mainly in their place of residence. Conversely lower values of FFDI are associated with people caught outside who are engaged in defending.

The Civilian fatalities also tended to occur close to or within their place of residence, with 82% of the 'in structure' fatalities being in their place of residence, and 61% of other fatalities were with 100m of their residence. Of the fatalities which occurred inside structure in a location that was specifically known, 41% occurred in rooms with reduced visibility to the outside conditions.

The gender analysis shows a higher proportion of males dying in earlier fires when compared to more recent fires. The gender role could demonstrate an evolution of behaviour in the different roles of men and women over the century. A greater number of male civilian fatalities have occurred in open air than in any other location, particularly earlier in the century. A greater proportion of female fatalities have occurred inside structures.

Preliminary work has been performed to explore the use of a weather based life lose index which has demonstrate significantly strong correlations than using FFDI, hence with some additional effort in this are a new index can be derived. This index could either be based in weather parameters alone or be a combination of weather and spatial variables.

2 Introduction

This project was commissioned as a foundation component of the National Fire Danger Rating System (NFDRS) project. The NFDRS project is focused on the development of a fire danger rating system for agency and community awareness and warnings. A wide variety of related spin off products are also included to support other agency activities. The existing Fire Danger Rating System has been historically based on the Fire Danger Index (FDI). The FDI relates the expected fire behaviour and rate of spread in common fuel types in eastern Australia (McArthur 1967; Luke 1978) to the large-scale weather conditions and was originally developed for fire suppression. There is a need for the fire danger rating system to also reflect the potential for damage to a community. A detailed spatial categorisation of the circumstances of fatalities is necessary to underpin the assumptions and processes employed within the broader fire danger rating system. This report details how this requirement was met and delivered in the form of a database associated with spatial files. Preliminary analysis of the data is also provided in the report.

The database, known as the Attorney General Department's (AGD) NFDRS Life Loss database (Life Loss database), is a dataset containing past life-loss in relation to the spatial, temporal and the localised context in which the life had been lost as a result of a bushfire. The spatial nature of the dataset will allow a wide range of future analysis to be undertaken.

The Life Loss database was developed by collating different available data on bushfire related life loss in Australia over the past 110 years (1901-2011). A range of circumstances leading up to the fatal exposure was also captured, including:

- fire arrival and severity,
- weather conditions,
- proximity to fuels, and
- activity defined by the decisions made up to the time of fatal exposure.

The circumstantial qualifiers and parameters used were limited to those deemed relevant to the broader NFDRS project and developed through consultation with the NFDRS – Science Subgroup (see Appendix 1 – Database Structure). Civilian fatalities are the key focus of this project, however efforts were also made to collate and partially analyse firefighter fatalities.

This report details the Life Loss database development process and statistical analysis performed. The analysis focuses principally on understanding the strength of correlations between the activity leading up to fatality, fire weather severity, proximity to fuel and other objects (houses and/or vehicles).

The statistical analysis sought to quantify minimum thresholds, potential surrogate qualifiers (including house loss), and the specific role houses play in contributing to the causality of fatality. The analysis attempts to answer the following questions:

- What is the type and prevalence of activities leading up to the fatalities and how are these linked to qualified against other circumstantial drivers?
- What is the minimum weather threshold for the potential for life loss to occur?
- Is there a correlation between fire weather severity and historic life loss?
- Is house loss or other alternatives such as fire severity, a potential surrogate indicator for predicting life losses if a number of key qualifiers are incorporated?
- How are life loss and the proximity to and prevalence of fuels related?
- Does multivariable analysis improve the statistical correlation between circumstance and life loss?
- Can a working classification of life loss risk be developed for use in the fire danger rating system?

The database is as comprehensive and as complete as practicable within the time frame and resources available to the project. There is an ongoing need to maintain the database with future losses and to integrate the knowledge and data from future analysis and data collection initiatives.

In parallel to this project the “Fire Severity Rating Project[1]” is focusing in community losses in relation to fire severity. This project seeks to conceptualise a fire severity scale based upon transitions between levels of fire severity. The two projects use an evidence based approach that draws upon data from past fire impacts on the wildland/urban interface. Both projects work in unison to provide a better understanding and quantifiable measures of improving the fire danger rating system.

[1] Victorian Department of Sustainability and Environment (DSE) and Bushfire CRC project

3 Background

The first known study of community safety at the urban interface occurred in Australia in 1945 consisting of a post bushfire survey and subsequent analysis to better understand the mechanisms of bushfire attack at the urban interface (Barrow 1945). Following this survey several studies have been conducted after each major bushfire involving house loss (e.g. Ramsay 1987; Leonard and McArthur 1999). The important points of consideration in those studies were on the building design, the immediate landscape, the type of urban interface and human activity and how they significantly influence the risk of loss (e.g. Barrow 1945; Ramsay 1987; Leonard 2003; Blanchi and Leonard 2008).

The study of human activities during bushfire have suggested that people sheltering in their house and implementing different protection strategies have a better chance of survival than people evacuating late (McArthur and Cheney 1967; Wilson and Ferguson 1984; Krusel and Petris 1999). Also it has been shown that active defence by residents or brigade members significantly increases the chances of house survival (Wilson and Ferguson 1986; Leonard 2003; Blanchi et al. 2006).

These findings have formed the basis of the Bushfire and Community Safety Position developed by the Australasian Fire and Emergency Service Authorities Council (AFAC) before the 2009 Victorian fires. This position was translated into the prepare, stay and defend or leave early policy in most jurisdictions. Also referred to as the 'Stay or Go' policy The policy recommended that either actively defending a well-prepared home or evacuating/relocating well in advance of a fire threat are the best survival options during a bushfire[2].

Some studies have been performed on the behaviour of civilian fatalities during bushfires in Australia (Tibbits et al. 2006; Handmer and Haynes 2008; Haynes et al. 2008; Haynes et al. 2010; O'Neill et al. 2010; O'Neill and Handmer 2012). The studies are mainly conducted within the context of the 'Stay or Go' policy. Tibbits and Handmer have discussed the 'Stay or Go' policy approaches in Australia and described the history of policy development in this area (Handmer and Tibbets 2005; Tibbits et al. 2008). Haynes et al (2010) completed a study of civilian fatalities in bushfires over the last century (up until 2008). The study explored the context of bushfire related fatality and focused on the activities, behaviour and decision making carried out at the time of fatality. The details of 552 civilian fatalities were collected and this study was able to verify and emphasise the danger of being caught outside during the passage of a bushfire. It also demonstrated a clear gender bias, with male fatalities most often occurring outside trying to protect assets and females inside sheltering or trying to flee (Haynes et al. 2010). O'Neil and Handmer (2010, 2012) have also performed a detailed study of the circumstances surrounding the deaths of 172 civilians during the 2009 Victorian bushfires; one of the findings was that most of the people could not respond appropriately to the risk the bushfire presented on 7th of February 2009.

While these studies on civilian fatalities have mainly focused on the behaviour of the victims, they have not included the spatial and environmental circumstances of their death, meanwhile other studies have focused on the influence of environmental circumstance on house loss for individual events (e.g. McArthur and Cheney 1967; Ramsay 1987; Leonard and Blanchi 2005) and across multiple events (e.g. Ahern and Chladil 1999; Chen and McAneney 2004; Blanchi et al. 2010; Harris et al. 2011). Several studies have shown that the number of houses destroyed decline as a function of the distance to wildland vegetation (Ahern and Chladil 1999; Chen and McAneney 2004; Crompton et al. 2011; Newnham et al. 2012). However, theses studies have some limitations. For example, they only looked into house loss and their distance from the wildland vegetation. They made no attempt to describe the fire behaviour. They also made no attempt to describe the characteristics of the houses burnt compared to those not burnt. Blanchi et al. looked at meteorological conditions and related houses loss in Australia (Blanchi et al. 2010). Crompton et al

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[2] AFAC (2005) Position Paper on Bushfires and Community Safety. AFAC Limited, Victoria, Australia

(Crompton et al. 2010) studied the history of building damage and loss of life since 1925, and normalised the historical records to 2008/09 to look at the influence of climate change. Harris et al have studied community losses from 79 fires (49 fires with fatalities, and 47 fires with house loss) in relation to fire power, fire weather and fuel load (Harris et al. 2012). The study found a relationship between the power of the fire and community losses when houses and population density were added to the statistical model (Harris et al. 2011).

Recent studies on house loss during post fire surveys have been conducted internationally (Cohen 2000; Cohen and Statton 2008; Manzello et al. 2010; Maranghides and Mell 2011). Other studies have investigated the circumstances of firefighter fatalities involving entrapment and burnovers (e.g. Butler and Cohen 1998; Cheney et al. 2001; Viegas et al. 2008).

Only a few datasets exist on bushfire events in Australia and their related fatalities, and these datasets only cover a partial amount of constituent data about the bushfire (e.g. losses, or cost, weather). There have been initiatives to aggregate information from historic bushfires such as:

- EMA database[3],
- COAG report (Ellis et al. 2004),
- Risk Frontier database Peril AUS (Crompton et al. 2010; Haynes et al. 2010),
- Romsey[4],
- Bushfire CRC dataset (Blanchi et al. 2010).

A variety of information is also contained in post bushfires survey studies conducted after a range of historic fires. However, these are related to a specific bushfire and focus on some aspect like losses, building design, fire behaviour (e.g. Barrow 1945; Cheney 1979; Country Fire Authority 1983; Wilson and Ferguson 1984; Ramsay and McArthur 1995; Leonard and McArthur 1999; Leonard and Blanchi 2005).

There is a need for the development of comprehensive datasets including specification of spatial extent and circumstances descriptions to suit the needs of the NFDRS project. The lack of a standard to collect data across Australia on bushfires or the existence of a central repository for this data has lead to the commission of this project.

[3] http://www.disasters.ema.gov.au/ (accessed 31/10/2012)
[4] http://home.iprimus.com.au/foo7/firesum.html (accessed 31/10/2012)

4 Database description

This section presents the Life Loss database structure, data sources, and the processes employed to collect, aggregate and code the data. The development of the parameters and the structure of the database were presented to and discussed with the NFDRS – Science Subgroup, the result of these discussions are detailed in Appendix 1 – Database Structure. A database structure and set of aspirational parameters were agreed upon and pursued in the database aggregation process.

4.1 Database structure

4.1.1 STRUCTURE DEVELOPMENT

The AGD NFDRS Life Loss database is a spatial dataset of bushfire related fatalities and related losses and circumstances (such as house loss, weather context, fire severity, and distance to forest) in Australia for the past 110 years (1901-2011). Two data typologies were collected, tabular and spatial. Tabular data was stored in a Microsoft Access database and associated spatial data stored in ArcGIS and Google Earth compatible files. The data agreed upon with the NFDRS – Science Subgroup was collected within the limits of data and time availability (see Appendix 1 – Database Structure).

The database structure was developed with consideration of the potential interrelationships between the agreed parameters culminating in the linked data structure shown in Figure 1 below. The structure consists of a number of hierarchical tables. A hierarchical table means that each line item in a table is linked to the one listed directly below it. Tables are linked to each other where common line items existing in different tables, these are most often data tags such as an Object ID, Fire ID or a GIS Object code.

The final database structure varies only slightly from the one originally proposed with a change that merged the vegetation and fire front tables into a single table. Hence, each fire event was recorded with a specific ID and within each of these fire events various incidents were identified. An incident is a single fatality or a multiple fatality scene where individuals were sheltering or interacting as a collective group. This allowed collection of all relevant information specific to an incident and also to one or more fatalities.

4.1.2 STRUCTURE DESCRIPTION SUMMARY

The database structure diagram including tables is presented in Figure 1.

The spatial features contain location of fatalities and objects such as houses, vehicles, other objects associated with an incident. Spatial features are delivered in Shapefile (Environmental Systems Research Institute, 1998) and Keyhole Mark-up Language (KML) Zipped (KMZ)[5] file formats as these are the most commonly used.

Spatial Information on house loss was included for houses that were associated to a fatalities incident, but was not collected for an entire fire event as they are part of the data collected for the 'Fire Severity Rating Project'[6].

[5] https://developers.google.com/kml/documentation/ (accessed 30/10/2012)
[6] Victorian Department of Sustainability and Environment (DSE) and Bushfire CRC project

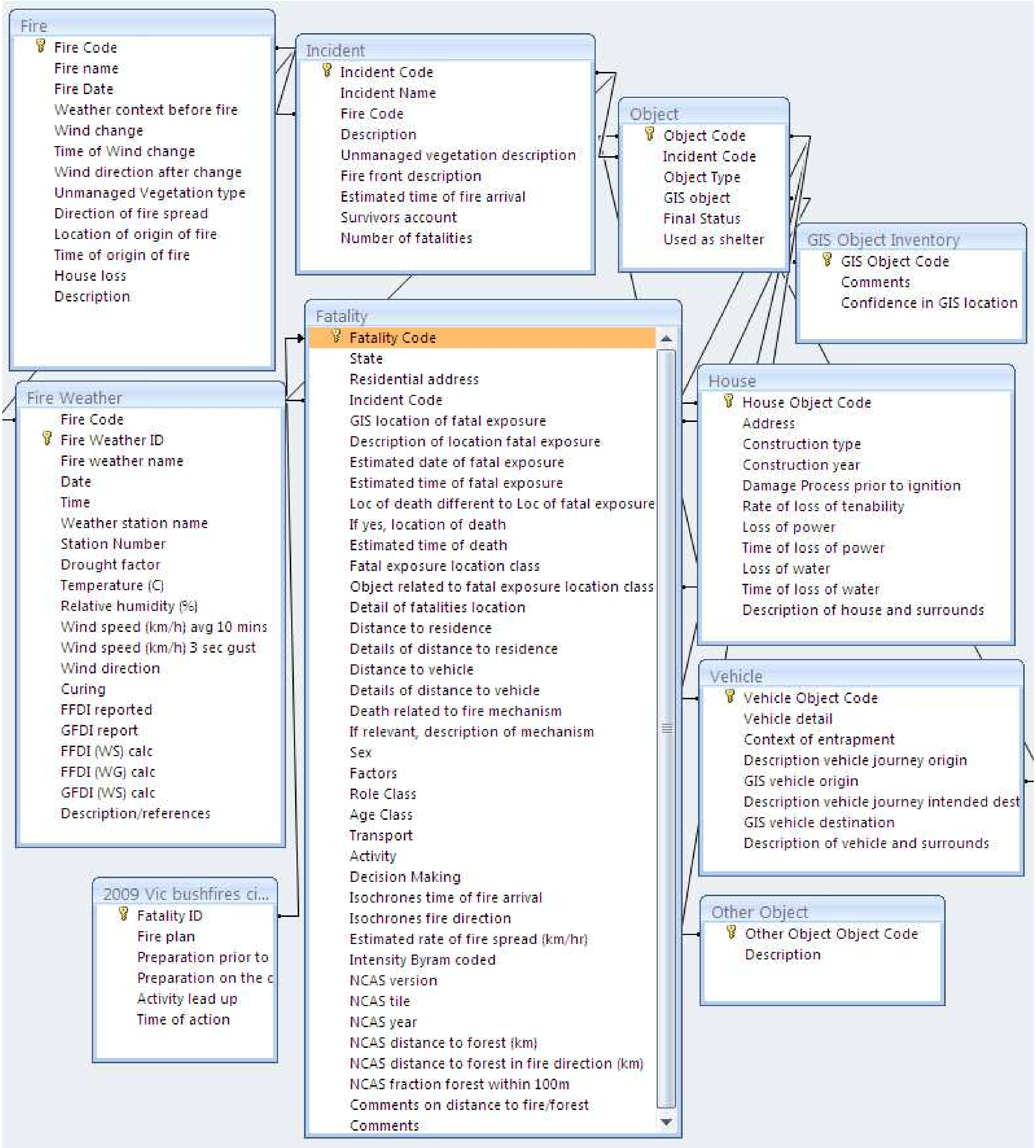

Figure 1 Database structure diagram

The main tables that form the database are provided in the following list (for further details of these tables and parameters please refer to Appendix 2 - Data category):

Fire	Contains information about a fire in which one or more incident occurred.
Incident	The incident table associates fires with fatalities and related objects. An incident can refer to more than one fatality where individuals were sheltering or behaving as a collective group.
Fatality	Contains information about the fatalities that occurred during an incident.
Fire Weather	Contains information about the weather conditions associated with the fatalities and/or proximal weather station records.
Object	Contains general information about the objects that are associated with an incident. These objects may be houses, vehicles, or other objects.
House	Contains information about houses associated with an incident.
Vehicle	Contains information about vehicles associated with an incident.
Other Object	Contains information about other objects associated with an incident. This may include sheds, fences, dams, trees, etc.
GIS Object Inventory	Contains information about Geographical Information System (GIS) objects that are associated with the database.
2009 Vic bushfires	Contains information on civilian fatalities for the 2009 Victorian bushfires (see Appendix 3 – Coding Scheme 2009 Victorian bushfires)

4.2 Data sources

A number of different data sources were accessed in order to assemble the Life Loss database. This includes coronial inquest records, royal commission reports, journal papers, books, post bushfire study reports, fire agency review documents of major fires, newspaper articles and collated datasets on past bushfire fatalities.

The most comprehensive listing of past fatalities provided was the Risk Frontiers / AFAC Landscape Fire Fatalities Database 2011 (covers fatalities Australia-wide). This dataset was initially developed by Risk Frontiers as part of PerilAus, a unique database on the incidence and consequences of Australian natural hazards (Crompton et al. 2010). The bushfire component of PerilAus was used by Haynes to develop a dataset of fatalities up until 2008 for the Bushfire CRC (Haynes et al. 2010,). The Risk Frontiers dataset included information on fatality's name, date of fatality, activity and behaviour prior to fatality (for further details see Haynes et al. 2010). AFAC augmented the Haynes et al. (2010) dataset to cover a total of 773 fatalities consisting of 723 civilians and 50 firefighters. This project originally intended to focus on populating the details of these 773 fatalities. However, through the process of collecting the data a number of additional civilian and firefighter fatalities were discovered and incorporated. For this report and analysis the Life Loss database covers a total of 825 fatalities involving 733 civilians and 92 firefighters.

Where possible, information about fatalities was obtained from official inquest documents. These were obtained either from the relevant state coroner's courts, or in the case of older records, from the state public records offices. An inquest is a court hearing into a single fatality, multiple fatalities and/or a fire, and is heard by a coroner. The coroner's role is to identify the person(s) whom died and to find out how their fatality occurred, including the cause and circumstances. Inquest documents may include police reports, witness statements, photographs, expert reports, medical examination reports, and the coroner's finding. However, there has not been an inquest held for every bushfire related fatality in Australia's history, and the amount of information recorded and retained for each inquest varies considerably.

In addition, information was obtained from Royal Commission reports and post fires inquiries for specific bushfires (e.g. McArthur and Cheney 1967; Ellis et al. 2004). For the 2009 Victorian bushfires no inquests have been held yet, hence the information was obtained from the main Royal Commission 2009 report (Teague et al. 2010) [7] and from case documents provided by the Coroners Courts of Victoria via a special permissions process.

Various other sources of information were used such as journal papers (e.g. Wilson and Ferguson 1984; Ramsay 1987; Cheney et al. 2001), books (e.g. Cheney 1979; Collins 2009), reports on post bushfire studies (including fire behaviour, surveys, etc.), fire management and fire service reviews of major bushfires (e.g. Country Fire Authority 1983; Krusel and Petris 1999; NSW Rural Fire Service 2000), the World Wide Web, newspapers articles sourced from libraries and state public records offices, memorials, discussions with various state-based fire agencies and personal communications with various fire agency personnel.

The location of spatial features was derived using Aerial imagery (Google Earth and other available aerial photography) and is detailed in the section on spatial features (see section 4.3.3).

The meteorological data compiled in the dataset and used in the analysis came from various reports and from standard synoptic observations made by the Bureau of Meteorology (detailed in section 4.3.5). No standard exists for the recording of meteorological data in reporting or analysing bushfire events and accommodations needed to be made to capture all the collected data.

Various other sources of data used in the analysis such as the forest layer, isochrones and intensity layers are described in the analysis methodology section (see section 5.1).

4.3 Data collection and aggregation approaches

This section describes the mechanisms and processes employed to collect and aggregate the data. It also describes the data elements and the uncertainty and variability associated with them.

Different types of data have been compiled in the dataset: quantitative variables (e.g. weather information), and categorisation variables (e.g. location of fatality). Some information was categorised (coded) to facilitate spatial and statistical analysis. Other potentially useful information has been collected and left as open text such as addresses, and descriptions.

Coding systems used in this project have built upon the coding scheme developed by Haynes et al. (2008) in the study of all Australian bushfire fatalities before 2008 and the study of 2009 Victorian bushfire fatalities (O'Neill and Handmer 2010). The additional coding developed for this project relates to the location, activity of fatality, fire behaviour and fire events. The coding includes both nominal variables (e.g. location of fatality) and dichotomous variables (yes/no answer). The data were coded by three researchers and the methods used were discussed and agreed upon during the data entry process.

The dataset also contains some derived variables such as distance to forest which has resulted from analysis of various database variables and other spatial datasets.

In total 825 fatalities were examined, including 733 civilians and 92 firefighters. The fatalities are unevenly spread over 260 Australian bushfire events.

4.3.1 FATALITIES

Information was collected on the fatality location, time and circumstances of death. The name, date of fatality and inquest number (if known) in the Risk Frontiers/AFAC dataset were used to identify the relevant documents. Our main objective was to determine the location and time of fatal exposure in order to spatially locate the fatality and to correlate them with other variables. The data collected is detailed in Appendix 2 - Data category tables and their contents.

[7] http://www.royalcommission.vic.gov.au/commission-reports/final-report (accessed 30/10/2012)

The level of detail available regarding the location of fatal exposure varied substantially. In some cases the only information available was the name of the bushfire in which the fatalities occurred. If no information was available 'unknown' was entered. For some cases 'not applicable' was entered where there is not a clear or direct link between the fatality and the bushfire event. Rather than removing these from the dataset they have been included for completeness as they may be useful for other analyses (e.g. still born baby, drowning, natural causes, and aircraft accident during or after bushfire events).

A variety of sources of information were used to determine the location of fatal exposure. Most locations were determined from Coroner's reports and associated maps and sketches. Some fatality locations could not be spatially determined and have been attributed 'NA' (not available).

The time at which the fatal exposure occurred was estimated from reports and other documents. In addition the isochrones of fire spread were used to determine the time of fire front arrival at the location of the fatality. However in the cases of people sheltering in their house, this time could vary depending on the time the house ignited and how long it took for it to lose its tenability.

The location of fatal exposure was coded in four categories:

- inside structure,
- inside vehicle,
- open air, and
- unknown.

A detailed description of the location of the fatal exposure was described for each fatality where sufficient information was available (e.g. the room where fatalities occurred, position in vehicle, precise distance from vehicle, or other relevant information). Some of the fatalities coded as 'open air' were exiting a car or evacuating a house and were found a distance from a structure or a vehicle. This information was kept in the detail description to allow further analysis of the distance from structure or vehicle. When possible a spatial object that the person was in or near when fatal exposure occurred was created.

The analysis is focused on fatalities that have occurred as a direct result of bushfire impact. Two categories were created to indicate whether a fatality was due directly to a fire mechanism during the bushfire (smoke, radiant heat flux, convection, flame, heat stress) or of a more indirect nature (natural causes, shock after the bushfire, drowning). This segregation was to improve the statistical relevance of how proximity and severity of fire mechanisms influence the life loss. It should be noted that for some fatalities that suffered from heat stroke or heart attack while fire fighting were included in the analyses due to the direct nature of their exposure around the time of death hence relevance to the nature of the local fire mechanisms. As there are many possible definitions that could be developed to define what direct or indirect loss is, it is suggested that these should be re-derived from the database to suit other specific purposes.

Other categories included in the Risk frontiers/ AFAC (Haynes et al. 2008) dataset were used (for details see Appendix 2 - Data category tables and their contents):

- Sex: categories indicating gender of person (male, female, unknown),
- Role class: categories indicating whether person was a firefighter or a civilian,
- Age class: categories indicating age group of person,
- Factors: categories indicating factors that contributed to fatality (e.g. flames, radiant heat, etc.),
- Transport: categories indicating the transport mode at the time of fatality (e.g. on foot, in car, etc),
- Activity prior to fatality: categories indicating the activity prior to death (e.g. sheltering, defending, evacuating), and
- Decision making: categories indicating the fire plan and decisions taken by a fatality.

The Risk Frontiers / AFAC dataset was quite comprehensive, however the transport activity and decision making categories were not coded for the 2009 Victorian fires fatalities and for additional fatalities discovered through the data collection process. These fatalities were coded according to the coding scheme developed by Haynes et al (2008). One classification category was added to the 'activity prior to fatality' field and that is: 'passively sheltering as a group, or separate families gathering at a 'community refuge'.

In addition, and because of the detailed information available on the 2009 Victorian bushfires, the coding scheme was expanded. This new coding describes the preparedness; intention and action of the fatality for this bushfire (see Appendix 3 – Coding Scheme 2009 Victorian bushfires). The new coding includes the following categories (taking into account the study done by O'Neil and Handmer 2010):

- Preparation prior to the 7th of February 2009 (well, some, none, unknown),
- Preparation on the day (well, some, none, unknown),
- Activity in the last few hours before fatality,
- Time when people carried out their first action,
- Intended fire plan.

4.3.2 OBJECTS (HOUSE, VEHICLE & OTHERS)

Three types of objects, which are directly related to the fatality, were recorded in the dataset: houses, vehicle and other objects. Objects were considered related to a fatality if they were in or near the object (e.g. house or vehicle fatality shelter in, house or vehicle fatality evacuated). For each object that could be located, the status of the object was identified and if it was used as a shelter or not. The status may be damaged, destroyed, untouched or unknown. All the objects that could be located are identified in the GIS Object Inventory table, including the precision error associated with them. Few objects could not be located but still hold interesting information (e.g. material and description of house, or context of entrapment of the vehicle) and were recorded in the database.

The House, Vehicle, Other Object tables are described in Appendix 2 - Data category tables and their contents.

4.3.3 SPATIAL FEATURES

Different sources of information were used to determine a person's location of fatal exposure and other features (houses, vehicle and other objects). In some cases an aerial photograph with the precise position of the fatality and objects were available (e.g. the 2009 Victorian bushfire fatalities). In other cases sketches, without scale or description were the only sources of information. In addition to ground photos, the description and indication of the location of a fatality from inquests or reports were used to find the location using Google Earth or other available aerial imagery. When no information on fatalities was available, the name of the fire was used to determine the approximate location of fatal exposure.

For the 2009 Victorian bushfires, the fatalities and house locations were obtained from aerial photography and sketches supplied by the Coroners court of Victoria (from Victoria Police forensic analysis). Additional spatial information collected during post bushfire surveys done by Victorian Fire Research Task Force (Bushfire CRC) were included (Leonard 2009).

The locations of fatalities were recorded using Google Earth and utilising GIS software (ESRI ArcGIS) to view the available geo-registered aerial photography. In each case an error precision was associated with the location: for high precision records a minimum of 5 metres error was attributed, and for the lowest precision record a maximum error of 100 km was given. This is recorded in the GIS Object Inventory table.

The variability on reported bushfire events and fatalities has an impact on the location of fatal exposure and other objects. Major Bushfires that have been the subject of detailed inquiries generally have more spatial information available on fatalities (including description, sketches or photos) independently of when the fire occurred. Conversely, some historical and even recent cases do not have precise information on the location of fatal exposure or incident related objects.

4.3.4 BUSHFIRE EVENT

A fire event is a fire resulting from a particular origin. Information on fire events came primarily from post bushfire reports (e.g. Cheney 1979; Leonard and McArthur 1999; Ellis et al. 2004; Blanchi et al. 2010). Information contained in the EMA Database, and in Risk Frontiers' database Peril Aus[8] were also used. The Peril Aus dataset was created using Sydney Morning Herald newspapers and various government reports and includes information on the physical characteristics of the bushfire event where available (Haynes et al. 2008). The data collected and recorded in the Fire table are described in Appendix 2 - Data category tables and their contents.

The date of the fire was set as the date of fatal exposure, for fires that have started earlier than the date of fatal exposure the date of origin was also recorded when available. The objective was to record information on the weather context before the fire and the broad changes of weather context during the day. For example indications of wind change were listed with time and direction of wind change. For some fire events there is only a mention of wind change during the day without the specific time or wind direction provided.

Information on the broad type of unmanaged vegetation that the fire travelled through was categorised as:

- forest,
- grassland,
- scrub, and
- combination (more than one type of vegetation, e.g. forest and grassland).

