Australian Journal of Emergency Management

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**AFAC19 powered by INTERSCHUTZ**

Extended abstracts from the Bushfire and Natural Hazards CRC Research Forum (non-peer reviewed)

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## Extended abstracts

# Foreword

Dr John Bates, Bushfire and Natural Hazards CRC

As emergencies and disasters caused by natural hazards increase in frequency and severity across the globe, it is more important than ever to provide decision-makers with the evidence, information and tools that they can use to make the necessary critical decisions.

Research is supporting our emergency services, government and community organisations as they work to prevent, prepare for, respond to and recover from natural hazards.

The Bushfire and Natural Hazards CRC's Research Forum, held as part of the AFAC19 conference powered by INTERSCHUTZ in Melbourne in August, showcased the latest natural hazards science and explored how outcomes can be further integrated into policy and practice to contribute to disaster risk reduction and to make our communities more disaster resilient.

This *Australian Journal of Emergency Management Monograph* special edition from the Research Forum provides a snapshot of current research happening right around Australia: including fire behaviour, predictive services and modelling; capability; risk, policy and practice.


Mika Peace

Image: Bushfire and Natural Hazards CRC

As our demographics change, we expand our cities further into the bush and increase our dependence on technology, our exposure to risk intensifies. The economic, social and environmental costs are forecasted to rise in a way that is unprecedented and unsustainable. These challenges are complex, and we should be wary of quick fix solutions. These research papers are a small contribution to the larger discussion.

This monograph is complemented by a companion monograph (Monograph 4), which includes peer-reviewed research papers from the Research Forum, and I encourage you to take some time to read both of these Monographs.

**Dr John Bates**

**Research Director**
**Bushfire and Natural Hazards CRC**

**Editor in Chief**
***Australian Journal of Emergency Management***

# Detecting active fires from space using Himawari-8: a report from the regional New South Wales trial

Chermelle Engel[1,3], Stuart Matthews[2], Simon Jones[1,3] and Karin Reinke[1,3]

1. RMIT University.
2. New South Wales Rural Fire Service.
3. Bushfire and Natural Hazards CRC.

Continuous monitoring of fires over Australia using Himawari-8 geostationary satellite data (available every 10 minutes) has the potential to change lives.

Active-fire hotspots are routinely available from polar-orbiting satellites such as MODIS and VIIRS (Giglio et al. 2003; Giglio et al. 2016; Schroder et al. 2014) over Australia. Active-fire hotspots from those systems are only available a few times a day, with the specific times dictates by the satellite orbits themselves. With satellite orbits not necessarily concurring with time of maximum fire activity. In late 2015 though, the Japanese Meteorological Agency launched the Himawari-8 geostationary satellite, with full-disk observations (including Australia) available every 10 minutes (Bessho et al. 2016). These frequent observations have the potential to support continuous real-time satellite monitoring of active fires over Australia.

## Scientific background

Mid-infrared satellite channels are sensitive to the radiant output from fires. The presence of fire causes mid-infrared brightness temperatures to increase. Mid-infrared satellite channels are so sensitive to fires, that even fires too small to be spatially resolved can cause rises in brightness temperature (Dozier 1981). The detection of fires using mid-infrared satellite channels is complicated though by the presence of clouds, as sunlight reflected from clouds can also cause rises in mid-infrared brightness temperature. Hence, the success of active-fire detection algorithms hinges on the successful removal of or handling of cloud-affected mid-infrared satellite data.

Existing systems either use additional data or cannot be used uniformly over all of Australia. The Wildfire Automated Biomass Burning Algorithm active fire hotspot system over North and South America uses GEOS geostationary satellite data uses additional numerical weather prediction cloud information (Schmidt et al. 2012). Other fire detection (Koltunov et al. 2016; Xu et al. 2017; Hally et al. 2019) and mapping algorithms (Wickramasinghe et al. 2016) require a separate cloud mask, tying the success of the algorithm to the success of the separate cloud mask algorithm.

In 2018, RMIT developed a geostationary fire-hotspot algorithm that required no separate cloud mask and no additional numerical weather prediction information. The algorithm (referred to here as H8IBRA) was applied to Himawari-8 data and involved calculating statistics over bio-geo-physical-regions, sub-seasons and times-of-day to detect rises in mid-infrared sky (MIR) brightness temperature that were unlikely to be due to cloud. The algorithm dynamically-tuned to 419 bioregions (Australia, 2000) over Australia (Engel et al. 2018). While the H8IBRA algorithm showed potential when applied to Himawari-8 data over all of Australia for a full year period, during daytime hours, when compared against active fire detections from MODIS/VIIRS polar-orbiting satellites, it had been set-up to run in over sub-seasons rather than in a real-time environment.

## Trial setup

As a way of accelerating the exciting H8IBRA research toward industry utilisation, the New South Wales Rural Fire Service (NSW RFS) proposed to the research team a real-world 'live' trial of the experimental satellite fire detection algorithm

