SA Power Networks

Supporting document 5.14

# Bushfire mitigation program CBA Methodology

**2020-2025 Regulatory Proposal**

January 2019

SA Power Networks

# Bushfire mitigation program

## Bushfire risk and cost-benefit analysis methodology

# Contents

# Document Control

| Version | Date | Author | Notes |
|---|---|---|---|
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# Foreword

During our 2015-2020 Regulatory Submission, the Australian Energy Regulator (**AER**) provided critical but informative feedback on the lack of quantitative analysis to support our bushfire risk management submission.

We therefore set about developing a Cost-Benefit Analysis (**CBA**) model which provided:

a) quantitative probabilities and consequences of fires starting from SA Power Networks assets; and

b) enabled us to select options whose costs were commensurate with that risk.

We believe the CBA model presented here is comprehensive and robust and meets AER's objective that regulatory submissions need to be accompanied by a formal quantitative risk assessment and cost-benefit analysis.

This model would not have been possible without the significant efforts of and collaborative cooperation between, Brian Nuttall (overall CBA model development), CSIRO (bushfire footprint modelling and suppression rate calculations) and Risk Spatial (losses from attendant fire footprints).

We also appreciated the constructive feedback of Country Fire Services (fire propagation) and Department of Environment and Water (fire suppression model).

Within SA Power Networks, Joel Beattie and Boris Celic prepared a number of inputs for the recloser modelling.

Frank Crisci
**Manager Emergency Management**

# 1. Purpose

The purpose of this document is to explain the methodology we have used to:

- estimate the bushfire risk due to our network; and
- perform the cost-benefit analysis that we have used to assess the bushfire mitigation capital program.

This document also explains why we believe that this methodology and its results are reasonable for our circumstances.

Where necessary to aid in the understanding of the methodology and support views on its appropriateness, this document provides some key results from our application of this methodology. However, this document does not present and discuss the overall results of this analysis, including the bushfire mitigation program that we have developed using this methodology. These matters are discussed in more detail in the **Bushfire Mitigation Program Strategy** document.

# 2. Introduction

## Background

In 2016, we commenced a significant project to develop a methodology and model to:

- more accurately assess and quantify the bushfire risk imposed by our network on the SA community; and
- provide an analysis framework to perform formal cost-benefit analysis of bushfire mitigation program options.

An important objective for this project was to ensure that we could demonstrate that our bushfire mitigation capital program provided a net economic benefit (ie the economic benefits from the program would exceed the costs of the program).

The need for this project followed the AER's criticisms of our previous regulatory proposal, which included a number of bushfire mitigation programs. The AER did not allow for these programs in its revenue decision as it considered that we had not demonstrated that our bushfire risk was sufficiently high and that there would be a net economic benefit in undertaking these programs.

We accept these criticisms and acknowledge that our previous analysis was limited. Its focus was to demonstrate that: (a) we *do* start fires each year in high bushfire risk regions[1] and (b) providing an estimate of the Maximum Probable Loss that could result if one of these fires developed into a major bushfire event. While this analysis provided a qualitative indication of our bushfire risk, it did not provide this in a way that allowed formal cost-benefit analysis and did not readily pinpoint which assets could be contributing most to the bushfire risk.

The methodology set out in this document has been developed partly in response to these criticisms.

***Caveat on the bushfire risk results given by this methodology***

Given major bushfires are rare events, there is inherent uncertainty and data sparsity in developing a model of this type. We have tried to ensure we are not overstating the bushfire risk, and therefore, we are not overstating the scale of the mitigation program that will provide a net-benefit.

However, it is important to also highlight that with these data limitations, there is also the possibility that our risks are *understated*. It is also important to note that the model's key bushfire risk output represents a *long-term average* annual bushfire risk, and so, actual outcomes in any year can be considerably different, and in some years very large.

We have been working with stakeholders and will continue to work with them to strike the right balance in using this model. Given these limitations, the results of this model should not be taken as the sole or primary determinant of bushfire mitigation decisions.

[1] Our historical fire start records support this assertion

## Why our methodology is appropriate

We believe our risk assessment and cost-benefit methodology aligns with the recent AER statements on its expectation for formal quantitative risk assessments and cost-benefit analysis.

The key features that we believe demonstrate the robustness of our analysis are:

- **We are calculating risks across a range of bushfire conditions**

  We determine the bushfire risk by separately calculating bushfire probabilities and bushfire consequences across a range of possible bushfire conditions. This ensures that we understand the make-up of the bushfire risk in the context of mitigation options, including supply switch-off conditions and the risks associated with this.

- **We have engaged expert advice on bushfire modelling**

  To understand the potential range of major bushfires, which could be started by our network, under different conditions, we engaged CSIRO to undertake extensive bushfire simulations in areas covered by our study. CSIRO performed around one million bushfire simulations using its bushfire simulation software called *SPARK*. These simulations cover:

  - 29,765 individual fire start location, which represents start locations at 500m increments along 417 of our feeders; and
  - 36 different weather and bushfire conditions for each of fire start location.

  We also engaged Risk Spatial to assist in developing and applying our methodology for estimating the economic losses associated with each of the CSIRO simulations. Risk Spatial has expertise in assessing and valuing major geographic hazards and risks, such as bushfires and floods. It also has significant experience using geographic information systems (GIS) to undertake these tasks. Risk Spatial is also familiar with use of the public GIS data-sets that have been used for calculating losses.

- **We have calibrated many aspects of our model using historical data of SA bushfire events**

  We have calibrated many of the inputs and assumptions of our model using our database of recent fire starts[2] plus other databases of SA bushfire events. Most notably:

  - we have estimated fire start probabilities from our own recent history, allowing for the improvement we have made over this period
  - we have used various data sources to ensure that fire suppression rates are appropriately moderated to ensure that fire sizes and event frequencies in the model reflect actual SA outcomes; and
  - we have tested our bushfire cost metrics within our model e.g. costs per hectare burnt) against actual public bushfire costs and our own recent insurance claims.

[2] This includes all fire starts that have been reported to us. We investigate each of these fire starts to confirm whether our network was responsible, and records information such as the cause and our response. For our analysis, to ensure we are not overstating the bushfire risk, we have only use fire starts we have confirmed were most likely due to our network.

- **Consultation with key stakeholders to validate model**

  In addition to the engagement of CSIRO, we also consulted with key SA stakeholders that have bushfire analysis and management expertise. This consultation has been used to test model assumptions and gain general support for our approach and its findings.

# 3. Model design, development and consultation

We have used a structured approach to develop and apply our bushfire cost-benefit model. This approach can be considered in terms of a number of phases, which include tasks covering the research, design, development and application of the model. At various stages during the model's development, we have consulted with key stakeholders that have bushfire management and modelling experience.

## Project phases

We structured the development of the bushfire cost-benefit model into three phases:

- **Phase 1** – Research, planning and scoping

  Phase 1 was conducted in early 2017. The key learning from Phase 1 was that we would need to undertake our own analysis and develop our own model to quantify our bushfire risk and evaluate mitigation programs.

  We found very limited information in the public domain that was useful for defining the economic costs from bushfires that we could start and provided in a way that would be helpful to perform formal cost-benefit analysis. Bushfire cost information is typically provided at the gross state level or for major bushfire events (eg catastrophic bushfires similar to those we used to support our previous revenue proposal). In both cases, it is difficult to infer an accurate value of our own bushfire risk and how different feeders contribute to this risk.

- **Phase 2** – Bushfire CBA model development, including bushfire risk analysis and model application

  This phase has been undertaken in two stages.

  - **Stage 1** - The first stage was undertaken in 2017 and involved the analysis of a known high bushfire risk area, the Adelaide Hills area. This more limited analysis was used to test concepts, gain a greater understanding of the scale of the bushfire risk, and allow initial development of the bushfire model form and structure.

  - **Stage 2** – The key finding of the first stage was that the bushfire risk in high bushfire risk areas traversed by our network was likely to be sufficient to warrant a modest bushfire mitigation program across our highest risk feeders. In the second stage, we undertook the analysis across all our feeders that traverse the remaining high bushfire risk areas covered by this study.

- **Phase 3** – Application and documentation

  In this final phase we applied the model to inform the development of the bushfire mitigation program, and prepared the documentation associated with the model and its application.

## Consultation

During the course of this project, we have consulted with a number of key stakeholders who have expertise in bushfire risk management, bushfire modelling and our safety obligations more generally. This consultation has been important for testing our approach, its underlying assumptions, and results.

This consultation involved an initial briefing where we sought CFS and DEW representative comment on our proposed approach, and a subsequent meeting to seek their comments on the model's findings. We also briefed the Office of the Technical Regulator on the latter. Their collective feedback has given us confidence that our approach has produced sound and reliable information.

The full list of key stakeholders consulted is:

- SA Country Fire Service (CFS);
- SA Department for Environment and Water (formally, the Department of Environment, Water and Natural Resources – DEWNR);
- Bushfire and Natural Hazards CRC; and
- SA Office of the Technical Regulator (OTR).

# 4. The scope of our study

## The areas covered by our analysis

Our methodology uses a large amount of analysis to ensure we can have a reasonably accurate estimate of the bushfire risk. Therefore, at this stage, we have limited our study area to the high bushfire risk areas only. This ensures that we have a good understanding and quantification of risk in our most critical areas, where we believe the bushfire mitigation programs would have the highest benefits. Initial analysis suggested that it was unlikely that bushfire risks in other areas would be sufficient to justify the types of mitigation program options being considered at this time. Therefore, we have focused on the high-risk areas for now, with a view to considering other areas in the future if our analysis suggests there may be merit in this.

There are 417 of our HV feeders in the high risk areas, representing approximately 13,900 route kms of distribution and sub-transmission lines. These feeders traverse the following regions (the pink regions shown in Figure 1):

- the Mount Lofty Ranges;
- the South East; and
- high risk regions of the Mid North, Flinders, Lower Eyre Peninsula, and Kangaroo Island.


**Figure 1 Coverage of our new bushfire risk analysis and cost-benefit model (the pink areas)**

## The resolution of our bushfire risk calculations

To produce an accurate estimate of the bushfire risk associated with our network, we have calculated the make-up of the risk across a range of conditions that cover:

- where we can start fires in the high risk areas; and
- how the bushfire and weather conditions associated with that region can affect the bushfire risk.

### The fire start locations and feeder segments

To ensure we are only considering risks due to locations we could start fires, we have defined fire start locations at approximately 500m increments along each of the 417 feeders covered by our study. Each fire start location is used to define a unique 500m segment of a feeder, such that the likelihood, consequence and risk can be calculated separately for each segment, based on simulated fire starts at the fire start location for that segment. There is an inherent assumption that the risks calculated for a fire started at that fire start location are reasonably representative of the risks for any fire that could start along the 500m feeder segment associated with that fire start location.

This 500m resolution was chosen, in agreement with our bushfire expert, CSIRO, as it was considered a reasonable distance that balanced analysis effort of higher resolutions with diminishing increases in accuracy[3].

In total, 29,765 unique fire start locations have been assessed. A more detailed explanation of our method to determine individual fire start locations is covered in Appendix A.

### The bushfire conditions covered by our study

The likelihood of us starting a fire and the scale of the bushfire that could result from such a fire start are influenced by the local bushfire conditions occurring at the time of the fire start and following it. Furthermore, how the bushfire may propagate, and in turn the scale of the resulting bushfire, is also influenced by the weather conditions during the fire event, most notably the wind speed and direction.

Therefore, for each 500m feeder segment, the bushfire risk is calculated for a range of different bushfire and weather conditions. These cover 36 different bushfire and weather conditions considered reasonably foreseeable at that location, covering:

- the six SA fire danger ratings (defined as the maximum rating for that day), where these six ratings are defined as *low-moderate*, *high*, *very high*, *severe*, *extreme*, and *catastrophic*; and
- six different weather patterns associated with that bushfire region and each of the six fire danger ratings, which CSIRO considered reflected the range of likely temperature, wind speed and wind direction.

CSIRO analysed historical BOM data to determine the weather patterns applicable to each location and bushfire rating. The CSIRO analysis also provided:

- the probabilities that a day during the bushfire season will be in the six different bushfire danger ratings

[3] During the course of our analysis, we tested this assumption using results from a single feeder, covering resolutions of 100m, 200m, 500m and 1000m. The results of this test tended to confirm that 500m provided a reasonable accuracy in the calculation of bushfire risk.

- the probabilities of the six weather patterns occurring, given a day of that bushfire danger rating[4].

[4] Note, in the CSIRO documentation, these probabilities are called “weightings”.

# 5. Overview of our methodology to calculate bushfire risk

## Overview of risk definition

Our method is focused on calculating the ***expected* bushfire risk** per fire danger season.

This can be considered the long-term average bushfire risk due to our network per bushfire season. In any actual year, the economic cost of bushfires due to our network will be lower or higher – and in some years, considerably higher. However, for performing formal cost-benefit analysis, these annual variations are averaged out to ensure we can calculate the average annual benefit (in terms of the avoided expected bushfire risk), which is compared with the program costs.

The quantitative *risk of an event* (e.g. a bushfire event) can be considered the product of:

- the *likelihood* of the event occurring (i.e. the likelihood of the bushfire event occurring); and
- the *consequence* of that event (i.e. the economic cost of that bushfire).

Where risks cover a range of possible events or conditions, the total risk will be the aggregation of the individual possible event risks.

Therefore, to calculate this expected – or average – bushfire risk, we focus on calculating the individual event risks associated with the 36 different bushfire and weather conditions for each of the 29,765 unique fire start locations. So in total, we are calculating the bushfire risk in a bushfire season from individual risk event calculations for over 1 million unique conditions[5]. We can combine these individual event risks in different ways to calculate a range of risk measures, such as the fire start location risk, the feeder risk, the region risk, the fire danger rating risk, etc.

[5] Note, by events here, we do not mean individual fire events. We mean the individual conditions that could be associated with a fire start event.