In this report the term 'unmanaged' is used to describe the typical vegetation types that supported the fire. Unmanaged is a common term to describe fuel that is not heavily modified or maintained e.g. an old growth forest is unmanaged and a cultivated garden is managed.

The number of houses lost for each fire event was compiled from different sources of information: various reports on post bushfire surveys (e.g. Cole 1983; Country Fire Authority 1983; Ramsay 1987, Ellis et al. 2004, specific studies on house loss (e.g. Leonard 1999, Blanchi 2010, Harris et al. 2011), and specific databases (e.g. EMA database[9]).

An attempt was made to record information on reported intensity of fire, rate of spread and direction of fire. However, since this was only available for a small number of fires, the data was not used for the analysis. In contrast, fire severity and fire direction have been calculated for a large number of individual fatalities and were used in the analysis phase (described in the section 5.1).

4.3.5 WEATHER CONTEXT

Meteorological data was obtained from information contained in fire behaviour reports, inquests, and other relevant reports (e.g. Foley 1947; McArthur and Cheney 1967; McArthur 1982), the Bureau of Meteorology's significant weather summaries[10] and standard synoptic observations. The intent was to choose data from the closest available weather station to the fatality, depending on whether the station data was available and captured the required time period.

Information from pre 1945 fires was obtained from Foley's report (Foley 1947). This report is an extensive study of the meteorological conditions of bush and grass fires from 1912 to 1945 in Australia. However, the report provides limited data on each fire day; either maximum temperature of the day or a combination of different climatic variables at different times of the day. Due to the inconsistency of early weather records, it was decided to record weather condition from 1926 (being the date of a major bushfire event in Victoria).

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[8] Information received October 2012
[9] http://www.disasters.ema.gov.au/ (accessed 31/10/2012)
[10] http://www.bom.gov.au/inside/services_policy/public/sigwxsum/sigwmenu.shtml (accessed 30/10/2012)

One fire may have a number of fire weather records associated with it. The number of and type of meteorological records for each fire was dependant on the availability of data. Meteorological data was recorded at different times throughout the day or recorded at different nearby weather stations. The two sources of data used were:

- The weather station observations. The set of observations[11] used in this project include a number of weather stations across Australia. Few stations have a complete unbroken record of climatic data; some sites have been closed, reopened or upgraded. Variations occur in the number of variables recorded and in the frequency of recordings each day (product from the Bureau of Meteorology[11]), and
- The historical fire weather dataset described by Lucas (Lucas 2007; Blanchi et al. 2010; Lucas 2010).

Several observations were recorded for each fire when possible and each record was given a name depending on the type and time of the observations. '3pm' were observations at 3PM, 'TOE' were observations at time of exposure, 'Max' were maximum of the variable recorded, and 'CLucas' were records from Lucas historical datasets (Lucas 2010).

Eighteen variables were recorded in the Fire Weather table. These include the date of the weather record, the time of weather record, the weather station name, station number, drought factor (from report or calculated from Griffiths, 1999), temperature (C), relative humidity (%),wind speed (km/h) average over 10 mins, wind speed (km/h) over 3 second gusts, wind direction, curing percentage, Forest Fire Danger Index (FFDI) reported, Grassland Fire Danger Index (GFDI) reported, FFDI calculated using wind speed average, FFDI calculated using wind gust, GFDI calculated using wind speed average, and description of the record or reference (for details see Appendix 2 - Data category tables and their contents). In total 320 records of weather information were captured for 146 bushfires.

The FFDI and GFDI calculation were based on the McArthur Forest Fire Danger Index meter Mark5 and Grassland Fire Danger Index meter Mark4 (McArthur 1967). The basic equations (see equation 1 and 2) come from Noble et al and Purton (Noble et al. 1980; Purton 1982), i.e.

$$FFDI = 2\exp\left(-0.45 + 0.987\ln DF + 0.0338T + 0.0234V - 0.0345RH\right) \quad (1)$$

where DF is a drought factor (using Griffiths 1999), T is temperature (ºC), V is wind speed (km/h) and RH is relative humidity (%).

$$GFDI = 10\wedge(0.009254 - 0.004096(100 - \mathrm{C}))^{1.536} + 0.01201\mathrm{T} + 0.2789\sqrt{\mathrm{V}} - 0.09577\sqrt{\mathrm{RH}}) \quad (2)$$

where C is percentage of grass curing and other variables hold the same definition as in equation (1).

The FFDI was originally developed for fire management purposes and relates the expected fire behaviour and rate of spread in common fuel types in eastern Australia (McArthur 1967; Luke and McArthur 1978). It is also used to provide a basis for forecasts, community warnings and setting of design fire intensity for urban design in Australia (Standards Australia 2009).

In this study the FFDI is used to characterise the fire weather intensity and its potential for destruction, and has been used in other studies for precisely that purpose (Bradstock and Gill 2001; Blanchi et al. 2010; Harris et al. 2011).

4.3.6 UNCERTAINTY AND VARIABILITY

The uncertainty and variability in the data is often due to the different sources and quality of data available and the processes used to generate the data.

The data collected in relation to bushfire events, fatalities and house losses are affected by the variability in source. The main causes are lack of evidence or information to locate a fatality or categorise some of the

[11] Product IDCJHCO1.200806 from the Bureau of Meteorology

information associated with it. Information was discussed amongst the researchers involved in the coding and data entry to ensure consistency where interpretation was required to categorise the data (e.g. variation in the reported information from different sources).

In regards to the precision of a fatality location, a lot of effort has been made to accurately determine the position of fatal exposure and related features. In some cases a variety of sources of information were used. In other cases, the lack of information (in particular for small fires or fires with a low number of fatalities) made it difficult to determine locations. To inform users, an error precision was assigned for every location to indicate its spatial accuracy. However, in some cases, locations and circumstances could not be determined. This mostly occurred for historical minor events which were often aggregated for the fire season or not reported.

The nature of the source information will undoubtedly have an influence in the results of the analysis. Generally there was a large quantity of information associated with large bushfires and missing data or highly inaccurate information for small events with a low number of fatalities. Another significant influence on data collection and the results of the analysis is the period the fire occurred, with older fires having less detail or little information available.

4.4 Dataset example

The example of the Cockatoo fire in 1983 is given to show an example of the data collected. The example of the data collected for the fire event is given in the Table 1. The weather conditions collected on the day are given in the Table 2. An example of information collected on vehicles is given in the Table 3. Finally an example of spatial information is shown in Figure 2.

Table 1 Description of data collected for the Cockatoo 1983 fire event

Variables	Data collected
Fire Code	2981
Fire name	Cockatoo, February 1983
Weather context before fire	Extremely hot conditions prevailed in February (analysed in BOM report)
Wind change	yes
Time of Wind change	17/02/1983 21:05
Wind direction after change	SW
Unmanaged Vegetation type	Forest
Direction of fire spread	S-SE to NE
Location of origin of fire	Wright road and Dalziell Road
House loss	307
Time of origin of fire	17/02/1983 19:30
Description	Ignition near Wright road and Dalzell road (Avonsleigh) spread through South to south east to the vicinity of Bailey road Cockatoo. This fire commenced around 7:30pm upon wind change at 9:07pm, fire swept north East. After the change it progressed in a series of spots, developing very quickly, crowning and fire storms, defoliation of canopy indicated high fire intensity. Deaths occurred after wind changes (between 9-10pm). Forest and undergrowth of sword grass, wire grass, bracken.
Associated documents	CFA, BOM

Table 2 Weather conditions collected for the Cockatoo 1983 fire

Variable	Data collected	Data collected	Data collected
Time	15:00	21:00	21:30
Weather qualifier	3pm	TOE* 9pm	TOE* 9:30pm
Date	16/02/1983	16/02/1983	16/02/1983
State	VIC	VIC	VIC
Station	Mel Airport	Mel Airport	Mel Airport
Station number	86282	86282	86282
Drought factor	10	10	10
Temperature (C)	41.2	29	27
Relative humidity (%)	7	37	42
Wind (km/h) avg 10 mins	44.6	70	52
Wind direction	360	250	250
FFDI Calculated	111	47	24

*TOE: time of exposure

Table 3 Data collected on vehicle object

Vehicle Object Code	Vehicle detail	Context of entrapment	vehicle journey origin	vehicle journey intended destination	Description of vehicle and surrounds
V0055	Honda Accord	Reversed into street sign and was driving in a panicked way they then confronted with a wall of flames and one fatality told all to exit & lie in gutter.	Fatality house	Not known	Scattered eucalyptus
V0056	Van support vehicle	Van failed to turn and struck a stump, driver escape with burns. Passenger (fatality) trapped in vehicle when it was engulfed in flames.	Unknown	Unknown	Heavy forested area. In a support vehicle when it was trapped by flames after the wind change

Figure 2 Example of spatial data collected on the Cockatoo 1983 fire (red point: fatality, white square: houses and other structure, Aerial photography from CFA)

5 Data analysis methodology

Two main approaches have been utilised to understand the circumstances surrounding each fatality:

- Spatial analysis was used to derive proximity information in relation to a fatality,

- Statistical analysis was performed on the dataset compiled on the fatalities and the relevant environmental circumstances.

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 understanding the circumstance of the fatality.

5.1 Spatial analysis

A collection of spatial information was used to determine the environmental circumstances such as the location and extent of objects directly related to an incident, vegetation layers, isochrones and fire severity layers. For consistency, accuracy and ease of comparison, distances between features were measured in a straight line and were only derived where proximal objects were able to be accurately geo-referenced.

- The spatial analyses were conducted in relation to: The distance to residence (where available)
  - The straight line distance from a fatal exposure location to their place of residence. Analysis included also the straight line distance from a fatal exposure location to the main structure with which the fatality interacted with (as for a small number of cases an alternative house than the residential house was the main house they interact with).
- The distance to an exited vehicle (where available and pertinent).
  - The straight line distance from a fatal exposure location to a vehicle which had been exited (noting that in some cases some partial exposure in the vehicle may have contributed to the death).
- The distance to forest (further explained in Figure 3)
  - The straight line distance from the fatal exposure location to the closest forest, and the straight line distance from the fatal exposure location to the forest in the direction of the approaching fire front, and
  - Calculation of the fraction of forest within 100 meters of the fatal exposure location. The arbitrary figure of 100 meters was determined to be the appropriate due to its use as a definitive distance in building regulations (Standards Australia 2009).
- The fire severity
  - Rate of spread obtained from isochrones,
  - Main direction of fire front from isochrones, and
  - Fire severity at the location of fatality.

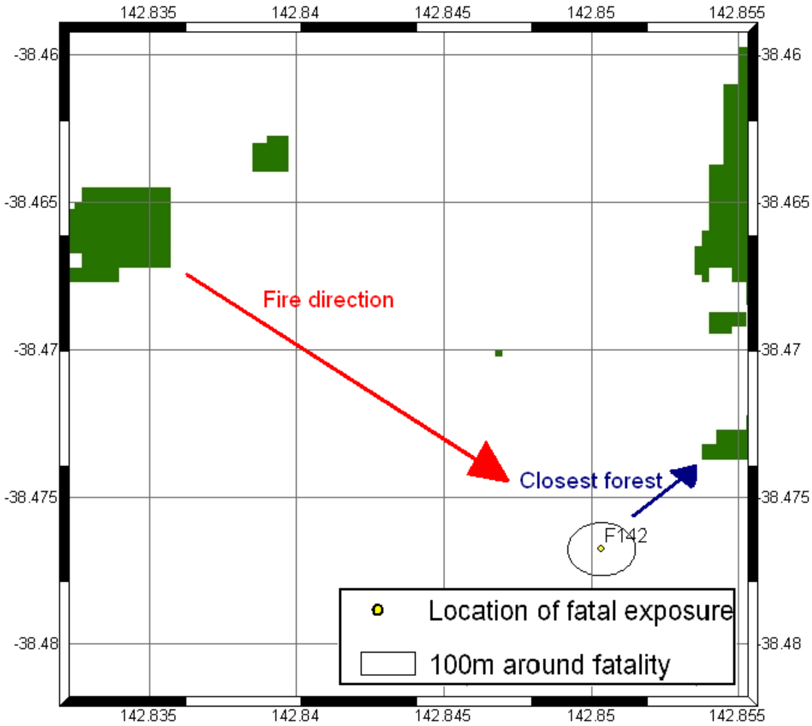

Figure 3 Representation of fraction of forest (green) and distance to forest used in the analysis

5.1.1 DISTANCE TO FOREST

The National Carbon Accounting System (NCAS) forest/non-forest (FNF) dataset and Lidar data were used to determine the distance to forest and surrounding forest density from a fatal exposure location where data was available.

The forest analysis does not inform us of grass or short vegetation fuel (less than 2 meters in height) or forests covering less than 0.2 hectares.

National Carbon Accounting System (NCAS) forest/non-forest layer (FNF)

The NCAS FNF products are binary images developed for the purposes of tracking forest extent and monitoring deforestation and reafforestation. Forest is defined according to the National Forest Inventory as vegetation with a minimum 20% canopy cover, potentially reaching 2 meters high and a minimum area of 0.2 hectares. The product is based on satellite imagery from Landsat sensors[12]. Candidate pixels for a yearly Australian mosaic are selected to minimise cloud cover and maximise the natural discrimination between forest and non-forest classes. A discriminate process is applied with localised training for each class. This effectively provides a probability of forest for each Landsat pixel. Based on a threshold of probability, a binary image of forest extent is produced. Much of the processing is conducted by contractors external to the federal government, with auditing conducted by the Department of Climate Change and Energy Efficiency (DCCEE). The processing methodology is described in detail in Furby (2002). The FNF product consists of 37 tiles of varying extent with a spatial resolution of 0.0025 degrees (approximately 25 meters).

The NCAS product tiles are classified in two categories; the intensive and non-intensive land use zone. The spatial coverage of each tile (outlined in red) and each of these zones can be seen in Figure 4. In general, this follows the relative population density for each tile and it is assumed that deforestation and reafforestation will occur more rapidly in areas of high human habitation. For this reason, processing of the intensive land use zone tiles is given priority over those that cover the non-intensive zone. Tile sg54 was not

[12] Namely, Landsat Multispectral scanner (MSS), Thematic Mapper (TM) and Enhanced Thematic Mapper (ETM).

produced until 2000 due to its lack of forest. The combination of these tiles covers the entire extent of Australia without overlap from 2000 – 2006. Data from 2007 to 2011 data is available for the intensive land use zones. The 2010-2011 data is also available for the priority rangeland zones.

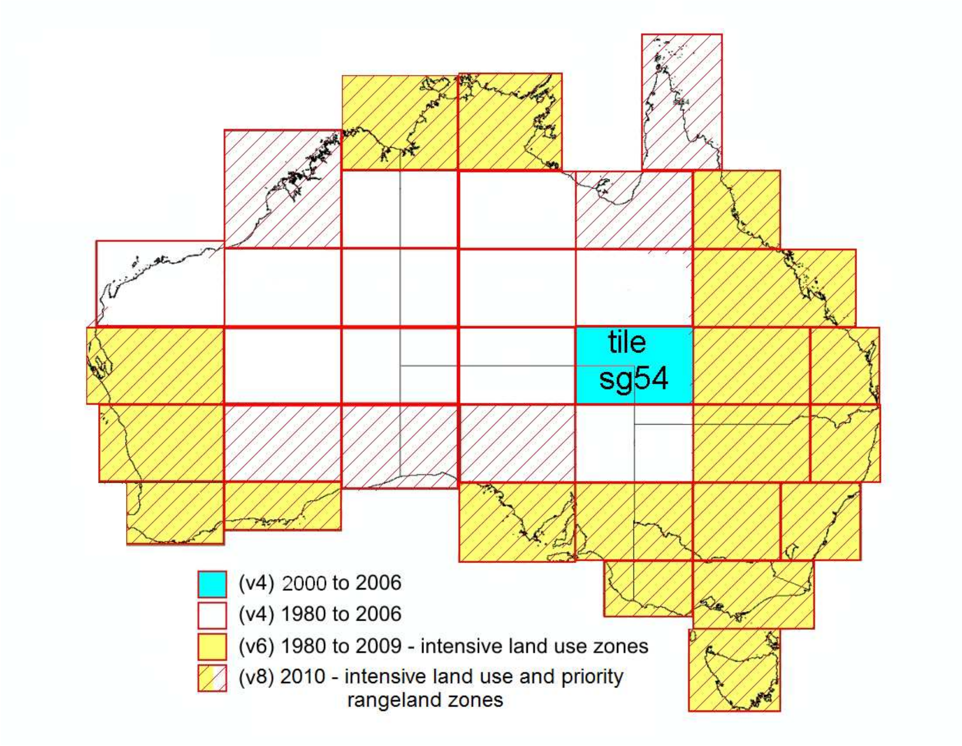

Figure 4 Extent and availability of NCAS imagery

For the spatial analysis, the forest layer of the closest preceding year to the fire was used to determine the distance to forest. It is assumed that the layer which coincides with the year of the fire has a high likelihood of the fire scare affecting extent of forest for that year. A spatial analysis was not undertaken where the preceding year data was not available.

Lidar data

The extent of a continuous unmanaged vegetation layer was determined by using Airborne Lidar data and morphological image processing described by Newnham et al. (2012). The Lidar data were collected over the Kinglake region in 2008 by a fixed wing aircraft using an Optech ALTM3100EA[13]. The primary purpose of the acquisition by the Victorian Department of Sustainability and Environment was for forest management. According to Newnham et al. (2012) the NCAS forest boundary is significantly simplified (due to the lower resolution for Landsat) relative to the lidar based estimates, resulting in generally balanced errors of omission and commission at the edges of the NCAS wildland extent.

5.1.2 FIRE SEVERITY

Two sources of data were used do describe the fire intensity: the fire isochrones[14] and the fire severity layers provided by the project Fire Severity Rating Project[15] and described in the methodology of Harris et al. (2012).

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[13] Source DSE
[14] A fire isochrones is a spatial line representing the fire arrival at the same time. The fire isochrones were obtained from diverse sources, (e.g. Department of Sustainability and Environment, Country Fire Authority, Fire Severity Rating project)
[15] DSE Bushfire CRC project, Project leader Musa Kilinc

The calculation of rate of spread of fire was completed between the two closest isochrones around the fatality location if it was available. However some of the high fire severity values need to be interpreted with caution due to the fact that they are based on improbably high rates of spread due to long distance spotting. Discrepancies between calculated time of fire arrival from isochrones and time of death are assumed to be due to the inaccuracies inherent in both data. Isochrones are primarily affected by temporal inaccuracies in climatic data.

The Byram (Byram 1959) fire intensity and power calculations were made by using estimates of: grass, surface, fine fuel load, near surface fuel load, elevated fuel load, bark fuel load and canopy fuel load. An assumption was made that all fuel was consumed at the flame front. In calculating fire intensity and power, the heat of combustion (H) was assumed to be 15,000 KJ/kg (Harris et al. 2012).

Fire intensity calculations were derived using the assumption that fire front progressed steadily from one fire isochrones to the next, this assumption becomes flawed when the fire progression rates become dominated by forward spotting. Under these conditions new fire fronts form well ahead of existing fire fronts which later fill in the gap between the two, hence the fuel would not consumed at a rate or intensity as high as would be assumed by the above assumption.

5.2 Statistical analysis

A range of statistical analyses were performed using the data extracted from official reports:

- Frequency analysis is used to describe the data collected (on fatality, fire events),
- Contingency table analyses (cross-tabulation analysis) have been used to understand the relationship between two (or more) variables (e.g. location of a fatality and forest fire danger index). 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.
- Regression analysis, and
- Tri-dimensional probability density visualisation.

Data queried from the Life Loss database developed for this project and the data extracted from the spatial analysis were used for the statistical analysis.

The following categories are considered in the analysis:

- The demographics: the analysis takes into account the two types of fatality (civilian and firefighter), the gender, the cause of fatality (directly related to the fire or not),
- The geographic distribution by state and time distribution of fatal exposure,
- The distribution of number of fatalities for each fire event are examined, the analysis includes the number of houses lost and fatalities for each year,
- The spatial locations of all fatalities in Australia are presented. The fatalities location categories (inside structure, inside vehicle, open air, unknown, describe in section 4.3.1) is examined to determined if there is any relationship with other variables (activity, decision making and weather context),
- Fatality activity and decision making are presented for the three time period and also for 5 major bushfires. The activity and decision making was also examined in relation to other circumstances such as the location of fatal exposure and weather context using multivariable analysis,
- The relationships between the fatalities, the location of fatal exposure and the fire weather conditions under which the event occurred was examined using the McArthur FFDI and its components at 3pm and at time of exposure (Luke and McArthur 1978, Noble et al. 1980). Other aspects such as wind changes and the consequences on fatalities are also covered,
- The relationships between the fatalities, the location of fatal exposure, the distance to forest, and fire severity are examined. The fatality locations with a precision confidence greater than 100m are removed from the analysis, and
- The Victorian 2009 bushfire was the object of a specific coding. The results from the coding are presented in a separate section (see 6.9 Results from the Victorian 2009 bushfires).

6 Results and discussion

The results of analysis in this section seek to qualify minimum thresholds, potential surrogate qualifiers, and the specific role houses play in contributing to the causality of fatality. In doing so the analysis attempts to answer the following questions:

- What is the type and prevalence of activities leading up to the fatalities and how are these qualified against other circumstantial drivers?
- What is the minimum weather threshold for the potential for life loss to occur?
- Is there a strong correlation between fire weather severity and historic life loss?
- Is house loss or other alternatives such as fire severity, a potential surrogate indicator for predicting life losses if a number of key qualifiers are incorporated?
- How are life loss and the proximity to and prevalence of fuels related?
- Does multivariable analysis improve the statistical correlation between circumstance and life loss?
- Can a working classification of life loss risk be developed for use in the fire danger rating system?

The results and discussion section is focused on the data and categories analysis in order to answer those questions. Each subsection will provide some relevant information to parts of these questions, a conclusive summary of these questions is later provided in conclusions.

The Life Loss database contains 825 fatalities, 733 are civilian and 92 are listed as firefighters. The data refers to fatalities between 1901 and 2011 inclusive during which time the average rate of civilian deaths was 6.6 per year. Of fatalities contains in the database 741 were directly related to the fire itself (674 civilians and 67 firefighters). Fifty fatalities are indirectly related to a fire event and the specific cause of death for 34 persons is unknown or unclear. The analysis of fatalities that were directly related to the fire mechanisms is a useful subset to describe fire severity and fire weather severity related factors

The results are first presented for all fatalities for the entire period, and then categorised into civilians and firefighters. The study analysis focused mainly on civilian fatalities as this is useful to describe issues of warnings and life loss locations that are not biased by the nature of firefighter related fatalities.

Some of the results are presented in two time periods. The separation of the data was explored in Haynes et al. (2010), with results presented before 1955 and after 1955. For this project the data was arbitrary split according to the density of data available. The first time period includes data from 1901 to 1964, for which less information is available. The second time period has been defined from 1965 to 2011 and represents the period where significantly more data was available on the fire events. This segregation of data also happens to be useful in distinguishing some patterns over the years, and provides an opportunity to compare demographic context relating to social behaviour and prevalence of technologies such as automobiles.

As stated in the original project description the analysis is limited to fatalities contained in the Life Loss database and does not attempt to study these as a proportion of the total population affected in the fires (unless it is specifically stated).

Fatalities were analysed with regard to their location. Categories of fatalities were used to explore the relationship with fire weather and distance to forest.

The following subsections draw on various subsets of this data focusing on the data's relevance to the variables being considered.

Significance tests have been performed on various variables to estimate the correlation between variables. To determine if the correlation is statistically significant the sample size and the critical value of the correlation coefficient is used with a minimum significance level of 0.05 (unless stated differently in the results).

6.1 Demographics

The gender, age and distribution of all fatalities (civilians and firefighters) were studied to help inform specific trends relating to assumed behaviours or activities. Data was grouped into three time periods; for the entire time period of data, pre 1965, and post 1965. The gender role could demonstrate an evolution of behaviour in the different roles of men and women over the century. Various other comparisons with gender, age and role are also provided in subsequent sections.

Table 4 shows the distribution of fatalities by gender and by age over the entire period and for the two sub-periods considered. The proportion of males dying in earlier fires (79%) is significantly greater than the proportion dying in recent fires (62.3%) (z=5.19, p<0.001). Conversely, the proportion of females that died in earlier fires (14.9%) is significantly less than the proportion that have died in the recent fires (35.8%) (z=6.65, p<0.001).

Table 4 Age and gender for the three time periods (all fatalities – civilians, firefighters and non-directly related fatalities)

	1901-1964	1965-2011	1901-2011 (total)	z	p
Total number killed	343	482	825		
Male	272 (79%)	300(62.3%)	572 (69.3%)	5.19	<0.001
Female	51 (14.9%)	173 (35.8%)	224 (27.2%)	-6.65	<0.001
Unknown	20 (5.8%)	9 (1.9%)	29 (3.5%)		
Age					
0-9	32 (9.4%)	29 (6%)	61 (7.4%)	1.81	<0.1
10-19	31 (9.1%)	36 (7.5%)	67 (8.1%)	0.83	>0.1
20-29	33 (9.6%)	50 (10.4%)	83 (10.1%)	-0.33	>0.1
30-39	29 (8.5%)	54 (11.2%)	83 (10.1%)	-1.27	>0.1
40-49	34(9.9%)	54 (11.2%)	88 (10.7%)	-0.57	>0.1
50-59	24 (7.0%)	74 (15.3%)	98 (11.9%)	-3.63	<0.001
60-69	27 (7.9%)	68 (14.1%)	95 (11.5%)	-2.74	<0.01
70-79	20 (5.8%)	34 (7.0%)	54 (6.5%)	-0.68	>0.1
80 and above	6 (1.8%)	31 (6.4%)	37 (4.5%)	-3.19	<0.005
Unknown	107 (31%)	52 (11%)	159 (19.3%)		

With regards to the differences in proportion of fatalities between earlier and later fires by age, significant differences were observed in the:

- 0-9 age group (significantly more deaths in the earlier fires)
- 50-59 age group (significantly more deaths in the later fires)
- 60-69 age group (significantly more deaths in the later fires)
- 80 and above age group (significantly more deaths in the later fires)

Z-values and p-values for these tests are displayed in Table 4 and are the results of a statistical test to compare the proportions dying in period 1901-1964 vs. period 1965-2011.

In summary, in earlier fires a higher proportion of the lives claimed were of young children, and more recent fires have claimed the lives of a higher proportion of older people. The distinction between civilians (further broken into gender) and firefighters is shown in Figure 5 for the two periods considered and for all known genders (29 unknown). This figure highlights the significant increase of female civilian fatalities in recent fires.

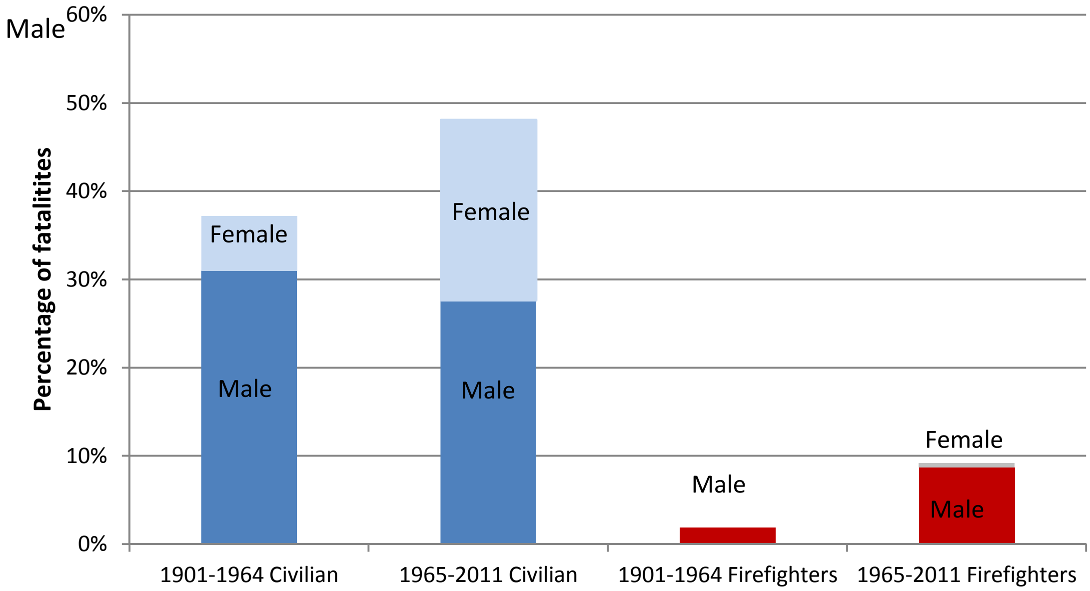

Figure 5 Number of fatalities by gender between the period 1901-1964 and the period 1965-2011 (distinction between civilian and firefighters)

6.2 Distributions of fatalities and house loss

The distribution of fatalities by year and by state is presented in this section to show the dominance of iconic events in the loss profile and the concentration of losses spatially across the continent. The losses per event and spatial distribution of loss is strongly influenced by fire weather severity which is not considered specifically in this section, refer to section 6.6 for a detailed review of fire weather related influences.

