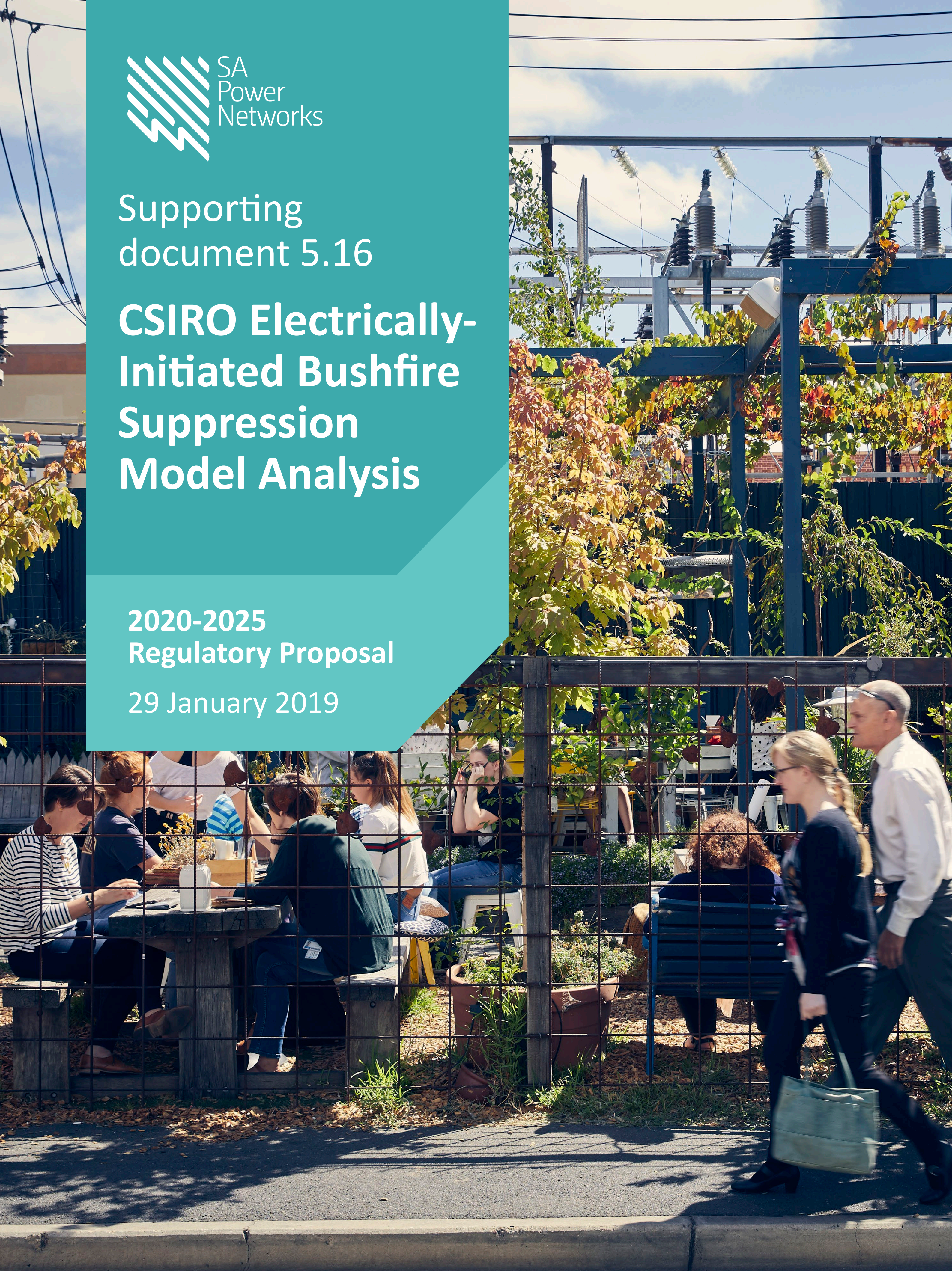

SA Power Networks

Supporting document 5.16

# CSIRO Electrically-Initiated Bushfire Suppression Model Analysis

**2020-2025 Regulatory Proposal**

29 January 2019

DATA61
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# Electrically-Initiated Bushfire Suppression Model Analysis

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**Final Update - 29 January 2019**

A Report Prepared for SA Power Networks

# Contents

# Acknowledgments

We gratefully acknowledge the assistance of the Department of Environment, Water and Natural Resources (DEWNR) in providing us with the following data in support of the analyses:

- The rural incidents spreadsheet - *Rural Incidents 01072005 09052018 CSIRO.xlsx*
- The qualitative landscape suppression model - *Combined_Suppression_v5_7class1.tif*

The Australian Bureau of Meteorology (BoM) provided the AWS weather data that has been used for the weather research and analysis.

# 1 Introduction

In 2017, SA Power Networks (SAPN) commissioned CSIRO Data61 to produce datasets using bushfire numerical simulations, where the data represents estimates of the extent and intensity of wildfire that has become established in the landscape and progresses unchecked. SAPN also sought estimates of the probability that a fire ignition in vegetation that occurs due to the SAPN electrical distribution system would escalate into an established fire, in various situations and under various conditions.