## Overview of risk calculation approach

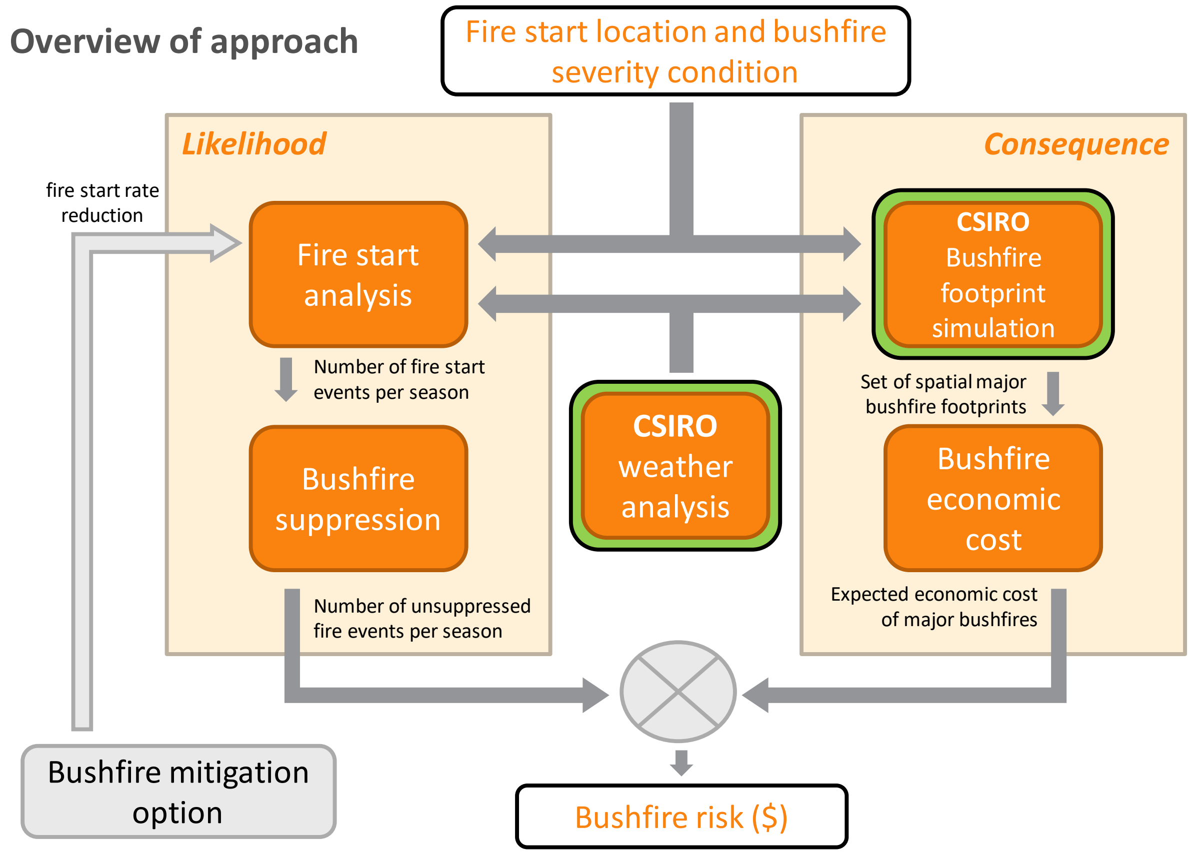


**Figure 2 Overview of bushfire risk calculation process**

Figure 2 provides an indicative overview of the process we use to calculate the individual bushfire event risks, associated with an individual fire start location and one of its 36 bushfire conditions (i.e. 1 element in the over 1 million risk calculations).

This diagram shows the two sides of our risk calculation, covering the *likelihood* and *consequence*.

The key elements of this process are as follows:

### Fire start analysis

For the feeder segment associated with each fire start location, we calculate the average number of fire start events per bushfire season for these bushfire conditions.

To calculate this, we have analysed our historical fire start database. This database records the details of every reported fire start since 2008. This database has been combined with historical fire danger rating data to develop relationships that define the average number of fire starts, per unit length of feeder, per day, in each fire danger rating band.

These relationships are developed at the network level. However, we also estimate various multipliers, which account for differences in fire start rates by region and various technical factors, including the feeder's nominal voltage.

We separately calculate these model parameters for:

- fire-prone open-style surge diverter technologies

- all other fire start events.

In this way, we can isolate the risk due to these two fire start mechanisms, which are important for determining the bushfire mitigation program.

Further details of the methodology we have used to develop these fire start rates are contained in Appendix B.

We use the fire start rates, along with information on the feeder segment associated with the fire start location (e.g. its length, voltage and region), to calculate the expected number of fire starts per day for those bushfire and weather conditions.

We then use the number of days in a bushfire season, along with the probabilities of the bushfire and weather conditions to calculate the final output of this stage of the calculation: the expected number of fire starts per season for this fire start location and the bushfire/weather conditions.

### Bushfire suppression

Although our assets typically start fires during the bushfire season, the majority of these self-extinguish or are extinguished by the public or CFS before they develop into a major bushfire. Therefore, we need to allow for the probability that the expected fire starts determined through the above calculations, result in the size of fire that is predicted through the CSIRO bushfire simulation for the equivalent fire start location and bushfire conditions.

Given elements of bushfire suppression relate to technical matters associated with the management of bushfires, we engaged CSIRO to estimate the proportions of our fire starts that will be suppressed and hence not result in the fire sizes predicted by their bushfire simulations.

CSIRO used a suppression model developed by SA Department for Environment and Water (DEW) as the basis for its model. The DEW suppression model assigns each location in SA to one of eight suppression levels. These levels define how likely it is that any fire start will be suppressed, which relates to factors such as the proximity to public and local fuel types and environment.

CSIRO used this model to produce a matrix of suppression probabilities, where each element in the matrix represents a unique combination of suppression level and fire danger rating (ie the probability of suppression reduces as either the suppression level increases or the fire danger rating worsens).

The probabilities were calibrated by CSIRO to ensure that the number and size of unsuppressed fires predicted by our model should reflect SA's actual historical distribution of fire sizes. These datasets included:

- our own fire start database, which has recorded fire events and fire sizes since 2008; and
- a database maintained by the SA Department of Environment and Water, that includes many SA fire events going back to the 1950s.

CSIRO then analysed each of our fire start locations to assign it to a suppression level based on the geographic information in the DEW suppression model.

The suppression matrix produced by CSIRO is shown in Table 1 below.

| Fire danger rating | Suppression level | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | S0 | S1 | S2 | S3 | S4 | S5 | S6 | S7 |
| **Low-mod.** | 100.0% | 99.6% | 99.6% | 98.4% | 96.7% | 95.6% | 95.6% | 95.6% |
| **High** | 99.4% | 99.1% | 99.1% | 98.0% | 96.5% | 95.7% | 95.7% | 95.7% |
| **Very high** | 99.3% | 98.7% | 98.8% | 96.9% | 94.5% | 93.1% | 93.1% | 93.1% |
| **Severe** | 96.7% | 95.9% | 96.0% | 94.1% | 92.3% | 91.6% | 91.6% | 91.6% |
| **Extreme** | 95.7% | 93.7% | 93.9% | 90.6% | 88.7% | 88.1% | 88.1% | 88.1% |
| **Catastrophic** | 77.6% | 65.8% | 67.1% | 46.5% | 33.3% | 29.0% | 29.0% | 29.0% |

**Table 1 CSIRO suppression model**

A paper prepared by CSIRO describing the methodology that it has used to prepare its suppression model is provided as an Attachment to this document.

## CSIRO bushfire footprint simulation

The CSIRO's bushfire simulations are used to estimate the physical footprint of the bushfires that would result from a fire start at the fire start location, given the bushfire and weather conditions and assuming the fire start is not suppressed. This analysis has been applied by CSIRO using its own bushfire simulation tool, known as SPARK.

Key features of this approach, include the following:

- Relevant land and topographical data have been sourced by CSIRO, including:
  - topographic data from Geoscience Australia Digital Elevation data;
  - land classification data from DEW; and
  - fuel load data and fuel age data from DEW.

- Rate of fire spread models are incorporated, based on CSIRO expert knowledge.

- All fires are assumed to start at 12pm weather conditions and run for 12 hours or until the rate of spread drops below 5m/hr[6].

The output of an individual simulation is a spatial file, which defines the extent of the bushfire's resulting footprint, and the intensity of the burn within that footprint.

A paper prepared by CSIRO describing the methodology and assumptions that it has used to undertake its bushfire simulations is provided as an Attachment to this document.

## Bushfire economic cost

We have estimated the economic cost of each bushfire simulation produced by CSIRO. Currently, the analysis only allows for the following costs:

- land damage;
- property damage, separately costing residential, commercial and industrial properties; and
- public deaths and injuries.

This analysis is performed within a GIS environment, as follows:

[6] Note, CSIRO considers that these represent typical condition associated with simulating major bushfire, which are likely to have escaped suppression.

- Land and property damage costs are estimated from the bushfire intensity footprints by overlaying these with property and land value information, using publicly available land use and property value data.  This information is processed via “vulnerability” curves that we have developed, which define relationships between the level of damage given the bushfires intensity.
- Deaths and injury costs are calculated using residential population estimates within the bushfire footprint, and casualty rates associated with actual major bushfires.

Further details of the methodology we have used to determine the economic costs associated with each bushfire simulation are contained in Appendix C.

### Weather analysis

The weather analysis stage provides important inputs to both the likelihood and the consequence streams of the risk calculation, covering:

- the bushfire and weather condition probabilities, which are used by the fire start stage; and
- the weather patterns that are used in the bushfire simulations to drive the propagation of the fires.

We engaged CSIRO to undertake this analysis.  CSIRO sourced historical BOM weather station data for a large number of weather stations across SA.

Further details of the methodology CSIRO used to determine these model parameters is contained in the paper provided as an Attachment to this document.

# 6. Our bushfire risk and cost-benefit analysis model

Our bushfire risk and cost-benefit model has been developed within excel. It can be considered in terms of two components as shown in Figure 3.

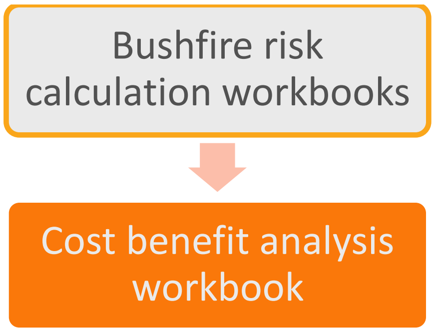


**Figure 3 Bushfire cost-benefit model structure**

## Bushfire risk calculation workbooks

The bushfire risk calculation workbooks are a series of workbooks that perform the calculations of risk as explained in the above section.

> The set of bushfire risk workbooks are very large and have therefore not been provided as part of the **Bushfire CBA model**, which we have provided as a supporting document to our regulatory proposal to the AER. However, we can demonstrate these workbooks to the AER and other stakeholders if required.

The risk workbooks hold the various inputs required for the calculations (e.g. fire start rates, suppression probabilities, simulation economic cost, bushfire condition and weather probabilities) and perform the risk calculations discussed above.

The main output of these workbooks is a consolidated table of risk results associated with each of the fire start locations and bushfire/weather combinations. It also consolidates these results in various other tables used as inputs to the cost-benefit analysis workbook.

It is important to note that the risk calculations use a very large amount of input data associated with the consequence calculations for each of the bushfire simulations (ie currently approximately 1 million simulations). These workbooks are required to process this information in order that more consolidated risk data can be input into the cost-benefit analysis workbook. As the risk calculations can be run independently of the cost-benefit analysis of a mitigation program, it significantly reduces the size and speed of operation of the cost-benefit analysis workbook.

## Cost benefit analysis workbook

The cost benefit analysis workbook provides an environment to consolidate the results provided by the bushfire risk calculation workbooks to the individual feeders covered by this study and then use this information to perform cost-benefit analysis on bushfire mitigation program options.

Importantly, this workbook also allows assumptions associated with the bushfire mitigation options to be input and studied. These inputs include the costs of the mitigation actions and expected fire start reduction rates that should be achieved by the option. Our assumptions associated with the mitigation program options that we have considered is discussed in more detail in the Bushfire Mitigation Program Justification document.

The cost-benefit analysis workbook provides a range of outputs that can be viewed for each feeder. In this way, the programs can be evaluated and optimised at the feeder and feeder segment level, using cost-benefit analysis formulations that are included in the workbook. As such, localised inefficiencies should not be masked by an overall net benefit of the program.

The cost-benefit analysis component of the workbook uses the concept of the *equivalent annualised cost*, which as the name suggests, transforms the capital and operating costs of potential mitigation programs to an equivalent annual cost using discounted cash flow techniques and the life of program assets. This allows these annualised program costs to be compared against the reduction in the annual bushfire risk costs to determine the net benefit of the program elements (ie the benefit is defined as the avoided bushfire risk cost achieved by the program).

This workbook represents the **Bushfire CBA model**, which we have provided as a supporting document to our regulatory proposal to the AER.

## Key workbook sheets
### *Feeder-level results*

The workbook includes two results sheets that tabulate the feeder-level results for:

- the current risk ("current feeder results" sheet)
- the bushfire mitigation program risk and cost-benefit analysis ("Option feeder results" sheet).

Both of these result sheets provide:

- a breakdown of the bushfire risk, indicating how this is distributed across the six Fire Danger Ratings, including:
    - the economic cost per season (risk)
    - the expected number of unsuppressed fires per season (likelihood)
    - the economic cost of an unsuppressed fire (consequence)

- indicative break-even investment levels for different fire reduction levels (ie where the benefits equal costs)

In addition, the bushfire mitigation program sheet, includes the cost-benefit results for an input mitigation program, including:

- the make-up of the program costs and annualised cost
- the current bushfire risk, the bushfire risk after the program, and the risk reduction (ie program benefit)
- the facility to add other benefits that could result from the program (which we have not used at this time)
- the net benefit (annual benefit minus annualised cost)
- the benefit-cost ratio (annual benefit / annualised cost).

**Note on setting up program options**
The bushfire mitigation program sheet also includes additional information and formulations relating to the program scope and cost. However, how these are formulated is specific to the options being considered and how they affect the bushfire risk. Therefore, these should be input and set up by the user.

In the bushfire CBA model that supports our proposal, we have included the program set-ups that were used to test the preferred program and options.

### *Risk result overview*

The workbook also includes a sheet that summarises the risk results ("Risk overview" sheet), which compares the current risk against the risk after the program. This sheet provides data and charts showing the average frequency (ie average mean time between events) for different values of bushfire event.

This sheet has also been used to generate other summary tables and charts, many of which are used to summarise the results provided in our Bushfire Mitigation Program Justification document.

### *Risk input sheets*

The workbook includes two sheets that hold two tables that are imported from the bushfire risk calculation workbooks discussed above:

- Segment Risk Table, which includes detailed risk information for all feeder segments in the model.
- Feeder Risk Table, which includes detailed risk information for all feeders in the model (this is essentially a consolidated view of the segment table, with additional information on each feeder).

These two sheets act purely as input sheets used by the results sheets discussed above. As such, these sheets are "hidden" in the Bushfire CBA model, which supports our proposal.

### *Other input sheets*

The workbook includes three other sheets that hold other general inputs that are used in the risk and cost-benefit analysis:

- "Mitigation strategies" sheet, which holds the general key assumptions associated with bushfire mitigation program options we have considered. This includes cost assumptions and fire start rate reduction assumptions.
- "SAPN program" sheet, which is a "special-purpose" sheet we have generated to hold the key assumptions associated with the program necessary to achieve the new ultra-fast fault clearance protection strategy. As discussed in our Bushfire Mitigation Program Justification document, this is a new strategy that involves a feeder-specific work scope and fire start rate reduction. This sheet is used to hold this feeder-level information.
- "Other inputs" sheet, which hold some other general inputs and assumptions that are not specific to the program options being studied.

# A. Defining the study fire start locations

The set of fire start geographic locations are used by CSIRO to define where it must start each fire within its simulations. We used our GIS data of the overhead routes of the HV feeders, covered by our study, to define this set of fire start locations. As such, each location represents a position along one of our HV feeders covered by our study.

To estimate locations along each feeder that would be approximately 500m apart:

- we used a GIS environment to cast a 500m grid across the feeders covered by our study (see an example of this grid in Figure 4)
- we then used this grid, via an automated process, to generate a individual fire start locations for each feeder that were located within each individual grid cell (see example in Figure 5).

All fire start locations were assigned a unique identifier, highlighting the bushfire region to which they belong. In addition, the geographic location (latitude and longitude) and feeder was also recorded to give spatial and network context.

A table of this information was then provided to CSIRO who used this to define the set of fire start locations that is used for the bushfire simulations.