6.2.1 DISTRIBUTION BY YEAR

Figure 6 and Figure 7 indicate that the number of fatalities is dominated by a few major events resulting in large number of the fatalities. This is in accordance with the finding of Haynes et al (2010).

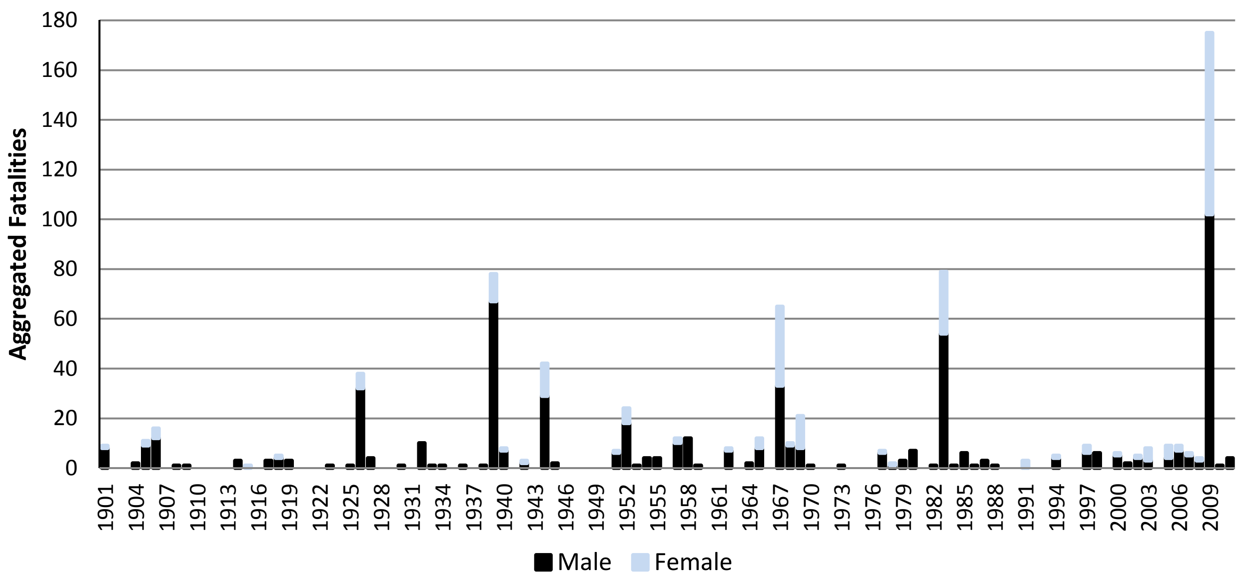

Figure 6 Distribution of number of fatalities over the time period (1901-2011) including civilian and firefighters

While the graph shows no consistent trend there is an increase in the loss per year rate when comparing the two time period categories (1901-1964 and 1965-2011). For the period 1901-1964, 5.1 civilian fatalities occurred per year and for 1965-2011, 8.6 fatalities occurred per year.

The number of houses lost for the period 1901-2011 shows a similar pattern (see Figure 7) and is dominated by the same iconic events (Blanchi et al 2010). There is a more noticeable bias toward losses in more recent years. This is in part due to the lack of house loss data in the 1901-1926 time period and also due to better record of house losses in recent years. Keeping this in mind the 1901-1964 house loss average is 44 per year and the 1965-2011 average is 168 per year. The correlation between house and life loss is explored in detail in section 6.3.2.

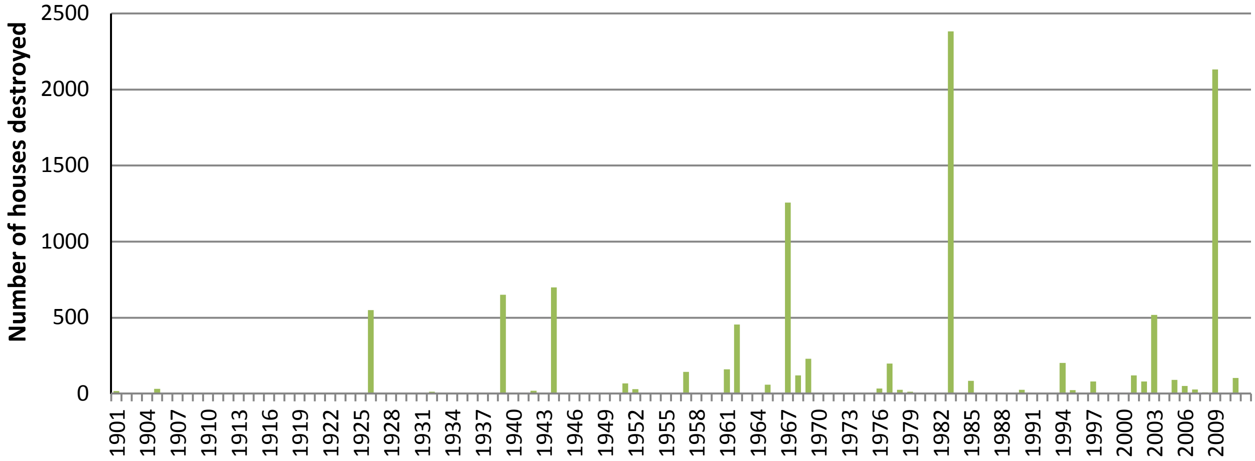

Figure 7 Distribution of number of house burnt (destroyed) over the time period (1901-2011)

6.2.2 DISTRIBUTION BY STATE

Each state of Australia has unique fire weather severity characteristics, policies, building stock, population sizes and vegetation characteristics. The Life Loss database allocates fatalities to the state in which they occurred. In considering the relative importance and stringency on a state-by-state basis it may be relevant to consider the historic loss as a breakdown into categories by state. The Table 5 and Figure 8 show the number of fatalities for each state over the entire time period and the two sub-time periods.

Table 5 Total fatalities by jurisdiction for the three time periods (all fatalities – civilians, firefighters and non-directly related fatalities)

	1901-1964	1965-2011	1901-2011 (total)
ACT	1 (.3%)	4 (.8%)	5 (0.6%)
NSW	74 (21.6%)	65 (13.4%)	139 (16.8%)
NT	0 (0.0%)	5 (1.0%)	5 (0.6%)
QLD	16 (4.7%)	9 (1.9%)	25 (3.0%)
SA	19 (5.6%)	38 (7.9%)	57 (6.9%)
TAS	2 (0.6%)	66 (13.7%)	68 (8.2%)
VIC	222 (64.0%)	284 (58.8%)	506(61.3%)
WA	9 (2.6%)	11 (2.3%)	20 (2.4%)
Total	342	483	825

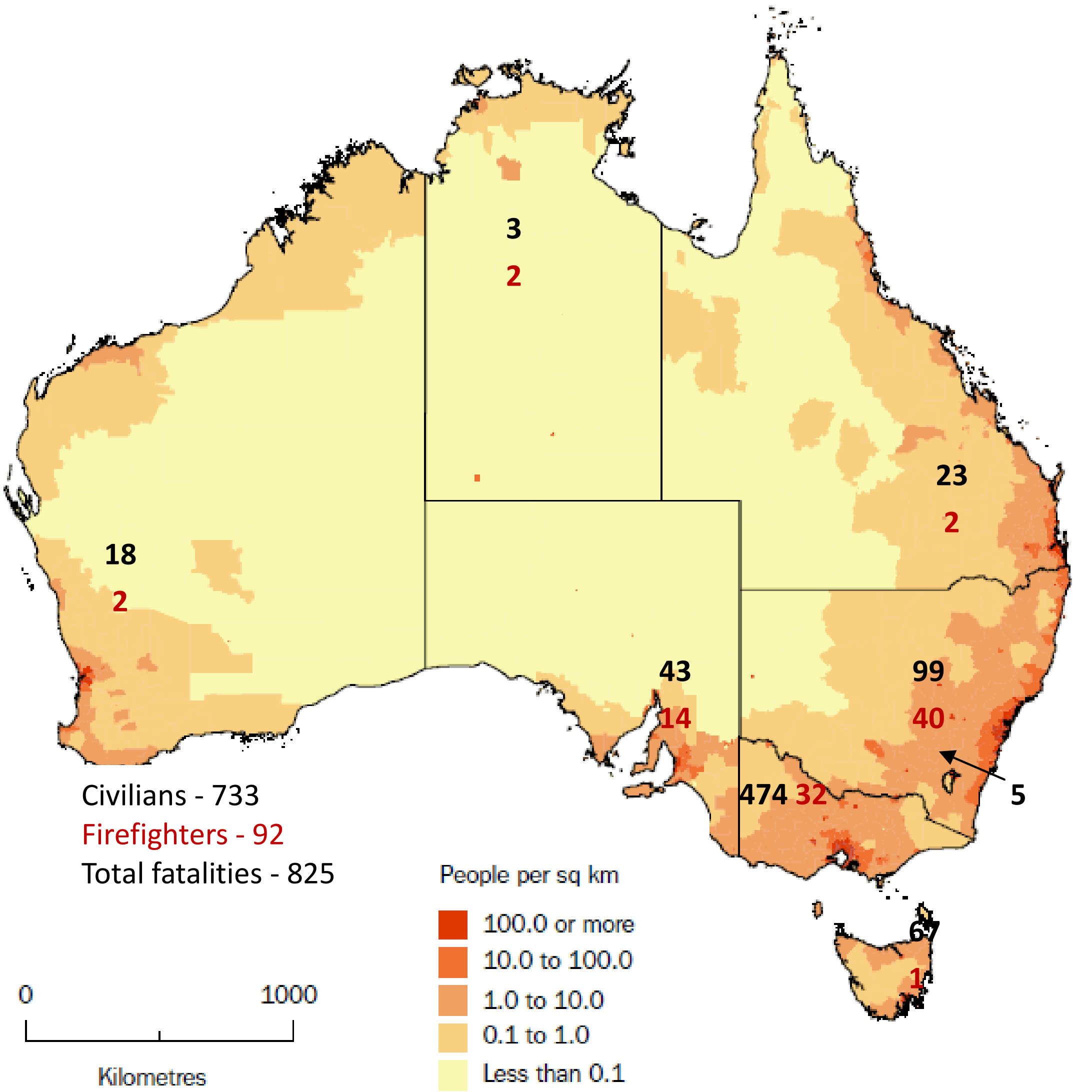

Figure 8 Distribution of fatalities by State (all fatalities – civilians, firefighters and non-directly related fatalities) on population density map June 2010 (From 3218.0 - Regional Population Growth, Australia -Year book Australia 2011 - http://www.abs.gov.au/ausstats/abs@.nsf/mf/3218.0 - accessed 07/01/2013)

The number of fatalities varies greatly in each state with more than 60% of all fatalities having occurred in Victoria. Five major events represent 66% of the losses in Victoria, Black Friday 1939 (64 fatalities), the January 1944 fire (33 fatalities), Lara fire in 1969 (18 fatalities), Ash Wednesday in February 1983 (46 fatalities) and the Victorian bushfires in 2009 (173 fatalities). Interestingly, 60% of house loss also occurred in Victoria during the same five major events (Blanchi et al 2010). To provide some qualification of the influence of population density on the spatial distribution of fatalities, Figure 8 provides a population density map (the data is from June 2010).

There is a clear trend for fatality rates to decrease when moving further north into the more tropical climate zones as climate conditions are less favourable to severe fire and population density reduce.

Figure 8 also shows the distribution of firefighters by State, the majority of the losses occurred in New South Wales (40) and Victoria (32).

6.2.3 DISTRIBUTION BY MONTH OF FATALITY

Fire weather seasonality can be highly influential in providing the necessary conditions for loss, hence it may be useful to profile fatalities with respect to the month that they occurred. Figure 9 shows the distribution of fatalities by month, 81% of all fatalities have occurred during the months of January and February which represent the peak of the fire season in the southern states (see Figure 10 bushfire season across Australia). There is not a representative profile for the fire season in the far north as losses occurred in a comparatively mild fire climate.

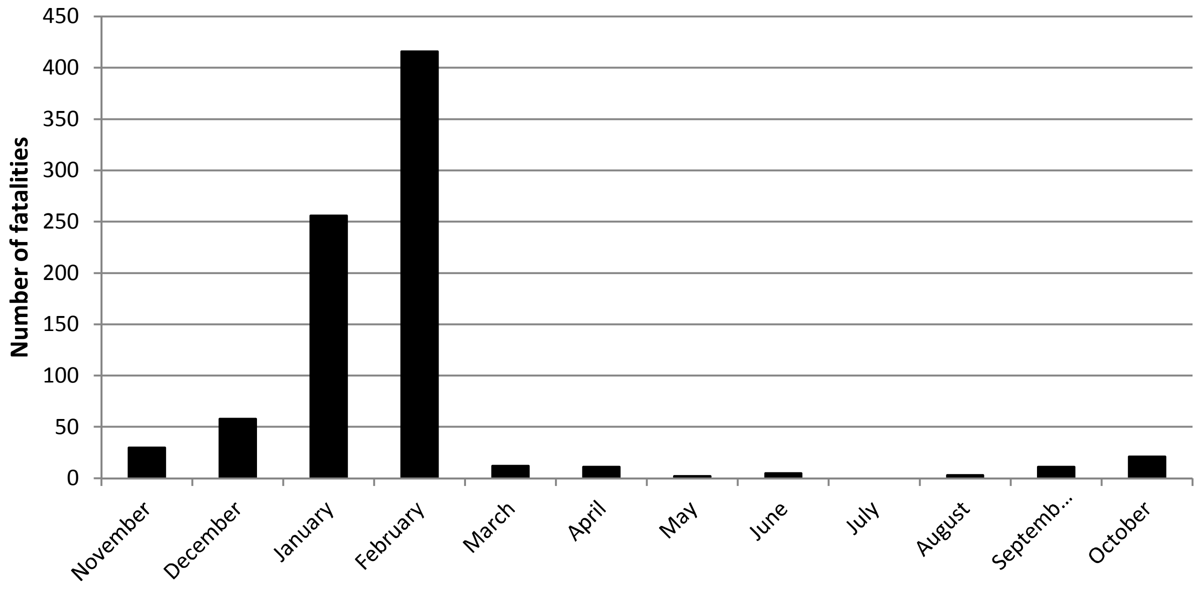

Figure 9 Number of fatalities per months (including civilian and firefighters)

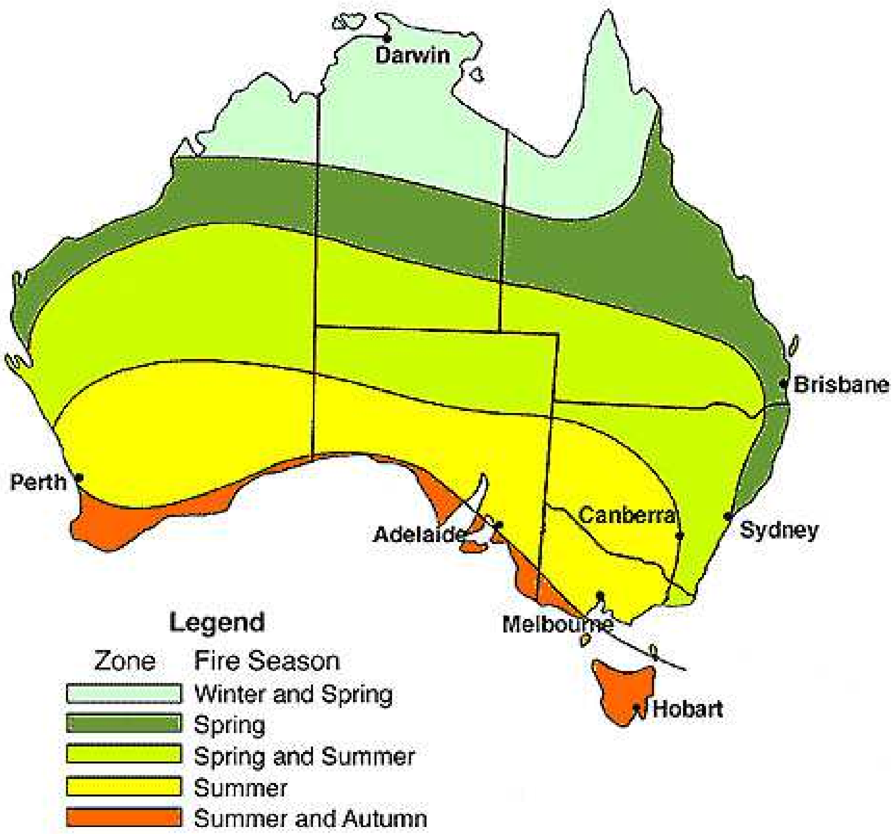

Figure 10 Bushfire season across Australia (from http://www.csiro.au/en/Outcomes/Environment/Australian-Landscapes/Fire-Season-Months.aspx[16])

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[16] Accessed 17/12/2012

6.2.4 DISTRIBUTION BY HOUR OF FATALITY

Understanding the timing implications for evacuation of areas forecast to receive severe fire weather is a key consideration for future bushfire risk management policy. Figure 11 profiles the time of fatal exposure (when known) for both firefighters (n44) and civilians (n397). This figure shows a clustering of civilian fatalities from 10am through to 11pm with one peak at 10am. This peak is mainly due to a single loss event, where 17 motorists lost their lives on the Princes Highway between 10am and 11am in the Victorian Lara fire in 1969. Without this anomaly, the civilian fatalities exhibit a normal distribution around 6pm. Firefighter fatalities have a similar fatality time distribution to civilians, however there is a very distinctive dip during the peak of civilian fatalities.

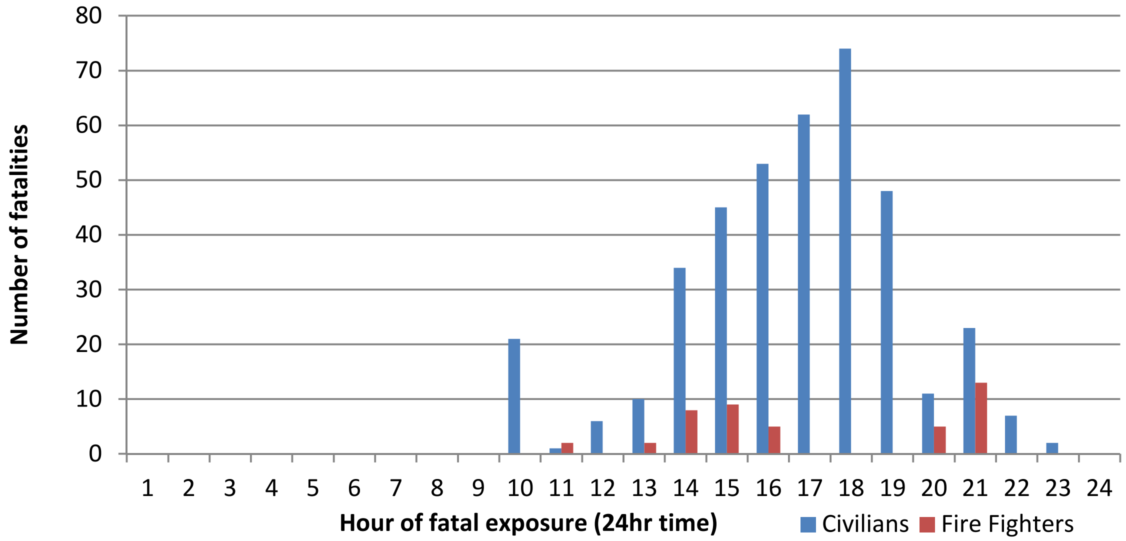


Figure 11 Hour of civilian and firefighter fatal exposure for all directly related deaths (each category is from 0:00 to 0:59)

Figure 12 also shows the distribution of civilian fatalities (n397) but is broken further into location categories (148 inside structure, 43 inside vehicle, 206 open air). The Lara fire is prominent as open air losses as all of the motorists were caught in the open after fleeing their vehicles. Fatalities in houses show than a large proportion of fatalities occurred around 6pm due to the 2009 black Saturday bushfires. The peak around 9pm is largely attributed to the Ash Wednesday 1983 fires in Victoria.

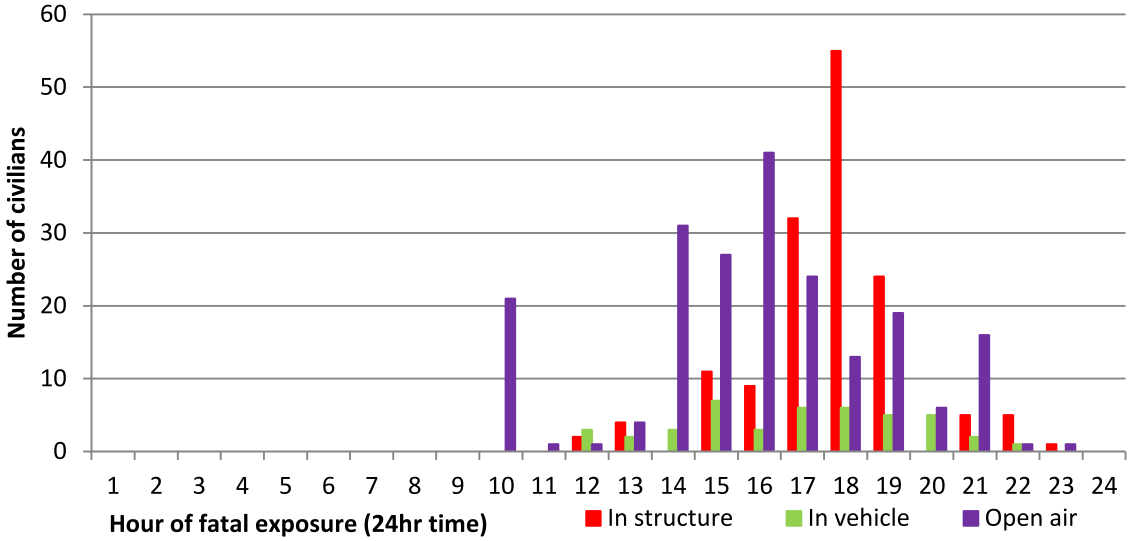


Figure 12 Hour of civilian fatal exposure for each location type (directly related to bushfire)

6.3 Loss per Fire events

The Life Loss database captures 825 fatalities occurring over 260 fire events. For some of these fire events the house loss levels are also known and have been added to the dataset. An analysis of the levels of loss within each event has been performed to understand the distribution of life loss number per event and to then examine any potential correlation between life and house loss levels per event. This understanding may be useful in broadening the understanding of future risk profiling methods that focus on either house or life loss specifically. Inquiry processes such as the Teague Royal Commission set out classification guidelines for defining a fire event[17]. Using these classifications there is, for example, Black Saturday 2009 as a single fire day that involved five separate fire events resulting in fatalities (Kilmore fire, Churchill Fire, Murrindindi fire, Maiden Gully fire, Beechworth fire).

6.3.1 LIFE LOSS PER FIRE EVENT AND INCIDENT

Figure 13 shows a breakdown of all 260 fire events in terms of the number of fatalities per event. Fire events have been classified according to the number of fatalities in an event. The figure shows an obvious exponential decline in the number of fatalities; significantly more fire events have a low number of fatalities per event. Both civilian and firefighter fatalities track with a similar trend.

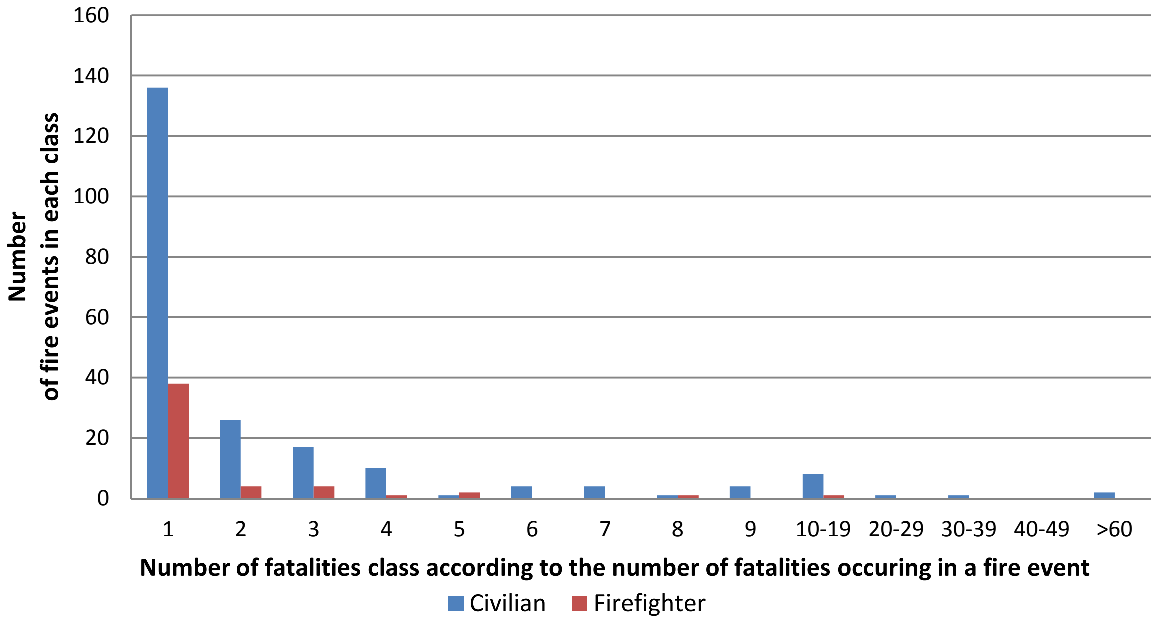


Figure 13 Number of fire events as a function of the number of fatalities class in a fire event (all fatalities)

Figure 14 emphasises the relative balance between many fire events with few losses compared to few events with many losses. Fifteen major fire events involving 9 or more fatalities per event represent 51% of all civilian fatalities. These events have occurred during 10 fire days and are detailed in the Table 6. The total number of fatalities during those days account for 65% of all civilian fatalities.