In the phase of work undertaken in 2017, this estimate of the *probability of suppression* was based on data from SAPN as well as data relating to distribution-system-initiated ignitions in Victoria (from AFAC and from Victorian electricity industry sources). The data was limited in quantity, yet for SAPN the data is considered to be well quality-controlled. The probability of suppression was expressed as a function of (local, instantaneous) Forest Fire Danger Index (FFDI): specifically on the categorical variable *Fire Danger Rating* (FDR) directly corresponding to the ranges of FFDI used across Australia in managing and communicating fire danger (between *Low-Moderate* and *Catastrophic* levels).

On consideration of the estimates, on the one hand the SA Country Fire Service expressed concern that the probability of suppression was too optimistic (i.e., too high) especially for FFDI in the intermediate range (around 35 to 70). On the other hand, SAPN and electricity industry stakeholders considered that the probability of suppression at higher FDR levels may have been too pessimistic (i.e., too low) when viewed relative to the actual electrically-ignited wildfire history in SA from the mid-2000s to present day.

This situation led to SAPN requesting CSIRO Data61 in May 2018 to review the probability of suppression estimates in more depth and using additional data and information. This report conveys the findings of this second phase of analysis.

The data on bushfire occurrence, spatial extent and response in Australia is of low quality in terms of completeness and accuracy. This is disappointing and somewhat surprising considering the magnitude of the threat posed by this natural hazard to our environment, industries and communities. In the case of electrically-initiated fires, there is additional data available in each jurisdiction yet an overall picture of mediocre data quality remains in contrast to the fact that electrically-initiated fires account for the vast majority of bushfire-related fatalities since 1950. This means that neither fire science nor data science has been able to satisfactorily explain why electrically-initiated fires have shown to be so dangerous (Miller et al 2017).

Importantly, in the current context of estimating suppression probability for electrically-initiated fires, the absence of good phenomena-based or data-driven explanation of why electrically-initiated fires present elevated dangers also gives us strong reason to caution against:

(i) putting undue weight on observed recent fire occurrence and suppression history, i.e., expecting it to actually be representative of the long-term;

(ii) considering a data-driven analysis of suppression probability to be unbiased and robust, i.e., we make no assurance that our analysis, based on relatively short-run and incomplete data, is quantitatively accurate — rather, it is an improved and best-effort approach tailored to the circumstances where decisions informed by data and science must be made in the near term.

New and influential information used within the analysis presented here does substantially improve the confidence that can be placed in the suppression probability estimates. This information is *qualitative suppression category maps* produced by the Department of Environment, Water and Natural Resources (DEWNR) and provided to CSIRO Data61 in May 2018 prior to the maps being publicly released. The information has proven valuable because statistically it can explain strong trends in suppression success data, and has a solid (qualitative) foundation in bushfire firefighting practice. It also has the desirable by-product of maintaining consistency between SAPN and DEWNR approaches to considering the ability to suppress fires.

Further work will always be able to extract additional insight, and the findings here are geared to fit into a particular analysis framework for the overall impact of electrically-initiated fires. We do however claim that the results are fit-for-purpose and represent a substantial improvement in the quantitative understanding of electrically-initiated fire escalation in South Australia.

# 2 Inputs for Suppression Analysis

## 2.1 Input Data Sources

Purchased Automated Weather Station (AWS) data from the Bureau of Meteorology (BoM) has been used to calculate local FFDI values that can then be linked to other data sources based on location. Automatically collected weather data up until 2017 was used.

DEWNR is acknowledged for providing us with the following data sources in order for us to conduct the analyses:

- The rural incidents spreadsheet – "Rural Incidents 01072005 09052018 CSIRO.xlsx"
  - This contains the time, day and location of reported incidents. It is the closest data source we can get to the ignition locations for fires within South Australia.
- The qualitative landscape suppression model – "Combined_Suppression_v5_7class1.tif"
  - The suppression level is the DEWNR qualitative measure of the difficulty of suppression based on several static landscape factors, including proximity to roads/suppression resources, land use and steepness/ruggedness of terrain. 0 is the most likely to be suppressed and 7 is the least likely. The static values were produced as a 100m resolution raster.
- Fire scar shapefiles were sources from https://data.sa.gov.au/data/dataset/fire-history
  - Shapes of planned burns and bushfires were in this database. Attributes of burned area and day of ignition were contained in the data.

## 2.2 Input Data Limitations and Uncertainty

**BoM AWS data**

BoM AWS data is collected automatically at 30 or 60 minute intervals. For this analysis, we were interested in the maximum FFDI for the days that incidents occurred (fire ignitions) and for days which fires occurred (shapefile data). The data is generally of high quality, however there are certain times at which the AWS recording goes down (potentially during a fire), as well as some sparsely covered regions and some AWSs only coming online in recent years.