A summary of the fire start locations generated through this process are provided in Table 2. This table also indicates the volume of simulations performed by CSIRO for each region (as discussed in Section 4, CSIRO performs 36 simulations for each fire start location, covering the six fire danger ratings and six weather patterns).

| Region | Feeders | Fire Start Locations | GIS Simulations |
|---|---|---|---|
| **MOUNT LOFTY RANGES** | 211 | 12,052 | 433,872 |
| **ADELAIDE METROPOLITAN** | 5 | 114 | 4,104 |
| **FLINDERS** | 3 | 314 | 11,304 |
| **KANGAROO ISLAND** | 5 | 221 | 7,956 |
| **LOWER EYRE PENINSULA** | 16 | 1,104 | 39,744 |
| **MID NORTH** | 38 | 2,957 | 106,452 |
| **MURRAYLANDS** | 2 | 308 | 11,088 |
| **UPPER SOUTH EAST** | 5 | 991 | 35,676 |
| **LOWER SOUTH EAST** | 132 | 11,704 | 421,344 |
| **Total** | **417** | **29,765** | **1,071,540** |

**Table 2 Summary of fire start locations**

[redacted]

[redacted]

# B. Fire start rate analysis (risk likelihood)

## Introduction and background

This appendix describes the methodology we have used to produce the **network fire start rates**, which forms an important input into our calculation of bushfire risk. It also provides some key results from this analysis that should aid in the understanding of our approach and why we consider it appropriate.

The fire start rates provide a critical starting point for our calculation of the likelihood component of bushfire risk. In this regard, they enable the expected annual number of fire starts per bushfire season to be calculated for each fire start location, allowing for factors such as asset type, feeder voltage level, bushfire conditions, and bushfire region to be included in this calculation.

It is important to note that these rates concern the likelihood of feeders starting fires, during the bushfire season. They do not allow for the likelihood of major bushfires resulting from these fires, which is the second element in the likelihood calculations, the fire suppression probability.

**Critical caveat on results presented in this appendix**

It is very important to stress that certain results presented in this Appendix, including the key outputs which are inputs to the CBA model, are sensitive to which weather station CSIRO assigns to a feeder and hence fire start location. Due to how we calibrate the model to historical outcomes, this should not significantly affect the overall risk results we require for our cost-benefit analysis.

However, caution should be applied in drawing conclusions from these results alone on the true likelihood of a specific asset causing fires under specific fire danger conditions specific to that location, and the relative pattern when moving from one fire danger rating to the next. These results could provide misleading information for these purposes. This would most likely require further analysis to ensure results are fit for this purpose.

## Why our methodology is appropriate

We believe that there are a number of features of our analysis that should provide confidence that the fire start rates, which we are using to estimate bushfire risk, are appropriate for our circumstances.

Firstly, we have calculated different fire start rates to allow for a range of factors and conditions where we would expect fire start rates to vary. We consider that capturing this variation was important for us to understand the make-up of the bushfire risk and in turn to determine the most appropriate strategies to reduce this risk.

The factors we have allowed for, cover:

- **Fire danger rating** – We calculate separate rates for the six fire danger ratings. We see significant variations in fire start rates for each fire danger rating.

- **Asset type** – We have calculated separate rates for two asset types: one is our most common fire start prone asset (our open-style surge arrestors); and the other is an aggregate line rate (which captures the causes of all other fires). This separation was important in order that we can distinguish risks associated with our fire prone assets from other fire start events, in order that we can separately determine whether there is a net benefit to replacing these assets.

- **Bushfire region** – We also define different rates for the various bushfire regions covered by this study. We see variations in fire start rates between the different bushfire regions, noting these can be affected by different climatic and vegetation conditions. Therefore, it was considered important to capture this to improve the locational accuracy of the bushfire risk.

- **HV feeder voltage** – We also define different rates for the different nominal voltages of the HV feeders covered by this study. The feeder voltage can affect fault currents, and in combination with other factors, can affect whether network faults can initiate fires. Therefore, it was considered important to capture this effect to improve the accuracy of the bushfire risk associated with individual feeders.

Secondly, our fire start rates have been derived and calibrated to reflect our recent historical network fire start performance during the fire danger season, of the feeders covered by our analysis. Most notably:

- The fire start rates are derived directly from our historical fire start database, which we have been using to record every fire started by our network since 2008 (i.e. a 10-year period).

- Using this data, we have calibrated the fire start rates to ensure they reflect the actual historical fire start rate of ***our*** network.

- We have also analysed the improving trend in fire start numbers that we can estimate from our historical data, and then used this to predict the current fire start rates that are appropriate for assessing bushfire risk moving forward.

Using our historical data and ensuring the model rates are calibrated to this data provides us with confidence that the fire start rates driving our model are appropriate for our circumstances and the predicted fire start number will not be biased by fire start rates in other jurisdictions.

## Key outputs

The two key outputs of this analysis (which form inputs to the bushfire risk calculations in the CBA model) are as follows:

- **Network-level fire start rates –** Individual fire start rates have been calculated for the six fire danger ratings and two asset types (arrestors and lines). These rates define our estimate of the current average fire start rate of all our feeders in the study region. The rates define the expected number of fire starts that the asset type could cause per a single day in that fire danger rating (the maximum for that day) and per 1000 assets.

- **Regional and voltage multipliers** – Individual multipliers have been calculated that are used to scale these network-level rates to allow for variations in the rate depending on the voltage of the feeder and bushfire region the feeder is located in.

We used network-level rates that are then scaled with multipliers as we considered there was insufficient fire start data to determine individual regional and voltage rates across the six fire danger ratings and two asset types. Our view is that this alternative approach would have resulted in data sets being too small, such that the inherent variability in the data due to the random nature of fire start events, would mask any useful patterns that may result from the analysis. As such, this alternative approach would have increased effort, but most likely, reduced the accuracy and information content of the key outputs of the analysis.

The network-level fire start rates and rate multipliers we have calculated through this methodology, which form an input to the CBA model, are shown in Table 3 and Table 4.

| | Expected fire starts per day per 1000 assets – by fire danger rating | | | | | |
|---|---|---|---|---|---|---|
| | low-mod | high | very high | severe | extreme | catastrophic |
| Arrestor fire start rate | 0.0008 | 0.0012 | 0.0013 | 0.0021 | 0.0023 | 0.0023 |
| Line fire start rate | 0.0026 | 0.0045 | 0.0093 | 0.0314 | 0.0254 | 0.0086 |

**Table 3 Network-level fire start rates**

| | Arrestor rate multipliers | | | | Line rate multipliers | | | |
|---|---|---|---|---|---|---|---|---|
| | 33kV | 19kV | 11kV | 7.6kV | 33kV | 19kV | 11kV | 7.6kV |
| LOWER SOUTH EAST | 1.46 | 0.00 | 0.28 | 0.00 | 0.92 | 0.23 | 0.79 | 6.17 |
| MID NORTH | 0.96 | 0.00 | 3.47 | 0.00 | 0.84 | 0.15 | 2.40 | 2.29 |
| MOUNT LOFTY RANGES | 1.68 | 0.00 | 1.29 | 0.00 | 1.15 | 0.20 | 2.11 | 2.09 |
| FLINDERS | 0.96 | 0.00 | 5.45 | 0.00 | 1.65 | 0.20 | 1.20 | 2.29 |
| ADELAIDE METROPOLITAN | 0.96 | 0.00 | 1.11 | 0.00 | 1.65 | 0.20 | 1.69 | 2.29 |
| KANGAROO ISLAND | 0.96 | 0.00 | 1.11 | 0.00 | 6.81 | 2.40 | 1.69 | 2.29 |
| UPPER SOUTH EAST | 0.96 | 0.00 | 1.11 | 0.00 | 1.65 | 0.74 | 0.43 | 2.29 |
| LOWER EYRE PENINSULA | 0.96 | 0.00 | 3.56 | 0.00 | 7.72 | 0.20 | 1.68 | 2.29 |
| MURRAYLANDS | 0.96 | 0.00 | 1.11 | 0.00 | 1.65 | 0.20 | 5.68 | 2.29 |
| **Total** | **1.04** | **0.00** | **1.20** | **0.00** | **1.68** | **0.20** | **1.73** | **2.34** |

**Table 4 Model regional and voltage fire start rate multipliers**

## Key input data sources

There are number of data sources we have used to calculate the key outputs defined above.

There are two key data sources that are most critical to our method, which are as follows:

- **SA Power Networks fire start database** – Since 2008, we have been maintaining a database that provided detailed records of every fire start that can be associated with our network. We used this database to make various counts of fires we have started that can be associated with the different factors covered by our fire start rates. This database holds a range of information for each fire start event. However, the most relevant for our purposes here are:
    - the date of the fire;
    - the feeder;
    - whether we were found to be the cause, and whether this was due to an HV or LV asset; and
    - the asset that caused the fire.

- **Daily SA maximum fire danger indices across SA weather station data** – CSIRO provided us with a set of data that provides CSIRO's estimate of the daily maximum FFDI and GFDI over the historical period of our fire start database. This data covers the majority of BOM weather stations in SA. This data allowed us to assign fire danger ratings to the days our assets started fires and the days when they did not start fires.

In addition to this data, we also used various internal sources of feeder data to calculate feeder lengths and define the bushfire region and voltage of the feeders. CSIRO also detailed which SA weather station it had assigned to each of our feeders, when it developed the weather input data used for its simulations. We used the same weather station assignment for our fire starts data to ensure we maintained consistency with CSIRO's analysis[7].

[7] It is worth noting that we also assign weather stations to feeders for fire risk operations.

We will discuss the use of this data further in the section below where we explain our methodology in more detail.

## Explanation of our methodology and key results

### Overview of our methodology

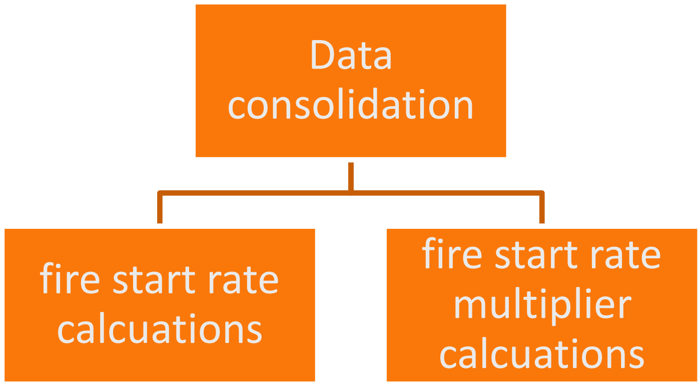


**Figure 6 Overview of fire start rate analysis**

The methodology we have used to produce the fire start rate input data can be considered in terms of three tasks, as shown in Figure 6:

- **Data consolidation** – the data consolidation task assembled the various data sources, covering SAPN's fire start and network data and CSIRO's weather station data to provide the data tables that form the inputs to the two calculation tasks.

- **Fire start rate calculations** – this task calculated the network-level fire start rates (both historical average and a predicted current rate), which form a key input to the SAPN's bushfire CBA model.

- **Fire start rate multiplier calculations** - this task calculates the regional and voltage multipliers, which form the other key input to the SAPN's bushfire CBA model.

These three tasks are explained in more detail below. These subsections also provide explanations of key assumptions we have used to undertake the analysis and presents some key results of the analysis, where we consider that these will aid the understanding and validity of our methodology.

### Data consolidation

As we will discuss below, the fire start rates used by the model define the *expected number of fire start per some period in the fire danger ratings*. Given we calculate these rates from the historical fire start data, it was important that we could also establish a daily time series of the fire danger rating for the weather stations most relevant to the regions covered by our study. In this way, we can know the fire danger rating associated with the network on the days when we started fires and on the days when we didn't.

We used data provided by CSIRO to prepare daily time series data of the fire danger rating. The data provided by CSIRO for this purpose covered:

- CSIRO's time series data of its estimate of the maximum daily forest fire danger index (FFDI) and grass fire danger index (GFDI) for the majority of BOM weather stations in SA (CSIRO calculated these indices using an accepted methodology[8] from hourly weather data provided by BOM for each weather station).

We used the FFDI estimated by CSIRO for weather station as the basis for defining the fire danger rating for that day and weather station, as we considered that the FFDI was more representative of the fire danger rating for the areas covered by our study.

- CSIRO advised on the most appropriate weather station to measure the fire danger rating for each fire start location in our study area.

Importantly, this data has been assembled by CSIRO and used as a basis for its bushfire simulations, and the assignment of these simulations to the various fire danger bands. Therefore, we can have confidence that there is consistency in the weather data assumptions that underpin both our underlying fire start rates and the bushfire simulation inputs to the CBA model.

We used this CSIRO data:

- to assign each fire start in our fire start database to the fire danger rating appropriate for that fire start location

  This was achieved by cross referencing the date of the fire start and associated HV feeder (which are both recorded in our fire start database) with CSIRO's advice on the weather station most appropriate for that feeder and CSIRO's estimate of the FFDI for that weather station on that date.

- to estimate the proportion of the network (covered by our study) in the six fire danger rating bands for each day across the period spanned by our fire start database (1 January 2008 to 22 May 2017)

  This was achieved by calculating the length of overhead HV feeder that CSIRO had assigned to each weather station. This length was then used to calculate the portion of the network (by length) in each fire danger rating band each day, based on the feeder lengths assigned to the weather stations that were in the six bands on that day.

## Calculating the asset fire start rates

As noted above, a key output of our fire start analysis (which forms an input to our bushfire CBA model) are the fire start rates associated with our network. As also noted above, we calculate a set of fire start rates to cover the two asset types covered by our CBA model (old arrestors or line) and the six fire danger ratings.

**Fire start rate definition**

The *fire start rate* ($FSR_{A, FDR}$) for a given asset type (*A*) and fire danger rating (*FDR*) is defined here as the *average number of fire starts per 1000 units of asset, A, per day with a maximum fire danger rating, FDR*, where the units for the two asset types are defined as follows:

- Arrestors - the units for arrestors will cover a 3-phase set for a 3-phase circuit or single-phase unit for single-phase units

[8] See further discussion of this CSIRO's explanation of its bushfire simulation methodology in the attached CSIRO paper.

- Line – the unit is the route length of line, measured in kilometres.

The fire start rates calculated in this task represent average network-level rates for all the feeders covered by our analysis. The multipliers discussed in the following section adjust these network-level rates to allow for the regional and voltage variations we would expect across the covered feeder. As noted above, the approach of using network-level rates and multipliers was chosen over calculating specific rates for each region and voltage due to the limitations in fire start numbers.

We have used our historical fire start data to directly calculate these rates[9]. Our method can be considered in terms of two steps:

1. Calculating the average historical fire start rates
2. Using annual trends in the historical rates to predict the future fire start rate.

### *Calculating the average historical fire start rates*

In this step, we calculated our average fire start rates over the full 10-year period that we have been maintaining detailed records of each fire start due to our network (ie since 1 January 2008).

**Average fire start rate formula**

The *average fire start rate* for a given asset type (*A*) and fire danger rating (*FDR*) is calculated from the database using the following formula:

$$\frac{total\ count\ of\ fire\ start\ events\ for\ asset, A, assigned\ to\ a\ day\ with\ fire\ danger\ rating, FDR}{number\ of\ days\ with\ fire\ danger\ rating, FDR \times average\ number\ of\ units/1000}$$

The count of fire start events uses all fire start events recorded in our database that have been confirmed in the database to be caused by our assets and have occurred on a feeder covered by our study. To ensure we have a reasonable estimate of the total bushfire risk, we have included fires caused by faults on both our HV and LV networks. The counts only cover fire start events on days within the bushfire season, which we have defined from the start of November to the end of April for our analysis.

