# Utilisation of fire spread simulators to assess power network fire risk

Jackson Parker[1] and Adrian Allen[2]
1. Western Australian Department of Fire and Emergency Services.
2. Landgate.

## Abstract

Western Power is a Western Australian State Government owned power network and energy corporation. In 2013, an external review commissioned by Western Power, recommended the development of an improved bushfire risk map for the network based on the consequences of potential network bushfire ignitions. In response to the review Western Power entered into a joint collaboration with the Department of Fire and Emergency Services (DFES) and Landgate to develop a multiple ignition point based bushfire risk analysis product suitable for use on the power network across the south west of Western Australia.

The objective of this project is to assist Western Power in prioritising their asset renewal and maintenance budget to ensure they've addressed sites with the highest potential consequences, realising better public safety out-comes. The utilisation of the fire spread simulator system Aurora, to model the consequences of a bushfire ignition from power poles and wires has been investigated to provide this intelligence. Western Power maintains approximately 800,000 power poles within the south west of Western Australia. The development of an appropriate methodology to provide the required intelligence for the prioritisation of appropriate asset renewal and maintenance implementation programs in response to the risk of bushfire ignition, has proven to be challenging.

Aurora is a web-based bushfire spread prediction system that simulates the probable direction, intensity and rate of bushfire spread. The simulator considers ignition location, vegetation, time of last burn, fuel accumulation models, forecasted weather, drought factor, grassland curing and slope to calculate fire behaviour and spread. For this project, the simulator architecture uses 99.5th percentile Forest Fire Danger Index (FFDI) weather conditions for each of the 8 cardinal wind directions to produce 6 million fire spread simulations. These simulations together with a building location dataset are used to estimate asset numbers that could potentially be impacted by a fire running for one hour, from each power pole. Using this methodology maintenance can be prioritised for individual power poles based on the potential impact of a bushfire caused by a fault.

The successful completion of this project will result in a well-developed methodology, Information Communication and Technology (ICT) system infrastructure and potential consequence datasets with the potential to utilise multiple activities and assets as potential ignition sources, therefore providing DFES with enhanced evidence-based datasets to support strategic decision making for early community warning and preparedness.

## Introduction

Bushfires initiated by power line faults are disproportionately associated with a majority of bushfire fatalities and asset losses in southern Australia (Roozbahani et al. 2015). Locally there have been several bushfire incidents caused by power infrastructure fires in the rural urban interface of Western Australia. In 2009 a power pole fell to the ground causing arc flashes that ignited crop stubble, the resultant bushfire destroyed 38 homes and severely damaged 70 more. In 2013 a fire sparked by ageing power poles threatened homes in Chidlow. In 2014 a private power pole sparked a bushfire and destroyed more than 50 homes in the Parkerville area.

Catastrophic bushfires have resulted under elevated fire weather conditions due to power transmission system failures, under these conditions multiple ignitions due to power infrastructure over a broad geographic area can stretch fire suppression resources and simultaneously threaten multiple communities Such instances have been observed in the US state of California in 2007, and several times in recent Australian history - most notably the lethal Black Saturday fires of 2009 (Mitchell 2013).


**Figure 1: Project region of interest. Source: Western Power Annual Report, 2014.**

A common response from governments and utility providers has been to embark on optimised electricity network asset improvement and replacement programs where the aim is for the cost-effective reduction of power line sparked ignitions in bushfire hazard areas under elevated fire weather conditions.

Power infrastructure ignitions can occur from a variety of modes of failure across the array of components forming the distribution and transmission network infrastructure and the environment of their alignments. These failures fall into two general categories; those caused by a contact event though increased proximity of either the conductors or surrounding objects (such as tree limbs) causing electrical contact and asset failures through arcing, and fatigue under high strain conditions affecting system components (conductors, poles, cross arms) or surrounding objects (trees). Both failure classes show a strong dependence on increasing wind speed (Mitchell 2013) and or temperatures (line sagging). Power distribution pole networks are also vulnerable to a changing climate. Climate change can increase wind speeds, and changes in rainfall and temperature can accelerate timber decay, affecting the residual capacity of timber power poles (Ryan & Stewart 2017).