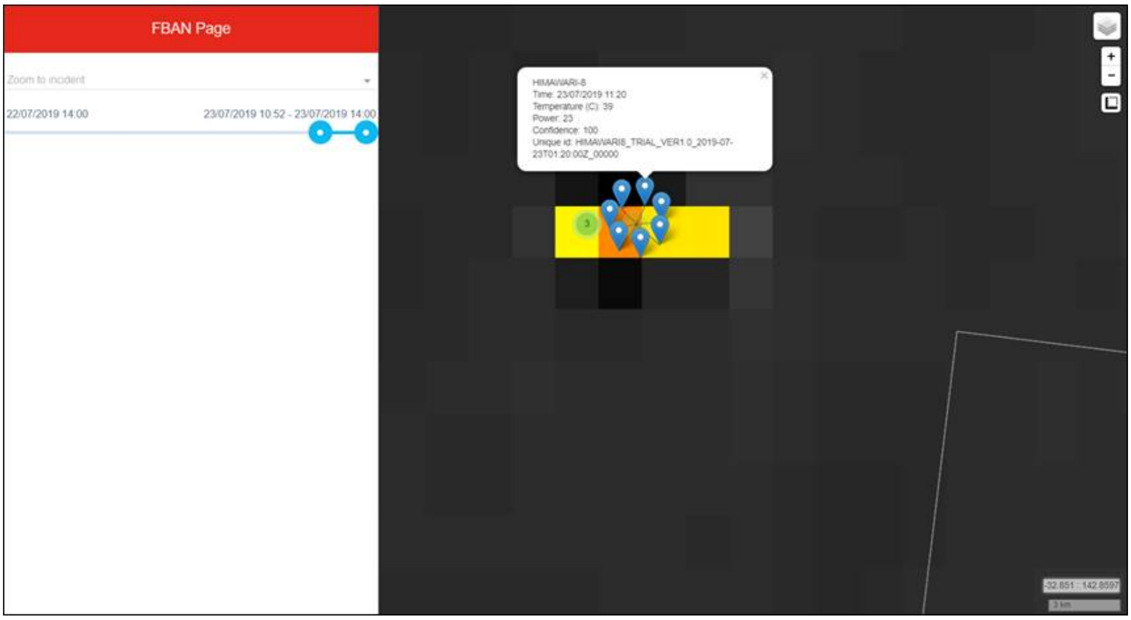


**Figure 1: Example of operational use of the H8IBRA trial hotspots.**

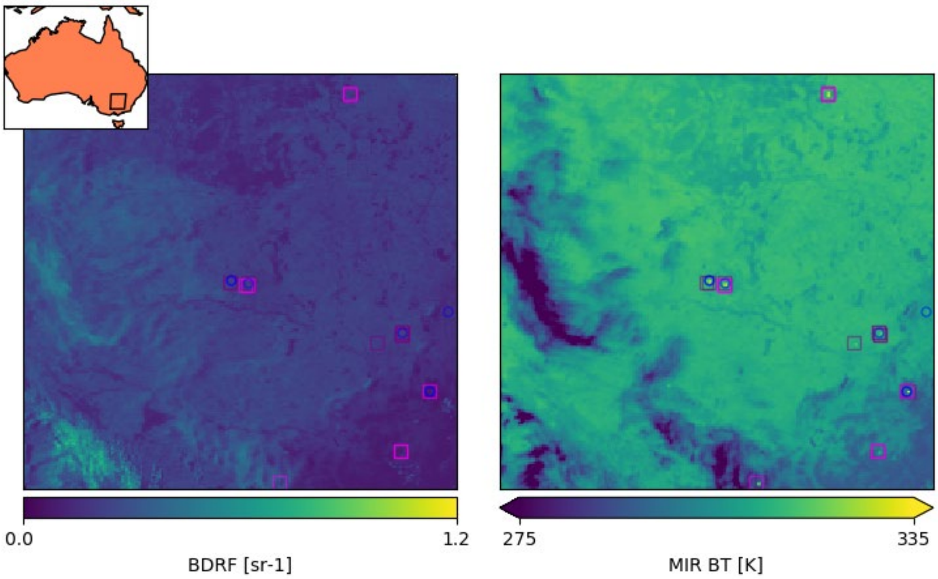


**Figure 2: 0410 UTC 17th April 2019 Himawari-8 0.64 μm (at 2km resolution) (left) and 3.9 μm (right) data over NSW (see inset). Hotspot detections are shown from VIIRS (blue circles) and H8IBRA (magenta -- 0410 UTC; purple -- 0400 UTC).**

under development. The RMIT project leaders were keen to pursue the near-real-time (NRT) trial to identify opportunities to refine their work in a practical setting, as well as obtain real-world performance data.

A trial was set up that ran over NSW every 10 minutes over 24 hours, from 0500 UTC 12 March 2019 to 05 UTC 18 April then from 0500 UTC 6th May 2019 to 0500 UTC 24 July 2019. First, RMIT researchers modified the H8IBRA algorithm to make it produce NRT active fire hotspots (manuscript in preparation). The Australian Bureau of Meteorology then provided access to the Himawari-8 data in NRT. RMIT researchers downloaded Himawari-8 data in NRT to a local machine, processed the data, and uploaded the active-fire hotspots to NSW RFS. The delay between data arrival and hotspot delivery (using limited computing resources) being on the order of minutes.

The NSW RFS invested time and expertise to incorporate RMITs work into existing systems so it could run in parallel with currently operational satellite detection systems. Hotspot data were ingested by a server at the NSW RFS and published through existing map server infrastructure as a geoJSON feature layer. Users were then able to view hotspots through an internal website along with latest MIR and false-colour visible images, and incident information. Controls in the website allowed users to filter hotspots reported over the previous 24-hour period and to view information about each hotspot (Figure 1).

The website was available to a limited number of skilled fire behaviour analysts who were briefed on the use and limitations of the hotspots information.

Integration of RMIT produced hotspots with agency systems made it much easier to interpret hotspots by providing context through incident information and other base layers such as vegetation maps or air photos. The real-time trial also provided an opportunity to rapidly adjust and iterate the detection algorithm. Feedback on the algorithm sensitivity was used to make adjustments which were then visible to users almost immediately.

Embedding research data into agency systems was a powerful way of validating user needs and providing feedback on the algorithms. This approach could be used in future for other research projects where trial data can be produced and tested in an operational context.

Evaluation of the accuracy of the H8IBRA hotspot is still being completed. An example though of the satellite inter-comparison of H8IBRA hotspots to MODIS and VIIRS hotspots can be seen in Figure 2. Initial findings indicate that bright hotspots in Himawari-8 are routinely detected, but that H8IBRA thresholds may be set too high to detect dimmer Himawari-8 hotspots. There is also evidence of "brand new" H8IBRA active-fire hotspots detections becoming available be due to the higher spatiotemporal availability Himawari-8 observations.

## Future

Future areas of work stemming from this study may include modifications to the H8IBRA algorithm to attempt to detect dimmer Himawari-8 hotspots. Additional trial may also be run in different seasons, and different Australian regions. Finally, further investigations into the optimal use of such high-volume NRT active-fire hotspots in an operational setting may be completed.


### Acknowledgements

We would like to thank the Australian Bureau of Meteorology for providing near-real-time access to the Himawari-8 data. We would also like to acknowledge the use of data from LANCE FIRMS operated by NASA's Earth Science Data and Information System (ESDIS) with funding provided by NASA Headquarters.


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# Fuels3D: barking up the wrong tree and beyond

Karin Reinke, Luke Wallace, Sam Hillman, Bryan Hally and Simon Jones, RMIT University & Bushfire and Natural Hazards CRC.

Emerging remote sensing technologies for data collection and methods for repeatable and quantitative measurements of fuel hazard.

Improvement of the understanding of how fuel characteristics correlate with fire behaviour and severity is critical to the ongoing handling of risk and recovery in fire-prone environments. Current standards and protocols for describing fuel hazard (for example, 'Overall Fuel Hazard Assessment Guide', Victorian Department of Sustainability and Environment) and post-burn severity (for example, 'Fire Severity Assessment Guide', Victorian Department of Sustainability and Environment) were written for collection of information in the field. The data collected are largely subjective descriptions of the landscape. The ability of information from these assessment techniques to be adapted to modern risk assessment tools such as fire behavior models, or for the calibration and validation of datasets, is limited. Quantitative data-rich methods of measuring and assessing fuel load and structure are the missing link between the knowledge of land management personnel in the field, and the model drivers and decision makers at organizational level.

Handheld devices with high quality sensors, in the form of off-the-shelf cameras, are increasingly ubiquitous, as is the availability of 3D point cloud data collected from active sensing instruments on terrestrial and aerial platforms. Rapid and comprehensive capture of information by these devices, coupled with the use of computer vision techniques, allows for the 3D description of the surrounding environment to be exploited to provide robust measurement of metrics that can be built into existing fuel hazard assessment frameworks. Providing key metrics as data products rather than a single product enables flexibility across jurisdictions and ecosystem types, and capacity to adapt as end-user requirements change.

The Fuels3D project has created a suite of tools and methods for image capture in the field during fuel hazard assessments. 3D point clouds are generated using computer vision and photogrammetry techniques. From these 3D point clouds, scale is added, and decision rules are programmed to calculate quantifiable surface / near-surface metrics that replicate those used in current fuel hazard visual assessment guides. Case studies are highlighted here.

## Background

It is common practice for fuel hazard assessments to be conducted based on in-situ, visual field assessment. In Victoria, methods for fuel hazard assessment use the Overall Fuel Hazard Assessment Guide (OFHAG) in which visual estimates of vegetation or fuel variables within defined fuel layers are made, and which when combined provide a fuel hazard rating. These vegetation-based fuel variables characterise the structure (e.g. height) and cover (e.g. horizontal percentage cover) of fuels for each of the four fuel layers, surface litter, near-surface, elevated and canopy.