It is important to note that we have excluded from our counts any fire starts, recorded in our database, where we have not been able to confirm that they were caused by our assets. This exclusion is used to ensure we are not overstating our fire start rates by including fire events that may not have been caused by our network – and hence not overstating the potential economic benefits of our mitigation programs in our CBA model.

We have been able to assign fire start events to the old arrestor asset type based on the following rules:

1. The failed component field is defined as either Rod Air Gaps, CLAHs, or Arcing Horns, which represents one of our older fire-prone arrestor types; AND
2. The cause of failure field is defined as Bird, which represents the failure mode of concern to us with this asset type.

[9] Our approach could be viewed as type of “calibration” exercise, where the fire start rates used in the model are “calibrated” to ensure they reflect recent historical. “Calibration” in this context is similar to how the AER discusses calibrating asset lives or unit costs to reflect historical outcomes in the context of its repex modelling.

All other fire events caused by our network are assigned to the line asset type.

The counts of the number of days in each fire danger band is calculated as the sum of the proportion of the network in that fire danger rating on each day. For example, if 50% of the network was in the low-medium bands for two days, 25% of the network was in the high band and the remaining 25% of the network was in the very high band then this would amount to a count of a single day in the low-medium band, half a day in the high band and half a day in the very high band over this two-day period.

Based on this methodology, the average fire start counts per bushfire season, between 2008 to 2017 (regulatory years inclusive), for the two asset types and six fire danger ratings are shown in Figure 7[10]. This chart also shows on the secondary axis the percentage of time in each fire danger rating.

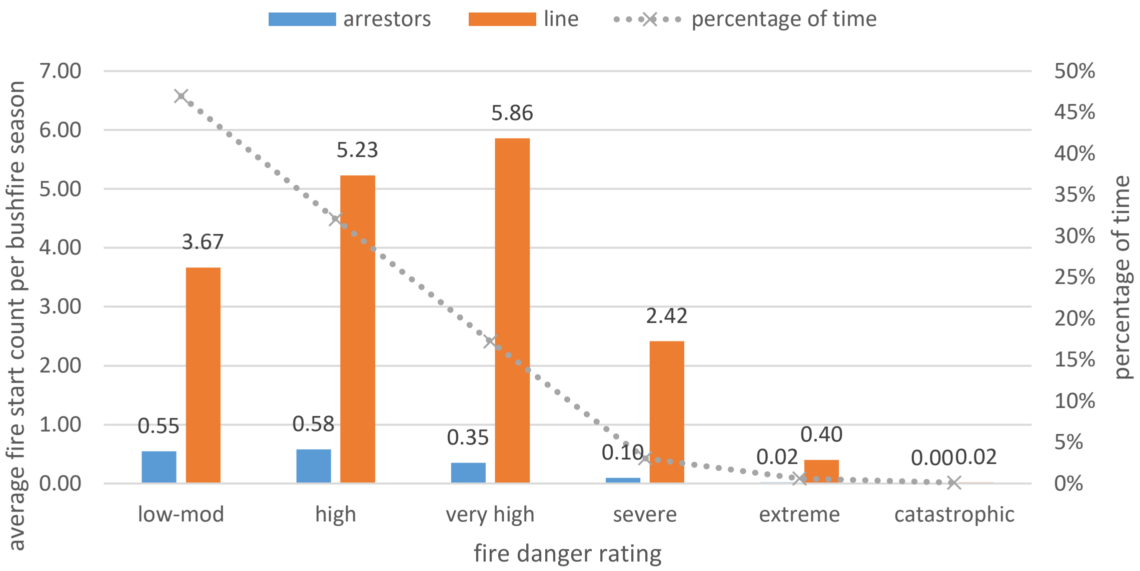


**Figure 7 Fire start counts from our fire start database (2008 to 2017 inclusive)**

This chart shows that on-average there have been 19.2 fire starts per bushfire season across the regions covered by our analysis. 1.6 of these have been due to our old arrestor types and the remaining 17.6 are due to the other line assets.

A large portion of these fires (85%) are occurring on days with a fire danger rating between the low-moderate to very high bands. But these three bands cover approximately 96% of the bushfire season. The remaining 15% of fires are occurring over the remaining 4% of the bushfire season, when the fire danger rating is significantly higher. Although there are very few fire starts in the extreme and catastrophic fire danger ratings, there are only a very small number of days in this band, with on-average 1.1 day in the extreme band per season and only 0.2 days in the catastrophic band (ie 1 day per 5 bushfire seasons across the regions covered by our study[11]).

[10] This represents the total count over this period dived by 10.

[11] Note, there can be locations in the covered regions with more days in these bands. But this reflects the averages, based on only the weather stations CSIRO has assigned to our feeders.

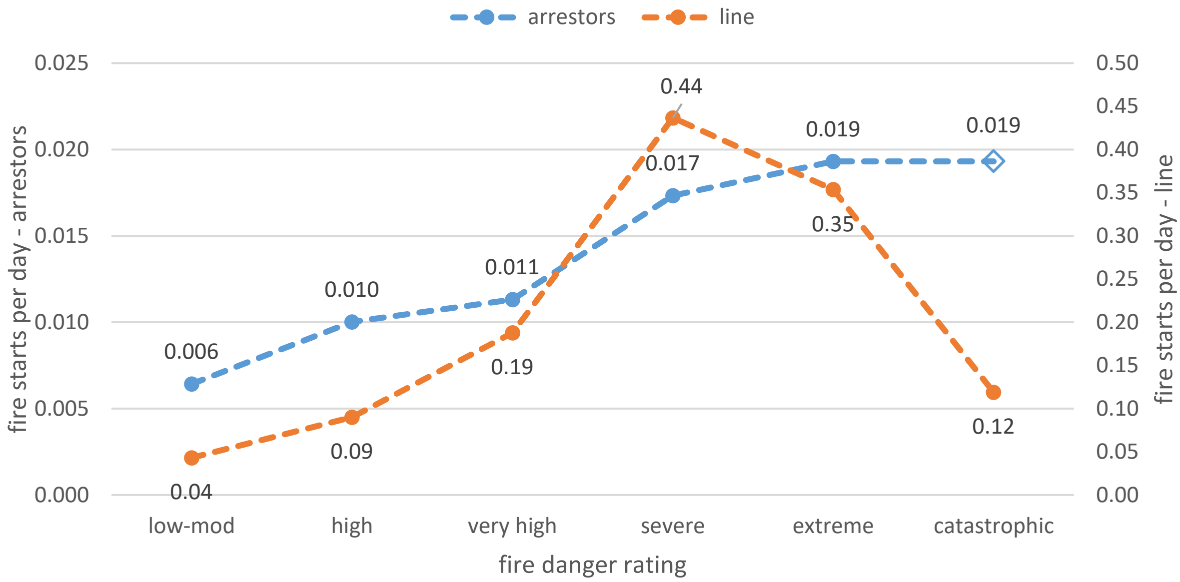


**Figure 8 Average fire starts per 100 days in fire danger rating**

The relationship of the average number of fire starts to the fire danger rating is shown further in Figure 8, which shows the average number of fire starts for a single day in the six fire danger ratings. This shows that for lines, the fire starts per day increases substantially for days classified as low-moderate to days classified as severe. However, fire starts then reduce from this point.

Arrestors on the other hand show a more linear upward trend from the low-moderate rating to the extreme rating. Importantly, for arrestors, we have not had a fire start in a day classified as a catastrophic fire danger rating. As such, we cannot define what the average rate is for this fire danger rating. However, we consider this result is more likely a statistical anomaly due to the very low number of days classified as catastrophic and low number of arrestor fire starts, rather than the fire start rate is likely to *actually* drop to zero. Therefore, for modelling purposes we have assumed that the rate for catastrophic days is equivalent to the rate on extreme days. This seems a reasonable assumption given the upward linear trend in the preceding ratings.

To produce the historical average rate per day per 1000 units, we divide the daily rates shown above in Figure 8, by the number of units in the study regions associated with each asset type. The asset unit numbers in the study region are as follows:

- 13,910 km of HV feeder, which is the length of overhead HV line in our study region, based on line route lengths in the GIS system
- 8,449 arrestors, which is an estimated number calculated as the pro-rata proportion determined from the HV line length in the study region compared to the total HV line length, using our estimate that we have approximately 20,000 of the old arrestor types on our network[12].

The average historical fire start rates (fire starts per day per 1000 units) that we have calculated by this method are shown in Figure 9 (old arrestor types) and Figure 10 (lines).

[12] We do not record specific counts and locations of these older arrestor types, and therefore, this estimation method was necessary.

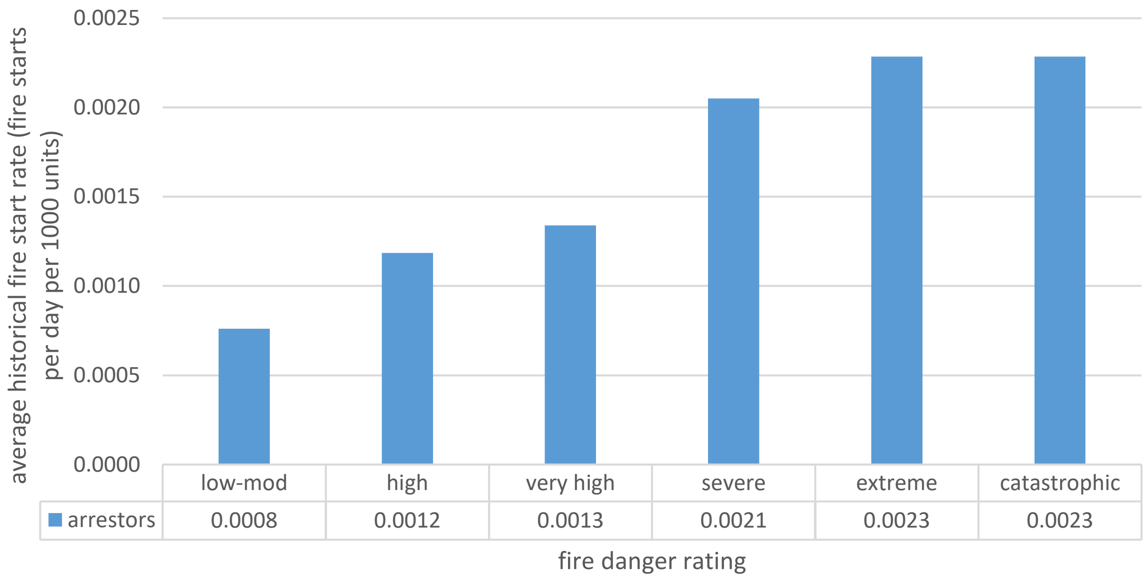


**Figure 9 average historical fire start rate – old arrestor types**

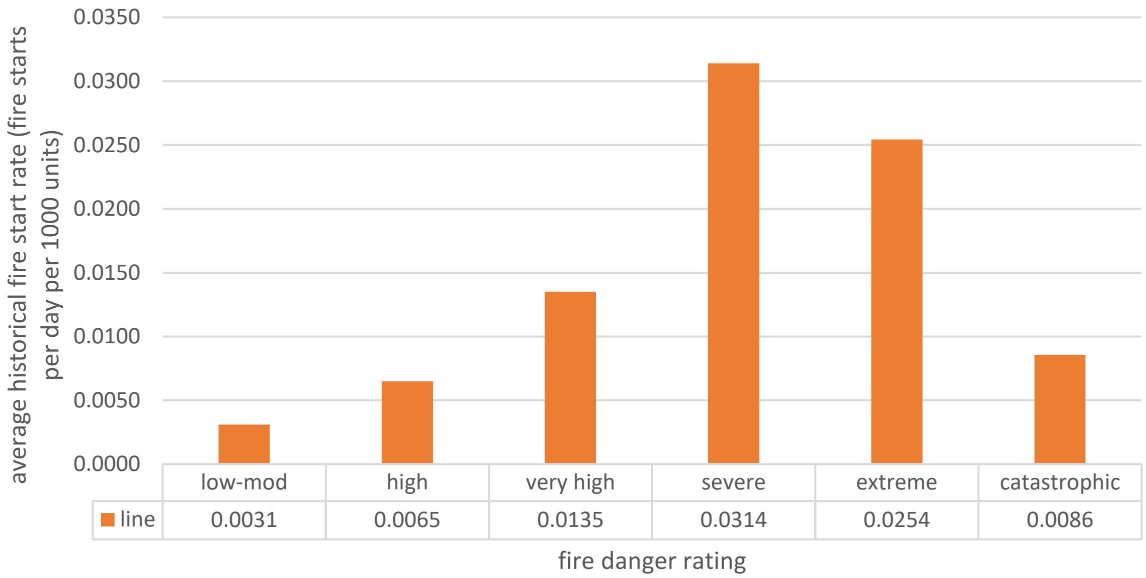


**Figure 10 average historical fire start rate – lines**

### *Using annual trends in the historical rates to predict the future fire start rate*

The average historical fire start rates discussed above provide a useful starting point for understanding the likelihood of our network starting fires. However, we know we have been improving some of our practices in bushfire risk areas over this same period. Therefore, it is reasonable to assume that there has been some level of improvement occurring over this historical period, and as such, this average historical rate could overstate our current fire start rates – and hence overstate the benefits of our bushfire mitigation program.

Therefore, we have also analysed the linear trends in annual fire start rates and used these to predict the current fire start rates. We believe that improvements in our practices can have different effects in the different fire danger ratings. Therefore, to improve the accuracy of this approach, we have examined annual trends for the different fire danger ratings. Where we can see a reasonable trend of improvement in the fire start rate for that fire danger rating, we have used this trend to estimate the current fire start rate for that rating, which we can then use in the CBA model.

To ensure we have a comparable basis from year to year, for this analysis we have used a fire start rate that reflects the average fire starts in the regions covered by this study in that year per 100-day period (i.e. 100 x fire counts in that year during days with that fire danger rating / number of days in that year with that fire danger rating). The assumptions for the fire start counts and day counts are the same as those discussed above for calculating average historical rates.

Importantly, we have only undertaken this analysis for the line asset type. This form of analysis is more prone to statistical error for the arrestor type as the number of arrestor fire starts in each fire danger rating of each year is very low. Moreover, the fire start mode for our old arrestor types is relatively independent of the recent changes to our maintenance practices over the historical period. We have commenced replacing some of these units over this period, which will reduce the overall fire start rate. But, to date, the replacement volumes in the covered regions is low[13]. Therefore, we do not expect this volume of replacement to have caused a material change in the fire start rate for the arrestor that could be deduced from the data. Therefore, for the arrestors, we have assumed that the current fire start rate is reasonably represented by the average historical rate discussed in the section above.

Figure 11 shows the average aggregate (covering all fire danger ratings) annual fire start rate per 100 days for lines with a linear trend added. Although there is significant variation from year to year (as we would expect given the random nature of network faults and fire starts), this chart indicates a downward (improving) trend in the fire start rate. This trend indicates that the aggregate annual fire start rate has been improving by approximately 3% per annum since 2008.

The breakdown of this improvement to fire starts in the six fire danger ratings can be seen in Figure 12 and 13. Figure 12 shows a similar chart for the fire starts in the three lowest fire danger ratings: Low-moderate, High and Very High. This shows similar variability, but downward (improving) trends. This indicates improvements from 2.2% per annum in the low-moderate bands to 4.4% in the very high band.

