Bushfire Risk Modelling

2025-30 Regulatory Proposal

Supporting document: 5.6.3

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SA Power Networks

Empowering South Australia

Contents

Glossary

Acronym / term	Definition
ABC	Aerial bundled cable
AER	Australian Energy Regulator
Augex	Augmentation expenditure
Capex	Capital expenditure
CBA	Cost-benefit-analysis
CSIRO	Commonwealth Scientific and Industrial Research Organisation
FDPS	Fire Danger Protection Settings
HV	High voltage
Opex	Operating expenditure
PSPS	Public Safety Power Shutoffs
SCADA	Supervisory control and data acquisition

1 Introduction

This document sets out details of SA Power Networks' Bushfire Model Framework which has been developed to define the functional characteristics of SA Power Networks' bushfire risk mitigation forecasting models.

1.1 Purpose

The Model Framework is one of a set of documents that together enable the selection of the optimal set of investments in support of bushfire risk mitigation programs.

The Model Framework document is intended to define how bushfire risk is assessed and evaluated to enable the selection of the optimal set of investments to support bushfire risk management. It does this by calculating bushfire risk in monetary terms and optimising the set of investment options applied to maximise net economic benefits.

The bushfire risk and benefits calculations within the Model Framework have been developed to align with SA Power Networks' Value Framework, which defines the dimensions and parameters that should be used to value risks and benefits across SA Power Networks.

1.2 Scope

This document describes the forecasting approach for augmentation expenditure (**augex**) aimed primarily at reducing the risk of bushfires started from network assets, including explanations of how:

- bushfire risk is defined and calculated in the context of the fires that our network can start; and
- options to reduce bushfire risk are defined within the model and evaluated to calculate their reduction in bushfire risk and their net-benefits.

Caveat on scope of bushfire risk calculations and this Model Framework document

It is important to note that bushfire risk can be a driver of other programs, including some asset replacement programs and some operational and maintenance programs. The specifics of the risk calculations can vary between these programs, depending on their specific circumstances (eg some programs may only need to focus on certain fire start causes).

This Model Framework document *only* sets out the bushfire risk calculations associated with the evaluation of the bushfire risk mitigation programs that form part of SA Power Networks' augex.

1.3 Objectives

The objective of the Model Framework is to document the methodology for forecasting bushfire risk mitigation augex. This includes forecasting for internal uses and for forecasts provided to the Australian Energy Regulator (**AER**) as part of a Regulatory Proposal.

The Model Framework has been developed to be compatible with the National Electricity Rules (NER) and guidance the AER has published on its expectation of expenditure forecasts provided within regulatory proposals, including guidance in its Better Resets Handbook[1].

Caveat on the objectives and audience of this Model Framework document

It is important to note that this document aims to explain at a functional-level how the bushfire risk calculation is undertaken and the evaluation of mitigation options are performed. Its intention is to provide sufficient understanding of the models and underpinning analysis to inform a technical review of the forecasting methodology.

It is *not* intended as a user-reference to the physical models contained within the Model Framework, and as such it does not explain how a user should set-up and run the models to conduct the calculations and evaluations discussed in this document.

[1] AER, *'Better Resets Handbook',* December 2021, available via: [www.aer.gov.au/industry/registers/resources/guidelines/better-resets-handbook-towards-consumer-centric-network-proposals]

2 Model Development

2.1 Regulatory Requirements

The specification of SA Power Networks' Model Framework is guided by the need to align with the National Electricity Rules and regulatory guidelines and expectations. The Model Framework supports the development of an efficient and prudent investment portfolio that seeks to at least maintain safety, while also looking to maximise benefits to customers.

The AER *Better Resets Handbook*[2] provides guidance on capital expenditure forecasts for regulatory submissions and includes the latest guidance on the AER's expectations. In looking at bushfire augmentation capital expenditure, we have had regard to the Handbook's expectations that where capital expenditure is predominantly made up of large non-recurrent projects / programs, networks need to provide quantitative cost benefit analyses to demonstrate that these projects / programs achieve expected service performance levels (in this case, safety) and maximise net benefits to consumers.

The Model Framework for the bushfire mitigation program is specifically aimed at providing a robust methodology for quantifying bushfire risk and performing formal cost-benefit analysis of options to mitigate this bushfire risk.

2.2 Principles

The development of this model framework uses a bottom-up modelling methodology.

The model framework is intended to produce forecasts that reflect the prudent and efficient operation and management of the electricity network while maintaining compliance with all applicable laws, regulations and industry standards.

2.3 Alignment with Corporate Risk Management Framework

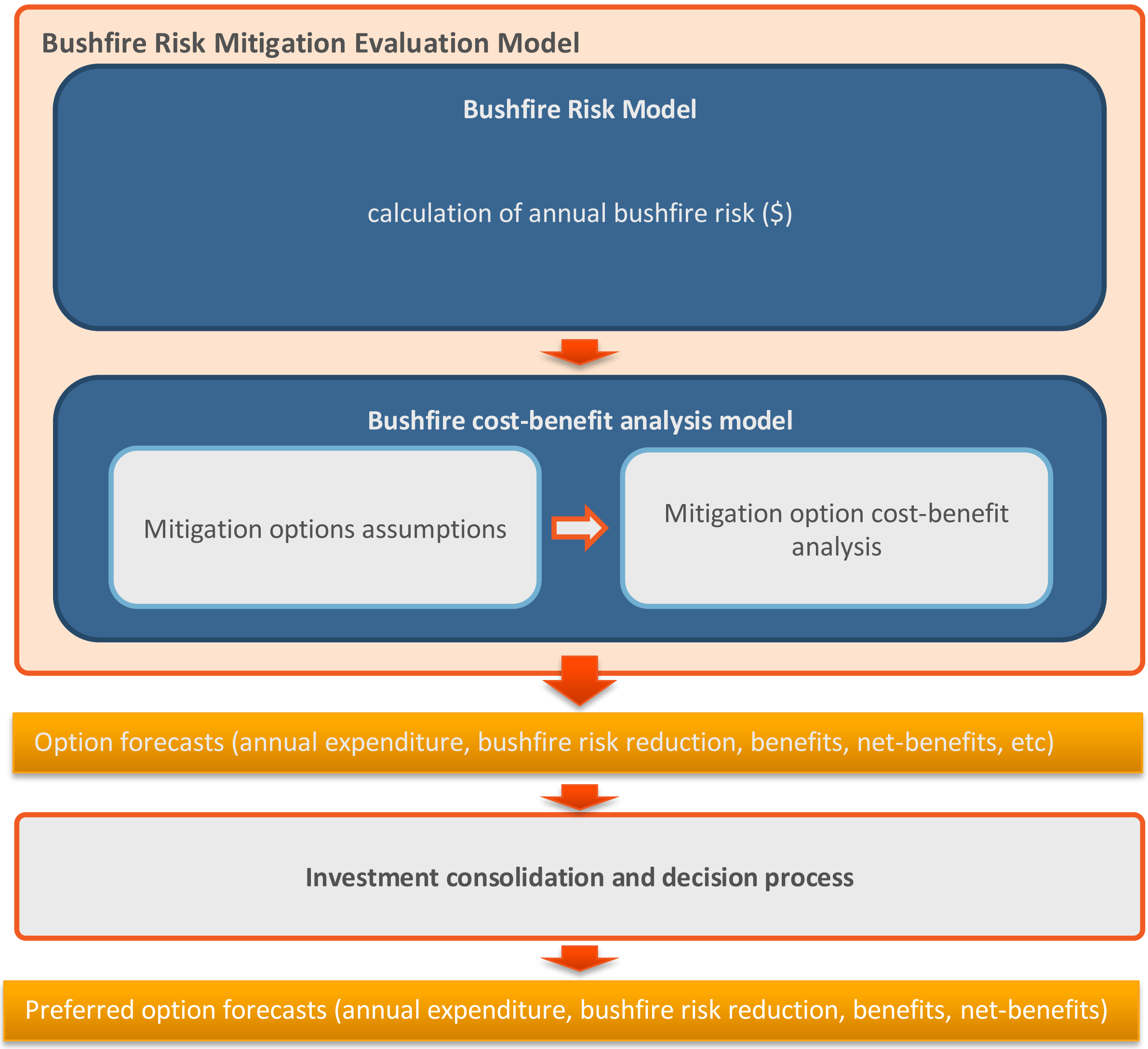
The model framework provides the means of translating the risks identified in the Value Framework into investment decisions and budget forecasts that reflect the economic value of those risks. The Value Framework is aligned with the Corporate Risk Management Framework, so by applying the Value Framework, the Model Framework is also aligned to the Corporate Risk Management Framework.

[2] AER, *'Better Resets Handbook',* December 2021, available via: [www.aer.gov.au/industry/registers/resources/guidelines/better-resets-handbook-towards-consumer-centric-network-proposals], last accessed 25/01/2024

3 Bushfire Risk Mitigation Evaluation Model - Model Framework overview

The overall Model Framework to develop the forecast for the bushfire risk mitigation programs is shown in Figure 1 below.

Figure 1 Overview of Model Framework for developing the bushfire risk mitigation program forecast



The Model Framework consists of two major components:

- **Bushfire Risk Mitigation Evaluation Model**

  This Bushfire Risk Mitigation Evaluation Model is a physical model that we have developed to calculate bushfire risk and undertake formal cost-benefit analysis of mitigation options. Its key outputs are various forecasts of the mitigation options, including forecasts of option expenditure, annual bushfire risk and bushfire risk reduction, annual benefits and annual net-benefits.

  This Bushfire Risk Mitigation Evaluation Model consists of two separate components:

  - the **Bushfire Risk Model**, which takes various inputs and calculates the current annual bushfire risk, due to fires that our network can start in bushfire risk areas over the bushfire season; and

  - the **Bushfire Cost Benefit Analysis Model**, which performs a cost-benefit analysis of various pre-defined bushfire risk mitigation options.

  The sections below discuss these model components in more detail.

- **Investment consolidation and decision process**

  This investment consolidation and decision process can be viewed as a post-processing stage of the physical modelling, performed by SA Power Networks personnel to develop the preferred option forecast that forms a component of the expenditure forecasts contained in our regulatory proposals or actual investment plans.

  A key purpose of this process is to ensure interactions with other programs have been allowed for, double counting has not occurred, and the proposed bushfire mitigation program is deliverable.

  This process can take a range of inputs and considerations to develop and optimize the preferred option forecast. For example, this process can consider the interactions of the options forecasts (both physical scope, expenditure and risk reduction) with other program forecasts (eg asset replacement) and other business considerations (eg deliverability) to develop a final preferred annual forecast over the planning horizon.

  It is important to note that this process is procedural and is not conducted within a physical model. Therefore, this process is not defined in further detail in this Model Framework document. However, important considerations and findings from the application of this process are set out in the business cases associated with the bushfire risk mitigation programs.

4 Bushfire Risk Model

As shown above in Figure 1, the Bushfire Risk Model is a component of our Bushfire Risk Mitigation Evaluation Model. This section explains how the bushfire risk due to the SA Power Networks network is calculated in the Bushfire Risk Model. This calculation is performed in accordance with the SA Power Networks Value Framework.

4.1 Risk definition used in the Risk Model

The risk measure calculated in the model represents the *expected* (monetised) bushfire risk ($) due to the network per bushfire season. This *expected* risk can be viewed as a weighted-average bushfire economic cost over the bushfire season, allowing for all probable bushfire events that could occur in any year, where the likelihood of those events represents the weighting.

In any actual year, the economic cost of bushfires due to the 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 the average annual benefit (in terms of the avoided expected bushfire risk) can be calculated, which is compared with the program costs.

Important note on the *risk* value ($) calculated by the Bushfire Risk Model and a *maximum loss* value

As noted above, the risk value discussed in this document can be viewed as the average economic loss per bushfire season due to bushfires started by the SA Power Networks network (ie the *mean* loss per bushfire season). This metric is calculated as it is most appropriate for evaluating mitigation options through a formal cost benefit analysis approach.

