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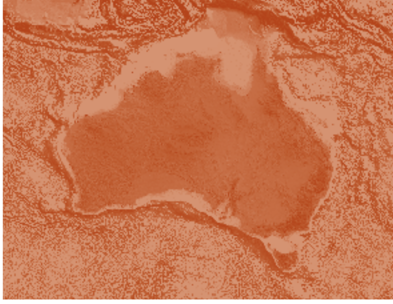

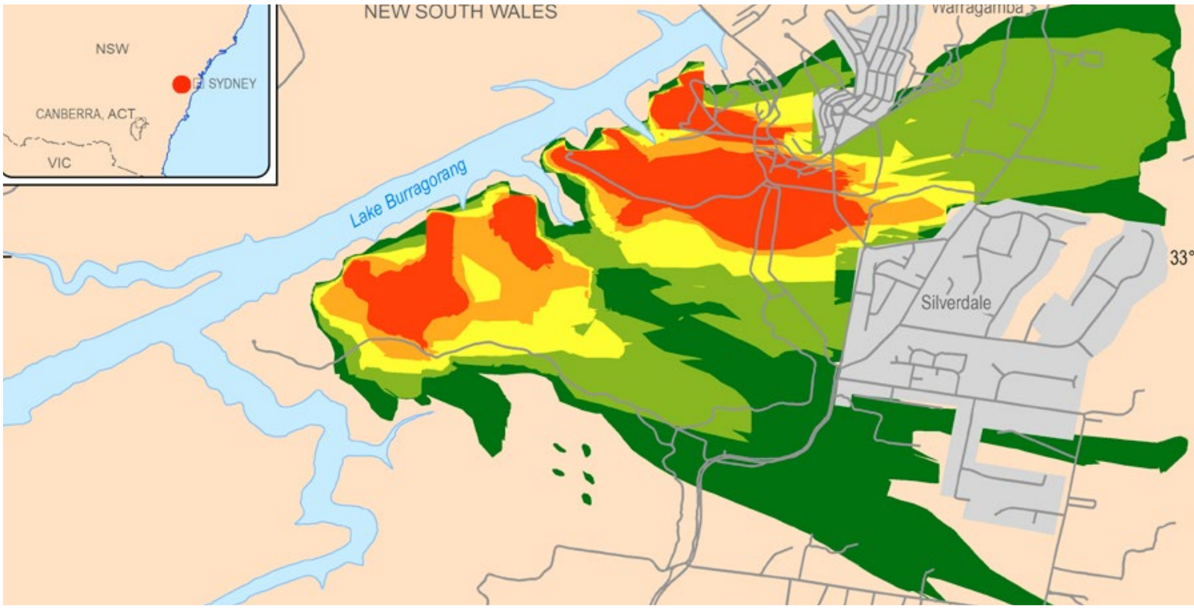

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Acknowledging and Understanding Variability in Simulating Bushfires

Part 3 - Evaluation of FireDST against the Mt Hall fire of 24 December 2001

Ian A French, H. Martine Woolf, Bob P. Cechet, Tina Yang, L. Augusto Sanabria

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GEOSCIENCE AUSTRALIA
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Contents

Audience

This document contains scientific information and technical content. It is intended for scientists and emergency services practitioners who have an understanding of the management of bushfires and controlled burns. The results of this work should be interpreted in the context of the aims and scope of the study. This report does not give a comprehensive risk assessment of the study area, and should not be used as a basis for decision making about planning or emergency response.

Acknowledgements

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- The Bushfire CRC for funding and supporting the FireDST project team;
- Derek Ming Onn Chong of the University of Melbourne who modified PHOENIX RapidFire to accept transport layer wind direction and wind speed files;
- Dr Mick Meyer and Dr Martin Cope from C.S.I.R.O Marine and Atmospheric Research who provided the combustion gas profiles that have been used to create the ensemble smoke output;
- Dr Jeff Kepert and Dr Robert Fawcett of the Bureau of Meteorology (CAWCR) who supplied the ACCESS weather simulations; and
- The end users on the F.I.R.E-D.S.T. Project Board for their in-depth knowledge of fire-fighting practices and for their support in looking to the future.

Abbreviations and Glossary

The following terms and abbreviations have been used throughout this document. Abbreviations that are part of the scenario labels are specified in Appendix B.

Term	Definition
ACCESS	Australian Community Climate and Earth-System Simulator, the Bureau of Meteorology weather model used in this study.
AWS	Automated Weather Station managed by the Bureau of Meteorology to record actual weather.
Boundary layer	The air layer in the atmosphere that is adjacent to the earth's surface.
Bushfire CRC BCRC	Bushfire Cooperative Research Centre
Collection District	Unit in the 2006 Australian Bureau Statistics Census. Now called Statistical Area Level 1 (SA 1). Generally has a population of 200-800 people with an average of 400 people.
CSIRO	The Commonwealth Scientific and Industrial Research Organisation
Ensemble Footprint	The fire shape that encompasses the fire spread in all the ensemble members.
FireDST	The simulation system developed as part of the F.I.R.E.-D.S.T. project.
F.I.R.E.-D.S.T.	Fire Impact and Risk Evaluation Decision Support Tool.
Fire Ensemble	An ensemble refers to a set of different individual fire simulations that have been collected together
Mesh Block	The smallest geographical region published by the Australian Bureau of Statistics. Only limited Census data (total population and dwelling count) are published at this level.
PHOENIX RapidFire	The model developed by the University of Melbourne that provided the core fire spread modelling capability for the FireDST system.
Vulnerability curve	Vulnerability curves are used to specify the probable level of damage to a building as a function of the hazard. The higher the hazard, the more likely the house will be destroyed.

1 Executive Summary

Introduction

In 2011, the Bushfire Cooperative Research Centre (BCRC) funded a multi-agency research project called the Fire Impact & Risk Evaluation Decision Support Tool (F.I.R.E-D.S.T) Project. The project team comprised Geoscience Australia, the Bureau of Meteorology, the University of Melbourne and CSIRO.

The F.I.R.E-D.S.T. Project aimed to investigate how uncertainty within fire spread modelling could be examined while assessing the potential consequences (impacts) of an event. FireDST was designed to generate an ensemble of scenarios, that is: different realisations of the potential fire spread based on variations in the conditions in which the fire occurs. Geoscience Australia developed an approach and the tools to meet the following research objectives:

1. Develop a methodology to assess and visualise the sensitivity of the modelled fire spread to a range of parameters describing:
    - surface weather;
    - weather conditions in the upper atmosphere;
    - fuel conditions; and
    - ignition location and time.
2. Develop a methodology to assess the sensitivity of the estimated numbers of people and buildings exposed to a fire to these parameters.
3. Develop a methodology to assess the sensitivity of the buildings that are at risk of being destroyed by a fire to a range of parameters describing:
    - Surface weather;
    - fuel conditions;
    - and ignition; and
    - Engineering vulnerability.

These research questions focus on sensitivity of the modelled fire spread and impact. Sensitivity analysis is a key component of a better understanding of the robustness and error of model outputs. By addressing the questions above, the project aims to achieve the following outcomes:

1. Development of an integrated fire spread and impact assessment methodology and tool;
2. Incorporation of the functionality to explore variability in key parameters as part of an integrated fire spread and impact modelling tool;
3. Demonstration of a product that can provide a range for the modelled fire spread and fire impact, rather than a best estimate. This allows stakeholders to explore the potential benefits of such information, as well as issues around user requirements and adoption;
4. Improved understanding of uncertainty in fire spread and impact modelling through sensitivity analysis of key input parameters;

5. Development of a ‘proof-of-concept’ for a system or approach that enables ensemble fire spread modelling, given the right input parameters. This includes an improved understanding of the information and system requirements for such a system; and
6. Improved understanding of the information and system requirements for future products based on the methodologies developed by F.I.R.E-D.S.T. This could be either an integrated fire and smoke spread and impact system, or a system quantifying uncertainty around projected fire and smoke spread or impact, or a combination of the two.

Project approach

Answering the research questions and objectives outlined above required the development of a proof-of-concept simulation system, called FireDST. FireDST is a modular system that combines a range of models and inputs from across the project team:

1. New numerical weather prediction model (ACCESS) from the Bureau of Meteorology;
2. Updated PHOENIX RapidFire bushfire simulator from the University of Melbourne;
3. Information on the built environment and population from the National EXposure Information System (NEXIS) developed by Geoscience Australia; and
4. Census information obtained from the Australian Bureau of Statistics.

The core of the FireDST functionality is its ability to model a fire spread and estimate the fire’s impact. The FireDST system simulates a fire spread based on particular weather, fuel and ignition conditions. It assesses the people and buildings in the fire spread, and models the potential damage to the buildings. One of its distinguishing features is that FireDST was built to generate multiple scenarios of the possible fire. Each instance of the fire is created using a variation in the input conditions (such as slight changes in temperature and wind direction). In doing this, FireDST creates ensembles of fire spread and impact. The ensemble data enables assessment of the sensitivity of the modelled fire spread due to the variations in the input parameters.

FireDST was applied in three case studies:

- the Victorian Black Saturday Kilmore fire of 7 February 2009;
- the South Australia Wangary fire of 10 January 2005; and
- the New South Wales Mt Hall fire of 24 December 2001.

This report evaluates the sensitivity tests using FireDST in the case study of the Mt Hall fire of 24/12/2001.

Objective 1 – Assess and visualise variability in the fire spread

The range of fire spread within an ensemble was visualised by FireDST by overlaying the fire spread scenarios, and scoring the percentage of scenarios that overlap at any point. Ensembles provided key information on the sensitivity of fire spread simulation through the size of the fire spread envelope.

To allow the ensemble fire spread to be interpreted in terms of probability of fire spread, the ensemble would have had to sample the full distribution of the uncertainty in input parameters. Defining this distribution was outside the scope of the project, and FireDST currently considers all ensemble scenarios equally likely. However, even a ‘pseudo-probabilistic’ sensitivity ensemble gives information on the potential development of an event that cannot be provided by a single deterministic model run. Moreover, with the right input, FireDST provides the capability to do probabilistic fire spread modelling before, during or after an event.

Objective 1.1 – Sensitivity of fire spread to the surface weather

The F.I.R.E.-D.S.T project aimed to develop a methodology for integrating the individual uncertainties in surface weather parameters into the FireDST system. The methodology was tested by assessing the sensitivity of the fire spread to the surface weather conditions as defined by the wind direction, wind intensity, temperature, humidity and combinations of those parameters. In addition, the sensitivity of the fire spread was assessed against the temporal and spatial resolution of the weather model.

The weather was simulated for the conditions during the Mt Hall fire in terms of temperature, humidity, wind direction and wind speed. The weather simulations were produced by the Bureau of Meteorology ACCESS Weather model at 0.036º, 0.012º and 0.004º grid spacing (approximately 4000 m, 1200 m and 440 m grid resolution), in time steps of five minutes.

The fire spread modelled by FireDST for the Mt Hall fire underestimated the size of the historical event, compared against the available reconstruction data. The underestimate could be due to three contributing factors.

1. There is significant uncertainty in the accuracy of the fire reconstruction. The event occurred nearly a decade ago and limited information is available;
2. The Mt Hall fire that was studied here was part of a bigger fire that was still burning across Lake Burragorang. This larger fire was not simulated in its entirety, and this may have limited the ability to model the fire spread in the Warragamba component; and
3. Validation indicated that wind speeds were underestimated in the ACCESS output at all resolutions. Additional correction of the modelled wind to reflect local effects using the ‘Wind Ninja’ modifiers made slight improvements for the fire spread based on weather data at those resolutions.

A series of tests showed evidence of the sensitivity of the modelled fire spread to the following weather parameters: temporal and spatial resolution of the weather model, wind direction, wind intensity, temperature, humidity and timing of the weather. It is worth noting that the FireDST ensemble of the Mt Hall event included simulations that matched the reconstructed fire spread much better than that based on the (best estimate of the) historical weather, fuel conditions and ignition.

The results also demonstrated that sensitivity of the modelled fire shape to perturbations in key parameters cannot be judged in isolation. The modelled process is sensitive to interactions between the parameters, caused by the physical processes that drive the fire. When assessing robustness of a fire spread prediction or generating a probabilistic fire spread forecast, this interaction between the input parameters has to be explicitly built into the sampling design of ensembles.

Objective 1.2 – Sensitivity of the fire spread to the weather conditions in the upper atmosphere.

Upper level wind speed and direction are key drivers of the spread of embers from a fire. FireDST includes a version of PHOENIX RapidFire with an improved parameterisation of ember transport, based on conditions in the upper atmosphere. Tests assessed the sensitivity of the modelled fire spread to the wind direction and speed in the upper atmosphere using this parameterisation scheme. The atmospheric conditions in the upper atmosphere were simulated by the Bureau of Meteorology ACCESS model, which modelled the vertical atmosphere at 50 heights (levels) each with 4 km horizontal resolution and time steps of 15 minutes.

The results indicated that despite the fact that Mt Hall traversed forest, there was little sensitivity of the fire spread to the conditions used to for the ember transport layer. It is likely that the lack of sensitivity was because FireDST only computed a limited impact of ember transport as a fire spread mechanism. It is likely that the small size of the fire did not propagate sufficient embers in the model to result in sensitivity to the ember transport conditions. This effect would be compounded by the underestimated wind intensity in the modelled weather conditions.

Objective 1.3 – Assessing the sensitivity of the fire spread to fuel load

Fuel characterisation can be a major source of uncertainty for fire modelling. This project modelled the sensitivity of fire spread and impact projections to the fuel load. Scenarios varying the fuel loads were tested based on varying the burning history, and the shape of the fuel regeneration curves. The results showed that the simulated fire spread for the Mt Hall event was sensitive to fuel load. A larger burn fire spread resulted when fuel load was increased. At the same time, results indicated there was little sensitivity to burning history in this case study, as the area had not burnt for many years and fuel load was already maximised.

Objective 1.4 – Assessing the sensitivity of the fire spread to ignition

FireDST was used to generate ensembles of scenarios with a perturbed ignition location and ignition time. Tests indicated that the fire shape was sensitive to ignition location. A reasonable approximation of the historical fire shape could be attained by introducing multiple ignition points, as opposed to the reconstructed (single) ignition point. This indicates that there is likely to have been more than one spot ignition from the main fire across the lake.

The Mt Hall simulations were insensitive to ignition time variation. Up to 20 minutes difference produced only minor changes in the simulation shape, most likely due to the consistency in the weather and fuel.

Objective 2 – Estimating exposure and impact by the fire spread

The ability to generate an inventory of the buildings and people that are exposed to a fire is a fundamental part of an assessment of fire impact modelling. F.I.R.E-D.S.T. implemented a framework for the derivation of exposure associated with fire. A database of building and population statistics was developed based on existing information, mainly from Geoscience Australia and the Australian Bureau of Statistics. In combination with the fire spread information, FireDST system can quantify and visualise exposure information for either a single fire scenario or a fire spread ensemble.

Objective 2.1 – Estimating building loss using a fire spread ensemble

The FireDST system estimates the probability that a building is destroyed by fire, based on the building location and the bushfire characteristics. Building loss information can be directly related to the corresponding area of the ensemble fire spread. A set of four vulnerability curves was implemented that estimated house loss as a function of radiation intensity and ember density. In order to apply these curves, the FireDST system integrates the large-scale fire spread modelling with a parameterisation of sub-grid scale fire conditions.

Based on the fire spread that best matched the historical fire, FireDST was 33% accurate in predicting the house loss for the Mt Hall event, indicating that vulnerability modelling requires further development and validation. Results demonstrated that the performance of the vulnerability model is sensitive to the error in the fire spread modelling itself, which in this case are most likely related to inaccuracies in the ACCESS weather simulation.

Estimated house loss was also shown to be sensitive to the assumptions of the vulnerability function. Ideally, vulnerability functions should reflect differences in relevant building characteristics, such as construction type, age, building-code compliance and maintenance level. As the FireDST functions did not capture this, the results could only be expected to attain a limited level of accuracy for individual buildings.

In summary, the results of the building loss modelling show that it is possible to estimate building damage as part of a fire spread approach. However, the Mt Hall case study demonstrates that at this point in time, model accuracy can still be very limited, firstly by issues in the fire spread modelling itself, and secondly by the lack of maturity and validation of the vulnerability modelling itself.

2 Introduction

2.1 Background

Australia needs to develop and use sophisticated fire modelling techniques as an aid in the prevention and mitigation of bushfires (COAG 2002). In 2011, the Bushfire Cooperative Research Centre (BCRC) funded a multi-agency research project called the Fire Impact & Risk Evaluation Decision Support Tool (F.I.R.E-D.S.T.) Project. F.I.R.E-D.S.T. aimed to investigate how uncertainties within fire spread modelling could be incorporated into a more robust assessment of the potential consequences (impacts) of a fire event.

The last few decades have seen the development of numerous computational bushfire spread models. These models include PHOENIX Rapidfire (Tolhurst *et al.,* 2008) in Australia, FireSite (Finney, 1998), FlamMap (Finney, 2006), WFDSS- FSPro (Wildland Fire Decision Support System- Fire Spread Probability Model) (McDaniel, 2007) in the USA, and Prometheus, the Canadian wildland fire growth simulation model (Tymstra *et al.,* 2009). These models propagate a fire through the landscape in time. Such models typically assimilate information on the weather, terrain, and fuel load and type. Other models link fire spread to impact on buildings and people.

While fire modelling has advanced significantly, none of the existing fire spread and impact models are able to fully replicate historical fire spreads. As is the case with any model of a complex phenomenon, there are many uncertainties in the output from fire spread and impact models. These uncertainties are associated with both the model parameterisation and the input data. The model output, typically a single ‘best estimate’ of projected fire spread or impact, conveys limited or no information on the impact of those uncertainties. Understanding the sensitivity of the model output to those uncertainties is essential to assessing the robustness of the projected fire spread and impact. It can help determine the probable range of variation around a modelled ‘best estimate’. The F.I.R.E-D.S.T Project developed an approach to assess and visualise the sensitivities of fire spread and impact modelling to those uncertainties in the modelling. Ultimately, the outcomes from this project should contribute to an improved robustness of decisions made on the basis of fire spread and impact modelling outputs.

The F.I.R.E-D.S.T Project comprised five sub-projects, undertaken by the following organisations:

Risk Assessment Decision Toolbox (Geoscience Australia):

- Development of a computational risk assessment framework; and
- Development of a simulation system integrating outputs from the other four sub-projects as well as databases with building and socio-economic information.

Enhancement of fire behaviour modelling (University of Melbourne):

- Enhancement of the fire spread model PHOENIX Rapidfire to incorporate the three-dimensional meteorology;
- Enhancement of fire suppression within PHOENIX Rapidfire; and
- Analysis of vegetation mapping and properties within PHOENIX Rapidfire.

Enhancement of weather predictions under extreme conditions (Bureau of Meteorology):

- Development of a high-resolution numerical weather prediction (NWP) capability for use in natural disaster modelling;
- Examination of how sub-scale weather phenomena can be parameterised (for NWP); and
- Assessment of the sensitivity of extreme fire behaviour to weather.

Regional and local impacts from bushfire dispersion (CSIRO Marine and Atmospheric Research):

- Development of a high-resolution smoke dispersion model; and
- Examination of the health impacts of bushfire smoke.

Enhancement of local impacts – vulnerability parameterisation (CSIRO Ecosystem Science):

- Examination of the impact of the local environment on house survivability; and
- Parameterisation of the vulnerability of houses to hazard (radiation, ember-attack).

The approach followed by the F.I.R.E-D.S.T Project implemented a computational risk assessment framework for quantitative bushfire risk assessments (Jones *et al.,* 2012). This approach complied with the National Emergency Risk Assessment Guidelines (NERAG 2010). Figure 2.1 displays the linkages between the research components undertaken by each of the teams. A full description of the project can be found in the FireDST Final report (Cechet *et al.,* 2014). This report describes the Geoscience Australia simulation system component, the 'proof-of-concept' FireDST system.

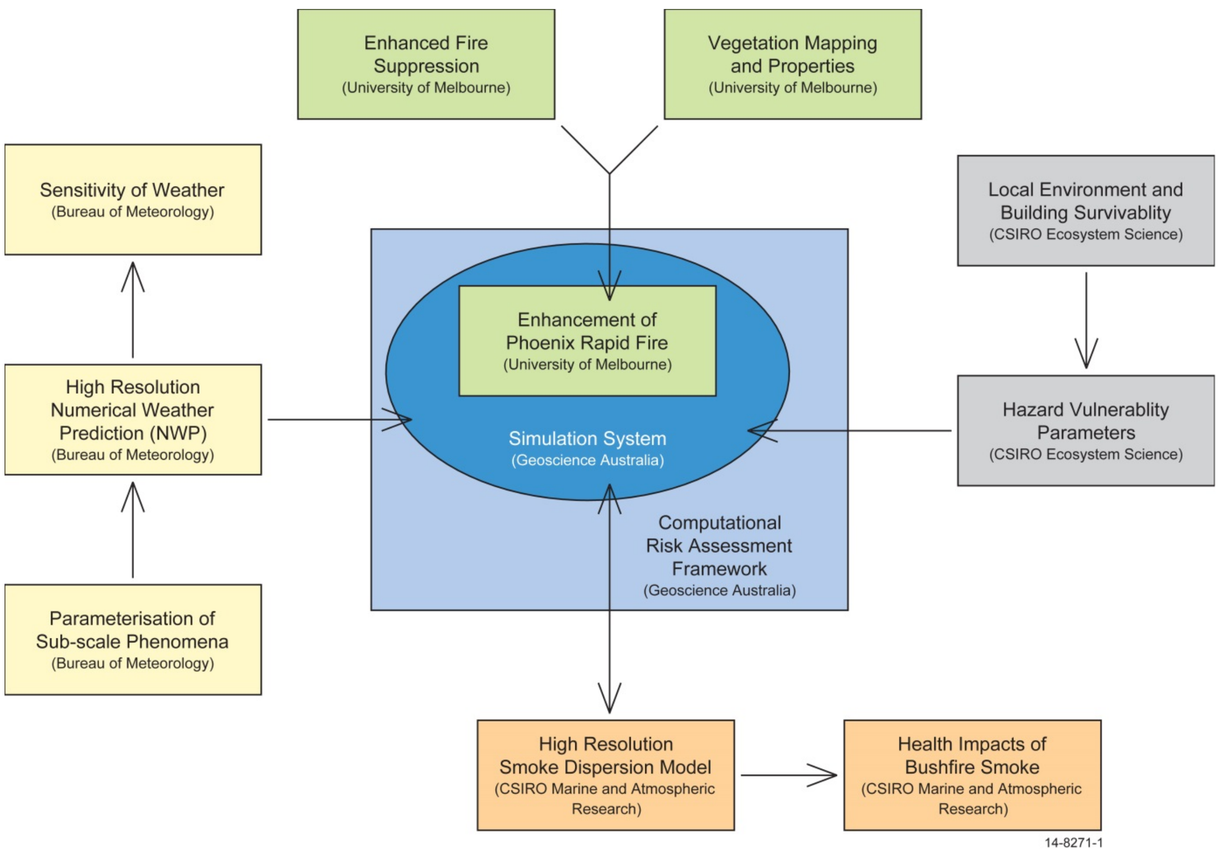

Figure 2.1 Relationship between the F.I.R.E.-D.S.T Project components.

FireDST is a computer system that integrates all of the components provided by the organisations mentioned earlier as part of the F.I.R.E-D.S.T Project. FireDST was developed to enable research on issues related to hazard, exposure, vulnerability and impact of bushfires.

The 'proof-of-concept' FireDST system has been applied in three case studies of historical fires. The case studies were selected based on their range of characteristics in terms of terrain and topography, fire severity and complexity of extreme fire weather. The case studies were utilised to develop, test and validate the components of FireDST, as well as the FireDST simulation system outputs (spatial pattern of fire spread, house loss and people likely to be affected by smoke inhalation).

2.2 Research objectives

As outlined in the previous section, the primary objective of the F.I.R.E-D.S.T. research was to investigate how uncertainty within fire modelling could be incorporated into an estimate provided by a fire spread and impact model. The FireDST proof-of-concept simulation system was used to explore the sensitivities of fire spread and impact modelling to key parameters in the modelling process to address the following research objectives:

1. Develop a methodology to assess and visualise the sensitivity of the modelled fire spread to a range of parameters describing:
   - surface weather;
   - weather conditions in the upper atmosphere;
   - fuel conditions; and
   - ignition location and time.
2. Develop a methodology to assess the sensitivity of the estimated numbers of people and buildings exposed to a fire to these parameters; and
3. Develop a methodology to assess the sensitivity of the buildings that are modelled to be destroyed by a fire to a range of parameters describing:
   - Surface weather, fuel conditions and ignition, and
   - Engineering vulnerability.

The research described in this report focuses on sensitivity of the modelled fire spread and impact. Sensitivity analysis investigates how outputs from a model or process change when the inputs are varied. Sensitivity analysis is a key component of a better understanding of the robustness and uncertainty of model outputs. A methodology that contributes to improved understanding of the possible range of variability around a 'best estimate' supports a more robust interpretation of those model outputs in a decision making process. It has to be noted that this project did not generate probabilistic fire spread and impact estimates. This would involve quantifying the distribution of the error in the model parameters, and this was beyond the scope of the F.I.R.E-D.S.T. Project. However, with that additional information, the methodology used by the FireDST system could be applied directly to generate probabilistic fire spread and impact estimates.

By addressing the questions above, the project therefore achieves the following outcomes:

1. Development of an integrated fire spread and impact assessment methodology and tool;
2. Incorporation of the ability to explore variability in key parameters as part of an integrated fire spread and impact modelling tool;

3. Demonstration of a product that provides a range of fire spread and impact, rather than a deterministic ‘single point of truth’. This allows stakeholders to explore the potential benefits of such information, as well as issues around user requirements and adoption;
4. Improved understanding of the drivers of uncertainty in fire spread and impact modelling through sensitivity analysis of key input parameters;
5. Development of ‘proof-of-concept’ for a system or approach that enables full uncertainty modelling, given the right input parameters. This includes an improved understanding of the information and system requirements for such a system; and
6. Improved understanding of the information and system requirements for a future operational product based on (part of) FireDST. This could be either an integrated fire and smoke spread and impact system, or a system quantifying uncertainty around projected fire and smoke spread or impact, or a combination of the two.

2.3 Outline of this report

The F.I.R.E-D.S.T. Project focused on three case studies to develop and validate the approaches needed to address the research objectives. This report describes the results of the case study of the Mt Hall fire of 24 December 2001 Two other documents specify the results of the analyses of the case studies on the Kilmore East bushfire in Victoria on Black Saturday (February 2009) (French *et al.*, 2014a) and the Wangary fire in 2005 (French *et al., 2*014c). An overall summary of the research across the entire project is given in the F.I.R.E-D.S.T. Final Report (Cechet *et al., 2*014).

The remainder of this introductory chapter will outline some details of the historical Mt Hall bushfire. Chapter 3 describes the FireDST system, used to address the research objectives. Chapters 4 to 10 discuss the results of the Mt Hall Case Study. In particular:

- Chapter 4 discusses how FireDST assesses and visualises variability in the fire spread; Visualisation of the variability of the simulated fire shape or impacts is key to understanding the sensitivity of the model;
- Chapter 5 discusses how FireDST assesses the sensitivity of the fire spread to the surface weather;
- Chapter 6 discusses how FireDST assesses the sensitivity of the fire spread to the weather conditions in the upper atmosphere;
- Chapter 7 assesses the sensitivity of the fire spread to fuel parameters;
- Chapter 8 assesses the sensitivity of the fire spread to variation in ignition;
- Chapter 9 discusses estimating the number of buildings and people exposed to the fire spread; and
- Chapter 10 discusses the methodology used for estimating house loss using a fire spread ensemble.

2.4 The Mt Hall fire, 24 December 2001

This section provides an outline of the 24 December 2001 Mt Hall fire in NSW. It details the data sources used in this case study.

The fire started at Mt Hall (southern Blue Mountains region, about 50 km west of Sydney) on the evening of 23 December 2001 after a lightning strike hit a tree. The fire was initially reported to the NSW RFS Blue Mountains District Office from the Narrow Neck Fire Tower at 09:57 EDT on 24 December in the vicinity of the area known as Mt Hall in the Blue Mountains National Park; smoke was reported at two nearby locations later referred to as Brereton Bend and Mt Hall. After some initial fire suppression work at Brereton Bend, all resources were withdrawn from the fire ground in the early afternoon due to the deteriorating fire ground conditions (i.e. aerial water-bombing was no longer possible). At the time of withdrawal, the Mt Hall fire was rapidly expanding. No further aerial reconnaissance of this fire was carried out on 24 December due to all available aircraft being committed to property protection on other fires (about 20 fires were active in NSW at the time).

At about 14:00 EDT on 25 December the Mt Hall fire which was moving in a south-easterly direction, jumped across Lake Burragorang and burned in an easterly direction towards the small townships of Warragamba, Silverdale and Mulgoa., The fire destroyed 30 properties (homes and businesses) and damaged a number of properties in these townships later that afternoon. The loss of electricity affected 4,500 homes in these townships and surrounding areas.

On 25 December 2001, more than 4000 firefighters were battling over 100 blazes across New South Wales, mainly in areas within and adjacent to the Blue Mountains. Most of these fires were ignited by lightning or arsonists, and were part of the longest official continuous bushfire emergency in NSW, which took place between 21 December 2001 and 13 January 2002. At the end of this fire period some 733,342 hectares had been impacted upon, with the fires burning across 25 local government areas stretching from the Richmond Valley in the north, out to Narromine and as far south as Batemans Bay.

The FireDST team was most interested in the component of the fire that impacted on the communities of Warragamba and Silverdale, due to the information that was available on the house losses. This case-study concentrates on the time between the spot fire ignition (jumping the narrow arm of Lake Burragorang) and the fire impacting the townships. The University of Melbourne team developed a reconstruction of the progress of this part of the fire. The reconstruction is the best that can be produced from available information about the progress of the fire. Unfortunately due to the age of the fire (2001) locating accurate information about the fire progress proved difficult. Figure 2.2 shows the initial spot fire area on the eastern side of the lake at around 13:20 EDT and reconstructed time intervals until 15:30 EDT. More information on the Warragamba/Mt Hall fire can be found in:

- NSW Rural Fire Service – Bushfire Bulletin / Christmas Fires 2001[1]
- Brief History of Bush Fires in NSW[2]
- Warragamba – local webpage[3]
- Dowdy et al., (2009) CAWCR Technical Report No. 10[4]

[1] http://www.rfs.nsw.gov.au/file_system/attachments/State/Attachment_20050302_626D4CE1.pdf
[2] http://www.rfs.nsw.gov.au/dsp_content.cfm?cat_id=1180
[3] http://www.warragamba.net.au/warra/wiki/doku.php?id=2001_bushfires
[4] http://cawcr.gov.au/publications/technicalreports/CTR_010.pdf

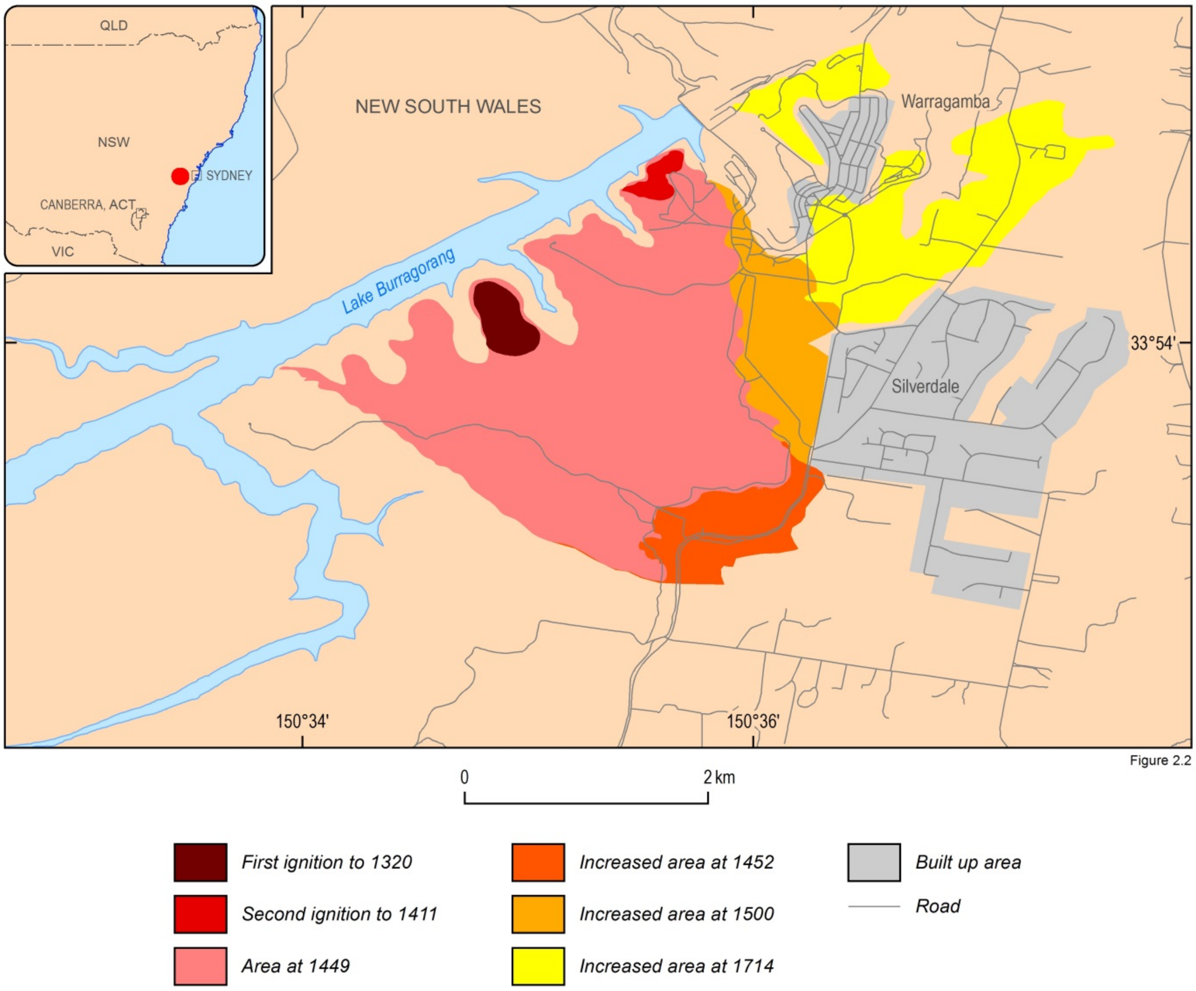

Figure 2.2 Extent of the Warragamba/Mt Hall fire scar (reconstruction) in the region of Warragamba and Silverdale (up to 15:30 EDT on 25 December 2001). Map provided by Kevin Tolhurst, University of Melbourne.