[17] http://www.royalcommission.vic.gov.au/commission-reports/final-report (accessed 30/10/2012)

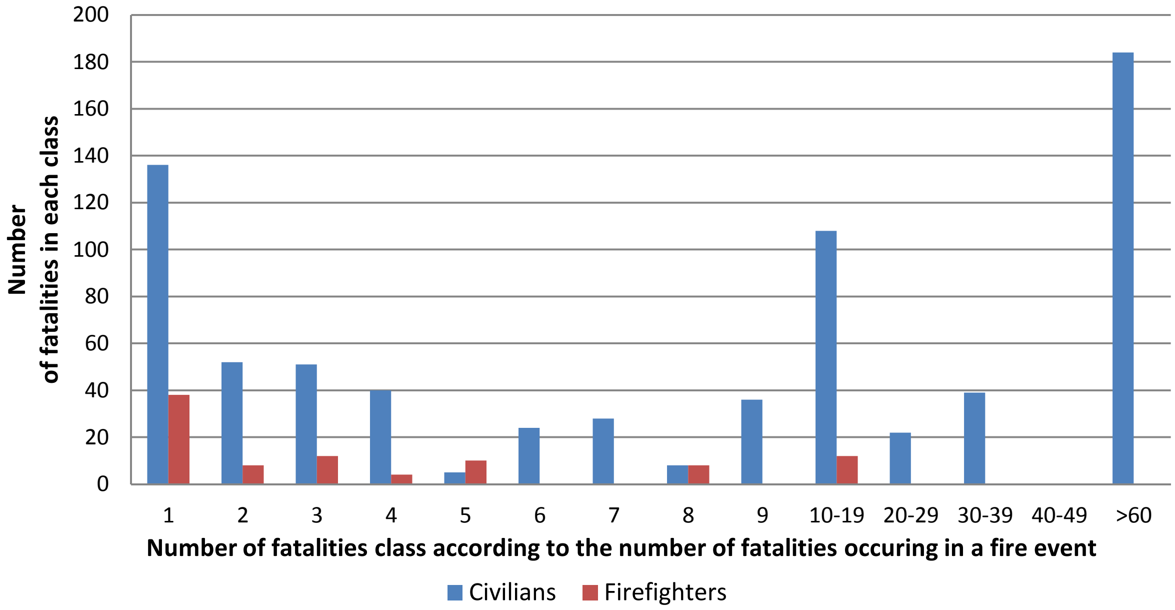


Figure 14 Aggregated fatalities function of fatalities class (fire event have been classified according to the number of fatalities in an event)

Table 6 Ten major fire days in Australia involving fatalities

Date of fire	Total number of civilian fatalities	Number of events	Number of house loss*	Major fire event >9 civilian fatalities (number in bracket)	Weather context
14/02/1926	31	7	550 (number varies)	Gippsland – VIC - Gilderoy & Powelltown (16)	FFDI 67. Described as “hot North wind’
10/01/1939	19	2	650 houses reported for all 1939 fire	Black Friday bushfires - VIC – Rubicon 12)	FFDI 72.These bushfires affected a large area of Victoria (during heatwave). Described as a very hot day, “wind blowing as hurricane”
13/01/1939	47	12	Around 650 houses reported for all 1939 fires	Black Friday bushfires - VIC– Matlock (22), Tanjil (9)	FFDI 72.These bushfires affected a large area of Victoria (during heatwave). Described as “a very hot day with strong wind”
14/01/1944	35	11	Around 700 for all 1944 fire	Linton – VIC (12)	FFDI around 100-150. Described as “very hot day and strong wind”
14/02/1944	13	2	Around 700 for all 1944 fire	Morwell bushfires - VIC (9)	FFDI 66
7/02/1967	64	1	1257	Black Tuesday, Hobart - TAS (64)	FFDI 95 (reported 85).
8/01/1969	20	3	230	Lara (18)	FFDI 134
16/02/1983	27	2	383	Ash Wednesday - SA - Narraweena (14), Adelaide Hills (13)	FFDI 130
16/02/1983	46	5	2060	Ash Wednesday – VIC - Beaconsfield (9), Warrnambool (9)	FFDI 145
7/02/2009	172	5	2021	Black Saturday – VIC – Kilmore East (120), Murrindindi (39), Churchill (11)	FFDI 155

*Number of house loss could vary depending on the source of information

A fire event includes incidents which relate fatality and related objects to a fire. An incident can refer to more than one fatality where individuals were sheltering or behaving as a collective group. The number of fatality per incident shows many incidents with one loss compared to fewer incidents with 2 or more fatalities behaving as a group. The incident with the most civilian fatalities was the death of 17 motorists during the Lara bushfire (1969). The most firefighters lost in an incident occurred when 12 people were trapped in their tankers during the Ash Wednesday Beaconsfield bushfire in 1983). The highest number of fatalities found inside a structure occurred during the Black Saturday fire 2009, where 9 civilians (3 families) sheltered together at a neighbour's house.

Table 7 Number of fatalities per incident (all fatalities – civilians, firefighters and non-directly related fatalities)

Number of fatalities per incident	Civilian (733)	Firefighter (92)	Total(825)
1	314	38	352
2	67	4	71
3	30	4	34
4	17	1	18
5	4	2	6
6	5	0	5
7	2	0	2
8	1	1	2
9	1	0	1
12	0	1	1
14	1	0	1
15	1	0	1
17	1	0	1

6.3.2 LIFE AND HOUSE LOSS COMPARISON PER FIRE EVENT AND FIRE DAY

Bushfire risk assessment has traditionally focused on house loss as a metric for comparing the relative loss of various historic bushfires (Blanchi et al. 2010, Harris et al. 2012), hence it could be useful to determine the extent to which house loss levels can act as a surrogate indicator of expected life loss levels on a given fire day or fire event. Figure 15 is derived from 110 fire events with either life loss, house loss or both. Figure 15 shows a correlation between these two factors with a coefficient of determination R^2 value of 0.67. The only word of caution with the R^2 value is the consideration of the level of dependency between life and house loss events as in a proportion of cases the life loss occurs in direct association with house loss, see section 6.4.

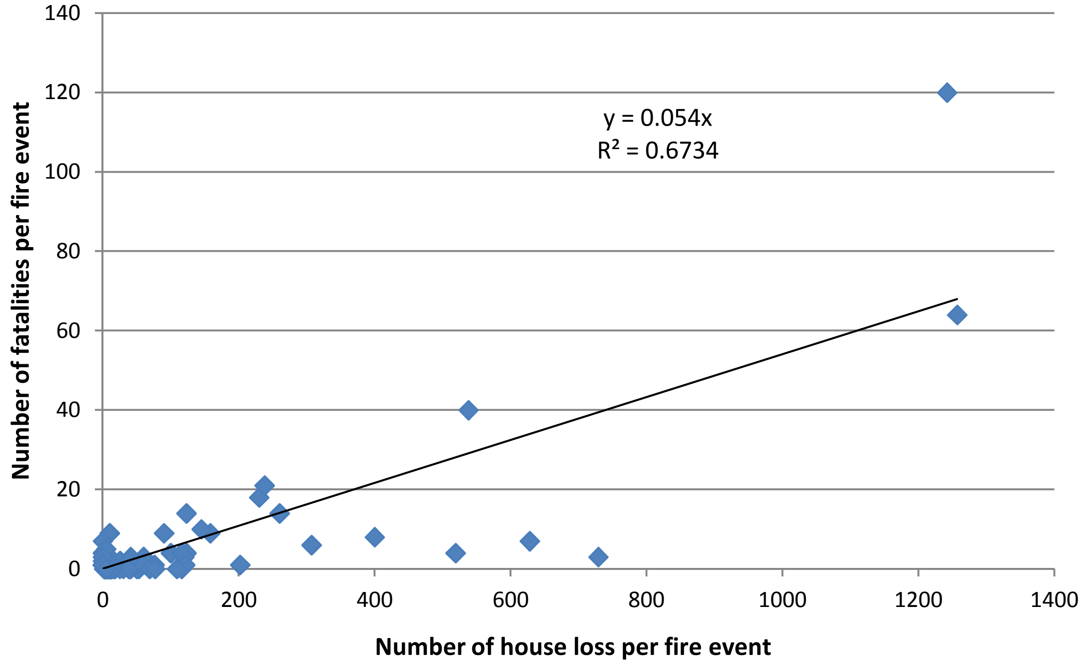


Figure 15 House and life loss correlation per fire day

As an alternative approach a correlation based on aggregated fire days rather than fire events as is the case for Figure 15 was performed. Figure 16 below shows the correlation per fire day with a R^2 of 0.83.

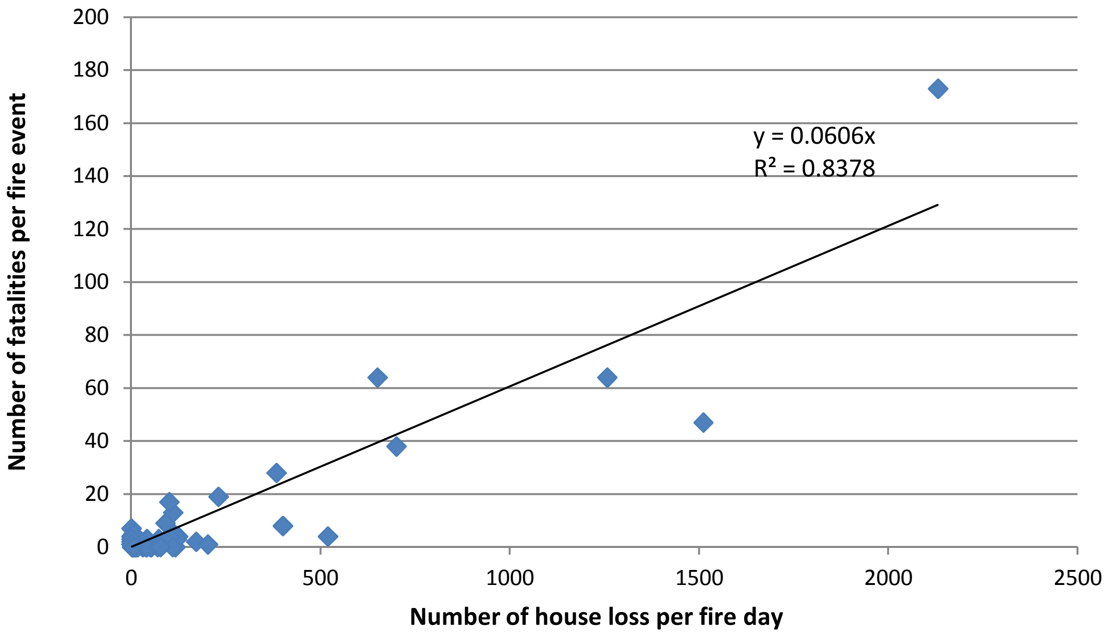


Figure 16 House and life loss correlation per fire event with additional house loss data included

The comparative correlation is so close that there is no key learning to be gained from the relative benefit of using fire days or fire events to establish the relationship. Given that fire danger forecasting tends to relate to regions of fire weather influence in which there can be multiple fires, it may be more appropriate to use the slightly stronger correlated approach of fire days.

6.4 Location of fatal exposure

To better understand the circumstances of fatalities this section explores the spatial location of the fatality and its relationship to surrounding elements such as the location of the deceased's residence. Analysis of the spatial accuracy recorded in the Life Loss database shows a larger spatial error exists for the early part of the century. This in part can be attributed to the advanced in mapping and recording of locations for recent bushfires. Figure 17 shows the distribution of spatial error associated with the fatal exposures. Fifty percent of locations have a spatial error greater than 1km. This occurs most often when little information was available (e.g. only the name of a bushfire event, the fatality occurred on a farm or on a large area), 37% of fatalities have a spatial error less than 100m and these were considered in the following spatial analyses.

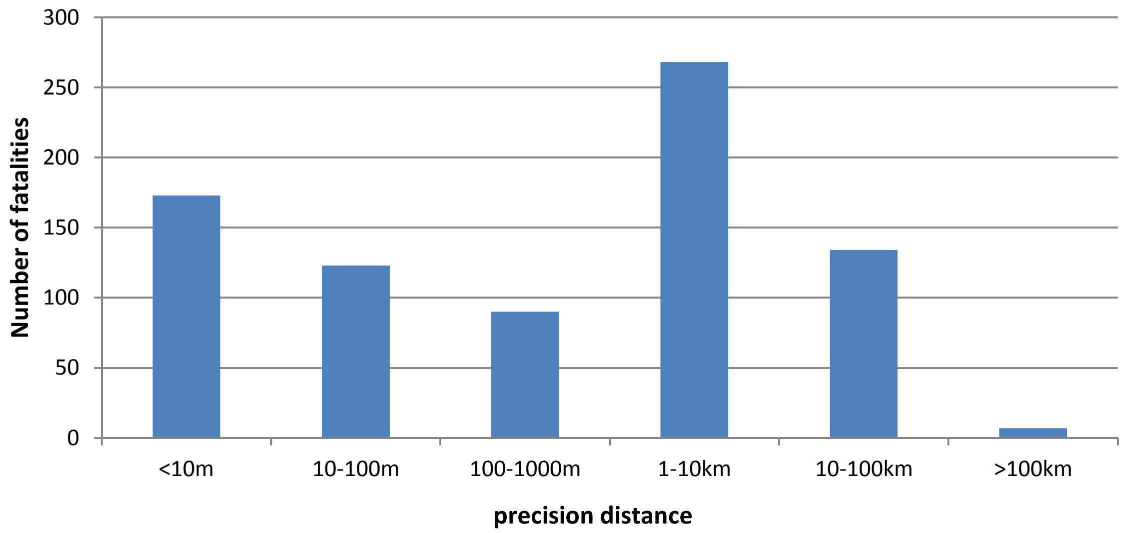


Figure 17 Error precision for each fatal exposure location (presented in categories)

6.4.1 SPATIAL LOCATION IN AUSTRALIA

A description of the location of fatal exposure for 806 fatalities was recorded in the Life Loss database (18 were either unknown or considered not applicable). For 111 cases the death occurred after the fire event at a distant location (e.g. in hospital). For these cases both a location of fatal exposure and a location of death are recorded. The locations and time of fatal exposure are used later to correlate circumstances such as weather and proximity. Table 8 summarises the location of death with respect to the location of fatal exposure.

Table 8 Location of fatal exposure and location of death

	Civilian	Firefighter	Total
Same location	614 (83.8%)	82 (89.1%)	696 (84.4%)
Different location	101 (13.8%)	10 (10.9%)	111 (13.5%)
Unknown	17 (2.3%)	0	17 (2.1%)
NA	1 (0.1%)	0	1 (0.1%)
Total	733 (100%)	92 (100%)	825

Each of the 795 known locations of fatal exposure can be seen in Figure 18. This figure shows a larger number of fatalities in more populated regions of Australia (see also Figure 8).

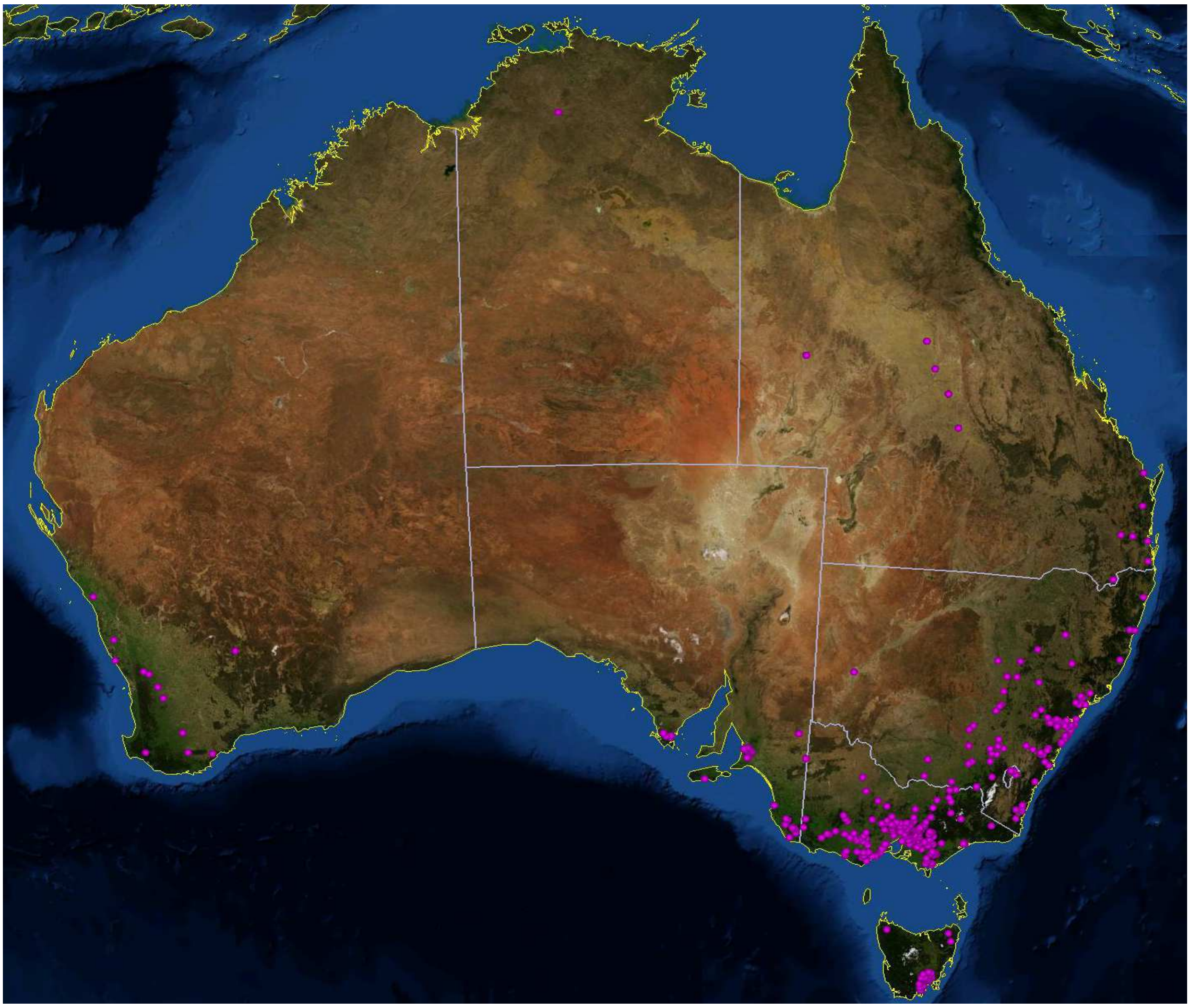


Figure 18 Location of all fatalities in Australia (background map from Google Earth)

6.4.2 LOCATION OF FATAL EXPOSURE CATEGORIES

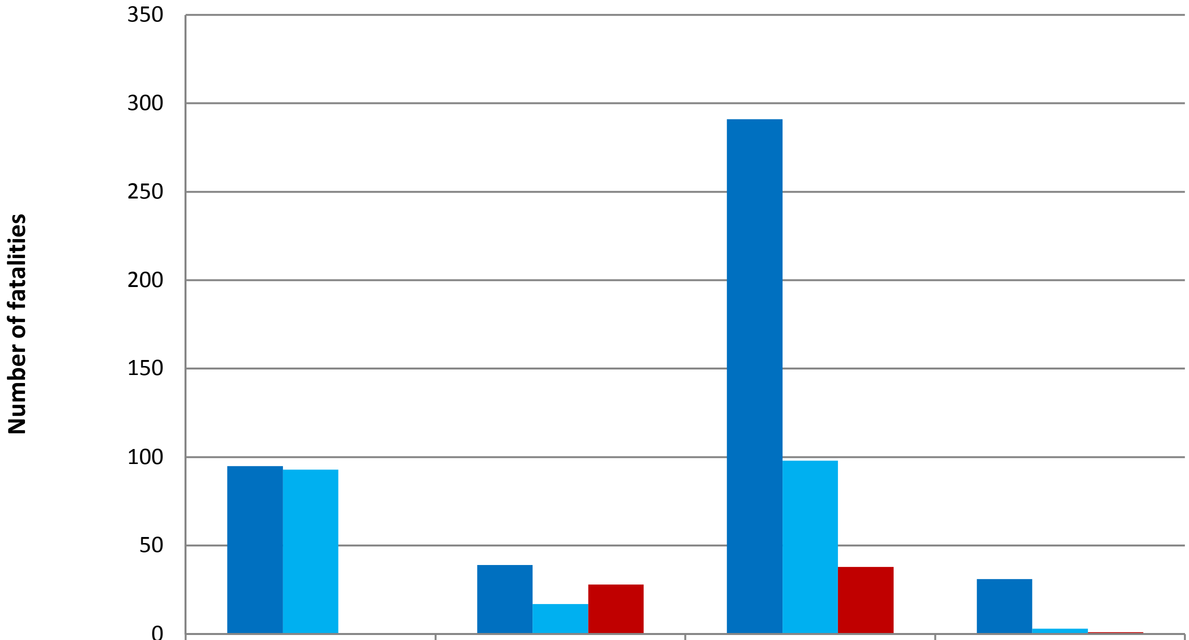
The location of fatalities were categorised into 'In structure', 'In vehicle' & 'Open air' to better understand the specific level of shelter a person had when they died. The summary Table 9 shows the location categories of fatal exposure for the three time periods (1901-2011; 1901-1964; and 1965-2011). A significantly greater proportion of fatalities occurred inside structures or inside vehicles in recent fires, compared to earlier fires. The higher proportion of fatalities inside vehicles in the time period 1965-2011 is explained by higher prevalence of cars and their use during this period. This summary also highlights that a significantly greater proportion of fatalities occurred in earlier fires in the open air, compared to more recent fires.

Table 9 Fatal exposure location categories over the three time periods (civilian)

	1901-1964	1965-2011	1901-2011 (total)
Inside structure	21 (7.1%)	167 (44.4%)	188 (27.9%)
Inside vehicle	11 (3.7%)	45 (12.0%)	56 (8.3%)
Open air	232 (77.8%)	158 (42.0%)	390 (57.8%)
Unknown	34 (11.4%)	6 (1.6%)	40 (5.9%)
Total	298 (100 %)	376 (100%)	674 (100%)

Figure 19 shows the same data summary presented in Table 9 further broken into civilian gender and firefighter fatalities. A greater number of male civilian fatalities have occurred in open air than in any other location, particularly earlier in the century. This is possibly related to job profiles that involve remote location work such as timber felling where shelter is not easily sort or farmers attempting to save livestock.

Firefighter fatalities occurred either in open air or inside vehicles in fire fighting vehicle burn-over incidents or involved with falling trees. Sheltering within a structure is a relatively rare and often unavailable strategy for firefighters.



	inside structure	inside vehicle	open air	Unknown
civilian male	95	39	291	31
civilian female	93	17	98	3
fire fighter	0	28	38	1

Figure 19 Location categories of fatal exposure compared with role and sex

6.4.3 DISTANCE FROM RESIDENCE

The distance of a fatality to the location of their residence can help qualify the prevalence of behaviours in relation to last minute evacuation or alternative shelter and defence strategies. A sample set of 116 fatalities was queried from the Life Loss database in which residential address and fatal exposure locations were both accurately known. This sample involves 79 fatalities that occurred in open air, 18 that occurred inside vehicle and 19 inside structure (other than their residence, e.g. a neighbouring house, bunker etc). These cases have been plotted as cumulative graph in Figure 20.

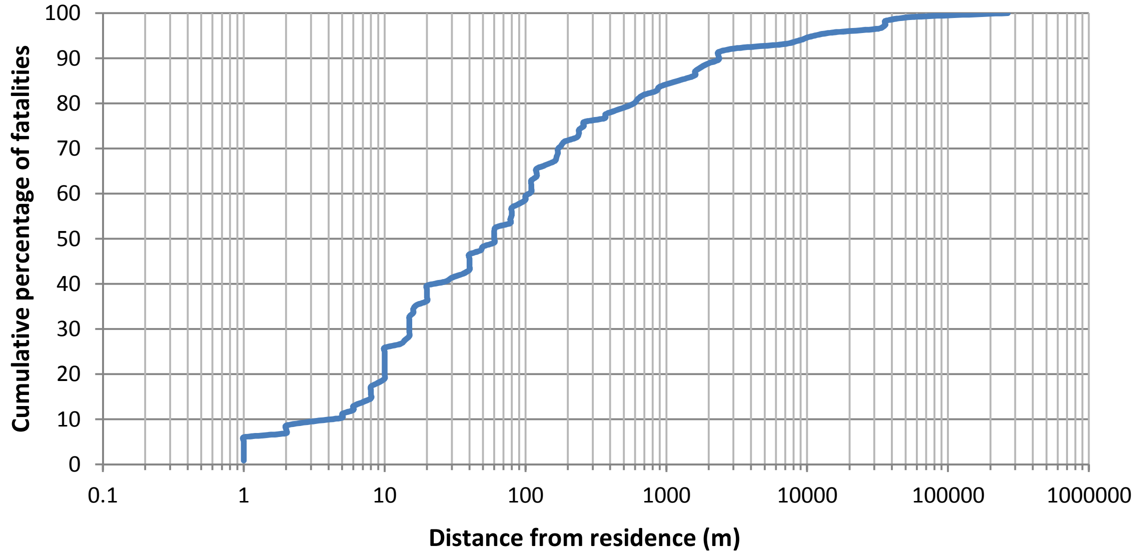


Figure 20 Distance between residential address and fatal exposure location (civilian)

The Figure 20 shows a close association with the place of residence, with 61% of fatalities occurring within 100m of their location of residence and 84% occurring within 1km. Of the locations of residence of the deceased considered, 10 houses were not damaged and were not used as a shelter. 89 houses were completely destroyed and of these 20 houses were used as a place of refuge during the event. The main activity of the fatalities considered in the analyses is late evacuation (48.3%), then outside saving livestock, livelihood or defending wider property (20.7%), and people sheltering as a group (11.2%).

6.4.4 DISTANCE FROM VEHICLE

A set of 54 fatalities were studied where both the fatal exposure location and the vehicle location were accurately known. These cases involved situations where the vehicle was left and fatalities occurred in the open air. Forty-eight cases involved completely burnt out vehicles, 3 were untouched and 4 damaged. Of the 3 cases of untouched vehicles, 2 cases involved an attempt to shelter together 100m away from the same vehicle under synthetic blankets and 1 case 270m away with no protection in an area were heavy smoke was present during the fire's passage. Figure 21 below shows a logarithmic profile with 40% of fatalities occurring within 10m of the vehicle and 67% within 100m of the vehicle. The context of entrapment of vehicle was captured in the data collection phase; information was available for 18 fatalities (33%). In 14 cases the car was bogged or trapped by fallen tree, and for the remaining 4 the vehicle ran off the road due to poor visibility.

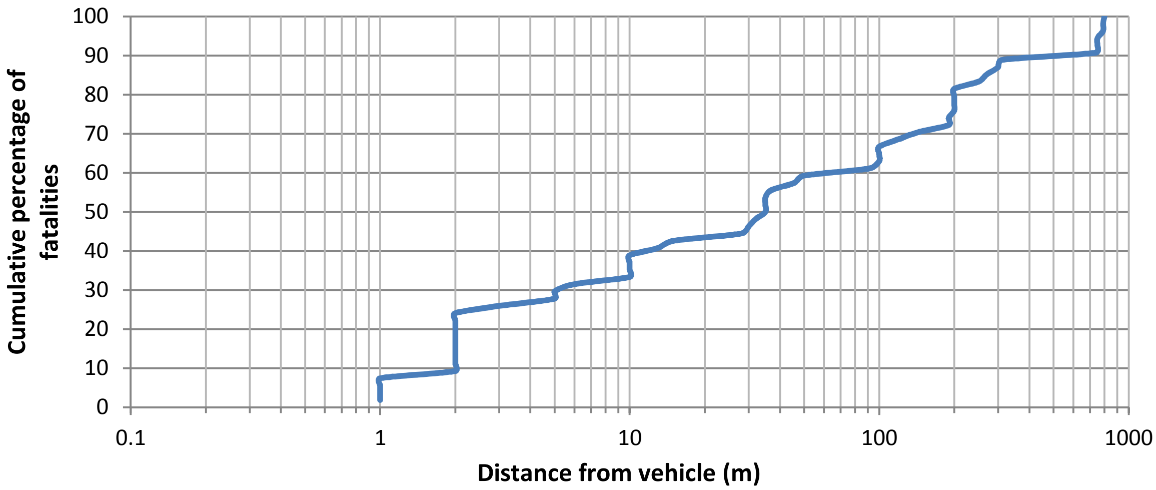


Figure 21 Distance between vehicle and fatal exposure location (civilian)

6.4.5 LOCATION WITHIN STRUCTURE

For the fatalities that occurred inside structures it is useful to understand the location within the structure in which the fatal exposure occurred, as this will help to understand the behaviour adopted and the modes in which the house may have lost its tenability. Table 10 details the location of the fatality inside the structure in which the specific location of body was known.

The study of the 1983 Ash Wednesday fire in Victoria (Krusel and Petris 1999) and the study of the 1967 Hobart fire (McArthur 1967) showed that a small number of fatalities occurred inside a house and mainly involved occupants sheltering in a closed room (e.g. bathroom) with no clear view of the circumstances outside of the structure. The detailed study of the location of fatalities inside a structure (n188) shows that 37% of the fatalities with known locations occurred in a room with reduced visibility to outside conditions (bathroom, enclosure, laundry, study, toilet block, bunker), the location of 34% is unknown (see Table 10).

Table 10 Known fatality locations inside structure detailed location

Detail inside structure	Number of fatalities	Percentage of known
Unknown	64	34%
Bathroom	36	19%
Kitchen	25	13%
Bedroom	17	9%
Study	10	8%
Under house enclosure	9	5%
Entrance	5	3%
Lounge	4	2%
Cool-room	3	2%
Laundry	3	2%
Outdoor spa	3	2%
Toilet block	3	2%
Bunker	2	1%
Shed	2	1%
Independent garage	1	1%
Shack	1	1%
Total	**188**	**100%**

Table 10 shows that 10% of cases where fatalities occurred in buildings that were not their main residence, these have been highlighted in blue. By removing the non-residential structure cases we can derive Table 11 including 109 fatalities occurring inside residential structure with known locations.

Table 11 Known fatality locations inside residential structures detailed location

Detail inside structure	Number of fatalities	Percentage of known
Bathroom	36	33%
Kitchen	26	23%
Bedroom	17	16%
Study	10	9%
Enclosure under house	9	8%
Entrance	5	5%
Lounge	4	4%
Laundry	3	3%
Total	**109**	**100%**

Of these cases 33% of the fatalities occurred in bathrooms which typically have no clear visual cues to outside conditions. All other cases either involve an opportunity to monitor outside conditions or be adjacent to an exit to facilitate egress when the house approaches untenable conditions. Eight percent of cases were in either the entrance or laundry: both typically are adjacent to an exit door providing an option to egress if conditions allowed.