**DEWNR Rural Incidents Spreadsheet**

Alarm date and time are well recorded. Incident location is only recorded consistently from the 2011/12 fire season onwards, and even when it is recorded it is often estimated to the nearest road intersection or park centroid. The cause of each incident is recorded inconsistently and was not included in the analyses.

**DEWNR Qualitative Landscape Suppression Model**

The DEWNR suppression model was supplied as a raster which covered a large proportion of South Australia. There were some incident locations which fell outside of this raster, decreasing some of the linking which could be done across data sets.

**DEWNR Fire Scar Dataset**

There are comments at location.sa.gov.au about completeness and accuracy of the data set. In summary:

- The dataset may be incomplete (fires missing)
- The positional accuracy (size and shape of fires) is not guaranteed to always be accurate, and will depend largely on the data capturing process.
- The fire date is contained in the dataset, however this comes with a date reliability measure. Some ignitions are recorded accurately to the day, while some are only known/recorded to within a month or even to within a fire season.
    - This in particular made matching incident data and FFDI to fire scars quite challenging.

# 3 Suppression Model Development

We have not identified a single dataset which is of sufficient completeness and data quality to support the analysis necessary for estimating the long-run probability of an electrically-initiated bushfire surpassing 5Ha and 100Ha thresholds in South Australia. Our estimates are based on combining insights from several datasets: in this Section we describe analyses of particular datasets, and the estimation process is described in Section 4.

## 3.1 South Australian Fires Data

The goal of this analysis was to develop a suppression model such that the probability of suppression could be estimated based on available (measurable) factors, and applied to Spark bushfire simulations previously conducted such that fire return periods and expected damages could be estimated.

### 3.1.1 Data Linking Process

In order to analyse the relationship between fire size (i.e., area), FFDI on the day of the fire, and the suppressibility level of the ignition location of the fire, the various datasets that were sourced needed to be linked.

### 3.1.2 Fire Scars to Incidents

The fire scar dataset was linked to the rural incidents spreadsheet based on comments for some fires that contained a unique fire reference number identifying which incident occurred. Unfortunately these matches highlighted problems between the data sets, as ignitions points were sometimes not located within their fire scar, but instead allocated to nearest road or similar. There was also some uncertainty when attempting to match by start dates. Matches were further confirmed by comparing ignition dates and reviewing ignition locations relative to fire scars. Matching was also restricted as the incident data was only considered reliable post 2011, and AWS information was only available up to the end of 2017.

Due to the limitations of the datasets and the uncertainty associated with the linking variables described in Section 2.2, as well at the temporal overlap of the datasets (the fire scar data goes back decades before the incident data started being recorded), only 163 out of the approximately 5500 fire scars were able to be linked to incident locations with confidence.

### 3.1.3 Fires with Ignitions to FFDI

For each ignition location with a fire matched to it, the closest BoM AWS (Automated Weather Station) was identified. The daily maximum FFDI at these AWSs for the given day(s) of fire ignitions was calculated and linked back to the ignition and matched fire.

Due to the limitations of the datasets described in Section 2.2 such as missing data from AWS locations, only 145 out of the 163 fires were able to have FFDI linked to them.

### 3.1.4 Qualitative Landscape Suppression Model to Locations

The qualitative landscape suppression category was able to be extracted from the DEWNR provided data layer at each matched ignition location using GIS. This process was repeated for the simulation ignition locations so that any dependence on suppression category found in the actual fire data could be applied to the fire simulations when implementing the suppression model developed.

### 3.1.5 Logistic regression estimation

Previous research into estimation of bushfire suppressibility was conducted by Plucinski (2012, 2013). In this work, fire size below a certain threshold (say 5 or 20 hectares) were considered *suppressed* for the purposes of the analysis. This binary criteria of suppressed or not suppressed allowed for examination of the influence of various covariates through the use of logistic regression analysis (Agresti, 2003). Regression analysis is a statistical generalised linear modelling approach that optimises estimation of covariates based on the observed data. Resulting estimates based on the model are maximum likelihood estimates, which minimises the distance between the estimated and observed fire suppressibility.

In the current analysis, covariates available for model fitting were FFDI band (A-F, directly relating to the established Fire Danger Rating categories *Low-Moderate* to *Catastrophic*) at the time of fire start, and a suppressibility value (0-5) based on the DEWNR qualitative landscape suppression model.

Prior to fitting the logistic regression model, exploratory data analysis of the relationship between hectares burned, fire size, and qualitative suppressibility value was conducted to inform which models to fit. This review indicated that qualitative suppressibility would improve the model considerably compared to FFDI alone. Further improvements were indicated for a model that considered an interaction between FFDI and suppressibility. To fit an interaction model using the limited number of data points available involves collapsing across both FFDI and suppressibility categories to obtain results (A:C->A; D->B; E->C; F->D 0:3->1 ;4->2 ;5->3). There was little loss of information due to this collapsing of categories.

Both the linear FFDI and suppressibility, and the interaction (collapsed FFDI and suppressibility) models were fit. A suppressed fire was defined as one that was below 100 hectares, and unsuppressed as one greater than 100 hectares. This threshold was chosen as it gave enough suppressed and unsuppressed fires to estimate the model effects well. Choosing a smaller threshold would lead to similar trends/relationships in the results, but with higher probability of suppression in most cases.