It is important to stress that this risk value is not a *maximum loss* value (ie the maximum economic loss a bushfire started by SA Power Networks could result in), which may be more appropriate for matters such as insurance valuation. Such a maximum loss value would be considerably higher than this risk value.

That said, as we will discuss below, the Bushfire Risk Model is developed from individual calculations of the likelihood and consequence of a very large range of possible bushfire events. Therefore, maximum economic loss values can be deduced through the Bushfire Risk Model if required (eg a 1 in 50-year loss event, or 1 in 100 loss year event, etc.). However, for the avoidance of doubt, these types of calculation are not discussed further below.

4.1.1 Network coverage and resolution of the risk calculation

The Bushfire Risk Model calculates the risk resulting from bushfires our network could start across an area that encompasses all our network feeders traversing High and Medium Bushfire Risk Areas (**HBFRA** and **MBFRA**), covering 1,111 feeders and approximately 48,000 route km of overhead High Voltage (**HV**) line.

The overall risk calculation covers a very large range of unique bushfire events, which cover the different locations the SA Power Networks network could start a fire and the different fire danger conditions and weather patterns specific to each of those locations. CSIRO has been engaged by SA Power Networks to define these locations and determine the set of applicable fire danger rating and weather patterns applicable to each location.

In total, the risk calculation encompasses approximately 122,000 unique ignition locations across the covered regions, and on average approximately 40 different weather patterns and fire danger rating combinations for each of these locations. This amounts to a resolution of approximately 5 million unique bushfire events that define the calculation of the total risk from bushfires that the SA Power Networks network can start across these bushfire risk areas.

In this way, each unique bushfire event is defined by:

- the location of the start of the fire – which is also uniquely defined to a portion of one of our feeders (we call these portions of a feeder as 'segment' in this document);
- the bushfire conditions, defined as one of the six SA Fire Danger Ratings (Low/Moderate, High, Very High, Severe, Extreme, and Catastrophic) used in the historical dataset (noting that these Fire Danger Ratings changed in September 2022 with the introduction of the new Australian Fire Danger Rating System); and
- the weather pattern driving the bushfire (eg temperature, wind speed and direction over the duration of the bushfire).

This very fine resolution in bushfire events being studied allows for the accurate calculation of the bushfire risk due to individual feeders and even small sections of a feeder. It also allows this risk to be broken down into the components associated with the different Fire Danger Ratings.

The level of granularity in the risk calculation is critical for estimating the benefits of the mitigation options being evaluated through the bushfire cost-benefit analysis model. For example, if an option being evaluated can reduce the risk on a feeder, but this option will only be implemented during days with 'Extreme' and

'Catastrophic' Fire Danger Ratings, this risk component can be calculated for an individual feeder in order to determine the benefit (in terms of avoided risk) of implementing the option on that feeder.

Definition of the Fire Danger Ratings used in the bushfire risk model

In 2022, the Australian Fire Danger Rating System (AFDRS) was revised[3]. This change reduced the number of categories from six to five, and altered the underlying definition and calculation of each category.

As much of the bushfire risk model development occurred prior to this time, the six previous Fire Danger Rating categories and their definitions are used in the model and its documentation. The table below shows the indicative relationship between the six Fire Danger Rating categories in the previous system (used in our model) and the five categories in the new system.

Table 1 Comparison of previous and new Fire Danger Rating categories

Previous rating system (used in SA Power Networks bushfire risk model)			Revised rating system (indicative alignment)	
Previous fire danger rating	Forest Fire Danger Index (FFDI)	Grass Fire Danger Index (GFDI)	Revised fire danger rating	Fire behaviour index (FBI)
Catastrophic	100+	150+	Catastrophic	100+
Extreme	75-99	100-149	Extreme	50-99
Severe	50-74	50-99		
Very high	25-49	25-49	High	24-49
High	12-24	12-24	Moderate	12-23
Low-moderate	0-11	0-11	no rating	0-11

4.2 Risk calculation

The model calculates the risk associated with each of the individual bushfire events (ie approximately 5 million unique events noted above) based on the product of:

- the **likelihood** of the bushfire event occurring, which is defined as the long-term average number of this bushfire event occurring each bushfire season; and
- the **consequence** of that event (i.e. the monetised economic loss if that bushfire event occurred).

The calculation of risk value for each event is shown in more detail in Table 2 below. This shows the various components of the likelihood and consequence terms in the risk calculation. This table also indicates the parameters that define each component (for example, the fire start rate is a function of the event's fire danger rating, the asset type causing the fire, and the feeder voltage and feeder region (which are uniquely defined by the event's fire start location).

The individual bushfire event risks are then grouped and summed to provide whatever risk value is needed for further analysis. For example:

[3] See https://afdrs.com.au for the revised system and https://www.afac.com.au/initiative/afdrs for more detailed information on the development of the revised system.

- total bushfire risk is the sum of all event risks;
- an individual feeder's bushfire risk is the sum of event risks, only for those events where the fire start location of the event is associated with that feeder (noting each fire start location is mapped to a unique feeder); and
- an individual feeder's bushfire risk associated with a specific fire danger rating is the sum of event risks, only for those events where the fire start location of the event is associated with that feeder and the fire danger rating defined for that event matches the required rating.

Table 2 Bushfire event risk calculation

Event risk components				Risk component definition	Component parameters
Risk			**event risk**	average long term monetised loss ($) per bushfire season for those study parameters	event parameters (fire start location, fire danger rating, weather pattern)
=			=		
Likelihood	average number of unsuppressed bushfires due to our network per bushfire season for these event parameters	average number of fire starts due to our network per bushfire season for these event parameters	**fire start rate**	average number of fire starts per asset per day in this fire danger rating	Fire danger rating, asset type causing the fire, feeder voltage and feeder region (fire start location)
			x		
			asset quantity	Asset quantity associated with location	feeder (fire start location)
			x		
			days per season	average number of days per season for these event conditions	event parameters (fire start location, fire danger rating, weather pattern)
			x		
			1-suppression probability	probability that a fire start will not be extinguished (or self-extinguish) resulting in a significant bushfire	location suppression level (fire start location), fire danger rating
x			x		
Consequence			**event economic loss**	the monetised economic loss ($) of the bushfire, allowing for the factors set out in our Value Framework (namely land and property damage, and public injuries and fatalities)	event parameters (fire start location, fire danger rating, weather pattern)

Each component of the above event risk calculation is described further in the subsection below.

4.2.1 Fire start rate

The 'fire start rate' defines the average number of fire starts per asset per day during the bushfire season in one of the six Fire Danger Ratings. The rate applicable for any specific bushfire event is specified by the following parameters associated with the event:

- Fire Danger Rating for that event (ie Low/Moderate, High, Very High, Severe, Extreme, Catastrophic); and
- the feeder voltage and feeder regions (which are defined by the fire start location).

Separate rates are defined for asset types relevant to the analysis of the mitigation options. This requires specific rates to be defined for any fire-prone assets being evaluated for upgrade.

Currently, separate rates are only calculated for:

- fire-prone surge arrestors (on a feeder unit length basis ie fires started by fire-prone surge arrestors per unit length of the feeder) – this rate is necessary to assess the risk associated with this fire-prone asset; and
- all assets constituting the feeder (using feeder length to define the asset unit ie all fire starts per unit length of feeder) – this rate is sufficient to assess all other current mitigation options.

The fire start rates have been determined using the SA Power Networks' historical fire start database. This database records the details of every reported fire start since 2008. This database has been combined with historical daily fire danger rating data (from 2014) to develop relationships that define the average number of fire starts, per unit overhead length of feeder, per day, in each of the six fire danger rating bands.

This analysis only uses fires started by the 1,111 feeders covered by the model, which were started during the bushfire season ie it should provide a fire start rate applicable to the feeders being studied and the bushfire season.

The fire start rate associated with each of the six fire danger ratings are defined at the network level (ie the average rate across all studied feeders) for each asset type. Scalar multipliers are calculated that can be applied to these network-level fire start rates to account for differences in rates between network regions and the feeder nominal voltages[4].

In this way, the fire start rate applicable to an individual bushfire event and an asset type is:

*asset type's **network-level rate** for that event's fire danger rating* x ***multiplier** for that event's region and feeder voltage*

A more detailed explanation of the analysis used to calculate the fire start rates and rate multipliers is provided in Appendix A.

Note on implications of future changes in the policy on applying Public Safety Power Shutoffs (PSPS)

SA Power Networks has the right to de-energise portions of its network for public safety reasons under the South Australian Electricity Act 1996. These events are called Public Safety Power Shutoffs (PSPS).

We can apply PSPS to reduce the likelihood of our network starting a major bushfire. But we only apply PSPS in localised circumstances when the bushfire risk at that time in these locations is very high – typically when the fire danger rating is 'Catastrophic' and/or wind speeds are very high.

We have a current policy that defines when we should apply PSPS for these circumstances, and our methodology to develop the fire start rates used in the Bushfire Risk Model should allow for the effects of this policy on current fire start rates.

It may be that we will alter this policy in the future or circumstances could change such that the number or extent of PSPS could increase or decrease during future bushfire seasons. For example, a component of our resilience improvement programs is to add additional switches on some feeders with a very high bushfire risk to reduce the number of customers that have their supply interrupted during a PSPS or

[4] This approach of calculating a network-level rate and then adjusting this rate by regional and voltage multipliers has been adopted as there are insufficient fire starts to produce statistically significant fire start rates by fire danger rating for individual regions and voltages.

bushfire event affecting that feeder. This could mean that for those feeders, we can apply PSPS more often.

We have not elected to try to adjust the fire start rates used in our 'base case' evaluation to allow for these potential future changes. This is because the likelihood of these changes occurring and the effect on the fire start rates if they do occur is uncertain at this time.

Therefore, given these uncertainties and the changes would typically affect the highest bushfire risk feeders, we do not consider it would be prudent to not apply a bushfire risk mitigation option to a feeder (ie Hot Line Tag - see Section 6) if its benefits using current fire start rates are sufficient to justify the investment.

We do however test the sensitivity of the fire start rate assumptions through the sensitivity analysis that supports the evaluation of mitigation options (see Section 7.4).

4.2.2 Asset quantity

The asset quantity component is the quantity of the asset type applicable to the relevant fire start rate and that bushfire event's fire start location.

Each fire start location is assigned an asset quantity (of each asset type). Currently, all rates are calculated on a per overhead unit length of feeder basis, and therefore, the asset quantity assigned to each fire start location represents a portion of the feeder's overhead length.

The quantity assigned to each location is calculated at the feeder level, and given by:

the total overhead length of the feeder / total fire start locations for that feeder

This method inherently assumes that the feeder segment length associated with each fire start location is approximately equal. This is not strictly the case. However, it is not anticipated that these variations will be material to risk calculations due to the aggregating of risks relevant to the evaluation of mitigation options.

4.2.3 Days per season

The days per season component defines the average number of days per bushfire season that the event conditions would occur. That is, the average days per season for the combination of the fire danger rating and weather pattern conditions occurring for that fire start location.

The days per season for each individual event have been provided by CSIRO as part of its involvement in calculating the event consequence component (discussed further below).

4.2.4 Bushfire suppression probability

Although distribution network assets can 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, it is very important that the probability that a fire start will not result in a major bushfire is allowed for in the risk calculation.