3 The FireDST system

The development of the proof-of-concept FireDST system represents a key achievement of the F.I.R.E-D.S.T Project. The FireDST system integrates the project's research components and enables the research questions to be addressed (see Section 2.2). This section discusses FireDST and its inputs and outputs. Later chapters examine each of the research questions in turn.

The core of the FireDST functionality is built around its ability to model a fire spread and estimate the fire's impact. One of FireDST's distinguishing features is its ability to generate multiple scenarios of possible fire spread. FireDST creates 'ensembles' of fire spread scenarios by applying variations to the modelling input parameters or modelling assumptions.

Figure 3.1 displays the information flow in the FireDST system. The next sections give more detail on the system.

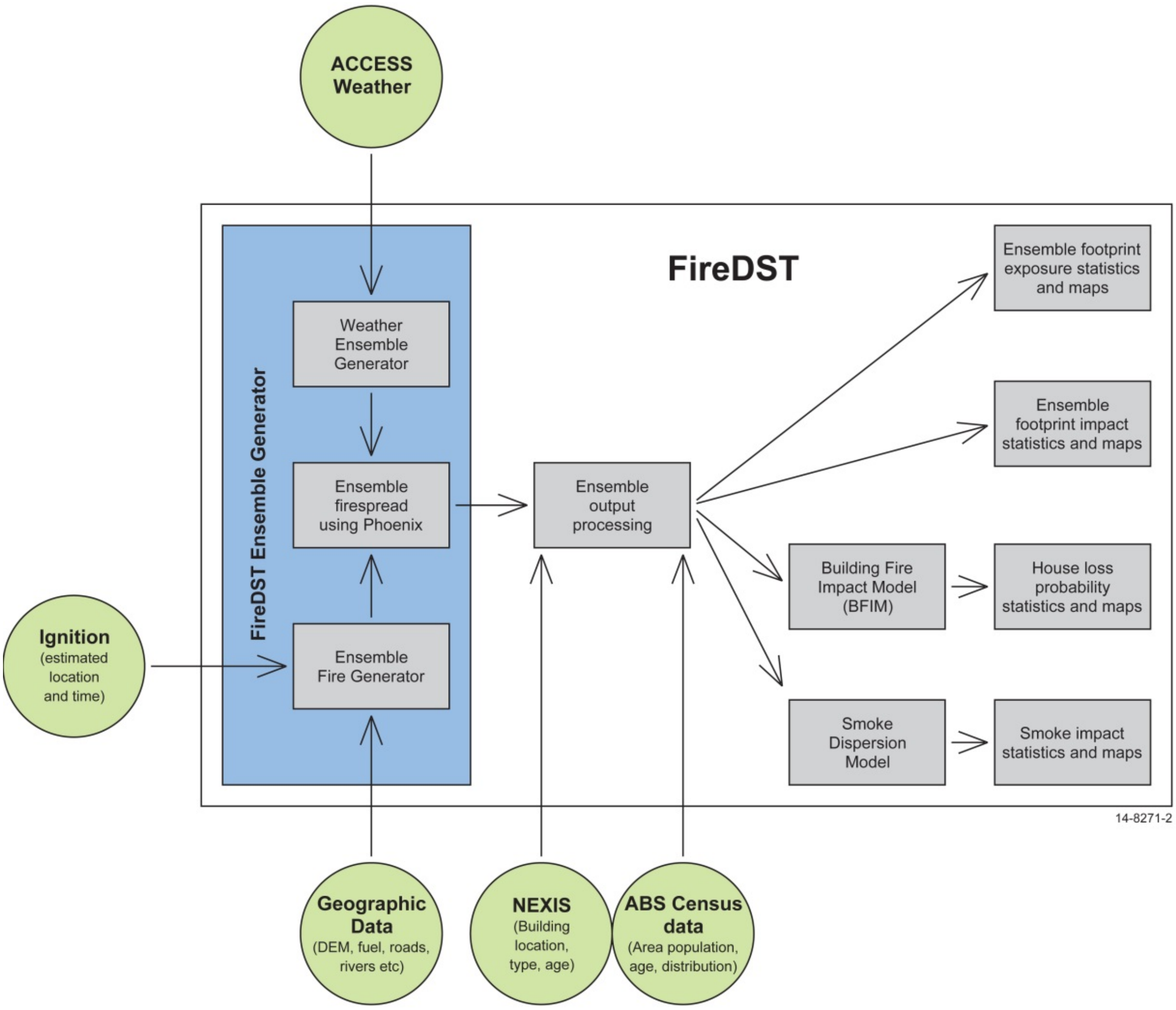

Figure 3.1 Information flow in FireDST.

3.1 FireDST input information

This section briefly describes the nature and source of the input data for FireDST. To model the fire spread, the system ingests information on the location and timing of a fire's ignition as well as the fuel and the weather at the time of the fire (see Figure 3.1). To model the impact of the fire, the system requires information on the exposed assets. This information is stored by FireDST in three input databases (shown outside the largest dashed box at the bottom of Figure 3.1), geographic data (vegetation and fuel type), and exposure data, based on NEXIS and ABS census data.

The Bureau of Meteorology supplied information on the meteorology during the Mt Hall event, based on a weather model run for the conditions at the time. The Bureau of Meteorology numerical weather prediction model is known as ACCESS (Australian Community Climate and Earth-System Simulator) (Puri, 2011). A set of files is produced for the temperature, humidity, wind speed and wind direction at 10 m height above ground. For this case study, research ACCESS files were specifically generated for a 48 hour period from 10:30am on 24/12/2001 at grid resolutions 0.036º, 0.012º and 0.004º (which is approximately 4000 m, 1200 m and 440 m) in 5 minute time steps.

In addition the Bureau of Meteorology provided extra information about the atmospheric conditions. Wind speed and wind direction at 50 different altitudes in the atmosphere were modelled for the 4000 m resolution ACCESS simulation at 15 minute intervals. Comparison of the ACCESS simulation with observations showed that significant aspects of the AWS observations were missing or otherwise inadequately represented. These include the nocturnal moistening at many sites (e.g., Sydney Airport) in the early hours of the morning of 25 December, the overnight cooling at some sites (e.g., Richmond RAAF), and the period of dry air during the afternoon of 24 December at some sites (e.g., Canterbury Racecourse).The relatively poor simulation may be due to the initial conditions, the complex topography or that the synoptic forcing was weaker (Cechet *et al.,* 2014).

The geographic information ingested by FireDST can be split into two categories: data for the fire spread simulator PHOENIX RapidFire (Tolhurst *et al.,* 2010) and data for the visualisation of the output maps. PHOENIX RapidFire input data includes a vegetation database (10 m grid), disruptions database (10 m grid), asset database (10 m grid), Digital Elevation Model (DEM 100 m grid) and fire history database (10 m grid). For the Mt Hall case study, most of this information was supplied by the University of Melbourne.

The visualisation data consists of ArcGIS shapefiles showing roads, rivers, railways and lakes. This information was supplied by Geoscience Australia from their 250K map series (www.ga.gov.au). The information allowed the visualisation of the fire simulations and ensembles in the context of the Mt Hall region.

Ignition location and timing was sourced from the Mt Hall fire reconstruction conducted by the University of Melbourne.

The exposure database in FireDST contains information on assets that are exposed to the fire, that is, people and buildings. Geoscience Australia supplied building information sourced from the National Exposure Information System (NEXIS) (Nadimpalli, 2007; Canterford, 2011). Population statistics were extracted from the 2006 Australian Bureau of Statistics Census at the Collection District reference level and allocated as an average to all the individual houses in that collection district. This information was then used to calculate exposure and loss statistics for the ensemble. The 2006 Census was used because the Australian Bureau of Statistics had released only a small amount of the required digital Census information in 2002 and no digital information in 1998.

3.2 FireDST information flow - overview

The FireDST approach of creating multiple scenarios for a single event is implemented by the Ensemble Generator, comprising the Weather Ensemble Generator and the Ensemble Fire Generator (Figure 3.2). An ensemble refers to a set of different individual fire scenarios, in this context exploring potential variation in the parameters that specify the fire conditions. The Weather Ensemble Generator creates a set of different weather scenarios, referred to as the weather ensemble. It is based on permutations of the originally supplied weather. The Fire Ensemble Generator creates an ensemble of different fire spread scenarios. The fire spread scenarios in the ensemble are based on variations of the specified ignition location, ignition time, vegetation, and the weather permutations created by the Weather Ensemble Generator.

For each scenario in the ensemble, the fire spread is simulated using the PHOENIX RapidFire fire spread model. The complete process is described in more detail in the next section. Once FireDST has simulated an ensemble of fire spread scenarios, there is a variety of ways of viewing the ensemble fire spread information. FireDST can display statistics and maps of residents and structures exposed to the ensemble fire spread. The system also analyses the potential fire impact at the building level.

The two final components of FireDST were not conducted in the Mt Hall case study. The Building Fire Impact Model (BFIM) was not conducted due to not enough details being known about the actual population and housing stock. The smoke impact modelling was not attempted due to the excessive time for each simulation. However, results in both these areas were completed for the Kilmore case Study (French *et al., 2*014a).

3.3 FireDST Ensemble Generator

This section describes how FireDST creates an ensemble view of the selected fire scenarios using the Weather Ensemble Generator, the Fire Ensemble generator, PHOENIX Rapidfire and the Ensemble View Generator (Figure 3.2).

3.3.1 Weather Ensemble Generator

The Weather Ensemble Generator (Figure 3.2) varies the weather conditions to produce different weather scenarios. The permutation is based on simple rules, for example: increasing wind speeds by 5 m/s, or increasing the temperature by 2ºC. More complex weather scenarios are created using combinations of varied humidity, temperature, and wind speed or wind direction parameters.

The resultant weather ensemble is stored by the FireDST system as a set of alternative weather files. Storage allows different combinations of weather to be used by the Ensemble Fire Generator. In this case study, the weather ensembles were generated by perturbing the historical conditions for the Mt Hall fire, as specified in the ACCESS files. The variability used to generate the ensembles for this case study was based on an initial assessment of the likely range; within that range the probability distribution was assumed to be ‘flat’ (all values have equal probability). Chapters 5 and 6 discuss the generation of ensembles by the FireDST Weather Ensemble Generator for the surface weather (Chapter 5) and the conditions in the vertical atmosphere (Chapter 6).

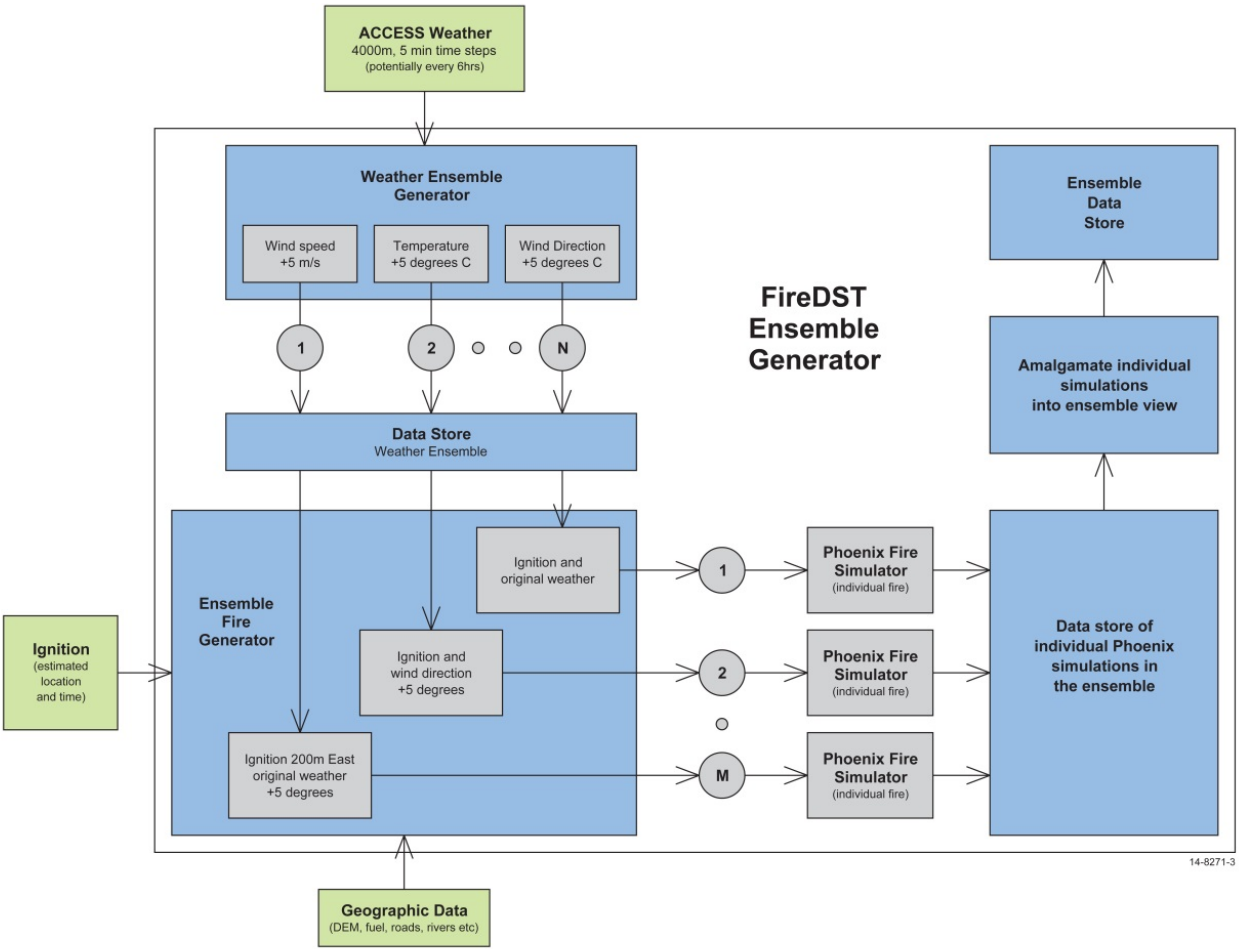

Figure 3.2 The FireDST Ensemble Generator.

3.3.2 Ensemble Fire Generator

Analogous to the perturbation of the weather, the Ensemble Fire Generator creates an ensemble of scenarios by varying the ignition point parameters. The case study described in this report created an ensemble by varying the historical ignition point and time for the Mt Hall fire. As above, the range of perturbations used in this case study were based on an initial assessment of likely range of error of the parameters; within that range the probability distribution was assumed to be 'flat' (all values had equal probability).

The FireDST Ensemble Fire Generator can also perturb the vegetation conditions by varying fuel load and curing parameters. All these scenarios can be modelled separately and then combined with a set of weather from the Weather Ensemble Data Store. The Ensemble Fire Generator creates a specific PHOENIX RapidFire input file defining the combinations of parameters to be used in the individual simulation. This input file allows further modification of wind speed based on the local terrain/topography using the Wind Ninja system (Forthofer *et al.,* 2009).

3.3.3 Fire spread simulation

For each of the individual scenarios in the ensemble, FireDST simulates the fire spread using PHOENIX RapidFire V4.0 (Tolhurst *et al.,* 2010). This requires spatial information, including a vegetation grid, the Digital Elevation Model (100 m grid resolution), areas where roads have decreased the amount of fuel in a cell, and fire history database (180 m resolution), all supplied by The University of Melbourne. Chapter 7 provides examines the sensitivity of the modelled fire spread to the fuel information.

The v4.0 PHOENIX RapidFire model includes a module which simulates the impact of suppression by emergency services teams that ‘attack’ the flanks at the back of the fire in equal proportion on each flank. The impact of the suppression module could potentially amplify or mask the sensitivity of the fire spread modelling, as length of the flanks will differ between scenarios. To enable like-for-like comparison across scenarios in an ensemble, the suppression component was deactivated in FireDST. Therefore, none of the results reported in this document consider suppression activities in the fire spread modelling.

3.3.4 Ensemble View Generator

The FireDST Ensemble Generator takes all the individual fire spread simulation results for the ensemble and produces an ensemble footprint of the complete collection of simulations in the ensemble. This shows the range of locations that will be burnt, based on the scenarios in the fire ensemble. This ensemble footprint is determined by overlaying the individual simulated fire spread extents. Figure 3.3 shows an example of how an ensemble burn extent is derived from four fire shapes. Locations within each fire shape are allocated a value of one; locations outside the shape are set to zero. Values in the final ensemble shape are determined by the percentage of individual simulations that overlapped with each location. The percentage overlap shape is then displayed as shape files in percentage intervals (e.g. increments of 5%, 10% or 25%).

The FireDST system can display the ensemble view at various steps through the simulated timeframe (to identify the fire progression) and at different percentage bins. Chapter 4 discusses the assessment and visualisation of the ensemble fire spread for the Mt Hall fire.

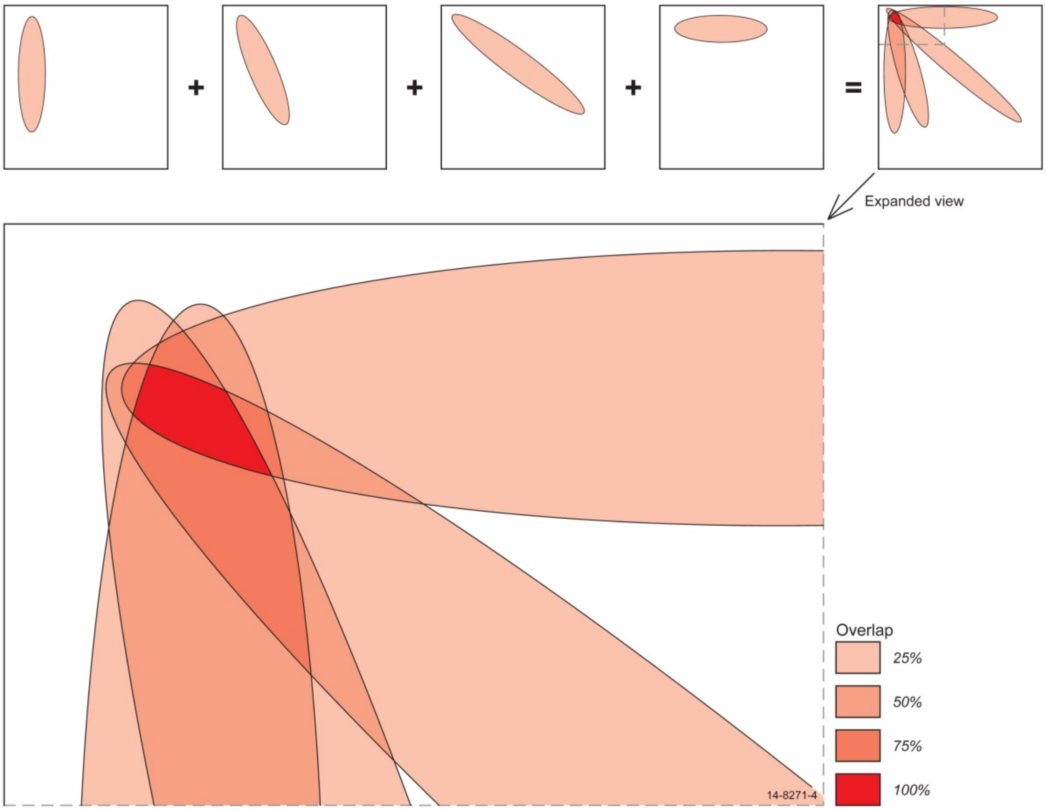

Figure 3.3 Example of how an ensemble shape of a burn extent is produced. The polygons show the fire spread of individual simulations.

3.4 FireDST system implementation

This section provides a brief overview of the implementation of the proof-of-concept FireDST system. FireDST is constructed using Python v2.6.2, PHOENIX RapidFire v4.0 and ArcGIS v10.0.

All components (shown in Figure 3.1) except the Weather Ensemble Generator were developed on the Microsoft Windows XP platform. The choice of platform was imposed by Phoenix RapidFire (developed in .NET, with limited or no option of deployment on other platforms). The FireDST Ensemble Main Control Panel (Figure 3.4) manages the interaction with the user, and there is no direct interaction between the user and PHOENIX RapidFire or any other components of FireDST.

The FireDST Weather Ensemble Generator was developed for the Unix Ubuntu system. This decision was driven by the choice to use the Unix-based package NCO Tools to manipulate the ACCESS netCDF Weather files. The output weather ensemble files are then transferred to the Microsoft Windows XP system as input into FireDST.

When FireDST is started, the user is prompted to select a case study and then an ensemble of scenarios that make up an ensemble fire spread. FireDST then opens and displays a main control panel, a visual control panel and the ArcGIS view of the ensemble (Figure 3.4). The main output for FireDST is delivered in ArcGIS as this was a common platform in emergency service agencies.

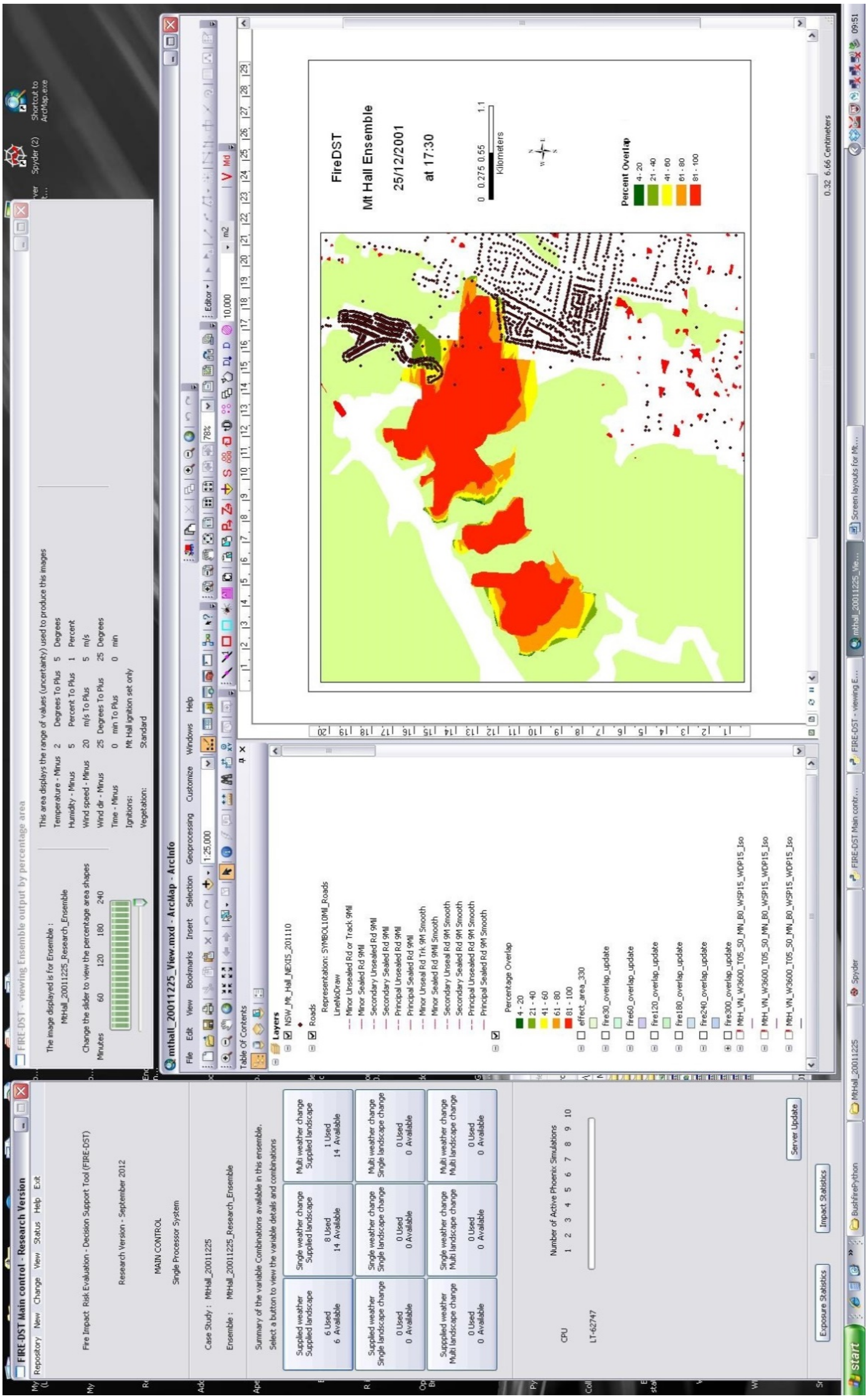

Figure 3.4 Full screen layout for FireDST.

The FireDST main control panel (Figure 3.5) maintains the standard Windows XP look and feel, with the main functions appearing in the menu bar at the top of the window. The nine large buttons in the centre of the FireDST main control panel (Figure 3.5) allow the user to select what simulations are included in the ensemble. The nine functions provide an efficient way to manage the complex number of individual simulations that can form an ensemble. The functions allow the user to change the ensemble contents or create a new ensemble.

The exposure statistics and impact statistics functions produce statistics for the current ensemble's footprint.

Top row (left to right)

Button 1 – Supplied ACCESS weather simulations and supplied landscape

Button 2 – Single change in weather and supplied landscape

Button 3 – Multiple changes in weather and supplied landscape

Middle row (left to right)

Button 4 – Supplied weather and single change in landscape

Button 5 – Single change in weather and single change in landscape

Button 6 - Multiple changes in weather and single change in landscape

Bottom row (left to right)

Button 7 - Supplied weather and multiple changes in landscape

Button 8 – Single weather change and multiple changes in landscape

Button 9 - Multiple changes in weather and multiple changes in landscape

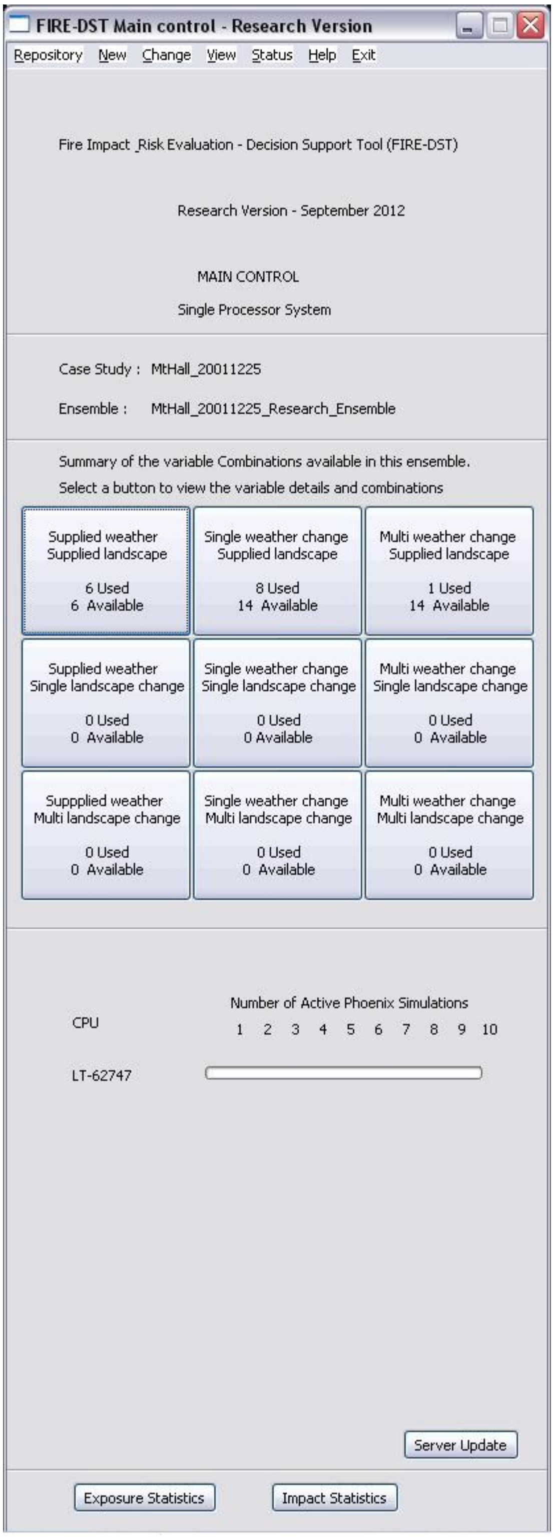

Figure 3.5 FireDST Main Control Panel. 'Landscape' refers to fuel and ignition parameters.

Once an ensemble is selected a window appears that controls the visualisation of the ensemble (Figure 3.6). This window contains a slider that allows the user to step the ensemble through time in increments of 60 minutes up to four hours ahead of the start time of the simulation. The window also displays the outer bounds of the parameters used in the ensemble.

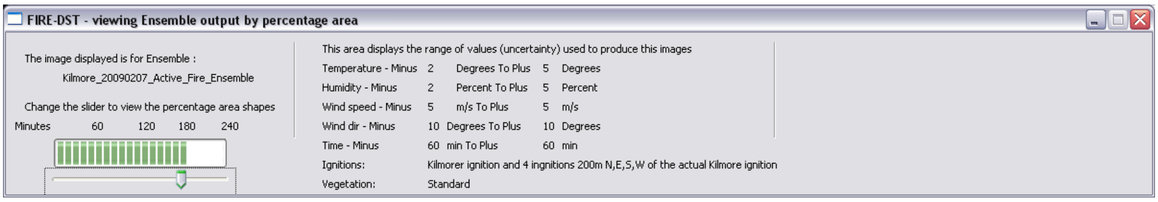

Figure 3.6 Viewing ensemble control panel.

3.5 FireDST research code

The F.I.R.E-D.S.T Project was funded by the Bushfire CRC. The FireDST research code produced in this project is included as a deliverable of the project and can be accessed on request through the Bushfire CRC.

The following chapters discuss the research questions outlined in Section 2.2. An overall summary of all of research for each of the project teams is provided in the F.I.R.E-D.S.T Final Report (Cechet *et al.,* 2014).

4 Assessing and visualising variability in the fire spread

4.1 Objective

FireDST was designed to generate an ensemble of scenarios, that is: different realisations of the potential fire spread based on variations in the conditions in which the fire occurs. The output from FireDST can be used to assess the sensitivity of simulated fire spread to the conditions surrounding the fire, for example meteorology or the fuel conditions. A system such as FireDST is an essential part of the ability to integrate uncertainty into fire spread modelling. This chapter investigates how to visualise the variability in the ensemble fire spread.

The work described in this chapter used the Mt Hall fire as a case study for:

- Evaluating the techniques used to create an ensemble simulation of bushfire spread;
- Validating the 'proof-of-concept' system for the generation, management, and analysis of ensemble fire spread and impact; and
- Understanding the potential benefits of ensemble fire spread modelling.