The estimated probability of suppression has been calculated for each of the unique FFDI and qualitative suppressibility categories, as was the standard error for each of the estimates. The estimates for both the linear and interaction models along with their standard errors are provided in the following tables. Standard errors were included to emphasize the fact that there is always some uncertainty in model results.

### Table 1. Probability a fire is suppressed based on a 'straight lines' model of FFDI and DEWNR defined suppression categories

| | Probability of Suppression (<100 hectares) | | | | | |
|---|---|---|---|---|---|---|
| FDR Band | 0 | 1 | 2 | 3 | 4 | 5 |
| A | 0.8211 | 0.7684 | 0.77504 | 0.61146 | 0.3678 | 0.22072 |
| B | 0.78507 | 0.72532 | 0.73275 | 0.55605 | 0.31648 | 0.18395 |
| C | 0.7749 | 0.71335 | 0.72099 | 0.54137 | 0.3038 | 0.17521 |
| D | 0.57969 | 0.49925 | 0.50867 | 0.32108 | 0.14881 | 0.07843 |
| E | 0.1401 | 0.10537 | 0.10898 | 0.05291 | 0.02024 | 0.00995 |
| F | 0.25378 | 0.19734 | 0.20337 | 0.10444 | 0.04133 | 0.02056 |

### Table 2. Standard error in probability a fire is suppressed based on a 'straight lines' model of FFDI and DEWNR defined suppression

| | Standard Error in Suppression Prediction | | | | | |
|---|---|---|---|---|---|---|
| FDR Band | 0 | 1 | 2 | 3 | 4 | 5 |
| A | 0.08132 | 0.09981 | 0.10224 | 0.17405 | 0.20982 | 0.2031 |
| B | 0.10295 | 0.11578 | 0.12656 | 0.2106 | 0.21882 | 0.18727 |
| C | 0.07348 | 0.08843 | 0.09716 | 0.18218 | 0.18667 | 0.16059 |
| D | 0.11213 | 0.13701 | 0.13537 | 0.17501 | 0.11258 | 0.08596 |
| E | 0.13349 | 0.10561 | 0.1062 | 0.06326 | 0.02692 | 0.01531 |
| F | 0.21762 | 0.19131 | 0.20149 | 0.12726 | 0.05606 | 0.03256 |

### Table 3. Probability a fire is suppressed based on an "interaction" (intersecting lines) model of FFDI and DEWNR defined suppression

| | Probability of Suppression (<100 hectares) | | | | | |
|---|---|---|---|---|---|---|
| FDR Band | 0 | 1 | 2 | 3 | 4 | 5 |
| A | 0.731183 | 0.731183 | 0.731183 | 0.731183 | 0.5 | 0.2 |
| B | 0.731183 | 0.731183 | 0.731183 | 0.731183 | 0.5 | 0.2 |
| C | 0.731183 | 0.731183 | 0.731183 | 0.731183 | 0.5 | 0.2 |
| D | 0.565217 | 0.565217 | 0.565217 | 0.565217 | 6.38922E-08 | 6.39E-08 |
| E | 0.111111 | 0.111111 | 0.111111 | 0.111111 | 6.38922E-08 | 0.013575 |
| F | 0.25 | 0.25 | 0.25 | 0.25 | 6.38922E-08 | 0.029727 |

### Table 4. Standard error in probability a fire is suppressed based on an "interaction" (intersecting lines) of FFDI and DEWNR defined suppression

| | Standard Errors in Estimates | | | | | |
|---|---|---|---|---|---|---|
| FDR Band | 0 | 1 | 2 | 3 | 4 | 5 |
| A | 0.045973 | 0.045973 | 0.045973 | 0.045973 | 0.25 | 0.178885 |
| B | 0.045973 | 0.045973 | 0.045973 | 0.045973 | 0.25 | 0.178885 |
| C | 0.045973 | 0.045973 | 0.045973 | 0.045973 | 0.25 | 0.178885 |
| D | 0.103367 | 0.103367 | 0.103367 | 0.103367 | 7.6656E-05 | 0.00015 |
| E | 0.104757 | 0.104757 | 0.104757 | 0.104757 | 0.00015331 | 0.017504 |
| F | 0.21651 | 0.21651 | 0.21651 | 0.21651 | 0.00015331 | 0.046847 |

## 3.2 SA Power Networks Occurrence Data

SA Power Networks data on electrically-initiated fire occurrences covers the period January 2008 to May 2017 (SAPN data spans a wider interval but we restricted our attention to 2008-2017). The data we expect to be complete and accurate. Each fire event is associated with a date and time, feeder, bushfire risk area classification, basic equipment information including LV/HV classification, and area burnt.

Location information in this data is imprecise but nevertheless good enough to enable the closest of 40 AWS stations to be assigned to each fire occurrence. Meteorology leading up to the time of ignition is used to calculate an instantaneous FFDI value at the time that the ignition occurred. A relationship between FFDI (band) and electrically-initiated fire size is the most valuable aspect of this data.