One approach to removing the risk posed by an electricity network of starting a fire is to pre-emptively de-energise those parts of the network at high risk of starting a bushfire on extreme fire weather days. This is not an option adopted in Western Australia but is an option adopted in South Australia and other parts of the world. De-energisation reduces the risk of and prevents electricity infrastructure being the source of a bushfire because any damage that does occur to the network due to high winds, temperature and debris, does not result in arcs. However, de-energising a network is a 'last resort' approach because it leaves communities and industry without power for extended periods of time (Cainey 2019).

Before the bushfire season, power network agencies are often preparing assets and line alignments in high risk bushfire zones, to reduce the chances of a network-related spark that could cause a fire. These activities may include cutting back vegetation from poles and wires, clearing vegetation at the base of poles and the washing of lines and insulators is also carried out in rural areas where there is a lot dust and for coastal areas where salts build up. The failure of assets is also something that the network can manage, fire mitigating treatments can range from the installation of new electrical fault detection systems at zone sub-stations; burying individual sections of power line; installation of automatic circuit reclosers (ACRs); adjusting the settings on existing ACRs and insulating bare lines (Roozbahani et al. 2015).

Western Power is a Western Australian State Government owned power network and energy corporation. Western Power is responsible for building; maintaining and operating the electricity network (transmission and distribution assets) in the south-west corner of Western Australia called the South West Interconnected Network (SWIN). The network consists of approximately 102,000km of circuit wire, 264,000 street lights, 860,000 poles and towers, transporting 17,047 gigawatt (GWh) of electricity, to over 1.1 million customers annually (Western Power 2014).

In 2013 Western Power commissioned an external review of its Bushfire Mitigation Strategies, with the key recommendation to

> "Develop a new fire risk map for the network based on the fire start consequences agreed and used by agencies in Western Australia involved in Bushfire Risk Mitigation"
>
> Western Power (2014).

Following up from this report with safety recognised by Western Power as the primary driver for expenditure and bushfire mitigation being the major safety component, the Western Power Annual Report for 2014 made the following observations and commitments:

> "With approximately 25% of Western Power's wood poles located in extreme or high bushfire risk areas, the potential for electricity network assets to ignite bushfires is one of the most significant public safety risks for the Western Power network."

“Western Power’s challenge is to maintain and replace these distribution assets in an orderly and appropriate manner to continue safe and reliable operations.”

“A primary focus is on investing in activities that minimise the risk of harm to the public and reduce the potential for bushfires to be initiated by Western Power’s network assets.”

Western Power (2014).

The main objective of this project therefore is to use bushfire spread simulator technology from the Aurora system, utilising the Australis simulator, to inform Western Power’s asset maintenance and replacement program to minimise the potential for a bushfire started by Western Power network infrastructure threatening the well-being of people and communities and the functionality of infrastructure that supports them.

Aurora is a national bushfire spread prediction system for Australia that simulates the probable direction, intensity and rate of bushfire spread. The web-based system ingests data such as active fire hotspots, forecast weather (Temperature, Relative Humidity, wind speed and direction), Drought Factor, vegetation type and age as well as topography. The system processes the fuel accumulation and rate of spread models to produce a 100m resolution simulated fire spread prediction to enable fire management agencies to run a range of fire incident scenarios, for operational and training purposes.

In regard to the state emergency management policy context the relative significance of assets in no specific order except for the primacy of the protection of life, is based on the Western Australian State Emergency Management Committee (SEMC) Bulletin Oct. 2016, being:

- Protection and preservation of life
- Community Warnings and Information
- Protection of critical infrastructure and community assets,
- Protection of residential property,
- Protection of assets supporting individual livelihood and community financial sustainability,
- Protection of environmental and heritage values.