For a full uncertainty analysis, the variability would be determined by the probability distribution of the error in particular parameters. This fell out of the scope of this study.

4.2 Methodology

4.2.1 Background

FireDST is a 'proof-of-concept' system that generates an ensemble of scenarios by perturbations in the input parameters to the fire spread model. The resulting ensemble fire spread summarises the variability in the predicted fire spread, specifying for each location in what proportion of the scenarios it was burnt. Mapping the ensemble fire spread illustrates the sensitivity of the fire spread to the variation of the input parameters used to create the ensemble. With the correct input parameters, the ensemble fire spread represents the probability that a location will be burnt.

This chapter discusses the method that was developed to visualise the ensemble output information in more detail.

4.2.2 Method

The methodology to create fire spread ensembles using the FireDST Ensemble Generator is described in Chapter 2. In this case study, the fire spread ensemble was a set perturbation range in the input parameters. As described in Chapter 2, the ensemble members are considered to be equally likely. Where a location is burnt in all scenarios in the ensemble, the ensemble fire spread scenario is 100%; where it is burnt in some but not all scenarios, the location value is proportionally lower.

4.3 Results & Discussion

4.3.1 Ensemble visualisation

Figure 4.1 shows a fire ensemble of 25 scenarios for the Mt Hall fire (based on the reconstruction ignition isochrones on 25/12/2001 at 13:00) at 19:30 on 25/12/2001. The ensemble footprint is displayed in intervals of 20% coincidence of the individual scenarios (see Appendix C for the scenarios).

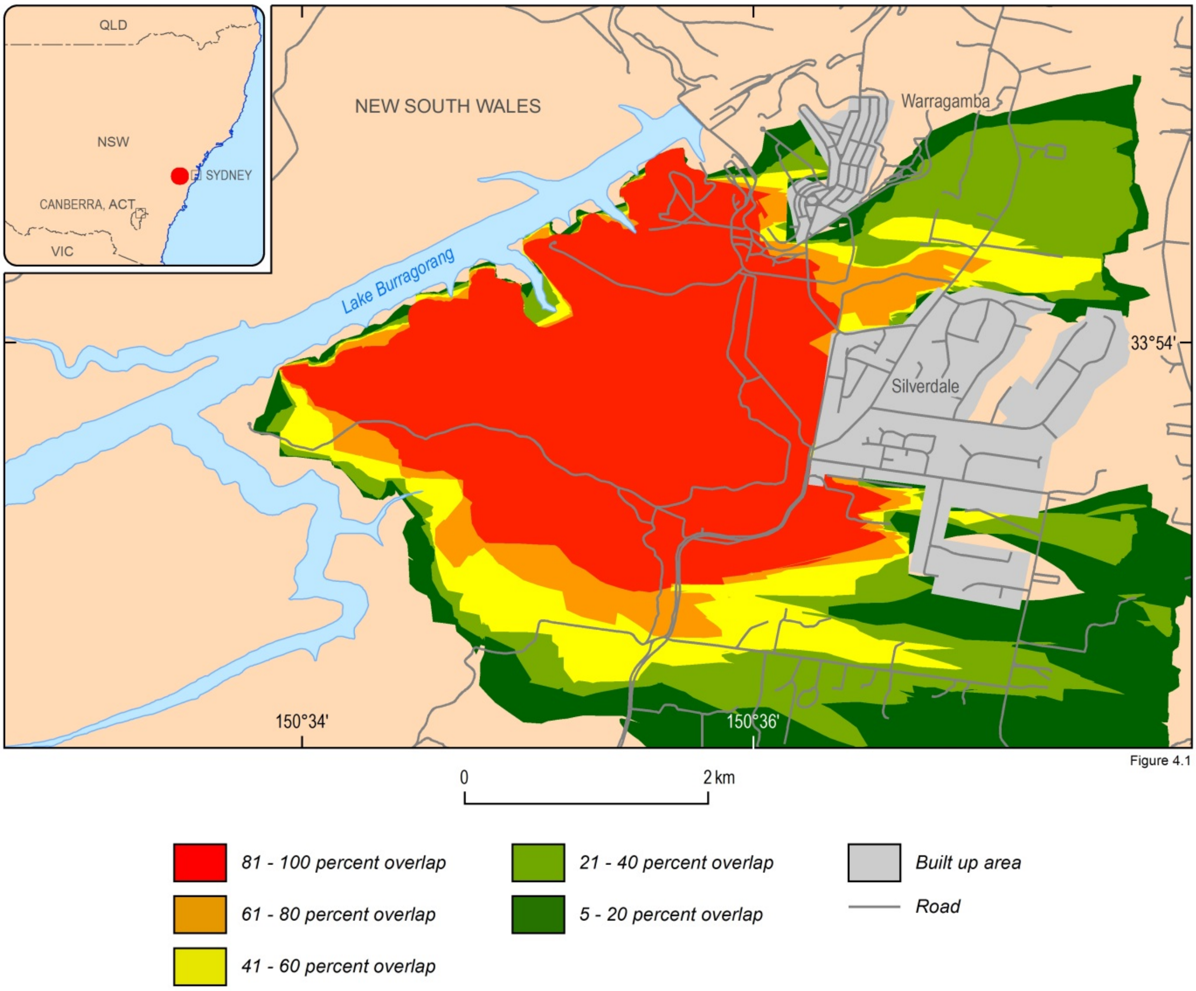

Figure 4.1 An ensemble view of the Mt Hall fire based on a 25 member ensemble using reconstructed isochrones for ignition and ACCESS weather up to 19:30 on 25/12/2001.

4.3.2 Comparison of ensemble and reconstruction

A reconstruction of the Mt Hall fire is described in Chapter 2. The ensembles generated based on the supplied ACCESS weather files (instead of the weather reconstructed from using AWS data) and using the reconstructed ignition did not lead to reasonable results (see for example one of the individual simulations in Figure 4.2). As a result of the reconstructed single ignition location, none of the individual simulations covered the southern and northern region of the historical fire.

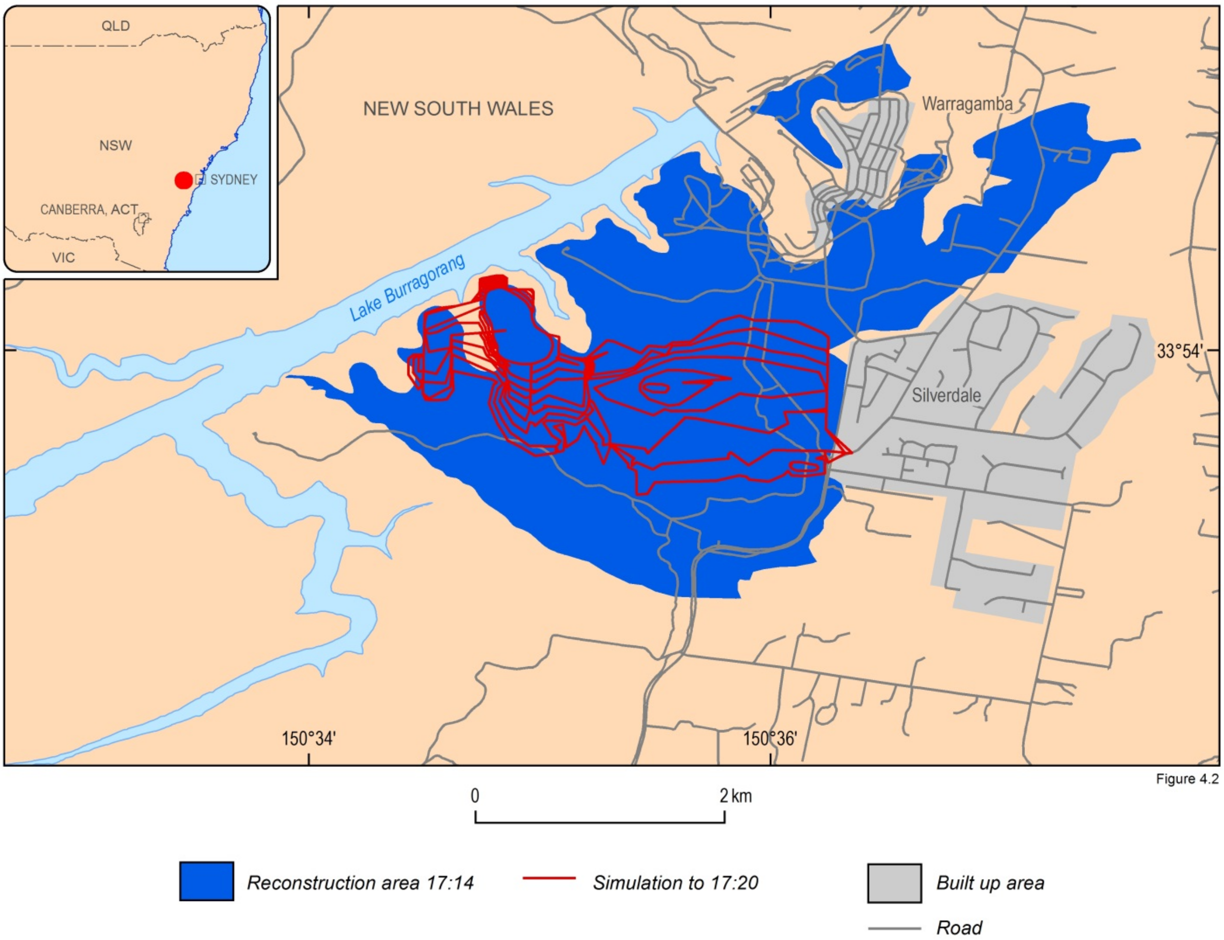

Figure 4.2 An individual simulation of the Mt Hall event, based on the single ignition from the historical reconstruction

To overcome this issue, multiple ignition points were introduced along the top of the escarpment to match the ridge–top locations of the fire spread in the reconstruction (Figure 4.3). This improved the correspondence between the historical and modelled fire spread to an extent; a result that could otherwise not be achieved. This suggests that the historical event may have included several spot ignitions, probably from the main fire that was burning across Lake Burragorang.

The additional ignition points were used in all simulations in the remainder of this report. Appendix C contains a list of the additional ignition point locations and times.

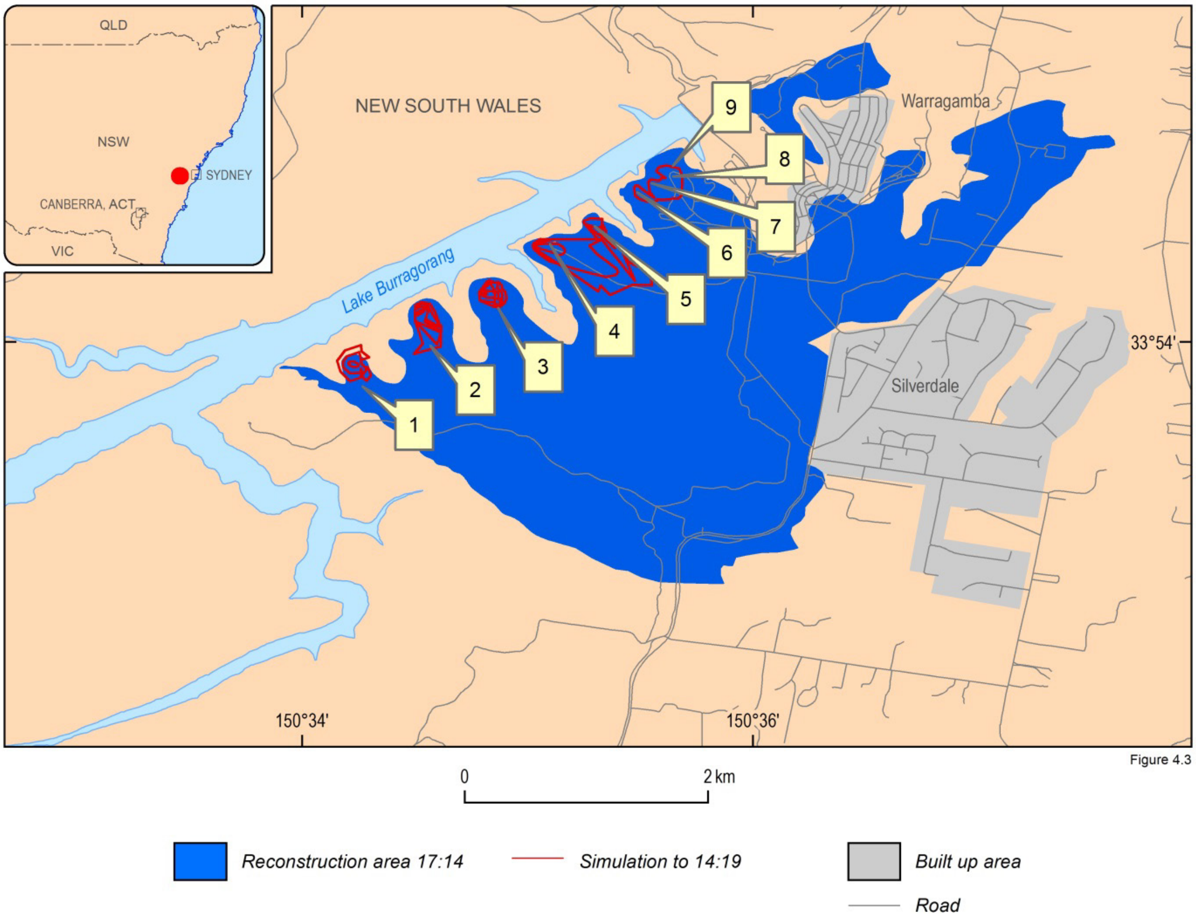

Figure 4.3 Ignition points introduced into the Mt Hall fire spread simulations (Appendix C contains a table of location and times).

Despite the additional ignition points, the fire spread simulations based on the ACCESS weather for the Mt Hall event still did not expand sufficiently to match the historical fire shape (Figure 4.4). As mentioned in Section 3.1, the ACCESS weather simulation used in this case study was found to be relatively poor in matching the AWS data (see Section 3.1.5 in the final report Cechet *et al.,* 2014). This resulted in a significant underestimate of the actual fire spread based on the 'best estimate' of the historical conditions.

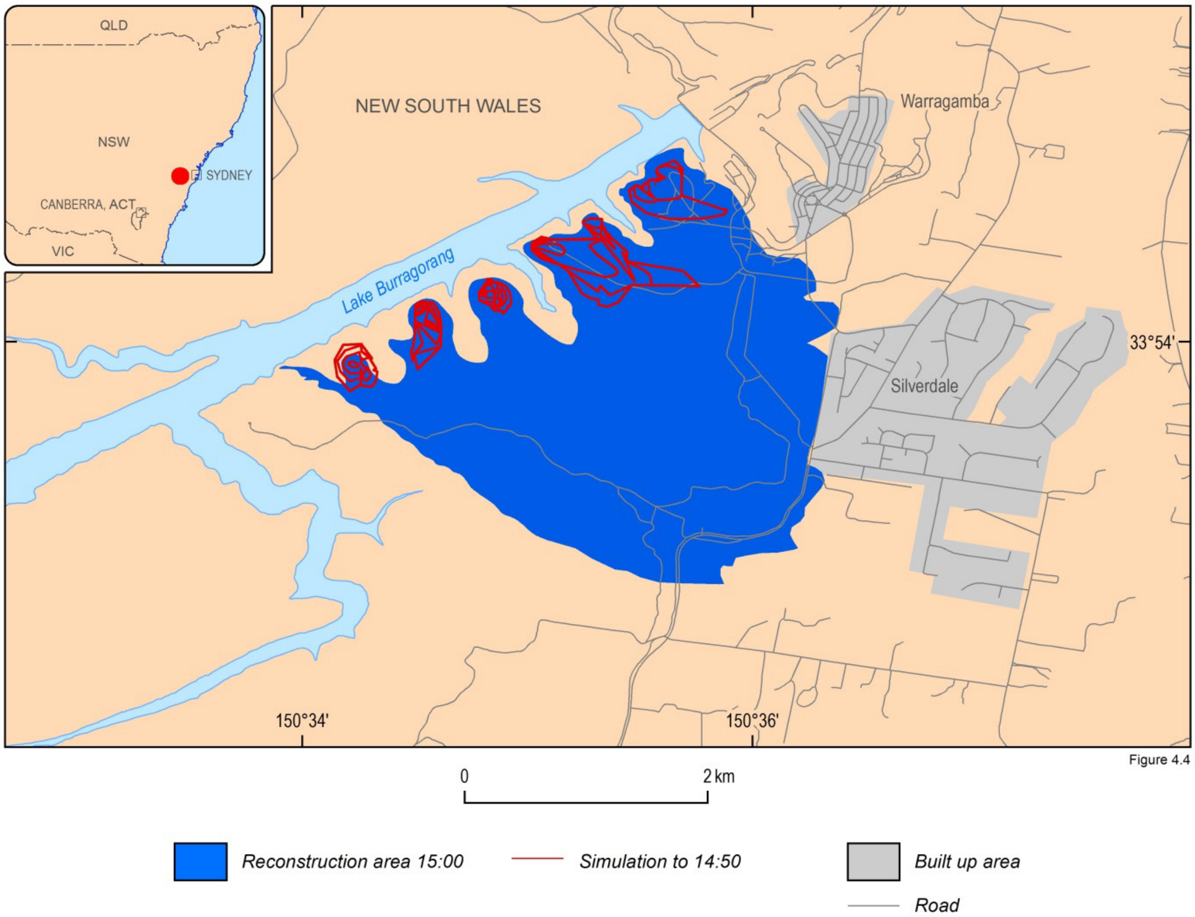

Figure 4.4 Fire spread simulation of the Mt. Hall fire based on ACCESS data produced at 4 km resolution, 5 minute time steps with Wind Ninja and no suppression or bias correction.

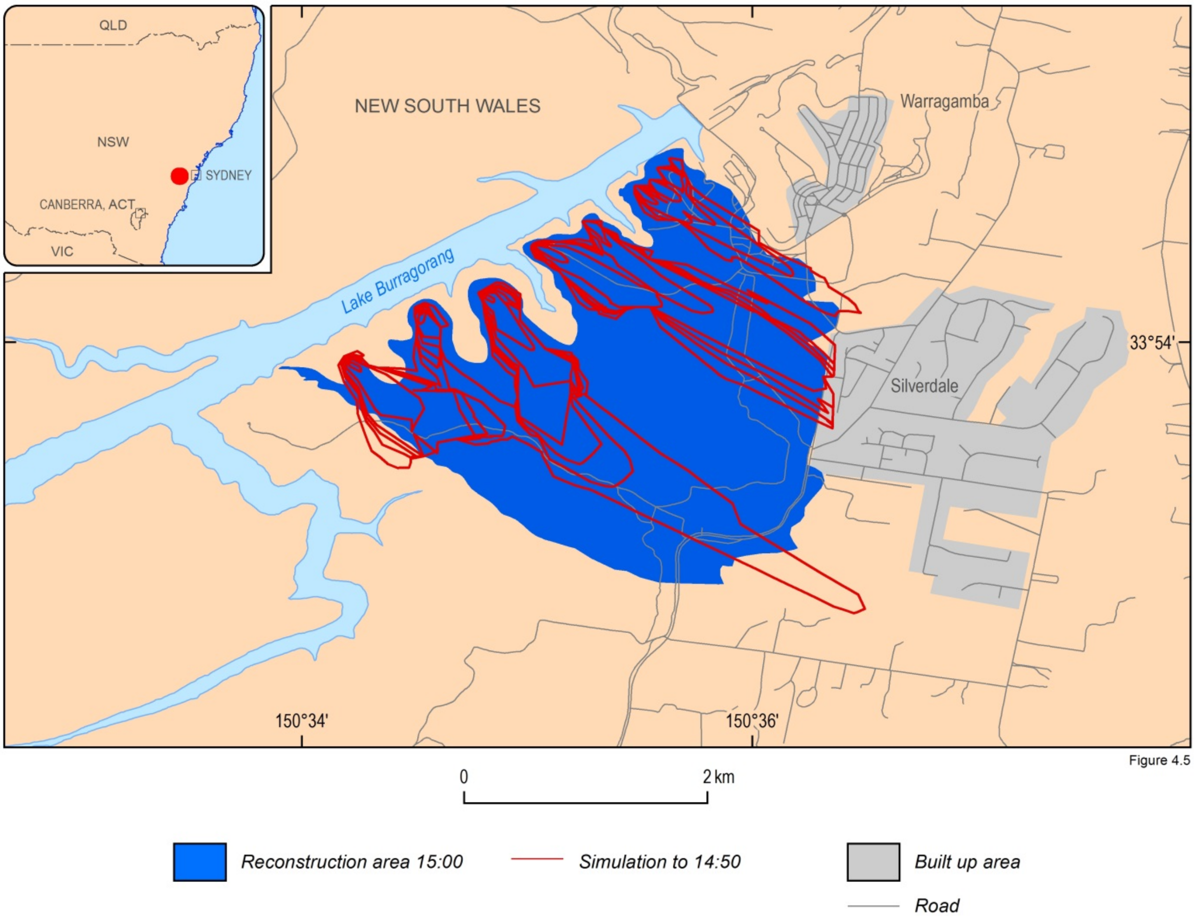

Figure 4.5 Fire spread simulation of the Mt. Hall fire based on ACCESS data at 4 km resolution, 5 minute time steps with Wind Ninja and no bias correction, and wind speeds increased by 10 m/s and wind directions increased by 25º.

The fact that individual simulations were unable to generate a reasonable approximation of the Mt Hall fire spread demonstrates the potential value of the FireDST ensemble approach. Even with the 'pseudo-probabilistic' approach to scenario creation used in this study, the ensemble can visualise potential event outcomes that are realistic. For example, Figure 4.5 shows the fire spread from a simulation of the Mt Hall fire that impacted on Warragamba and Silverdale at approximately the correct time. The simulation provided a good estimate of the forward rate of spread of the fire but not the full extent. The presence of divergent scenarios in the ensemble has the potential to improve understanding of the robustness of the 'best estimated' fire spread, and suggest different decision making than that based on a single model scenario.

Nevertheless, the ensemble approach in itself is not guaranteed to include the 'real' outcome. Figure 4.6 displays a 23 member ensemble (Appendix B) produced using extensive variations in the modelled historical weather (Table 4.1) as well as the new ignition points (Appendix C).

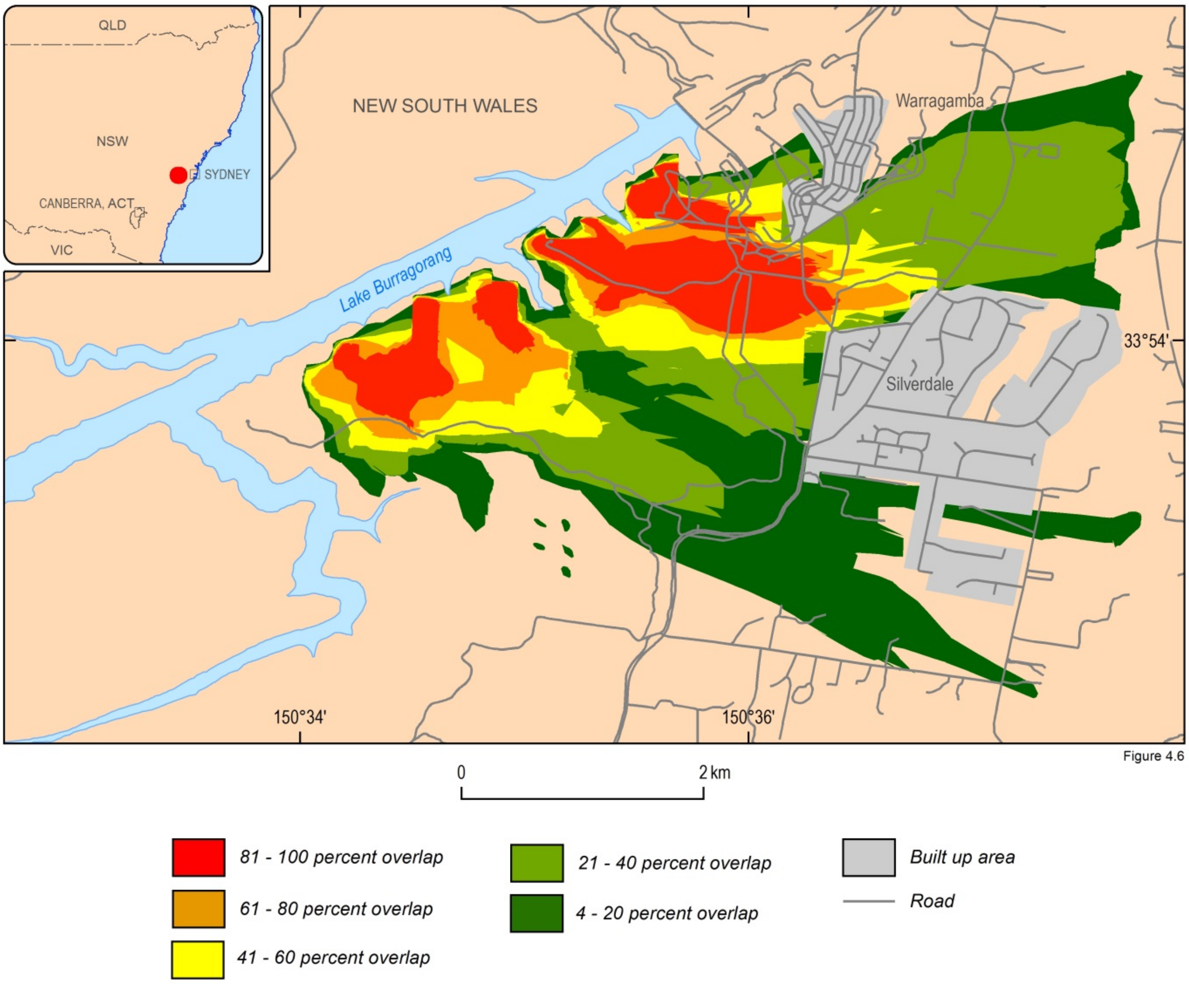

Figure 4.6 Simulated fire footprint from a 23 member ensemble based on the multiple ignition points and ACCESS weather at 4000 m resolution, 5 minute time steps with Wind Ninja and no bias correction. Ensemble from 12:35 to 16:35 on 25/12/2001.

Table 4.1 Range of variability sampled to produce the ensemble shown in Figure 4.6. 'S' stands for the supplied value in the ACCESS weather.

	Min	Max	Units
Temperature	S	+10	ºC
Humidity	-5	S	%
Wind Direction	-25	+25	º
Wind Speed	-5	+20	m/s

The ensemble underestimated the potential fire spread, in particular in the south where the ignitions mostly remained as individual fires and the ensemble shows only 5-20 percent of the simulations covered this area. The gaps between the individual fires (Figure 4.5) suggest that the model did not adequately represent the local fluctuations in the wind direction caused by variations in the underlying terrain (despite using Wind Ninja). It is also possible that the ignition times for ignition points 1, 2 and 3 were set too late, which would leave insufficient time for those fires to spread in the model. A compounding factor could be that the modelling did not account for the influence of the main Mt Hall fire which was burning on the western side of Lake Burragorang at the time.

This example highlights that the variation in the fire simulations is critical for generating a realistic ensemble. As stated previously, the FireDST ensembles described in this report were based on a limited range of scenarios, and were not selected on the basis of probability. In an event such as Mt Hall, where input data are known to be uncertain, the perturbation range of the ensemble should be adjusted appropriately. Perturbations should also include more sophisticated modifications to the input and modelling assumptions, as was done in this case by introducing multiple ignition points. The results also show that model limitations will impose additional uncertainty in the final ensemble output, even with a well-selected ensemble range.

4.4 Conclusions and Future Work

The objective of the work described here was to develop a methodology to assess and visualise the variability in the ensemble fire spread. An ensemble fire spread simulation can be constructed based on any number of individual simulations or simulation scenarios. The ensemble fire spread is computed as the percentage of overlap of the component ensemble scenarios.

This chapter gives an initial demonstration of a potential benefit of understanding sensitivity and uncertainty through an ensemble approach. There is not a good match between modelled and historical fire spread if the fire spread for the 2001 Mt Hall event is modelled deterministically, i.e. as a single model run based on the reconstructed conditions at the time the fire occurred. This is due to uncertainties and inaccuracies in the parameter estimates of those historical conditions (this is further discussed in Chapters 5 and 6), as well as the internal parameterisation of the fire spread.

However, an ensemble based on perturbation of the parameters was shown to produce a footprint that was closer to the reconstruction. This shows that understanding the model sensitivity allows a user to attach due consideration to the variability of model outcomes. Ultimately, this reduces the risk of over-interpreting inaccurate model results.

The FireDST output should not be interpreted as a true probabilistic fire spread, as the range and frequency of the parameters used to create the scenarios is unrepresentative of the true uncertainty in the simulation process. Nevertheless, the results presented here demonstrate the following outcomes are achieved:

- FireDST ensembles provide key information on the sensitivity and robustness of fire spread simulations through the spread of the fire spread envelope; and
- Even a ‘pseudo-probabilistic’ sensitivity ensemble such as generated in this report gives information on the potential development of an event that cannot be provided by a single deterministic model run.

However, the Mt Hall results also demonstrated that the ensemble approach remains subject to limitations in data and model assumptions, and in itself cannot be a guarantee for yielding accurate outputs.

In conclusion, the results discussed in this chapter demonstrate that Fire DST can provide valuable information on the sensitivity in the fire spread modelling. Moreover, given the input, it provides the capability to integrate uncertainty into fire spread modelling. In either form, the FireDST capability improves the ability to interpret the outputs of a fire spread model.

4.4.1 Future Work

- Specifying the uncertainty in the various FireDST parameters, and building this into the Ensemble Generator is key to generate a fully probabilistic fire spread ensemble that could be interpreted in terms of uncertainty of the outcome of an event; and
- Understanding the decision making processes of operators would define the user requirements to enable suitable interaction with the ensemble information. Such business analysis could flag for example, the need to sub-select, add or exclude specific scenarios from an existing ensemble as an event unfolds or as additional information becomes available. Further work would have to determine efficient ways of including such information without compromising the validity of the results.

5 Assessing sensitivity of the fire spread to the surface weather

5.1 Objective

Fire spread, and fire spread modelling, is sensitive to the weather, in particular to variation in the wind speed (Cechet *et al.,* 2014). It is important for users of fire spread models to understand the sensitivity of the outputs to potential uncertainties in the weather inputs. The PHOENIX RapidFire fire spread model used in FireDST is parameterised to be driven by surface (at 10 m height above ground) weather conditions, and this is the focus of this chapter. Chapter 6 focuses on the potential sensitivity to weather conditions in the higher layers of the atmosphere.

The objective is to assess the sensitivity of the fire spread model to the surface weather by:

- Demonstrating the methodology used by the FireDST Weather Ensemble Generator to create an ensemble that samples variability in the supplied surface weather parameters; and
- Demonstrate the resulting sensitivity of the fire spread modelling to the perturbations in surface weather.

FireDST produces fire simulations using ACCESS weather files rather than the standard PHOENIX RapidFire weather input that is based on historical Automated Weather Station (AWS) readings. To enable this work, the University of Melbourne team produced a version of PHOENIX RapidFire that was able to read the ACCESS netCDF weather files.

The research described here used the standard ACCESS surface weather files supplied by the Bureau of Meteorology. Analysis of the sensitivity of the fire spread modelling to the spatial resolution of the weather files was conducted by the University of Melbourne. The outcome of this research is covered in Cechet *et al.,* (2014).

5.2 Methodology

5.2.1 Input Data

The Bureau of Meteorology's numerical weather prediction system, ACCESS (Australian Community Climate and Earth-System Simulator) (Puri, 2011) provided four netCDF format files for the temperature, humidity, wind speed and wind direction at 10 m height. These files represent the standard weather forecast for the forty eight hours from 11:00 on 24/12/2001 at grid resolutions 0.036º, 0.012º and 0.004º (approximately 4000 m, 1200 m and 440 m) at 5 minute time steps.

The FireDST Weather Ensemble Generator perturbs weather conditions in the ACCESS files and uses these to create an ensemble fire spread. The Weather Ensemble Generator creates a modified netCDF file for each weather variable setting in the range. Changes are applied equally across the whole grid. For instance, a user creates a scenario with a temperature decrease of 2ºC. The decrease is applied equally to all the temperatures in the file and there is no location sensitive nature to these changes. If the supplied temperature at 2pm is 32°C at Sydney airport and 43°C at Warragamba, then that particular scenario specifies that the temperature for 2pm at Sydney airport is 30°C and 41°C at Warragamba

FireDST imposes restrictions to ensure that scenarios are physically realistic when sampling potential bushfire scenarios. For example, the humidity cannot be set to 0% and the temperature cannot go below 0°C.