## 3.3 Victorian Fire Occurrence Data

CSIRO obtained Victorian bushfire occurrence data from AFAC in 2013, and the data about electrically-initiated fires in the period 2000-2012 in the dataset was augmented and corrected as part of work eventually reported in Miller et al (2017). This data is useful because the Victorian HV powerline network is several times larger than the South Australian network, and so gives rise to proportionally more data. Of particular interest are Victorian fires recorded at periods where the FFDI is near or exceeding 100, because South Australian data is insufficient in this domain.

**Table 5. Number of electrically-initiated fire occurrences in Victoria, 2000-2012, by fire size and Fire Danger Rating**

| | TOTAL | LOW-MODERATE | HIGH | VERY HIGH | SEVERE | EXTREME | CATA-STROPHIC |
|---|---|---|---|---|---|---|---|
| **VIC occurrence data - counts** | | | | | | | |
| Less Than 5Ha | 1062 | 634 | 268 | 131 | 22 | 3 | 4 |
| Five Or More Ha | 207 | 86 | 71 | 43 | 6 | 1 | |
| 100Ha+ | 69 | 20 | 17 | 19 | 8 | 1 | 4 |
| Grand Total | 1338 | 740 | 356 | 193 | 36 | 5 | 8 |
| **VIC occurrence data - proportions** | | | | | | | |
| Less Than 5Ha | 0.794 | 0.857 | 0.753 | 0.679 | 0.611 | 0.600 | 0.500 |
| Five Or More Ha | 0.155 | 0.116 | 0.199 | 0.223 | 0.167 | 0.200 | 0.000 |
| 100Ha+ | 0.052 | 0.027 | 0.048 | 0.098 | 0.222 | 0.200 | 0.500 |
| **VIC occurrence data - probabilities** | | | | | | | |
| Less than 5Ha | 0.794 | 0.857 | 0.753 | 0.679 | 0.611 | 0.600 | 0.500 |
| Less than 100Ha | 0.948 | 0.973 | 0.952 | 0.902 | 0.778 | 0.800 | 0.500 |
| **VIC occurrence data - transition probability** | | | | | | | |
| 5Ha to 100Ha Survivability | 0.250 | 0.189 | 0.193 | 0.306 | 0.571 | 0.500 | 1.000 |

## 3.4 Hybrid SA Data

The SA fires data (Section 3.1) is inherently biased because only 163 out of the approximately 5500 fire scars could be linked to ignition causes, dates and times. As such, the data is taken as being indicative of certain trends and relationships but we do not consider it to be quantitatively reliable.

We constructed a “fire phase” model that sought to address gaps and biases in the data. In this model, separately for each DEWNR fire suppression category between zero and six, we seek to quantify fire transition between several phases:

- Phase 1: **Undetected fire** (all fires begin at this phase). We realise that not all fire starts are detected: for example, a bird electrocuted by spanning phases might not trip a fuse, may start a small ground fire, but never be detected by humans.
- Phase 2: **Fire on Asset**. These are fires that are detected. Every fire in the SAPN dataset has reached this phase.
- Phase 3A: **Fire on Ground**. Every fire in the SAPN dataset that has an area greater than zero square metres is a ground fire. Not every electrically-initiated fire transitions to ground (in Victoria, about half of fires remain restricted to the asset, for example pole-top fires).
- Phase 3B: **Fire Established on Ground**. This is where a fire begins to propagate in vegetation, rather than only “singe” it with burning material that has fallen to ground (e.g., parts of electrical asset, vegetation or animals).
- Phase 4: **Fire No Less than 5Ha in Size**. Propagation is significant and the fire reaches 5Ha or more.
- Phase 5: **Fire No Less than 100Ha in Size**. That is, a major incident.

The transition probabilities were estimated using DEWNR, SAPN and Victorian data. The aim was to “correct” the suppressibility data (Table 1 to Table 4), in order to create a revised version of Table 1 that better accounts for what is observable, and which distinguishes fires that reach 5Ha and those that reach 100Ha (i.e., Phases 4 and 5 of escalation). The result of this analysis is conveyed in Table 5.

**Table 6. Corrected suppressibility estimates using DEWNR, SAPN and Victorian data**

| Probability that fire size is less than 5 Ha | | | | | | |
|---|---|---|---|---|---|---|
| | LOW-MODERATE | HIGH | VERY HIGH | SEVERE | EXTREME | CATASTROPHIC |
| ALL LEVELS | 0.860 | 0.879 | 0.806 | 0.811 | 0.416 | 0.000 |

| Probability that fire size is less than 100 Ha | | | | | | |
|---|---|---|---|---|---|---|
| | LOW-MODERATE | HIGH | VERY HIGH | SEVERE | EXTREME | CATASTROPHIC |
| LEVEL 0 | 0.975 | 0.974 | 0.956 | 0.921 | 0.498 | 0.254 |
| LEVEL 1 | 0.968 | 0.967 | 0.944 | 0.906 | 0.478 | 0.197 |
| LEVEL 2 | 0.969 | 0.968 | 0.946 | 0.907 | 0.480 | 0.203 |
| LEVEL 3 | 0.946 | 0.946 | 0.911 | 0.872 | 0.447 | 0.104 |
| LEVEL 4 | 0.912 | 0.917 | 0.865 | 0.839 | 0.428 | 0.041 |
| LEVEL 5 | 0.891 | 0.901 | 0.840 | 0.826 | 0.422 | 0.021 |
| LEVEL 6 | 0.891 | 0.901 | 0.840 | 0.826 | 0.422 | 0.021 |