# Methodology

The bushfire consequence assessment methodology can be summarised into four components, which are:

- Source of Risk; Ignition of bushfire prone vegetation from Western Power’s network infrastructure
- Buildings; Location where human life and property is most likely to be endangered during a bushfire
- Consequence Severity; The potential consequences of a bushfire were defined by intersecting the footprint of modelled bushfires emanating from Western Power’s network and a layer depicting the density of buildings
- Policy; The risk assessment project aligns with AS/NZS ISO 31000:2009 the Australian Standard for Risk Management, SEMC State Emergency Management Policy and SEMC State Emergency Management Plan

## Datasets used within the modelling

### Consequence Dataset: Buildings

Landgate’s topographic mapping program has captured building locations from aerial photography for map production purposes. For this project, these data required further processing to be in a form suitable for analysis. These data exist either as building location points, building footprint polygons, or a polygon defining an urban area consisting of a dense number of buildings. Landgate’s cadastral and valuation data attributes were also used in areas where building points or polygon data were not available. To allow for unmapped buildings a process was created to allocate a building location point to land parcels less than 1 hectare in areas that are zoned to allow for residential development and contain an attribute in their cadastral data noting that a building is present.

### Vegetation / fuel type data

The Aurora system has utilised the major vegetation sub-groups from the National Vegetation Information System (NVIS), vegetation class dataset. The NVIS dataset contains 67 classification groups that represent the dominant vegetation occurring in each 100m x 100m cell, across Australia (Executive Steering Committee for Australian Vegetation Information, 2003). As a National vegetation dataset, there were some limitations that led to vegetation information gaps that needed to be filled for this project. These data did not separate agricultural areas from cleared or built up areas, and there was a need for better quality water body mapping. These were important factors for this project, therefore, the NVIS data was modified by integrating the DFES Bushfire Risk Analysis (BRAn) dataset, which provided an improved quality of vegetation mapping, urban area mapping, other land use features, and water bodies, for the south west of Western Australia.

### Weather and soil moisture data

DFES had previously engaged with the Bureau of Meteorology Atmospheric high-resolution Regional Reanalysis for Australia (BARRA) with a reanalysis over the Western Australian domain now available with a resolution of approximately 6 km from 2005 to 2016 at an hourly time step, with further expansion in the number or years planned in order to give greater confidence in the extreme weather values calculated.

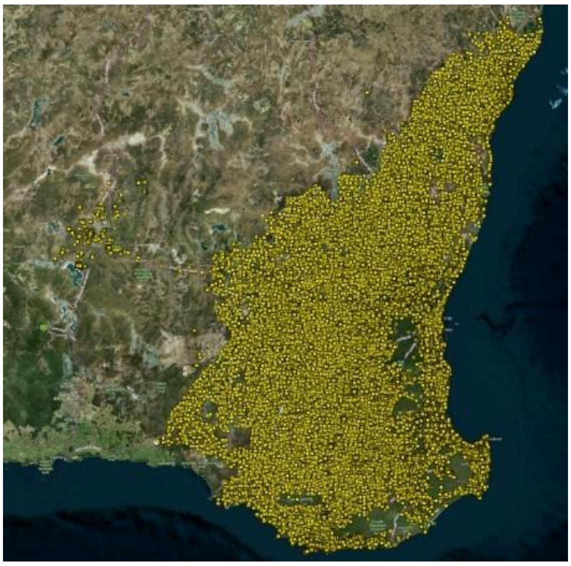

**Figure 2: Building location points dataset for the SW of WA**

The project currently uses the BARRA weather parameters for the worst 1 in 200-day bushfire weather event based on the Forest Fire Danger Index (FFDI) to provide the discrete extreme fire weather values per approximate 6 km grid cell. The Drought Factor is a key soil moisture input into the forest and woodland fire spread models (Kelso & Mellor 2012) outside of the Dry Eucalypt Forest Fire Model (DEFFM) areas. The Draught Factor using the Keetch-Byram Drought Index (KBDI) is generated for each 6 km gridded weather cell within the weather reanalysis data. Before the BARRA was available the project initially used a universal set of extreme fire weather parameters across the region based on the calculated 1 in 50 year annual exceedance probability for Perth of an FFDI of 80 (Global 2018).