Six tests were used to assess the ability of FireDST to generate an ensemble that samples a range of weather conditions (Table 5.1). These tests also demonstrated sensitivity of the simulated fire spread to the surface weather parameters and are described together with a sample result in the following sections.

Table 5.1 Weather perturbations for Mt Hall generated by the FireDST Weather Ensemble Generator

Parameter	Unit	Range	Comment
ACCESS Grid Resolution	Metres	4000,1200,440	Supplied
Temporal Resolution	Minute	5	Only 5 minute was supplied
Wind Direction	º	-25 to +25	Clockwise from north
Wind Intensity (speed)	m/s	+ 20	
Temperature	°C	+10	
Humidity	%	-5	

In reality, weather will be uncertain in all of these parameters at the same time so FireDST was also tested with various parameter combinations. For example, the Weather Ensemble Generator was used to produce a scenario with the temperature increased by 2°C, the humidity down by 1% and the wind speed increased by 2 m/s.

For each of the scenarios in the respective weather ensembles, the simulated fire shape was visually compared with the Mt Hall reconstruction fire shape. All landscape and environmental conditions were kept constant.

The following sections show a single example result for each test.

5.2.2 Bias correction of the ACCESS Wind Speed

The Bureau of Meteorology conducted a verification of the ACCESS model against their Automated Weather Station (AWS) network. This verification found that the ACCESS simulations were not as accurate as those produced for the other case studies (Cechet *et al.,* 2014). Significant aspects of the AWS observations were missed or otherwise inadequately represented. There were several possible reasons for this, the initial ACCESS model conditions, the complex topography or that the synoptic forcing was weaker.

Unfortunately as the fire occurred in 2001 it was not possible for the Bureau of Meteorology to investigate these issues. Furthermore due to the distance of the nearest AWS it was also impossible to calculate a wind speed bias correction factor (as was done in the other two case studies).

5.2.3 Correction of the ACCESS Wind Speed by using wind multipliers

Phoenix RapidFire optionally uses the Wind Ninja wind modifier system, in which the terrain is resolved on a 100 m grid. The higher resolution terrain should allow more accurate reflection of modifications in wind speed and direction caused by the terrain. The effect of using the Wind Ninja wind modifiers was tested by running the same simulation conditions with and without using Wind Ninja (Table 5.2).

Table 5.2 Digital elevation models used in FireDST.

Model	4000 m grid resolution	1200 m grid resolution	440 m grid resolution
ACCESS	1.0 m height every 4000 m	1.0 m height every 1200 m	1.0 m height every 440 m
Wind Ninja	1.0 m height every 100 m	1.0 m height every 100 m	1.0 m height every 100 m

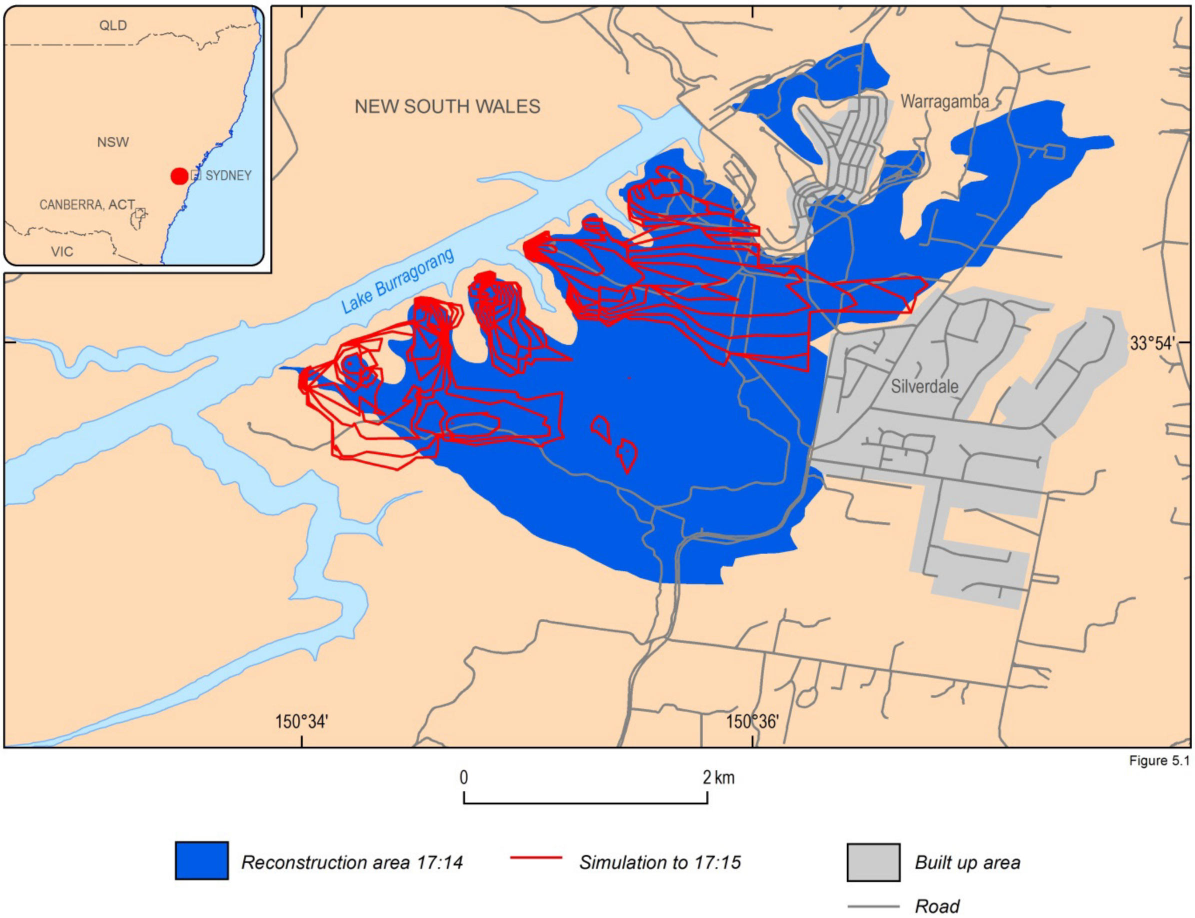

Figure 5.1 Fire spread simulation based on ACCESS weather information at 4000 m 5 minute, no bias correction, no suppression, no Wind Ninja (red) of the Mt Hall Fire up to 17:15, and the reconstruction of the fire at that time (blue).

5.3 Results and Discussion

5.3.1 Sensitivity of fire spread to resolution of the ACCESS weather grid

Figure 5.1 (4000 m), Figure 5.2 (1200 m), and Figure 5.3 (440 m), show the simulation shape for the supplied ACCESS weather files for the Mt Hall fire. Irrespective of grid resolution, all simulations have impacted the north section of Silverdale at approximately the same time as the real fire. However all underestimate of the real fire size compared to the reconstruction of the historical Mt Hall fire in the south. Three factors were possible contributors to this underestimate:

1. As stated in Section 2.4, it was exceedingly difficult to produce an accurate reconstruction of this fire, mainly due to the elapsed time since 2001;
2. The ACCESS model was not able to capture the differentiation of the weather across the fire ground (Kepert *et al* 2013, Cechet *et al.,* 2014); and
3. Only the Warragamba component of the Mt Hall fire has been modelled here. The full Mt Hall fire was raging just across Lake Burragorang to the west and may have influenced the fire spread in the Warragamba component of the Mt Hall fire. This was not reflected in the modelling of this case study.

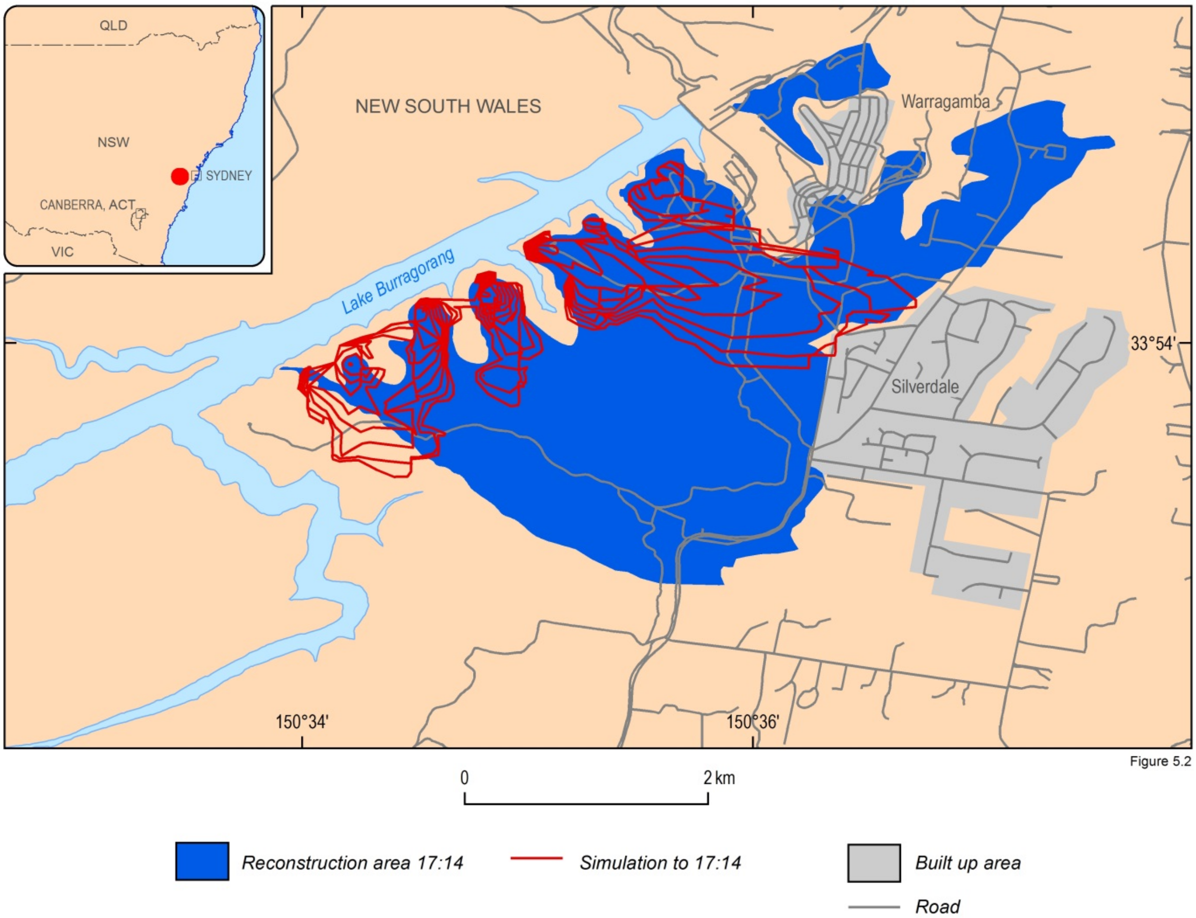

Figure 5.2 As for Figure 5.1, for 1200 m ACCESS resolution to 17:14.

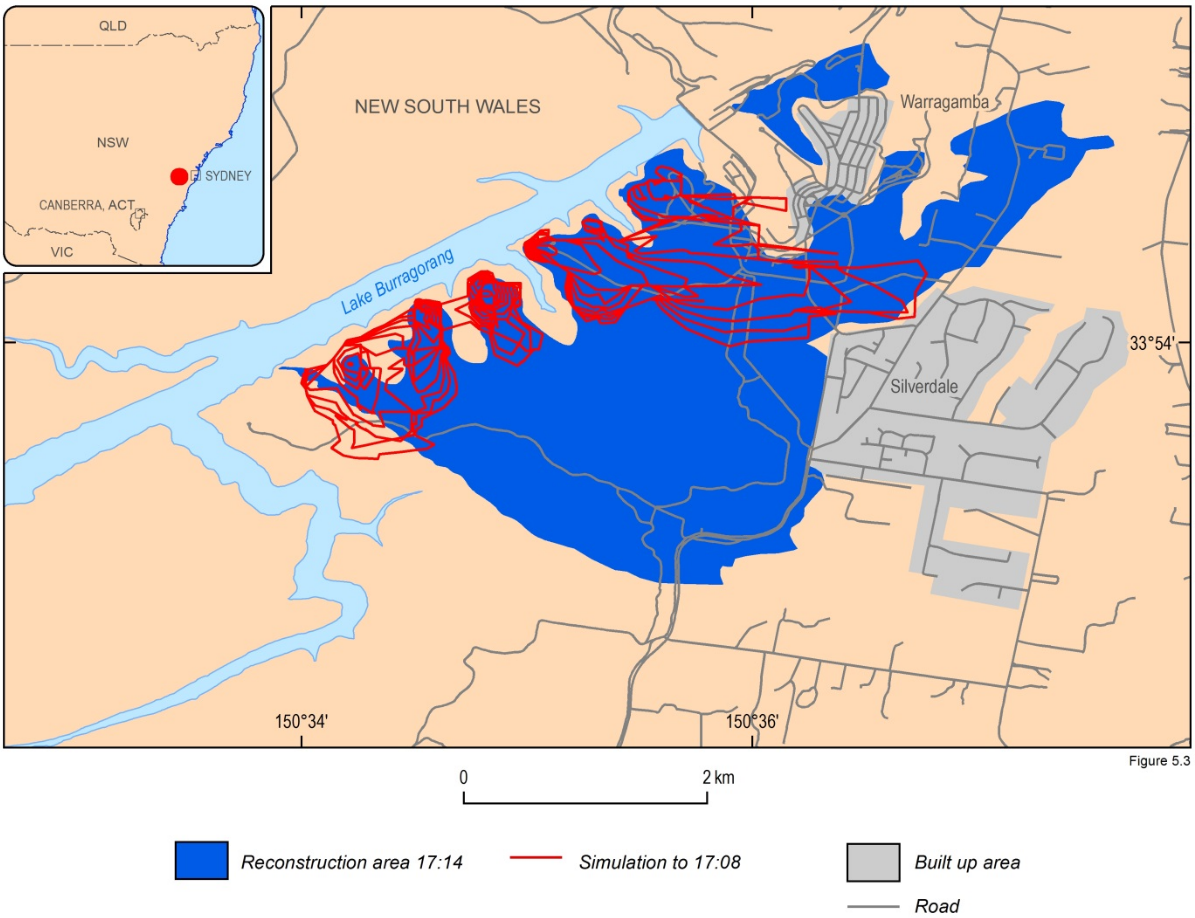

Figure 5.3 As for Figure 5.1, for 440 m ACCESS resolution to 17:08.

5.3.1.1 Effect of the introduction of local wind modifiers

This section discusses the impact of correcting the wind strength and direction for local effects of topography.

Figure 5.4 (4000 m) , Figure 5.5 (1200 m) and Figure 5.6 (440 m) show the simulations based on surface wind speed and direction generated for winds modified using Wind Ninja modifiers. Figure 5.4 and 5.5 show only a slight difference in the fire shape compared with the simulations purely using the ACCESS winds (Figure 5.1 and Figure 5.2). This shows that the Wind Ninja methodology did not correct the wind bias sufficiently to produce a larger fire spread. However, the 440 m resolution Wind Ninja-based simulation has produced a markedly larger fire spread in the south west portion of the simulation. This demonstrates that at this resolution the Wind Ninja wind modifiers can make a significant contribution to the accuracy of fire spread modelling in high-relief terrain, such as that in this case study.

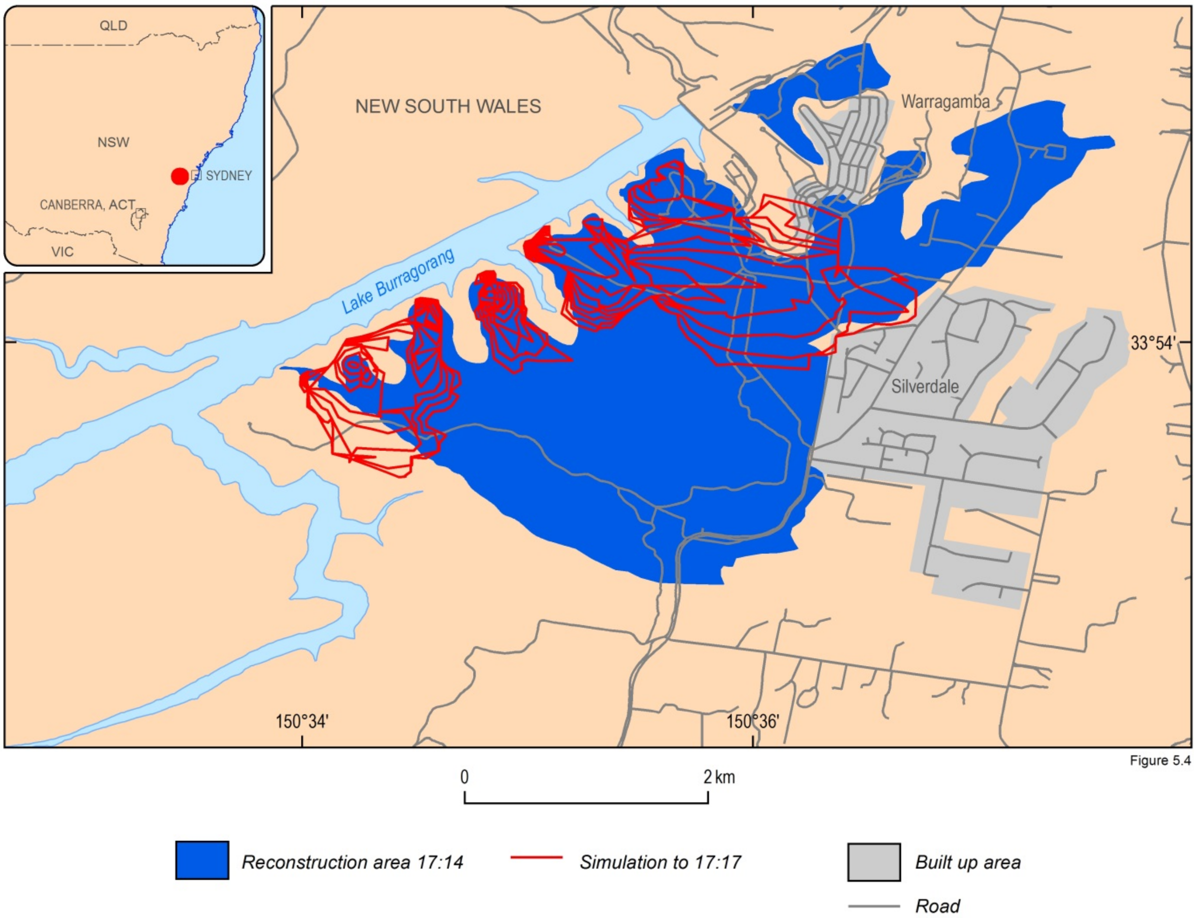

Figure 5.4 Simulated fire spread for the Mt Hall event, based on 4000 m 5 minute ACCESS weather with no suppression, no bias correction, Wind Ninja (red) and the fire reconstruction (blue).

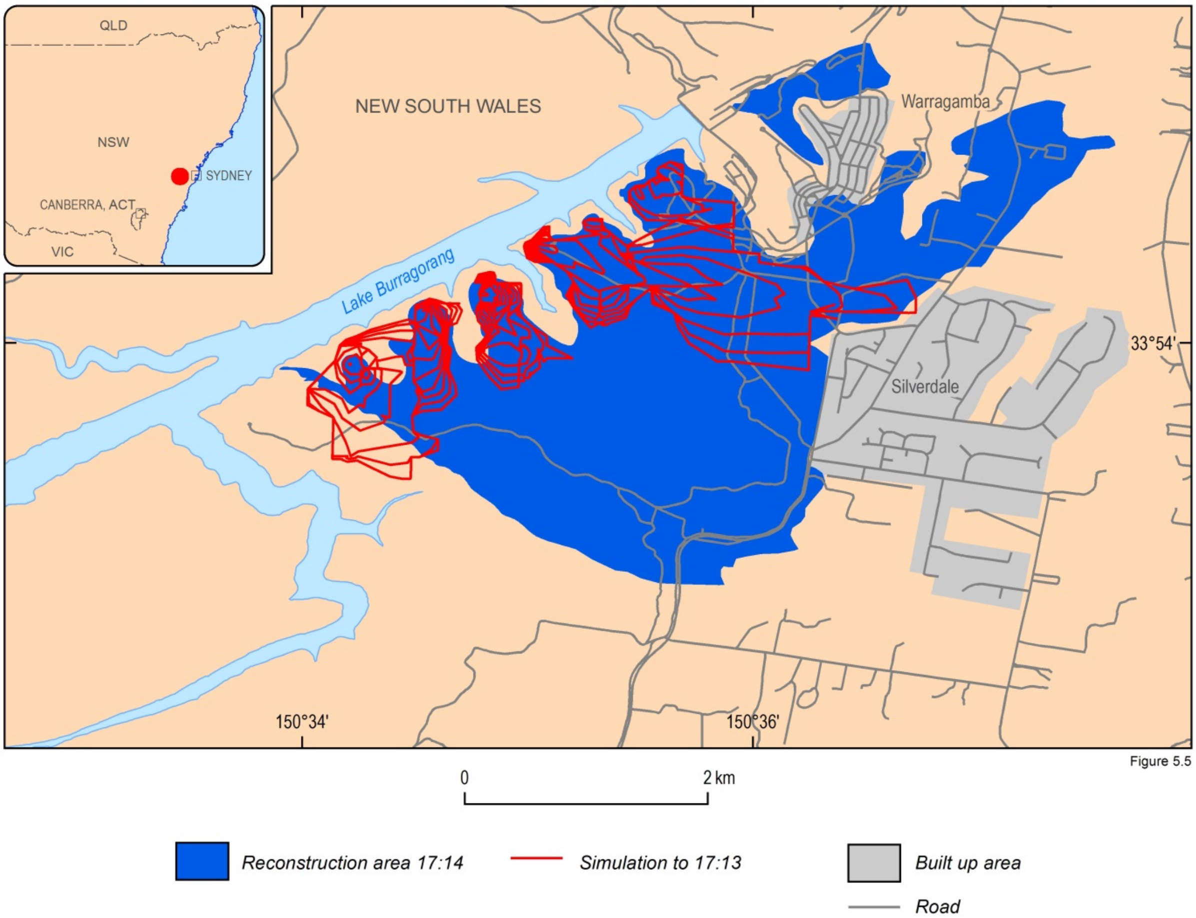

Figure 5.5 As for Figure 5.4, for 1200 m ACCESS.

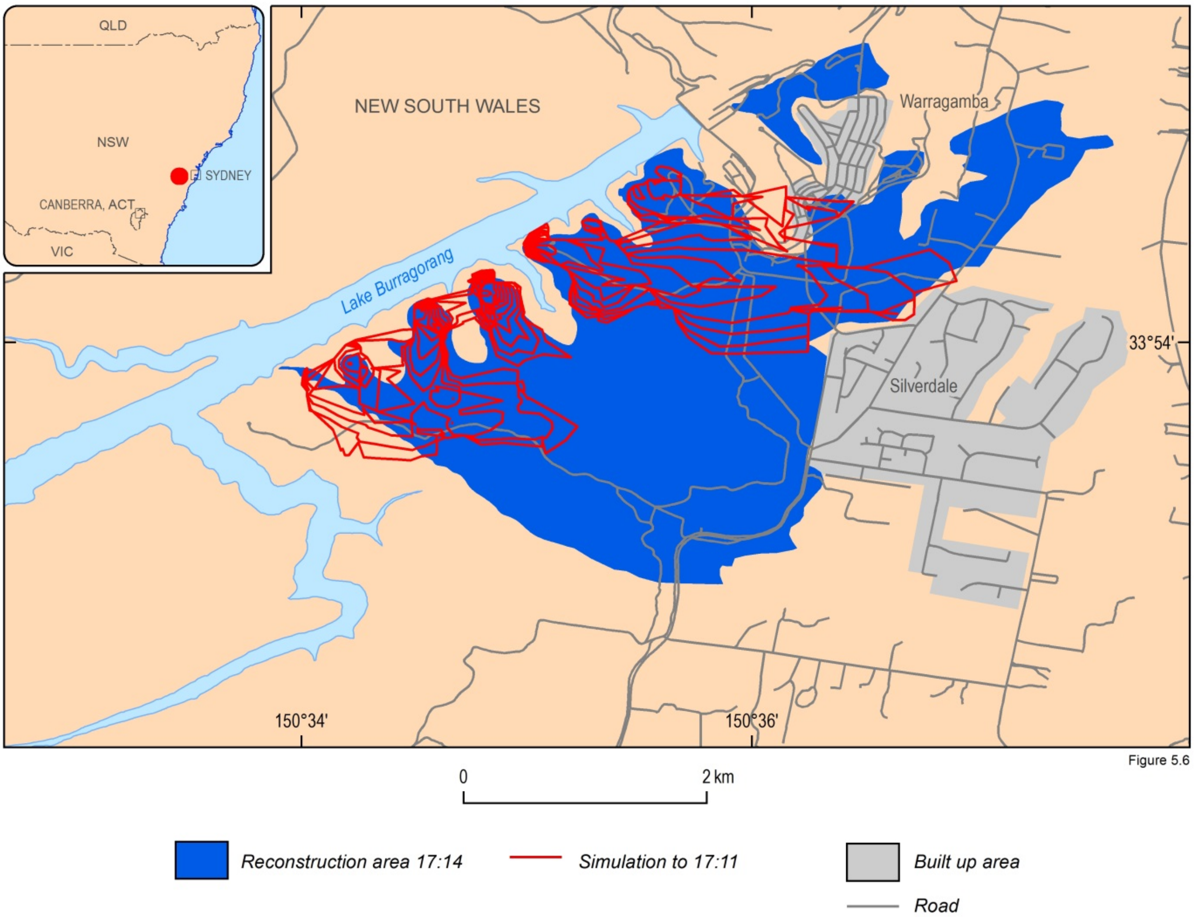

Figure 5.6 As for Figure 5.4 for 440 m ACCESS to 17:08.

5.3.2 Sensitivity to temporal resolution

Because of the small time frame of the Mt Hall event (under five hours), it was not possible to assess the sensitivity of the fire spread to the temporal resolution of the ACCESS files. For instance sampling the weather at 30 minute intervals would have only resulted in 10 different time steps. Please see French *et al.* (2014a) and French *et al.* (2014b) for the results from the other case studies.

5.3.3 Sensitivity to wind direction

Figure 5.7 (wind direction -25º) -and Figure 5.8 (wind direction +25º) show two direction shifts in the wind direction. The figures demonstrate a change in the direction of the simulated fire as a result of the perturbed wind direction. This indicates that the Mt Hall simulations were sensitive to wind direction despite the issues with the ACCESS weather simulations as outlined in Section 4.

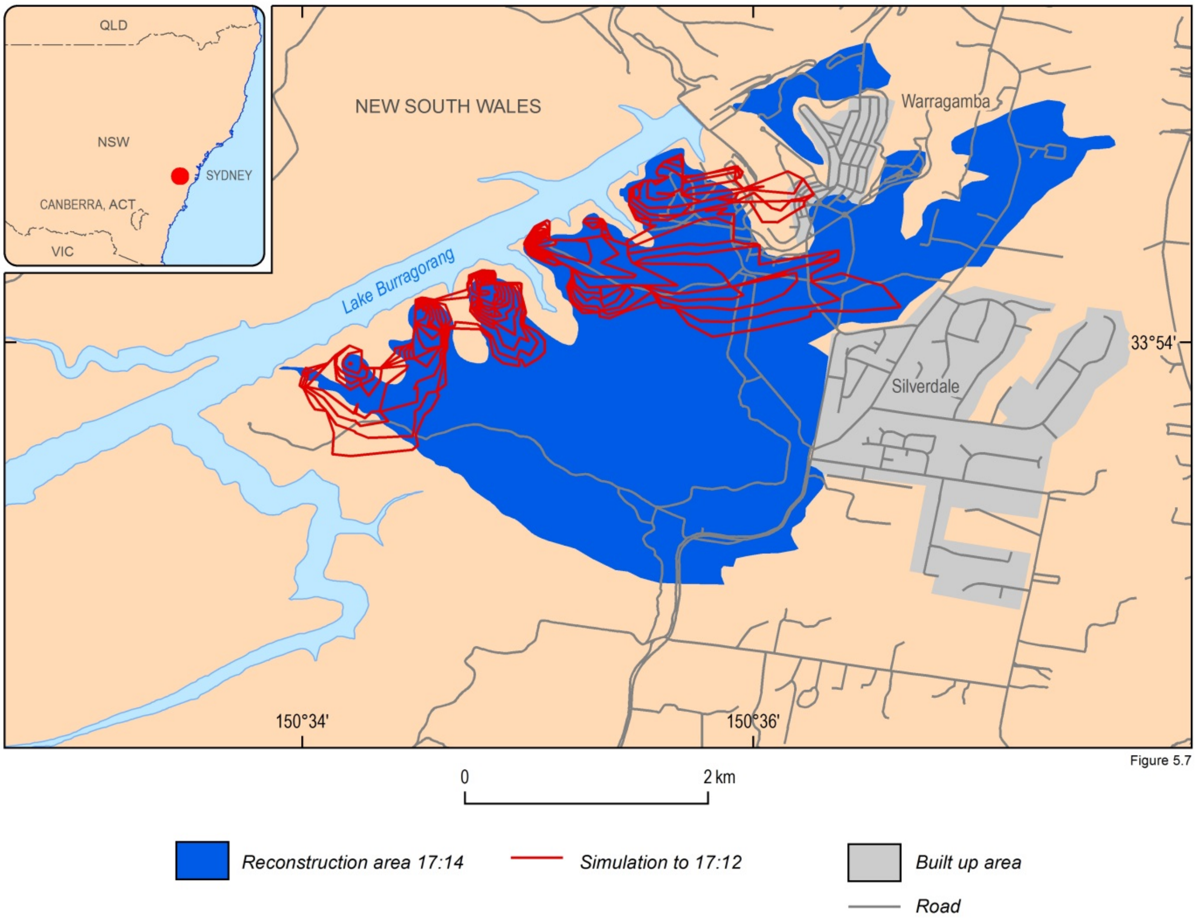

Figure 5.7 Simulated fire spread based on 4000 m 5 minute ACCESS with Wind Ninja, no suppression, no bias correction, wind direction -25º (red) and the Mt Hall fire reconstruction (blue).

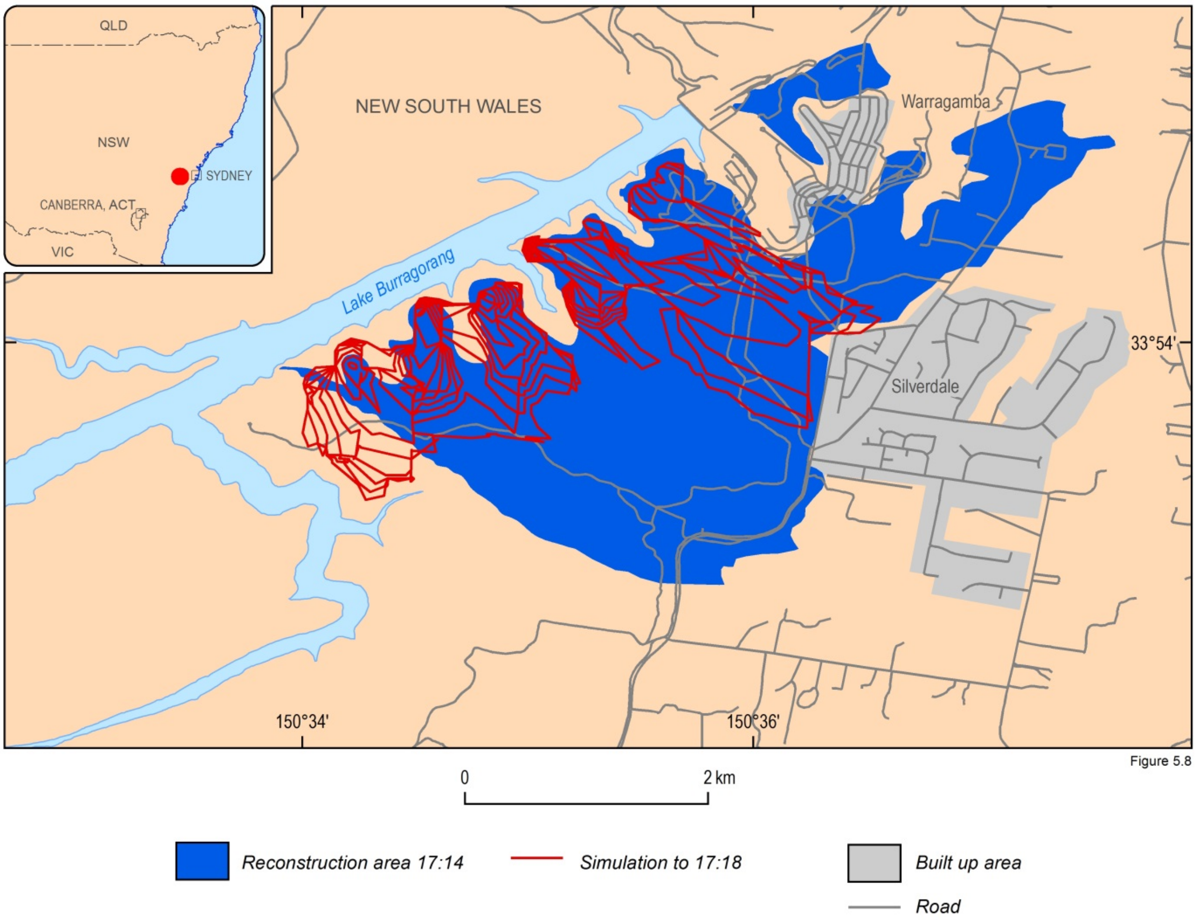

Figure 5.8 As for Figure 5.7, with wind direction +25º.