Figure 13 shows the equivalent chart for the three highest ratings – Severe, Extreme and Catastrophic. The fire start rates for the Severe (49.5 – 74.5) and Extreme (74.5 – 99.5) rating are shown separately in this chart. However, there are insufficient fire starts and days in the Catastrophic rating to get meaningful results. Therefore, we have also provided an aggregate fire start rate combining the three ratings on this chart (line D+E+F). In contrast to the results of the three lower ratings, the trends in these higher ratings shows no improvement, rather they suggest the fire start rate is increasing.

However, there are much lower numbers of fire starts and days in these three bands, and therefore, caution is needed in inferring a worsening level of performance from such a limited dataset. Nonetheless, they do support a view that the fire start rates are unlikely to be improving in these rating bands. To some degree, this also corresponds with our engineering understanding of this result, which is that much of our fire start improvements come from our comprehensive Summer Preparations Planning (SPP). Our SPP includes increased emphasis on maintaining vegetation clearance within the legislated zones, and an annual pre-fire danger season asset inspection/patrol and repair program. This Program is effective at the lower fire danger rating bands[14] but for the higher bands, the higher wind speeds associated with these bands increases the likelihood that vegetation or other third-party object will blow onto our lines from outside the legislated clearance

[13] Of the 417 feeders in high bushfire risk areas, the open-type surge arrestors of only 13 feeders (3%) have been replaced

[14] This typically also corresponds to lower wind speeds and hence less vegetation movement and lower wind force on our assets

zones. Therefore, despite our enhanced practices, these are less likely to produce significant improvements at the higher fire danger rating bands

For these reasons, we have allowed for the improvements, deduced through this analysis, to be applied to the fire start rates in the three lowest fire danger ratings in order to define the current fire start rates for these ratings.  However, for the three highest ratings, we have used the average historical rates as the best estimate of the current fire start rate.

The percentage improvement and resulting current fire start rates, calculated through this method, are shown in Table 5.

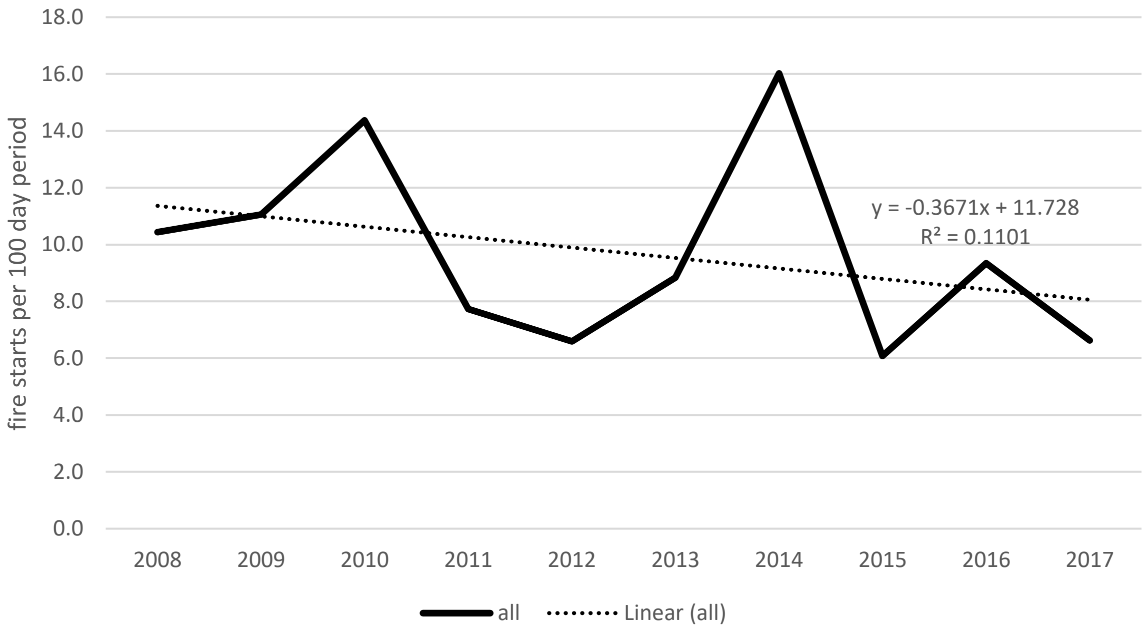


**Figure 11 Overall annual trend in the average fires starts per 100 days**

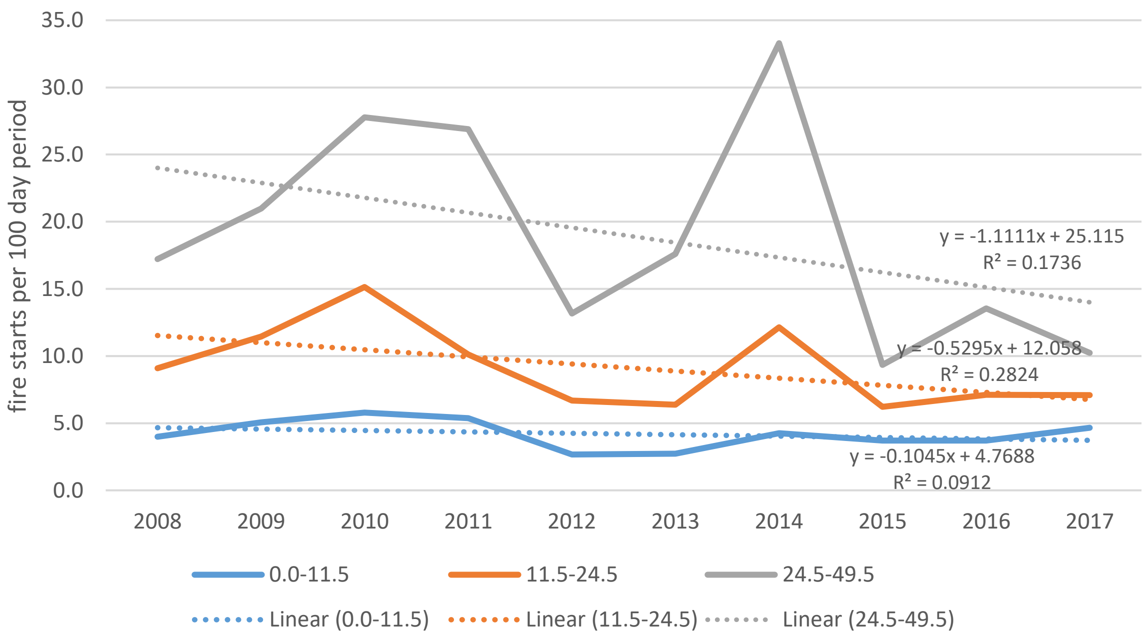


**Figure 12 Annual trend in the average fires starts per 100 days – Low-moderate, High and Very High fire danger ratings**

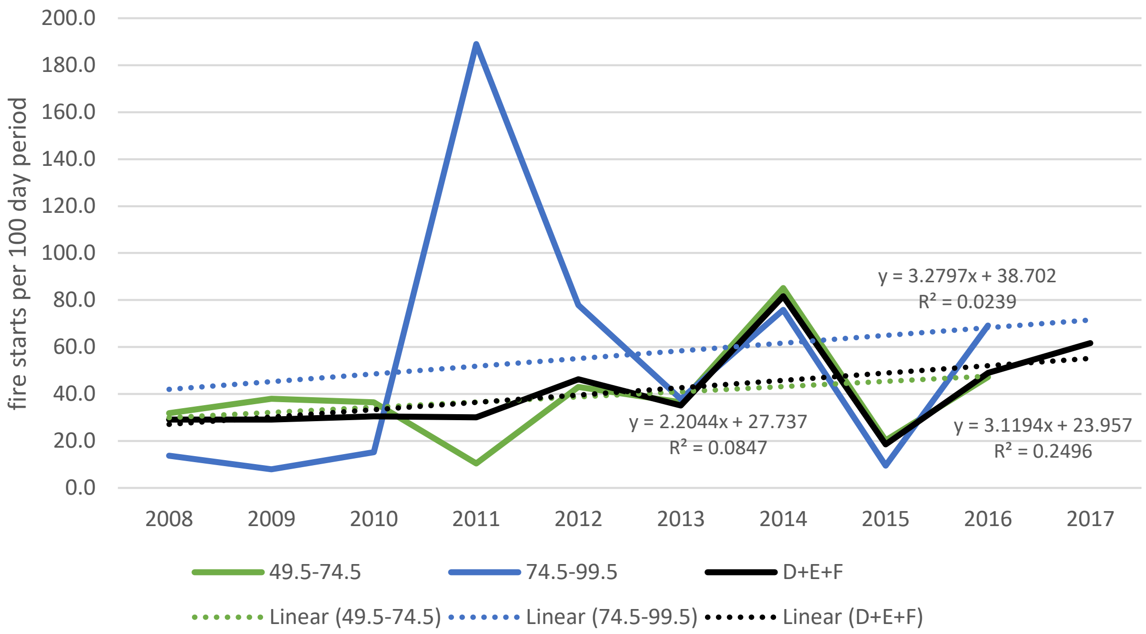


**Figure 13 Annual trend in the average fires starts per 100 days –Severe, Extreme and Catastrophic fire danger ratings**

| | low-mod | high | very high | severe | extreme | catastrophic |
|---|---|---|---|---|---|---|
| average historical fire start rate | 0.0031 | 0.0065 | 0.0135 | 0.0314 | 0.0254 | 0.0086 |
| percentage improvement | -16% | -31% | -31% | 0% | 0% | 0% |
| predicted current fire start rate | 0.0026 | 0.0045 | 0.0093 | 0.0314 | 0.0254 | 0.0086 |

**Table 5 Calculated fire start rate improvement and predicted line current fire start rate**

### Calculating fire start rate multipliers

As the name suggests, the fire start rate multipliers are used to scale the fire start rates (discussed in the above section) when they are applied on any particular feeder in the studied regions. As noted above, the fire start rates are network-level rates that reflect average rates across the network covered by the study. These multipliers are necessary to ensure that the fire start rate applied to any feeder reflects regional and voltage variations that exist. In this way, the calculated fire start numbers and bushfire risk associated with a region, a feeder, or even a fire start location should be a more accurate estimate of the true value.

We have produced two sets of multipliers: one to be applied to the arrestor fire start rates and one to be applied to the line fire start rates. Each set can be considered a 2-dimentional matrix of multipliers that reflect the bushfire region the feeder is located and the nominal voltage of the feeder.

The individual multiplier elements provide a fixed scaling across all the fire start rates. That is, the multiplier is not dependent on the fire danger rating. As such, this assumes that any regional or voltage differences in rates are relatively constant to fire danger ratings. We applied this simplification, as there are insufficient fire start events to produce reasonable estimates of the fire start rates with this additional breakdown ie observed difference are far more likely to be due to the random nature of the events than any actual pattern in the data. We also considered that this simplification was reasonable because, although we may expect some variation to the fire danger rating, we would expect there to be reasonably consistent pattern across the fire danger ratings. That is, if one region or voltage has, on-average, a higher fire start rate then we'd expect to see this pattern across the fire danger ratings.

The methodology we have used to calculate these two sets of multipliers can be considered a type of calibration exercise, where we are determining the set of multipliers that cause the model's prediction of the number of fire start events across the covered regions and voltages to match the actual number of fire start events across the same regions and voltages.

The methodology we have used to calculate the two sets of multipliers can be considered in terms of the five steps discussed below.

### *Step 1 -Actual fire start counts by region and voltage*

In the first step, we count the total number of actual fire starts by region as recorded in our fire start database. Separate counts for arrestors and lines are made. The rules for these counts are equivalent to the rules discussed above when calculating the average historical fire start rates.

The results of the counts of actual fire start events are summarised in Table 6

| | Actual arrestor count | | | | Actual line count | | | |
|---|---|---|---|---|---|---|---|---|
| | 33kV | 19kV | 11kV | 7.6kV | 33kV | 19kV | 11kV | 7.6kV |
| LOWER SOUTH EAST | 1 | 0 | 1 | 0 | 4 | 5 | 18 | 1 |
| MID NORTH | 0 | 0 | 3 | 0 | 2 | 1 | 15 | 0 |
| MOUNT LOFTY RANGES | 1 | 0 | 8 | 0 | 5 | 0 | 97 | 2 |
| FLINDERS | 0 | 0 | 1 | 0 | 0 | 0 | 2 | 0 |
| ADELAIDE METROPOLITAN | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| KANGAROO ISLAND | 0 | 0 | 0 | 0 | 2 | 1 | 0 | 0 |
| UPPER SOUTH EAST | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 |
| LOWER EYRE PENINSULA | 0 | 0 | 1 | 0 | 9 | 0 | 3 | 0 |
| MURRAYLANDS | 0 | 0 | 0 | 0 | 0 | 0 | 6 | 0 |
| **Total** | **2** | **0** | **14** | **0** | **22** | **8** | **142** | **3** |

**Table 6 Actual regional and voltage fire start counts**

### *Step 2 – Calculate fire starts predicted by the model over the equivalent period*

We then run the model using the average historical fire start rates (as discussed above) to calculate the fire starts predicted by the model over the equivalent period. The model's results are then counted into the same asset types, regions and voltages.

The results of the fire start event counts predicted by the model are summarised in Table 7.

| | Actual arrestor count | | | | Actual line count | | | |
|---|---|---|---|---|---|---|---|---|
| | 33kV | 19kV | 11kV | 7.6kV | 33kV | 19kV | 11kV | 7.6kV |
| LOWER SOUTH EAST | 0.6 | 0.0 | 3.3 | 0.0 | 4.2 | 21.4 | 22.2 | 0.2 |
| MID NORTH | 0.3 | 0.0 | 0.8 | 0.0 | 2.3 | 6.7 | 6.1 | 0.2 |
| MOUNT LOFTY RANGES | 0.6 | 0.0 | 5.8 | 0.0 | 4.3 | 6.1 | 45.1 | 0.9 |
| FLINDERS | 0.0 | 0.0 | 0.2 | 0.0 | 0.0 | 0.9 | 1.6 | 0.0 |
| ADELAIDE METROPOLITAN | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.3 | 0.0 |
| KANGAROO ISLAND | 0.0 | 0.0 | 0.0 | 0.0 | 0.3 | 0.4 | 0.0 | 0.0 |
| UPPER SOUTH EAST | 0.1 | 0.0 | 0.3 | 0.0 | 0.6 | 1.3 | 2.3 | 0.0 |
| LOWER EYRE PENINSULA | 0.2 | 0.0 | 0.3 | 0.0 | 1.1 | 1.3 | 1.7 | 0.0 |
| MURRAYLANDS | 0.0 | 0.0 | 0.1 | 0.0 | 0.0 | 0.4 | 1.0 | 0.0 |
| **Total** | 1.8 | 0.0 | 10.8 | 0.0 | 12.8 | 38.6 | 80.5 | 1.3 |

**Table 7 Model regional and voltage fire start counts – without multipliers applied using average historical fire start rates**

### *Step 3 – Initial multiplier estimate*

An initial estimate of the set of multipliers is then generated as the actual count divided by the model count for each element of the two sets of multipliers.

In some circumstances where there are only short lengths of line, there may have been no actual fire starts over the period of records, but we know that the line should still pose a risk of starting fires. Therefore, in these circumstances the average multiplier for that voltage level is applied, rather than setting the multiplier to zero. This is to ensure that the model still estimates some bushfire risk for these feeders.