# 4 Hybrid Suppression Model

Each of the results and analyses of Section 3 are useful, yet to estimating the long-run probability of an electrically-initiated bushfire surpassing 5Ha and 100Ha thresholds in South Australia we must form a "hybrid" model which makes optimal use of each.

- The dataset on SAPN electrically-initiated fires (Section 3.2), augmented with (local and instantaneous) FFDI calculated for each ignition using AWS data, we take as being accurate and complete. There is not enough data in the dataset for it to be relied upon for long-run estimations relating to large fires (100 Ha or more) or periods of greater fire danger. For higher FDR (*Extreme* and *Catastrophic*) the data is too sparse to be useful. For *Severe* FDR and below, we accept that the long-run proportion of electrically-initiated fires exceeding 5Ha or more in South Australia is able to be estimated from the SAPN data.
- The logistic regression of SA Fires data (Section 3.1.5) estimates fire suppressibility as a function of categories in the DEWNR qualitative landscape suppression model and bands of FFDI. We propose that this captures the trends in the categorical variables well, but that it is quantitatively unreliable because the quantity of data able to be linked is small, and is not representative (i.e., the ability to link data is not independent of fire surface area).
- The re-analysis of the SA Fires data (Section 3.4) we claim makes for a more representative analysis of relative fire suppressibility but still does not meet the accuracy afforded by the SAPN data.
- The AFAC-sourced dataset on Victorian fires as updated by CSIRO (Section 3.3), is taken as a better estimator of the long-run proportion of fires exceeding 5Ha or more when the FDR is *Extreme* or *Catastrophic*. Unlike the SAPN dataset, it has electrically-initiated fires of greater than 100Ha, and so is our only source of information about the long-run probability of these.

In the hybrid model for estimating suppression probability, we consider LV and HV separately, and also pooled. LV and HV are distinguished in SAPN data, and initial fire behaviour might be different in lower-energy LV ignitions. However, there is not sufficient LV fire start data to support an analysis which reliably captures the effect of fire danger rating when LV is considered separately.

The hybrid model has five calculation steps. The details on these steps follows.

## 4.1 Step One: Estimation of suppression success

In this step we estimate (using simple descriptive statistics based on observations) the initial suppression success, where fire size is successfully kept to less than or equal to 5Ha. This uses SAPN data, except for higher FFDI (Extreme and Catastrophic) when Victorian data is used, and as such does not make use of DEWNR suppressibility categories (which are integrated into the estimates in later steps). Note that the differences between LV and HV are considered in these estimates, and that the estimates differ from those in Table 6 because here we use the SAPN data directly. The LV suppression probabilities at high FDR are unrealistically high (at 100%) but of the very little data available, there are no unsuppressed fires.

**Table 7. Probability of initial suppression (fire size 5Ha or less)**

| Voltage | AVERAGE | Low-Mod | High | Very High | Severe | Extreme | Catastrophic |
|---|---|---|---|---|---|---|---|
| **LV** | 0.931 | 0.947 | 1.000 | 0.833 | 0.900 | 1.000 | 1.000 |
| **HV** | 0.896 | 0.928 | 0.916 | 0.892 | 0.900 | 0.823 | 0.494 |
| **LV & HV** | 0.908 | 0.944 | 0.939 | 0.889 | 0.900 | 0.857 | 0.500 |

## 4.2 Step Two: Estimation of proportion of fires less than 100Ha

The next step is to estimate the proportion of fires that terminate at less than 100Ha in size. For each fire danger rating band, fires either are: (i) kept to 5Ha or less, i.e., Table 7; (ii) lie in the 5Ha to 100Ha range; (iii) reach or exceed 100Ha. There are no electrically-initiated fires exceeding 100Ha in the SAPN dataset and Victorian data is used in order to estimate the proportion of electrically-initiated fires that transition from the 5Ha to 100Ha state to a 100Ha-plus state (refer Table 8).

**Table 8. Fire size transition from 5Ha or more, to in excess of 100Ha**

| | AVERAGE | Low-Mod | High | Very High | Severe | Extreme | Catastrophic |
|---|---|---|---|---|---|---|---|
| **5Ha to 100Ha Survivability** | 0.250 | 0.189 | 0.193 | 0.306 | 0.571 | 0.500 | 1.000 |

The Table 7 and Table 8 data is then combined to give the proportion of fires that do not reach or exceed 100Ha, across all DEWNR suppression categories: refer Table 9.