5.3.4 Sensitivity to wind intensity

To demonstrate the ability of FireDST to reflect the sensitivity of fire spread to wind intensity, two intensity perturbations are displayed in Figure 5.9 (all wind speeds +5 m/s) and Figure 5.10 (all wind speeds +20 m/s). The difference in fire spread between the two figures shows the sensitivity of the fire spread simulation to the variation in wind speed.

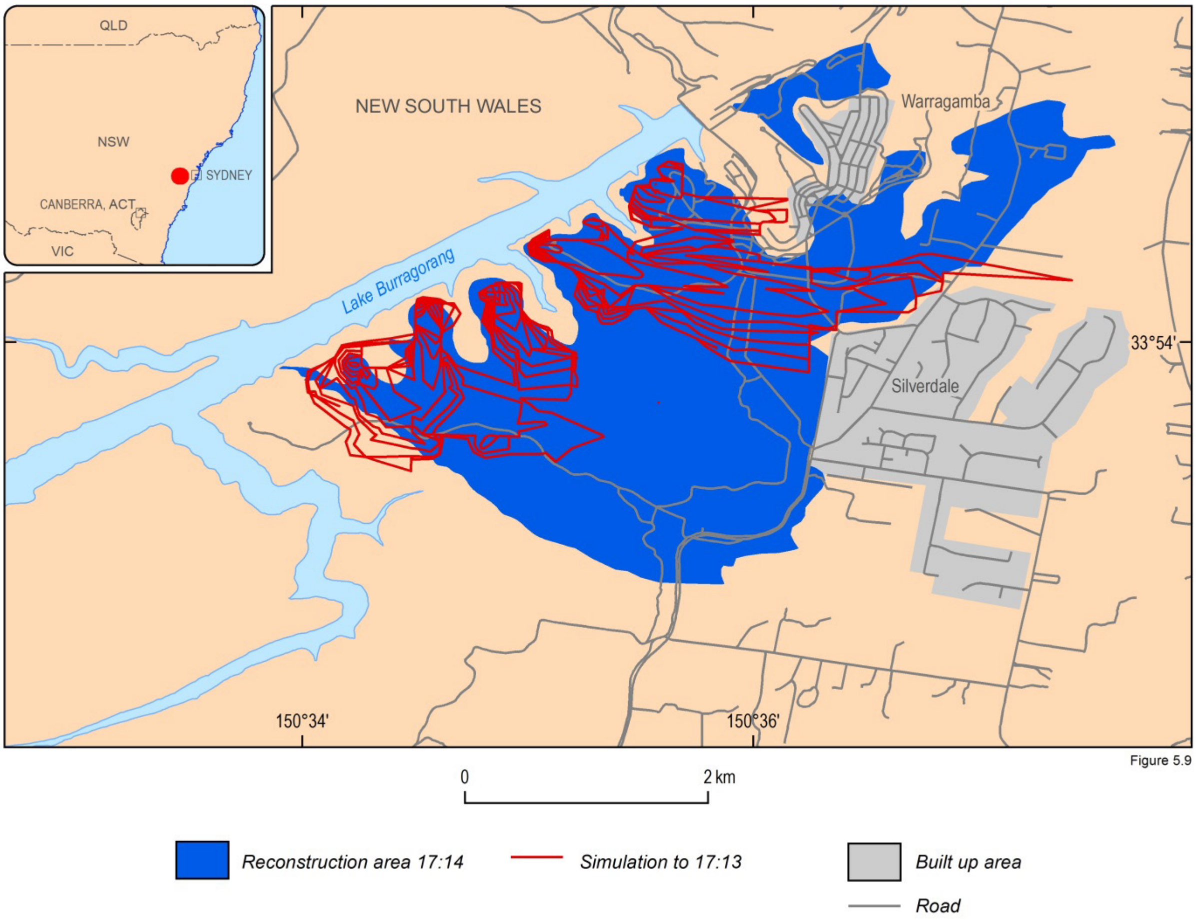

Figure 5.9 Simulated fire spread based on 4000 m 5 minute ACCESS with Wind Ninja, no suppression, no bias correction, wind speed +five m/s (red) and the Mt Hall fire reconstruction (blue).

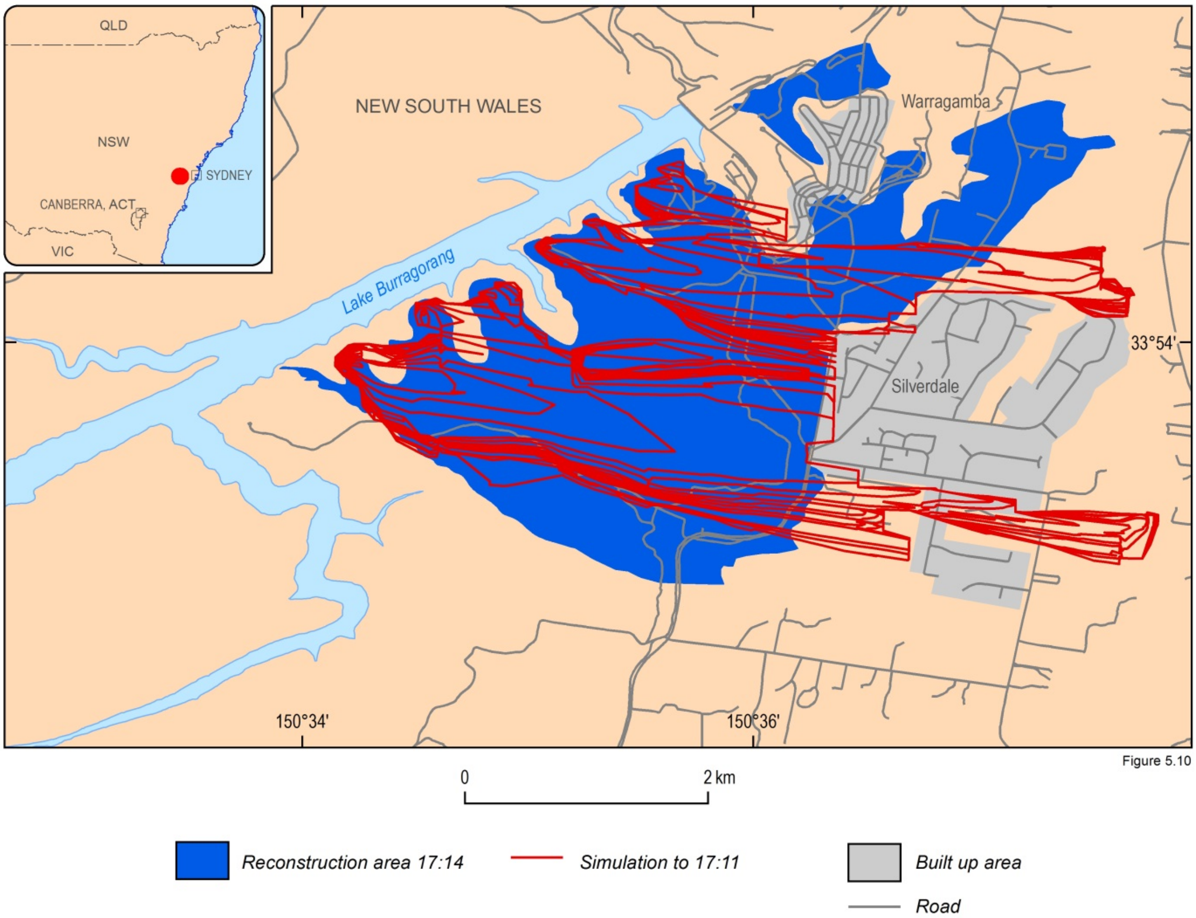

Figure 5.10 As for Figure 5.9 with wind speed +20 m/s.

5.3.5 Sensitivity to temperature

The fire spread for two temperature scenarios are shown in Figure 5.11 (temperature -2°C) and Figure 5.12 (temperature +10°C). The increase in temperature has allowed the fire to spread slightly further to the north of Silverdale. However the results indicate that the Mt Hall simulations were not particularly sensitive to temperature.

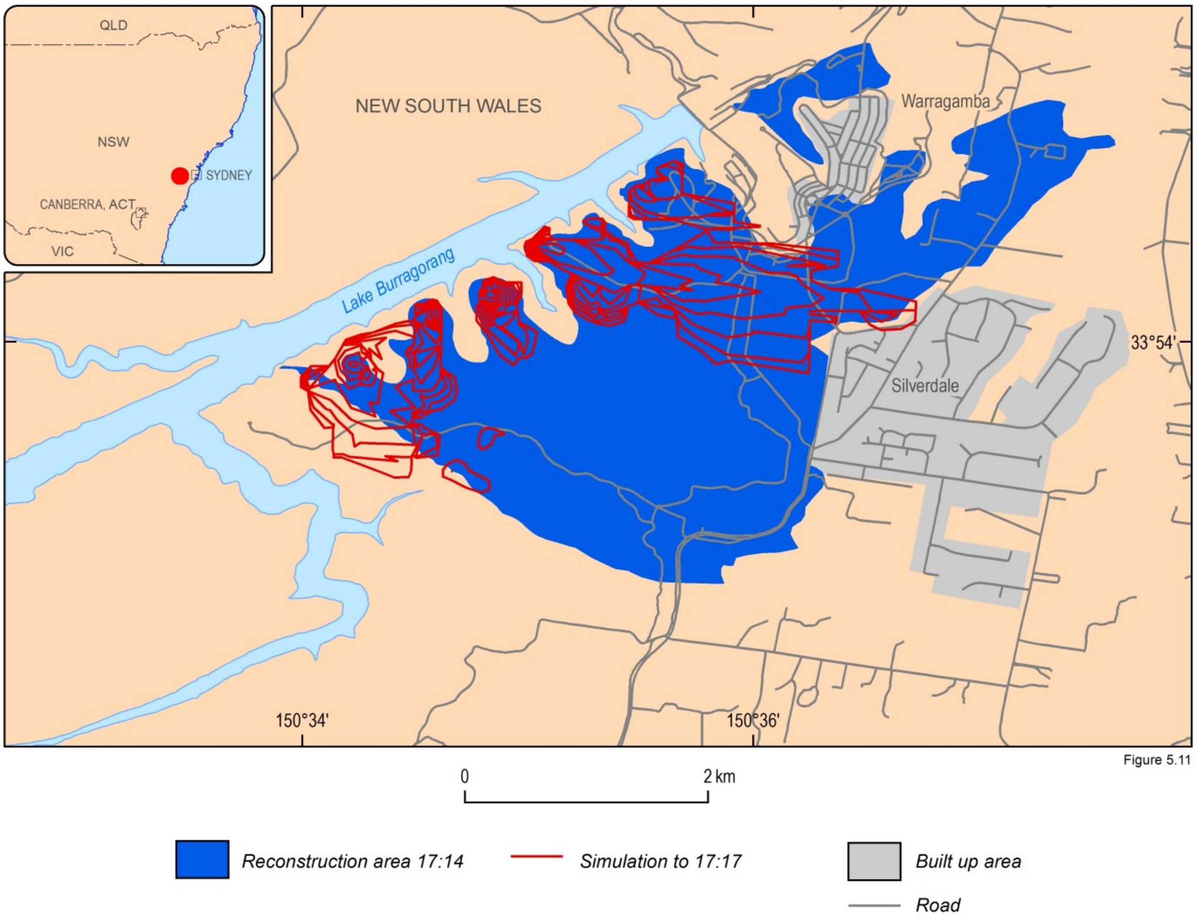

Figure 5.11 Simulated fire spread based on 4000 m 5 minute ACCESS with Wind Ninja, no suppression, no bias correction, temperature -2°C (red) and Mt Hall fire reconstruction (blue).

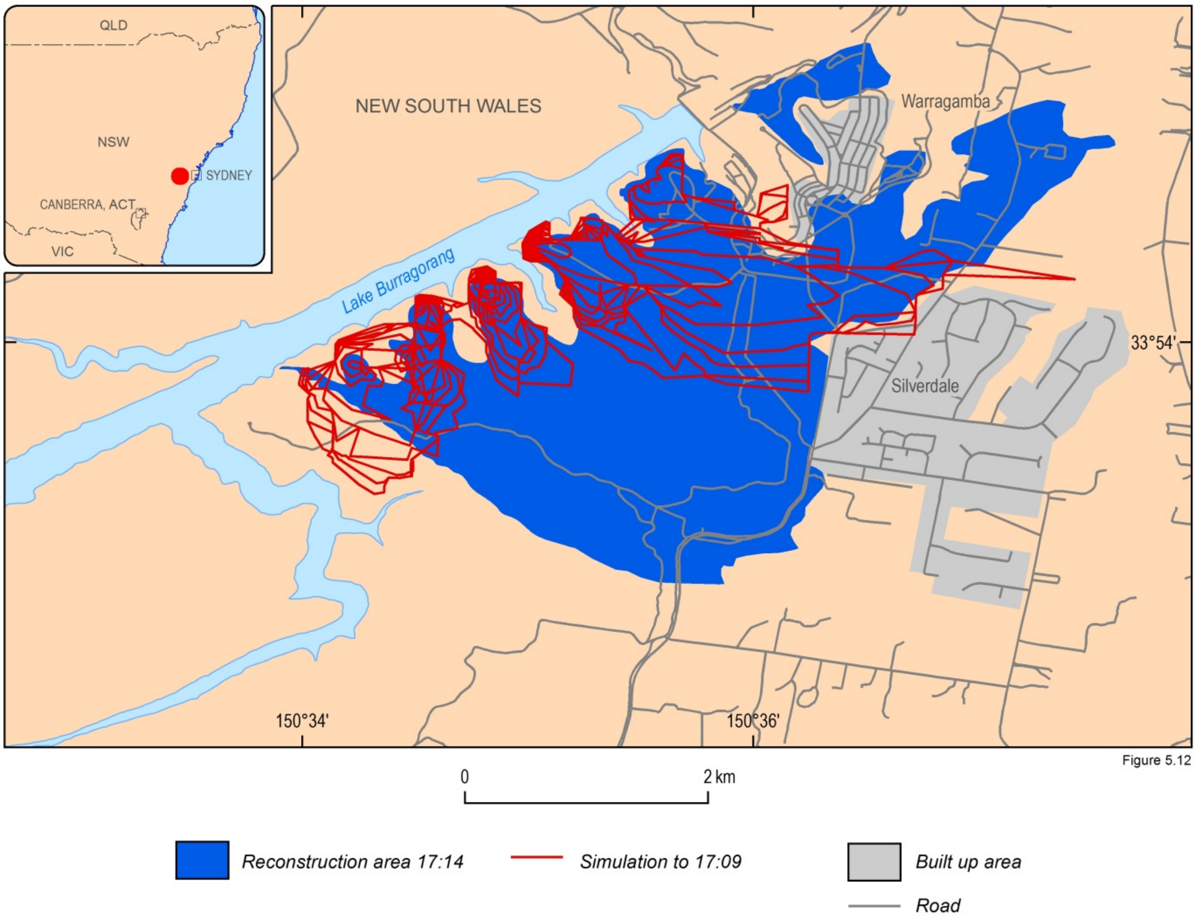

Figure 5.12 As for Figure 5.11 with temperature +10ºC.

5.3.6 Sensitivity to humidity

To demonstrate that FireDST can reflect sensitivity to humidity, two humidity shifts are shown in Figure 5.13 (humidity -5%) and Figure 5.14 (humidity +1%). As expected, a decreased humidity results in a larger fire shape in length and overall area (Figure 5.13) however there is not a big difference in the sizes which indicates that the fire spread modelling is only mildly sensitive to changes in humidity.

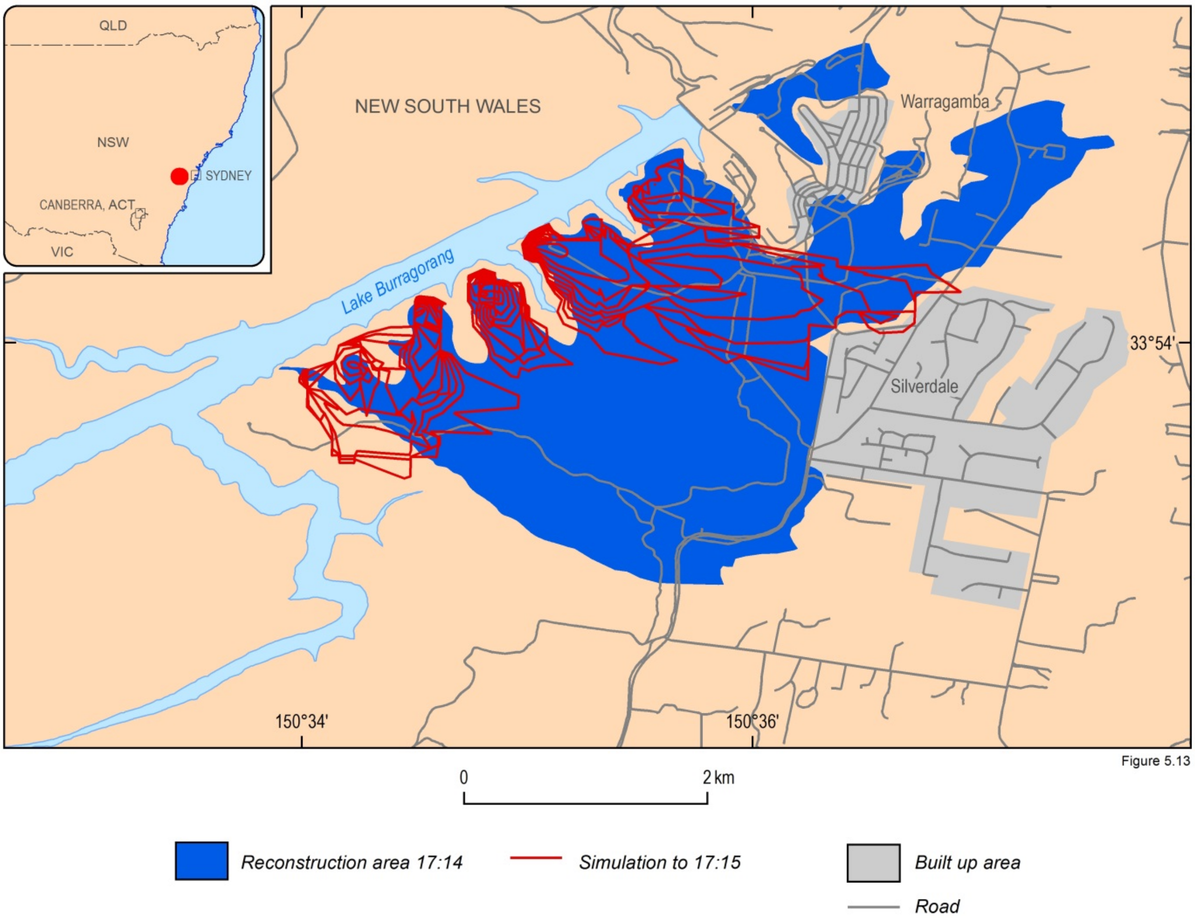

Figure 5.13 Simulated fire spread based on 4000 m 5 minute ACCESS with Wind Ninja, no suppression, no bias correction, humidity -5% (red) and the Mt Hall fire reconstruction (blue).

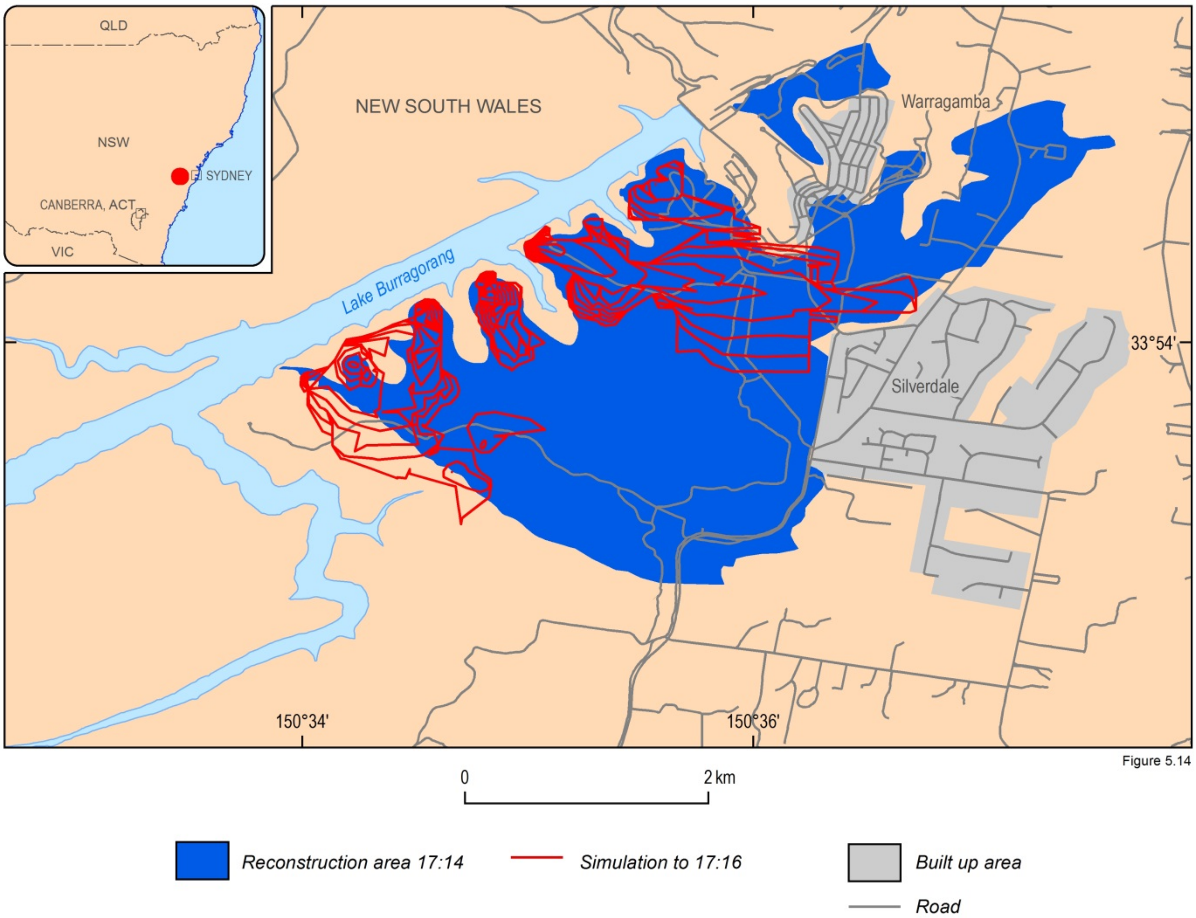

Figure 5.14 As for Figure 5.13 with humidity +1% to 17:16.

5.3.7 Sensitivity to multiple variations in the weather

The FireDST Weather Ensemble Generator enables any combination of the single weather files to be grouped into a weather scenario. Figure 4.15 shows a scenario where the following modifications were made to the conditions of the original Mt Hall fire:

- Wind speed +5 m/s
- Wind direction +10°
- Temperature +5°C
- Relative humidity -5%

Multiple variations in weather meant the fire spread exhibited more complex interactions between weather variables. Comparing the results of this scenario with those shown in the previous sections of this chapter illustrates these complexities. The resulting fire spread shown in Figure 5.15 does not closely reflect the influence of single individual parameter that defines the scenario. For example, the change in direction of the fire shape is less than that caused by the same perturbation to the wind direction in isolation (compare to Figure 5.8), and the size increase is larger than that caused by an increase in wind speed that generated Figure 5.9. This underlines that sensitivity of the modelled fire shape to key parameters cannot be judged in isolation when the modelled process is also sensitive to interactions between the parameters, caused by the physical processes that drive the fire.

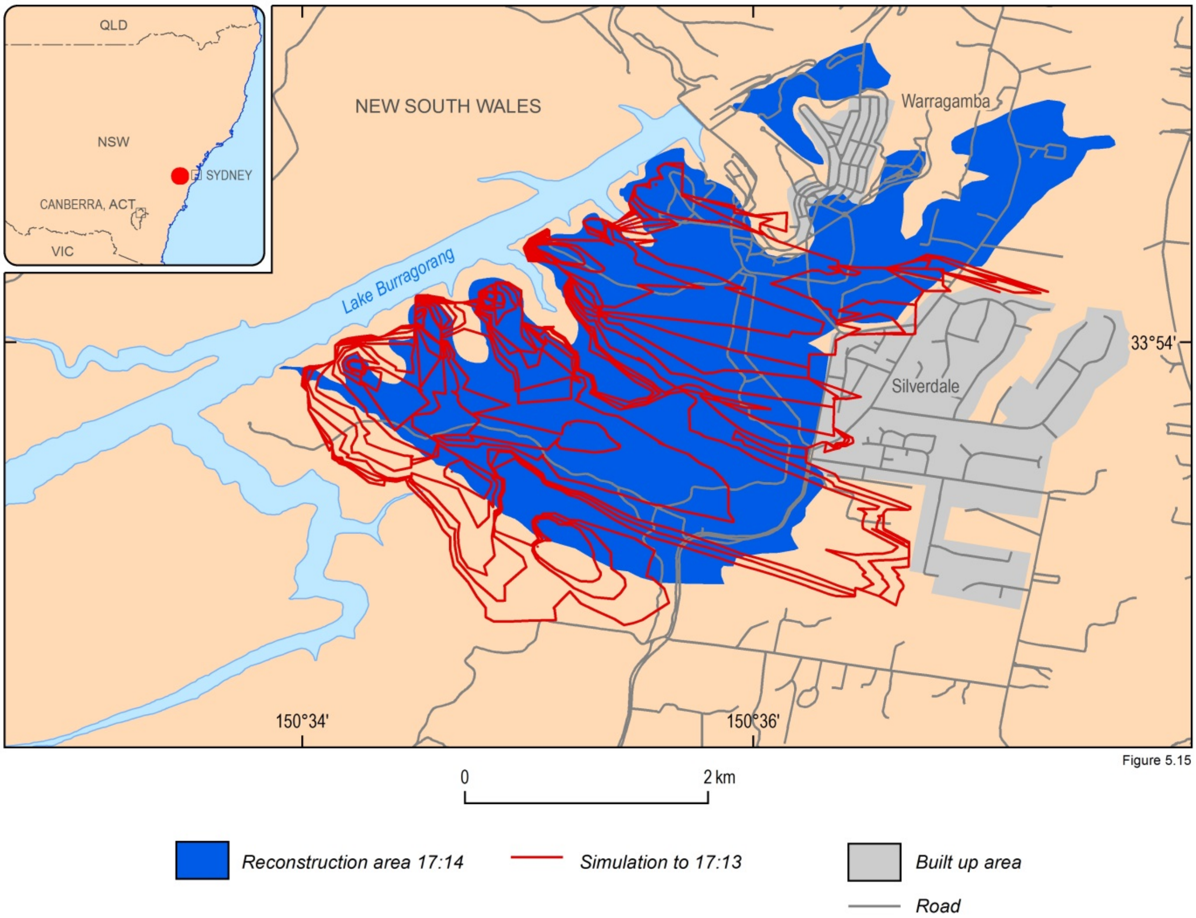

Figure 5.15 Mt Hall fire spread simulation based on 4000 m 5 minute ACCESS weather with humidity -5%, temperature +5°C, wind direction +10° and wind speed +5 m/s.

5.4 Conclusions and Future Work

The results in this chapter lead to the following conclusions on the variability of the fire spread to the surface weather conditions. Firstly, the ACCESS weather predictions generated for Mt Hall were the least accurate of the three case studies (Cechet *et al*., 2014) with significant aspects of the AWS observations missing or otherwise inadequately represented. The fire spread modelled by FireDST for the Mt Hall fire underestimated the size of the historical event, based on the reconstruction of that event. The introduction of local wind modifiers (from Wind Ninja) improved the accuracy of the modelled fire spread. However, the limitations in the weather data remained a constraint on the fire spread modelling. Three reasons were likely contributors:

- As stated in Section 2.5, it was exceedingly difficult to produce an accurate reconstruction of this fire, mainly due to the elapsed time since 2001;
- The ACCESS model was not able to capture the differentiation of the weather across the fire ground (Kepert *et al* 2013, Cechet *et al.,* 2014); and
- Only the Warragamba component of the Mt Hall fire has been modelled here. The full Mt Hall fire was raging just across Lake Burragorang to the west and possibly could have influenced the fire spread in the Warragamba component of the Mt Hall fire. This was not reflected in the modelling of this case study.

The FireDST Weather Ensemble Generator generated any range of simultaneous modifications of temperature, humidity, wind speed and wind direction. Thus, the Weather Ensemble Generator provided a method for reflecting sensitivity to uncertainties in the surface weather inputs in the fire spread modelling.

The results demonstrated that sensitivity of the modelled fire shape to perturbations in key parameters cannot be judged in isolation. The modelled process is also sensitive to interactions between the parameters, caused by the physical processes that drive the fire. When assessing robustness of a fire spread prediction or generating a probabilistic fire spread forecast, this interaction between the input parameters has to be explicitly built into the sampling design of ensembles.

5.4.1 Future Work

- The relatively poor simulation may be due to the initial conditions, the complex topography or that the synoptic forcing was weaker(Cechet *et al.,* 2014).These three possible reasons should be investigated for their relevance to improving the accuracy of the numerical weather prediction;
- The whole of the Mt Hall fire should be simulated to examine if the main fire was affecting the fire spread in the Warragamba region. This research will examine the hypothesis that part of a fire cannot be simulated as has been suggested in the results of this case study;
- The scope of this research was limited to simple changes in the weather conditions. The choice of scenarios was not based on an understanding of the actual variations in the weather that could occur. In the future it may be possible to the Bureau of Meteorology to use historical information to generate a probability of a certain scenario occurring (similar to the UK Met Office[5]); and
- Furthermore, the changes implemented for each scenario were applied ‘globally’ across the landscape. Such global changes are not realistic, as local terrain and vegetation will affect the local conditions of the weather. For example bias in temperature or wind speed may vary between deep, vegetated river valleys and smooth exposed hill sides. Further work should identify the benefit of quantifying variations in local weather conditions at specific locations across the landscape.

[5] http://www.metoffice.gov.uk/research/areas/data-assimilation-and-ensembles/ensemble-forecasting

6 Assessing sensitivity of the fire spread to the weather conditions in the upper atmosphere

6.1 Objective

Upper level wind speed and direction are key drivers of the spread of embers from the fire. The objective of this research was to develop a methodology for integrating uncertainties in the wind direction and speed at different altitudes into the FireDST system. The main aims of this research were to evaluate the vertical atmosphere weather conditions as a driver of the ember transport layer in the fire spread modelling.

6.2 Methodology

6.2.1 Background

Bushfires have been known to generate convective columns up to 15 km and, once lofted by convection embers can be transported over large distances by the winds that tend to be much stronger at such altitudes than at the surface (Cruz *et al.,* 2012). To investigate the effect of both ground ember generation and lofted embers on the modelled fire spread, the analysis described here tested different vertical layers up to the top of the simulated atmosphere as input for the fire spread modelling.

The standard PHOENIX RapidFire model parameterised the ember transport based on input weather data at 10 m. The PHOENIX RapidFire convection bubble model was modified by the University of Melbourne to incorporate an extra ‘transport layer’ based on wind direction and wind speed. The Bureau of Meteorology generated a simulated atmospheric profile from 10 m to 60 km for the Wangary fire at 4000 m grid resolution at 15 minute time steps and 50 vertical heights (levels) for both wind speed and wind direction. Details of the 50 levels are shown in Table 6.1.