We call this effect bushfire 'suppression' within the model framework and define the *suppression probability* as the probability that a fire will be suppressed and not result in the simulated bushfire event. In this way, the probability that the fire start is not suppressed resulting in the bushfire event consequence (as shown above in Table 2) can be calculated as:

$$probability\ fire\ start\ is\ not\ suppressed\ =\ 1 - the\ suppression\ probability$$

Given bushfire suppression relates to technical matters associated with the management of bushfires, CSIRO was engaged to estimate these suppression probabilities. CSIRO used a suppression model developed by SA Department for Environment and Water (**DEW**) as the basis for its suppression probabilities. The DEW suppression model assigns each location in SA to one of eight suppression levels. These suppression levels grade how likely it is that any fire start within that location will be suppressed, which relates to factors such as the proximity of the location 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 validation datasets included:

- SA Power Networks' 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 fire start location 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 3 below.

Table 3 CSIRO suppression model

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%

Following the initial application of these suppression rates to the set of events CSIRO has simulated (as discussed below on the calculation of event economic loss), CSIRO then apply a renormalizing process across the full set of events to adjust individual event rates to ensure that average fire sizes reflect actual outcomes.

4.2.5 Event economic loss

The economic loss for each bushfire event (ie the event's consequence in the risk calculations) has been calculated by CSIRO and SA Power Networks.

The process applied by CSIRO involves two steps:

- Bushfire footprint simulation - a simulation for each bushfire event of the spread of the bushfire, given it has been started at the fire start location under the relevant bushfire and weather conditions, using CSIRO's bushfire simulation software.
- Bushfire loss calculation - the calculation of the loss associated with each simulated bushfire footprint, including estimates of:
  - the physical damage to land and property, and the number of public injuries and deaths; and

  - the loss value (in $) associated with the land and property damage.

  SA Power Networks calculated the public safety loss value (in $) for each bushfire event using CSIRO's estimate of the number of public injuries and deaths for each bushfire event and SA Power Networks internal safety unit cost assumptions defined in its Value Framework. This public safety loss value is then added to the land and property loss value, calculated by CSIRO, to define the total loss value for each bushfire event.

These two steps are described further below. A paper prepared by CSIRO describing the methodology it used to undertake these two stages is provided as an Attachment to this document. This paper also describes how it determined the set of fire start locations and the set of weather patterns for each location and Fire Danger Rating.

CSIRO bushfire footprint simulation

The CSIRO's bushfire simulations are used to estimate the physical footprint of the bushfire event 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 the Spark Wildfire Toolkit (version 2).

Key features of this approach include the following:

- Land and topographical spatial data that are relevant to the fire intensity and spread have been sourced by CSIRO and incorporated in the simulation model, including:
  - SA vegetation data, which defines the vegetation type and in turn fuel load available to the fire; and
  - SA topographic data defining the land elevation, which is an important factor in how the fire can spread and the speed of the spread.
- 24-hour time-varying weather patterns that 'drive' each bushfire event being simulated, were defined by CSIRO based on its analysis of the historical weather data (note, this analysis was part of the analysis discussed above associated with defining the 'days per season' for each bushfire event).
- Rate of fire spread models were incorporated, based on CSIRO expert knowledge, which define how the bushfire will behave over time given the land and topographical data and driving weather pattern.
- Bushfires are assumed to start when the Fire Danger Index reaches 23 based on the driving weather pattern or by 2pm (whichever is earlier) and run until 6am on the next day or after 14 hours (whichever is earlier).

The output of an individual simulation is a geographic spatial file, which defines the extent of the bushfire's resulting footprint, and the intensity of the burn within that footprint[5].

Bushfire economic cost

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

[5] Each simulation output is provided as a raster data file giving the maximum fireline intensity per pixel.

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

The analysis to calculate land and property damage and the number of deaths and injuries is performed by CSIRO within a Geographic Information System (GIS) environment, as follows:

- 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.

  The spatial bushfire simulation outputs are processed using “vulnerability” curves that CSIRO has developed, which define relationships between the level of damage that can be expected given the bushfire’s intensity. This processing provides an estimate of the physical damage to land and properties (ie areas burned of different land usage types and property damage) for each simulation.

  Data on current land and property values associated with the bushfire location are then used to estimate the loss (in $) associated with the physical land and property damage estimate.

- Deaths and injury quantities are calculated using estimates of the exposed population within the bushfire footprint and relationships of this exposed population size to the average number of fatalities, severe injuries and minor injuries that have occurred in actual bushfire events.

  CSIRO estimated the exposed population for each bushfire event from the results of its bushfire simulation for that event, ABS population data, and spatial land use and management data (ALUM).

  CSIRO used two approaches to estimate the quantities of deaths and injuries from this estimate of the exposed population:

  – One approach used the same relationship that was used in the bushfire modelling underpinning the SA Power Networks 2015-20 and 2020-25 proposals to estimate the quantity of deaths, severe injuries and minor injuries[6]. This relationship was developed by a previous expert advisor to SA Power Networks (Willis Risk Services) for our 2015-20 regulatory proposal, based on analysis the expert conducted of the actual number of injuries compared to its estimate of the exposed population for the Victorian 2009 bushfires.

  – CSIRO used another approach to provide an alternative estimate of the quantity of deaths. This method uses a more complex ‘function’ of the exposed population and fireline intensity for each event. The function was derived from statistical analysis of actual bushfire across Victoria and other southern states[7], and has been used by the Bushfire and Natural Hazard CRC[8].

SA Power Networks applied its safety unit costs assumptions to CSIRO estimates of the injuries and deaths to calculate the safety loss (in $) for each bushfire event. CSIRO’s alternative estimate of deaths was used

[6] The relationships assume the number of injuries are a fixed proportion of the exposed population, of 0.031% of exposed population for deaths, 0.4% of exposed population for severe injuries and 7.6% of exposed population for minor injuries.

[7] Sarah Harris, Wendy Anderson, Musa Kilinc, and Liam Fogarty. The relationship between fire behaviour measures and community loss: an exploratory analysis for developing a bushfire severity scale. Natural Hazards, 63: 391–415, 2012

[8] Kate Parkins, Brett Cirulis, Veronique Florec, and Trent Penman. Quantifying Catastrophic Bushfire Consequences. Technical report, Bushfire and Natural Hazards CRC, 2020.

for these calculations[9]. The table below summarises the SA Power Networks safety unit cost assumptions applied for the deaths and injury loss calculations.

Table 4 Safety unit cost assumptions

Safety component	Total unit cost	Base unit cost	Disproportionality factor
Deaths	$30,600,000	$5,100,000	6
Severe injuries	$6,000,000	$1,500,000	4
Minor injuries	$30,400	$15,200	2

4.3 Bushfire risk calculation

The above risk calculations are performed in a set of models.

The models hold the various inputs required for the calculations (e.g. fire start rates, suppression probabilities, event economic costs, event days per season, etc) and perform the risk calculations discussed above.

The main outputs of these models are consolidated tables of risk results associated with each of the fire start locations and bushfire/weather combinations. Importantly, these workbooks also include the tables that map the fire start locations to SA Power Networks feeders, and provide relevant feeder physical parameters (eg nominal voltage, feeder lengths, etc.). These feeder tables allow the risk results to be consolidated into feeder and feeder segment risk tables, which form the risk inputs to the bushfire cost-benefit analysis model discussed below.

[9] It is worth noting that this alternative estimate tended to provide a lower estimate of the quantity of deaths compared to the previous approach. At this time, we are unsure which approach could provide the most accurate estimate, and therefore, we are elected to use the alternative approach for the bushfire risk calculation informing the cost-benefit analysis, to ensure that we are no overstating the benefits of the mitigation program.

5 Mitigation options

5.1 Overview of mitigation options

The bushfire risk model allows a range of mitigation options to be set up and evaluated. For each option, the following key input assumptions are required:

1) assumptions that define the life-time costs of the option, which include the option's:

    a) capital cost;

    b) average annual operating and maintenance costs;

    c) expected life, in years; and

    d) cost 'unit', which can be defined as either a 'feeder-level' cost (ie the cost that is necessary to implement the option across the whole feeder) or the 'segment-level' costs (ie the cost that is necessary to implement the option on the feeder segment, which is defined by the relevant fire start location).

2) assumptions that define the expected percentage reduction in the current fire start rate that should be achieved by the option, which include:

    a) the asset fire start rate the option addresses (ie the aggregate lines rate or the old fire prone arrestor rate); and

    b) the percentage reduction in that rate for each fire danger rating.

In appreciating how these assumptions are set within the model to evaluate different option types, it is important to note the following:

- The cost 'unit' should reflect how the option would be applied, including the scope of its effect in reducing fire starts along the length of the feeder. For example, an option that could avoid fire starts along a feeder (eg upgrading protection devices for ultra-fast fault clearance) would be defined as a 'feeder-level' option, whereas an option that only avoids fires in a feeder segment it is applied (eg upgrading the overhead conductor in that segment to underground conductor) would be defined as a 'segment-level' options with cost units that reflect that segment (eg per km of segment length).

- The percentage reduction by Fire Danger Rating should be defined to reflect both the portion of fire starts that that option could avoid (eg some options may only avoid certain fire start causes or portions of fire starts along a feeder) and the Fire Danger Rating where the mitigating action of the option would be enabled (eg options such as upgrading protection devices for ultra-fast fault clearance may only have those settings enabled during the highest risk Fire Danger Ratings).

The current bushfire risk model requires the specific options for evaluation to be pre-defined and the fire start reduction formulations to be set up within the model to correctly evaluate each option[10]. The current model is setup to allow the following four mitigation options to be evaluated:

- upgrading protection devices and protection settings on feeders to enable ultra-fast fault clearance to be applied (ultra-fast protection upgrades);

[10] It is worth noting that, for the future development of the model, the option formulations could be generalised within the model to allow any options to be input and evaluated without the user needing to set up the specific correct formulations for that option.

- replacing old fire-prone arrestors;
- upgrading sections of bare overhead conductor with covered conductor or Arial Bundled Conductor (**ABC**); and
- undergrounding existing feeder sections.

These four options represent the most likely capital solutions applicable to our network that can provide a reduction in bushfire risk in the short to medium term. As part of the overall evaluation of this program, we may also consider other solutions, including increased operating expenditure (**opex**)/maintenance to provide shorter term solutions and installing Rapid Earth Fault Current Limiter (REFCL) devices at zone substation. However, the suitability of these other options for our network and any underlying assumptions will be discussed in the business case for this program.

5.2 Option assumptions for the cost-benefit analysis

The evaluation of the four options is performed as a two-stage process:

1. In the first stage, a set of option assumptions (ie option unit costs, lives, fire start reduction rates) is used to perform an initial screening of all feeders to identify the most likely candidates for upgrade and indicative program outcomes (eg program costs and benefits). These assumptions are fixed across all feeders being evaluated, and reflect our view of the average for that option.

2. In the second stage, the candidate feeders identified through the first stage are reviewed in more detail by relevant SA Power Networks subject matter experts to determine more accurate feeder-specific upgrade costs and fire start rate reduction assumptions. These feeders are then re-evaluated using their feeder-specific assumptions.

The cost-benefit analysis occurring in both stages of the evaluation is conducted through the bushfire cost-benefit analysis model discussed in Section 7.

The tables below summarise the input assumptions for the four options above, which have been used in the first stage of the evaluation to determine the candidate feeders (and feeder segments where relevant) for re-evaluation through the second stage. The feeder-specific assumptions applied in the second stage of our evaluation (which form our program forecast in our regulatory proposal) are provided in the bushfire mitigation program business case document.

Table 5 Mitigation options cost assumptions

Option	Capital cost ($)	Average annual operating cost ($)	Life (years)	Cost unit
Ultra-fast protection upgrades	$83,339	$1,667	15	Feeder-level (per feeder upgraded)
Replacing old fire-prone arrestors	$100,000	$2,000	25	Feeder-level (per feeder upgraded)
Covered conductor or ABC	$84,132	$1,683	25	Segment -level (per km upgraded)
Undergrounding	$168,265	$0	25	Segment -level (per km upgraded)

Table 6 Mitigation options fire start reduction assumptions

Option	Fire start rate reduction – by fire danger rating						Mitigated fire start rate
	Low-mod	High	Very high	Severe	Extreme	Catastrophic	
Ultra-fast protection upgrades	0%	0%	0%	70%	70%	70%	Aggregate line
Replacing old fire-prone arrestors	95%	95%	95%	95%	95%	95%	Old fire-prone arrestor
Covered conductor or ABC	90%	90%	90%	90%	90%	90%	Aggregate line
Undergrounding	99%	99%	99%	99%	99%	99%	Aggregate line

Further details of these four mitigation options, including the basis of the assumptions in the first and second stages of the evaluation are discussed further in the following sections.