Fuels3D is a method to support in-field data collection for fuel hazard estimation. It has been designed to support and improve existing field observations and provide an easy, quick and repeatable method by which observations can be collected, providing improved reliability and accuracy of fuel hazard assessments. Fuels3D is a process and technology for applying photogrammetry and computer vision techniques to produce 3D point clouds of the environment from which fuel hazard metrics can be derived. Fuels3D supplements existing visual assessments with repeatable and quantitative estimates of surface and near surface fuel. Trials have been undertaken with end-user agencies across Victoria, South Australia and the Australian Capital Territory, and are planned in Queensland.

Fuels3D+ is an extension of the concept supporting the use of fuel hazard data and information from a wider range of sources than Fuels3D. Fuels3D+ is a process and technology for taking 3D point clouds, derived from Fuels3D or from a range of other sources such as aerial LIDAR, to generate spatial data layers of fuel layer height and cover and tables of fuel metric summaries. and provides quantitative data as input into fuel accumulation over time, burn severity, fire behaviour and spread models. Figure 1 below illustrates the Fuels3D+ concept as well as the original Fuels3D concept as two separate modules, delineated by the stages up to and including point cloud creation, and subsequent postprocessing to generate fuel related information.

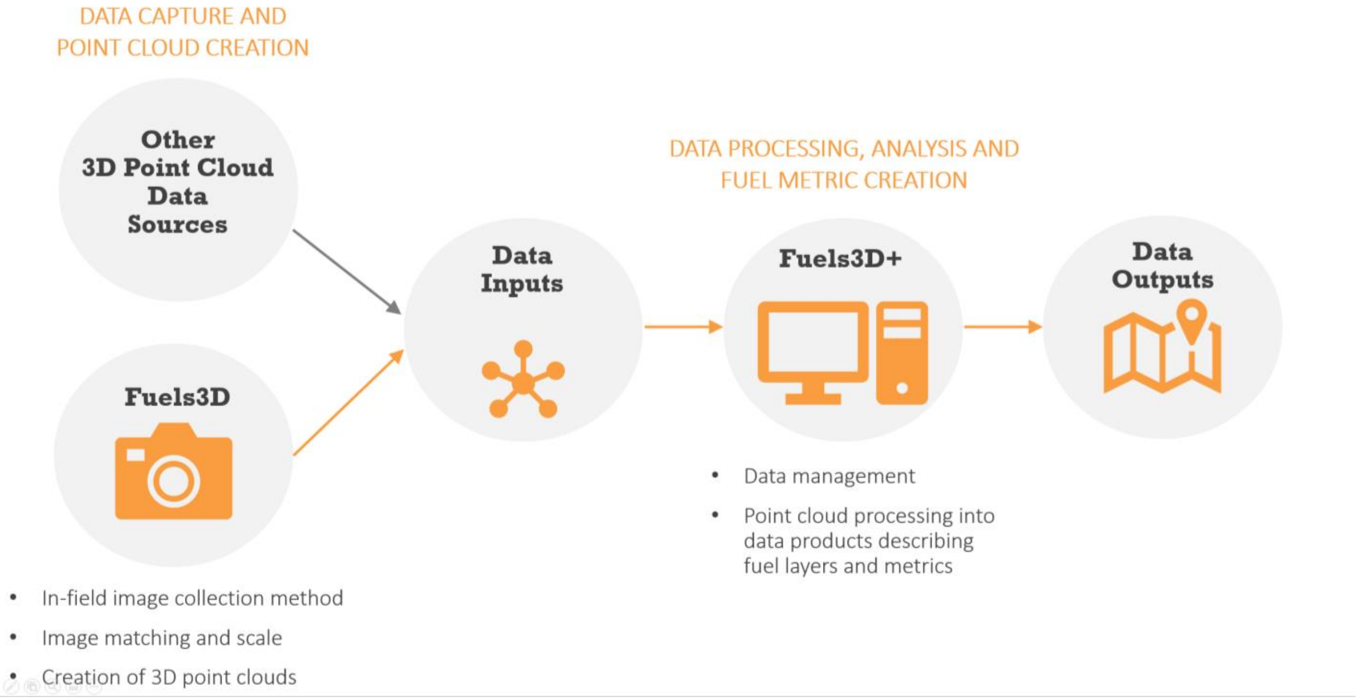


**Figure 1: Overview of the key concepts and tasks in the Fuels3D and Fuels3D+ solution workflow.**

However, it is important for users to understand that not all point clouds are created equal and different sources of point clouds (terrestrial systems versus aerial systems, image based versus laser-based sensors), landscapes types (closed tall forests versus open woodlands) and environmental conditions (illumination, wind and rain) can all affect the resultant outputs. Providing a solution that enables these different sources to be captured and processed is a step forward to improving current and future fuel hazard assessments.

## Case study 1: repeatability and accuracy

Visual estimation is the standard practice for land management agencies across Australia for collecting fuel hazard assessments. Visual assessment provides a low-cost and efficient method to rapidly describe and estimate fuels and individual fuel layers. However, it is well known and documented in the literature, that visual assessments are subjective and can vary greatly between assessors. In response to understanding the performance of Fuels3D against visual assessments using the 'Overall Fuel Hazard Assessment Guide', an end-user field day was held with end-users from the South Australian Department of Environment and Water, ACT Parks and Conservation Service, Victorian Department of Land, Water and Planning (DELWP), the Victorian Country Fire Authority, Melbourne Water and Parks Victoria. The field day aimed to introduce end-users to the Fuels3D collection protocol and to assess its ease of use and repeatability between data collectors in comparison to traditional visual assessment techniques. Participants were asked to undertake a visual assessment and collect Fuels3D data across three plots in a lowland forest in a water catchment east of Melbourne.

The results, published in *Sensors* in 2017 (Spits et al. 2017), indicated that surface and near-surface metrics related to fuel hazard can be measured with greater repeatability between different observers. Even more critical was the propagation of this variation when the metrics were combined to calculate hazard ratings. The range of surface cover and height variation using the Fuels3D approach is in comparison to the visual assessment, significantly lower. This translates into fuel hazard classes spanning over two hazard class across all plots in the study in comparison to the visual assessment approach which resulted in an overall fuel hazard rating spanning across almost four classes.

Subsequently, studies were conducted to investigate the validity, accuracy and completeness of 3D point clouds. Quantitative measurements of above-ground vegetation biomass are vital to a range of ecological and natural resource management applications including fuel hazard mapping. In this study (Wallace et al. 2017), surface biomass of small area plots were imaged and scanned, and then destructively sampled. Volume is calculated, using the 3D point clouds and regressed against dry weight to provide an estimate of biomass. The results of this study demonstrate that image-based point cloud techniques are potentially viable for the measurement of surface biomass. However, while this study investigated the utility of point clouds to resolve end metrics such as biomass (and in other studies diameter at breast height, tree height etc.), there is still a fundamental requirement that assesses the accuracy of the point cloud itself. To date, there has been no standard method for validating the accuracy of a point cloud. A method for validating the structural completeness of understorey vegetation models captured with 3D remote sensing has been designed and implemented across a range of landscapes across Australia, South America and North America. This work is currently in review and expected to be published shortly.