Fifty-eight percent involved fatalities in the bathroom, bedroom or study which all typically have only one point of exit to the rest of the house. Twenty-seven percent of cases involving kitchens and lounge areas which usually have opportunities for viewing outside conditions and multiple options to progress through the house towards an exit if it is recognised that the house is losing tenability.

In summary, for 59% of the fatalities there was the opportunity to effectively monitor both the internal and external conditions and make decision to move towards and exit as the house lost tenability. So either people were not aware of this strategy (or the need to leave) or the houses lost tenability at a rate in which safe passage from these locations to an exit door was not possible.

Also to consider are the air toxic species emitted and exposure concentrations inhaled by residents both indoors and outdoors. Reisen et al. have shown that during prescribed burning firefighters are exposed to a range of hazardous pollutants in particular fine particles, carbon monoxide (CO), formaldehyde and volatile organic compounds (VOCs) (Reisen and Brown 2009; Reisen et al. 2011). At the urban or rural urban interface additional air pollutants resulting from the combustion of the structural material are a concern such as asphyxiants (CO and hydrogen cyanide) and other irritants (e.g. formaldehyde, acrolein, hydrogen chloride). Some of those pollutants could potentially impair the judgement and behaviour of residents if present at elevated concentration (Reisen 2011).

Regarding the demographic of fatalities found inside structure 51% were male and 49% were female. This represents a higher proportion of female fatalities compared to other locations; 70% male and 30% female were found inside vehicle; 75% male and 25% female were caught in the open air (see Figure 19). Some studies have also found that people dying in houses were old or suffered from disability (McArthur 1967, Hobart fire). The analysis of age categories shows a prevalence of elderly (over 70) fatalities, particularly when observing the subset of fatalities that occurred inside a structure to the entire sample (21.3% inside structure compare to 12.1% for all locations; see Table 12). Eleven percent of fatalities inside structures were physically or mentally incapable of implementing survival strategy (21 people) compared to 5% of all civilian fatalities (32 people).

Table 12 Comparison age group between fatalities inside structure and all civilian

Age	All civilian	Inside structure
0-9	57 (8.5%)	11 (5.9%)
10-19	61 (9.1%)	13 (6.9%)
20-29	67 (9.9%)	17 (9.0%)
30-39	69 (10.2%)	23 (12.2%)
40-49	67 (9.9%)	17(9.0%)
50-59	88 (13.1%)	33 (17.6%)
60-69	86 (12.8%)	30 (16.0%)
70-79	48 (7.1%)	21 (11.2%)
80 and above	34 (5.0%)	19 (10.1%)
Missing	97 (14.4%)	4 (2.1%)
Total	674 (100%)	188 (100%)

6.5 Activity and decision making

The influence of human behaviour by their activity and decision making plays an important role in their chance of survival and the survival of their assets (e.g. McArthur and Cheney 1967; Wilson and Ferguson 1984; Krusel and Petris 1999; Blanchi and Leonard 2008; Haynes et al. 2010). This section reviews the activities and decision making using the coding scheme developed by Haynes et al. (2010) in her study of the 1900-2008 fatalities. To explore the relationship between activity and other variables, two types of multivariable analysis were performed:

- Exploration of the relationship between activity, decision making and the FFDI (Forest Fire Danger Index) at 3pm
- Linear regression to characterise the activity undertaken immediately prior to death as a function of other variables

6.5.1 FREQUENCY ANALYSIS OF ACTIVITY AND DECISION MAKING

The activities of the person immediately prior to their death are shown in Table 13 below. When considering the total time period, late evacuation is the most common activity (30.4%), followed by sheltering inside a structure (24.8%) and defending a property outside (22.4%). Late evacuation is the most common activity for the 1901 - 1964 time period (37.2%), followed by defending property outside (30.2%). In comparison, the most common activity for the 1965-2011 time period is sheltering inside a structure (40.2%). Sheltering is not a common activity for the 1901 - 1964 time period and the difference between the two time periods for this activity is significantly different at the <0.001 level. The second most common activity for the most recent time period is late evacuation (24.8%) followed by defending property outside (16.3%). The proportion of those engaged in a late evacuation and defending wider property outside at the time of their death has significantly decreased between the two time periods (<0.005 level). During the former part of the last century a slight majority of those evacuating were doing so from a place of work outside as well as from a place of shelter. Whereas, in more recent time periods almost all the fatalities attempting to evacuate were doing so from a place of shelter.

Late evacuation was also the most common activity found in Haynes study (2010), however the percentage of people dying inside a structure has greatly increased from 8.3% in Haynes study to 24.8% in this study. This can be mostly attributed to 2009 Victorian bushfire where 118 fatalities died inside structures.

Table 13 Activities of civilian fatalities over the three time periods (percentage of civilian fatalities data)

	1901-1964	1965-2011	1901-2011 (total)	z	p
Late evacuation	**111 (37.2%)**	**93 (24.8%)**	**204 (30.4%)**	**3.94**	**<0.005**
Of these:					
from shelter	46	87	133		
from a place of work outside	51	2	53		
destination or origin unknown	14	4	18		
from an un-defendable shelter (dugout, culvert, shed)	0	0	0		
Defending property outside	**90 (30.2%)**	**61 (16.3%)**	**151 (22.4%)**	**4.30**	**<0.005**
Inside property	**18 (6.0%)**	**152 (40.2%)**	**168 (24.8%)**	**-10.41**	**<0.001**
Of these:					
Actively defending	3	27	30		
Engaged in some defence before sheltering	3	45	48		
Passively sheltering	9	56	65		
Passively sheltering as a group (3 or more people from separate families or any number of separate families gathering at a 'community refuge')	-	17	17		
Activities unknown	1	7	8		
Travelling through the area unaware	**22 (7.4%)**	**44 (11.8%)**	**66 (9.8%)**	**-1.89**	**<0.1**
Of these:					
Travelling for work	2	4	6		
Travelling for pleasure (picnic, camping)	9	27	36		
En route to defend or rescue	11	13	24		
Waiting rescue	**1 (0.3%)**	**6 (1.6%)**	**7 (1%)**	**-1.61**	**>0.1**
Assisting fire fighting operations	**6 (2%)**	**2 (0.5%)**	**8 (1.2%)**	**1.76**	**<0.1**
Returned into burning building	**2(0.7%)**	**6 (1.6%)**	**8 (1.2%)**	**-1.10**	**>0.1**
In an un-defendable shelter (dugout, shed)	**8 (2.7%)**	**3 (0.8%)**	**11 (1.6%)**	**1.92**	**<0.1**
Activity unknown at time of fatality	**42 (14.1%)**	**9 (0.8%)**	**51 (7.6%)**		
Total	**298 (100%)**	**376 (100%)**	**674 (100%)**		

Table 14 Comparison of the five major bushfires (civilian fatalities)

	1926	1939	1967	1983	2009
Total fatalities	**39**	**79**	**64**	**60**	**172**
Men	32 (82.1%)	68 (86.1%)	32 (50%)	36 (60%)	99 (57.6%)
Women	6 (15.4%)	11 (13.9%)	32 (50%)	24 (40%)	73 (42.4%)
Unknown	1				
Late evacuation	**23**	**37**	**19**	**18**	**35**
Of these:	(59%)	(50.6%)	(29.7%)	(30%)	(22.1%)
from shelter	5	9	17	18	35
from a place of work outside	18	24	2	0	0
destination or origin unknown	0	4	0	0	0
from an un-defendable shelter (dugout, culvert, shed)	0	0	0	0	0
Saving livestock or defending property outside. Caught outside their home, friend's home, local community etc.	**3** (7.7%)	**23** (29.1%)	**17** (26.6%)	**18** (30%)	**7** (4.1%)
Inside property	**0**	**4**	**12**	**11**	**118**
Of these:		(5.1%)	(18.8%)	(18.3%)	(68.6%)
Actively defending	0	0	1	0	26
Engaged in some defence before sheltering	0	0	4	0	37
Passively sheltering	0	3	6	9	35
Passively sheltering as a group (3 or more people from separate families or any number of separate families gathering at a 'community refuge')	0	0	0	0	17
Activities unknown	0	1	1	2	3
Travelling through the area unaware	**3**	**4**	**0**	**11**	**9**
Of these:	(7.7%)	(5.1%)		(18.3%)	(5.2%)
Travelling for work	0	0	0	1	0
Travelling for pleasure (picnic, camping)	1	3	0	2	6
En route to defend or rescue	2	1	0	8	3
Waiting rescue	**0**	**0**	**4**	**2**	**0**
Assisting fire fighting operations	**0**	**2**	**2**	**0**	**0**
Returned into burning building	**0**	**0**	**4**	**0**	**0**
In an un-defendable shelter	**1**	**3**	**0**	**0**	**3**
Activity unknown at time of fatality	**9**	**6**	**6**	**0**	**0**

Table 14 explores the activity at the time of death over five fires where significant losses occurred. Here the relationships seen in Table 13 are examined in greater detail. For all fires, apart from the 1967 Hobart fires, men die in higher numbers. However, the fires in the first time period are characterised by men dying in far greater numbers than women. Late evacuation was the most common activity and decreases almost linearly from 1926 to 2009. In comparison the proportion of those who are dying inside a structure has increased from 0% in 1926 to 68.6% in 2009. Saving livestock or defending property outside was a fairly common activity in the 1939, 1967 and 1983 fires, engaged in by over a quarter, to one third of the fatalities. However, this was an activity only undertaken by 4% of fatalities during the 2009 fires.

As would be expected the majority of firefighters have been killed while undertaking official fire fighting activities (see Table 15).

Table 15 Activity at the time of fatality for firefighters

Late evacuation from shelter	2
Saving livestock, livelihood or defending wider property or	1
Undertaking official firefighting activities for a control agency.	77
Travelling to and from official firefighting or supporting activities.	8
Unknown	4
Total	92

For the most recent time period, a slightly greater proportion of fatalities were aware of the fire with enough time to save their lives and were following a plan (41.9%) compared to those who were unaware or were not following a plan (combined total of 27.7%). In the first half of the last century the split between those who were following a plan and those who were unaware or not following a plan is roughly equal (28.2% and a combined total of 24.8% respectively, see Table 16). However, having a plan and actually making long term preparation in order to enact that plan are very different. This issue will be explored further in the detailed analysis of the 2009 fatalities (see section 6.9).

Table 16 Decision making over the three time periods (civilian fatalities)

	1901-1964	1965-2011	1901-2011 (total)
Were aware of fire with enough time to save their lives. Had a fire plan and were following intended actions which were ineffective	84 (28.2%)	157 (41.9%)	241 (35.8%)
Were aware of the fire with enough time to save their lives. Either had no fire plan, plan was unclear or didn't follow their plan. Includes people were 'waiting to see'	59 (19.8%)	82 (21.8%)	141 (20.9%)
Were unaware there was a fire and only realised when it was too late to implement an effective survival strategy	28 (9.4%)	41 (10.9%)	69 (10.2%)
Unknown	71 (23.8%)	25 (6.7%)	96 (14.3%)
Extenuating circumstances affected plans (heart attack)	10 (3.4%)	8 (2.1%)	18 (2.7%)
Children or adults who followed the instructions of another person	37 (12.4%)	40 (10.7%)	77 (11.4%)
Physically or mentally incapable of implementing an effective survival strategy (shock, drugs etc)	9 (3.0%)	23 (6.1%)	32 (4.8%)
Total	298 (100%)	376 (100%)	674 (100%)

Table 17 shows the relationship between decision making and gender over five of the most significant fires. A chi-square test of association was conducted to compare the combined 1926, 1939, 1967 and 1983 deaths against the 2009 deaths. Only the variables "Had a plan" and "Didn't have or follow a plan" were examined. For females the results produced a indicating a highly significant difference. The analysis indicates that in 2009 significantly more females than previous fires were following a fire plan (Chi-square of 28.66 (1 degree of freedom), $p<0.0001$). For males the result is similar (Chi-square = 7.32 (1 degree of freedom), $p<0.01$) and in 2009 significantly more males than previous fires were following a fire plan. However, the result is not as significant, and the difference in terms of fire planning between previous fires and the 2009 fires is not as great for men as it is for women.

Table 17 Gender and decision making

Decision making	2009		1983		1967		1939		1926	
	men	women	men	women	men	women	men	women	men	women
Following plan	59	39	17	2	12	5	15	0	4	0
Didn't have plan, a clear plan or didn't follow plan	16	14	7	12	6	13	12	4	9	4
Unaware	9	6	1	1	3	2	18	1	4	1
Following others decisions (children)	7	7	3	4			5	5	9	0
Physically unable	5	3	4	4	2	5	2	0	0	0
Total	96	69	32	23	23	25	52	10	26	5

6.5.2 RELATIONSHIP BETWEEN ACTIVITY DECISION MAKING AND FFDI

The relationship between activity decision making and Forest Fire Danger Index (FFDI) at 3pm has been studied using a tridimensional probability visualisation. The probability distribution of the three variables of interest: activity, decision making and FFDI was determined by applying a kernel smoothening technique that transforms each point in the event space into a "cloud" and adds them together. In this way, regions with larger number of points have more "clouds" superimposed, resulting in a larger value for the probability mass.

This probability distribution can be visualized by performing tomography, that is, by plotting cross sections of this distribution. In this case, the probability in a plane perpendicular to the "upward" variable (FFDI) was cut (which are represented for visualisation by the 12 tiles in Figure 22). Each plane in Figure 22 corresponds to a constant value of FFDI, for which the probability is encoded in the colour scheme (red, or "hot" regions have higher probability) as a function of the "x" (decision making) and "y "variables (activity). A full image of the distribution is obtained by "stacking" plots of increasing FFDI, with the fourth dimension (the probability) shown as the colour intensity. Details of the activity codes (1 to 19), and decision making codes (1 to 8) are described in Appendix 2 - Data category tables and their contents. In summary, the activity codes between 1 to 4 and 14 represent people sheltering, the code from 5 to 8 are fatalities evacuating, codes 10,11,13,15 are fatalities travelling (for saving own property or for pleasure), 16 is outside saving livestock, 12 is the code for fatalities waiting rescue, 17 to 19 are linked to fire fighting activities, 20 is linked to burn off activities. The decision is coded from 1 (fatalities that have a plan that was ineffective), 2 (aware of the fire but plan unclear), 3 (unaware of fire), 4 (unknown), 5 (extenuating circumstances), 6 (children or adults who followed the instructions of another person) to 7 (physically or mentally incapable of implementing an effective survival strategy).

Figure 22 indicates that fatalities that occur during a very low FFDI (corresponding to the first 4 tiles) are associated with people who are defending wider property or caught outside in highly exposed positions. Many of these people did not have plans or were unaware of the fire until it was too late to implement a successful survival strategy. More moderate FFDI's are associated with a range of activities including defending wider property, late evacuation and sheltering with some defence. These people are split between those who had plans and were carrying out a premeditated action and those who did not have a plan, and those with a firm plan but did not follow their plans. Extreme FFDI is associated with those sheltering (including defending) at the time of death and also included in higher numbers those who had a plan and were carrying out a premeditated action (mainly for 2009 Victorian bushfires).

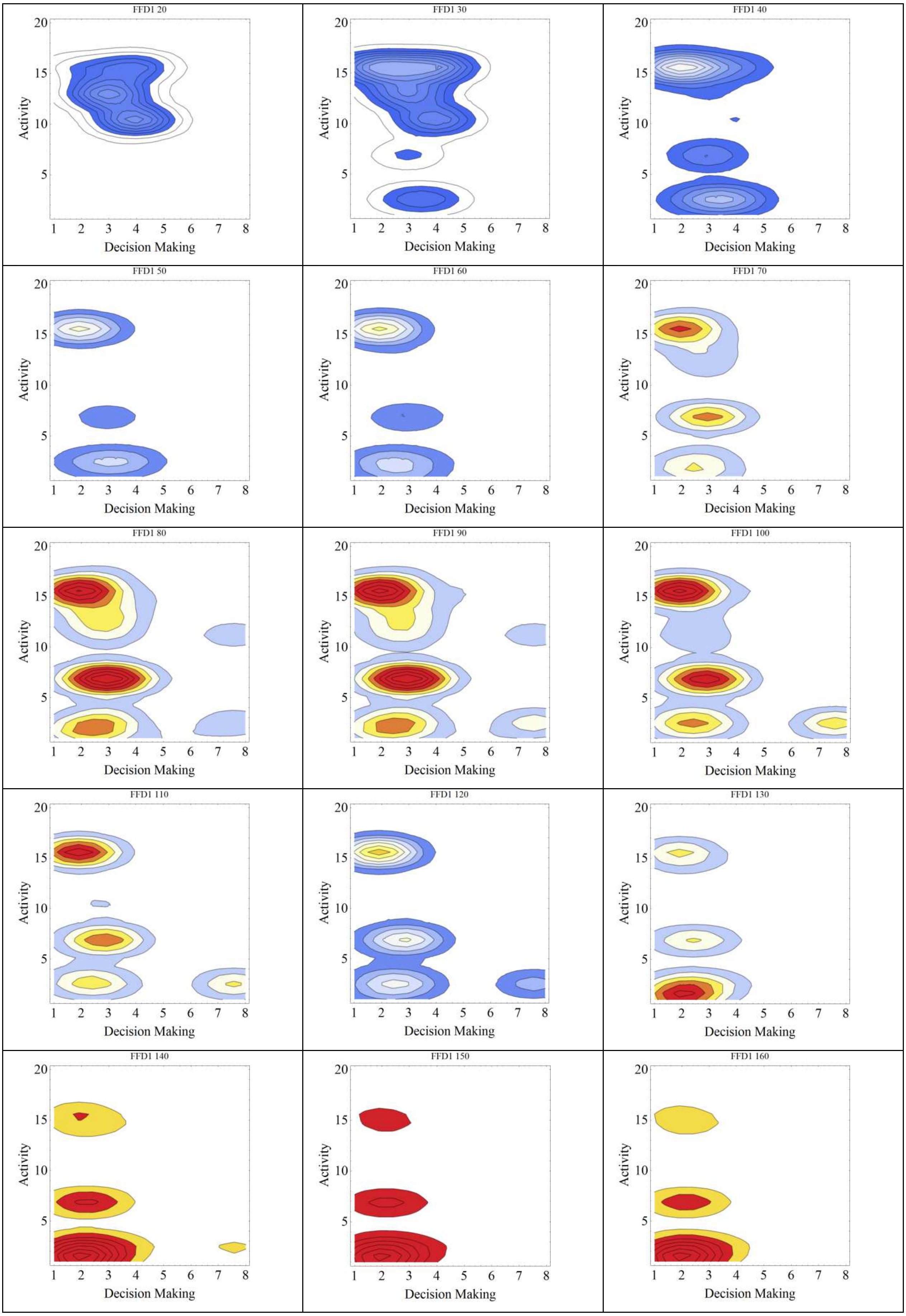


Figure 22 Tridimensional probability visualisation of the following variable Decision making, Activity and FFDI ((a) FFDI (at 12 different values of FFDI)

6.5.3 REGRESSION

A multiple linear regression was used to identify and explore the relationships within the data. A linear regression analysis fits a statistical model to the data in order to investigate how a set of independent (or predictor) variables relate to the level of a dependent variable.

All the expected predictor variables measured in the study were entered into the first iteration of a regression model with the categorical variable 'Activity' as the dependent variable. Only the data from 1965 onwards was analysed as more information was available in this time period. The predictor making the least statistically significant contribution to the reduction in the variance in the dependant variable was then removed. The model was then re-estimated and the remaining predictor with the least statistically significant contribution was again removed. This '*backward elimination*' method was continued until the variation in the dependant (Activity) variable was best explained by a set of predictors, all of which were statistically significant in the regression model. The two remaining predictors (FFDI and Gender) explain 15.5% (R^2=0.155 x 100) of the variability in activity. Although this percentage might appear low, it is statistically significant (F=27.5, p<0.0001), due to the large sample size (n=303).

The regression indicates that the average coded activity level was 15.5 (Activity 16 is defending wider property outside). This indicates the activity of the average victim in the sample. Table 18 indicates that female fatalities (Gender=2) occurred more frequently than male fatalities (Gender=1) to be engaged in activities with lower codes (i.e. related to sheltering and evacuation, for detail of code see Appendix 2 - Data category tables and their contents).

Table 18 Correlation coefficients (activity, gender and FFDI)

	Beta	Sig.	Exp (B)
Gender (1=male, 2=female)	-.234	.000	-2.489
FFDI (WS) calc	-.311	.000	-.037
Constant		.000	15.537
F statistic = 27.469 p 0.000			

By contrast males are more likely to be engaged in activities with higher activity codes (i.e. related to defending activity outside). As the FFDI increases people of both sexes are likely to be engaged in activities associated with a lower activity code (e.g. sheltering with some defence and evacuating).

6.6 Fire weather context

This section demonstrates the relationships between meteorological conditions and fatalities. The objective is to show the statistical profile (with and without firefighters) in order to provide a basis for discussion on fire weather thresholds and trends. The first section (6.6.1) first qualifies issues of timing with regard to fire weather parameters, the second section (6.6.2) shows the weather conditions and aggregated fatalities by fire event and the third section (6.6.3) shows the categorisation of weather conditions for fatalities and their location and gender.

6.6.1 WEATHER DATA QUALIFICATION AND TIMING

320 weather observations have been recorded for 146 fires. The range of data recorded varies from qualitative information from reports or inquests, to quantitative information on weather conditions at different times of the day (time of exposure and 3pm observations).

Standard meteorological observations at 3pm, and data from the historical fire weather dataset described by Lucas (Lucas 2010) have been obtained for 114 fires.

The 3pm FFDI and the FFDI at time of exposure were used to represent the weather conditions during the event. However using FFDI at fixed time of the day may not be indicative of the daily maximum fire danger as noted by Lucas (2010). It might also not be representative of the weather conditions most influential on the fatality. For example, by taking into account the summertime cool change, which may have occurred before or after the time considered in the analysis. The summertime cool change, often crosses southern Australia during the day and is associated with dropping temperatures, rising Relative Humidity (RH) and abrupt wind direction and strength changes (Luke 1978; Wilson and Stern 1985; McCaw and Hanstrum 2003). The minimum weather thresholds are discussed considering observations for each fatality at 3pm. The FFDI at 3pm is compared to the FFDI values obtained in relation to summertime wind change to better characterise the weather conditions experienced by the people at the time of death.

The FFDI at the time of exposure could be higher or lower than the one at 3pm for a particular fatality (see Figure 23) hence would occur above or below the midline shown in Figure 23.

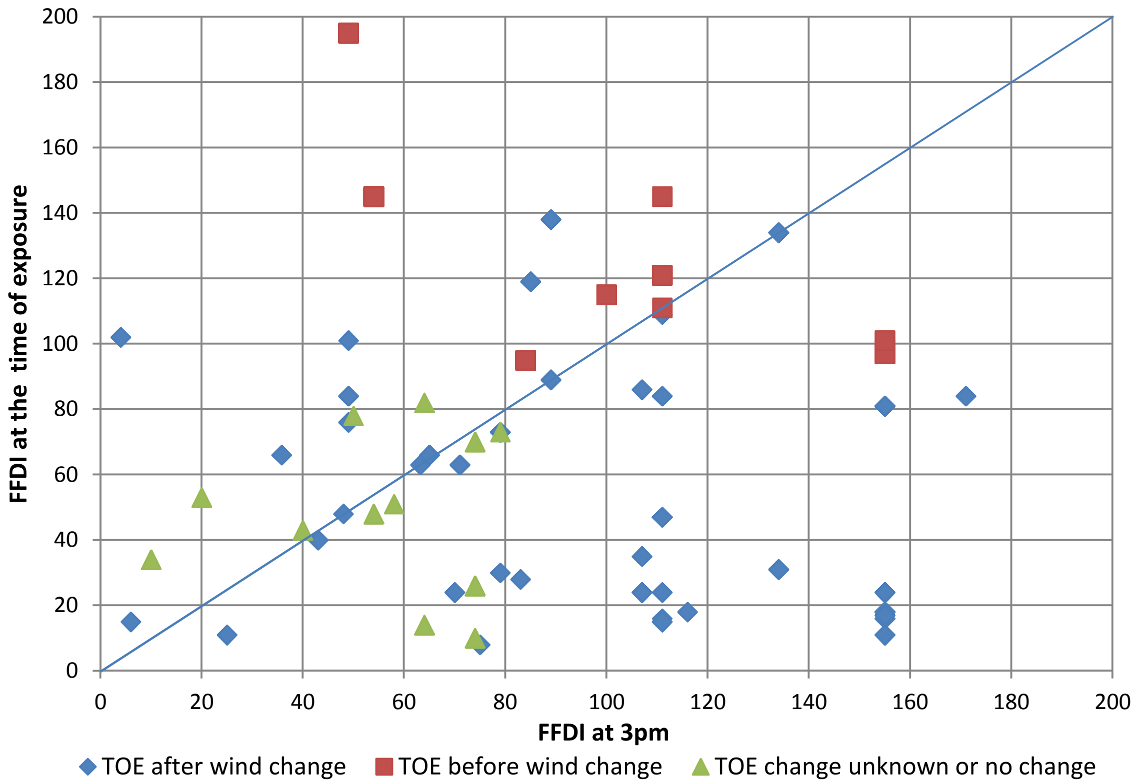


Figure 23 Comparison FFDI at 3pm and at time of exposure for civilians (before wind change, after wind change and no or unknown wind change) - 430 observations at 3pm and time of exposure (TOE)

The time of exposure in relation to the cool change makes a distinctive difference, as after a cool change, FFDI at the time of exposure are usually lower than the 3pm value (note that 75% of exposures occurred after 3pm). It is interesting to note that in those cases the FFDI value at time of exposure might not represent the weather conditions at the fatal exposure location. Several reasons could be envisaged: high local winds are associated with the changes that might not be recorded at the weather station (Luke and McArthur 1978 and anecdotal evidences), fuel moisture lag (which correspond to the time delay in fuel moisture content to respond to change in environmental conditions).

It is though difficult to determine a time where weather conditions are representative of the peak weather experienced by the person exposed. Ideally using the peak FFDI of the day (on an hourly basis) would reduce the inconsistency in using a fixed time. However this data is not consistently available across the time scale in which fatalities have occurred.

The summertime cool change and associated wind change and weather pattern has affected in total 50% of all the fatalities (414 civilians and firefighters), 90% have died after the change and 10% before the change.

6.6.2 METEOROLOGICAL CONDITIONS AND NUMBER OF FATALITIES BY FIRE EVENT

Numbers of losses per fire event are often used as a metric to rate the level of impact, this method has been used with house loss analysis in Blanchi et al. (2010). Figure 24 provides a similar analysis using life loss rather than house loss. The analysis displays the relationship between number of fatalities (on a logarithmic scale) and weather variables at 3pm (FFDI, temperature, wind speed and RH) based on 93 observations.