### Fuel age and fuel loads

The project utilised the Joint Agency Fuel Age dataset that combines Fire Burnt Area (FBA) mapping sourced from several government agencies into a single dataset that represents the time of last burn for Western Australia. The dataset is updated on a monthly basis, if the same fire is mapped by different agencies, a hierarchy for the inclusion of data based on the level of quality assurance and resolution. Polygons from the other agencies will be excluded from the processing at this stage; this is to avoid 'halo' zones around the FBA depending on the mapping resolution of the fire. The FBA is sourced from the Department of Biodiversity Conservation and Attractions (DBCA), DFES, North Australian Fire Information (NAFI) and Landgate using a number of different capture methodologies:

I. The Landgate FBA data is mapped from NOAA/AVHRR 1km resolution satellite imagery. The data archive extends from 1988. Areas less than 4 km2 or under persistent cloud cover are unlikely to be mapped

II. NAFI data is source from https://www.firenorth.org.au/nafi3/ and is mapped from the MODIS sensor on-board the TERRA/AQUA Satellites at a resolution of 250 m

III. DFES mapping is incident related and a variety of capture methodologies are utilised

IV. DBCA FBA mapping is captured over DBCA tenure using a variety of methodologies. The archive extends from 1922.

There is not a dataset to determine neither the variability of grassland fuel loads nor the density of urban areas. For this project, an approach was adopted that utilised building density per hectare in reference to the Residential Design Codes (R-Codes), as a surrogate to define grassland fuel load, as seen in table 1.

**Table 1: Building density as a surrogate for grassland fuel loads.**

| Number of Buildings per hectare | Surrogate grassland fuel load / model |
|---|---|
| **0-2 buildings p/ha (R2)** | 4.5 t/ha (natural grass) |
| **3-5 buildings p/ha (R5)** | 1.5 t/ha (grazed grass) |
| **6-10 buildings p/ha (R15)** | 0.5 t/ha (eaten out grass) |
| **>10 buildings p/ha (>R15)** | 0.0 t/ha (no spread) |

**Table 2: Building density as a surrogate for grassland fuel loads, in industrial and commercial areas.**

| Number of Buildings per hectare | Surrogate grassland fuel load / model |
|---|---|
| **0 buildings p/ha** | 4.5 t/ha (natural grass) |
| **>=1 building p/ha** | 0.0 t/ha (no spread) |

With regards Industrial and Commercial properties the following rule set was applied:

**Elevation data**

Slope is a key parameter in determining fire behaviour. To determine the elevation and slope, a resampled version of the one-second (30m) smoothed digital elevation model (DEM—S) derived from the Shuttle Radar Topographic Mission (SRTM) data. This Digital Elevation Model has undergone several processes in order to remove noise and its vertical accuracy is approximately 5m (Geoscience Australia & CSIRO Land & Water, 2010).

**Western Power infrastructure data**

A challenge existed as to how to model the predicted fire spread of ignitions from the power network. The project initially did not have access to a cloud computing environment, therefore the first approach was to try and process this vast amount of data as efficiently as possible with the available infrastructure and within a suitable time frame. The initial approach was to break up the power network into long line segments. The next approach was to break the network up to approximately 2km line segments. With the advancements in ICT and the acquired knowledge of the potential of cloud computing, the project then focused on utilising each individual power pole within the modelling, each with its own unique identifier. This enabled the modelling results to focus directly on each pole as an independent measure of risk and consequence.

## Fire spread simulation modelling

Aurora is a web application that extends of the capabilities of Landgate's FireWatch web application to include fire-spread simulation (Steber 2012) by including Australis. Aurora can help bushfire managers quickly test various ignition points and weather conditions in order to run a series of scenarios to optimise fire-suppression outcomes during an operational incident. Aurora was developed during the period 2010—2013 and grew out of a partnership between Landgate, the University of Western Australia, and the then Fire and Emergency Services Authority (now DFES) with additional funding from the Federal Department of Broadband, Communications and the Digital Economy. The Aurora system was significantly modified for this project to enable the bushfire modelling of potential ignitions from the Western Power infrastructure efficiently.