## Case study 2: inter-comparison of point cloud capture technologies

Examples of studies have demonstrated the potential of satellite and airborne remote sensing for assessing and measuring changes in vegetation or fuel structure, with recent examples of terrestrial remote sensing demonstrating the potential for precise measurements of change in understorey forest environments. Much of these technologies, such as those utilising Light Detection and Ranging (LiDAR) systems or Terrestrial Laser Scanners (TLS), offer a precise insight into the physical structure and arrangement of environments. However, at this point in time, these are cost-prohibitive and require expertise, in both data collection and data processing stages. As image capture devices or platforms, such as off-the-shelf point and shoot cameras, and unmanned aerial vehicles become increasingly powerful, cheap, portable and ubiquitous, there exists an opportunity for simple and rapid image acquisition. When coupled with computer vision and photogrammetric principles overlapping images can be reconstructed into scaled 3D point clouds from which geometric properties of vegetation or fuel structure can be calculated. The case study presented here investigates the performance and utility of non-destructive, remote imaging and laser scanning technologies, specifically Terrestrial Laser Scanning (TLS), Terrestrial Structure from Motion (TSfM) and Unmanned Aerial Systems Structure from Motion (UAS SfM), for quantifying vegetation and fuel characteristics.

The study area was located in the Mallee region of north-west Victoria. Three key Ecological Vegetation Divisions (EVDs) in the region were identified as Hummock Grass Mallee, Lowan Mallee and Heathland Sands. For each EVD three different age classes were identified as at disturbance, intermediate and mature. Suitable locations for plots within each of the EVDs and age class combinations were identified in consultation with DELWP, and finalised during field visits in July 2017 for Hummock Grass and Lowan Mallee, and in September 2017 for Heathland Sands. For each EVD plus age class combination a 50m x 30m plot was located, in which data was collected using TLS and UAV SfM to allow for wall-to-wall data to be created. Within the plot, up to six smaller 2m x 2m subplots were located to follow approximate transects across the larger plot. Each sub-plot was captured using TSfM. Ground control targets were distributed throughout the larger plot in locations that provided clear-sky views and maximised line of sight to TLS set up locations. The relative positioning of ground control targets varied between plots. Vertical targets consisting of 1m tall white PVC pipes were used to define the corners of each 2m x 2m plot. The survey was designed, and positioning established, in such a way as to support revisits to sites (e.g. post burn), and to allow for spatially and (near) temporally coincident inter-comparison of technologies. The Fuels3D+ workflow was used to extract fuel descriptors from the 3D point clouds produced from each of the technologies listed.

The biggest issue for the data capture using these technologies was the presence of wind, particularly for UASSfM. This presented significant logistical challenges for operation and impacted on the quality of data collected. While the UAV was able to be flown in winds up to 35km/h, all aerial and terrestrial technologies and resultant datasets were compromised in quality if captured during windy or gusty conditions; recognising certain vegetation types and elements being more susceptible to movement caused by wind than others. In terms of operator expertise, time and initial equipment costs, the TLS data capture was by far the most costly of the three approaches. Similar expertise overheads exist for UASSfM given the specific CASA and land management permit requirements necessary for flight approvals and operations, however, data capture per unit area can occur much more rapidly. In comparison, TSFM requires minimal expertise but performs as a sampling tool rather than as a wide-area data capture technology. Processing of the data for all three technologies required both CPU intensive automatic processing along with manual steps for digitisation of the ground control and vertical targets, and spatial co-registration of datasets collected by each of the three technologies.

Some key observations were made in respect to the overall quality of the data produced by each of the three technology approaches relative to the different fuel characteristics. TLS performs better at capturing elevated and canopy layers but becomes compromised in capturing the lower layers where obscuration and occlusion increases. In contrast, TSFM was found to be best suited to capturing information of the surface and near-surface layers, and to a degree the elevated layer. Being human operated it is limited in its ability to capture elements higher than the elevated fuel layer. The performance of the UASSfM using the current setup offered the least information value of all technologies assessed due to its decreased ability to offer a below canopy perspective and its sensitivity to wind. However, changing the camera and camera setup for UASSfM could offer substantial improvements and should be tested further.

## Case study 3: pre- and post-burn change

Fuel reduction burns are commonly used in fire prone environments in Australia as a mechanism to reduce the risk of wildfire and increase ecosystem resilience. As such producing quantified assessments of fire-induced change is important to understanding the success of the intervention. Remote sensing has also been employed for assessing fuel hazard and fire severity and change (see Wallace et al. 2016). Satellite, airborne and UAV remote sensing, for example, have shown potential for assessing the effects of large wildfires and fuel hazard in areas of open canopy. Fuel reduction burns, however, often take place under dense canopy and result in little or no change to the canopy cover. Here, terrestrial techniques are needed to quantify the efficacy of these burns. This study presents a case study on the use of image-based point clouds, captured terrestrially for describing the change in fuel structure induced by a low intensity fuel reduction burn. The specific objectives of this study were to evaluate whether fuel structure maps produced from Fuels3D point clouds are sensitive to the changes that occur during a low intensity fuel reduction burn, and how these changes may be quantified.

The study was conducted in Cardinia Reservoir, Emerald, Victoria. An autumn prescribed burn was conducted by Melbourne Water on 28 April 2016. Pre-burn field data and imagery was collected on 11 March 2016 and post-burn data on 5 May 2016 for the same location across time points. The plots, 10m diameter in size, were selected based on being close to known ignition points in order to increase the likelihood of the vegetation undergoing fire induced change. From these image sets, point clouds were produced, from which metrics representing fuel volume, horizontal connectivity, and vertical stratification were derived. Fire-induced change in these metrics are assessed from which the efficacy of the burn in relation to fuel hazard are able to be quantified and mapped in terms of changes to fuel layer height, percent cover and amount burnt.

## Future and conclusions

Remote sensing technology, when combined with computer visions methods allows for the 3D description of the surrounding environment. This project exploits this technology to provide robust measurement of vegetation structural metrics that can be built into existing fuel hazard assessment frameworks. Key metrics are provided as data products and can be combined into single assessments of fuel hazard. Use of 3D point clouds enables flexibility across jurisdictions and ecosystem types, and capacity for ongoing adaption to changes in the way fuel layers are defined and/or new fuel metrics arise. The project has completed numerous case studies for proof-of-concept and is continually extending the solution capacity into new elements of fuel hazard such as in-field mapping of bark hazard. Fuels3D uses point and shoot cameras to sample the environment and build in scale to create a 3D point cloud. Fuels3D+ is the part of the solution that takes a point cloud and derives measures of fuel hazard that form part of the case studies into point cloud capture technology and their comparisons indicate no single technology provides the whole solution for every landscape. As such, Fuels3D+ provides the processing solution for taking 3D point clouds (and this is being examined to extend to ingest 3D point clouds sourced from other commonly available and different technologies such as TLS and ALS) and transforming the data into measures of fuel hazard.

### Acknowledgements

The project gratefully acknowledges funding from the Bushfire and Natural Hazards CRC, and the valuable support, advice and feedback offered by numerous end-users from across agencies including Melbourne Water, Victorian Country Fire Authority, Victorian Department of Land, Water and Planning, South Australian Department of Environment and Water and the ACT Parks and Conservation Service.

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# Probability and consequence of post-fire contamination events in a water supply catchment

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Large cities around the world source their drinking water from forested catchments, which deliver water that is treatable at minimal costs.

## Introduction

These forests are often prone to wildfire, which tend to increase surface runoff, destabilize soils and trigger increased sediment delivery into water supply systems (Emelko et al. 2011; Hohner et al., 2019; Smith et al. 2011). The consequences of wildfire for water supply are a significant concern, with the potential for extended periods of water supply disruption, increased water treatment cost, and a demand for catchment restoration and investment in expensive treatment infrastructure (Bladon et al. 2014; White et al. 2006; Writer et al. 2014). Moreover, with climate change, the likelihood of wildfire is increasing in many forest ecosystems making water supply systems increasingly exposed to post-wildfire contamination (Khan et al. 2015, Sankey et al. 2017).