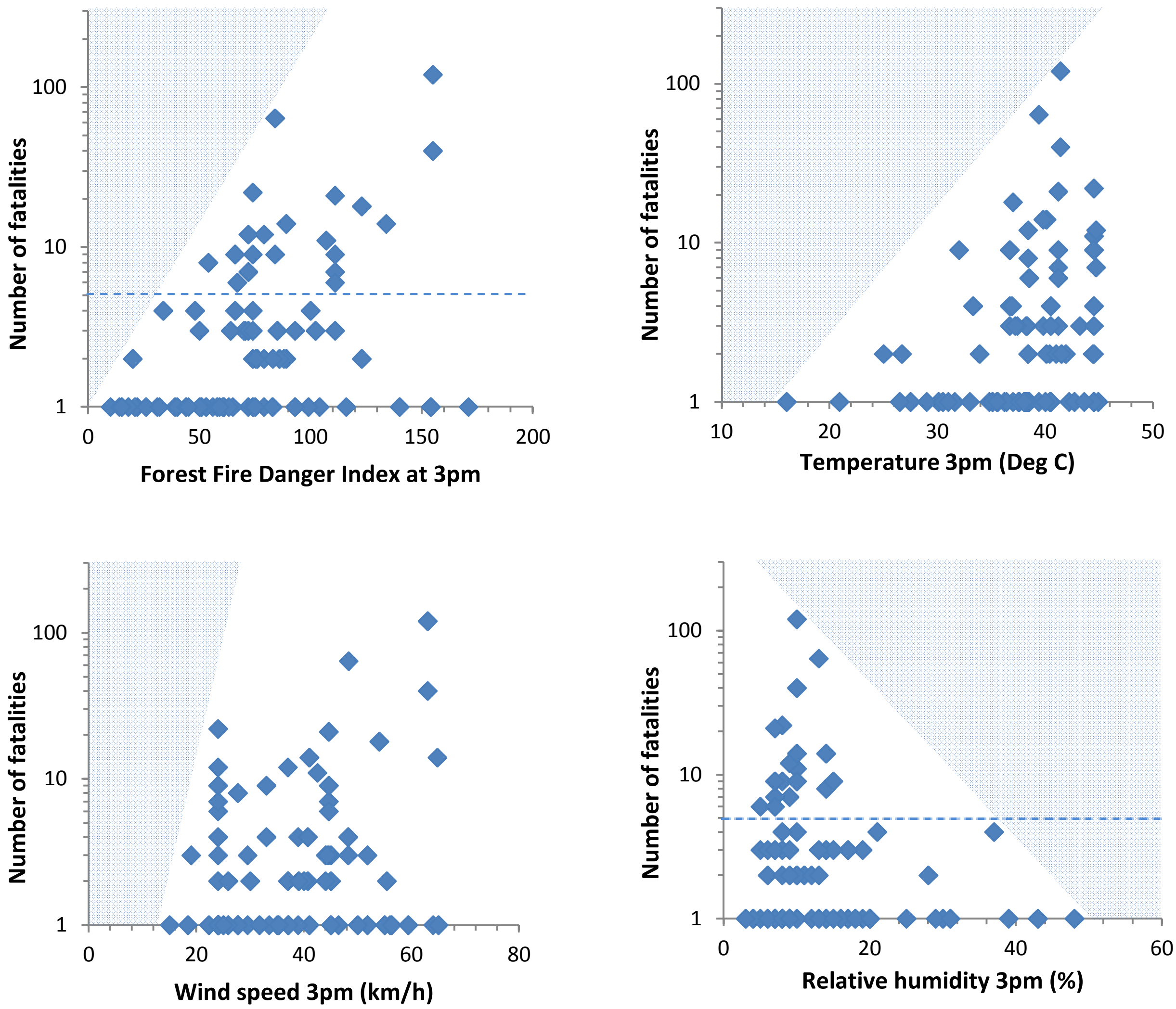


Figure 24 Relationships between the number of houses lost (logarithmic scale) and FFDI at 3pm, temperature, wind speed and RH

These graphs can be particularly useful in deriving thresholds for the conditions above which significant loss of life per event have occurred. The shaded regions in each of the plots in Figure 24 are clear regions where no losses been recorded. The bounds of these regions could be further refined as there are no specific reason why they should or should not intersect the x axis at the given values or have a log linear boundary. However regions such as these can serve as a sound basis for establishing appropriate weather severity thresholds for policy implementation based on acceptable levels of life loss per event. As an example the five fatalities per event line is drawn for each graph (blue dotted line on Figure 24). For FFDI the plot shows that lowest FFDI event involving five or more fatalities occurred above an FFDI of 50 and its intersect with the shaded region occurs around and FFDI of 35. For the other weather parameters the minimum temperature in which 5 or more losses occurred was 33 degrees Celsius, minimum wind speed was 24 and maximum relative humidity was 16%.

One fire with one fatality occurred at low FFDI (<11). This single fatality occurred during a burn off with a sudden change of wind, the weather conditions might have been mild and the sudden change might not have been recorded at the weather station used for this event. Seven fire events with mainly one fatality have occurred at high FFDI (11-24). Two fires with 4 fatalities, one with 2 fatalities and 14 fires with one fatality have occurred at very high FFDI (25-49). The potential range of number of fatalities by event is increasing with the level of FFDI (for example for a FFDI of 50 the range of fatalities is between 1 to 10, for a FDI of 75 the range of fatalities is from 1 to 20). Each of the weather parameters shows a distinctive transition from lower values to high (reversed for relative humidity). Section 6.6.3 explores these in more detail.

The correlation coefficients R^2 between number of fatalities and FFDI, along with its individual components are shown in the Table 19. The log of number of fatalities is correlated with temperature (0.5% level), FFDI (0.1% level), wind speed (2% level) and relative humidity (5% level).

FFDI has the highest correlation, which is not surprising as it is an aggregation of factors that all have some degree of correlation.

Table 19 Correlation of logarithmically (log-10) transformed number of fatalities under different weather variables

Variables	R^2
FFDI	0.376
Temperature (C)	0.301
Wind speed (km/h) avg 10 mins	0.253
Relative humidity (%)	-0.216

6.6.3 METEOROLOGICAL CONDITIONS AND FATALITIES

In some analyses the FFDI is categorised according to the existing national danger rating scheme[18]:

- 0-11: low - moderate
- 12-24: high
- 25-49: very high
- 50-74: severe
- 75-100: extreme
- >100: catastrophic (Code Red in Victoria)

Meteorological conditions at 3pm minimum thresholds

Figure 25, Figure 26, Figure 27 and Figure 28 show the number of civilian fatalities per classes of FFDI, temperature, wind speed and relative humidity at 3pm (452 observations). Ninety-one percent of civilian fatalities have occurred for each of the following conditions:

- FFDI values above 50,
- temperature exceeded 35°C,
- relative humidity was below 20%, and
- wind speeds greater than 20km/h.

[18] http://www.cfa.vic.gov.au/warnings-restrictions/about-fire-danger-ratings/ (accessed 15/11/2012)

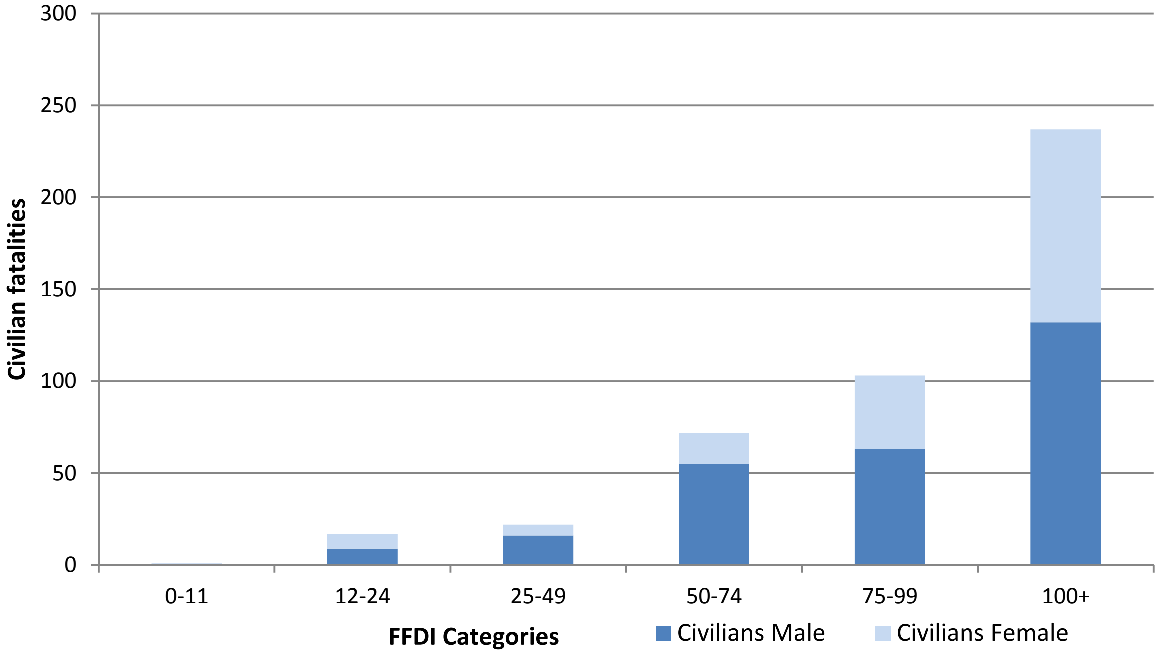


Figure 25 Number of civilian fatalities by gender and FFDI (3pm value)

Figure 25 shows that the proportion of male fatalities is significantly greater for the mid class of FFDI 25-49, 50-74, 75-99 and most often involved death in the open suggesting that they are more directly engaged in direct fire fighting or defence activities under these dangerous conditions.

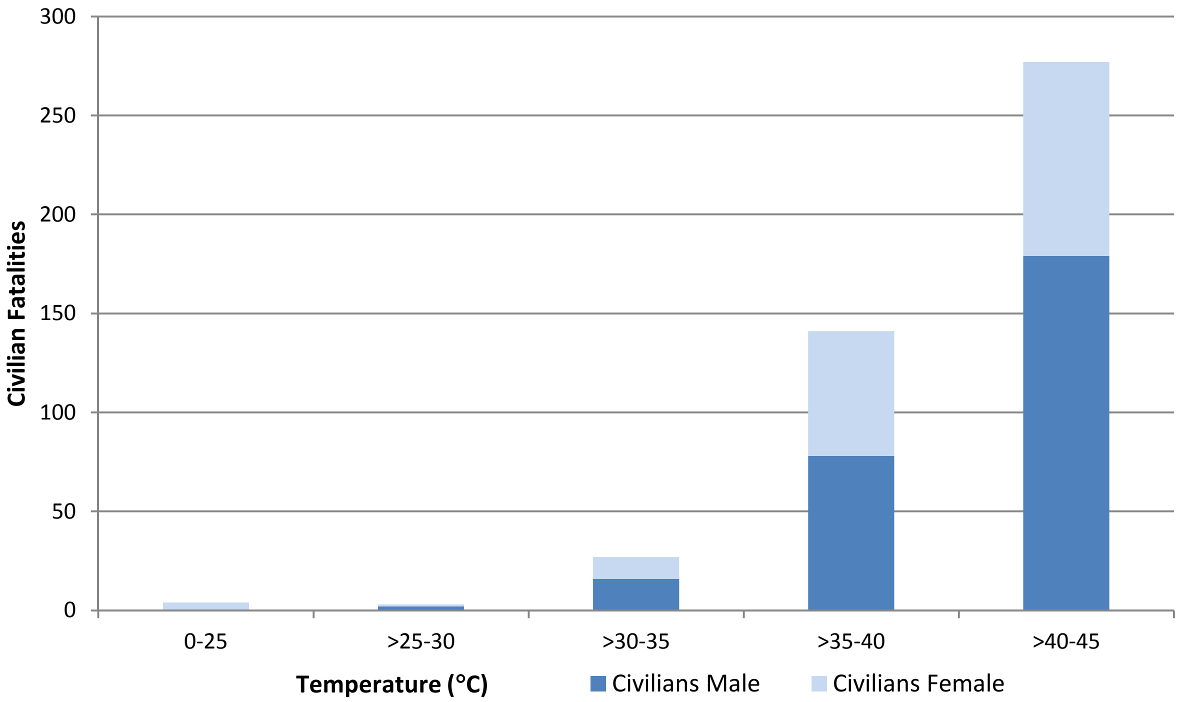


Figure 26 Number of fatalities by gender and 3pm temperature (degree Celsius)

Figure 26 show a very significant temperature threshold for the onset of bushfire fatalities begin at around 35 degrees, with significant loss levels in the 35-40 range and the majority of loss in the 40-45 degree range. The proportionality of male to female fatalities is does not appear to trend strongly with temperature.

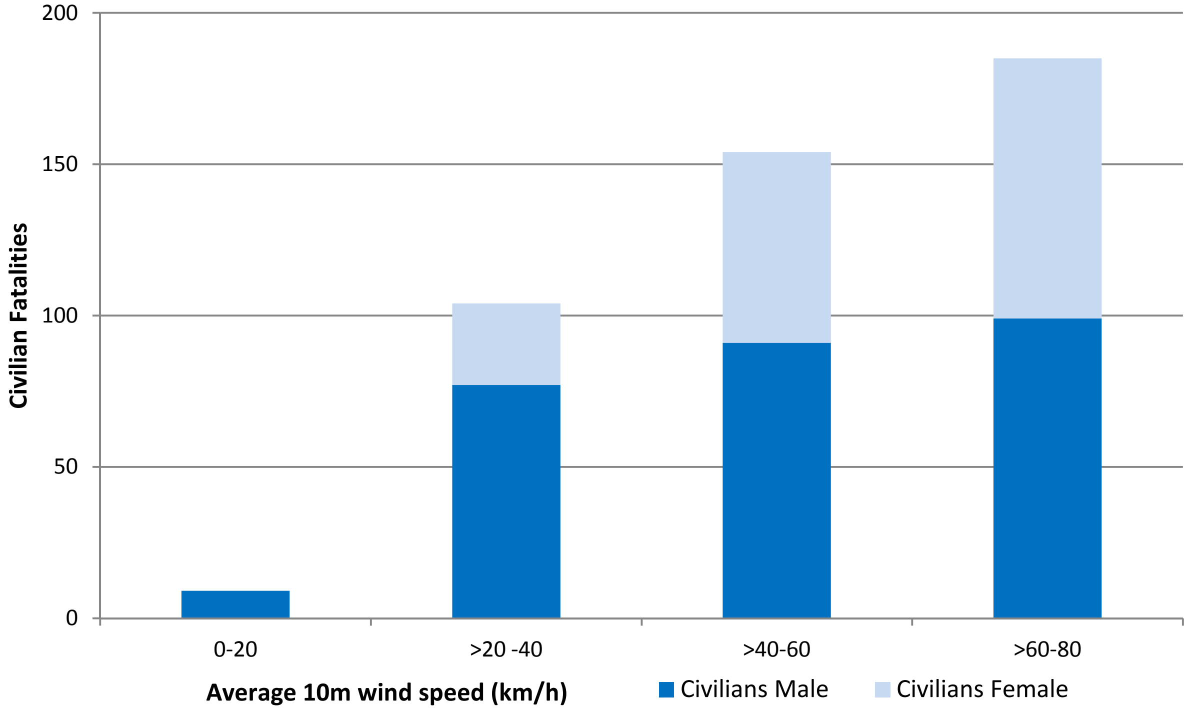


Figure 27 Number of fatalities by gender and wind speed (3pm value)

Figure 26 shows a significant wind speed threshold for the onset of bushfire fatalities beginning around the 20km/hr region, loss in the high categories is greater in the higher wind speed categories however there is not the same heave bias towards the upper category as is the case with temperature. The proportion of Male to Female fatalities tends to be higher in the lower wind speed categories.

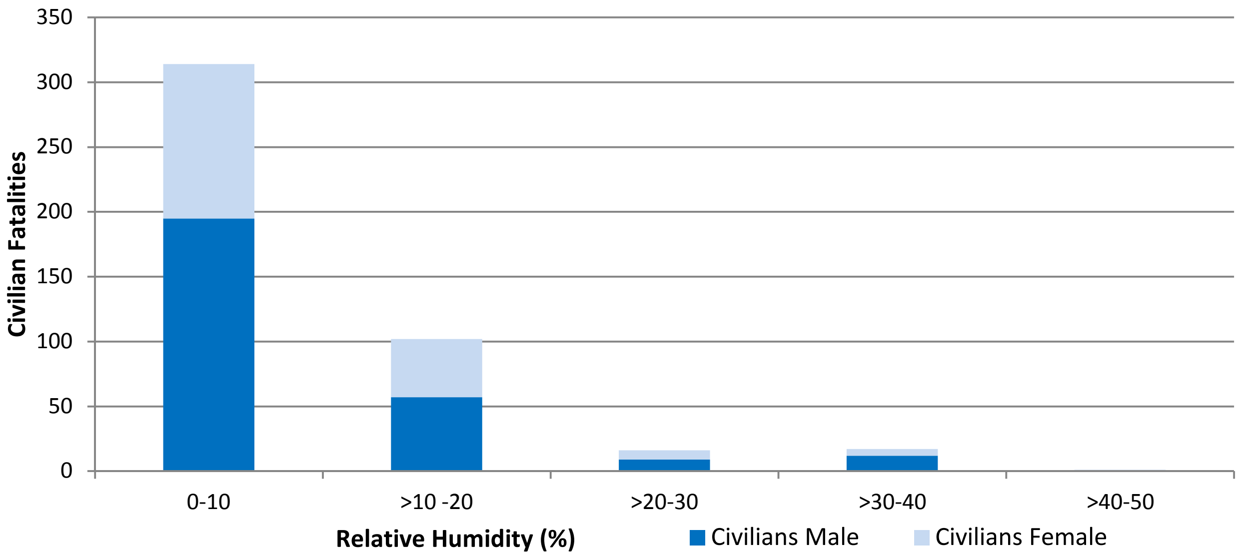


Figure 28 Number of fatalities by gender and 3pm relative humidity (%)

Figure 28 shows a significant relative humidity threshold for the onset of bushfire fatalities below 20%, with the vast majority of loss in the 10% or less region.

Meteorological condition and fatalities location

There is expected to be a link with the location of fatal exposure and fire weather severity owing to the different vulnerabilities of each location context. To observe this data has been extracted to compare FFDI class with location category, see Figure 29.

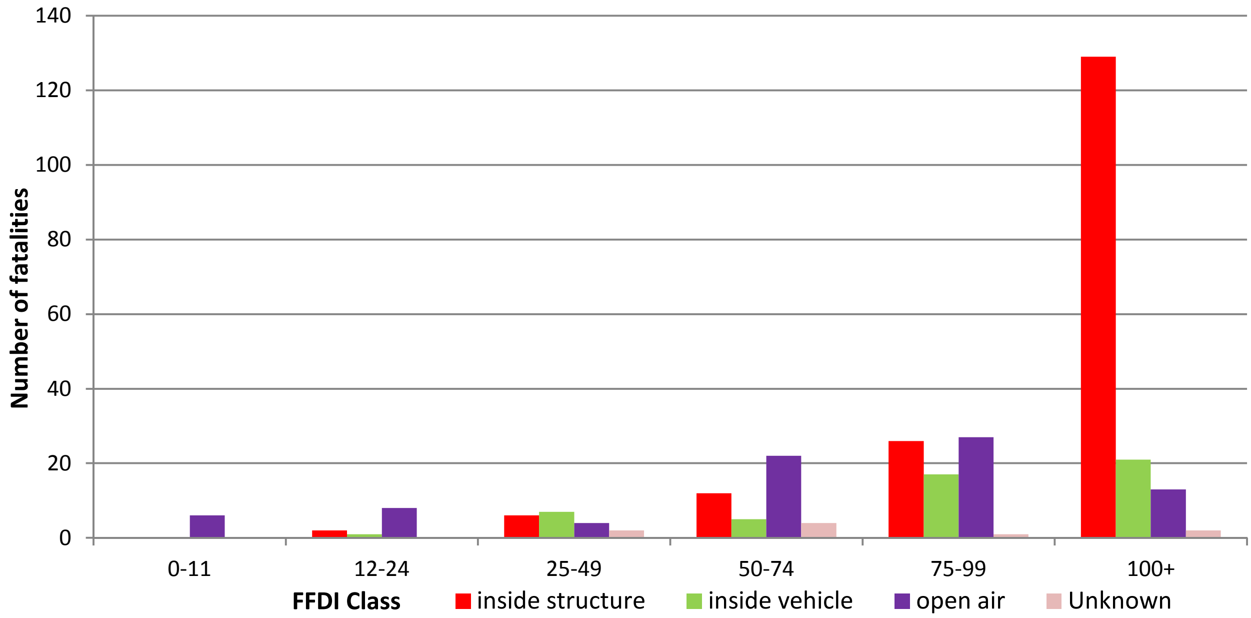


Figure 29 FFDI at 3pm and location of fatality

There is no clear trend in the location categories for the FFDI range between 0-49, all categories tend to generally increase with increasing FFDI with the notable exception of open air over FFDI 100. This may be due to a tendency seek shelter from both the weather severity and the fire under such intense conditions, this point is considered in section 6.5.2. The most noticeable result is the characteristic of loss for the inside structure which has near exponential profile with FFDI. At lower levels of FFDI civilians are caught outside as the predominant loss location category due to the inherently vulnerably nature of being caught outside even in mild fire conditions.

6.7 Fire Weather index for fatalities

Given the extensive dataset on fatalities developed there is an opportunity to explore the possibility, using a regression analysis approach, to link fire weather parameters to bushfire fatalities via a novel index. The correlative power of this index can then be compared to the FFDI index.

To explore the approach two options have to be considered:

- To use either a first order or second order regression equation (the FFDI index is a first order equation)
- To consider the whole dataset including single fatality fires or to consider only multiply fatality fires with a minimum number of x fatalities per fire event.

The Table 20 shows the correlation factor (R^2) with these options.

Table 20 Correlation values for a novel regression based Life Loss Index

	Correlations (R^2)			Data qualification	
Events with life loss greater than:	FFDI	Life Loss Index First order (LLI1)	Life Loss Index Second order (LLI2)	Number of Fatalities in data sample	Number of events in data sample
0	0.137	0.167	0.212	515	89
1	0.163	0.222	0.351	470	44
2	0.235	0.299	0.459	450	34
3	0.330	0.543	0.736	420	24
4	0.247	0.527	0.785	400	19

Table 20 shows that the first order life loss index (LLI1) is marginally better than FFDI for data involving all fatality events, the life loss index is significantly better than FFDI when attempting to predict events with 3 or more fatalities. A life loss index derived using second order regression (LLI2), is significantly better than FFDI and LLI1 in all cases suggesting that a non-linear fit is more appropriate for matching weather parameters to life loss. Because second order equations have a much great number of degrees of freedom than first order equations, they require large datasets to prevent over fitting. As an example, a second order equation (using 4 parameters drought factors, temperature, relative humidity and wind) has 15 degrees of freedom. Hence the underlined numbers detailed in the Table 20 will have a significantly degree of 'over fitting' as it is reliant only on 19 data points hence it's high R^2 value can not be attributed to a strong link between life loss an weather. The light grey figure representing a strong correlation between events with greater than 3 losses per event is based on 24 data points which is much more reliable but still may be due to some degree of over fitting.

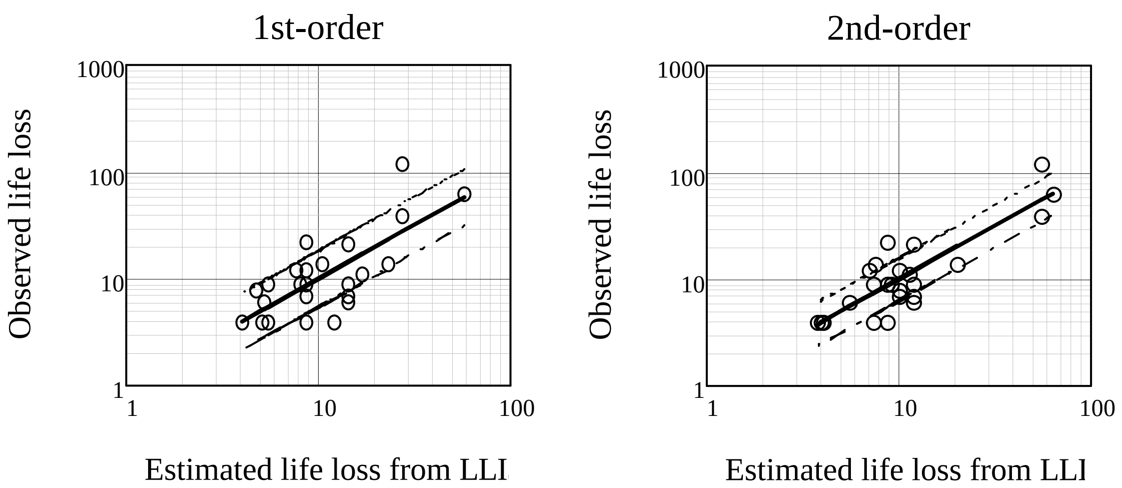


Figure 30 Correlation plots for events with more than three fatalities; show the observed loss vs the estimated loss for both a first and second order correlation

Figure 30 above show the mean and one standard deviation lines for matching observed and predicted loss using the first and second order life loss index for matching events with greater than 3 fatalities. The plots show how the data set largely consists of loss in the 8 to 20 range with three events in the 30 to 100 range.

6.8 Distance to forest

The separation between bushfire fuels and the fatality is an important risk assessment metric to classify likely exposure levels on the person, vehicle or structure. For this analysis forest has been used, hence does not account for any non-forest fuel types or areas of forest cover less than minimum threshold as defined in section 5.1.1[19]. Two specific types of analysis were undertaken, these were distance to the closest forest in any direction and the distance to forest in the direction of fire approach; the approaches used to describe these are also detailed in section 5.1.1.

Figure 31 shows the cumulative loss profiles for fatalities as distance to closest forest and distance to forest in the direction of fire approach.

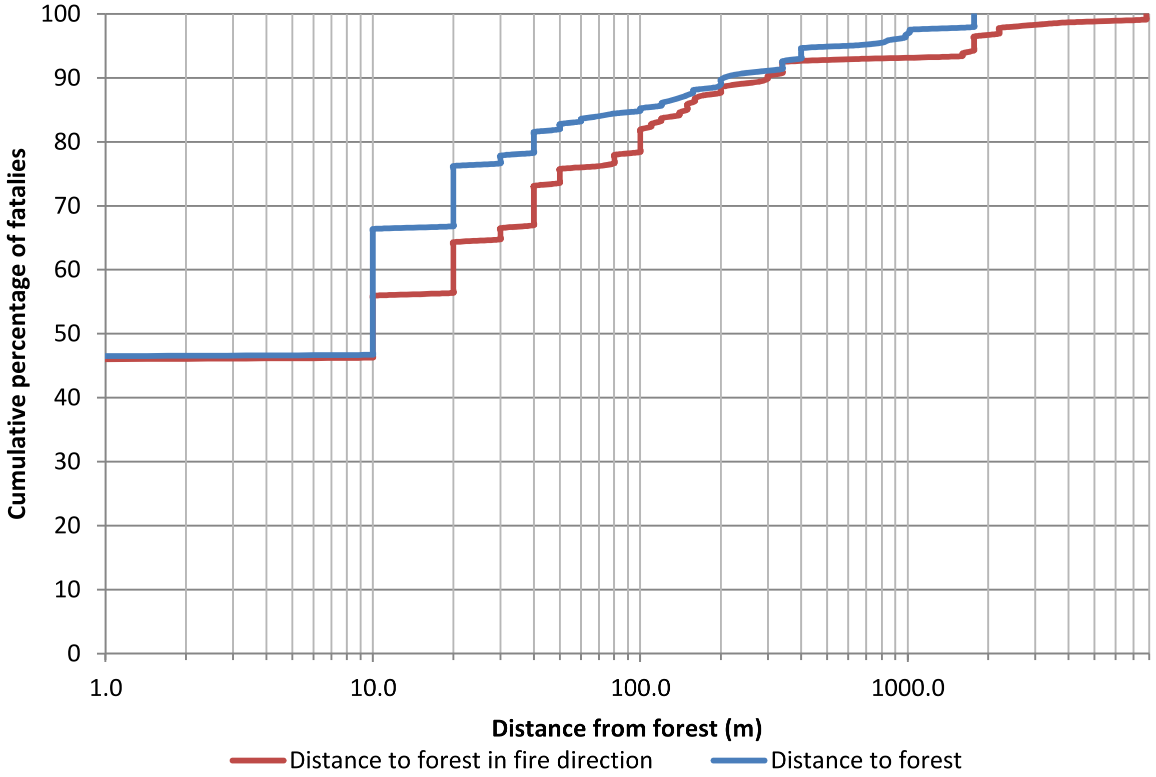


Figure 31 Cumulative loss profile of fatalities distance to forest

By definition the distance to forest in fire direction will be equal to or greater than the closest distance in any direction. What is interesting regarding this graph is that the curves are relatively close to each other with some deviation in the 20-100m range where radiation exposure from flame front emission for forest could play some role in defining the impact on buildings, people or vehicles. Of particular interest in this plot is the observation that over 50% of all fatalities occurred less than 10m from the forest, 78% in less than 30m and 85% in less than 100m. This provides a strong qualification of the possible influence of forest proximity as a factor in defining exposure resulting in fatal outcomes. For the purposes of future comparisons, distance to forest will be used as the comparative metric.

To expand on this discussion the same dataset was compared to fatality location category and plotted also as a cumulative percentile resulting in Figure 32.