5.3 Ultra-fast protection upgrades

Implementing an ultra-fast protection scheme on a feeder, also known as 'Hot line Tag' (HLT), was the primary preferred solution found through SA Power Networks' modelling for its previous regulatory proposal to the AER.

The scope of works of this option includes installing, upgrading and/or recommissioning protection devices with the following features:

- Fire Danger Protection Settings (**FDPS**): upgrading devices to allow for a protection setting profile that provides near instantaneous fault clearance for all faults detected by the device – these settings can then be applied on high fire danger days.

- Supervisory control and data acquisition (**SCADA**) control: installing SCADA communication facilities on devices to enable remote disabling of reclose, remote application of FDPS and remote disconnection.

This option does not reduce the likelihood of a fault occurring, but reduces the likelihood that fault currents will last long enough to start a fire. Further background on this option is provided in the Bushfire Mitigation Programs Forecasting Approach paper. More detailed explanations of this option and how we implement it are contained in the following internal SA Power Networks practice and policy documents:

1) Bushfire Risk Management Manual No.8

Modelling considerations

Implementing this option on a feeder tends to reduce the likelihood that a fault will result in a fire along the whole feeder. Therefore, costs, risks and benefits for this option are evaluated within the bushfire CBA model at the individual feeder level.

Enabling FDPS on a feeder can reduce the reliability of that feeder (because the protection settings necessary to achieve such high-speed fault clearance do not allow the usual discrimination and coordination between devices to be achieved). Consequently, these protection settings are usually only enabled during the two highest Fire Danger Ratings (ie 'Extreme' and 'Catastrophic'). Therefore, within the bushfire cost-benefit analysis model, it is assumed that the fire start reduction is only achieved on days with these Fire Danger Ratings[11].

Caveat on the assumed bushfire conditions when Fire Danger Protection Settings are applied

The time when FDPS are *actually* enabled on any specific feeder can extend into the Fire Danger Ratings below 'Extreme' and 'Catastrophic' under certain circumstances. Most notably:

- FDPS can be applied for periods during the 'Severe' fire danger rating if wind speed measurements at relevant weather stations are sufficiently high. In these circumstances, the network is at a much greater risk of a wind-related fault, and so, a potential fire start.
- FDPS can remain on for short periods after fire conditions return below the 'Extreme' fire danger rating. This typically occurs so SA Power Networks personnel can verify that conditions are likely to remain below 'Extreme' before returning the protection settings to 'normal'.

These circumstances typically occur for short periods (ie usually less than a day), and therefore, we would not expect them to have a significant effect on the forecast risk reduction. Consequently, we have not tried to allow for these circumstances in our fire start reduction assumptions to ensure we do not overstate the anticipated risk reduction achieved by this option.

The specific works necessary on any feeder to implement FDPS and the resultant reduction in the likelihood of starting a fire is dependent on the current protection devices on that feeder. Therefore, to balance the effort to assess each feeder with the accuracy of the forecast necessary for customer engagement and inclusion in our regulatory proposal, we have applied a two-stage process to estimate the cost and fire start reduction assumptions:

- Stage 1 - basis of assumptions for determining candidate feeders for upgrade (provided in above tables)

  In this first stage, we use a simplified approach to estimate the average capital cost and fire start reduction assumptions that were applied across all feeders in our cost-benefit analysis evaluation.

  The feeder average costs and fire start reduction assumptions were calculated from the individual feeder upgrade capital cost and fire start reduction estimates that were derived by SA Power Networks to evaluate the final program that was included in our previous proposal to the AER (which covers the program we are currently implementing in this regulatory period).

- Stage 2 - basis of assumptions for finalising the program

  In this second stage, we use a more comprehensive approach to provide more accurate estimates of the upgrade capital cost for individual feeders and the fire start reduction assumptions.

  The capital cost to upgrade individual feeders is prepared using the following methodology:

  a) A detailed review of each candidate feeder for upgrade is undertaken, covering the current protection devices and their suitability for applying FDPS and SCADA communication; and

[11] Note, this reflects the assumptions for the base case analysis. However, extending (or reducing) when these settings are enabled can be examined through sensitivity analysis.

the make-up of the feeder and profile of the bushfire risk along the feeder to determine where additional devices should be located. The findings of this review are used to develop the scope of upgrade works necessary to implement FDPS on that feeder and optimize the coverage of ultra-fast clearance of faults along the length of the feeder.

b) The detailed review of the costs associated with the actual feeder upgrades that have been applied in the current period has been undertaken to develop a set of scope unit costs relevant to implementing this program (eg the average cost to define and apply settings to existing devices, the average cost to replace existing devices, the average cost to provide SCADA facilities to existing devices, the average cost to install new devices).

c) The unit cost assumptions are applied to the individual feeder scope of upgrade works to prepare individual feeder upgrade capital costs.

The fire start reduction percentage assumptions are prepared using the following methodology:

a) The actual fire start performance of the feeders that we have already implemented FDPS on devices protecting those feeders has been analysed to develop an estimate that should reasonably reflect actual outcomes[12].

b) The analysis compares the fault and fire start performance prior to and after the upgrade of the protection on that set of feeders to estimate of the proportion of fire starts that the upgrade is likely to be avoiding.

The basis of the operating cost and life assumptions are equivalent across both stages of evaluation:

- Average annual operating costs are assumed to be 2% of the capital cost, which is consistent with a general SA Power Networks assumption applied to this type of asset for undertaking cost-benefit analysis of capital programs.

- The 15-year life is assumed, which reflects SA Power Networks' regulatory treatment of these types of modern protection devices that can achieve ultra-fast fault clearance and communications via our SCADA system.

5.4 Replacing old fire-prone arrestors

The main asset type on the SA Power Networks' network that is considered fire-prone are old types of surge arrestor with open air gaps. These arrestor types have had a history of starting fires through animals, particularly birds, bridging the air gaps.

Modelling considerations

Replacing these arrestor types on feeders largely eliminates this fire start event mechanism from that feeder. Given we have produced a specific fire start rate for this fire start mechanism, we use that rate (ie the old fire-prone arrestor rate) for defining the fire start reduction percentage.

We do not have good internal knowledge of where these old arrestor types are located and it is costly to determine a-prior for this type of cost-benefit analysis. Experience from implementing this program in the current period found that we need to undertake replacements along the length of a feeder – rather than targeting specific high-risk sections. Consequently, we assume that this option will be applied at a feeder-level (ie all of the old fire-prone arrestor types will be replaced along the length of a feeder if it is selected

[12] It is worth noting that the previous fire start reduction assumptions, which are the bases of the stage 1 estimates , where prepared from a theoretical analysis of the likely fire start reduction.

for upgrade). Therefore, we have defined the costs for this option as a feeder-level cost (ie the cost to replace all arrestors of this type on a feeder), rather than the cost to replace the set of arrestors at a single location. Similarly, we assess the risk reduction for the whole feeder if this option is applied to a feeder.

The following summarises the basis of the assumptions for this option.

- Capital cost
  - In this first stage evaluation, the feeder-level capital cost (provided in the above table) is an indicative estimate of the cost to upgrade whole rural feeders.
  - For any candidate feeder determined through the first stage, the feeder-level capital cost will be calculated as the average of the actual costs to upgrade individual feeders, based on the set of feeders that have been upgraded in the current period.
- Average annual operating costs are assumed to be 2% of the capital cost, which is consistent with a general SA Power Networks assumption applied to this type of asset for undertaking cost-benefit analysis of capital programs.
- A 25-year life is assumed, which reflects our regulatory treatment of these types of devices.
- The fire start rate reduction is assumed based upon our experience of the scale of reduction we should expect from this fire start mechanism being removed. It is important to note that this fire start reduction is only applied to the fire start rate which we have calculated for these fire-prone arrestor types (see further discussion in Appendix A).

5.5 Covered conductor, ABC and undergrounding

These options involve upgrading sections of the existing overhead bare HV conductor by either:

- installing conductor coverings or replacing the conductor with ABC; or
- removing the overhead section and replacing it with underground cable.

Both options reduce the likelihood that that section will start a fire by avoiding certain fault mechanisms associated with fire starts:

- Installing conductor coverings and ABC can avoid many vegetation fault mechanisms, particularly none-destructive vegetation 'grow-ins' and 'blow ins'. They also reduce the possibility that some asset failures will cause a fire start.
- Undergrounding sections of a feeder can avoid all fault and fire start mechanisms associated with the existing overhead assets associated with that section.

Modelling considerations

These mitigation options are relatively high-cost solutions (on a per km of feeder mitigated basis), and consequently, we would typically only apply these options to sections of a feeder where the bushfire risk associated with that section is high enough to justify the upgrade. Therefore, these options are defined at the feeder segment level, where costs are defined on a per-km of route length basis. As noted above, from a modelling perspective, a feeder segment is the length of feeder associated with one of the individual simulation fire start locations.

Importantly, however, implementing these options on sections of rural feeders can have significant other benefits; for example, improved reliability and resilience. In most cases, these other benefits could exceed the bushfire risk reduction. Therefore, for these options, the two-stage evaluation process operates differently to the other options:

1. The first stage still uses simplified assumptions that are fixed across all feeders being evaluated (shown in the Table 5 and Table 6 above), and this stage is used to identify candidate feeders and feeder segments for more detailed evaluation. However, this stage is not aimed at identifying feeder segments that have a positive net benefit; rather the feeder segments with a sufficiently high benefit in bushfire risk reduction to justify its further evaluation of all benefits. The cost-benefit criteria for this evaluation is discussed further in Section 7.

2. The second stage still employs a detailed technical review to determine the feeder-specific scope of upgrade works and cost. However, this review considers the works necessary to co-optimise all benefits, and the evaluation is focused on assessing all benefits. Depending on the proportion of the bushfire risk reduction benefits to total benefits, the upgrade could be allocated to other programs. This detail would be set out in the relevant business case.

The following summarises the basis of the assumptions for these options (use for the bushfire risk reduction evaluation).

- Capital cost
  - In this first stage evaluation, the capital unit cost (per km of route length upgraded) is consistent with the general SA Power Networks’ cost assumption for these two options, which we use to assess other needs (eg reliability improvements) when applied in rural areas. These unit costs are based on similar actual recent upgrades we have applied in rural regions.
  - For any candidate feeders and feeder segments determined through the first stage, the feeder-level capital costs are calculated based upon the detailed technical review discussed above.
- Average annual operating costs are assumed to be:
  - 2% of the capital cost for the covered conductor or ABC option, which is consistent with a general SA Power Networks assumption applied for this type of asset for undertaking cost-benefit analysis of capital programs
  - zero for the undergrounding options as it is assumed that operating and maintenance for cables buried in rural locations will be negligible
- The asset lives for both options are assumed to be 50 years.
- The fire start rate reduction is assumed based upon our experience of the scale of reduction we should expect from the fault cause and fire start mechanisms being removed.

6 Investment Evaluation – the Bushfire CBA model

The bushfire cost benefit analysis model (bushfire CBA model) provides the environment to conduct the cost-benefit analysis of the mitigation options discussed above.

6.1 Model inputs and outputs

The key inputs to the bushfire CBA model are:

- feeder and feeder segment tables of the bushfire risk, as calculated by the Bushfire Risk Model discussed in Section 4 above;
- mitigation option assumptions (ie unit costs, lives and fire start reduction assumptions), as discussed in Section 6 above; and
- other general model and cost benefit analysis assumptions, such as the discount rate.