There are numerous uses for models that predict water quality impacts. On an operational level, models that reveal spatial variation in the erosion susceptibility provide catchment managers with a means to prioritize risk mitigation through fuel reduction or post-wildfire response. In such cases, spatial mapping of erosion risk in a relative sense (e.g. Sheridan et al. 2009) may be sufficient to provide effective tools for allocating resources and mitigating risk in the areas of the catchment that are most likely to be producing sediment. When developing strategic plans and making decisions about the future management of a water resource, the demands on predictive models increase. For instance, a water supply agency may want to determine if there is a case for upgrading water treatment capability or adjusting the water supply network to reduce the likelihood of water supply interruptions due to wildfires. In this setting, a detailed understanding of risk is required for cost-benefit analysis to inform decisions about such investments.

In this study we are motivated by the need amongst water supply managers to know '*For how long is it likely that my reservoir will be offline due to contamination by post-wildfire erosion?*'. In addressing this question, we seek to provide the means for developing policy and investment strategies within environmental management frameworks that are underpinned by economics and risk (e.g. Investment Framework For Environmental Resources, INFFER: Pannell et al. 2009). The specific objective of the study is to model how frequency and magnitude of erosion in headwaters translates to probability and duration of water contamination exceeding treatability thresholds at the water offtake. In this study we only consider sediment in our risk model because treatment facilities are often highly vulnerable to turbidity caused by suspended sediment (Khan et al. 2017).

Our paper outlines a parameter-reduction approach whereby empirical transfer functions are used to link a probabilistic model of sediment delivery from burned headwaters and a reservoir hydrodynamic model. With these transfer functions we produce a direct measure of risk (i.e. probability of consequence) and discuss practical questions around potential cost of the wildfire threat to water supply agencies and the capacity for catchment managers to mitigate such costs. Furthermore, we use the model to evaluate how different model components contribute to uncertainty in risk.

## Study area

The study was carried out in the Upper Yarra catchment, which is located ~100km east of Melbourne in SE Australia and flows into a 200 GL reservoir that is central to the potable water supply to more than 4 million people. The reservoir also receives transfers from the larger nearby Thomson Reservoir. Unfiltered water from the Upper Yarra reservoir is then transferred to smaller off-stream storages before treatment and supply into the metropolitan distribution network.

The 337 $km^2$ Upper Yarra catchment includes mixed species of dry Eucalyptus forests at lower elevations and on equatorial facing slopes, wet forests dominated by Mountain Ash at higher elevations, and damp mixed species forest in intermediate locations. The relief is 850 m and based on the Köppen classification the climate is temperate with no distinct dry season and mild to warm summers. Annual rainfall at the reservoir dam wall is ca 1100 mm $yr^{-1}$. At the catchment divide, the rainfall is 1700 mm $yr^{-1}$. The geology is predominantly sedimentary, and the soils are typically clay loams.

## Modelling framework

The model is an implementation of the conceptual framework for assessing water contamination risk presented by Nunes et al. (2018). It includes three major components for predicting the probability and duration of water supply disruptions:

- Propagation of fine sediment within the reservoir, from entry point to the offtake
- Susceptibility of the landscape to extreme erosion events
- Stochastic spatial-temporal rain fields which cause erosion.

The models are coupled conceptually in a risk framework for predicting the probability and duration of water contamination events that exceed treatability thresholds (Figure 1).

In presenting the model and the results we take an asset-centric approach and begin with the processes that govern the transport of sediment between the reservoir boundary and the water offtake at the dam. With this we produce a reservoir transfer function, which is an empirical relation for linking magnitude of sediment delivery events at the reservoir boundary to sediment concentration at the water offtake (Figure 1). The link is realized by choosing four inflow locations that represent likely locations for post-fire sediment delivery events. Then we present the catchment response model, which predicts rainfall thresholds for erosion in contributing headwater catchments that have variable fire severities. Finally, we simulate the actual sediment delivery from headwaters to the reservoir boundary, using rainstorms from two types of stochastic rainfall generators. Together, the reservoir transfer function and simulated sediment delivery events are used to represent the probability and magnitude of water contamination events from post-fire erosion (Figure 1).

## Results: probability of consequence

Applying the modelling framework in Figure 1 to the Upper Yarra catchment gives a distribution of probabilities for days of interrupted supply (Figure 2). The distributions are different depending on where in the catchment the storm cells are centered. However, all distributions are equally likely. Thus, the maximum impact shown in solid black line in Figure 2 is the most relevant one because that represents the highest risk to reservoir water quality. The duration of undeliverable water for exceedance probabilities of 0.5, 0.4, 0.3, 0.2 and 0.1, marked with arrows in Figure 2, are 15, 130, 320 and 450 and 900 days, respectively. When centered on an erosion hotspot, a storm with an AEP of 0.3 will produce about 2000 Mg of clay from debris flows. This equates to 30 times the median clay load (i.e. 62 Mg) from debris-flow producing headwaters.

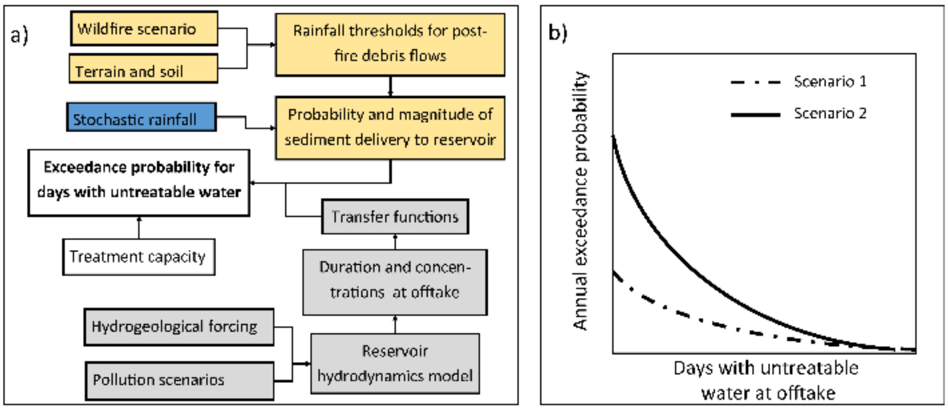


**Figure 1: a) Model framework showing the workflow for producing a risk metric from transfer functions that couple an erosion model with a reservoir hydrodynamics model. b) Example of the final risk metrics which is the probability of consequence.**

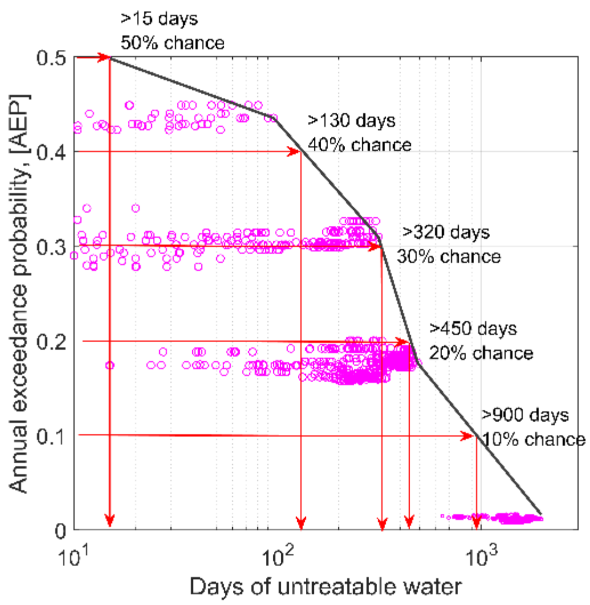


**Figure 2: Annual exceedance probabilities (AEPs) for days of undeliverable water. Produced from the modelling framework presented in Figure 1. The scatter plot is the number of days that water exceeds treatability threshold for storms cells with different exceedance probabilities. The variation stems from storm cells being centered on different locations in the catchment. The solid black line is the AEP when storms are centered at a location most susceptible to debris flows.**