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[19] Note: Forest is defined according to the National Forest Inventory (NFI) as vegetation with a minimum 20% canopy cover, potentially reaching 2 meters high and a minimum area of 0.2 hectares

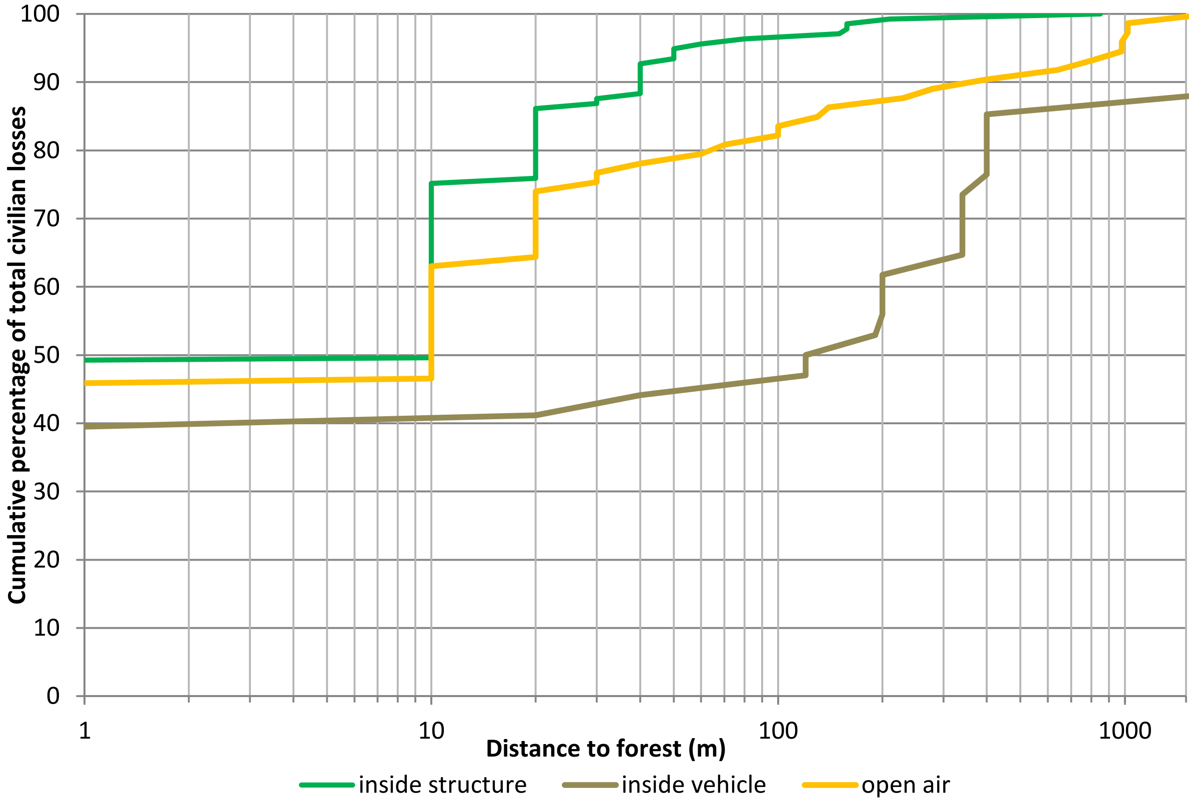

Figure 32 Cumulative loss profile of fatalities distance to forest (per location categories)

For Figure 32, the distance from forest to fatalities inside a structure (n137), inside a vehicle (n34), and in open air (n73) is shown. A distinctive profile is present for fatalities within structures, where 76% has occurred within 10m of the forest, 88% within 30m and 95% within 50m. This suggests that fatalities within structures are strongly associated with high radiant heat and possible flame contact circumstances potentially resulting in a rapid rate of tenability loss of the structure. Comparing these percentages with the broader dataset of house loss as a function of distance to forest demonstrates that house loss involving fatal exposure are far more dominant in the 0-30m from forest regions. Compared to house losses not involving fatalities, less than 60% of all house losses occurred less than 30m from the forest (Newnham et al. 2012). To be noted than 30m is a distinctive threshold for direct radiant heat ignition of structures identified by Cohen (2008).

Open air fatalities have similar proportions at close distances and then tracks much higher than the inside structure profile, highlighting the fact that people are more exposed to fire effects outside of structures. Although, the effects of non-forest fuels have an influence on the fatal exposure for a number of the fatalities on the open air. This data is only available where recorded in reports. Exact details of the fuel load of non-forest fuels was unavailable for analysis.

Vehicle fatalities track even higher than open air and structure based fatalities. This is likely to be due to these fatalities occurring adjacent to roadside vegetation (which might not be sufficiently large to qualify as continuously forest in the analysis).

6.9 Results from the Victorian 2009 bushfires

For the 2009 Victorian bushfires additional coding classes were developed to utilise the detailed information available on the circumstances surrounding each fatality of data availability (see Appendix 3 – Coding Scheme 2009 Victorian bushfires). This expanded coding describes the preparedness, intention and action of the fatality for this bushfire with the intent to compare it with other environmental variables (fire intensity, distance to forest).

The coding scheme was informed by the work of O'Neil and Handmer (2010) but it is not strictly based on it as it was not possible to have access to their coding scheme and base datasets for use in this work. Hence a new coding was developed based on the O'Neil and Handmer (2010) final report and using data from the Royal Commission final report[20]. The different coding scheme used and material of which it is based would explain some of the different results obtained with O'Neil and Handmer study.

The following relationships between the variables have been considered and are presented in this section (for detail definition see Appendix 3 – Coding Scheme 2009 Victorian bushfires):

- The relationship between the fire plan and the location of fatality (definition of fire plan in this case include people with detail fire plan or intent actions and thoughts of what they would do)
- The relationship between the fire plan and the level of preparation prior to the 7th February 2009
- The relationship between the level of preparation prior to and on the 7th February 2009
- The relationship between the level of preparation prior to February 7th 2009 and activities in the lead up to death
- The relationship between the level of preparation prior to February 7th 2009 and activities at the time of death

A linear regression was performed between the variables 'fire plan', 'activity', 'activity leading up to death', preparation prior, preparation on the day and decision making are all well correlated. The factor analysis shows that the linear combination of these variables explains 50% of the variance of the deaths.

A multivariable linear regression was performed between all these variables coded into a single activity-factor, which ranges from defending (low values) to evacuating as the dependant variable and fire intensity and distance to forest as independent variables. The objective is to verify whether intensity and distance to forest is a predictor for activity.

6.9.1 FREQUENCY ANALYSIS OF ACTIVITY, DECISION MAKING AND PREPARDNESS

The following results are presented as percentage of civilian fatalities that have occurred as a direct result of landscape bushfire mechanisms (total number 168, or less if data was not available for 168 fatalities).

Table 21 and Table 22 explore the relationship between fire plan, preparation prior to February 7th 2009 and the location of the fatality. The largest group of fatalities in the 2009 fires had intended to stay and defend (65 fatalities). This is followed jointly by those who were intending to leave when threatened and those who didn't have a plan or didn't have a clear plan (31 fatalities). The majority of people died within a structure (118 fatalities). Of these, 40% had intended to stay and defend, 23% had planned to leave when threatened and 9% didn't have a plan or for whom the plan was unclear. Of those who died in the open air (39), 33% had planned to stay and defend and 32.5% didn't have a plan or a clear plan (see Table 21). In terms of preparation, the majority (78%) of people who were intending to stay and defend were well prepared prior to February 7 (see Table 22). The remainder had undertaken some preparation (21.5%). Those who were planning to leave when threatened are characterized by the largest mix of preparation types and the highest number of people who had undertaken no preparation. Within this group 45.2% had undertaken no preparation, 35.4% had undertaken some and 16.1% were considered well prepared.

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[20] http://www.royalcommission.vic.gov.au/commission-reports/final-report (accessed 30/10/2012)

Table 21 Relationship between fire plan and location of fatality

Fire plan	Inside structure	Inside Vehicle	Open air	Total
Stay and defend	48 (40.7%)	2(18%)	13 (33%)	63 (38%)
Stay and defend but leave if threatened	4 (3.4%)	0 (0.0%)	7 (17.5%)	11 (7%)
Leave early	8 (6.8%)	0 (0.0%)	0 (0.0%)	8 (5%)
Leave when threatened	27 (22.9%)	1 (8.3%)	3 (7.5%)	31 (18%)
Wait and see what bushfire is like before deciding to stay or leave / plan unclear	9 (7.6%)	0 (0.0%)	2 (5.0%)	11 (7%)
Shelter passively at home	0 (0.0%)	0 (0.0%)	1 (2.5%)	1 (1%)
Shelter passively at a friends or community refuge	6 (5.1%)	1 (8.3%)	0 (0.0%)	7 (4%)
No plan/ unclear if they had a plan	11 (9.3%)	7 (58.3%)	13 (32.5%)	31 (18%)
Defend and shelter	4 (3.4%)	0 (0.0%)	0 (0.0%)	4 (2%)
Evacuating people or animals and intending to return to defend	1 (0.8%)	0 (0.0%)	0 (0.0%)	1 (1%)
Total	118 (100%)	11 (100%)	39 (100%)	168

Table 22 Relationship between fire plan and preparation prior to February 7th

Fire plan	Well prepared	Some preparation	No preparation	Unclear	Total
Stay and defend	49(78%)	14 (21.5%)	0	0	63
Stay and defend but leave if threatened	7 (63.6%)	4 (36.4%)	0	0	11
Leave early	0	4 (50 %)	4 (50 %)	0	8
Leave when threatened	5 (16.1%)	11 (35.4%)	14 (45.2%)	1 (3.2%)	31
Wait and see what bushfire is like before deciding to stay or leave / plan unclear	8 (72.7%)	1 (9.1%)	2 (18.1%)	0	11
Shelter passively at home	0	0	0	1 (100%)	1
Shelter passively at a friends or community refuge	0	2 (28.6%)	3 (42.9%)	2 (28.6%)	7
No plan/ unclear if they had a plan	4 (16.7%)	5 (20.8%)	7 (29.2%)	8 (33.3%)	24
Defend and shelter	4 (100%)	0 (0.0%)	0 (0.0%)	0	4
Evacuating people or animals and intending to return to defend	0 (0.0%)	1 (100%)	0 (0.0%)	0	1
Total	77	42	30	12	161

Only 44.1% of people who were considered well prepared prior to February 7th were also considered to have prepared well on the day (see Table 23). Thirty six percent undertook some preparation and 7.8% undertook no preparation on the day. 83.3% of those who were considered to have taken some preparation prior to February 7th also took some preparation on the day. The majority of people who had undertaken no preparation prior to February 7 also did not undertake any preparation on the day (Table 23).

Table 23 Relationship between preparation prior to and on 7th of February 2009

	Prep on Feb 7th				
Prep prior to Feb 7th	**Well prepared**	**Some preparation**	**No preparation**	**Unclear**	**Total**
Well prepared	34(44.1%)	28(36.4%)	6 (7.8%)	9 (11.7%)	77 (47.8%)
Some preparation	2 (4.8%)	35 (83.3%)	3 (7.1%)	2 (4.8%)	42 (26%)
No preparation	0 (0.0%)	8 (26.7%)	17 (56.7%)	5 (16.7%)	30 (18.6%)
Unclear	0 (0.0%)	3 (25%)	4 (33.3%)	5 (41.7%)	12 (7.4%)
Total	36 (22.3%)	74 (45.9%)	30 (18.6%)	21 (13%)	161

It is interesting to compare the results on preparation and fire-planning with the analysis of interviews and surveys conducted with survivors in the fire impacted areas immediately following Black Saturday. Analysis of interview data reveals that the majority of residents (86%) reported having a plan or an intention about what they would do in the event of a bushfire (McLennan et al. 2011). When examined in more detail, 65% of those who said they were either planning on staying to defend or leaving early "had made more than minimal long term preparation to implement the plan" (McLennan et al. 2011p16). This is further corroborated by quantitative survey data where 69% of respondents claimed to have had a firm plan for what they would do in the event of a fire (Whittaker et al. 2013). The data presented here on the 2009 fatalities shows a remarkably similar trend, with 82% of fatalities associated with a plan or intention in relation to their actions during a bushfire threat (from Table 21). Of those who had a firm plan to stay and defend throughout the fire, defend then shelter or evacuate early, 78% were considered well prepared prior to February 7th (Table 22). However, when all fatalities are considered, irrespective of their intended actions only 47.8% are considered well prepared. Furthermore, the numbers of those considered prepared declines once preparations on the day are also considered (Table 23). Determining adequate preparedness is a challenging issue and discussion of those fatalities who were actually prepared to stay and defend on Black Saturday is discussed further in section 6.9.3.

Table 24 shows the relationship between preparation prior to February 7th and activities in the lead up to death. As would be expected from the relationship between fire plan and preparation prior to February 7th (Table 24) the majority of those who were considered to be well prepared prior to February 7th were defending in the hours leading up to their death (76.9%). Those who had undertaken some preparation prior to February 7th were split between a slight majority who were defending (45.2%) and those who were waiting to see if circumstances required it (38.1%). Those who had undertaken no preparation prior to February 7th were split between a slight majority who were waiting to see (50%) and those who were not engaged in any action in relation to the fire in the hours leading up to their death (43.3%).

Table 24 Relationship between preparation prior to February 7th and activities in the lead up to death

	Activities in the hours leading up to death			
Preparation prior to Feb 7th	**Defending**	**Waiting to see**	**No prior action /sheltering from heat / caring for others[1]**	**Total**
Well prepared	59 (76.9%)	6 (7.7%)	12 (15.4%)	77
Some preparation	20 (45.2%)	16 (38.1%)	6 (16.7%)	42
No preparation	2 (6.7%)	15 (50%)	13 (43.3%)	30
Unclear	4 (33.3%)	3 (25%)	5 (41.7%)	12
Total	85	40	36	161

[1]Includes individuals who were inside taking care of children or others with special needs while others were defending or making preparations to defend. Although this is recognised as an important supportive role it is not classified here as active defense.

Table 25 shows the relationship between preparation prior to February 7 and activities at the time of death. The majority of those who were considered to be well prepared were split between three dominant actions at the time of death, those who were defending and then sheltering (33.7%), defending (27.3%) and those who were sheltering (14.2%). Fourteen percent of those who had been considered prepared were engaged in a late evacuation at the time of their death. Those who were considered to have undertaken some preparation were also split between three dominant actions, those who were sheltering (35.7%), late evacuation (26.2%) and those defending and then sheltering (26.2%). The majority of those who had undertaken no preparation prior to February 7 were sheltering at the time of death (66.7%).

Table 25 Relationship between preparation prior to February 7th and activities at the time of death

	Preparation prior to Feb 7th				
Activities at the time of death	**Well prepared**	**Some preparation**	**No preparation**	**Unclear**	**Total**
Defending*	21 (27.3%)	4 (9.5%)	0 (0.0%)	1	26
Defending and then sheltering**	26 (33.7%)	11 (26.2%)	0 (0.0%)	4	41
Sheltering	11 (14.2%)	15 (35.7%)	20 (66.7%)	1	47
In shelter but activities unknown	2 (2.6%)	0 (0.0%)	1 (3.3%)	0	3
Late evacuation	11 (14.2%)	11 (26.2%)	6 (20%)	6	34
Indefensible shelter	0 (0.0%)	0 (0.0%)	3 (10%)	0	3
Saving livestock or defending wider property	6 (7.8%)	1 (2.4%)	0 (0.0%)	0	7
Total	77	42	30	12	161

*May have sheltered at the time of death but evidence of considerable defending
**Includes those who had one or more of the following characteristics: didn't conduct final preparations on the day, sheltering was a large component of their plan, and key individuals who were part of the plan were not present

Table 26 Relationship between activities in the hours leading up to death and activities at the time of death

	Activities in the hours leading up to death			
Activities at the time of death	**Defending**	**Waiting to see**	**No prior action/sheltering from heat/ caring for others[1]**	**Total**
Defending*	25 (29.4%)	0 (0.0%)	1 (2.3%)	26
Defending and then sheltering**	35 (41.2%)	3 (7.3%)	3 (7.0%)	41
Sheltering	5 (5.9%)	21 (51.2%)	22 (51.2%)	48
In shelter but activities unknown	0 (0.0%)	2 (4.9%)	1 (2.3%)	3
Late evacuation	13 (15.3%)	12 (29.3%)	9 (23.3%)	34
Indefensible shelter	0 (0.0%)	3 (7.3%)	0 (0.0%)	3
Traveling through area for pleasure	0 (0.0%)	0 (0.0%)	6 (14%)	6
Saving livestock or defending wider property	7 (8.2%)	0 (0.0%)	0 (0.0%)	7
Total	85	41	42	168

*May have sheltered at the time of death but evidence of considerable defending
**Includes those who had one or more of the following characteristics: didn't conduct final preparations on the day, sheltering was a large component of their plan, and key individuals who were part of the plan were not present
[1]Includes individuals who were inside taking care of children or others with special needs while others were defending or making preparations to defend. Although this is recognised as an important supportive role it is not classified here as active defense.

Table 26 explores the relationship between activities leading up to and at the time of death. Those who are defending in the lead up to their deaths are dominantly found to be defending and then sheltering at the time of death (37%) or defending (29%). Just over half (51%) of those who are waiting to see and those who had undertaken no prior action in relation to the fire in the lead up to their deaths are found sheltering at the time of death followed by those engaged in a late evacuation (29% and 23% respectively).

6.9.2 FATALITIES AND ENVIRONMENTAL IRCUMSTANCES

A multivariate linear regression analysis was performed between a single activity-factor, as the dependant variable and fire intensity and distance to forest as independent variables. This model has very small linear coefficients, which signifies that activity is uncorrelated with intensity and distance to forest. The R^2 value for this regression is 0.03 (Adjusted R^2 0.017).

The results are not significant to find a relationship between activity of fatality and intensity and distance to forest. This appears to indicate that the actual potential exposure level a person may receive may not be an effective predictor of the tendency for a person to have a predetermined plan. Also it has to be emphasized that the exceptional nature of the 2009 Victorian bushfires. Under intense weather conditions and fire severity[21] and as stated by O'Neil and Handmer (2010) on that day, some people could not respond appropriately to the risk the bushfires presented to them.

6.9.3 EXPLORATION OF THOSE WHO WERE 'WELL PREPARED'

It is acknowledged that judging preparedness based on the preparations people undertook prior to Black Saturday is problematic. In order to improve the examination of those who were prepared to defend on Black Saturday, a more sophisticated variable was calculated which included preparations, fire-plan, age, physical ability and ability to focus on defence.

Included in this analysis are those people who were considered well prepared in terms of their preparations prior to Black Saturday and on February 7th, had a clear fire-plan to stay and defend throughout the fire whatever the conditions, were 16 years or older and under the age of 70, were in good physical health and were not responsible for dependents (children, elderly, sick or immobile people) on the day of the fire. When these factors are combined, only 21 of the total fatalities are considered 'well prepared'. This number includes 14 males and 7 females. Table 27 documents the location at the time of death of these 21 fatalities, the majority are found inside the home with one in a vehicle and four in the open air. Table 28 lists the activities engaged in during the hours leading up to and at the time of these deaths. Only three activities are represented: defending, defending and sheltering and defending wider property (those killed outside their home, their neighbour's home or their place of work).

Table 29 describes the details of the 21 fatalities. All but three of the fatalities are in their 50s and 60s. These fatalities are associated with 11 incidents. In 7 of these incidents a possible weakness in their planning can be identified. Four of the incidents were associated with bunkers or under house enclosure and from the descriptions supplied in the Final Report of the Victorian Bushfires Royal Commission[21] it appears that all 8 of those who died where highly reliant on the bunkers as a 'safe haven' to which they could retreat if conditions deteriorated. All these bunkers were unsuccessful in sustaining life. Although these families were all considered to be well prepared, it is questionable whether they would have stayed to defend in the conditions experienced on Black Saturday if they did not have bunkers as a form of back up. In all of these cases, those who died were aware of the fire threat and had sufficient time to evacuate safely.

Three cases (including one associated with a bunker) represent people defending on their own and in at least one of these cases the fire plan was for other members of the family to assist. The findings of the Victorian Bushfires Royal Commission[21] identified the dangers of singular defence and the importance of assistance.

Finally, in one case, livestock needed care and this extra responsibility may have distracted the deceased and be a causal factor in their death. By comparison, the husband, who did not attend to the livestock as the fire-front hit, survived).

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[21] http://www.royalcommission.vic.gov.au/commission-reports/final-report (accessed 30/10/2012)

This leaves only 4 incidents. One represents a father and son who were caught on the road while returning to their property after assisting a neighbour with defence. The other 3 incidents involved properties where more than one person was present and all were well prepared to defend throughout the fire. However, all 3 properties were within densely forested areas where, in the conditions experienced on Black Saturday, defence would have been extremely difficult. Indeed, in all but 2 of the incidents involving the 21 fatalities the properties or location of the deceased was very close to the forest and for 9 incidents having more than 70% forest cover within 100m of the house. .

Table 27 Location at the time of death of fatalities that were considered highly prepared

Location	Number
Inside structure	16
Inside vehicle	1
Open air	4
Total	21

Table 28 Activities leading up to and at the time of death for those considered highly prepared

	Activities in the hours leading up to death
Activities at the time of death	**Defending**
Defending*	10
Defending and then sheltering**	7
Saving livestock or defending wider property.	4
Total	21

*May have sheltered at the time of death but were defending up to the point of their death.
** Where defending prior to death however, sheltering a large component of their plan and all found in a bunker

Table 29 Details of those who were considered well prepared on Black Saturday

Details of the deceased and property[1]	Activity at death, and location of fatality	Other environmental information
Couple in their 60's. Considered that the cellar would be a safe refuge in all fires.	Sheltering in their cellar. Could not judge the progression of the fire.	20m from forest 78% forest cover (100m around house)
Couple in their 50's with their son and son's friend, both in their early 20's. The home was brick-veneer with a corrugated iron roof. Considered that the workshop was a safe haven to shelter from fire. The workshop had a concrete base and ceiling and double brick walls with a roller door and a steel shutter over the window.	Sheltering in the workshop under the house. Could not judge the progression of the fire and became trapped.	10m from forest 66% forest cover (100m around house)
Couple in their 60's. The house was built of rough-sawn mountain ash. Inside, the walls were of rough-sawn timber and plaster.	Male in the back of house and female in the bedroom	Touching forest 72% forest cover
Male in his late 50's defending alone. Built a bunker in the side of the hill about 30 metres from the house. The bunker had a thick door. The walls were lined with either sleepers or corrugated iron and were supported by star pickets. The roof was a concrete slab covered with a layer of soil.	Inside bunker. Could not judge the progression of the fire.	Touching forest 100% forest cover
Couple in their early 50's and their male neighbour in his mid 40's. Where initially defending their respective homes but it is believed the neighbour joined the couple to assist with their defence or when his defence became untenable. Both homes were built of mud brick.	All found in the kitchen	Touching forest 70% forest cover
Father (early 60's) and son (early 30's) were assisting a neighbour / brother in law with defence. Father had been an active member of the CFA for 27 years. They were returning to defend their property (4km away) in two vehicles when their passage was blocked by a tree that had fallen across the road.	Father found 30m from vehicle. Died in hospital on the February 22nd. Son found in the back of vehicle.	10m from forest Touching forest
Mud-brick home with a corrugated iron roof. Female in her late 60's. Couple looked after 40 dairy goats and eight cows. Couple were defending together, husband lost contact with his wife when she went to check on their goats.	Found in the home. Exact location not known.	100m from forest 0% forest cover
Two-storey mud-brick house part of a complex of art studios and workshops. Male in his early 60's was defending alone, although his son was defending his property 500 meters away and they had been supporting each other with their preparations. Two areas in the main house were set up as fire bunkers with metal shutters.	Found in the home in the doorway of the bunker	Touching forest 100% forest cover
Five-bedroom weatherboard homestead with a corrugated iron roof. Male early 20's. Defending his family property on his own. Son and father were members of the CFA. Parents were away and although the sister had been assisting with the preparations during the day she left for work prior to the arrival of the fire.	Found in the kitchen	30m 25% forest cover
Two-storey mud-brick house. Couple in their mid 50's and early 60's.	8m from house	Touching forest 100% forest cover
Steel-framed brick house on brick stumps with a corrugated metal roof. Couple in their late 50's.	Found in the remains of their home. Exact location not known.	Touching forest 100-75% forest cover (top of ridge heavily forested and hilly area)

[1]Details of the deceased and property are from the Final Report of the Victorian Bushfires Royal Commission: http://www.royalcommission.vic.gov.au/commission-reports/final-report/volume-1/, information on forest cover and distance to forest are from NCAS data.

7 Conclusions

An extensive dataset has been developed to spatially and temporally locate all know Australian bushfire fatalities over the past 110 years (1901-2011). The dataset has attempted to cover all reported deaths occurring up to the end of 2011 and includes 733 civilian and 92 firefighter deaths (known as the Attorney General Department's (AGD) NFDRS Life Loss database/Life Loss database). An extensive range of qualifying parameters has also been included to assist in developing the context under which the deaths occurred. The database contains details of fire weather (using the McArthur Forest Fire Danger Index (FFDI) and its individual components), fire properties, distance to forest, incident circumstances, fatality details, activities and associated object locations and properties related to the fatality. It is hoped that the database will be maintained by adding future and newly discovered historical deaths to the dataset and to build on the range and quality of qualifying parameters it contains.

Analysis has been performed as a first step in exploring the newly developed dataset. This included the analysis of spatial information to determine the environmental circumstances such as the location and extent of objects directly related to a fatality, the proximity to forest and predicted fire weather severity. The following provides a list of the key conclusions from this analysis:

Timing and weather:

- The 825 fatalities in the database occurred during 260 separate fire events. With 10 major fire days accounting for 65% of the total number of fatalities. The number of fatalities is dominated by few iconic events resulting in large numbers of the fatalities (such as Black Friday 1939, Hobart 1967, Ash Wednesday 1983, and Black Saturday 2009).
- Over 80% of all fatalities have occurred in the months of January and February. Of these deaths the fatalities generally occur in daylight with a peak between 3pm and 7 pm. Firefighter Fatalities are distinctly different with a peak at 3pm and another at 9pm. There have been no known civilian deaths and only one firefighter death between 12pm and 9am.
- Fire weather severity is a key qualifier in setting the context of life loss in bushfire with all events involving 5 or more deaths occurring on days where FFDI at 3pm was over 50. The weather thresholds for individual parameters where losses of 5 or more occurred were:
    - Temperatures above 33 degrees Celsius
    - Wind speeds above 24km/hr
    - Relative Humidity below 16%.
- There is a prominence of life loss around the time of a wind change during a fire event.
- Over 50% of all civilian fatalities occurred on days where the FFDI at 3pm exceeded 100 meaning that it would occur under the newly defined 'catastrophic' weather conditions. Over 60% occurred on days that exceed 40 degrees Celsius. Over 35% occurred on days were the 10 minute average wind speed exceeded 60km/hr. Approximately 70% of all fatalities occurred on days where the relative humidity was below 10% at 3pm.
- Fatalities occurring in open air are more prevalent for FFDI values below 100. Fatalities within structures are the most prevalent for FFDI values above 100.
- An exploration of a new life loss index based on fire weather parameters (temperature, wind, relative humidity and drought factor) was developed from the dataset to provide an improvement in the degree of correlation compared to the currently used McArthur Forest fire danger index.
- Statistical analysis demonstrated a tendency for fatalities occurring on moderate fire weather days to occur while defending property, evacuating late or sheltering with some defence. This group

consisted of a mix of people with and without fire plans. While under the most severe fire weather days, fatalities were mainly sheltering and following a pre-considered plan.

Spatial location:

- Victorian fatalities account for over 60% of all Australian fatalities. Victoria's house loss also accounts for a similar proportion of Australia's total. While New South Wales had the greatest number of firefighter fatalities per state.
- Over 50% of all fatalities occurred as either single or double loss incidence. The largest group of civilian fatalities was 17 motorists during the Lara bushfire (1969), and the largest group of firefighter fatalities was 12 trapped with their tankers during the Ash Wednesday Beaconsfield bushfire in 1983.
- Approximately 84% of all fatalities occurred at the location of fatal exposure, the remaining 14% occurred at a different location (e.g. in Hospital) with 2% unknown.
- Fatalities occurred in various locations: 58% in the open air, 28% inside structures, 8% inside vehicles and 6% unknown. There were no known firefighter fatalities within structures, 28 occurred inside vehicles and 38 in the open. Male and female civilian fatalities within structures were evenly represented, while male fatalities out in the open were approximately 3 times greater.
- Proximity to forest appears to be a highly influential factor with over 78% of fatal exposures occurring within 30m and 85% within 100m of the forest edge. If we specifically consider fatalities inside structures, 88% occurred within 30m of the forest and 95% within 50m. This suggests that fatalities inside structures are strongly associated with high radiant heat and possible flame contact circumstances potentially resulting in a rapid loss of tenability of the structure.
- Civilian deaths tended to occur within close proximity to their place of residence. Of the civilian fatalities occurring inside structures approximately 82% were in their place of residence. Of the fatalities with known residential addresses and accurately known location of fatality that died in placed other than their place of residence, 61% were within 100m and 84% were within 1km of their place of residence.
- Fatal exposure in open air but related to a vehicle show that 40% died within 10m of the vehicle and 67% within 100m.
- Of the civilian deaths occurring inside a structure with a specific locations known, approximately 41% occurred in bathrooms or under house enclosures where reduced capability to monitor outside conditions.