The model provides a range of outputs that can be viewed for each feeder, including:

- current feeder risk, including its breakdown into fire start quantities, unsuppressed fire quantities, and average consequence per fire (by fire danger rating);
- indicative break-even investment levels associated with the current risk for different fire start reduction levels (ie where the benefits equal costs);
- resulting feeder risk based on the input option set-up details, including a similar breakdown of the resulting risk; and
- option benefit, and cost-benefit metrics (eg net benefit and cost/benefit ratio).

6.2 Determining options with a net-benefit

The formulations set up within the bushfire CBA model allow the model to identify whether options should provide a net-benefit for individual feeders, and where relevant, the quantity of the segment-level options for that feeder that will provide a net-benefit.

The basis for this calculation depends on whether the reduction in fire starts achieved by the option occurs at the feeder level or the feeder segment level.

6.2.1 Feeder-level option evaluation

For the feeder-level options, formulations are included to enable the user to test the benefits and net-benefits of applying the option to each individual feeder. These formulations allow the user to:

- identify all the feeders where there would be a positive net-benefit and apply the option to those feeders;
- for the protection option, identify the minimum amount of capital expenditure (**capex**), based on that option's assumptions, to achieve a positive net-benefit (noting that this amount can be helpful to gauge the extent of device-level upgrades that could be applicable for that feeder through the detailed individual feeder costings that are undertaken in the second stage of the estimation of the assumptions for that option, discussed in Section 6 above); and
- for all feeders, determine the benefit to cost ratio for each option, which is important for the covered conductor and undergrounding options to identify which feeders may be suitable as candidates for a more detailed co-optimised evaluation with other benefits (see the discussion in Section 6.5).

6.2.2 Feeder segment-level option evaluation

The segment-level options would only be applied to the specific feeder segments where the benefits of upgrading that segment exceeds the cost of the upgrade of that segment.

As discussed in Section 6.5, for the covered conductor and undergrounding options, the benefits due to reduced bushfire risk may only be a component of the total benefits of the upgrade (eg improvements in reliability and resilience could also be significant).

Therefore, for all relevant segment-level options, the model formulations have been set up to evaluate each individual feeder segment to determine the following:

- To identify the specific feeder segments where the bushfire risk reduction achieved by the upgrade of that segment would outweigh the cost of the upgrade of that segment. In this way, the model provides the optimum quantity of the option for each individual feeder, where this quantity should maximise the positive net benefit for each individual feeder with regard to the bushfire risk reduction.

- To determine the benefit-to-cost ratio for each option and feeder segment, which is important for the covered conductor and undergrounding options to identify the portion of the feeder and individual feeder segments that may be suitable as candidates for a more detailed co-optimised evaluation with other benefits (see the discussion in Section 6.5).

6.2.3 Option net-benefit criteria

The table below shows the net-benefit criteria we have used in the bushfire CBA model to test each option. This table also summarises whether the test is applied at the feeder or feeder segment level and how it relates to the first or second stage of the evaluation within the bushfire CBA model.

Table 7 Option net-benefit criteria

Option	Criteria	Feeder scope	Evaluation stage
Ultra-fast protection upgrades	Net-benefit > 0	Feeder total	Stage 1 and Stage 2 within bushfire CBA model
Replacing old fire-prone arrestors	Net-benefit > 0	Feeder-total	Stage 1 and Stage 2 within bushfire CBA model
Covered conductor or ABC	Benefit/cost ratio > 0.5	Feeder segment	Stage 1 (stage 2 assesses total co-optimised benefits outside the bushfire CBA model using a net-benefit > 0 criteria)
Undergrounding	Benefit/cost ratio > 0.5	Feeder segment	Stage 1 (stage 2 assesses total co-optimised benefits outside the bushfire CBA model using a net-benefit > 0 criteria)

6.3 Defining and calculating option costs, benefits, net-benefits and benefit-to-cost ratio

To undertake the above evaluation of options, the bushfire CBA model uses the concept of annualised costs and benefits to evaluate mitigation options.

As discussed in Section 4, the bushfire risk (which forms an input to the bushfire CBA model) can be considered to represent the *expected* annual measure of bushfire risk ie the weighted-average annual risk across all probable outcomes. Therefore, to put the bushfire risk and option cost on an equivalent basis for evaluation, the model uses the concept of the equivalent annualised cost of any option. That is, the capital and operating costs of potential mitigation options are transformed to an equivalent annual cost, using discounted cash flow techniques, where this equivalent annual cost stream and the actual costs should be equal over the assumed life of the option (in present value terms).

This allows the equivalent annual costs of the option to be compared against the reduction in the annual bushfire risk provided by the option in order to determine the annual net benefit and benefit-to-cost ratio of implementing the option (ie the option benefit is defined as the avoided annual bushfire risk achieved by the option).

Using this approach, the annual net benefit for any option is calculated as:

$$annual\ net\ benefit\ =\ annual\ benefit\ -\ equivalent\ annual\ option\ cost;$$

where

$$annual\ benefit\ =\ current\ annual\ bushfire\ \mathrm{risk}\ -\ annual\ bushfire\ risk\ after\ option\ [+\ any\ other\ annual\ benefits]$$

and

$$equivalent\ annual\ option\ cost\ =\ equivalent\ annual\ capital\ cost\ +\ average\ annual\ operating\ cost.$$

Similarly, the annual benefit-to-cost ratio for any option is calculated as:

$$annual\ benefit\_to\_cost\ ratio\ =\ annual\ benefit\ /\ equivalent\ annual\ option\ cost.$$

The equivalent annual capital cost is defined as the constant annual cost stream over the life of the asset that is equivalent to the capital cost, occurring in year 0, in present value terms, which can be calculated as:

$$equivalent\ capital\ annual\ cost = \frac{discount\ rate \times capital\ cost}{1-(1+discount\ rate)^{-life}}.$$

This annualizing approach simplifies the evaluation calculation across individual feeders and feeder segments without loosing accuracy. It also inherently ensures that the optimal year of the upgrade is allowed for in the evaluation (ie the earliest year for the upgrade would be when the annual bushfire risk reduction becomes greater than the equivalent annual cost).

6.4 Sensitivity analysis

The current model set up also provides a set of additional inputs that can be used to define changes to some of the above inputs in order to rapidly test inputs and perform sensitivity analysis on these inputs. The input parameters that can be altered cover:

- the average number of days during a bushfire season in the six fire danger rating categories (note, as discussed in Section 5, this approach is used to test the sensitivity of climate change on future bushfire risk);
- the fire start rates, which are used to calculate the current bushfire risk;
- option capital cost percentage change – applied across all options being evaluated;
- the assumed average annual opex rate (as a percentage of the capital cost);
- the discount rate;
- individual option assumptions, covering the assumed capital cost, the percentage reduction in the fire start rate, and asset life;

- the portion of the time in the 'Severe' fire danger rating that the ultra-fast protection option will be enabled (noting this is zero in the base case);
- the opex change (per km) associated with the undergrounding option (noting that this is zero in the base case); and
- Climate change sensitivity, defined as the increase in the number of days per season in the higher fire danger ratings under RCP4.5, using data from the Electricity Sector Climate Information (ESCI) project.

Other sensitivities associated with any other inputs to the bushfire risk calculations or option evaluation should be able to be tested through the bushfire CBA model. However, these sensitivities may require special-purpose adjustments to the bushfire risk model or bushfire CBA model or their input assumptions to test their sensitivity on the model outputs and the options evaluation.

6.5 Comment on incorporating other mitigating options, costs and benefits in the evaluation

It is worth noting that it should be straightforward to incorporate any other costs or benefits in the evaluation within the current bushfire CBA model set-up, provided these can be quantified in terms of their average annual value at the feeder or segment level. It should also be relatively straightforward to incorporate other mitigating options by defining the equivalent option assumptions as discussed in Section 6.

Importantly, other options do not need to be capital options. For example, if an operating option was being evaluated (eg increasing vegetation management spend) then the option could have a zero capex cost and the opex cost would represent the increase in average annual opex.

However, the following are important to appreciate when considering whether this annualised approach remains appropriate in these circumstances:

- This annualised approach assumes that the expected annual bushfire risk is constant over the life of the asset, or in effect, the future external and internal factors that could alter the expected bushfire risk in any year are fixed, or are no more likely to get better or worse.

  This is a reasonable assumption for the base case analysis, as it would be particularly onerous to try to predict all the factors that could change the bushfire risk into the future (eg spatial changes in land use and fuel types in the future). As such, given the recent historical basis for preparing the inputs to the bushfire risk calculation, it is reasonable to assume that this produces the best estimate of the expected annual bushfire risk in the future (excluding the effects of climate change).

  In scenarios where the expected annual bushfire risk is assumed to be increasing year on year (eg through an assumed climate change scenario) then the annualised approach can still be applied to test the optimal time for an upgrade. In this case, all economic upgrades at a point in time (eg by the end of the next regulatory period) should be all those where the expected annual bushfire risk at that point in time (eg allowing for the percentage change at that point in time due to climate change) is greater than the equivalent annual cost of the option.

  That said, if there was a scenario were the expected annual bushfire risk is reducing or is variable across the asset life then a full evaluation of the net-benefit across all years during its asset life would be required, making use of the changing profile of the expected annual bushfire risk over the life of the asset.

- This annualised approach is suitable for evaluating simple options where all capital costs at the relevant feeder or segment level can be assumed to occur in a single year. This is reasonable for the set of options listed above.

  However, if more complicated feeder- or segment-level option needs to be evaluated (eg a staged project for an individual feeder or group of feeders) then it could be important to evaluate that option more formally over the life of the asset associated with that option, allowing for the year when option costs are incurred and how these affect the bushfire risk over the installation period and life of the option.

A.1 Fire start analysis

A.1.1 Introduction and background

This appendix describes the methodology used to produce the **network fire start rates**, which forms an important input into our calculation of bushfire risk (see overview of bushfire risk calculation in Table 2 above and Section 4.2.1). It also provides some key results from this analysis that should aid in the understanding of the 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 SA fire ban 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 (see Section 4.2.4).

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 bushfire 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.

A.1.2 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 due to these factors. 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:

  – Arrestor - our most common fire start prone asset, our open-style surge arrestors; and
  – Aggregate line rate - an aggregate rate, which captures the causes of all fires along a feeder.

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 bushfire season, of the 1,111 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 details of every fire started by our network since 2008.

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

- We have calculated fire start rates that reflect the average fire start rate for the period from 2014 to 2021. This period was chosen as it reflects the period we have historical daily fire danger ratings for the set of weather stations relevant to the bushfire risk areas traversed by our feeders. Starting from 2014 also avoids using earlier fire start rates, which may not allow for some of the fire start reduction initiatives we have undertaken since we have been recording all fire starts.

- We have also tested the statistical evidence of an improving trend in fire start numbers over this period to confirm that the average fire start rate for the period from 2014 to 2021 is a reasonable estimate of the current fire start rate.

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 bushfire risk 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 bushfire risk 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 1,111 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 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.

The network-level fire start rates and rate multipliers we have calculated through this methodology, which form an input to the bushfire CBA model, are shown in Table 8, Table 9, and Table 10.