# Discussion

We present a comprehensive approach to water quality risk assessment in flammable water supply catchments. The research draws on the best available models of reservoir hydrodynamics, a stochastic rainfall generator and a validated post-fire erosion model to predict the probability and magnitude of impact on treatability. This is the first time that the threat of catchment erosion after wildfire is linked to actual impacts on water supply by accounting for sediment propagation in a reservoir. Ultimately, we use the output from our modelling to estimate the potential cost associated with post-fire erosion in the Upper Yarra catchment that directly delivers water to 4 million residents of Melbourne in SE Australia. The novelty of the work lies in how the different models are linked and the risk metrics that we can produce with our approach. It is a template approach for future studies that aim to derive information from post-fire hydrological models that can be used to directly guide cost-benefit analysis, investment and policy in the water resources sector.

We estimate that a high severity wildfire in the Upper Yarra catchment can lead to water supply interruptions lasting for periods of months to years. The debris-flow susceptibility is spatially variable within the catchment, with hotspots on the eastern flank of the northern reservoir arm representing highest risk. These areas receive lower annual rainfall and have soil properties that are more likely to produce runoff than the those in high rainfall areas at higher elevation. This pattern stems from the way in which infiltration is parametrized in the debris-flow response model, where aridity and fire severity are both causing variation in infiltration (Langhans et al. 2016, Van der Sant et al. 2018). Much of the risk in Upper Yarra catchment can be attributed to a very small area. Thus, mitigation efforts can be highly targeted at specific areas of the water supply catchment.

The model was developed using the Upper Yarra catchment (and reservoir) as a case study. However, the approach of linking reservoir hydrodynamics with an event-based erosion model to quantify risk is generally applicable and could be applied to debris-flow prone water supply catchments elsewhere. The approach can be easily adapted to operate with debris-flow models that have been developed for other hydro-geomorphic settings (e.g. Gartner et al. 2014).

## Acknowledgements

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# JASMIN: a high-resolution soil moisture analysis system for fire prediction

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## Abstract

Soil moisture is found to be a key factor that influences fuel moisture content. Consequently, operational forest fire prediction systems typically include soil moisture as one of the inputs for fire behaviour calculations. The soil moisture input to these fire prediction models is usually provided in the form of moisture deficit. There is evidence that the current operational methods used in Australia for fire prediction perform poorly in estimating soil moisture status. A research project was initiated in partnership with the Bushfire and Natural Hazards Cooperative Research Centre to develop an advanced, state-of-the-art soil moisture analysis for Australia. Consequently, a prototype, high-resolution, land surface modelling-based soil moisture analysis called JULES based Soil Moisture Information (JASMIN) has been developed. JASMIN can provide hourly moisture estimates for four soil layers, at a spatial resolution of 5 km.

The present paper will discuss the evaluation of JASMIN carried out against observations from ground-based networks. Among the results, the mean Pearson's correlation for surface soil moisture across three in-situ networks is found to be between 0.78 and 0.85. We also focus on the research carried out to downscale the JASMIN product from 5 km to 1 km spatial resolution. The downscaling research is motivated by the desirable impact a higher resolution soil moisture product can provide for fire prediction, considering the high spatial variability in soil moisture and fuel moisture. We discuss the application of three downscaling algorithms: two regression-based methods and one with a theoretical basis. The three methods applied in the present study are based on the information derived from characterizing a two-dimensional surface temperature/vegetation index scatterplot domain obtained from thermal and optical remote sensing observations. We present an overview of the application of each method, along with an evaluation against ground-based soil moisture observations. Evaluation results indicate that the regression methods, in general, fail to capture the observed temporal variability. The theoretically based method, on the other hand, provides a temporal correlation of 0.81 and captures the skill of the parent JASMIN product.

## Introduction

In a fire prediction context, soil moisture status, usually provided in the form of moisture deficit, is a key parameter to assess the fuel availability. In Australia, there is evidence that the Keetch Byram Drought Index (KBDI) and Soil Dryness Index (SDI) methods used to estimate soil moisture deficit in operational fire prediction perform poorly (Vinodkumar and Dharssi 2017). A prototype, high resolution, land surface modelling system has been developed by the Bureau of Meteorology (Dharssi and Vinodkumar 2017) to provide soil moisture estimates with high accuracy and precision. This prototype system is based on the Joint UK Land Environment Simulator (JULES; Best et al. 2011) land surface model and is forced mainly by observation based meteorological analyses. The new system is called the JULES based Australian Soil Moisture Information (JASMIN) and estimates soil moisture at a spatial resolution of 5 km.

For applications like fire prediction, there is a requirement for soil moisture information at even higher spatial resolution than currently provided by JASMIN. A common practice to overcome such a problem is to employ downscaling methods to increase the spatial scale of the product. Recent advances in optical remote sensing have allowed researchers to use different remote sensing products that reflect soil moisture variability as ancillary information. A method based on a "universal triangle" concept is used in several studies where a relationship between soil moisture, vegetation index (VI) and surface radiant temperature (Ts) from optical remote sensing sensors is established. The universal triangle concept arises from the emergence of a triangular or trapezoidal shape when VI and Ts measures taken from heterogeneous areas are plotted in two-dimensional feature space – forming a Ts/VI scatterplot. Of the different land surface parameters, normalized difference vegetation index (NDVI) and land surface temperature (LST) are the most widely used. Theoretical and experimental studies have demonstrated the relationship between surface soil moisture, NDVI and LST for a given region under specific climatic conditions and land surface types.

Based on the triangular space paradigm, an empirical, polynomial fitting downscaling method was proposed by Piles et al. (2011) over south-eastern Australia to retrieve soil moisture at 1 km resolution from Soil Moisture and Ocean Salinity (SMOS) mission using NDVI and LST data from Moderate Resolution Imaging Spectro-radiometer (MODIS). Merlin et al. (2008; 2012) had developed a physics based method to downscale soil moisture by exploring the direct relationship existing between soil moisture and Soil Evaporative Efficiency (SEE; the ratio of actual to potential evaporation), leading to the emergence of the "Disaggregation based on Physical And Theoretical scale Change (DisPATCh)" model (Merlin et al. 2012). The DisPATCh method was found to yield a temporal correlation of 0.7 when compared to ground-based observations over the semi-arid Murrumbidgee catchment.

The present study explores the applicability of the multiple linear regression method discussed in Piles et al. (2011) and the DisPATCh method to downscale JASMIN soil moisture from 5 km to 1 km spatial resolution using MODIS LST and NDVI data. The main reason for selecting these methods is that they have been tested and documented to derive soil moisture information at 1 km spatial resolution over Australian regions. Further, the input data used in these methods are readily available. To investigate whether the skill of the multiple linear regression method can be improved further by regularization, we implemented the Least Absolute Shrinkage and Selection Operator (LASSO; Tibshirani et al. 1996) regression using the same feature variables used in the multiple linear regression method. The downscaling algorithms are only applied to the top JASMIN soil layer (0-10 cm). One of the main factors controlling the shape of Ts-VI scatter is the surface soil moisture. Studies have shown that the combined use of optical and thermal infrared data can be used to derive moisture estimates for the top 5 cm soil layer (e.g., Sandholt et al. 2002). Even though there are mismatches in scales for the soil column each method represents, the topmost soil layer in JASMIN is a good approximation to that the Ts-VI method represents.