### *Step 4 – Fine tuning the multipliers*

The process to this point tends to still result in a small difference between the model estimate and the actual outcomes. Therefore, two global scaling factors are then calculated: one for arrestors and one for lines. These two factors are used to scale the relevant set of multipliers up or down to ensure the model's prediction of the total number of fires started matches the actual outcomes.

The two sets of multipliers resulting from this process are summarised in Table 8.

| | Actual arrestor multipliers | | | | Actual line multipliers | | | |
|---|---|---|---|---|---|---|---|---|
| | 33kV | 19kV | 11kV | 7.6kV | 33kV | 19kV | 11kV | 7.6kV |
| LOWER SOUTH EAST | 1.46 | 0.00 | 0.28 | 0.00 | 0.92 | 0.23 | 0.79 | 6.17 |
| MID NORTH | 0.96 | 0.00 | 3.47 | 0.00 | 0.84 | 0.15 | 2.40 | 2.29 |
| MOUNT LOFTY RANGES | 1.68 | 0.00 | 1.29 | 0.00 | 1.15 | 0.20 | 2.11 | 2.09 |
| FLINDERS | 0.96 | 0.00 | 5.45 | 0.00 | 1.65 | 0.20 | 1.20 | 2.29 |
| ADELAIDE METROPOLITAN | 0.96 | 0.00 | 1.11 | 0.00 | 1.65 | 0.20 | 1.69 | 2.29 |
| KANGAROO ISLAND | 0.96 | 0.00 | 1.11 | 0.00 | 6.81 | 2.40 | 1.69 | 2.29 |
| UPPER SOUTH EAST | 0.96 | 0.00 | 1.11 | 0.00 | 1.65 | 0.74 | 0.43 | 2.29 |
| LOWER EYRE PENINSULA | 0.96 | 0.00 | 3.56 | 0.00 | 7.72 | 0.20 | 1.68 | 2.29 |
| MURRAYLANDS | 0.96 | 0.00 | 1.11 | 0.00 | 1.65 | 0.20 | 5.68 | 2.29 |
| **Total** | **1.04** | **0.00** | **1.20** | **0.00** | **1.68** | **0.20** | **1.73** | **2.34** |

**Table 8 Model regional and voltage fire start rate multipliers**

These results tend to support other fire start analysis we have performed. The results indicate that our SWER lines (19kV lines) have a much lower fire start rate than other voltages. Our 11 kV lines, which form a large portion of the feeder in this study (61%), have a higher than average fire start rate. Our 7.6 kV lines have the highest fire start rate; however, we only have a very small length of this voltage in the study region, 116 km (1% of the length).

The Mount Lofty Ranges has the largest portion of the feeders in this study region (40% by length). This region also has a higher fire start rate than the average. This appears to be partly due to it having a large portion of 11 kV lines relative to SWER. But even its 11 kV feeders have a higher start rate than most other regions, with only the Murraylands and Mid North having a higher rate for this voltage.

It is worth noting that some regional voltages have unusually high multipliers e.g. 19kV feeders on Kangaroo Island. This can happen when regions only have small lengths of feeder, and so whether it had one or two fire start events can be quite significant on the apparent fire start rate. We believe that these higher rates are more likely a statistical anomaly than truly reflective of higher fire start rates in these regions. However, we have still used these multipliers in the model so the model provides an easier reconciliation to recent actual outcomes. Note however, because of this, care should be taken in drawing conclusions from the multipliers alone on the differences between regions. This would require further statistical analysis and a more detailed review of the actual fire start events.

## Verification of the model fire start predictions

To provide a final verification of the equivalence between the model fire start predictions and actual outcomes, we have used the model to predict the numbers of fire starts, using the average historical fire start rates and rate multipliers as discussed in the section above[15].

We have used the model, using these inputs, to do counts of the model's prediction of the number of fires in the various regions and feeder voltages in our study area. These results have then been compared to the actual outcomes as recorded in our fire start database to check for consistency.

The results of the fire start event counts as predicted by the model are summarised in Table 9. These counts, which cover fire starts over a 10-year period, should be comparable to the actual fire start counts provided in Table 6 above.

[15] Note, for this verification exercise, we did not use the predicted current fire start rates, which are discussed above, as these inputs should not produce a prediction of fire starts that should match the average historical performance.

| | Actual arrestor fire count | | | | Actual line fire count | | | |
|---|---|---|---|---|---|---|---|---|
| | 33kV | 19kV | 11kV | 7.6kV | 33kV | 19kV | 11kV | 7.6kV |
| LOWER SOUTH EAST | 0.9 | 0.0 | 0.9 | 0.0 | 3.9 | 4.9 | 17.6 | 1.0 |
| MID NORTH | 0.3 | 0.0 | 2.8 | 0.0 | 2.0 | 1.0 | 14.7 | 0.3 |
| MOUNT LOFTY RANGES | 0.9 | 0.0 | 7.4 | 0.0 | 4.9 | 1.2 | 95.0 | 1.9 |
| FLINDERS | 0.0 | 0.0 | 0.9 | 0.0 | 0.0 | 0.2 | 2.0 | 0.0 |
| ADELAIDE METROPOLITAN | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.5 | 0.0 |
| KANGAROO ISLAND | 0.0 | 0.0 | 0.0 | 0.0 | 2.0 | 1.0 | 0.0 | 0.0 |
| UPPER SOUTH EAST | 0.1 | 0.0 | 0.4 | 0.0 | 0.9 | 1.0 | 1.0 | 0.0 |
| LOWER EYRE PENINSULA | 0.2 | 0.0 | 0.9 | 0.0 | 8.8 | 0.3 | 2.9 | 0.0 |
| MURRAYLANDS | 0.0 | 0.0 | 0.1 | 0.0 | 0.0 | 0.1 | 5.9 | 0.0 |
| **Total** | 2.4 | 0.0 | 13.6 | 0.0 | 22.5 | 9.6 | 139.6 | 3.1 |

**Table 9 Model regional and voltage fire start counts – without multipliers applied using average historical fire start rates**

The difference in the model's prediction of fire starts over the bushfire season in the area covered by our study and our actual annual average fire start numbers is shown in Table 10. These results indicate that our model should represent the actual fire start performance of our network reasonably well. In total, our model predicts 0.02 fires per annum less than the average actual figure of 19.2 (0.1% difference).

| | Actual arrestor difference | | | | Actual line difference | | | |
|---|---|---|---|---|---|---|---|---|
| | 33kV | 19kV | 11kV | 7.6kV | 33kV | 19kV | 11kV | 7.6kV |
| LOWER SOUTH EAST | -0.01 | 0.00 | -0.01 | 0.00 | -0.01 | -0.01 | -0.04 | 0.00 |
| MID NORTH | 0.03 | 0.00 | -0.02 | 0.00 | 0.00 | 0.00 | -0.03 | 0.03 |
| MOUNT LOFTY RANGES | -0.01 | 0.00 | -0.06 | 0.00 | -0.01 | 0.12 | -0.20 | -0.01 |
| FLINDERS | 0.00 | 0.00 | -0.01 | 0.00 | 0.00 | 0.02 | 0.00 | 0.00 |
| ADELAIDE METROPOLITAN | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.05 | 0.00 |
| KANGAROO ISLAND | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| UPPER SOUTH EAST | 0.01 | 0.00 | 0.04 | 0.00 | 0.09 | 0.00 | 0.00 | 0.00 |
| LOWER EYRE PENINSULA | 0.02 | 0.00 | -0.01 | 0.00 | -0.02 | 0.03 | -0.01 | 0.00 |
| MURRAYLANDS | 0.00 | 0.00 | 0.01 | 0.00 | 0.00 | 0.01 | -0.01 | 0.00 |
| **Total** | 0.04 | 0.00 | -0.04 | 0.00 | 0.05 | 0.16 | -0.24 | 0.01 |

**Table 10 Difference between the model and actual outcomes – annual fire starts**

The largest differences are on the 11 kV feeders in the Mount Lofty Ranges, which is expected given it has the highest proportion of feeders (by length) and highest number of fire starts. For lines, the model predicts 0.2 less fires per annum than the average historical number, 9.7 (a 2.1% difference). We consider that these differences of this scale are reasonable, given the available data, and they will not affect the suitability of the model to estimate bushfire risk at the feeder level.

# C. Bushfire economic cost analysis (risk consequence)

## Introduction

This appendix describes the methodology we have used to calculate the economic cost associated with each bushfire simulation performed by CSIRO. These bushfire economic costs provide the critical ending point for our calculations for the consequence component of bushfire risk.

In this methodology, we have allowed for the direct costs that we consider are the most significant on the economic cost of bushfires and we can source reasonable accepted information on valuing these costs. These costs cover:

- agricultural land damage costs;
- property damage costs; and
- economic value of deaths and injuries (directly due to the bushfire).

We have not included other economic costs that are discussed in some literature, but of which there is less published information and their value is more contentious. This includes, among other things:

- indirect health and safety costs, such as ongoing mental health issues;
- costs due to smoke damage that could extend beyond the bushfire footprint;
- ongoing community economic impacts; and
- carbon costs.

We have been informally advised through discussions with the Bushfire and Natural Hazard Cooperative Research Centre that research they have conducted suggests these factors could increase economic cost by a material amount. This was suggested to be in the order of 10% to 20%.

Therefore, we consider it reasonable to assume that our methodology discussed here could understate the true economic cost of bushfires.

### Expert advice and assistance from Risk Spatial

Specialist expert services were engaged from Risk Spatial to develop and apply the methodology we have used to calculate the economic cost associated with each bushfire simulation.

Risk Spatial has expertise in assessing and valuing major geographic hazards and risks, such as bushfires and floods. It also has significant experience using geographic information systems (GIS) to perform and automate these tasks, and is very familiar with the public GIS data-sets that have been used for our purposes.

Using this expertise and experience, Risk Spatial developed the methodology discussed in this Appendix and developed and applied the underlying algorithms and techniques to apply this methodology.

This section has been prepared based on methodology papers prepared by Risk Spatial.

### CSIRO bushfire simulation output form for our analysis

The set of CSIRO bushfire simulation outputs were provided to us by CSIRO via file transfer and assessed for completeness and accuracy. The format of the data from CSIRO consisted of a set of GeoTIFF file[16] representing the results from each individual simulation CSIRO conducted.

Each of these files contain several layers describing the simulated fire event. The first layer in each GeoTIFF outlined the fireline intensity in KwH, with subsequent layers describing a percentage (to the nearest percent) for the likelihood of impact for that cell at each intensity range for a fire at the given FFDI range.

Box 1 below shows the name convention CSIRO used for this set of files

**Box 1 the naming convention for each CSIRO bushfire simulation GeoTIFF file**

The name of each CSIRO GeoTIFF file is in the following format:

*Intensity_SA_run_UID_<FireStartUID>_FID_<FeederID>_FFDI_<FFDIBAND>_REP_000_<REPNO>.tif*; where:

- FireStartUID – is the Unique ID of the fire start location
- FeederID – is the feeder ID number
- FFDIBAND – is the fire danger rating ID (A, B, C, D, E or F)
- REPNO – is the weather pattern ID (1, 2, 3, 4, 5 or 6)

## Our method to prepare loss exposure data

"Exposure" in the context used here refers to assets (in a general non-network sense[17]) that can have some economic value, such that these assets are exposed to the hazard being considered (ie bushfires in our study). Consequently, the community or economy can experience a loss in value as a result of an event caused by the hazard.

To calculate an economic loss estimate for each of the CSIRO simulations, we developed a repository of data sets that define the economic value for the various components of costs (e.g. land, property and public safety) that could be affected by the bushfires. We call these sets of economic value information, *exposure data*, as it reflects how the asset driving these losses will be exposed to each fire.

For example, we developed exposure data in the form of geographic maps of land and property values. The severity of the bushfire hazard, across the geographic extent of each event footprint, is then assessed against these exposure data sets in order to calculate the overall economic loss of each simulated fire event.

It is also worth noting that even though our network asset base remains in South Australia, the potential for an exposure loss from a bushfire caused by our network is not limited by state boundaries. Through discussion with CSIRO, it was determined that the potential existed for bushfire simulation footprints to extend into Victoria, because of fires started by our network assets in the

[16] GeoTIFFs are type of geographical spatial file format that can be loaded into GIS platforms.
[17] An asset in this context may be an inanimate object (building, contents etc), a natural entity (agriculture or other land type, human being etc) or an economic construct (business interruption, living expenses).

South East of South Australia. To ensure appropriate coverage of exposure information was made, all the datasets discussed here were extended some way into Victoria, to ensure that any event travelling in an easterly direction from the South East would be covered.

### Key exposure data sources

The exposure repository is developed from three main public data sources:

- the Cathment Level Land Use Management dataset (CLUM)
- the Geographic National Address File (GNAF); and
- the National Exposure Information System (NEXIS).

These key datasets are relied upon to provide a detailed understanding of the scope, mix and geographic distribution of exposed assets across the study area, and form the basis of loss calculations in the economic model.

#### *Land use data (CLUM data)*

The key source of information used for the determination of land use in this analysis is the Cathment Level Land Use Management dataset (CLUM), which implements the Australian Land Use and Management (ALUM) classification system

CLUM identifies 191 individual land use types, organised into broader categories that define the general land use for an area, covering the whole of Australia.

#### *Property data (GNAF data)*

The Geocoded National Address File (GNAF) is the foremost dataset on property data in Australia. It is developed by the Public Sector Mapping Agency (PSMA) in conjunction with several government and private organisations around the country, including the ABS, Australia Post and Geoscience Australia. The data identifies each address throughout the country and locates them using coordinates as a point.

Before the GNAF data can be used in our economic calculations, there are several refinements that we needed to make, so that it accurately reflects the actual number of properties in the real world. The GNAF data has a few peculiarities in the way information is stored, and this results in a larger number of addresses than actual buildings, meaning the dataset has to be reduced using queries on the raw data. These amendments are made manually and sequentially to the data, until we considered it appropriate for use in the economic model.

#### *Land and property volume and value data (NEXIS data)*

The National Exposure Information System (NEXIS) was created by Geoscience Australia and provides exposure information for the entire country at the ABS SA1 level[18]. Included in this dataset are the key metrics:

- Residential Structural Value;
- Residential Contents Value;
- Number of Residential Buildings;
- Population;
- Commercial Structural Value;
- Number of Commercial Buildings;
- Industrial Structural Value;

[18] See ABS website for definition.

- Number of Industrial Buildings;
- Agricultural land area; and
- Agricultural land value

This information underpins our economic assessment for this analysis, and all land and property losses are derived from this base dataset.

## Developing a geographic map of land type or use

To understand the impact of what economic loss may occur from a bushfire, it is first important to understand where the potential for exposure exists, and to this end, the first step is to identify the types or uses of land across the study area.

### *Defining the land types used in our analysis*

We have defined four primary land types in our economic analysis to define the land types where we expect materially difference loss values. These are:

1. Agricultural – land that produces agricultural and plantation products;
2. Residential – land that is inhabited by humans;
3. Commercial – land that holds properties for commercial use; and
4. Industrial – land that holds properties for industrial use.

In addition to these four primary land types, we have defined two further types that allow for the entire scope of potential land uses:

5. Environmental – land uses which are not normally inhabited by humans and have no inherent commercial value (examples are lakes, deserts, etc); and
6. Unknown – land uses for which no identifiable land use from the other 5 land types (primary or environment) can be extracted.

For the above two alternative land types, when a property is located on them, it is assumed to be residential, though this is extremely rare and is unlikely to impact the results of this analysis.