Table 8 Network-level fire start rates

	Expected fire starts per day per 1000 assets – by fire danger rating					
	low-mod	high	very high	severe	extreme	catastrophic
Line fire start rate	0.00251	0.00394	0.00584	0.00683	0.01555	0.01538
Arrestor fire start rate	0.00017	0.00017	0.00017	0.00017	0.00017	0.00017

Table 9 Model regional and voltage multipliers for line fire start rate

	Line rate multipliers			
	33kV	19kV	11kV	7.6kV
RIVERLAND	1.55	0.15	0.80	1.00
UPPER SOUTH EAST	0.42	0.47	1.80	1.00
MURRAYLANDS	1.02	0.35	0.83	1.00
LOWER SOUTH EAST	2.56	0.24	1.38	1.00
MID NORTH	0.20	0.79	1.90	1.00
NORTH EAST PASTORAL	1.00	1.00	1.00	1.00
WEST COAST	1.00	0.28	0.54	1.00
LOWER EYRE PENINSULA	3.42	0.30	2.75	1.00
EASTERN EYRE PENINSULA	1.55	0.39	1.78	1.00
MOUNT LOFTY RANGES	3.62	1.07	3.30	2.44
FLINDERS	3.50	0.19	1.53	1.00
ADELAIDE METROPOLITAN	1.00	1.00	5.38	1.00
YORKE PENINSULA	2.18	0.40	1.25	0.00
KANGAROO ISLAND	1.55	0.79	0.90	1.00

Table 10 Model voltage multipliers for arrestor fire start rate

	Arrestor rate multipliers*			
	33kV	19kV	11kV	7.6kV
Total	3.24	0.31	1.78	0.00

*We only use voltage multipliers for fire-prone arrestors as there are an insufficient number of historical fire starts to calculate statistically significant regional multipliers.

Why we adopt this approach to define the fire start rates

We used a network-level rate that is then scaled with a multiplier as there is an insufficient number of fire starts over the historical period to determine individual regional and voltage rates across the six fire danger ratings and two asset types.

This alternative approach would have resulted in fire start data sets being too small, such that the inherent variability in the fire start numbers 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.

Most concerningly, this approach would result in some regions and voltages appearing to have a zero fire start rate in some of the more severe Fire Danger Ratings (due to no fire being started on the feeders of that voltage, in that region, and during the few days in those Fire Danger Ratings), which is far more likely to be a statistical anomaly than the true fire start rate for those regions and voltages.

In our view, in the absence of sufficient actual fire start volumes to prove the contrary, it is reasonable to assume that the fire start rate will scale relatively uniformly across the fire danger ratings within a region and voltage, largely in line with the network average. Therefore, our approach is reasonable given these data constraints.

A.1.3 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** – We have calculated daily maximum fire danger ratings from 2014 for the set of weather stations relevant to feeders covered by our model. 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. This also allows us to assign the fire danger rating most applicable to the feeder associated with each fire start in our fire start database.

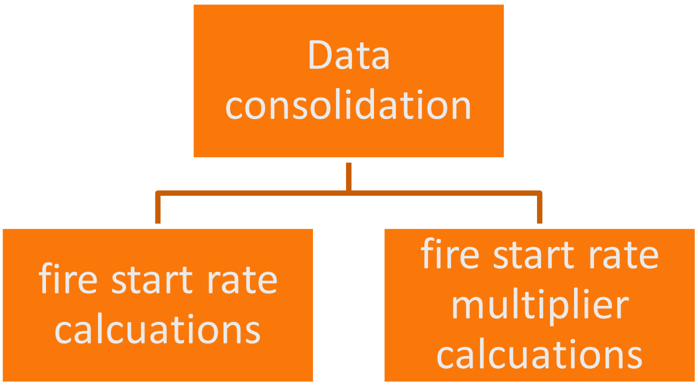
In addition to this data, we also used various internal sources of feeder data to calculate feeder lengths and define the bushfire region and voltage of the feeders. CSIRO also details which SA weather station it had assigned to each simulation fire start location in its simulation output file (see section 4.2.5). We have prepared a table that uniquely maps each fire start location to an individual feeder, and therefore, we use the same weather station assignment for our fire start data as used by CSIRO for its simulations to ensure we maintain consistency with CSIRO's analysis.

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

A.1.4 Explanation of our methodology and key results

Overview of our methodology

Appendix B. Figure 2 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 3:

- **Data consolidation** – the data consolidation task assembled the various data sources, covering SA Power Networks' fire start and network data and weather station daily maximum fire danger rating 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 (Table 8), which form a key input to the SA Power Networks' bushfire CBA model.

- **Fire start rate multiplier calculations** - this task calculates the regional and voltage multipliers (Table 9 and Table 10), which form the other key input to the SA Power Networks' 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 starts per day in each of the six 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 the days when we didn't.

We used historical daily weather station data to prepare a daily time series of the Fire Danger Rating for each weather station. These calculations determine both the maximum Forest Fire and Grass Fire Danger Index (FFDI and GFDI) for each day within the bushfire season from the beginning of the 2014/15 bushfire season. These daily maximum FFDIs and GFDIs are then transformed into a daily Fire Danger Rating using the standard FFDI and GFDI ranges[13].

We then use this daily Fire Danger Rating time series (by weather station) to perform the following:

[13] The daily Fire Danger Rating is defined as the maximum of the Forest Fire Danger Rating and the Grass Fire Danger Rating for that day as that will defined the worst case fire start conditions for that location on that day. This approach is also in line with how CSIRO has defined the applicable Fire Danger Rating for each of its bushfire simulation studies.

- We assign each fire start in our fire start database to the Fire Danger Rating appropriate for that fire start location and that day.

  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 our estimate of the Fire Danger Rating for that weather station on that date.

- We estimate the total number of days during the bushfire season in the six Fire Danger Ratings each year, applicable to the study area of our network.

  We estimate this using the weighted average number of days across the set of weather stations, where we use the network length associated with each weather station as the weighting. The network length associated with each weather station is calculated from the sum of the length of overhead HV feeder that CSIRO has assigned to each weather station[14].

Calculating the network-level 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 applicable to each of the six Fire Danger Ratings for two asset types:

- an aggregate line rate (covering all assets that make up the overhead line)
- an aggregate of all the old fire-prone arrestor types.

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.*

The units for the two asset types are defined as the route length of overhead line, measured in kilometers.

Note, in this definition, the number of arrestors used in its rate formula is not the actual number of arrestors as this is not known with any accuracy. Instead, the arrestor rate formula will provide the average number of fire starts due to the old fire-prone arrestor types per unit length of feeder, which assumes the arrestors are uniformly spread along the feeder. This assumption should be reasonable for estimating feeder-level risks due to these arrestor types, which is the approach we use in the bushfire CBA model to assess arrestor replacement needs (see Section 6.4).

However, this assumption will be less accurate for assessing risks associated with specific fire start locations and line segments. Therefore, if risks are required to be determined at this finer level then further work may be required to determine the actual locations of arrestors on a feeder and an alternative fire start rate for individual arrestors.

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

[14] This can be calculated as each fire start location being studied by CSIRO is assigned to both a unique weather station and HV feeder.

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.

The method we have used to determine the network-level rates that form an input to the bushfire risk model can be viewed as having three components:

1. Calculating the average historical asset fire start rate
2. Assessing the historical annual trend in the fire start rate
3. Defining the most appropriate fire start rate to use in the bushfire risk model to reflect the current fire start rate.

These three components are discussed in turn below.

Calculating the average historical asset fire start rates

We have used our historical fire start data to directly calculate the average historical fire start rates using the following approach.

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 counts of the fire starts are based upon the following fire inclusion rules:

- all fire start events recorded in our database that have been confirmed in the database to be possibly caused by our assets and have occurred on a feeder covered by our study[15]
- fires caused by faults on both our HV and LV network to ensure we have a reasonable estimate of the total bushfire risk[16]
- only 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
- only fire starts over the 8-year period from 1 November 2014 to 30 April 2022, which reflects the period we have weather station daily fire danger rating time series (2014/15 to 2021/22).

[15] Note, in some limited circumstances, it is not possible to identify with certainty whether our assets are the primary cause of the fire. However, where an alternative cause cannot be identified with some certainty, we classify this as a network fire start for this analysis.

[16] Note, we allow for how the various options can avoid HV and LV fires through the fire reduction assumptions applied in the CBA model.

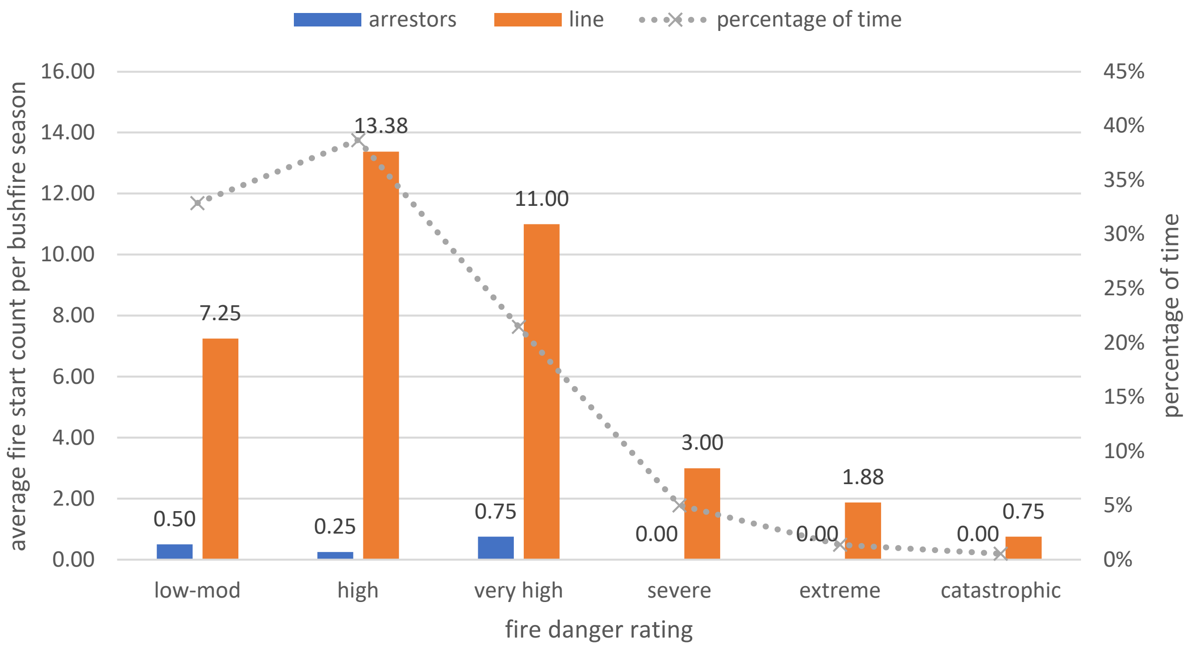
We have been able to assign fire start events to the old arrestor asset type based on the following rules:

1. The fire start description field includes the terms 'rod air', 'CLAH', 'horn' or 'air gap', which represents one of our older fire-prone arrestor types; and

2. The cause of the fire field is defined as 'Bird', which represents the failure mode of concern to us with this asset type.

Based on this methodology, the average fire start counts per bushfire season, between 2014/15 to 2021/22 (inclusive), for the two asset types and six Fire Danger Ratings are shown in Figure 4[17]. This chart also shows on the secondary axis the percentage of time in each Fire Danger Rating.

Figure 3 Average annual fire start counts from our fire start database (2014/15 to 2021/22 inclusive)



This chart shows that on-average there have been 37.3 fire starts per bushfire season across the regions covered by our analysis, of which 1.5 (on average per bushfire season) of these have been due to our old arrestor types.

A large portion of these fires (82%) are occurring on days with a fire danger rating between the low-moderate to very high bands. But these three bands cover approximately 93% of the bushfire season.

The remaining 18% of fires are occurring over the remaining 7% 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 2.5 days in the Extreme band per season and only 1.0 day in the Catastrophic band[18].

It is important to note that our analysis indicates that we have not started any fires due to the old fire-prone arrestor types over the analysis period in the three highest Fire Danger Ratings. However, significant caution should be placed on drawing inferences from this outcome, particularly with regard to inferring that this

[17] This represents the total count over this period dived by 8.

[18] 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.