# Results and discussions

## Verification of JASMIN against ground observations

The skill of JASMIN is compared against that of KBDI and SDI using ground observations from the CosmOz (Hawdon et al. 2014), OzNet (Smith et al., 2012) and OzFlux (Beringer et al. 2016) networks. For direct verification, all SM products and indices are converted to soil wetness (normalized between [0, 1]) using their own maximum and minimum values from respective long time series. Pearson's product-moment correlation (R), unbiased root mean square difference (ubRMSD) and bias metrics are used here to evaluate the skill of each product against in situ observations. The scores are computed for all stations and for the whole period where comparing data overlaps. Only scores for significant correlations with p-values < 0.001 are presented. In order to calculate correlations with seasonal effects removed, we compute the anomalies for each dataset using $\hat{\theta}_{an}=\hat{\theta}-\hat{\theta}_{av}$, where $\hat{\theta}_{av}$ is the mean and is calculated over a 31 day sliding window. The results are depicted as scatter plots (Figure 1).

JASMIN generally exhibits a stronger correlation compared to the other two models (Figure 1a). This is especially true over CosmOz and OzNet networks. The median correlation for JASMIN obtained against CosmOz, OzNet and OzFlux is 0.85, 0.81 and 0.78 respectively. JASMIN consistently display a strong positive correlation over CosmOz sites where R > 0.60 at all sites. Out of the total 45 sites in OzNet network, JASMIN display R > 0.60 for all except 4 sites. For OzFlux, JASMIN captures the temporal patterns well for 19 sites out of 21, with R > 0.60 at all these sites. KBDI exhibits a larger scatter in correlations compared to SDI. KBDI shows a relatively better performance over OzFlux compared to OzNet and CosmOz. A majority of OzFlux sites are situated in high rainfall regions, and some among them are in the tropics. KBDI is known to perform well in regions with warm climates and higher annual rainfall totals. This is typical of the region (south-eastern US) for which KBDI was designed and calibrated.

The lower ubRMSD in JASMIN compared to other two models is represented by the general clustering of points below the reference line in the respective scatter plot (Figure 1b). This indicates that the amplitude of short-term variations in observations is well captured by JASMIN compared to the other two models. The closer agreement of JASMIN and observed amplitudes is reflected by the lowest median scores of ubRMSD across all networks. KBDI generally shows large deviations from observations (Figure 1b). KBDI in fact has the largest median ubRMSD values for all networks and, in general, shows a wet bias - a result reported in earlier studies as well (e.g. Vinodkumar et al. 2017).

The ability of each model to capture the short-term fluctuations in observations is quantified by the anomaly correlation metric (Figure 1d). It is worth noting here that all models considered in the present study have the same resolution and are driven by the same precipitation analysis. Hence differences in fluctuations characterized by each model cannot be due to the difference in rainfall amounts for an event in the driving data. These differences, however, can be due to how each model represents surface energy and water balance processes. JASMIN is found to have a relatively higher anomaly correlation when compared to KBDI and SDI.

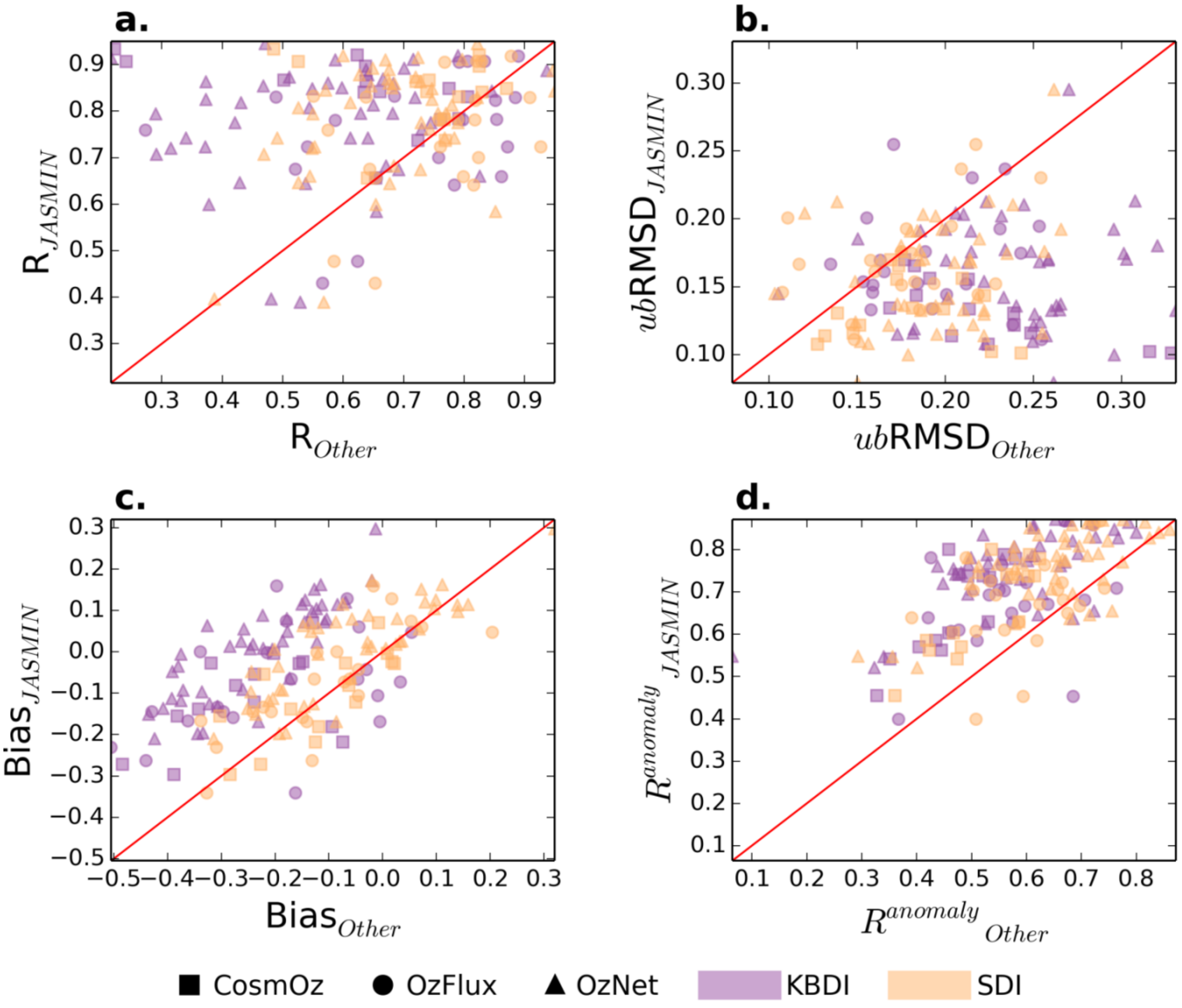


**Figure 1: Scatter plots depicting a) correlation, b) unbiased RMSD, c) bias and, d) anomaly correlation. The y-axis shows the skill scores of JASMIN against in-situ observation. The x-axis corresponds to the skill scores of the other two models (KBDI and SDI) against in-situ observations. Each colour represents a model type depicted on x-axis (i.e., KBDI and SDI). Each symbol represents an observation network type. The red line indicates equal skill between two products.**

Given the complexity of physical processes that govern surface soil moisture dynamics, these results indicate a robust modelling approach in JULES Land Surface Model. The governing complex physical processes also explain the low skill in KBDI and SDI. For example, neither of these models consider many physical factors including soil type, vegetation type, or terrain aspect which affect soil moisture. Further, no information on atmospheric controls of evapotranspiration such as net radiation, wind speed, or relative humidity is used.