### *Mapping detailed land categories information to our defined land types*

Using the CLUM dataset described above, a mapping table is designed to categorise the 150+ broad CLUM categories into our 6 land types. The final land use dataset is then dissolved[19] to create a single expectation of land type at any location in these six categories (see Figure 14).

[19] "Dissolved" is in this context is a GIS process, which involves removing the boundaries between features of the same type. In this instance, where the general land use category of two or more adjacent features is the same, the boundary between them is removed to make a single feature. For example, if a farm is identified as being used for growing barley, and the farm next door grows wheat, these will both have the same land type of Agriculture, and subsequently the boundary would be removed between them and they would be viewed as a single feature.

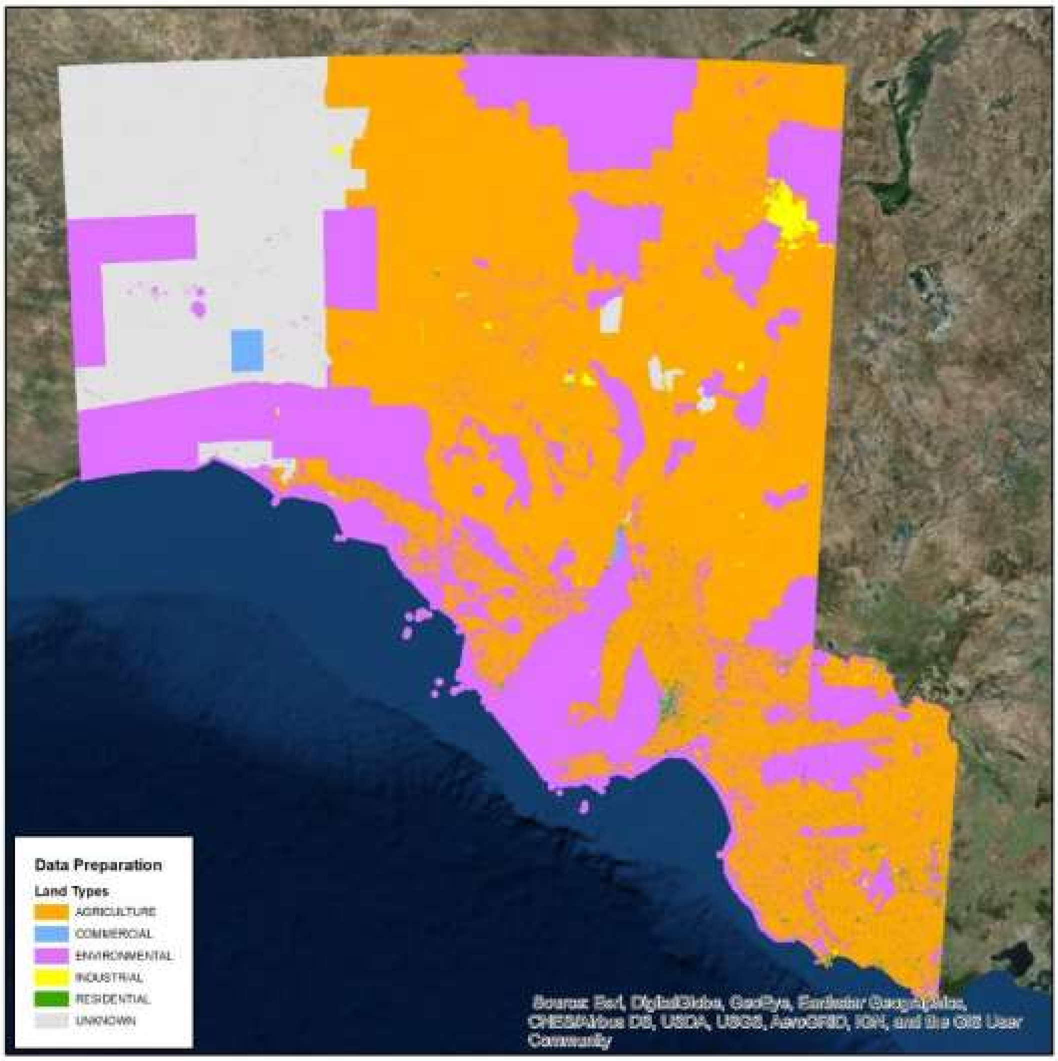


**Figure 14 Our land type map**

## Creating exposure (value) data

Using the exposure information defined in the GNAF and land use data described above, we then attribute value to this data by incorporating the NEXIS values by category, as described in the following sub-sections.

## Calculating agricultural land value

This process extracts data from the Land Use dataset with the agricultural land type and isolates them in a separate dataset. This dataset defines the extent of agricultural land across the study area (as shown in Figure 15).

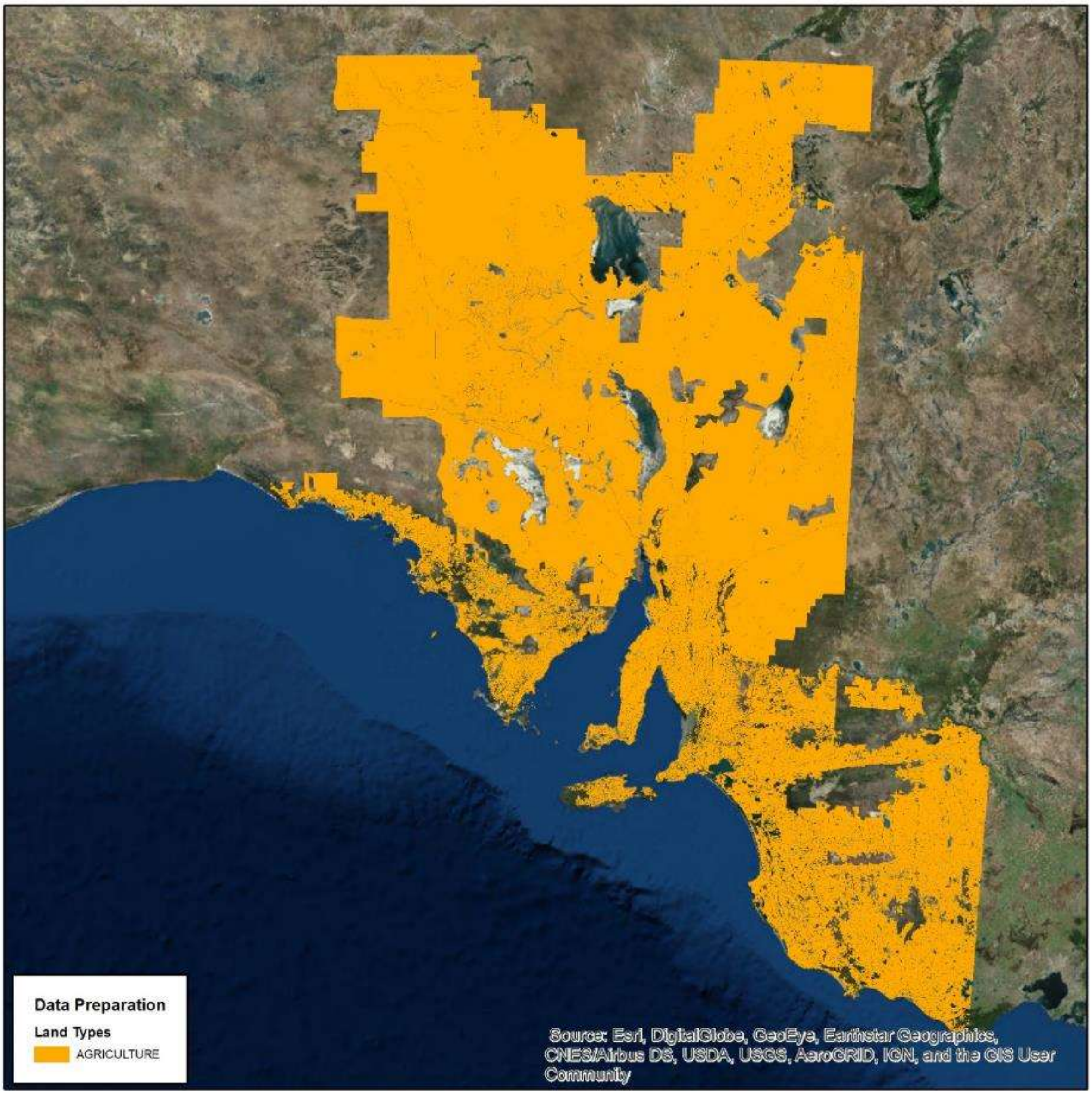


**Figure 15 Agricultural land type map**

We calculated the value for the land type we have defined as agricultural from the land values provided in the NEXIS database. We then process this further[20] to produce a consistent view of agricultural land exposure across the entire dataset (as shown in Figure 16).

[20] This involves dividing the Agricultural Land Value by the Agricultural Land Area to produce a value at the SA1 level per square metre. This value per square metre is then applied to each agricultural land cell, and is multiplied by 900 as there are 900 square metres in each cell (30m x 30m)

[redacted]

**Developing property type data**

We then identify every property location and assign a land type.

To achieve this, we extract the GNAF data (ie points representing property locations) and assign land types defined by the generalised Land Use dataset, based on the 4 Land Types (Agricultural, Residential, Commercial and Industrial) (see Figure 17).

As part of this process, we assume that all Agricultural GNAF property locations to reflect residential properties, as we consider that the majority of agricultural properties will be residential homes on agricultural land.  From this point forward, these properties are treated as residential in our analysis.

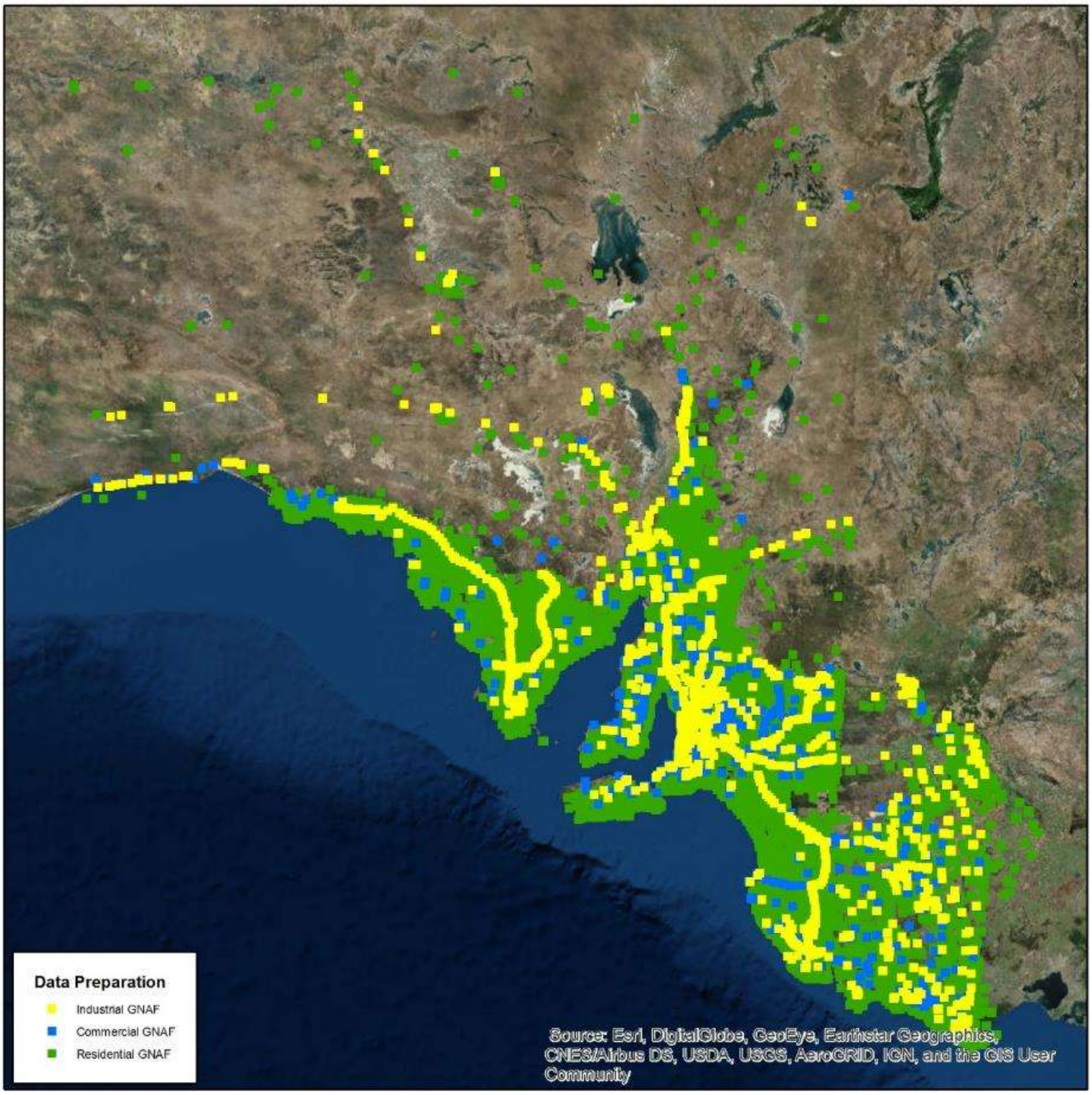


**Figure 17 Extraction of land use types to GNAF property locations**

## Extracting land and property values from the NEXUS data

This process takes the exposure economic values from the NEXIS database and applies them to the relevant Land Types identified in the two previous steps.

### *Calculating property values*

We calculated the value per property for each SA1[21]. These values are then attributed to the individual property locations, defined in the GNAF data using the following metrics:

- Residential Structural Value;
- Residential Contents Value;
- Commercial Structural Value; and

[21] SA1 are the Census Statistical Area Level 1 areas. The NEXIS data provides values for each SA1 level area for each of Residential, Commercial and Industrial (and Agricultural) with the number of properties and the sum value of those properties. To get the average value of individual land use types, we divide these by each other (eg Land Use Type Value / Land Use Type Property count).

- Industrial Structural Value.

This results in an exposure value for each individual property across the entire study area (as shown in Figure 18).

[redacted]

**Economic Exposure Adjustments**

The NEXIS data provides an estimate of the potential exposure across the country to gross insured losses at a fixed point in time. It is excepted however that these types of gross insured value tend to underestimate the true economic value. It is generally accepted that the economic value could be in the order of [redacted] than the insurance value. Therefore, we have applied a range of adjustments to convert the expectation of insured loss calculated from the NEXIS data into a value that we consider will more reasonably reflect an economic loss and convert from nominal to real (2017) dollars.

[redacted]

| | [redacted] | |
|---|---|---|
| [redacted] | [redacted] | [redacted] |
| [redacted] | [redacted] | [redacted] |
| [redacted] | [redacted] | [redacted] |
| [redacted] | [redacted] | [redacted] |
| [redacted] | [redacted] | [redacted] |
| [redacted] | [redacted] | [redacted] |
| [redacted] | [redacted] | [redacted] |

[redacted]

[redacted]

- [redacted]
- [redacted]
- [redacted]
- [redacted]
- [redacted]

### Manual Adjustments

In addition to the broad adjustments described in the section above, several manual adjustments were made to intervene in areas where issues occurred. This process ensured an accurate reflection of the exposure was accounted for in the final analysis and removed inequities in the data creation process.

These manual adjustments included the adjustment of individual exposure values for median values where the calculated values were deemed too high or low. This ensured a return to the median of total values across the NEXIS database, and reduced the incidence of spikes in losses where the input data from the three different inputs (Land Use, GNAF and NEXIS) were out of date, incorrect or did not appropriately reflect the methodology used to estimate exposure.