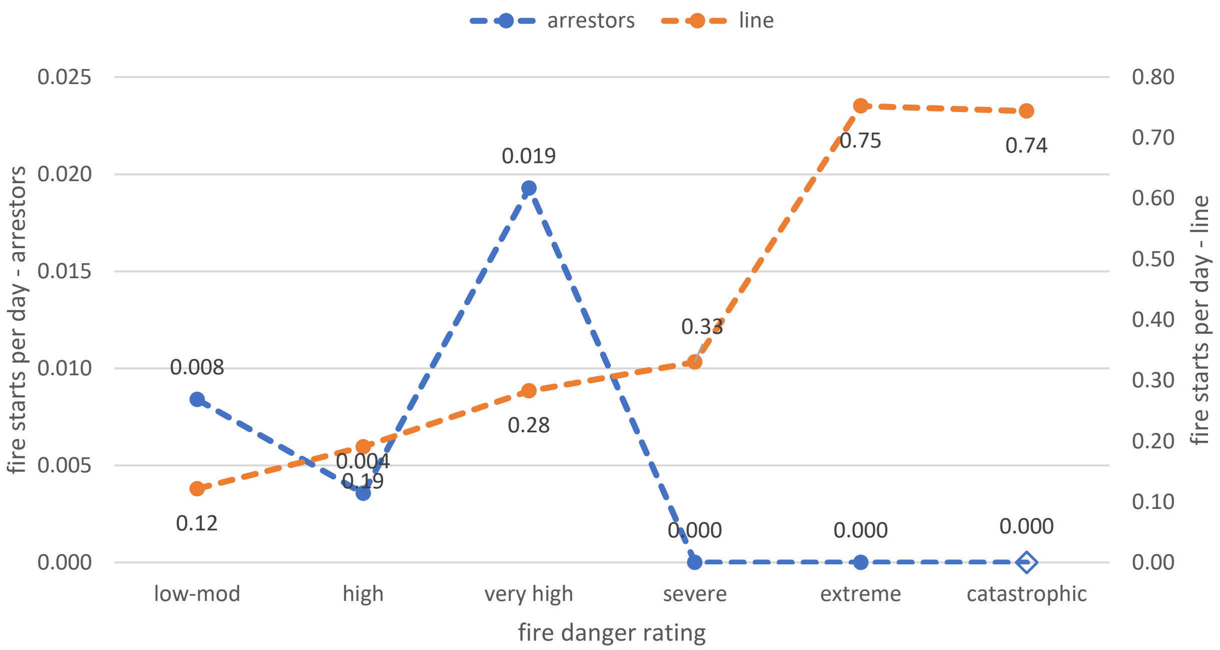
means that the fire start rate is lower or even zero during these times. This matter will be discussed further below.

The relationship of the average number of fire starts to the Fire Danger Rating is shown further in Figure 5, which shows the average number of fire starts across the study area for a single day in the six Fire Danger Ratings.

This chart shows that for the aggregate line fire starts, the frequency of fire starts per day increases substantially as we move from the less severe to more severe fire danger ratings, with an apparent plateauing from the 'Extreme' Fire Danger Rating.

Arrestors on the other hand show a more variable daily frequency of fire starts across the Fire Danger Ratings. There is an apparent zero rate for the three most severe Fire Danger Ratings. However, as noted earlier, this is because we have not recorded fire starts on these days. We consider that the variability and the zero rates across Fire Danger Ratings are more likely a statistical anomaly due to the low fire start rates, rather than a reflection of the true relationship across Fire Danger Ratings[19].

Figure 4 Average fire starts per day in each fire danger rating

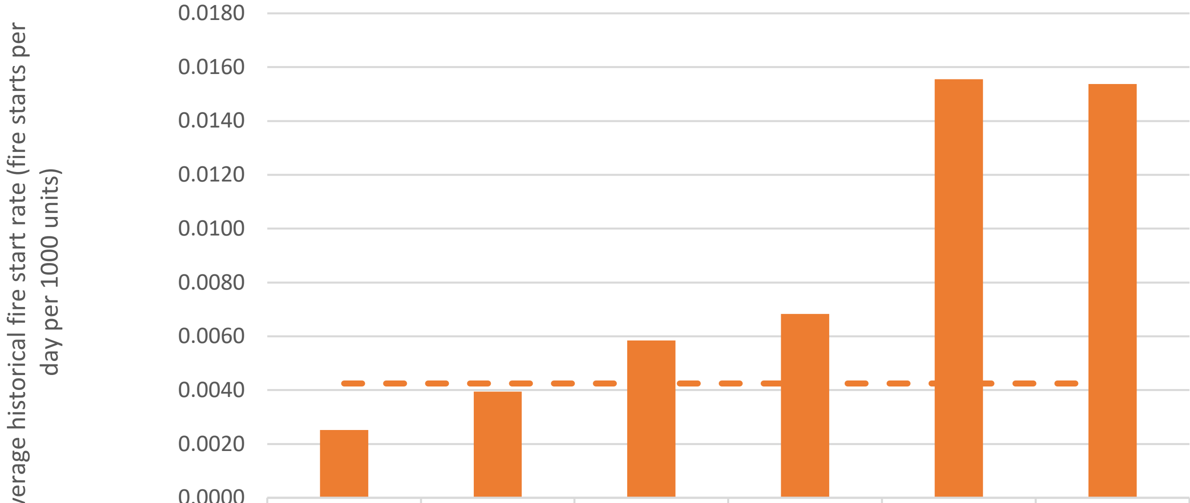


To produce the historical average rate per day per 1000 units, we divide the daily rates shown above in Figure 5, by the number of units in the study regions associated with each asset type. As noted above, we are defining both the aggregate line and old fire-prone arrestor rates on a per length of feeder basis. There are 48,400 km of overhead HV feeder associated with the 1,111 feeders covered by this study, and therefore, this value is used to produce the average daily rate per 1000 units.

The average historical fire start rates (fire starts per day per 1000 units) that we have calculated by this method are shown in Figure 6 (aggregate line rate) and Figure 7 (old fire-prone arrestor rate).

[19] For example. there are approximately 100 days in the three most severe fire danger ratings over the 8-year period of our analysis. Therefore, if the daily rate was at a similar level to that which we can calculate for the less severe fire danger ratings (around 0.008 per day), then the probability of no fire starts happening over this 8-year period is similar to the probability that there would have been one or more fire starts over this period.

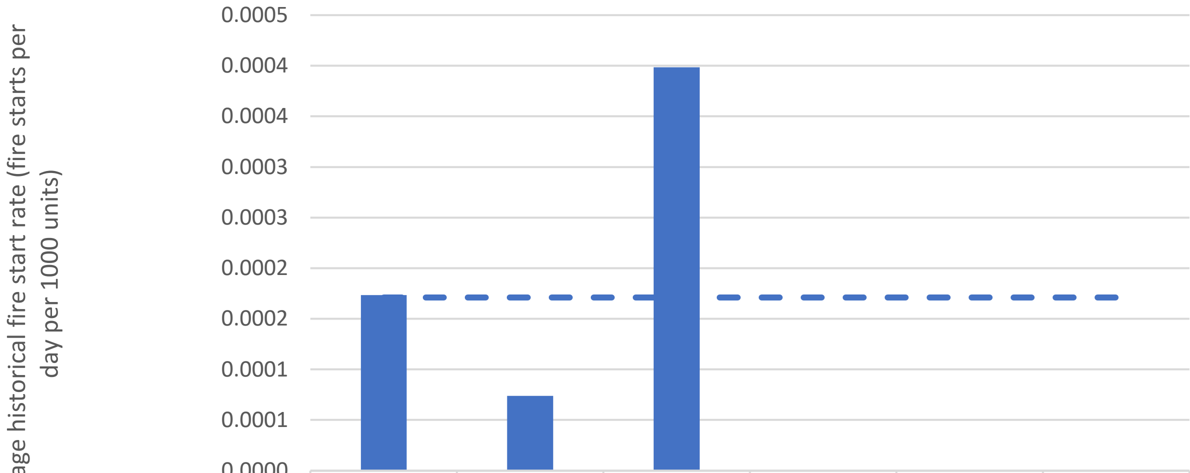
Figure 5 average historical fire start rate – aggregate line rate



	low-mod	high	very high	severe	extreme	catastrophic
line	0.0025	0.0039	0.0058	0.0068	0.0155	0.0154
average line rate	0.0042	0.0042	0.0042	0.0042	0.0042	0.0042

fire danger rating

Figure 6 average historical fire start rate – old fire-prone arrestor rate



	low-mod	high	very high	severe	extreme	catastrophic
arrestors	0.0002	0.0001	0.0004	0.0000	0.0000	0.0000
average arrestor rate	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002

fire danger rating

Assessing the historical annual trend in the fire start rate

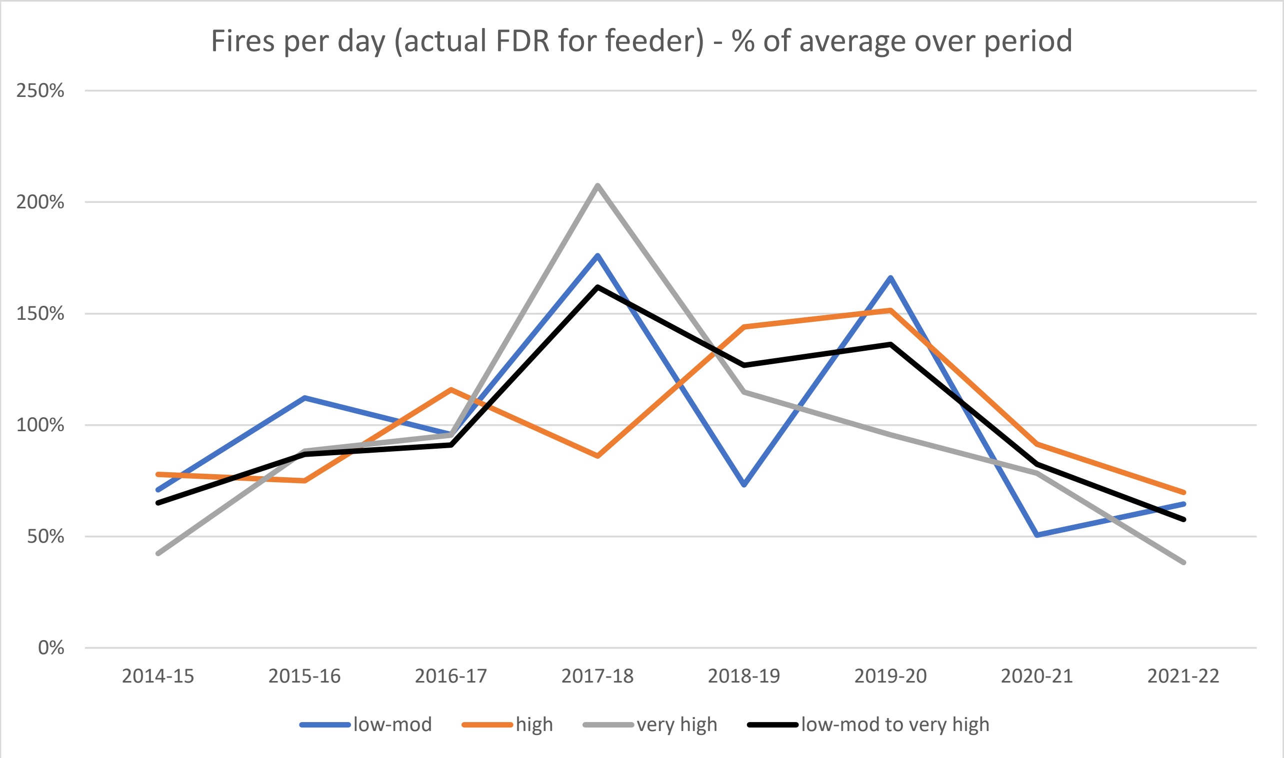
The average historical fire start rates discussed above provide a useful starting point for understanding the likelihood of our network starting fires. However, we know we have been improving some of our practices in bushfire risk areas over this period. Therefore, it is important to assess whether there is sufficient evidence that there is an improving (or worsening) trend in the annual historical rate, and the average historical rate should be adjusted to account for this trend.