**Table 9. Proportion of fires not reaching or exceeding 100Ha, on average across DEWNR suppression categories**

| | AVERAGE | Low-Mod | High | Very High | Severe | Extreme | Catastrophic |
|---|---|---|---|---|---|---|---|
| **Proportion of LV fires** | 0.978 | 0.990 | 1.000 | 0.949 | 0.943 | 1.000 | 1.000 |
| **Proportion of HV fires** | 0.960 | 0.986 | 0.984 | 0.967 | 0.943 | 0.912 | 0.494 |
| **Proportion of LV & HV fires** | 0.963 | 0.990 | 0.988 | 0.966 | 0.943 | 0.929 | 0.500 |

## 4.3 Step Three: Proportion less than 100Ha by DEWNR Suppressibility

Next, the average figures on fire exhaustion or suppression at less than 100Ha are disaggregated into DEWNR levels. This involves using the relative proportions from Table 6 and the relative fire occurrence data for each DEWNR suppressibility category (calculated from SA Fires Data, and tabulated in Table 10), to produce the average values given in Table 9. In doing this, a factor of 0.5 is used to weight the average value versus the varying value from Table 6. That is, we accept half of the variation predicted from Table 6 and for the remainder we revert to the average. This is necessary to avoid nonsensical values (i.e., greater than one) and justified because maintaining the correct average value (Table 9) is more important to the overall fire likelihood calculation than capturing the variability due to DEWNR suppression categorisation.

**Table 10. Number of fire events in each DEWNR suppression category area**

| | TOTAL | LOW-MOD | HIGH | VERY HIGH | SEVERE | EXTREME | CATA-STROPHIC |
|---|---|---|---|---|---|---|---|
| **LEVEL 0** | 167 | 63 | 54 | 23 | 18 | 7 | 2 |
| **LEVEL 1** | 133 | 43 | 42 | 23 | 8 | 13 | 4 |
| **LEVEL 2** | 196 | 59 | 60 | 55 | 14 | 6 | 2 |
| **LEVEL 3** | 117 | 25 | 19 | 43 | 21 | 6 | 3 |
| **LEVEL 4** | 175 | 44 | 30 | 56 | 23 | 14 | 8 |
| **LEVEL 5** | 102 | 26 | 22 | 28 | 11 | 14 | 1 |
| **LEVEL 6** | 7 | 3 | 2 | 1 | 1 | 0 | 0 |
| **TOTAL** | 897 | 263 | 229 | 229 | 96 | 60 | 20 |

The results are different depending on whether we are considering LV, HV or both. The data for LV and HV combined is given in Table 11, and the data for HV only in Table 12.

**Table 11. Proportion of electrically-initiated fires not reaching or exceeding 100Ha, by DEWNR suppressibility area for LV and HV fires combined)**

| | AVG | LOW-MOD | HIGH | VERY HIGH | SEVERE | EXTREME | CATA-STROPHIC |
|---|---|---|---|---|---|---|---|
| **LEVEL 0** | 0.988 | 1.000 | 0.999 | 0.992 | 0.967 | 0.975 | 0.786 |
| **LEVEL 1** | 0.980 | 0.999 | 0.995 | 0.986 | 0.959 | 0.954 | 0.667 |
| **LEVEL 2** | 0.981 | 0.999 | 0.996 | 0.987 | 0.960 | 0.956 | 0.679 |
| **LEVEL 3** | 0.961 | 0.987 | 0.984 | 0.968 | 0.941 | 0.923 | 0.471 |
| **LEVEL 4** | 0.939 | 0.970 | 0.969 | 0.944 | 0.923 | 0.903 | 0.337 |
| **LEVEL 5** | 0.929 | 0.959 | 0.961 | 0.930 | 0.916 | 0.897 | 0.293 |
| **LEVEL 6** | 0.929 | 0.959 | 0.961 | 0.930 | 0.916 | 0.897 | 0.293 |
| **AVG** | 0.963 | 0.990 | 0.988 | 0.966 | 0.943 | 0.929 | 0.500 |

**Table 12. Proportion of electrically-initiated fires not reaching or exceeding 100Ha, by DEWNR suppressibility area for HV fires only**

| | AVG | LOW-MOD | HIGH | VERY HIGH | SEVERE | EXTREME | CATA-STROPHIC |
|---|---|---|---|---|---|---|---|
| **LEVEL 0** | 0.985 | 1.000 | 0.994 | 0.993 | 0.967 | 0.957 | 0.776 |
| **LEVEL 1** | 0.977 | 0.996 | 0.991 | 0.987 | 0.959 | 0.937 | 0.658 |
| **LEVEL 2** | 0.978 | 0.996 | 0.991 | 0.988 | 0.960 | 0.939 | 0.671 |
| **LEVEL 3** | 0.958 | 0.984 | 0.980 | 0.969 | 0.941 | 0.906 | 0.465 |
| **LEVEL 4** | 0.936 | 0.967 | 0.965 | 0.945 | 0.923 | 0.887 | 0.333 |
| **LEVEL 5** | 0.926 | 0.956 | 0.957 | 0.931 | 0.916 | 0.881 | 0.290 |
| **LEVEL 6** | 0.926 | 0.956 | 0.957 | 0.931 | 0.916 | 0.881 | 0.290 |
| **AVG** | 0.960 | 0.986 | 0.984 | 0.967 | 0.943 | 0.912 | 0.494 |

## 4.4 Step Four: Proportion of fires reaching or exceeding 100Ha

The fourth step is simply to take the complement of the data in Table 11 or Table 12, to give the probability that a fire reaches or exceeds 100Ha, depending on fire danger rating and DEWNR suppressibility. SA Power Networks focussed on HV fires, so Table 12 is the most relevant.