Table 6.1 Levels used in the vertical ACCESS wind speed and direction files.

Level	Altitude (m)
0	9.99777
1	50.0014
2	130.003
3	250.001
4	410.003
5	610.003
6	850
7	1130
8	1450
9	1810
10	2210
11	2650
12	3130
13	3650
14	4210
15	4810
16	5450
17	6130
18	6850
19	7610
20	8410
21	9250
22	10130
23	11050
24	12010
25	13010
26	14050
27	15130
28	16250
29	17410
30	18590
31	19770.3
32	20951.7
33	22136.7
34	23329.7
35	24538

Level	Altitude (m)
36	25772.5
37	27048.4
38	28385.6
39	29809.8
40	31353.3
41	33055.1
42	34962.2
43	37130.1
44	39623.5
45	42516.9
46	45895.4
47	49855.8
48	54506.4
49	59968.6

A brief analysis is presented here of the supplied atmospheric profile to provide an overview of the simulated atmospheric wind speed conditions. The analysis will review the wind speed conditions at the closest (ACCESS 4000 15 minute) grid point to the Warragamba component of the Mt Hall fire. This point is between Warragamba and Silverdale at -33.896, 150.612 (Figure 6.1).

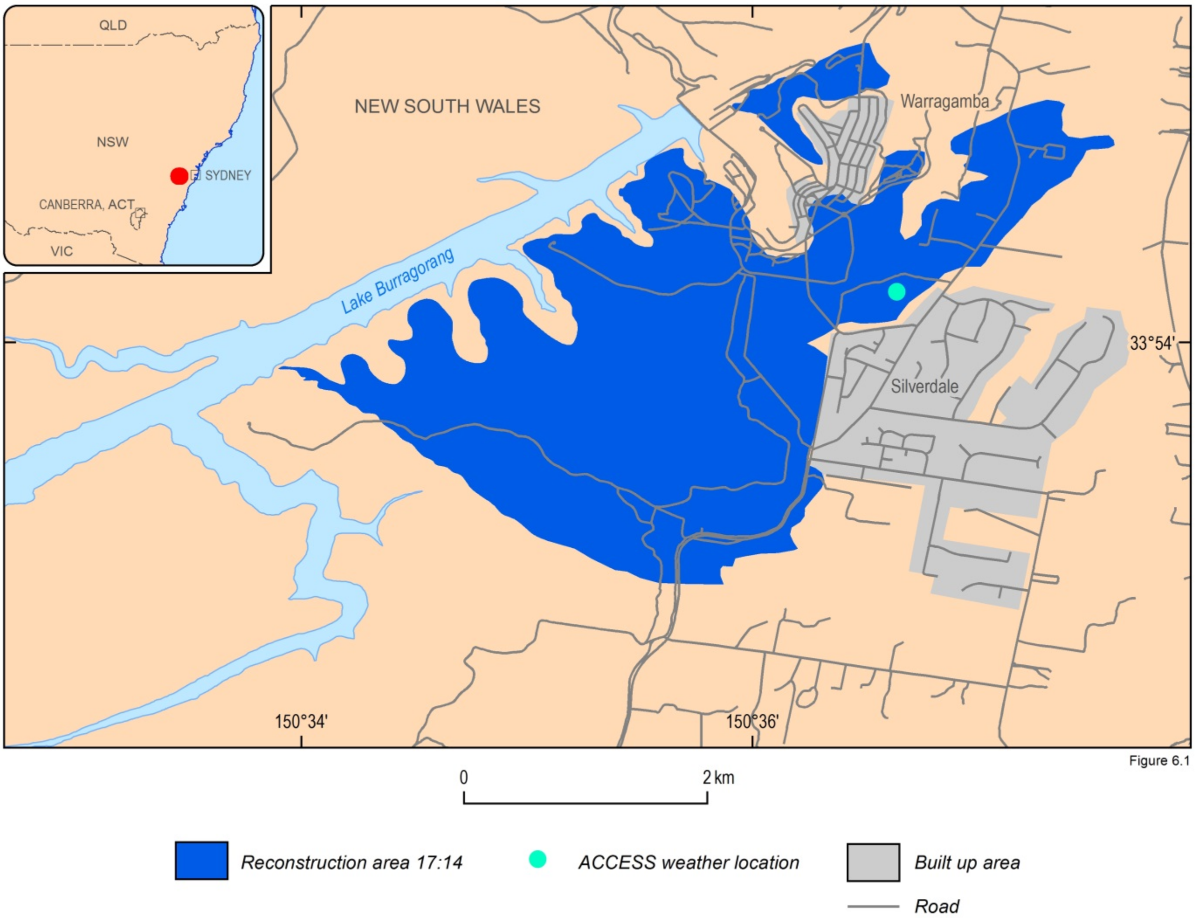

Figure 6.1 Map of the closest ACCESS weather grid point (-33.896, 150.612) to the Mt Hall fire.

An extract of the ACCESS modelled atmospheric profile wind speed over time at the weather location is displayed in Figure 6.2 to Figure 6.4. Only the boundary layer wind speeds are shown in Figure 6.2 (10 m, 50 m (level 1), to 850 m (level 6)). The wind speeds in the boundary layer followed a similar pattern, while increasing with altitude. Between 13:00 and 19:00, during the peak of the Mt Hall event, the wind speeds were fairly constant.

Figure 6.3 shows the layers just above the boundary layer (1130 m (level 7), to 3130 m (level 12)). At the start of the event, the wind speed increased with altitude as was the case in the boundary layer; however, for the period between 13:00 and 18:15, the wind speeds converge almost completely. Figure 6.4 shows the wind speeds above 10 km, with all exhibiting more consistency in wind speed than the lower levels.

Figure 6.5 displays the atmospheric wind speed profile for the first 60 km altitude at this location (-33.896, 150.612) 15 minutes after the Mt Hall (Warragamba complex) fire ignition (26 hours or 13:00 on 25/12/2001).

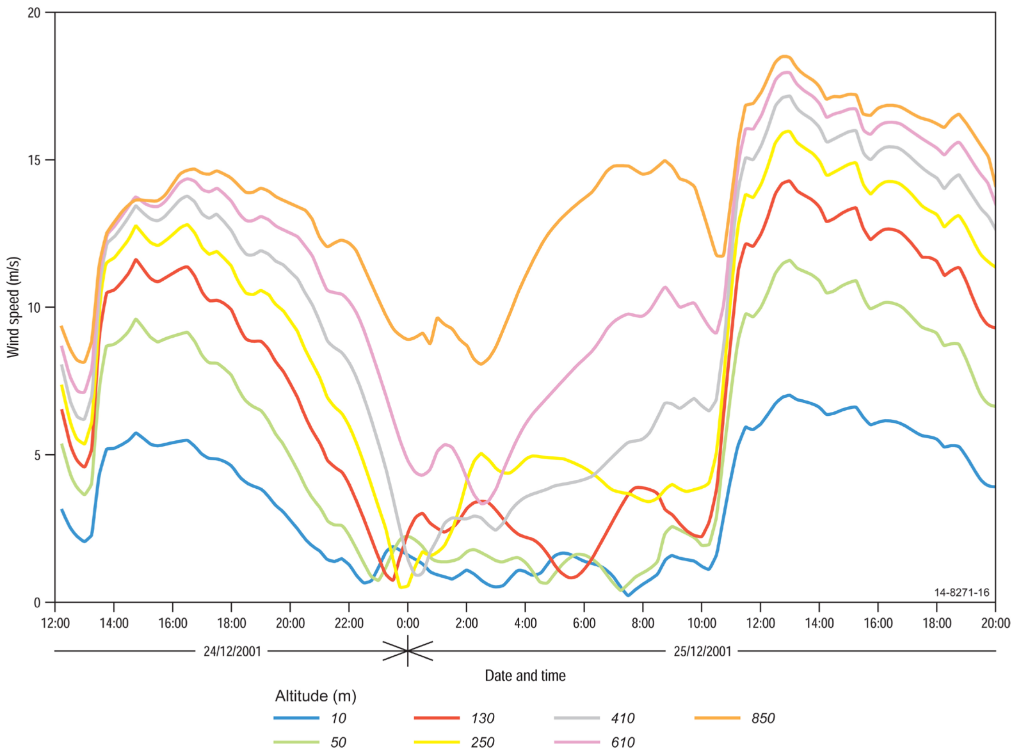

Figure 6.2 Wind speed at altitude (in boundary layer) by time on 25/12/2001 for location -33.896, 150.612

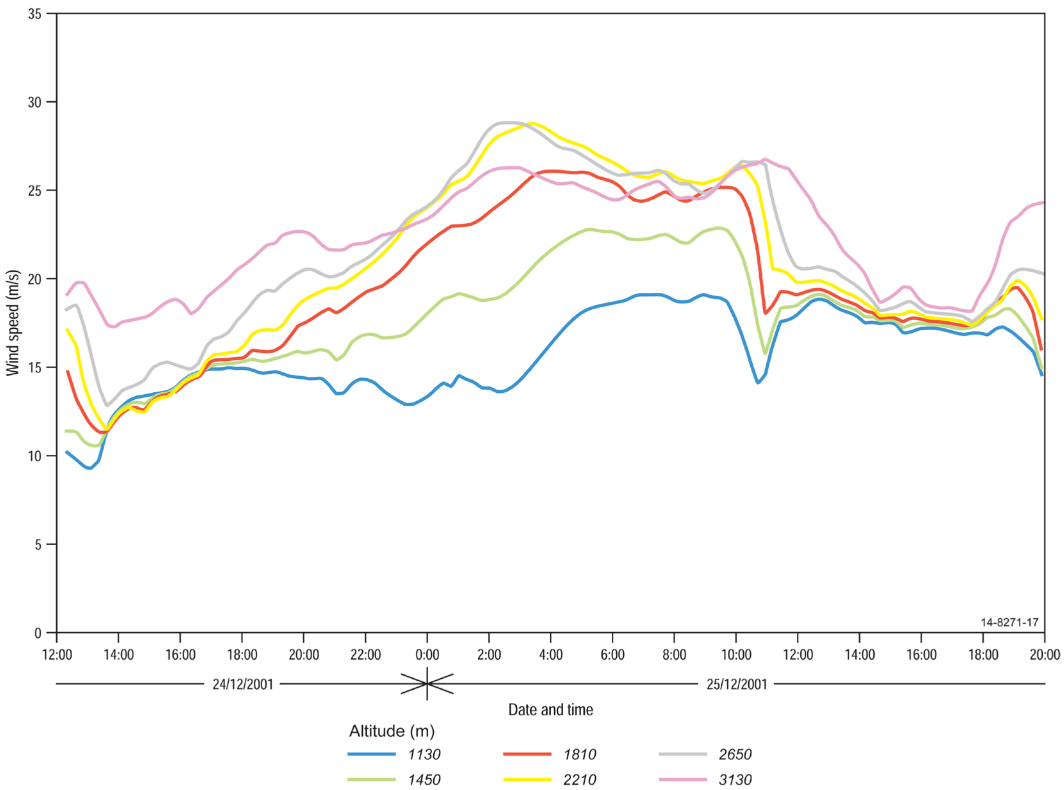

Figure 6.3 Wind speed at altitude (just above the boundary layer) by time on 25/12/2001 for location -33.896, 150.612

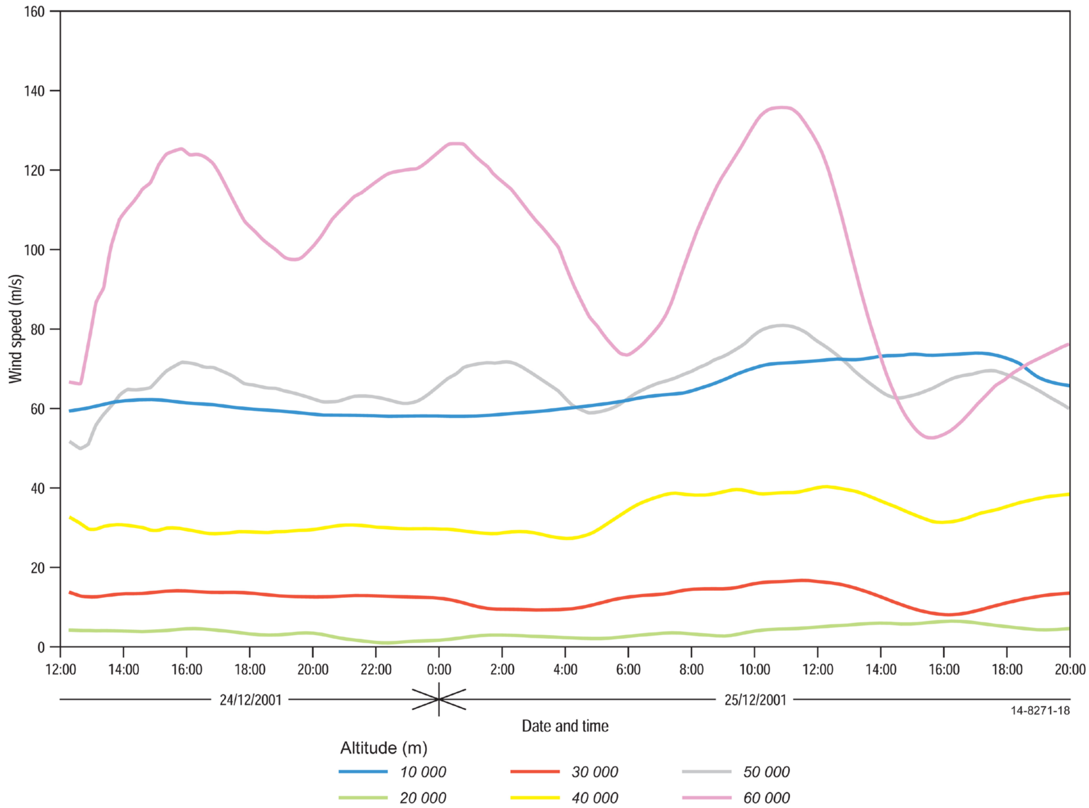

Figure 6.4 Wind speed at altitude by time on 25/12/2001 for location -33.896, 150.612

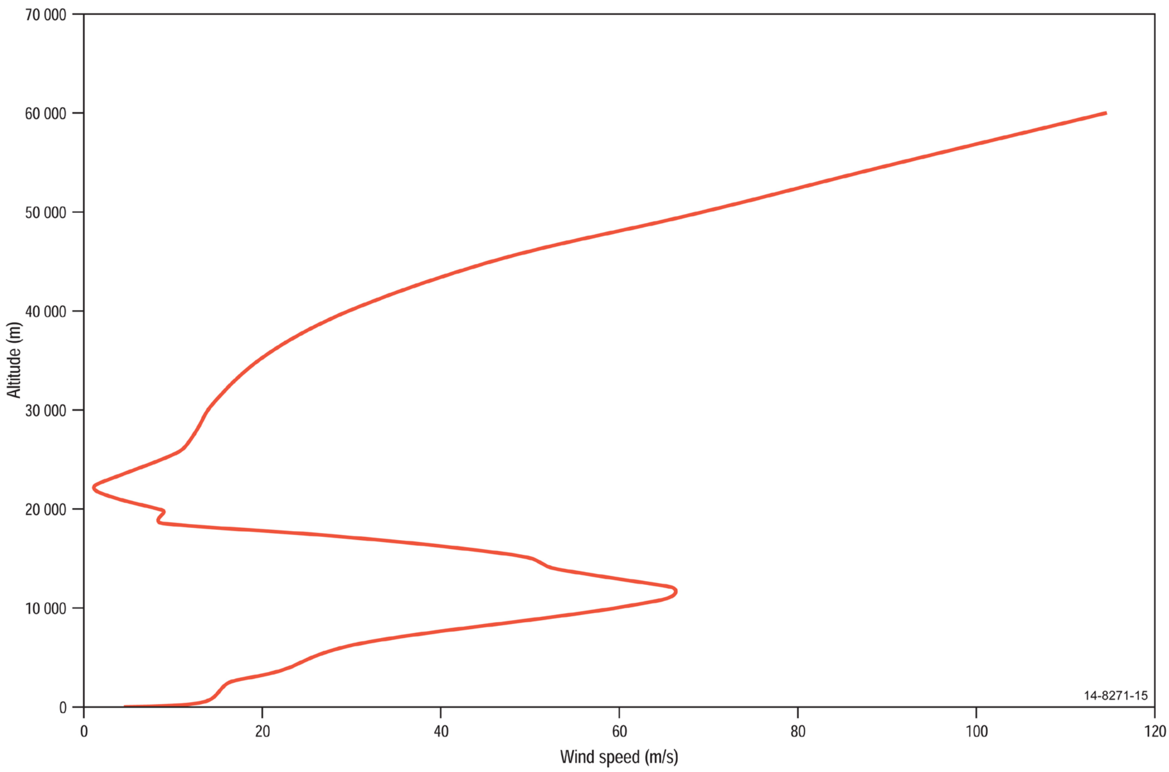

Figure 6.5 Altitude and wind speed for the first 60 km for location -33.896, 150.612 at 13;00 on 25/12/2001.

6.2.2 Method

Simulations were conducted using a single set of surface weather conditions and standard physical conditions for all of the vertical simulations. The surface weather conditions were defined by the ACCESS 4000 m, 15 minute weather, which adjusted using the Wind Ninja local wind modifiers (see Chapter 5). The upper level conditions were specified by each of the respective vertical layers in turn. This is the only section in this document where the 15 minute surface weather from ACCESS is used, as the upper level atmosphere was also modelled at a 15 minute resolution.

The fire simulation was halted at 17:15 on 25/12/2001. This time was selected to allow for the simulations to impact with Silverdale and provide a match with the reconstruction.

The simulations in Section 6 assess sensitivity to the vertical layer that was used to simulate the ember transport.

6.3 Results and Discussion

6.3.1 Sensitivity to atmospheric conditions

The simulated fire spread showed little or no sensitivity to the differences between the respective vertical layers used as transport layer. Figure 6.6 shows the minor differences between using level 0 (10 m) as the transport wind and using level 49 (60 km) as the transport wind. Analysis of the model output suggested that the limited area covered by the fire generated insufficient embers in the model to affect the fire spread in a more significant way (Figure 6.7). This might be compounded by the underestimated wind strength.

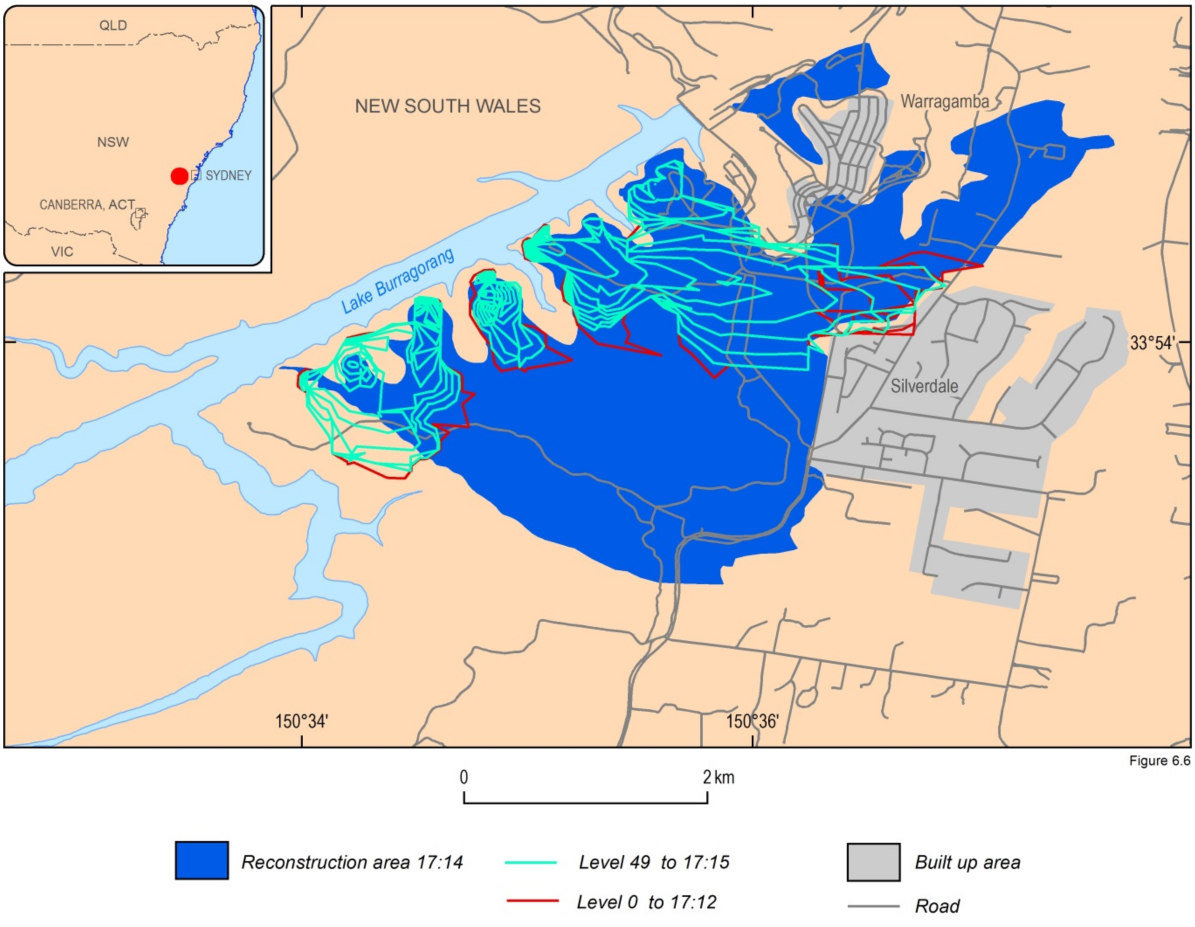

Figure 6.6 Comparison of the fire spread based on Level 0 (red) and Level 49 (light blue) for the transport layer.

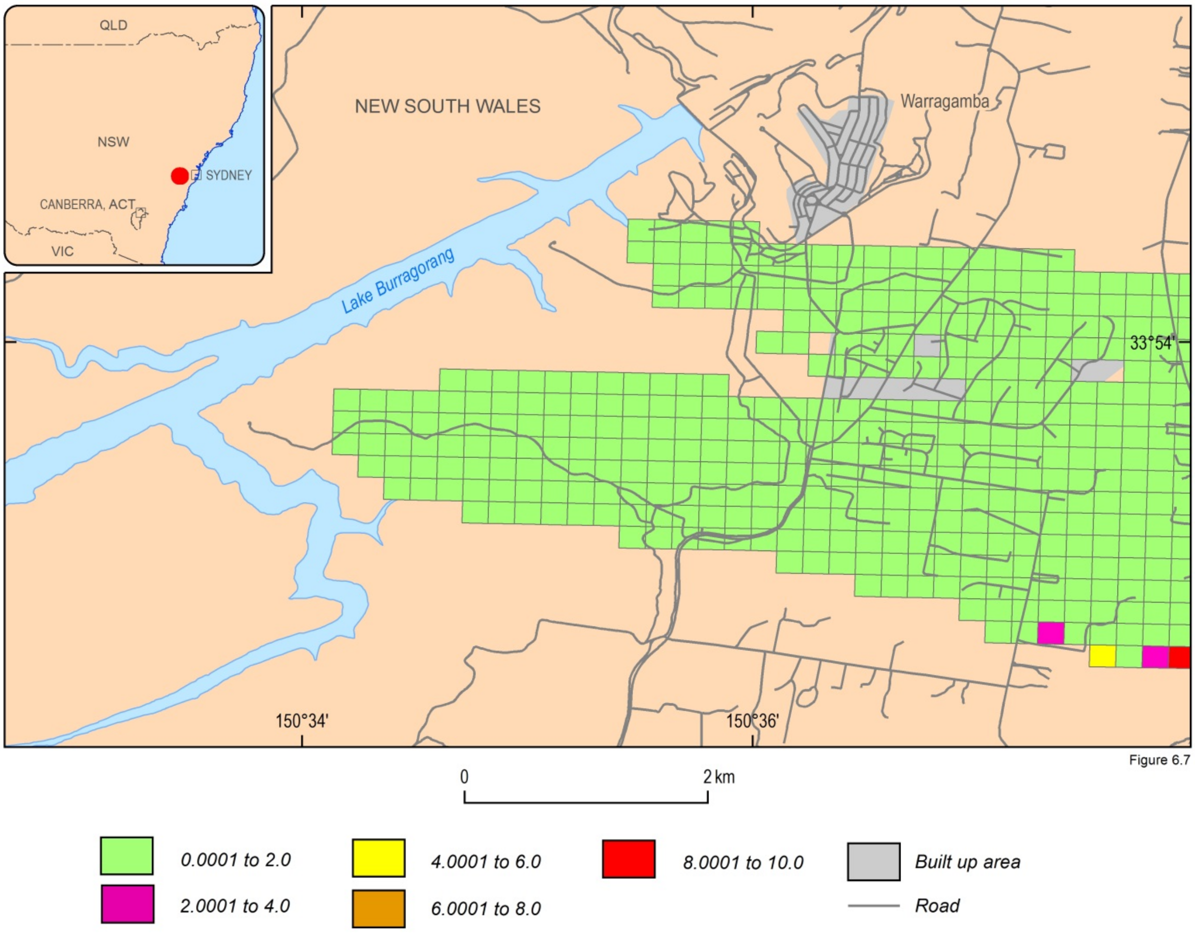

Figure 6.7 Ember density results for the fire spread simulation to 16:35 using Level 49 to define the transport layer, indicating the low ember density count.

6.4 Conclusions and Future Work

The work described in this chapter has yielded insights of the sensitivity of the Mt Hall fire modelling to the upper level atmospheric conditions. Any bushfire simulation that travels through forest fuel needs to consider the upper level wind direction, as it drives the transport of fire embers. However, the work described here indicated that despite the Mt Hall fire traversing predominantly forest fuel, there was little sensitivity of the fire spread to the choice of conditions used for the ember transport layer. This was possibly due to two factors:

- The small size of the fire did not propagate sufficient embers in the model to result in sensitivity to the ember transport conditions; and
- This effect would be compounded by the underestimated wind intensity in the modelled weather conditions.

The results in this chapter demonstrate the benefit of the FireDST approach for investigating sensitivity of fire modelling to uncertainty in model parameterisation. By visualising the variability in model inputs as an ensemble fire spread, the system allows for exploration of the impact of model parameters and assumptions that interact as part of the modelling of a highly complex physical process.

6.4.1 Future Work

- Further research is required to validate and improve the parameterisation of convection and ember transport in PHOENIX RapidFire. The University of Melbourne team has identified several PHOENIX RapidFire improvements that could improve the representation of ember transport in the model. These improvements are chiefly aimed at refining the physical basis for the generation of the convection column and related issues, such as the coalescing of two fire fronts which affects the convective power of the fire;
- Future work is needed to assess and validate the part of the vertical atmospheric profile that is most effective to generate the correct convective strength in simulations of ember transport within the fire spread model;
- The work here was initial research and only covered the use of the horizontal winds at each level. Future work should consider both the horizontal and vertical components in the ACCESS atmosphere to provide a more accurate model of the flow of embers between layers; and
- This research was based on ACCESS weather specified at 4000 m horizontal resolution and 15 minute time intervals. Future research could be conducted with 1200 m and 440 m resolution atmospheres that could then be directly matched with the supplied 10 m ACCESS weather (at 1200 m and 440 m). Also, the 4000 m ACCESS atmosphere could be examined in conjunction with the 1200 and 440 m 10 m ACCESS weather files. Comparison of the simulation results would determine the spatial resolution that would yield acceptable results for computational effort.

7 Assessing the sensitivity of the fire spread to the fuel load

7.1 Objective

This section examines the sensitivity of the fire spread modelling to the vegetation conditions, such as fuel load and fire history. The scope of the vegetation component of the research described here included varying two PHOENIX Rapidfire parameters that vary fuel load:

- The fuel regeneration curves; and
- The fire history.

In addition, the University of Melbourne conducted a sensitivity analysis of all the vegetation parameters used by PHOENIX RapidFire as part of the F.I.R.E.D.S.T. project. The results of this work are reported in the final FireDST Report (Cechet *et al.,* 2014).

7.2 Methodology

7.2.1 Background

PHOENIX RapidFire relies on the parameterisation of vegetation information on a 180 m resolution grid. PHOENIX RapidFire also includes internal equations and factors to characterise the vegetation further (Tolhurst *et al.,* 2010).This vegetation parameterisation can introduce error and uncertainty into the fire modelling process, notably in the vegetation type, fuel load and fuel curing prior to the simulated fire.

This analysis concentrates on two aspects of the fuel load:

- The fuel regeneration curves, which defines the amount of regrowth of fuel over time after a previous fire; and
- The fire history information.

7.2.2 Method –fuel regeneration curves

In PHOENIX RapidFire, each vegetation type contains a parameterisation schema for the amount fuel in three layers: surface fuel; elevated fuel; and bark. Each layer of fuel contains three variables which define the shape of the fuel regeneration curve (Tolhurst *et al.,* 2010). The variables used to calculate the fuel regeneration curves are:

- r – Potential magnitude of increase in hazard;
- k – rate of reaccumulation of hazard; and
- c – practical minimum level of hazard

Modifying these variables changes the regeneration curves for the layer in the fuel. A sensitivity analysis of the fuel regeneration curves was conducted by the University of Melbourne (Cechet *et al., 2*014).

The variability of the fuel load was evaluated by modifying the value of *r* (range 0 to 5) for all woodland and forest fuel types at the elevated and bark levels in the fuel. Increasing the value provided the simulated fire with more 'fuel' to drive the spotting mechanism. Hypothetically, the fire could then spread further. Decreasing the value decreased the amount of fuel available for ember transport, and so would produce a smaller fire shape.

7.2.3 Method – fire history

Phoenix RapidFire can ingest a grid based 'fire history' file. Each cell contains either a blank value (indicating no previous fire) or a date (of the most recent fire that burnt that cell) (Tolhurst *et al.,* 2010). Based on the time since a cell was last burnt (either in a prescribed burn or an actual fire) and the cell vegetation type, PHOENIX RapidFire calculates the fuel load for that cell. If no previous burn is specified, the maximum fuel load is assumed.

The section below discusses the results from two tests:

- Simulation of the fire assuming the historical fuel load of 24 December 2001, based on the fire history prior to that date, and
- Simulation of the fire assuming a maximum fuel load, ignoring any fire history data.

7.3 Results

7.3.1 Sensitivity to Fuel Regeneration Curves

Figure 7.1 shows the results for a simulation where the *r* values (elevated and bark) for the woodland and forest fuel types were elevated to 2.0 (from 1.3). The simulated fire shape was more extensive and had a larger forward rate of spread than the fire that assumed the standard fuel regeneration curves. This would be explained by the fact that the higher fuel load would generate more embers which spread the fire further and faster.

Figure 7.2 shows the results for a simulation where the *r* values (elevated and bark) for all woodland and forest fuel types were lowered to 0.2 (from 1.3). The resultant fire shape was far smaller than the fire that assumed the standard fuel regeneration curve. Again, the model behaved as expected as there was less bark and elevated material to drive ember based fire spread.