Within Aurora is the University of Western Australia designed fire-spread simulator called Australis. The Australis simulator uses a cell-based approach with an underlying irregular grid. This irregular grid of points is generated using a Poisson disk distribution. An approximation of the Voronoi diagram and Delaunay triangulation is then calculated to determine the polygon boundaries and neighbours of each cell (Johnston, Kelso & Milne 2008). The irregular grid approach aims to minimise the distortion of fire shape as the direction to the immediate neighbouring cells of a given cell are different from those of any other cell. To increase the efficiency of simulations and define the landscape across Australia, the irregular grid is divided in to a series of tiles. It also uses an efficient discrete-event simulation methodology to propagate the fire over the landscape changing the state of cell from unburnt, burning or burnt. The advantage of this technique is that the computational time is proportional to the number of cells that are ignited (Johnston et al. 2008). The Australis simulator has been written in Java so that it is portable across operating systems (Steber 2012).

## Fire spread simulation processing

The Aurora / Australis simulation system takes approximately 10 seconds to produce a 24-hour duration simulation from a single ignition point. Western Power's assets used for analysis in the south west of Western Australia comprise approximately 750,000 poles. Treating each pole as a discrete ignition point, the project is modelling each of the 750,000 poles in eight wind directions, equating to 6 Million fire spread simulations. Within the traditional Aurora system architecture, the simulation processing would take approximately 700 days to run at 10 seconds each. To efficiently process 6 million simulations, cloud computing technology was used, and software written to enable parallel processing of simulations across multiple servers and central processing unit (CPU) cores.

The 750,000 power poles were broken into 50,000 pole subsets as comma-separated values (CVS) files. The CSV files are the converted to Aurora simulation run-files that define all the required parameters needed for a simulation, this process created run files for each of the eight wind directions being modelled. The run-files are then compressed using tar and gzip software and stored in Amazon Web Services (AWS) cloud infrastructure on their Simple Storage Service (S3). Landgate has written software to enable an AWS Elastic Compute Cloud (EC2) server to be created, that then selects each of the 50,000 power pole batch run files for processing.

The processing occurs on a Centos server. The AWS server architecture used consists of 72 virtual CPU's and 144 gigabyte (GB) of memory. Landgate has written software to allocate a simulation process to one of 54 virtual CPU's and allocates 1024 megabyte (MB) of random access memory (RAM) to each simulation. This allows for the simultaneous processing of 54 simulations at one time. By automating the process of creating over a hundred servers and allocating each 50,000 subset of power poles for the eight wind directions, the whole south west of Western Australia infrastructure can be modelled in days.

Once the fire spread simulation output files are created the next process is to create isochrones to determine the extent of where a fire may impact within the first hour. This process uses a series of routines within the spatial data processing libraries; Geospatial Data Abstraction Library (GDAL) and OpenGIS Simple Features Reference Implementation (OGR). The process also utilises parallel processing and multiple servers and CPU cores.

> By automating the process of creating over a hundred servers and allocating each 50,000 subset of power poles for the eight wind directions, the whole south west of Western Australia infrastructure can be modelled in days.

An isochrone is created for each ignition point being a power pole, for each of the eight wind directions. The results are merged back in to 50,000 simulation isochrone subsets, for each wind direction, to enable further processing and analysis.

## Consequence mapping and results

The risk posed by a bushfire started at each power pole along the power network is determined by intersecting the consequence severity layer and fire spread isochrones / footprints. This is a calculation of the number of assets that will be affected by a fire started at each pole along the network. It is repeated for each power pole and then all poles ranked according to risk to prioritise mitigation actions. The assignation of segments to risk categories is undertaken after the total distribution of risk is determined using an appropriate statistical method.