## 4.5 Step Five: Proportion of fires 5Ha to 100Ha in size

The fifth and final step is to estimate the proportion of electrically-initiated fires that are less than 100Ha but more than 5Ha, depending on fire danger rating and DEWNR suppressibility. The estimates are determined by simply arithmetic from the results computed in preceding steps.

**Table 13. Proportion of electrically-initiated fires terminating with a size greater than 5Ha but less than 100Ha, for HV fires only**

| | AVG | LOW-MOD | HIGH | VERY HIGH | SEVERE | EXTREME | CATA-STROPHIC |
|---|---|---|---|---|---|---|---|
| **LEVEL 0** | 0.089 | 0.071 | 0.078 | 0.101 | 0.067 | 0.134 | 0.282 |
| **LEVEL 1** | 0.081 | 0.068 | 0.075 | 0.095 | 0.059 | 0.114 | 0.165 |
| **LEVEL 2** | 0.082 | 0.068 | 0.075 | 0.095 | 0.060 | 0.116 | 0.177 |
| **LEVEL 3** | 0.062 | 0.056 | 0.064 | 0.077 | 0.041 | 0.083 | 0.000 |
| **LEVEL 4** | 0.040 | 0.039 | 0.049 | 0.052 | 0.023 | 0.064 | 0.000 |
| **LEVEL 5** | 0.030 | 0.028 | 0.041 | 0.039 | 0.016 | 0.058 | 0.000 |
| **LEVEL 6** | 0.030 | 0.028 | 0.041 | 0.039 | 0.016 | 0.058 | 0.000 |
| **AVG** | 0.064 | 0.058 | 0.068 | 0.075 | 0.043 | 0.088 | 0.000 |

## 4.6 Use of the data

The data on fire size proportion (less than 5Ha, 5Ha or more, and 100Ha or more) is combined in subsequent analyses (not by CSIRO, and not described in this report) with fire occurrence rate, fire numerical simulation, and fire consequence (damage cost) data in order to estimate the annual expected loss and the return rates of high-cost fires. Fires that are less than 5Ha can be considered as minor, low-cost events. Fires in the intermediate range can be costly but have been observed enough times in practice to enable this prior information to be used for estimations of future costs. The larger fires are not observed frequently and the numerical simulation data needs to be used.

# 5 Discussion

**For the SA Fires Data Analysis** (Section 3.1) the data used to create these models tells an interesting story, despite it being of limited size relative to either the fire scar or DEWNR incident data sets. Although the DEWNR suppression categories are described as “qualitative”, or developed based on heuristic rather than quantitative rules, they clearly capture an important part of the fire suppressibility story in SA, extra to that captured by FFDI alone.

In terms of interpretation, the “straight lines” model implies that there is a constant decrease in the probability of suppression as both fire weather worsens and suppressibility number increases. The advantage of this model is in its ease of explanation, and because it uses all of the explanatory FFDI and suppressibility categories.

Interpreting the interaction model is slightly different. The interaction in this case implies that rather than a smooth decrease across categories, that there can be a ‘jump’ such that as FFDI category indicates worse weather, a suppressibility category can become relatively much worse. Such an interaction also makes sense and is interpretable in the context of the data. This trend is most noticeable in the bottom right hand corner of estimates, starting with FFDI D and suppression category 4. The drop-off in suppressibility is much higher in the interaction than the straight lines model. The fit of this model is superior, but it comes at the cost of being unable to estimate unique values for each of the different FFDI and suppressibility categories (notice blocks of estimates are the same).

For applying the results of either model, both models can be considered fit for purpose and scientifically defensible. Estimates are fully data driven in both cases, and the model to data fit is statistically significant in both cases. As stated earlier, the 100 hectare cut-off for defining suppressed vs. unsuppressed fires was chosen to maximise the ability of the modelling approach to detect effects. Relative trends for different suppressibility definitions would be similar, but with slightly less reliable estimates from a statistical perspective.

The **Hybrid Suppression Model** (Section 4) seeks to merge insights from the various data and delivers refined estimates of suppressibility by fire danger rating and DEWNR suppressibility category that appropriately reflect SA Power Networks’ recent history (2008 to 2017) without discarding insight from much larger interstate datasets nor that of the SA Fires Data Analysis. It is the estimates from this model that have been used by SA Power Networks in quantifying risk from electrically-initiated bushfires in South Australia.

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