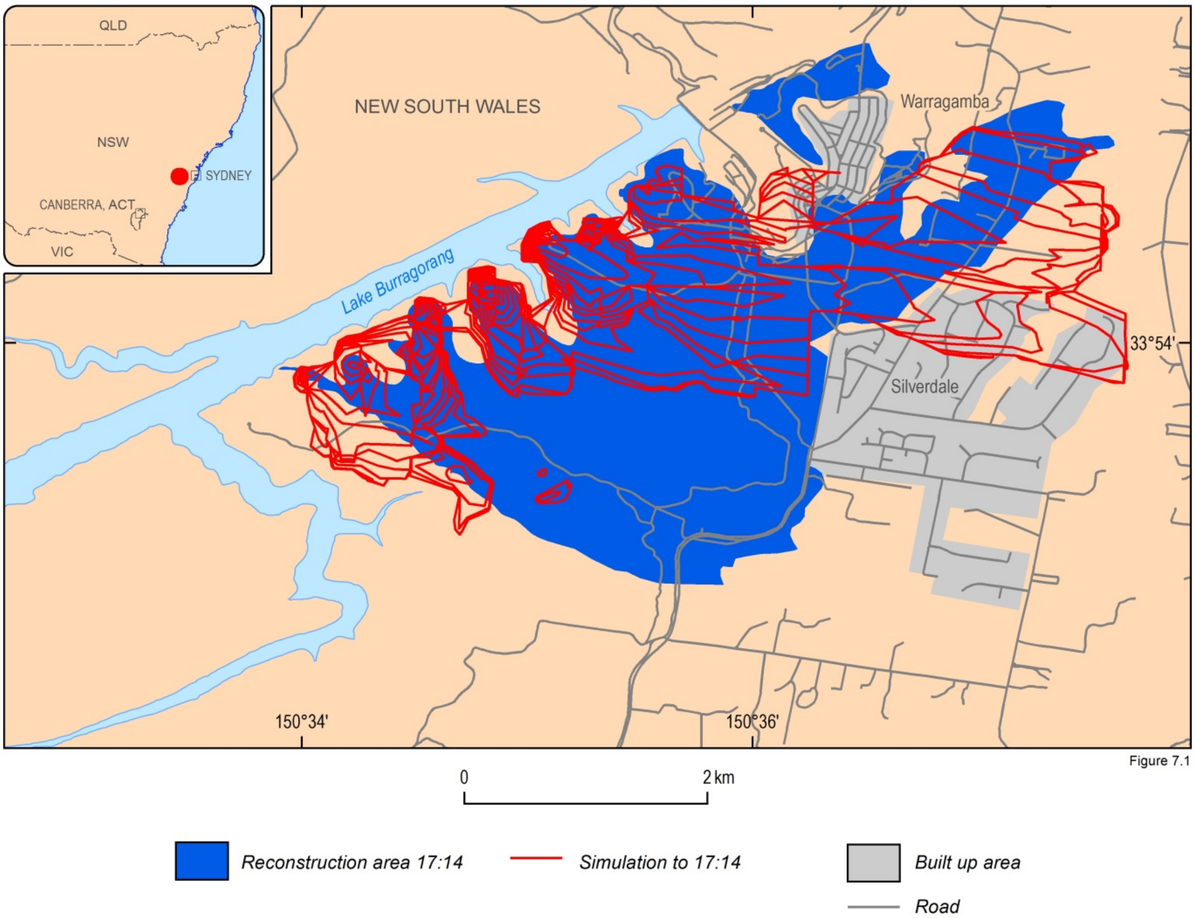

Figure 7.1 The effect of increasing the fuel regeneration curves for the forest fuel type by setting bark_r =2 and elevated_r = 2, using 400m 5 minute, Wind Ninja, no bias correction and no suppression.

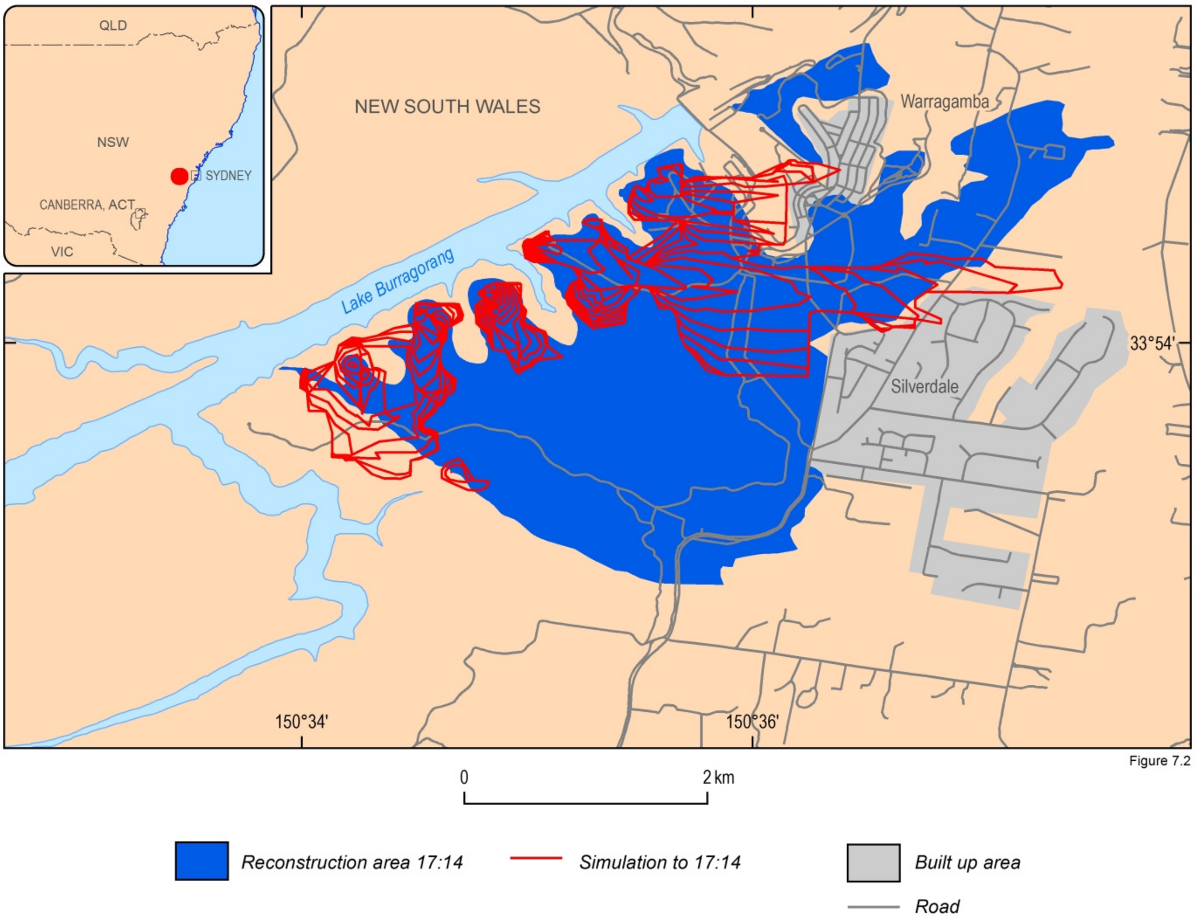

Figure 7.2 The effect of decreasing the fuel regeneration curves for the forest fuel type by setting bark_r =0.2 and elevated_r = 0, using 400m 5 minute, Wind Ninja, no bias correction and no suppression.

7.3.2 Sensitivity to Fire History

The simulations using 'no fire history' and 'fire history' information produced exactly the same simulation shape. This is because the fuel load in this small area was already at maximum as there had been no fire in that region for many years. This meant that there was no effect on the fuel load by using the fire history file.

7.4 Conclusions and Future Work

This chapter discussed how FireDST enabled the assessment of the sensitivity of the fire spread simulation to the fuel load. Fuel load is determined by the time since a cell was last burnt, using fuel regeneration curves for each fuel type. Scenarios varying fuel loads were introduced by perturbing the fire history (time since last burnt) and the shape of the fuel regeneration curves. The results showed that the simulated fire spread was sensitive to the fuel load, in line with expectations.

7.4.1 Future Work

- Phoenix RapidFire includes a good method for parameterisation of the regeneration of each fuel type following bushfires. These curves apply globally to the individual vegetation type across the landscape. It is known that the same vegetation type will regrow at different rates based on location specific information (e.g. shrubs in a wet gully as opposed to shrubs growing on a dry plateau). Further work could investigate the benefit of including location specific factors that take these conditions into account and modify the regrowth curves accordingly; and
- PHOENIX RapidFire includes fire history for when cells were last burnt and this is used by the fuel regeneration curves to predict the fuel load. However, when a fire burns it does not necessarily scorch every area to the same extent. For instance a crown fire may occur at one location but at another only the understory burns. Further work could investigate how this variability in post-fire fuel load can best be parameterised in the fire spread model.

8 Assessing the sensitivity of the fire spread to changes in ignition

8.1 Objective

This section examines the sensitivity of the fire spread modelling to changes in the ignition location and ignition time. There is always uncertainty in recording the actual ignition location and time because the first sighting of the fire is always subject to human interpretation. The scope of the research described here includes:

1. Examining the sensitivity to ignition location.
2. Examining the sensitivity to variation in the ignition time of the fire

In this study, the input time is the best estimate of the ignition time and location of the Mt Hall event. The ignition time and location for the historical Mt Hall event was not well specified (Supreme Court NSW, 26/06/2012) and uncertainty remains.

8.2 Methodology

8.2.1 Method –ignition location

The FireDST Ensemble Generator generated scenarios based on perturbations to an ignition point and time. Ignition location was sampled by introducing offsets in distance along the cardinal axes (i.e. north, east, south and west). The minimum offset from the input ignition location was set at 200 m to ensure that scenario ignitions were located different PHOENIX RapidFire grid cells (which are 180 m).

8.2.2 Method –ignition time

The temporal variation was sampled as 5, 10, 15 and 20 minute deviations around the input ignition time.

8.3 Results and Discussion

8.3.1 Sensitivity to ignition location

As discussed in Section 4.2.2, additional ignition points had to be introduced in the fire spread modelling to approximate the historical fire shape. The potential location of these extra ignition points was limited because of the proximity of Lake Burragorang. PHOENIX RapidFire did not model ignition in cells that mainly contained water.

The effectiveness of the introduction of these additional points indicates the large degree of sensitivity of the modelled fire spread to the ignition location. It must be noted that the FireDST project only introduced multiple simultaneous ignition points in the Mt Hall case study, and this was not done for the other case studies. The results highlight that the assumptions used to generate scenarios are a critical factor that determines the value of the ensemble output.

8.3.2 Sensitivity to ignition time

FireDST produced an ensemble consisting of eight scenarios with ignition times 5, 10, 15 and 20 minutes prior to, and 5, 10, 15 and 20 minutes after the (best estimate of the) Mt Hall ignition time for each of the nine ignition locations.

None of the individual simulations (using 4000 m, 5 minute Wind Ninja ACCESS weather) in the ensemble showed much change in the simulation shapes when the ignition times for the Mt Hall case study were varied. Figure 8.1 shows the variation in simulated fire shape for +/- 10 minutes. The earlier start to the fire has produced a larger fire shape in the southern region, as expected based on the longer burn time. The comparative lack of sensitivity in the fire spread is likely to be due to the uniformity of the weather over the day. The result also implies that the conditions of the fuel (fuel moisture and curing) were not sensitive to the variability in ignition time.

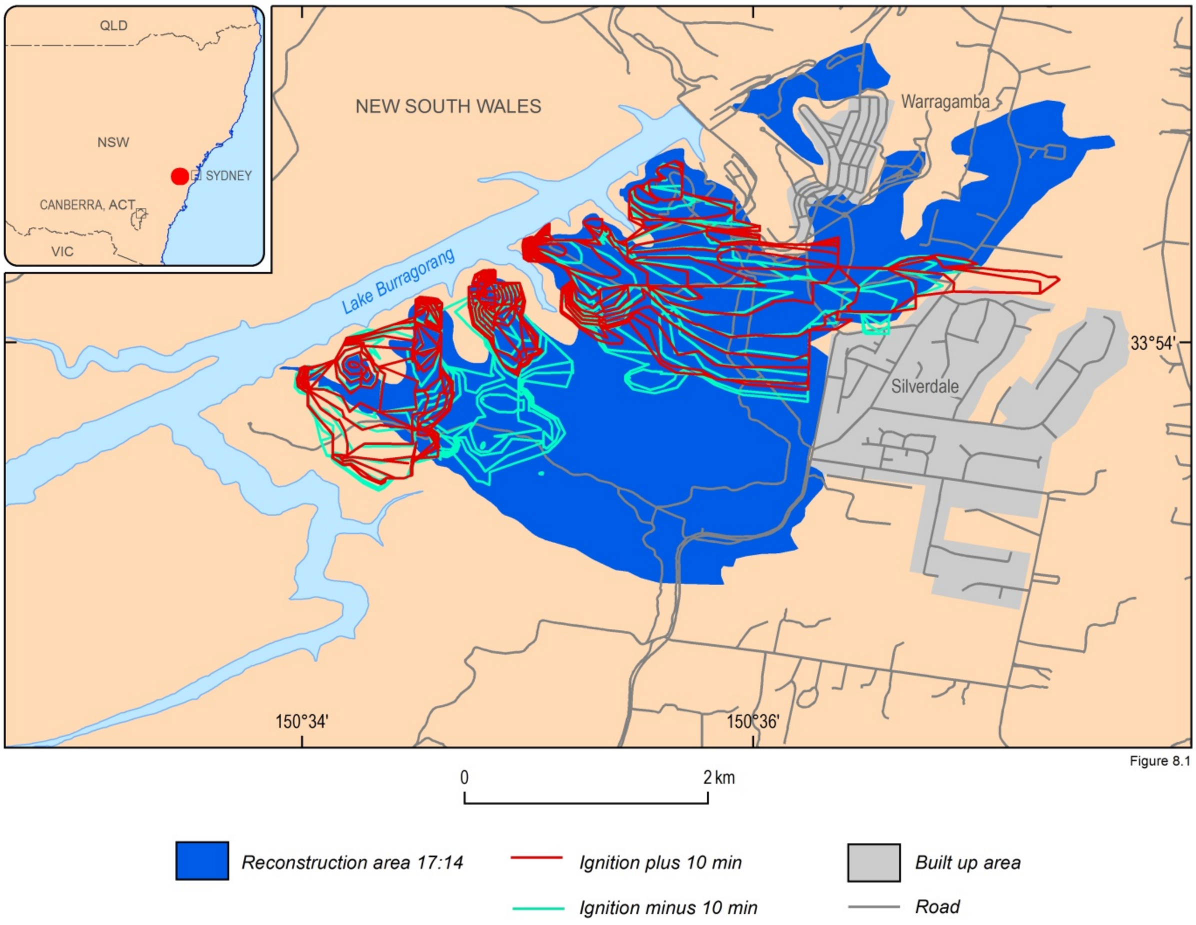

Figure 8.1 Simulated fire spread to 17:14 based on ignition time +/-10 minutes, using 4000 m, 5 minute, not bias corrected, Wind Ninja ACCESS weather.

8.4 Conclusions

This chapter discussed the results of an assessment of the sensitivity of the simulated fire spread to variations in the ignition conditions. FireDST was used to generate ensembles of scenarios with a perturbed ignition location and ignition time. Tests did indicate that the fire shape was sensitive to the ignition location. A reasonable approximation of the historical fire shape could be attained by introducing multiple ignition points, as opposed to the reconstructed (single) ignition point. This indicates that there is likely to have been more than one spot ignition, probably from the main fire across the lake. Results also showed that the modelled fire spread was comparatively insensitive to variations in the ignition time, probably mostly related to the uniform weather conditions over the day.

9 Estimating the number of buildings and people exposed to a fire spread ensemble

9.1 Objective

The work described in this chapter aimed to assess and visualise the number of buildings and people exposed to the fire as part of an integrated assessment of the fire spread and impact modelling.

9.2 Methodology

In risk assessment terminology, 'exposure' is commonly defined as the assets that are potentially at risk from bushfires. This could be buildings, people, roads and other infrastructure, or ecosystems. In this project, exposure was restricted to residential buildings and people because this was the extent of the information available at the time.

The exposure information that underpinned the impact assessments in FireDST drew heavily on the National Exposure Information System database (NEXIS). NEXIS (Nadimpalli 2009; Canterford 2011) has been designed to provide exposure information for impact and natural hazard risk assessments. It provides comprehensive and nationally consistent exposure information, derived primarily from reliable and publicly available datasets. The objective of NEXIS is to compile and maintain information at building level compatible with vulnerability assessment models for multi-hazards such as earthquakes, tsunami, tropical cyclones, floods, and bushfires.

The FireDST exposure information adopted the residential building information available in an older version of NEXIS for the case study, to reproduce as closely as possible the exposure that would have been around at the time of the Mt Hall event. The 2011 version of NEXIS that was used contains information from the 2006 ABS Census.

Table 9.1 details the attributes (spatial, structural and economic) used in the FireDST exposure database based on the 2011 NEXIS residential exposure information. For each building, the database specifies the age of the building, the wall type and the roof type. All of these attributes are relevant in evaluating whether a building will be destroyed by fire (see Chapter 10). The database also contains an estimate of contents value and building replacement value.

Table 9.1 Spatial, structural and demographic/economic attribute fields for residential exposure derived from the 2011 version of NEXIS for FireDST.

	RESIDENTIAL
SPATIAL	Latitude Longitude Address Block size Floor area
STRUCTURAL	FCB type Roof type Wall type Age
DEMOGRAPHIC/ ECONOMIC	Income group No. residences No. people Structural value Tenure Contents value Motor Vehicle Access Age Group Need Assistance Volunteer Years at residence

The NEXIS demographic/economic information is statistically derived from a variety of sources including the 2006 Census Collection District aggregate information. This means the demographic and economic results are accurate when aggregated, but only an average is available at the individual building level within each Collection District. The version of NEXIS (2011) used for the Mt Hall Case Study located the house location at the centre of the land parcel in the study area. For larger rural parcels, this is likely to be significantly different from the true location of the building, and could have caused issues with PHOENIX RapidFire not burning the cell around the house correctly because of the different conditions in each 180 m cell.

The FireDST exposure also contains a variety of socio-economic information derived from the Australian Bureau of Statistics (ABS) 2006 Census. The NEXIS and ABS 2006 Census information was integrated so it could be stored as building-specific data. The 2006 Census information contains 14 vulnerability indicators (Metz and Canterford 2011) that have been included in the FireDST database. These indicators are listed in Appendix C Table C.1.

Unfortunately, the 2006 Census information was only published electronically at the Collection District level (this is at the resolution of a town or suburb between 200 and 800 people with an average of 400). For FireDST, the Collection District information from the 2006 Census was statistically averaged down to each house in the District.

Each house in a Collection District was allocated the same resident profile based on the Collection District information. An averaged profile is almost certainly inaccurate for most individual households, and may often not even be physically possible (e.g. 2.4 adults, or 0.5 people below 5 years of age). However, individual house statistics are aggregated back to larger areas (such as the mesh block – the smallest area available from the Australian Bureau of Statistics of about 50 houses) to serve as a reasonable approximation for the population profile exposed to the ensemble fire spread.

FireDST can display information on the local population exposed to the fire at the mesh block level (around 50 buildings). This information summarises the population either directly impacted by the ensemble spread or just outside the ensemble envelope, and includes some indicators of their potential vulnerability (Figure 9.2). To quantify the buildings and people exposed to the fire, the exposure is extracted for all locations within the ensemble fire spread. Statistics are produced for the buildings and people within each fire spread overlap interval.

The estimation of people exposed to the ensemble fire spread was based on the assumption that all residents were home. Clearly, this assumption is not valid where people have evacuated, are away at work, school or on holiday, or for empty holiday properties. This means that the exposure statistics are for the maximum number of residents that are potentially exposed to this fire ensemble.

9.3 Results and Discussion

9.3.1 Ensemble fire spread – viewing exposure statistics

Figure 9.1 shows the ensemble fire spread near Warragamba overlaid with building locations. Table 9.2 contains the statistics for the population exposed to the full ensemble footprint (Figure 4.1). The table shows that 58 people live in the area that is burnt in over 80% of the ensemble scenarios. Table 9.3 shows that there are 24 houses in this area.

The statistics include the estimated value of the exposed property, and summaries of the age and mobility profile of the exposed population. The value estimates are not based on the relative severity of damage to the building, only on whether a building is exposed to the ensemble.

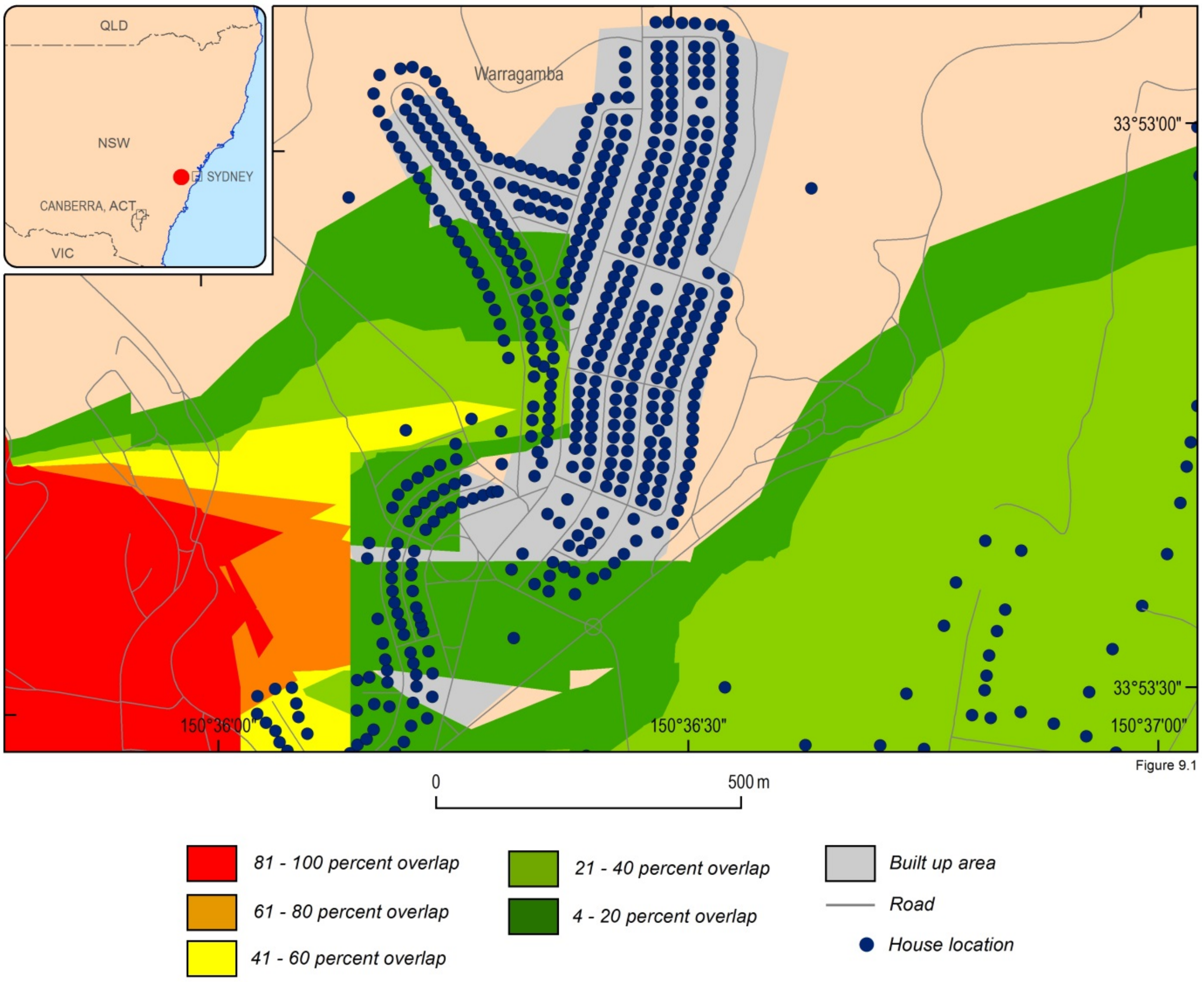

Figure 9.1 Part of the ensemble fire spread near Warragamba with house locations displayed.

Table 9.2 FireDST people related exposure statistics for the ensemble simulation shown in Figure 4.1.

Ensemble shape impact area likelihood	Number of people exposed	Number of people over the age of 65	Number of people under the age of five	Number of people who need assistance
81-100	58	6	10	2
61-80	173	22	29	7
41-60	237	38	45	11
21-40	322	53	63	16
5-20	1175	176	165	60

Table 9.3 FireDST building related exposure statistics for the ensemble simulation shown in Figure 4.1.

Ensemble shape impact area likelihood	Number of houses exposed	Estimated house replacement cost $	Estimated house contents value $
81-100	24	8,802,552	3,822,748
61-80	63	36,039,790	6,587,710
41-60	97	93,927,330	12,114,350
21-40	125	79,981,400	16,493,360
5-20	380	188,575,000	55,692,330

Figure 9.2 displays mesh block graphs (from left to right) showing four of the vulnerability indicators for population:

- The total population of the mesh block;
- The number of residents living in the mesh block area who are over 65 years old;
- The number of residents living in the mesh block area who are under the age of 5; and
- The number of residents living in the mesh block area who have indicated in the Census that they are in need of assistance.

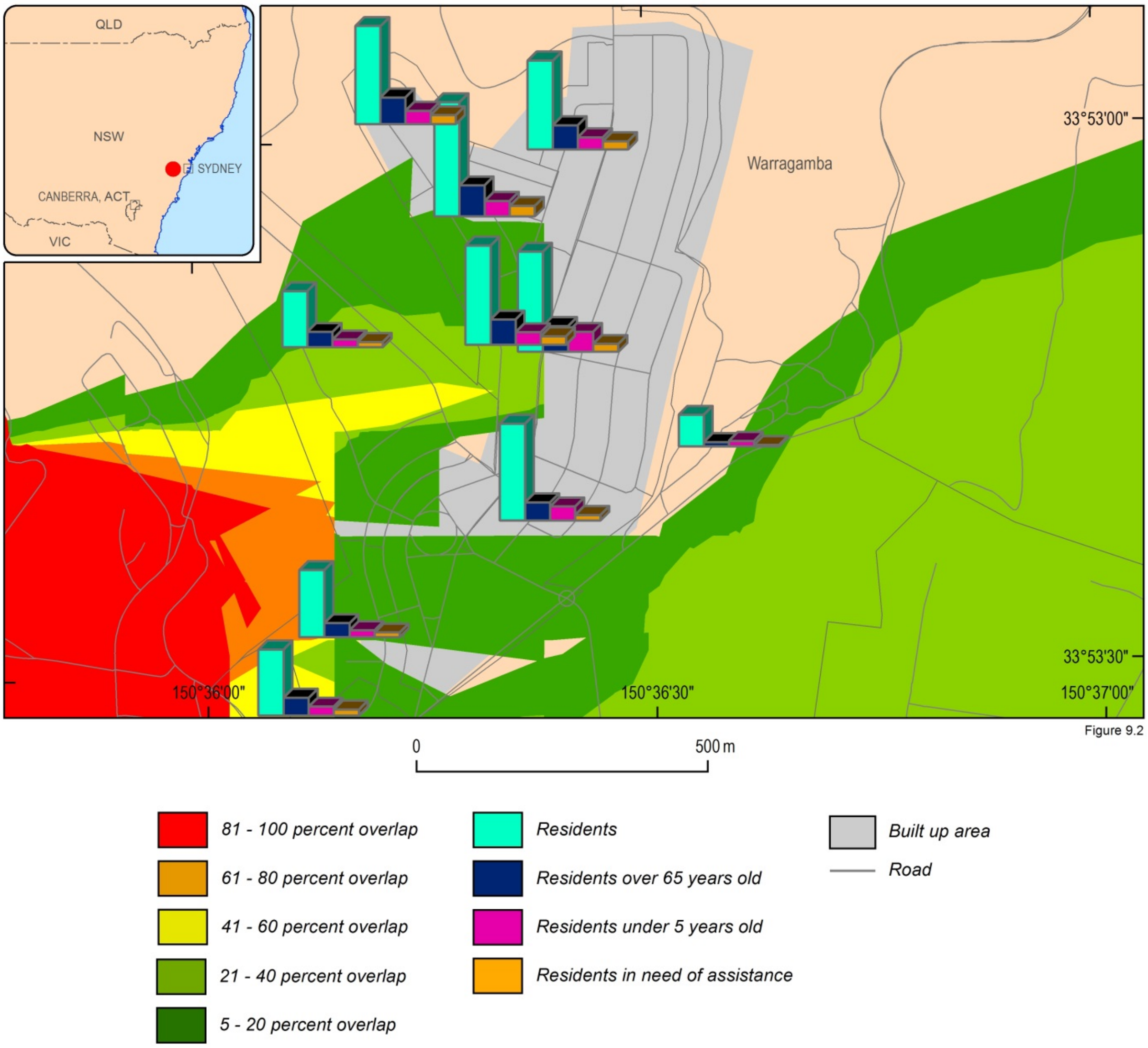

Figure 9.2 Part of the ensemble fire spread near Warragamba to 18:15 with mesh block statistics displayed for the population in or just outside the ensemble fire spread envelope.

9.4 Conclusions and Future Work

The results in this chapter demonstrate a method for estimating the assets exposed with the ensemble fire spread. The ability to generate an inventory of the buildings and people that are exposed to a fire is a fundamental part of fire impact modelling. A comprehensive database of building and population statistics was developed based on existing information, mainly from Geoscience Australia and the Australian Bureau of Statistics. In combination with the fire spread information, FireDST system can quantify and visualise exposure information for either an ensemble or different levels of overlap within the fire spread ensemble.

Both the building and population profiles in this case study were statistically derived, that is, averaged, information. Although such numbers are likely to be correct over larger areas, they may contain significant uncertainty for individual locations. They are therefore not an appropriate basis for operational decisions, such as allocating resources to properties where assistance may be required in an evacuation situation.

9.4.1 Future Work

Where actual population profiles are not available for individual households, Census population information is now available electronically at the Mesh Block resolution, which is approximately 50 houses. Further work could look at using this data in the impact analysis, to provide more accurate information on the population and their potential needs in fire events.

10 Estimating building loss using a fire spread ensemble

10.1 Objective

This research investigated how to assess the sensitivity of fire damage to buildings by developing an approach to quantify and view impact information for an ensemble fire spread.

10.2 Methodology

10.2.1 Background

Buildings can be destroyed by two main mechanisms; radiation and ember attack. As a fire front approaches, the building will experience an increasing level of radiation (heat) in front of the actual flames. This radiation will have a gradual effect on a building (for instance heating a window until it breaks) that could possibly lead to the building being destroyed. In this study direct flame contact is considered to be part of the radiation exposure received by the building. The second mechanism considered is exposure to embers. When a fire progresses through forested material much of the burning bark is lifted into the atmosphere and is dropped ahead of the main fire front in the form of burning embers. These embers can collect in gutters and crevices in buildings where they smoulder and eventually ignite.

FireDST developed an approach to integrate the hazard and impact model by computing the fire conditions at a building location for each fire simulation and then integrating these results into the ensemble. Chapter 9 describes the source and derivation of building location information used in FireDST.

10.2.2 Method

10.2.2.1 Individual building Damage Estimation for each simulation

The fire spread module in FireDST, driven by PHOENIX RapidFire, models the fire's characteristics at the resolution of 180 m grid cells. The PHOENIX RapidFire simulates the hazard in terms of:

- The maximum radiation intensity experienced in a grid cell (kW/m); and
- The total ember density received over the whole fire (Number/m^2).

The red square in Figure 10.1 shows an example of a 180 m grid cell for which PHOENIX RapidFire provides the physical parameters characterising the fire hazard. Figure 10.1 shows the location of various buildings in the cell, as well as the surrounding vegetation and roads.

Ideally the radiation and embers experienced by each building in the cell will be different depending on the direction that the fire approached, the surrounding vegetation and buildings that can provide shielding or act as a local radiation source. Modelling this is a very complex physical problem that was divided into an incremental series of steps.

Figure 10.1 Example of buildings in a 180 m grid cell that also includes trees, hedges and open space. While FireDST assumes radiation is a function of distance of a building to the fire, it is in reality moderated by the proximity of vegetation or structures that may either have a shielding function, or act as an additional source of radiation.