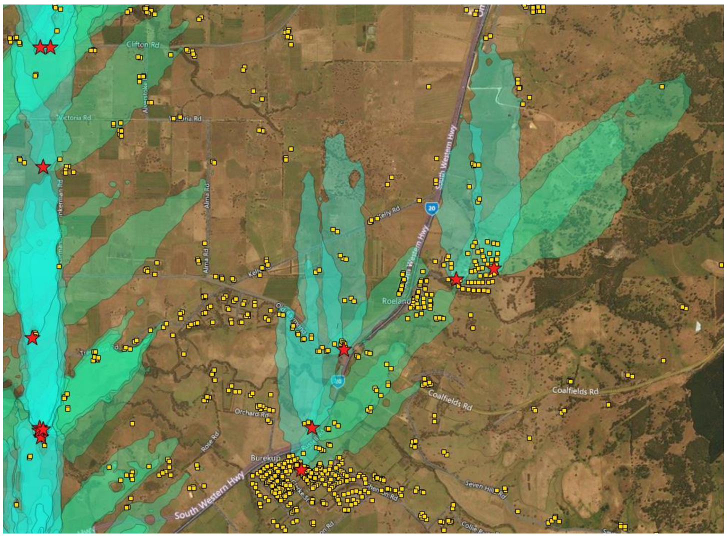

**Figure 3: 1-hour fire spread isochrones from northerly and south westerly wind directions from a sample of power pole ignition points and buildings likely to be impacted.**

**Figures 4 & 5: Example of fire runs modelled on 1 cardinal wind directions and further processing in the AWS to produce 8 cardinal wind directions from Western Power above ground power poles.**

To prepare the isochrone data for further analysis, some post processing steps were required. There are many power poles that fall within areas of no fuel however the isochrone creation process creates a circular isochrone at the grid resolution of approximately 100 m surrounding the power pole. Based on Western Powers desire to include poles outside of bushfire prone areas in the risk mapping the isochrones for power poles without fuel were retained. However, the radius of the potential hazard isochrone around the power pole was set to the equivalent of 1.5 times the height of the pole based on the potential of arcing and ember travel and the pole or parts of a pole to swing, fall and bounce (Office of the Technical Regulator 2016). A standard pole height of 10 m was applied based on Western Powers asset data, and therefore at 1.5 x the height, a hazard isochrone set to 15 m radius was created.

Within a geographic information system (GIS) environment, the isochrones from 1 hour of fire spread with no suppression in 8 wind directions were then intersected with the consequence layer being the building locations layer. This process determines the number of buildings with a possibility of being impacted within one hour of a fire igniting from each power pole. This process defined the area of potential consequence that each power pole being a single event may have.

The data processing outcomes of the consequence mapping were summarised and then able to be analysed and presented in a variety of forms. Spreadsheets ranking power pole unique identification numbers versus the total potential buildings impacted were developed, summarising in order individual power-poles with the highest consequence if ignited. GIS datasets were created to be able to visualize the spatial distribution of consequence across the power network infrastructure. These GIS datasets provided a valuable tool in spatially determining and visualising areas of high consequence across the power network.

# Conclusion

The outcomes from this project provide the potential bushfire consequence from a bushfire originating from Western Power's power-pole infrastructure, across the south west of Western Australia. It has assessed the bushfire ignition risk relativities across the entire south west interconnected network in order to prioritise network maintenance and improvement activities to reduce the communities of south west of Western Australia's exposure to power line related bushfire risk. It provides Western Power an evidence base to focus their asset renewal and maintenance program to ensure they have addressed areas with the highest potential consequences, realising better public safety outcomes.

The project has demonstrated the applicability of the Aurora fire spread simulation system to state-wide, risk analysis and consequence modelling requirements. It also highlights where there are significant data gaps and where there exists the opportunity to improve data quality for the State.

The project has also achieved successful development of a new bushfire risk analysis methodology. The workflows, ICT systems, software and processes developed within the project are significant outcomes and now provides the State capability to process state-wide datasets to produce intelligence products in a short time frame. The knowledge gained could be applied to other bushfire risk analysis questions; one example being where to best target investments in fuel mitigation, including mechanical fuel reductions and prescribed burning.

Furthermore, undertaking the project facilitated cross-agency collaboration, leveraging the information and skills from across the agencies, between specialists in bushfire behaviour, together with ICT and a critical infrastructure manager, to develop intelligence which supports best practice bushfire ignition risk management and bushfire mitigation planning and practices for the State.


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