Correlations:

- The context of the fire weather severity in understanding the location of death is important with a significant shift from open air fatalities at low FFDI's to a dominance of inside structure deaths at FFDI's greater than 100.
- Using fire weather days as a point of correlation between life loss and house loss, we find that house loss is a reasonably good predictor of the potential or life loss with a linear correlation factor of R^2=0.84. This equates to 16.5 houses lost per fatality.
- A regression was used to explore potential relationships between several variables to predict fatality activities. Two variables, gender and FFDI showed correlation. The regression indicates that females are more likely than men to die engaged in activities with lower codes (i.e. related to sheltering and evacuation).
- An exploration of the relationship of different environmental circumstances, fatality activities and fire plans was performed for the 2009 Victorian bushfires. The results of the multivariate linear regression analysis showed that there was not significant relationship between the activity undertaken and the intensity of fire or distance to forest. This appears to indicate that the actual

potential exposure level to a person may not be an effective predictor of the tendency for that person to have a predetermined plan.

- FFDI is a slightly stronger predictor of life loss than its individual components with an R^2 of 0.38 for FFDI and an R^2 of 0.30 for temperature (the strongest correlation of the individual parameters). However using FFDI threshold as a predictor for life loss is difficult as other factors influence the outcomes, such as fire severity, community attitude, response and decision making, management and education policies.
- Newly derived weather based life loss indices could provide an improved method to predict life loss potential compared to traditional indices such as FFDI which have been used for a broad range of purposes beyond their original intent.

Fatalities are dominated by a few fire events that have occurred under extreme weather conditions. These conditions should be used as the context for discussing appropriate defensive actions for communities faced with a bushfire threat. It should be highlighted that climate change projections are for more frequent fire weather event (Lucas 2010) of the level in which significant life loss has occurred in the past. Much can be gained from the understanding this dataset provides in relating the circumstances of death to these levels of fire weather severity.

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Appendix 1 – Database Structure

Science subgroup

The stakeholders are the members of the NFDRS –Science Subgroup. The members are listed below. The members represent all the end user agencies.

Name	Title	Branch/Organisation
Peter Channells	Chair	AGD
Darren Bretherton		AGD
Jeff Kepert		BoM
Kevin Tory		BoM
Richard Thornton		Bushfire CRC
Andrew Sullivan		CSIRO
Justin Leonard		CSIRO
Mark Chladil		TFS
Simon Heemstra		RFS (NSW)
David Nichols		CFA (Vic)
Geoff Conway		CFA (Vic)
Leigh Miller		CFA (SA)
Liam Fogarty		DSE (Vic)
Lachie McCaw	`	DEC (WA)
Neil Burrows		DEC (WA)
Rick McRae		RFS (ACT)
Ralph Smith		FESA
Ross Bradstock		University of Wollongong
Kevin Tolhurst		University of Melbourne
Samantha Setterfield		Charles Darwin University
Natalie Rossiter-Rachor		Charles Darwin University

Structure and parameters of database

The following tables describe the parameters intended for use in describing historic fatalities in the AGD NFDRS project. Each table represents a linked hierarchy with all parameters in the table being links to the line items below it. Tables are linked to each other where common variables existing in different tables such as an Object ID or Incident ID. The highest level table is the Incident table, an incident is a single fatality or a multiple fatality scene where individuals were sheltering or behaving as a collective group.

This spatial dataset will link directly to the Landscape Fire Fatalities Database 2011 09(LFDD) via the Fatality ID in the Fatalities table.

Each parameter will be populated in the table if it is available, for those not available a default indicating that it is unknown will be provided. For some of the variables free text fields are defined, as free text is problematic for spatial and statistical querying efforts will be made to categorise these parameters as their contents emerges.

It is expected that some fatalities in older fires will contain object associations without the specific location of the object being known. An approach using large confidence limits on the estimated location will be applied to deal with this case.

The parameters may be subject to change to make full use of the data as it is aggregated. Feedback on parameters and suggestions for change are very welcome at this stage of the project.

Incident table

Variable	Description	Comments
Incident ID	Unique number	Site map of an incident that include one or several fatalities inclusive of all relevant objects to those fatalities.
Objects ID	Unique number for each object	Relates all relevant objects to specific incidents
Object Type	House Car any surrounding object relevant to the case Fire front	Spatial description of the scene where fatalities has occurred. Geo-rectified aerial photo or map identifying locations of other relevant objects eg building vehicles, bushland, fire approach direction. (set of attribute to collect for each object, detail in each table)
Time of object ignition		
Time of loss of tenability		
Object description	Polygon, line, point	Geo-referenced object in GIS
Data sources used to populate parameters for each object	Develop table of codes to cover each data source used	

Fatalities table

Variable	Description	Comments
Fatality ID	Unique Number	from Landscape Fire Fatalities Database 2011 09(LFDD) from CRC/risk frontier/RMIT/Agency
Incident ID	Unique Number	Unique number
Location of fatality	Point	Geo-referenced object in GIS. Geo-rectified aerial photo or map identifying location of fatality and fatal exposure if different
Time of fatality	Time / Unknown (blank)	For each standard time descriptor: Time ± confidence limits Show as Date and local time in 24 hour minutes and seconds
Location of fatality different than location of fatal exposure	Y/N/Unknown	If Yes answer two following questions (time and location of fatal exposure)
Time of fatal exposure	Time / Unknown (blank)	Time ± confidence limits Show as Date and local time in 24 hour minutes and seconds
Location of fatal exposure	Point	Geo-referenced point object in GIS
Time of fire arrival (at location nearest to fatal exposure point)	Time / Unknown (blank)	Time ± confidence limits Show as Date and local time in 24 hour minutes and seconds
Location of fatal exposure text	-Inside structure (X distance from nearest structure) Inside vehicle (X Distance from their vehicle) -Open air (distance from structure or vehicle unknown)	In nearly all cases location of fatal exposure is the same as location of fatality. (Include additional shelter types if present in data)
Related Object to location above	Object ID numbers	
Detail of fatalities location	Free text, e.g what room inside structure, what distance for near structure case -to be broken down into generic categories	
All parameters from Landscape Fire Fatalities Database 2011 09(LFDD) from CRC/risk frontier/RMIT/Agency		See data entry spread sheet from the Landscape Fire Fatalities Database 2011 09(LFDD)
Related objects to fatal exposure	Object ID numbers 0 Unknown	List of one or several objects that were identified as being responsible for the fatal exposure
Exposure description	Free text, e.g. relevant information relating to fatal exposure for cases with little or no spatial data available	(preparedness?)

Surrounding Objects table

Variable	Description	Comments
Objects ID	Unique number	
Status of the surrounding object	Damaged, destroyed, untouched, unknown	
Object use as a shelter	Y/N/Unknown	

House table

Variable	Description	Comments
Objects ID	Unique number	
Address	Text	
Final status of house	Damaged, destroyed, untouched, unknown	
House used as shelter	Y/N/Unknown	
Construction type/ era/date	Various classes	
Known damage process prior to ignition	Radiant heat, Wind, tree impact, Combination, Unknown	
Known ignition process	Embers, Radiant heat, Flame	
Known source of ignition	Object ID	
Likely rate of loss of tenability of the house if lost	Class to be defined	
Time of loss of infrastructure (power)	Time/N/Unknown/Not Present	
Time of loss of infrastructure (water)	Time/N/Unknown/Not Present	
Time of loss of infrastructure (telephone)	Time/N/Unknown/Not Present	
Plan of house		Attach document if available
Description of house and surrounding	Free text, e.g. relevant information relating to fatal exposure for cases with little or no spatial data available, presents of spray protection system. Categorisation of defend-ability.	
Context of entrapment (inside structure)	Free text/ or classes	

Vehicle table

Variable	Description	Comments
Objects ID	Unique number	
Vehicle detail	Text	Brand/model/age
Status of vehicle	Damaged, destroyed, untouched, unknown	
Use as shelter	Y/N/Unknown	
Context of entrapment (inside vehicle)	Classes to be defined	
Likely rate of loss of tenability of the car if lost	Classes to be defined	
Origin of car journey	Point Location	Geo-referenced object in GIS
Intended destination of car journey	Point Location	Geo-referenced object in GIS
Description of car and surroundings	Free text, e.g. relevant information relating to fatal exposure for cases with little or no spatial data available	

Physical parameter table

Variable	Description	Comments
Incident ID	Unique number	
FDI reported (on the day)	Number, source, FFDI Type	
Nearest BOM station for which following data is derived	Point Location	Geo-referenced object in GIS
Temperature (degrees Celsius)		Daily summary and closest recorded to time of critical exposure
Relative Humidity (%)		“”
Drought factor		“”
Wind speed (km/h) average 10 minutes		“”
Wind speed (km/h) 3 second gust		“”
Wind direction	8 classes or bearing	“”
Weather context before fire (few days before fire arrived	classes	
FFDI calculated from factors above?		At time of fatality, peak for the day etc

Forest

Variable	Description	Comments
Forest ID	Unique number	
Description	polygon	Geo-referenced object in GIS
Type of unmanaged vegetation relevant to fire front behaviour nearest fatal exposure	AS3959 classification	
Last reduction burn if known	classes	

Fire front object

Variable	Description	Comments
Objects ID	Unique number	
Forest ID	Unique number	
Reported intensity of fire	Classes (fire line intensity)/Unknown	

Appendix 2 - Data category tables and their contents

TABLE OVERVIEW

Fire	Contains information about a fire that involved fatalities
Fire Weather	Contains information about the weather conditions around the time of fatalities in the vicinity of the fire. One fire may have a number of fire weather records associated with it giving weather conditions at different times throughout the day or recorded at different nearby weather stations.
Incident	Contains information about incidents involving fatalities that occurred during a fire. An incident is a single fatality or a multiple fatality scene where individuals were sheltering or behaving as a collective group.
Fatality	Contains information about the fatalities that occurred during an incident.
Object	Contains information about the objects that are associated with an incident. These objects may be houses, vehicles, or other objects.
House	Contains information about houses associated with an incident.
Vehicle	Contains information about vehicles associated with an incident.
Other Object	Contains information about other objects associated with an incident. This may include sheds, fences, dams, trees, etc.
GIS Object Inventory	Contains information about spatial objects that are associated with the database

FIRE TABLE

FIELD NAME	DESCRIPTION	VALUES
Fire Code	Unique fire identification number.	e.g. 256
Fire name	Fire name.	e.g. Barnawartha 2006
Fire Date	Date of fire on which fatalities occurred.	e.g. 21/01/2005
Weather context before fire	Description of weather context before fire (few days before fire arrived)	Text
Wind change	Indicates whether the wind changed direction on fire date (for some fire event there is only a mention of wind change during the day without specific details of time or direction).	yes/no/unknown
Time of Wind change	Date and time of wind change.	e.g. 21/01/2009 4:30PM Blank if unknown
Wind direction after change	Wind direction after wind change.	e.g. NW Blank if unknown
Unmanaged Vegetation type	Broad type of unmanaged vegetation that fire travelled through.	e.g. forest, grassland, combination (more than one type of vegetation, e.g. forest and grassland)
Direction of fire spread	Direction of fire spread.	e.g. SE
Location of origin of fire	Description of where the fire began.	Text
Time of origin of fire	Estimate of time that fire began.	e.g. 23/02/1960 10:00AM
House loss	Number of houses destroyed in fire.	e.g. 213
Description	General description of fire (weather, fire severity, rate of spread, vegetation, etc.).	Text

FIRE WEATHER TABLE

FIELD NAME	DESCRIPTION	VALUES
Fire Code	Identifies fire that the fire weather is associated with. Provides link to Fire table.	e.g. 256
Fire Weather ID	Unique fire weather identification number	e.g. 25
Fire Weather name	Weather name (e.g. TOE: time of exposure, 2PM).	Text
Date	Date of fire weather.	e.g. 02/02/1995
Time	Time of fire weather.	e.g. 2:00PM Blank are non-applicable (e.g. referring to a maximum record on the day such as maximum temperature on the day, or combination of records at different time)
Weather station name	Name of weather station from which fire weather data was collected.	e.g. Melbourne AP NA: non-applicable (for record with qualitative information) Unknown : station name is unknown
Station Number	Number of weather stations from which fire weather data was collected.	Number Blank when station number is not known or not applicable
Drought factor	Drought factor.	0-10
Temperature (C)	Temperature in degrees Celsius.	Number
Relative humidity (%)	Relative Humidity as a percentage.	Number
Wind speed (km/h) avg 10 mins	Average wind speed over 10 minutes in km/h.	Number
Wind speed (km/h) 3 sec gust	Gust wind speed over 3 seconds in km/h.	Number
Wind direction	Direction of wind.	Text
Curing	Level of grassland curing as a percentage.	Number
FFDI reported	Forest Fire Danger Index reported.	Number
GFDI report	Grassland Fire Danger Index reported.	Number
FFDI (WS)calc	Forest Fire Danger Index calculated using wind speed average over 10 minutes.	Number
FFDI (WG) calc	Forest Fire Danger Index calculated using wind gust.	Number
GFDI (WS) calc	Grassland Fire Danger Index calculated using wind speed average over 10 minutes.	Number
Description/references	Description of fire weather and/or indication of where data came from.	Text

INCIDENT TABLE

FIELD NAME	DESCRIPTION	VALUES
Incident Code	Unique incident identification code.	Format In, e.g. I0231
Incident Name	Incident name.	Text
Fire Code	Identifies fire that incident was associated with. Provides link to Fire table.	e.g. 256
Description	Description of incident.	Text
Unmanaged vegetation description	Description of localised unmanaged vegetation in vicinity of incident.	e.g. dense forest area
Fire front description	Describes fire front at location of incident.	Text
Estimated time of fire arrival	Estimated time of fire arrival at location of incident.	e.g. 12/12/2003 3:00PM
Number of fatalities	Number of fatalities involved in each incident.	Number
Survivors account	If there is a survivor involved in the incident. this field gives an account of their experience	Text

FATALITY TABLE

FIELD NAME	DESCRIPTION	VALUES
Fatality Code	Unique fatality identification number. Corresponds to AFAC ID.	e.g.432
State	The jurisdiction in which the fatality occurred.	ACT NSW NT QLD SA TAS VIC WA
Residential address	Residential address of person.	Text Unknown identifies where insufficient information was available on fatalities residential address.
Incident Code	Identifies the incident in which this person died. Provides link to Incident table.	e.g. I0012
GIS location of fatal exposure	Identifies the name of the spatial object that gives the location of the fatal exposure. These are also included in the GIS Object Inventory table.	e.g. F432 NA identifies where persons location is non-applicable (some indirectly related to the bushfire and/or not sufficient information to locate fatality)
Description of location fatal exposure	Describes the location at which the fatal exposure occurred.	Text/unknown/NA (no clear link between the fatality and the bushfire event)
Estimated date of fatal exposure	Best estimate of the date at which the fatal exposure occurred.	e.g. 12/12/2003
Estimated time of fatal exposure	Best estimate of the time at which the fatal exposure occurred.	e.g. 15:00
Loc of death different to Loc of fatal exposure	Indicates whether death occurred at a location different to the location of fatal exposure.	yes/no/unknown/NA

FIELD NAME	DESCRIPTION	VALUES
If yes, location of death	If death occurred at a location different to the location of fatal exposure, describes the location of death.	Text
Estimated time of death	Best estimate of time of death (if different from time of fatal exposure).	e.g. 14/12/2003 4:00AM
Fatal exposure location class	Classifies location of fatal exposure.	inside structure inside vehicle open air unknown
Object related to fatal exposure location class	Identifies the object that person was in or near when fatal exposure occurred. Provides link to Object table.	Object Code, e.g. V0023
Detail of fatalities location	Describes location of fatality relative to the object related to fatal exposure and/or other objects.	Text e.g. 5m from V0023, in bathroom.
Distance to residence	Straight line distance between location of fatal exposure and their residence (km).	Number
Details of distance to residence	Describes the location of residence to location of fatal exposure or identifies where residence was unable to be located.	Text e.g. Unable to location residence, fatality at residence, fatality near residence H0018
Distance to vehicle	Straight line distance between location of fatal exposure and vehicle related to incidence (km).	Number
Details of distance to vehicle	Describes the location of vehicle to location of fatal exposure or identifies where a vehicle was not involved in the incidence.	Text e.g. Fatal exposure unrelated to a vehicle, distance to vehicle too inaccurate to record, fatal exposure occurred near vehicle V0012
Death related to fire mechanism	Indicates whether death was due to a fire mechanism (smoke, RHF, convection, flame, over exertion from fire-fighting) or due to some other causes.	yes/no/unclear/unknown
If relevant, description of mechanism	If relevant, description of cause of death.	e.g. heart attack
Sex	Number that indicates gender of person (from AFAC/Risk frontier datasets with update on new fatalities).	1 = male 2 = female 3 = unknown

FIELD NAME	DESCRIPTION	VALUES
Factors	Number that indicates factors that contributed to death (from AFAC/Risk frontier datasets with update on new fatalities).	0 = unknown 1 = flames, radiated heat 2 = smoke, hot gas inhalation, asphyxiation, carbon monoxide 3 = tree, limb or elevated object impact 4 = vehicle incident – single vehicle 5 = vehicle incident – multiple vehicles 6 = aviation incident 7 = drowned 8 = heart attack, overexertion, shock 9 = dehydration, heat stroke 10 = pre-existing illness or medical condition 11 = natural causes 12 = falling
Role Class	Number that indicates whether person was a firefighter or a civilian (from AFAC/Risk frontier datasets with update on new fatalities).	1 = firefighter 2 = civilian
Age Class	Number that indicates age of person (from AFAC/Risk frontier datasets with update on new fatalities).	0 = 00-09 1 = 10-19 2 = 20-29 3 = 30-39 4 = 40-49 5 = 50-59 6 = 60-69 7 = 70-79 8 = 80-89 9 = 90-99 10 = 100+ 99 = Unknown
Transport	Number that indicates transport mode of person (from AFAC/Risk frontier datasets with update on new fatalities).	1 = on foot 2 = inside a closed car / vehicle 3 = exited a closed car or vehicle due to fire threat or found with the door open 4 = on open transport or working around or on a vehicle 5 = unknown 6 = not applicable for those found inside structures

FIELD NAME	DESCRIPTION	VALUES
Activity	Activity and location prior to death (from AFAC/Risk frontier datasets with update on new fatalities including 2009 fires).	0 = Unknown 1 = In defensible shelter and defending 2 = In defensible shelter and made meagre and unsuccessful attempts to defend 3 = In defensible shelter and passively sheltering 4 = In defensible shelter but activities unknown 5 = Late evacuation from indefensible shelter 6 = Late evacuation from outside work 7 = Late evacuation from shelter 8 = Late evacuation destination or origin unknown 9 = In an indefensible shelter i.e. dugout 10 = On route to defend home, property or (rescue) loved ones i.e. left safe area and deliberately 11 = Travelling through area for work unrelated to fire and unaware of the fire 12 = Waiting rescue 13 = Returned to burning building for possessions / rescue 14 = Passively sheltering as a group (3 or more people from separate families) Or any number of separate families gathering at a 'community' refuge (new code compare to AFAC/Risk Frontier dataset) 15 = Travelling through area for pleasure e.g. picnic 16 = Saving livestock, livelihood or defending wider property or place of work, caught outside their home, friend's home, local community or place of work. Could also be assisting fire fighting operations 17 = Undertaking official support activities for the control or supporting agencies 18 = Undertaking official fire fighting activities for a control agency 19 = Travelling to and from a landscape fire incident for the purposes of official fire fighting or supporting activities. 20 = Outside undertaking burn off of property
Decision making	Fatality decision making and plans on the day (from AFAC/Risk frontier datasets with update on new fatalities including 2009 fires). Note: codes changed from AFAC/Risk Frontier datasets.	1 = Were aware of fire with enough time to save their lives. Had a fire plan and were following intended actions which were ineffective 2 = Were aware of the fire with enough time to save their lives. Either had no fire plan, plan was unclear or didn't follow their plan. Includes people were 'waiting to see' 3 = Were unaware there was a fire and only realised when it was too late to implement an effective survival strategy 4 = Unknown 5 = Extenuating circumstances affected plans (heart attack) 6 = Children or adults who followed the instructions of another person 7 = Physically or mentally incapable of implementing an effective survival strategy (shock, drugs etc)

FIELD NAME	DESCRIPTION	VALUES
Isochrones time of fire arrival	Determination of time of fire arrival at the location of fatal exposure (possible when location of fatal exposure is known and isochrones of the fire event available).	e.g. 15:00 Blank: no isochrones or location of fatal exposure available
Isochrones fire direction	Direction of fire spread at location of fatal exposure	e.g. SW Blank: no isochrones or location of fatal exposure available
Estimated rate of fire spread (km/hr)	Estimated rate of fire spread (km/hr) at location of fatal exposure.	Number Blank: no isochrones or location of fatal exposure available
Intensity coded (from Byram)	Intensity categories	1 = 0-500 kW/m 2 = 501-4000 kW/m 3 = 4001-20000 kW/m 4 = 20001-60000 kW/m 5 > 60000 kW/m 6 = Unknown
NCAS version	The National Carbon Accounting System (NCAS) Forest/Non-forest dataset version.	Number Blank: no forest layer or location of fatal exposure available
NCAS tile	The National Carbon Accounting System (NCAS) Forest/Non-forest tile name.	Number Blank: no forest layer or location of fatal exposure available
NCAS year	The National Carbon Accounting System (NCAS) Forest/Non-forest year of tile.	Number Blank: no forest layer or location of fatal exposure available
NCAS distance to forest (km)	Distance from closest part of the forest to location of fatal exposure in a straight line distance.	Number Blank: no forest layer or location of fatal exposure available
NCAS distance to forest in fire direction (km)	Distance to closest part of forest and closest straight line distance to location of fatal exposure in the direction of the approaching fire front.	Number Blank: no forest layer or location of fatal exposure available
NCAS fraction forest within 100m	Calculation of fraction of forest around location of fatal exposure (100m buffer around the location of fatal exposure).	Number Blank: no forest layer or location of fatal exposure available
Comments on distance to fire/forest	Description of distance to forest and fire.	Text e.g. No isochrones, no location, outside of isochrones Blank: Fire isochrones and forest data available for location of fatal exposure
Comments	Description of the event and circumstances leading up to the fatality (from Risk frontiers/ AFAC dataset, Royal Commission report, media reports or inquest findings).	Text

2009 VIC BUSHFIRE CIVILIAN FATALITIES TABLE

(see Appendix3)

OBJECT TABLE

FIELD NAME	DESCRIPTION	VALUES
Object Code	Unique object identification code.	Format xnnnn, e.g. V1123 x='H' for object type 'house' x='V' for object type 'vehicle' x='O' for object type 'other'
Incident Code	Identifies the incident that this object is associated with. Provides link to Incident table.	e.g. I0211
Object Type	Identifies the type of object.	house vehicle other object
GIS object	Identifies the name of the spatial object that gives the location of the object. Provides link to GIS Object Inventory table.	e.g. H0254
Final Status	Indicates the status of the object.	damaged destroyed untouched unknown NA
Used as shelter	Indicates whether the object was used for shelter.	yes/no/unknown

HOUSE TABLE

FIELD NAME	DESCRIPTION	VALUES
House Object Code	Unique house identification code. Provides link to Object table.	Hnnnn, e.g. H0567
Address	Address of house.	Text
Construction type	Construction type of house.	e.g. single story brick home, with a second level made of timber attached to the rear half of the home
Construction year	Year house was constructed.	e.g. 01/01/1976
Damage Process prior to ignition	Process by which house was damaged prior to ignition, if known.	e.g. radiant heat, wind, tree impact
Rate of loss of tenability	Description of the loss of tenability process.	Text
Loss of power	Indicates whether power supply to house was lost.	yes/no/unknown
Time of loss of power	Time at which power supply to house was lost.	e.g. 23/01/1982 3:45PM
Loss of water	Indicates whether water supply to house was lost.	yes/no/unknown
Time of loss of water	Time at which water supply to house was lost.	e.g. 23/01/1982 3:45PM
Description of house and surrounds	Free text containing relevant information about house and surrounds, e.g. defend-ability.	Text

VEHICLE TABLE

FIELD NAME	DESCRIPTION	VALUES
Vehicle Object Code	Unique vehicle identification code. Provides link to Object table.	Vnnnn, e.g. V0237
Vehicle detail	Describes vehicle, i.e. make, model, type, age.	e.g. Holden Commodore 1988
Context of entrapment	Description of how person became entrapped in car.	Text
Description vehicle journey origin	Description of where vehicle was travelling from.	Text
GIS vehicle origin	Identifies the name of the spatial object that gives the location of where vehicle was travelling from. Provides link to GIS Object Inventory table.	e.g. H0030, V0003origin
Description vehicle journey intended destination	Description of where vehicle was travelling to.	Text
GIS vehicle destination	Identifies the name of the spatial object that gives the location of where vehicle was travelling to. Provides link to GIS Object Inventory table.	e.g. H0050, V0003destination
Description of vehicle and surrounds	Free text containing relevant information about vehicle and surrounds.	Text

OTHER OBJECT TABLE

FIELD NAME	DESCRIPTION	VALUES
Other Object Object Code	Unique other object identification code. Provides link to Object table.	Onnnn, e.g. O5237
Description	Describes what the object is and any other relevant information about its role in the incident.	Text

GIS OBJECT INVENTORY TABLE

FIELD NAME	DESCRIPTION	VALUES
GIS Object Code	Unique spatial object identification code. Provides link to object names in spatial files. Also attributes to records in the Fatality, Vehicle and Object tables.	Format xnnnn, e.g. V1123 X='F' for fatalities x='H' for object type 'house' x='V' for object type 'vehicle' x='O' for object type 'other'
Comments	Free text containing information relevant to GIS object, e.g. how it was created.	Text e.g. Created from aerial imagery, created using Google Earth
Confidence in GIS location	An estimate is made of the spatial accuracy of the object. This field shows the possible margin of error in this estimate in metres.	Number, e.g. 50

Appendix 3 – Coding Scheme 2009 Victorian bushfires

A new coding scheme was developed for the 2009 civilian fatalities directly impacted by the bushfire (n168) and include information on:

- Preparation prior to the 7th of February 2009 (well, some, none, unknown),
- Preparation on the day (well, some, none, unknown),
- Activity in the last few hours before fatality,
- Intended fire plan,
- Time when people carried out their first action.

Prior preparation – (prior to the 7th of February 2009) (from O'Neil and Handmer 1010).

Code	Description
1	Well prepared = an independent water supply (dam, tank, pool or creek). If the water supply is not gravity fed then there should be evidence of an electric pump connected to a generator or a diesel / petrol pump, evidence of fuel management (creation of a defendable space) and/or appropriate clothing, equipment (a minimum of buckets and mops) (as the evidences of appropriate clothing and equipment is subjected to information available in Royal commission report[22])
2	Some preparation = evidence of some fuel management, planning an independent water supply (water to be stored in buckets around the property), appropriate clothing, equipment (a minimum of buckets and mops),
3	None
4	Unclear

Preparation on the day (7th of February 2009)

Code	Description
1	Well (Prior to 1.30)– Getting equipment set up, last minute fuel management, filling water, checking equipment, etc.
2	Some – (After 1.30) – filling water, blocking downpipes. Not well informed of fire's progress.
3	None
4	Unclear

[22] http://www.royalcommission.vic.gov.au/commission-reports/final-report (accessed 30/10/2012)

Activity in the last few hours before fatality

Code	Description
1	Defending
2	Defending then evacuating to another home or shelter on or nearby the property and defending
3	Defending (one or more properties) then moving to another home or shelter on or nearby the property and sheltering
4	Defending (one or more properties) then moving to shelter in a parked car
5	Waiting to see if defend or evacuate
6	Moving around community actively seeking information on what to do
7	Preparing to evacuate
8	Waiting for a trigger to evacuate
9	No prior action – in denial or too tired
10	No prior action - unaware
11	Sheltering – includes those sheltering from heat
12	Defending then sheltering

Intended fire plan

Code	Description
1	Stay and defend
2	Evacuate to a friends and assist with defence
3	Stay and defend but leave if threatened
4	Leave early
5	Leave when threatened
6	Wait and see what bushfire is like before deciding to stay or leave / plan unclear
7	Shelter passively at home
8	Shelter passively at a friends or community refuge
9	No plan/ unclear if they had a plan
10	Defending and sheltering
11	Evacuating people or animals and intending to return to defend

What time started action that lead to fatality?

Time, indication of time (e.g. morning, afternoon), unknown

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