To assess this matter, we have analysed the annual fire start rate for each Fire Danger Rating (ie fire starts per day in that Fire Danger Rating) over the period of the historical analysis (ie the 8-year period from 2014/15 to 2021/22, inclusive). As part of this analysis, we have considered the overall variability in the annual rate over this period and considered various statistical tests of whether a linear trend developed from this annual series is useful for predicting the current rate[20].

Importantly, we have only undertaken this analysis for the aggregate line fire start rate. This form of trend analysis is more prone to statistical anomalies for the fire-prone arrestor type as the number of arrestor fire starts in each Fire Danger Rating in 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. Therefore, we have not undertaken this trend analysis for the arrestor fire start rate.

Figure 8 shows the annual average fire start rate for each of the three lowest Fire Danger Ratings (ie average fire starts per day in that Fire Danger Rating). The chart also shows the annual average fire start rate for the aggregate of all three of these ratings. The fire start rates shown have also been normalized using their average rate across the 8-year period to place all the time series on an equivalent basis (ie the annual rate shown is the percentage of the period average rates shown in the above charts).

Figure 7 Annual trend in the average fires starts per day – Low-moderate, High and Very High fire danger ratings



The main findings from the analysis of the annual pattern of these three Fire Danger Ratings is as follows:

- In general, there is an apparent worsening trend to around 2017-18 / 2018-19, and then an improving trend from that point. But there is noticeable variability from year to year, particularly in individual Fire Danger Ratings.
- If we consider the period from 2017-18 to 2021-22 (inclusive) then statistics of a linear improving trend over this period are not clearly conclusive of whether an improving trend exists.

[20] These tests include the calculation of the R^2, F and t statistics of a linear regression model.

- These statistics do not support an improving trend for 'Low-Moderate' and 'High' Fire Danger Ratings[21].
- However, the statistics do support an improving trend for the 'Very High' Fire Danger Rating. Further, if we assume that there could be some movement between the three bands (in terms of how fires could be classified into these three Fire Danger Ratings), and therefore, consider the aggregate fire start rate across all three, the statistics support an improving trend[22].
- Overall, although the analysis suggests there is a reasonable probability of an improving trend since around 2017/18 (in aggregate across the three Fire Danger Ratings), the higher variability from year to year means that there is lower confidence in where the current rate could be – relative to the average historical rate across the period.

Figure 9 shows a similar chart of the annual average fire start rates for each of the three highest Fire Danger Ratings, including the aggregate rate across these three Fire Danger Ratings.

The main findings from the analysis of the annual pattern of these three Fire Danger Ratings is as follows:

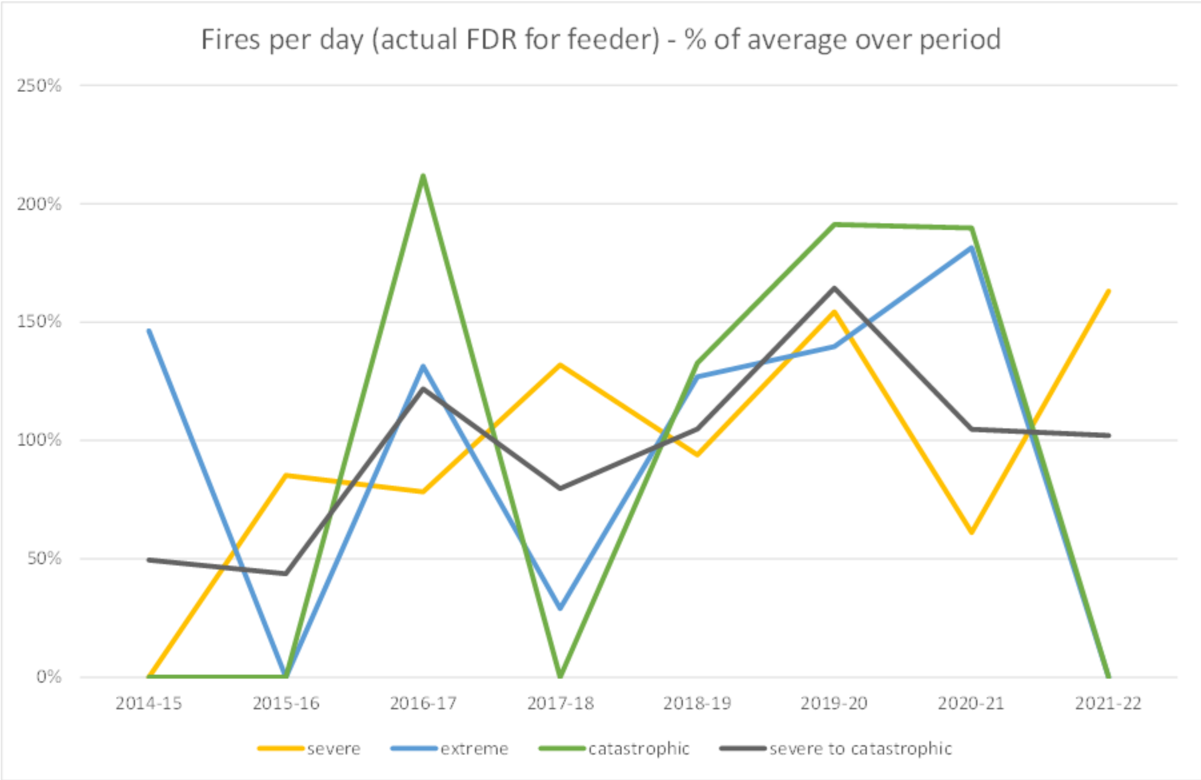
- In general, there is an apparent worsening trend in the fire start rate over the 8-year analysis period. But there is much greater variability in the rate from year to year. The greater variability could be expected to some degree, as there are far fewer days and in turn fire starts associated with these Fire Danger Ratings, and so, it could be expected that 'random' effects in any year will be more significant on annual outcomes.
- If we consider period from 2017-18 to 2021-22 (inclusive) then statistics of a linear trend over this period are not conclusive, suggesting that 'chance' is more likely to have caused the apparent trends[23].

[21] The p values for the slope coefficient of the regression formula for the 'low-moderate' line and 'high' line are 24% and 54% respectively, suggesting a reasonable probability that the apparent improvement suggested by the linear regression model could have occurred by chance.

[22] The p values for the slope coefficient of the regression formula for the 'high' line and 'low-mod to very high' line are 2% and 1% respectively, suggesting a low probability that the apparent improvement suggested by the linear regression model could have occurred by chance.

[23] The p values for the slope coefficient of the regression formula for the all lines, 'severe', 'extreme', 'catastrophic' and 'severe to catastrophic', are 86%, 99%, 88% and 72% respectively, suggesting a high probability that the apparent trend occurred by chance.

Figure 8 Annual trend in the average fires starts per 100 days –Severe, Extreme and Catastrophic fire danger ratings



Defining the most appropriate fire start rate to use as the current fire start rate

For the aggregate line fire start rate, we have elected to use the historical average rate by Fire Danger Rating over the period from 2014/15 to 2021/22 (as shown in Figure 6) as the most reasonable estimate of the current fire start rate for the 'base case' estimate of risk. This decision is based upon the following:

- We have a reasonable quantity of fire starts across this historical period and Fire Danger Ratings to estimate individual rates for each Fire danger rating, as we can see a reasonably stable rise in the rate across the fire danger ratings – as we may expect.

- As discussed above, our analysis of the annual trends in the recent historical fire start rates are inconclusive, across fire danger ratings, that an improving or worsening trend over this historical period can be reasonably estimated. Therefore, we consider that uncertainty in the current fire start rate can be better tested through sensitivity analysis.

For the old fire-prone arrestor fire start rate, we have elected to use the historical average rate across all Fire Danger Ratings over the period from 2014/15 to 2021/22 (as shown in Figure 7) as the most reasonable estimate of the current fire start rate for the 'base case' estimate of risk. This decision is based upon the following:

- We do not consider we can use the individual fire start rates by Fire Danger Rating as a reasonable estimate of the current fire start rate for each Fire Danger Rating. There is significant variability in the fire start rate across the Fire Danger Ratings and we have no fire starts in the three most severe Fire Danger Ratings, where we would expect the greatest bushfire risks. But our analysis suggests that this outcome could be as much a function of 'chance' as the true reflection of the actual fire start rate.

- Noting the above limitations, it is not feasible to conduct any form of annual trend analysis for the old fire-prone arrestor fire start rate.

- Therefore, we consider that the average fire start rate, averaged across all Fire Danger Ratings, is the best estimate of the current fire start rate.

Based on the above reasoning, the network-level fire start rates (fire starts per 1000 km of line per day) are shown in Table 8 above. These reflect the fire start rates we have used to calculate the bushfire risk in our 'base case' analysis, which we consider are a reasonable estimate of our current fire start rates (ie the rate applicable to the 2022/23 bushfire season.

B.1.2 Calculating fire start rate multipliers

As the name suggests, the fire start rate multipliers are used to scale the network-level 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 specific feeder reflects the regional and voltage variations in fire start likelihood that can exist between regions and voltages. 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:

1. Aggregate line fire start rate multipliers, which is a 2-dimentional matrix of multipliers that reflect the bushfire region the feeder is located and the nominal voltage of the feeder

2. Old fire prone arrestor rate multipliers, which is a vector of multipliers that reflect the nominal voltage of the feeder. We did not generate regional multipliers for the old fire-prone arrestors as there are insufficient fire starts across the regions to estimate multipliers at this level.

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 the 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 a 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 that we calculate from the SA Power Networks fire start database.

The methodology involves the following steps:

1. Calculate the actual number of fires using the SA Power Networks fire start database

   This count is performed over the 8-year analysis period, using the region associated with the feeder that started the fire.

   As part of his calculation, any fire started by the LV network or fire where the starting voltage is undefined are reallocated to the HV voltages for that region. This reallocation is applied pro-rata by the actual fire starts by HV voltage in that region (eg if there are x fires in a region that are assigned to LV or an undefined voltage then these are reallocated pro rata based on the number of fire starts by voltage for that region).

2. Calculate the predicted number using the network-level fire start rate

   The network-level rates (discussed above) are used to predict the model estimate of fire starts for that region and voltage over the same 8-year period.

   This calculation is based on the feeder lengths in each region by voltage and the average days in each fire danger band in each region over this period[24].

3. Calculate the multiplier necessary to ensure that the model number equals the actual number by region and voltage

   Each multiplier is calculated as the *adjusted actual number for each region and voltage* / *network-level prediction for each region and voltage*.

The above methodology has been applied to calculate the set of fire start rate multipliers shown in Table 9 and Table 10 above. These reflect the fire start rate multipliers we have used to calculate the bushfire risk in our 'base case' analysis, which we consider are a reasonable estimate of our current fire start rates (ie the rate applicable to the 2022/23 bushfire season).

It is worth noting that even allowing for the above form of 'calibration', the bushfire risk model still estimates fewer fires per bushfire season will be started, on average, compared to the actual average number – 32.8 in the model compared to 37.3 on average that actually occurred across the studied 1,111 feeders. This difference is due to the aggregate day count associated with the set of CSIRO studies typically not covering the whole bushfire season. As we understand it, studies are not performed where the environmental conditions would not permit a significant bushfire to form (either due to the local 'fuel' or the driving weather conditions). As such, some fire start locations will only have portion of the bushfire season covered by the CSIRO simulations.

[24] The estimate of the days in each Fire Danger Rating is calculated for each region, based on the overhead length-weighted average of the feeders and their assigned weather stations associated with that region.