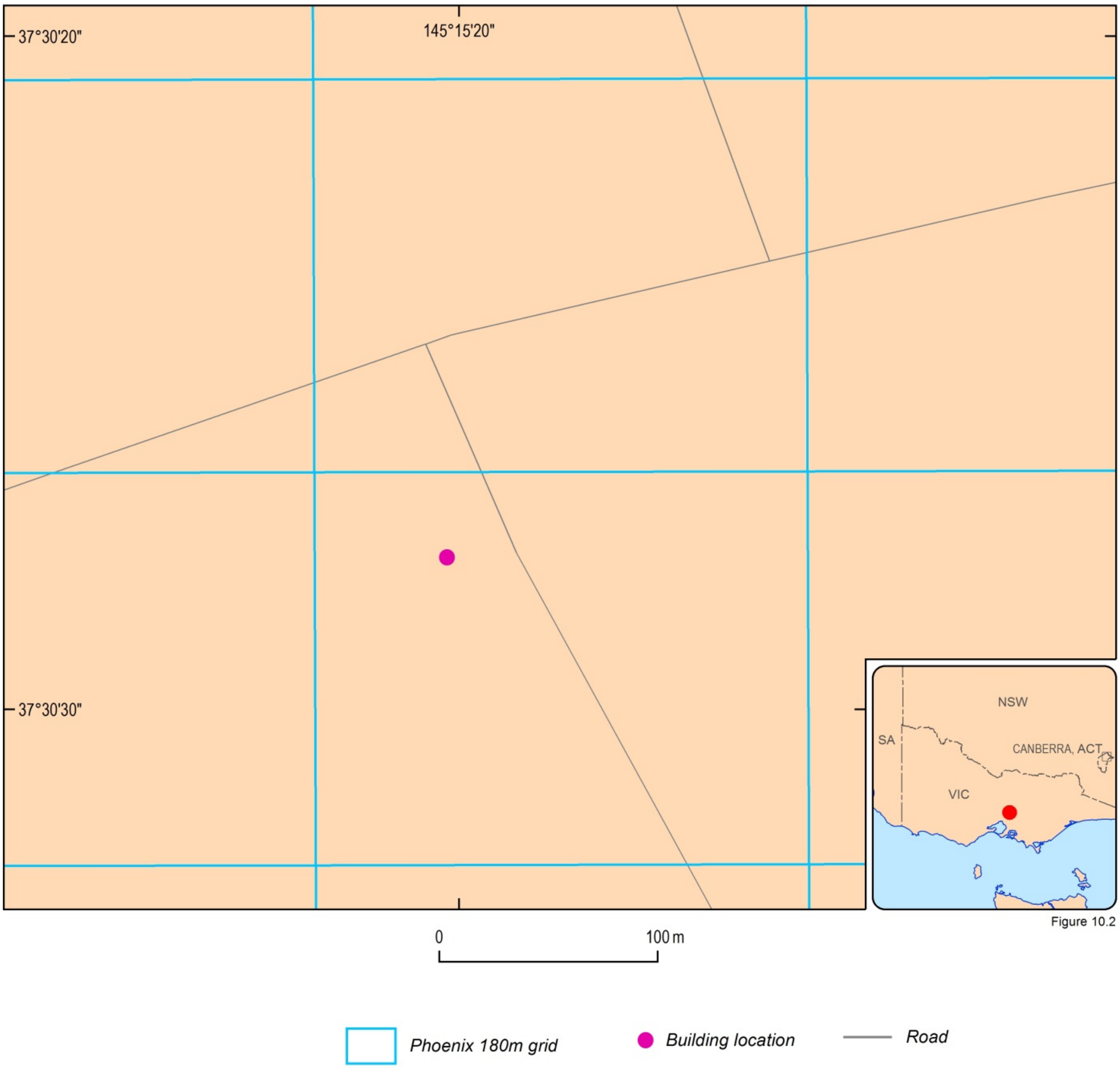

Figure 10.2 Contrast between the resolution of a single building location and a 180 m grid cell. The characteristics of the fire hazard need to be scaled down from the larger grid cell to the resolution of the individual building

10.2.2.2 Effect of radiation on the building

The 180 m grid cell fire characteristics are scaled down to the hazard experienced by the individual buildings in the cell. Each building is considered in isolation of its environment (Figure 10.2). Local information about vegetation surrounding the house is not considered, as this information was not available at the time of this research. Later chapters discuss the modelling of building to building ignition.

FireDST converts the maximum fire line intensity value in the 180 m cell (in kW/m) to the radiation experienced at various distances away from the house (in kW/m^2). This conversion assumes the radiation experienced by the building is a function of distance from the fire line. As a default, FireDST assumes that the radiation is generated by the fire line intensity being 5 m away from the building.

In the context of this project, vulnerability curves are then used to specify the probable damage to a building as a function of the radiation and ember hazard experienced at the building. Damage is specified as a percentage loss. The higher the hazard intensity, the higher percentage damage, until the building is considered to be so damaged that it is classed as destroyed. The vulnerability of a building is a function of its physical characteristics, such as age, construction type and materials, maintenance status etc. Vulnerability functions for fire can even be direction specific, as the characteristics determining the building vulnerability may vary on with different angles of the fire's approach to the building. FireDST has been designed to have the ability to apply a large suite of specific vulnerability curves based on building characteristics or approach angle. However, at the time of this project, such specific curves were not available. This research developed an approach to integrating building damage as part of impact modelling through applying a single set of 'average' curves to all buildings.

CSIRO Environmental Sciences in collaboration with Geoscience Australia produced a set of four average vulnerability curves that were applied to each house. The four curves consisted of one for radiation hazard and three for ember attack hazard. The curve for radiation attack is shown in Figure 10.3.

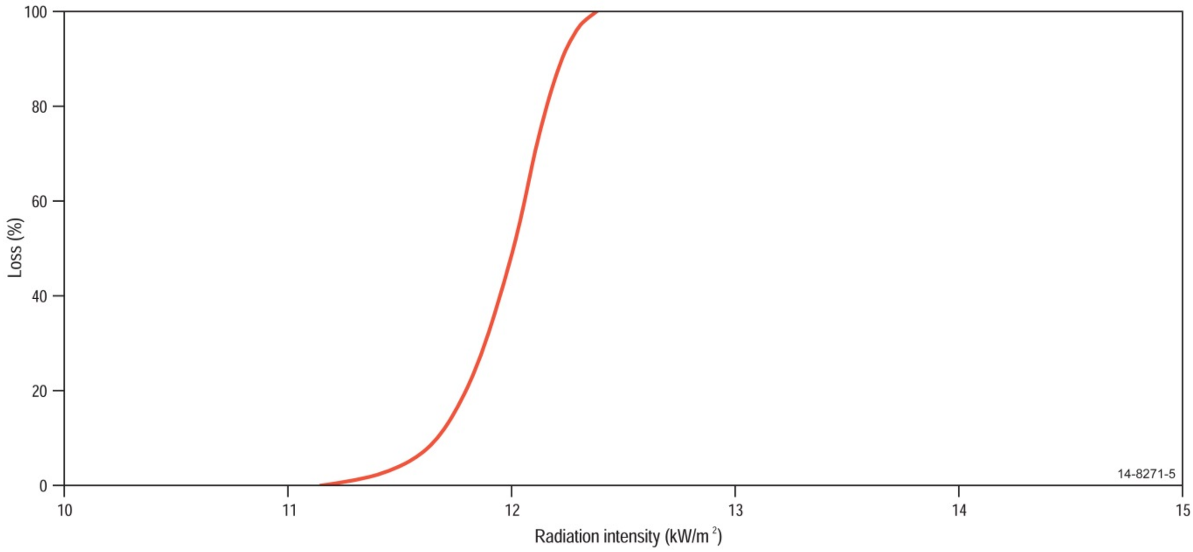

Figure 10.3 House loss as a function of radiation hazard, with total loss modelled at 12.5 kW/m2 of radiation.

The vulnerability curve for radiation hazard (Figure 10.3) reaches 100% loss when the radiation reaches 12.5 kW/m^2, which is the radiation level at which a standard pane of glass will break. Once windows are broken, radiation and burning embers can enter the building and cause catastrophic building fire (J. Leonard, 2011 pers. comm.).

10.2.2.3 Effect of embers on the building

FireDST computes the ember density hazard as the total number of embers per m^2 in each of the 180 m grid cells within the fire spread. The current building database does not include floor area so the ember density hazard at the building location was assumed to be the same value as the total ember density experienced on the cell.

The vulnerability curves for ember density hazard (Figure 10.4) are developed based on the understanding that fuel moisture content drives the probability that exposed wood in a house is ignited by embers. CSIRO research has indicated that building wood will not be ignited by embers if the fuel moisture content is greater than 10% (J. Leonard, 2011 pers. comm.). Table 10.1 shows the relationship between fuel moisture and the respective vulnerability curves.

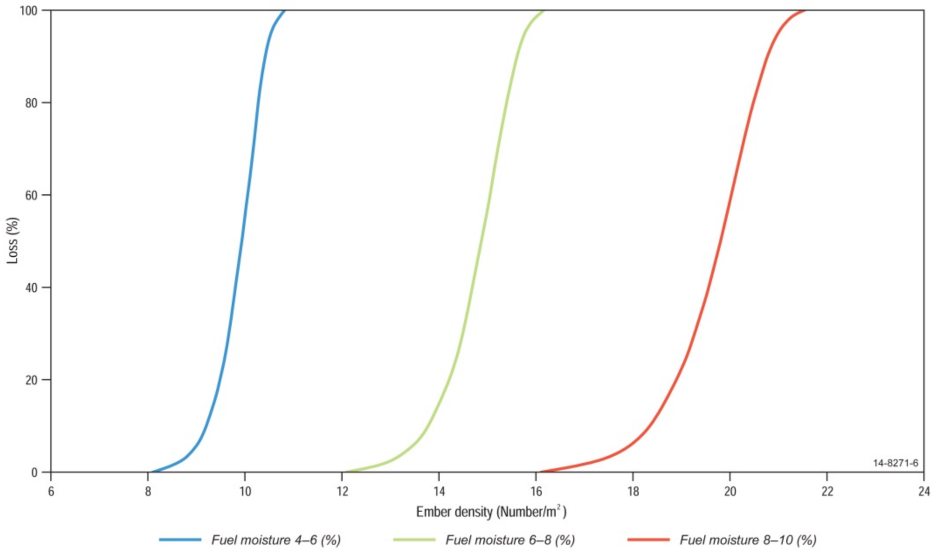

Figure 10.4 House loss as a function of ember density hazard (Number/sq.m.) for (a) 4 to 6% fuel moisture, (b) 6 to 8% fuel moisture and (c) 8 to 10% fuel moisture.

Table 10.1 Relationship between fuel moisture and the vulnerability curve.

Fuel Moisture	Vulnerability Curve
0-4%	House will be destroyed by ember attack, no curve required.
4-6%	4% curve
6-8%	6% curve
8-10%	8% curve
Greater than 10%	House is not vulnerable to ember attack, no curve required.

10.2.2.4 House loss modelling method

The vulnerability curves that were used in this study all have steep gradients as fire attack typically results in a quick transition between nearly undamaged (0% loss) state of a building to total damage (100% loss).

It is also possible that some houses will come close to being destroyed but will just remain damaged. This research defined a ‘destroyed threshold’ percentage where the building transitions from ‘damaged’ to ‘destroyed’ on the vulnerability curve.

As described above, the vulnerability of a building to radiation can be sensitive to the direction in which the fire approaches it. FireDST computes the angle of approach in 45º increments around each house to allow implementation of future angle-specific curves. However, in this study, the vulnerability was not actually modified with angle of approach.

The integrated approach of modelling fire spread and impact taken by FireDST was validated against the Mt Hall fire by comparing actual building damage against the modelled damage. For this experiment, the vulnerability curves specified above were used with an ember destroyed threshold of 50%, radiation destroyed threshold at 50% and radiation distance as 5 m. The vulnerability curve for radiation hazard assumed total loss (100%) at 12.5 kW/m^2.

In addition, the FireDST building information was augmented with additional data for buildings located within the Mt Hall case study region, shown in Table 10.2. This data included building damage recorded in post-event surveys in the respective fires, as well as parameters specifying the vulnerability curve. The historical event damage record was not required for the actual modelling, but allowed assessment of the accuracy of the modelled damage.

Table 10.2 Additional data parameters available within the FireDST exposure database utilised for the impact modelling.

Parameter name	Parameter description
Vulnerabilities	Consists of direction, ember_alpha and ember_beta, radiation_alpha and radiation_beta. These parameters define the vulnerability curve used for the direction of fire approach to each building
Damage	Results of the building survey after each fire. Contains DESTROYED, MINOR or NONE

10.2.2.5 Building Damage Estimation for the ensemble

The previous section has outlined how FireDST modelled whether a building in a fire spread simulation is damaged by the fire. When ensemble damage statistics are computed, building damage was summarised for each interval in the percentage overlap of the ensemble fire spread. A building in the ensemble is classified as destroyed if it has been destroyed in one or more of the simulations.

10.2.2.6 Sensitivity of house loss to vulnerability

The sensitivity of modelled house damage to various hazard and vulnerability parameters was assessed in a set of experiments. The sensitivity of house loss to the hazard was assessed through a 30-member ensemble sampling variability in weather and ignition information (Appendix C). Further tests examined the sensitivity of house loss to:

- The vulnerability curve for radiation hazard;
- The distance of the house to the fire front; and
- The threshold where the building is assumed to be destroyed (Appendix E).

For the sensitivity of house loss to radiation vulnerability, a suite of curves was tested with total loss assumed at 12.5, 19, 29 and 40 kW/m^2, respectively. These particular radiation levels were selected in line with the radiation levels listed in the AS3959 Building Standard, Bushfire Attack Level. For the vulnerability tests, the fire characteristics were based on the fire spread scenario that best matched the historical footprints. In this case, that was the 4000 m resolution ACCESS run for the historical conditions, adjusted with bias correction and Wind Ninja multipliers, and the historical ignition.

The sensitivity assessment for the destroyed threshold was tested by sampling the destroyed threshold value from 5% damage to 95% damage in steps of 5%. As the value increases, more buildings would be classed as damaged, rather than destroyed.

10.3 Results and Discussion

10.3.1 Damage Estimation

Table 10.3 shows the impact statistics for the 45 member ensemble simulation in Figure 4.1. The exposure analysis indicates there are 689 houses exposed to the ensemble fire spread footprint (Table 9.2), of which 413 houses were modelled to be destroyed in at least one scenario (Table 10.3). This is a snapshot of the fire damage during the ensemble, not the total house loss across the lifetime of the event.

Table 10.3 FireDST Building related impact statistics for the ensemble simulation shown in Figure 4.3

Ensemble shape impact area likelihood	Number of houses impacted	Estimated house replacement cost $	Estimated house contents value $
81-100	22	7,639,552	3,317,768
61-80	62	35,796,590	6,492,500
41-60	85	90,382,180	10,161,250
21-40	85	68,294,200	11,513,830
5-20	159	97,461,410	28,766,650

Based on the 'best fit' fire spread scenario and the default vulnerability curves, FireDST achieved an accuracy of 33% for the modelled house loss in the Mt Hall event (Table 10.4(a)). This demonstrates that vulnerability modelling still contains considerable uncertainty. Further investigation would be needed to confirm the main causes of this poor result.

The inability to match the historical fire spread is likely to be the main cause of the inaccurate damage estimate. Where the modelled fire spread did not cover the actual burnt area, accuracy was limited. This is further demonstrated by the results in Table 10.4(b), which present the average accuracy across the whole sensitivity analysis that samples the error in the fire conditions, in terms of the surface weather, fuel and ignition. The average accuracy is lower than the figures reported in Table 10.4 because it is lowered by the fire spread scenarios that did not approximate the historical event.

Modelled impacts showed sensitivity to changes in the radiation vulnerability curve. Both modelled impacts based on the 'best' scenario and the ensemble for the Mt Hall case study showed a decline in accuracy with an increase in the radiation vulnerability threshold. Comparison of the sensitivity results from both columns in Table 10.4(a) shows that the limitations of the fire spread modelling exacerbated the errors in the vulnerability assumptions. The estimate based on the single 'best' footprint showed little sensitivity until the threshold was raised to 40 kW/m^2, while the ensemble-based sensitivity was more even. This suggests that developing a better calibrated, validated, and particularly a more specific set of curves (based on house age or building type) is likely to contribute to improvements in the accuracy of loss modelling.

Table 10.4 Accuracy of modelled house loss using different radiation vulnerability assumptions (%). (a) Accuracy of modelled house loss based on hazard from the scenario that best matched the historical footprint. (b) Accuracy averaged across the whole sensitivity analysis sampling variability in surface weather parameters, ignition timing and location, and fuel conditions.

Radiation value (kW/m2)	Modelled Accuracy 'Best' Footprint	(b) Average Modelled Accuracy Ensemble
12.5	33	28.9
19	32.8	24.2
29	32.1	15.5
40	20.3	9.2

Tests showed that house loss was sensitive to the distance assumed to be between the building and the fire line, with losses decreasing with distance. The sensitivity analyses suggested that assumption of 5 m distance produced results that matched the historical losses, and this value was chosen as a default in the modelling.

Results showed there was little or no sensitivity of house loss to the destroyed threshold on the vulnerability curve. This lack of sensitivity is likely to be caused by the steepness of the vulnerability curves used in this study.

10.4 Conclusions and Future Work

The FireDST system estimates whether a building is destroyed by fire, based on the building location and the bushfire characteristics. Building damage information can be directly related to the corresponding area of the ensemble fire spread. The project implemented a set of four vulnerability curves that estimated house loss as a function of radiation intensity and ember density. In order to apply these curves, the FireDST system integrates the large-scale fire spread modelling with a parameterisation of sub-grid scale fire conditions.

The accuracy of FireDST using the vulnerabilities to predict house loss for the individual houses in the Mt Hall was 33%, demonstrating that vulnerability modelling requires further development and validation. Results demonstrated that the performance of the vulnerability model is sensitive to the uncertainty in the fire spread modelling itself. Estimated house loss was also shown to be sensitive to the assumptions of the vulnerability function. Ideally, vulnerability functions should reflect differences in relevant building characteristics, such as construction type, age, building-code compliance and maintenance level. The vulnerability functions applied in this project did not vary with these characteristics, and could therefore only be expected to attain a limited level of accuracy for individual buildings.

In summary, the results discussed in this chapter demonstrate that it is possible to estimate building damage information as part of a fire spread modelling approach. Such an integrated approach could present a significant improvement in terms of potential information and efficiency over separate modelling processes. Furthermore, it is shown that the ensemble approach can be extended to include building damage and loss. The information that is generated by ensemble output can further help to understand the robustness and limitations of the impact modelling.

10.4.1 Future Work

Numerous key gaps remain to be filled to improve the ability of estimating house loss in (Australian) bushfires. The following points highlight potential research opportunities:

- There is a need for an improved set of validated vulnerability curves based on expanded research and validated by observations. Ideally, such curves should be tailored towards different building types and their characteristics. Even a very good ‘average’ curve can only result in inaccuracies, as it cannot capture the variability between building damage because, for example, a wood structure is more vulnerable than a brick building. This research needs to reflect the vulnerabilities of Australian buildings, as these are likely to differ from those in other countries were similar research is undertaken;
- As an extension to the previous point, the vulnerability modelling approach should include a methodology to account for the influence of surrounding vegetation and buildings on house loss. Neighbouring ‘obstructions’ can decrease the amount of radiation that a building will experience and therefore decrease the vulnerability. However, if the obscuring object itself ignites it may produce more radiation or embers, thus increasing the vulnerability. This research area has been partly covered in Chapter 10;
- There is a need for a greater understanding, supported by observational evidence, of the sensitivity of building loss to the direction of the fire approach. This should validate the assumption that building vulnerability is determined by the dominant characteristics of the building that face the approaching fire. For example, for a brick structure, the effective vulnerability is assumed to be different if the fire approached a windowless wall as compared to a façade with glass doors and a wooden deck. While FireDST was designed to be able to modify the vulnerability based on direction of approach, there was as yet no evidence to support the implementation of this; and
- A confidence level could be calculated for the estimated damage to each building, based on the variability of the estimated damage across the ensemble.

11 Conclusions from the Mt Hall Case Study

The results presented and discussed in this report demonstrate the potential of the FireDST approach for assessing aspects of the sensitivity of modelled fire spread and impact for the Mt Hall 2001 event. In line with the research objectives laid out in Chapter 2, FireDST provides an integrated fire spread and impact model. Furthermore, it implements an approach to assess and visualise sensitivity of modelled fire spread and impact to input parameters and assumptions. The FireDST system is applied to assess the sensitivity of the fire spread and impact to surface weather, fuel load, ignition, and vulnerability assumptions. The methodology was extended to enable assessment of the sensitivity of smoke to a range of parameters.

The Mt Hall case study results demonstrate some fundamental benefits from ensemble information that are not easily achieved in ‘best estimate’ single scenario model outputs. The range of the ensemble fire spread or impact is a direct measure of the model sensitivity to the parameters sampled to generate the ensemble. Therefore, such information supports better understanding of the robustness of model outputs.

Key findings of this work include:

- The modelled fire spread for the Mt Hall event based on the ACCESS simulations of the surface weather, ignition and fuel at the time did not match the historical fire spread very well. The wind speeds were likely underestimated in the ACCESS simulation; however insufficient observations were available to correct the simulation;
- The modelled fire event could only approximate the historical fire spread by introducing additional ignition points. These additional ignitions may reflect actual spotting caused by the fire that was burning across Lake Burragorang at the same time, although this fire was not included in the modelling;
- This report does not attempt to rank the sensitivity of the fire spread and impact to different parameters. This would only have been possible if the perturbation range of parameters was set on a consistent basis to be comparable (i.e. based on the probability distribution of the uncertainty);
- Testing sensitivity of fire spread modelling to individual parameters in isolation ignores the interactions between the parameters and their impact on the fire. In other words, a scenario generated by a combination of perturbed parameters may not reflect the variation caused by the individual parameters. To ensure a realistic sensitivity assessment, ensembles should include combinations of parameters;
- As noted above, the scenarios in FireDST are not currently weighted by probability. With that information, the methodology used by the FireDST system would generate probabilistic fire spread and impact estimates;
- The accuracy of the impact modelling is fundamentally linked to, and limited by, the fire spread modelling; and
- The vulnerability model used to estimate house loss in FireDST is generic and not validated. Further work is needed to improve the maturity of this model.

The final report of the F.I.R.E-D.S.T. Project (Cechet *et al.,* 2014) discusses the Mt Hall case study in context of the other case studies and the objectives of the entire project.

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Appendix A Ensemble – Scenario Labelling

Each scenario described in this report is defined by a combination of parameter settings. The following list defines the codes with the parameter settings. The scenario names, specified in Appendices C and E, are a combination of these codes that specify the scenario's parameter settings.

- MtH – Mt Hall
- VN – No vertical atmosphere included in the modelling
- W400 – 440 m resolution weather, ie ACCESS model grid resolution 440 m
- W1200 – 1200 m resolution weather, ie ACCESS model grid resolution 1200 m
- W3600 – 4000 m resolution weather, ie ACCESS model grid resolution 4000 m
- T05 – 5 minute time steps
- T15 – 15 minute time steps
- T30 – 30 minute time steps
- T60 – 60 minute time steps
- S0 – no Suppression; the suppression component was deactivated in the Phoenix RapidFire module
- B0 – No bias correction of wind speed
- BC – Bias correction of wind speed
- M0 – No local wind modification was applied to the wind speed
- MN – Wind Ninja local wind modification was applied to the wind speed
- GP – Grid +2º Latitude
- GM – Grid -5º Latitude and Longitude
- TEP – Temperature plus
- TEM – Temperature minus
- RHM – Relative humidity minus
- RHP – Relative humidity plus
- WDP – Wind direction plus
- WDM – Wind direction minus
- WSP – Wind speed plus
- WSM – Wind speed minus

Appendix B Ensemble – Mt Hall Scenarios Applied in F.I.R.E.D.S.T.

These individual PHOENIX RapidFire simulations make up the 23 member ensemble shown in Figure 4.6. The meaning of the scenario labels is given in Appendix A.

- MtH_VN_W3600_T05_S0_MN_B0
- MtH_W3600_T05_S0_MN_B0_RHM5
- MtH_VN_W3600_T15_S0_MN_B0_TEP10
- MtH_VN_W3600_T15_S0_MN_B0_WDM25
- MtH_VN_W3600_T15_S0_MN_B0_WDP25
- MtH_VN_W3600_T15_S0_MN_B0_WSP5
- MtH_VN_W3600_T15_S0_MN_B0_WSP20
- MtH_VN_W3600_T15_S0_MN_B0_RHM5_TEP5_WSP5_WDM10
- MtH_VN_W3600_T15_S0_MN_B0_RHM5_TEP5_WSP5_WDM15
- MtH_VN_W3600_T15_S0_MN_B0_RHM5_TEP5_WSP5_WDM20
- MtH_VN_W3600_T15_S0_MN_B0_RHM5_TEP5_WSP5_WDM25
- MtH_VN_W3600_T15_S0_MN_B0_RHM5_TEP5_WSP5_WDP10
- MtH_VN_W3600_T15_S0_MN_B0_RHM5_TEP5_WSP5_WDP15
- MtH_VN_W3600_T15_S0_MN_B0_RHM5_TEP5_WSP5_WDP20
- MtH_VN_W3600_T15_S0_MN_B0_RHM5_TEP5_WSP5_WDP25
- MtH_VN_W3600_T15_S0_MN_B0_RHM5_TEP5_WSP10_WDM20
- MtH_VN_W3600_T15_S0_MN_B0_RHM5_TEP5_WSP10_WDM25
- MtH_VN_W3600_T15_S0_MN_B0_RHM5_TEP5_WSP15_WDM20
- MtH_VN_W3600_T15_S0_MN_B0_RHM5_TEP5_WSP15_WDM25
- MtH_VN_W3600_T15_S0_MN_B0_RHM5_TEP5_WSP20_WDM20
- MtH_VN_W3600_T15_S0_MN_B0_RHM5_TEP5_WSP20_WDM25
- MtH_VN_W3600_T15_S0_MN_B0_WSP15_WDP15
- MtH_VN_W3600_T15_S0_MN_B0_WSP20_WDP20

Appendix C Multiple ignition points used in Mt Hall simulations

Table C.1 Ignition points used in Mt Hall simulations.

Ignition Number	Time	PHOENIX RapidFire Easting	PHOENIX RapidFire Northing	Approx. Latitude	Approx Longitude	PHOENIX RapidFire number
1	13:10	275325	6246510	-33.901931	150.570631	21
2	12:40	275825	6246550	-33.897911	150.575126	18
3	12:35	276200	6246700	-33.896637	150.579911	17
4	12:55	276575	6247090	-33.892923	150.584235	15
5	13:00	276900	6247299	-33.891062	150.588452	14
6	14:03	277250	6247600	-33.888613	150.591155	19
7	13:55	277384	6247618	-33.888079	150.592614	1
8	14:00	277350	6247650	-33.887767	150.593237	22
9	13:55	277400	6247750	-33.886787	150.593923	23

Appendix D 2006 Census Human Vulnerability Indicators

Table D.1 2006 Census human vulnerability indicators used in FireDST.

Vulnerability Indicator	Description
Young at risk	Anyone under the age of 5
Aged at risk	Anyone aged 65 or older
Insufficient English	Any person who identified in the Census as able to speak English not at all or not well.
Not completed Year 12	Any person who has indicated in the Census that they have not completed schooling to Year 12 (approximately 18 years of age)
Need for Assistance	Any person who has identified in the Census that they need assistance with self care activities such as feeding, dressing and washing, or need assistance with communication
Volunteering rate	This Census indicator measures the number of people who spend time in volunteer activities.
Low Income Households	Households who have indicated in the Census that they have an income of less than $500
No Motor vehicle access	Measures the number of households that do not have access to a motor vehicle.
New One Year	Occupant lived in the property less than a year. This is based on the stated address of the person one year ago.
New Five Year	Occupant lived in the property less than five years. This is based on the stated address of the person five years ago.
Single Parent Families	All families that have children under 15 years old and that have only one parent living at that location.
Indigenous	All persons who identify as being Aboriginal or a Torres Strait Islander.
Public Housing	All persons who rent their house from a state or territory housing authority.
Unoccupied homes	When the Census is collected the collector notes if a form is not completed and if the house appears to be unoccupied at the time of their visit

Appendix E Vulnerability Sensitivity Analysis Simulation Set

Table E.1 lists the PHOENIX RapidFire scenarios that were used to assess the sensitivity of the house loss to the vulnerability functions, described in Chapter 9. See Appendix B for the meaning of the scenario labels.

Table E.1 FIRE-DST scenarios used in the vulnerability sensitivity assessment.

Number	Indicator
1	MtH_VN_W400_T05_S0_MN_B0_RHM5
2	MtH_VN_W400_T05_S0_MN_B0_TEP10
3	MtH_VN_W400_T05_S0_MN_B0_WDM25
4	MtH_VN_W400_T05_S0_MN_B0_WDP25
5	MtH_VN_W400_T05_S0_MN_B0_WSP5
6	MtH_VN_W400_T05_S0_MN_B0_WSP20
7	MtH_VN_W1200_T05_S0_MN_B0
8	MtH_VN_W400_T05_S0_MN_B0_RHM5
9	MtH_VN_W400_T05_S0_MN_B0_TEP10
10	MtH_VN_W400_T05_S0_MN_B0_WDM25
11	MtH_VN_W400_T05_S0_MN_B0_WDP25
12	MtH_VN_W400_T05_S0_MN_B0_WSP5
13	MtH_VN_W400_T05_S0_MN_B0_WSP20
14	MtH_VN_W3600_T05_S0_MN_B0
15	MtH_VN_W3600_T05_S0_MN_B0_RHM5
16	MtH_VN_W3600_T05_S0_MN_B0_RHM5_TEP5_WSP5_WDM10
17	MtH_VN_W3600_T05_S0_MN_B0_RHM5_TEP5_WSP5_WDM15
18	MtH_VN_W3600_T05_S0_MN_B0_RHM5_TEP5_WSP5_WDM20
19	MtH_VN_W3600_T05_S0_MN_B0_RHM5_TEP5_WSP5_WDM25
20	MtH_VN_W3600_T05_S0_MN_B0_RHM5_TEP5_WSP5_WDP10
21	MtH_VN_W3600_T05_S0_MN_B0_RHM5_TEP5_WSP5_WDP15
22	MtH_VN_W3600_T05_S0_MN_B0_RHM5_TEP5_WSP5_WDP20
23	MtH_VN_W3600_T05_S0_MN_B0_RHM5_TEP5_WSP5_WDP25
24	MtH_VN_W3600_T05_S0_MN_B0_RHM5_TEP5_WSP10_WDM20
25	MtH_VN_W3600_T05_S0_MN_B0_RHM5_TEP5_WSP10_WDM25
26	MtH_VN_W3600_T05_S0_MN_B0_RHM5_TEP5_WSP15_WDM20

Number	Indicator
27	MtH_VN_W3600_T05_S0_MN_B0_RHM5_TEP5_WSP15_WDM25
28	MtH_VN_W3600_T05_S0_MN_B0_RHM5_TEP5_WSP20_WDM20
29	MtH_VN_W3600_T05_S0_MN_B0_RHM5_TEP5_WSP120_WDM25
30	MtH_VN_W3600_T05_S0_MN_B0_TEP10
31	MtH_VN_W3600_T05_S0_MN_B0_WDM25
32	MtH_VN_W3600_T05_S0_MN_B0_WDP25
33	MtH_VN_W3600_T05_S0_MN_B0_WSM5
34	MtH_VN_W3600_T05_S0_MN_B0_WSP5
35	MtH_VN_W3600_T05_S0_MN_B0_WSP20

Tables E.2 to E.4 list the vulnerability functions that were tested as part of the sensitivity analysis.

Table E.2 Vulnerability sets used (VGR Generic set – applied to all houses).

Definition	Comments
Generic Radiation curve (centred on 12.5 kW/m^2)	Uses 12.5 kW/m^2 (mainly houses that are built to older building standards). BAL-12.5
Generic Ember Vulnerability for 4-6% Humidity	In using the Generic Vulnerabilities, FIRE-DST uses the 4-6% ember curves to use at the house based on the PHOENIX RapidFire cell Humidity.
Generic Ember Vulnerability for 6-8 % Humidity	In using the Generic Vulnerabilities, FIRE-DST uses the 6-8% ember curves to use at the house based on the PHOENIX RapidFire cell Humidity.
Generic Ember Vulnerability for 8-10 % Humidity	In using the Generic Vulnerabilities, FIRE-DST uses the 8-10% ember curves to use at the house based on the PHOENIX RapidFire cell Humidity.

Table E.3 Vulnerability sets used (Radiation Extension Sets – all use generic ember curves for all houses).

Primary Indicator	Definition	Comments
VR19	Radiation Resistant (centred on 19 kW/m^2))	Radiation curve shifted to the right to make houses more resistant to radiation – centred on 19 kW (matches BAL-19 in AS3959)
VR29	Radiation Resistant (centred on 29 kW/m^2))	Radiation curve shifted to the right to make houses more resistant to radiation – centred on 29 kW (matches BAL-29 in AS3959).
VR40	Radiation Resistant (centred on 40 kW/m^2))	Radiation curve shifted to the right to make houses more resistant to radiation – centred on 40 kW (matches BAL-40 in AS3959)

Table E.4 Variables used in testing the vulnerability sets.

Primary Indicator	Definition	Test values	Units	Test Environment	Comments
RAD	Radiation	5 to 95% in steps of 5	%	Ember Destroyed Threshold = 50% Distance = 5 m	The Table D.2 radiation sets are tested for sensitivity to variation in the radiation destroyed threshold on the supplied radiation curve in the Table D.2 set.
EMB	Ember	5 to 95% in steps of 5	%	Radiation Destroyed Threshold = 50% Distance = 5 m	The Table D.2 ember sets are tested for sensitivity to variation in the ember destroyed threshold on the supplied ember curve in the Table D.2 set selected from the actual humidity.
DIST	Distance	100,95,90,85,80,75,70, 65,60,55,50,45,40,35,30, 25,20,15,10, ,5, 1	M	Ember Destroyed Threshold = 50% Radiation Destroyed Threshold = 50% (centre of curve)	The Table D.2 sets are tested for sensitivity to variation in the distance. Maximum distance will depend on whether the change in distance is having any affect.