## Model Processing

The economic cost (i.e. economic loss due to a bushfire) for each of the CSIRO simulations has been calculated using the CSIRO simulation output file and the various exposure data sets and assumptions discussed above.

[redacted]

The following section describes the computation methodology employed in a Python scripting environment and distributed to the Azure processing resources, which we have used to perform these calculations.  To enable us to calculate the individual economic costs for approximately 1 million simulation outputs, we have developed a largely automated process that is captured in a single Python script.

## Compute environment for the economic costing

To facilitate the processing of more than 1 million simulations, a robust application and infrastructure framework was employed for performing the computations.

### *Application used*

The software environment was developed on geospatial platforms, reflecting the inherent geographic nature of the outcomes sought, the peril itself, and the various inputs to the methodology.

More specifically, the following applications were used to develop the economic model:

- **ArcGIS** – Esri's desktop software was used to initially develop and visualise the various elements of the project, and provide GIS support for the creation of the framework, including mapping visualisation outputs and data management
- **Python** – the powerful scripting tool forms the basis of the programmatic environment, and all components of the economic model process are encapsulated within Python
- **arcpy** – this Python site package provides Esri's bespoke spatial analysis tools in the native Python environment, and allowed the implementation of the tools developed in the ArcGIS desktop interface into the broad scripting framework of Python
- **GDAL** – the Geospatial Data Abstraction Library (GDAL) is a translator library for raster and vector geospatial data formats and is Open Source. This Library was used to perform simpler tasks in the Python environment with little processing overhead

### *Compute infrastructure used*

To facilitate such a processing intensive project, external computing resources were required to enable the economic simulations. For this purpose, Microsoft's Azure cloud computing platform was used.

Within this platform, the Virtual Machine resources were deployed to scale individual machines to run both larger and more powerful computing resource, and to run those resources concurrently. At the point of maximum processing, there were Azure 4 Virtual Machines running 16 cores each, providing 64 simultaneous processing nodes.

## Processing the CSIRO Simulation output files

The CSIRO data covers a rectangular area of fixed dimensions, describing both the affected burned area, and the remaining dimensions of the area covered (see Figure 19).  The first step in our compute process is to process these raw input data files from CSIRO, into an alternate native GIS format (File Geodatabase Raster) in order to extract only the burned areas from each of the CSIRO simulations.

An individual process was performed to extract these burned areas from the simulation output files and calculate the total area of the output burned by the event. This total area, called here the event footprint, describes all cells in the output layer that are non-zero, meaning it considers all fireline intensity values greater than 0, and is provided as a value in the final output (see Figure 20).  To conform to the standards used in this methodology, we also converted the intensity units from KwH to

MwH by simply dividing by 1,000.  This provided a standard input file for each simulation, which we used for the remainder of our analysis (see Figure 21).

[redacted]

[redacted]

**Comment on event footprints with a zero area**
If a simulation resulted in no area being burned, the model skipped the calculation processes and moved to the next event. CSIRO have advised that in these instances, the likely reason for the bushfire not extending beyond the fires start location was that the input conditions to the model suggest there was not sufficient or appropriate fuel for the fire to begin and subsequently no area burned.  For example, this would occur if the fire start location was located in an urban area, without vegetation to fuel the fire.

## Calculating land and property loss

The key component of loss in the economic model is encountered through losses to land and property. In our calculations, these losses typically account for the largest share of economic loss. As such the methodology for calculation of these losses is comprehensive, using the exposure data sets described in the previous sections.

The determination of these losses is divided into two components:

- agricultural land losses; and
- property losses.

### *Agricultural Land Loss*
To calculate the loss associated with agricultural land, we apply the following three-step process:

- Step 1 agricultural land area - First, we determine the affected agricultural area from the event footprint (as calculated above).
- Step 2 agricultural area exposure - We then extract the financial exposure data associated with that area from the relevant exposure data (discussed above).

- Step 3 calculating economic loss - Finally, we apply a vulnerability function we have derived to the exposure data to determine a final loss. This vulnerability function defines the portion of the exposure value that will define the loss given the fire intensity.

These three steps are described further below.

***Step 1 - Determining the Agricultural Area***

To determine the agricultural area affected by each event, the total agricultural exposure dataset described in the exposure section above is intersected with the bushfire event footprint. The output from this intersection describes the total area of agricultural land affected by each simulation, in addition to the fireline intensity at each location (as shown in [redacted]

[redacted]

***Step 2 – Determine the agricultural area exposure***

Using the agricultural area affected by the footprint, we can extract the inherent agricultural exposure value across the footprint, via the relevant exposure data, to determine the total amount of agricultural land exposed to each individual event (as shown in [redacted].

[redacted]

[redacted]

### *Step 3 – applying the vulnerability function to calculate the economic loss*

Once the agricultural exposure value has been determined and the commensurate fireline intensity distribution identified, a vulnerability function is applied to determine the expected loss ratio for defined ranges of fireline intensities.

The vulnerability curve we have used was developed using:

- loss functions defined in a previous bushfire risk study, performed for us by Willis Re (this was a study associated with our previous proposal to the AER); and
- adjustments we applied to consider the economic cost (not the insured loss).

Losses were assessed against historic events and vulnerability curves adjusted accordingly.

The vulnerability curve used to determine the expected loss is described [redacted] This vulnerability function is then applied to the event footprint to produce a vulnerability map for each bushfire simulation (as shown in [redacted]

[redacted]

[redacted]

This vulnerability map defines what percentage of the exposure value for that location is used to calculate the economic loss for that bushfire event. This vulnerability map is then applied to the agricultural land exposure value to calculate a map of the expected economic loss (see [redacted] The losses in each location can then be summed to produce the total economic loss value for that bushfire event.

[redacted]

***Property Loss***
The property losses for the remaining land use types (Residential, Commercial and Industrial) are calculated separately using the same methodology for each land type.

As the method used to calculate the economic losses for these three land types is the same, we will explain it below using the example of the calculations for residential losses. The methodology is very similar to the agricultural land loss method discussed above, involving the calculation of losses for each of the bushfire event footprints using the following three steps:

- Step 1 determining properties - First, we determine the affected residential properties from the event footprint
- Step 2 determining exposure - We then extract the financial exposure data associated with those properties from the relevant residential property exposure data.
- Step 3 calculating economic loss - Finally, we apply a vulnerability function we have derived to this exposure data to determine a final loss. As with the agricultural land calculations, the vulnerability function defines the portion of the exposure value that will define the loss given the fire intensity for that event footprint.

The three steps are described further below.

***Step 1 - Determining the properties***

For this calculation, individual properties (as determined in the exposure data section above) are intersected with the event footprint to identify the properties that are exposed to each individual event and the fireline intensity at each location (as shown in [redacted]

***Step 2 – Determine the residential property exposure***

A property value is defined for each property in the resulting property exposure intersection discussed above based on the residential exposure data map we developed above (as shown in [redacted]

[redacted]

### *Step 3 – applying vulnerability function to calculate the economic loss*

Once individual property values have been determined and the commensurate fireline intensity distribution identified, a vulnerability function is applied to determine the expected loss ratio for defined ranges of fireline intensities.

The vulnerability curve we have used was developed using:

- loss functions defined in a previous bushfire risk study, performed for us by Willis Re (as noted above); and
- adjustments we applied to consider the economic cost (not the insured loss).

The function was calibrated against expected outcomes from historic bushfires.

The vulnerability curve used to determine the expected loss for each of the three property types are described in [redacted] [redacted] and [redacted]

[redacted]

These vulnerability functions are then applied to the event footprint to produce a vulnerability map for each bushfire simulation (as shown in [redacted]

[redacted]

This vulnerability map defines what percentage of the exposure value for that location is used to calculate the economic loss for that bushfire event. This vulnerability map is then applied to the residential property exposure value to calculate a map of the expected economic loss (see [redacted] The losses in each location can then be summed to produce the total economic loss value for that bushfire event.

[redacted]

## Total Land and Property Losses

Once each of the component parts of agricultural land and property are calculated, they are provided as output to the end results mechanism, and spatially summated together to calculate a spatial map of the total land and property loss value (see [redacted]

The individual spatial maps of property and land losses of each bushfire event have been retained for the calculation of the final risk map, as described in the outputs section towards the end of this appendix.

[redacted]

**Calculating deaths and injuries losses for each bushfire event**

To complete the calculation of economic loss for each bushfire event, we estimate the number of deaths and injuries that would result from the event and apply economic values to these parameters to define the economic loss due to these deaths and injuries.

To do this, a methodology was developed to determine the specific losses using a combination of population data, our estimate of the population affected by an event (i.e. the death and injury rates per head of population affected), and assumptions on the economic statistical value of life.

This methodology followed a similar approach taken in previous studies we have commissioned to estimate the losses due to bushfires we could start, but has been revised to consider more detailed information on expectations of the affected population.

***Population data used for our analysis***

We have used the following information from the NEXIS data in our analysis:

- The estimate of the population per SA1 level, which is derived from ABS census data.
- The number of residential properties within which this population resided.

We consider that this information provides an accurate assessment of the total number of people living in each SA1 area, and the total number of houses within which they lived. This information is distributed in the input residential property data, described in the exposure section above.

### *Estimating the population affected for each event*

The number of residential properties affected by each bushfire event (calculated based on the methodology discussed above), the population size and the residential property number were used to calculate an estimate of the total number of people likely to be living within the bushfire footprint area[23].

### *Assumed death and injury rates*

Once we have estimated the number of people living within the event footprint, we then estimate the number of deaths and injuries using assumed death and injury rates per affected population size.

We have used the same assumed death and injury rates that were developed by Willis Re for us in a previous engagement (as noted above). These assumptions were estimated from previous major bushfires, by calculating the death and injury rates per head of population associated with these events. The events including the Black Saturday, Ash Wednesday and the Canberra fires.

[redacted]

### *Assumed death and injury cost rates*

Once the total number of deaths and injuries for each simulation were determined, assumed economic costs per death or injury suffered were used to assess the overall economic losses incurred due to deaths and injury.

[redacted]

### *Total Death and Injury Costs*

In addition to estimating the number of deaths and injuries and associated economic costs, the model outputs the total counts of deaths and injuries associated with each simulation, as well as the component parts of the economic losses.

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[23] The population for each SA1 is divided by the number of houses, giving the number of people in each house within that SA1.

## Post Analysis Adjustments

Following the modelling of the entire study area, we evaluated the results and identified two issues that had the potential to over or understate the economic loss calculated by the above methodology. The two issues were:

- misrepresented land use; and
- misrepresented bushfire simulation.

We corrected for these two matters via a post-processing exercise. These matters and our solutions to correct for them are discussed below.

### Misrepresented Land Use

We found an issue with the data we were using to generate the exposure data, which could result in the inaccurate allocation of property exposure to land type for some locations.

In this instance, the key driver of this issue occurs because of the difference between the vintage of the GNAF property database, and the CLUM land use database. As these public databases are developed and released, land use can change from what is defined in the database at the time it is assembled. As such, there can be inconsistencies in the two data sets.

As such, the allocation of GNAF property locations to the correct land type fails. A real-world example of where this occurs is when a segment of land has its land use type changed from industrial to residential for development purposes, and the address dataset updates faster than the land use dataset. This results in many residential properties being allocated to the old land use of industrial, and subsequently the values are overstated.

Further inspection of this issue identified that it only occurs during the transition from either industrial or commercial land to residential land and not the other way around. This is because residential land is rarely if ever requisitioned for industrial or commercial use.

The solution for this issue was to identify event outputs that had disproportionately large industrial or commercial losses compared to residential losses. Where this was encountered, the resulting losses were redistributed using the total property count, and the expected distribution of losses taking the average ratio of properties from events not affected by this issue.

### *Misrepresented Bushfire Simulation*

This issue occurs for similar reasons to the previous issue, but involves the underlying parameters used in the CSIRO bushfire simulations. There are examples on the periphery of major urban areas (Adelaide, Mt Gambier, Adelaide Hills) where development has occurred at a rapid rate. In these areas, it is probably that the land use allocated in the CSIRO model reflected the previous usage, which in these areas was uninhabited and in many cases bushfire-prone grassland or forest. The outcome of this is that the CSIRO bushfire simulation presumes these areas to be burnable, when in fact they have most recently changed to residential (and to a lesser extent commercial and industrial), and subsequently they demonstrate a property substantial loss when in fact it is highly unlikely this would occur.

The solution for this issue was to reduce the number of residential properties affected to reflect the expected number affected, determined by an average of unaffected events. This was then converted through to the final loss.

## The key output of the analysis used by our bushfire CBA model

The key output from this process, which provides an input to the bushfire CBA model, is a table that summarises the results. This table is a key input to the risk calculation workbooks, which are discussed in Section 6.

Each row in this table provides the aggregate results for each simulated bushfire event, including aggregate metrics of both the physical and economic loss (see [redacted] The data described in the output table consists of the fields defined in Table 18.

| Field | Definition |
|---|---|
| **uniqueID** | The Unique ID for the individual fire start location |
| **FeederID** | The ID of the Feeder to which the fire start location belongs |
| **FFDI** | The FFDI used for this simulation (one of A, D, C, D, E or F) |
| **REP** | The simulation weather scenario ID (one of 1, 2, 3, 4, 5 or 6) |
| **Area** | The total non-zero area burned for the event |
| **AgriculturalArea** | The total non-zero agricultural area burned for the event |
| **ResProperties** | The number of residential properties within the even footprint |
| **CommercialProperties** | The number of commercial properties within the even footprint |
| **IndustrialProperties** | The number of industrial properties within the even footprint |
| **Population** | The total population within the event footprint |
| **Deaths** | The number of deaths from the event |
| **SevereInjuries** | The number of severe injuries from the event |
| **MinorInjuries** | The number of minor injuries from the event |
| **AgriculturalLandLoss** | The total financial loss from agricultural land from the event |
| **ResPropertyLoss** | The total financial residential property loss from the event |
| **ComPropertyLoss** | The total financial from commercial property loss from the event |
| **IndPropertyLoss** | The total financial loss industrial property loss from the event |
| **LandPropertyTotal** | The total financial loss from land and property from the event |
| **DeathsInjuriesTotal** | The total financial loss from deaths and injuries from the event |
| **Total** | The total financial loss from the event |

**Table 18 Economic cost output table field definitions**

[redacted]

## Key references to our economic analysis method and input assumptions


1. CSIRO Bushfire Simulation Model - SPARK - https://research.csiro.au/spark/
2. Esri Desktop GIS Software - ArcGIS - https://desktop.arcgis.com/en/
3. Programming Language - Python - https://www.python.org/
4. Native Python Esri scripting module - Arcpy - http://pro.arcgis.com/en/pro-app/arcpy/get-started/what-is-arcpy-.htm
5. Native Python geographic scripting module GDAL - http://www.gdal.org/
6. Public Sector Mapping Agency - PSMA - https://www.psma.com.au/
7. Geocoded National Address File - GNAF - https://www.psma.com.au/products/g-naf
8. National Scale Land Use Dataset - CLUM - http://www.agriculture.gov.au/abares/aclump/land-use/land-use-mapping
9. National Exposure Information System - NEXIS - http://www.ga.gov.au/scientific-topics/hazards/risk-and-impact/nexis
10. Reserve Bank of Australia - Inflation Calculator - http://www.rba.gov.au/calculator/annualDecimal.html