## Verification of downscaled JASMIN soil moisture

This section discusses the temporal skill of each downscaling product against ground-based observations. The scores are computed using the same methodology discussed in the previous section. An evaluation of each model's skill over different land use / land cover (LULC) is presented in Figure 2. The LULC classification is made based on the land cover types over which the observation sites are located. We broadly classify the land cover types into forests, woodlands, grasslands and croplands. Of the 60 sites in total across three networks, 12 are classified as croplands, 12 as forests, 9 under woodlands, and the remaining 27 under grasslands.

The temporal skill is reduced when JASMIN is downscaled using the two regression-based methods. For example, the median values obtained by the LASSO method over woodlands for correlation, ubRMSD, bias and anomaly correlation are 0.41, 0.08, -0.08, and 0.26 respectively. For the multiple linear regression method, the above scores are 0.37, 0.11, -0.1 and 0.32 respectively. The LASSO method produces a higher skill than the multiple linear regression, highlighting the fact that there was some overfitting in the multiple linear regression method which is reduced in the LASSO method. Because of its safeguarding against noise, LASSO has a higher correlation and lower ubRMSD than the multiple linear regression method. This is demonstrated through the timeseries plot over the

Weany Creek site in the northern Queensland, which is part of the CosmOz network (Figure 3). This site is in a grazed open woodland with grassy and shrubby understory. The multiple linear regression method is found to have larger temporal variability than the LASSO method and the other two products (JASMIN and DisPATCh). This is particularly noticeable during the dry seasons where the multiple linear regression method shows large variability compared to the observations. A possible reason for this is the large sensitivity of estimated soil moisture in multiple linear regression to noise in the LST data. The uncertainties involved in the thermal infrared based LST retrievals are found to be about 2 K (Li et al., 2014). By applying regularization through LASSO, this sensitivity is reduced to some extent, but not to a point where the LASSO estimates match the temporal skill of the JASMIN product at 5km (Figure 2c).

In the case of DisPATCh, the temporal skill is similar to the JASMIN 5 km product and better than the other two downscaling methods. The average correlation of DisPATCh over the three networks is 0.81, identical to JASMIN. In the woodland, cropland and grassland cases, disaggregation either marginally improves or retains the mean R, bias and ubRMSD.

The similar skill of DisPATCh and JASMIN can be appreciated from the box and whiskers provided in Figure 2 Specifically, DisPATCh shows an increase in R and reduction in bias over the woodland sites. The good performance of the DisPATCh over woodlands is re-affirmed by the timeseries plot at the Weany Creek, which is an open woodland site (Figure 3d). The DisPATCh shows similar temporal variability to the observations and does not produce the large variability observed in the other two downscaling methods.

However, it is observed that DisPATCh has lower skill than the JASMIN product over forested sites, possibly due to the increase of random uncertainties attributable to the models and data used by DisPATCh. Studies have shown that DisPATCh performs better over low-density vegetated areas in semi-arid environments (Merlin et al. 2012). A possible reason for this behaviour is the weaker coupling between evaporation and surface soil-moisture in temperate (where most forested sites are located) than in semi-arid climates. Further, the presence of dense vegetation poses a challenge in the retrieval of the soil temperature from thermal infrared data. The vegetation water stress may increase the remotely sensed land surface temperature independent of near-surface soil moisture.

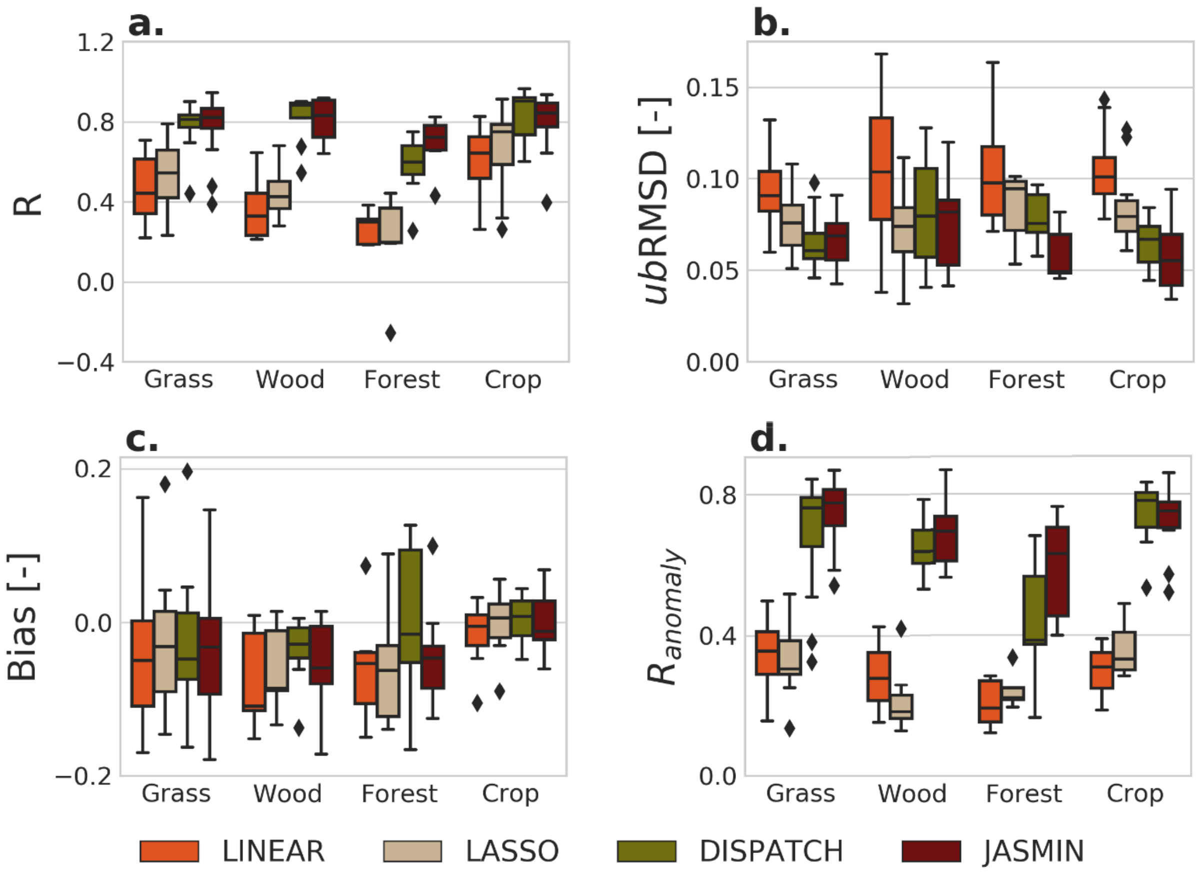


**Figure 2: Skill of soil wetness products over various land cover types: a) Pearson's correlation, b) unbiased RMSD, c) bias, and d) anomaly correlation. The grouping is done based on the land cover type of the observing site. The outliers are marked as diamonds. The orange boxes represent multiple linear regression method, light khaki colour represents LASSO method, the green boxes represent DisPATCh and the magenta coloured boxes represent the original JASMIN product at 5 km resolution.**

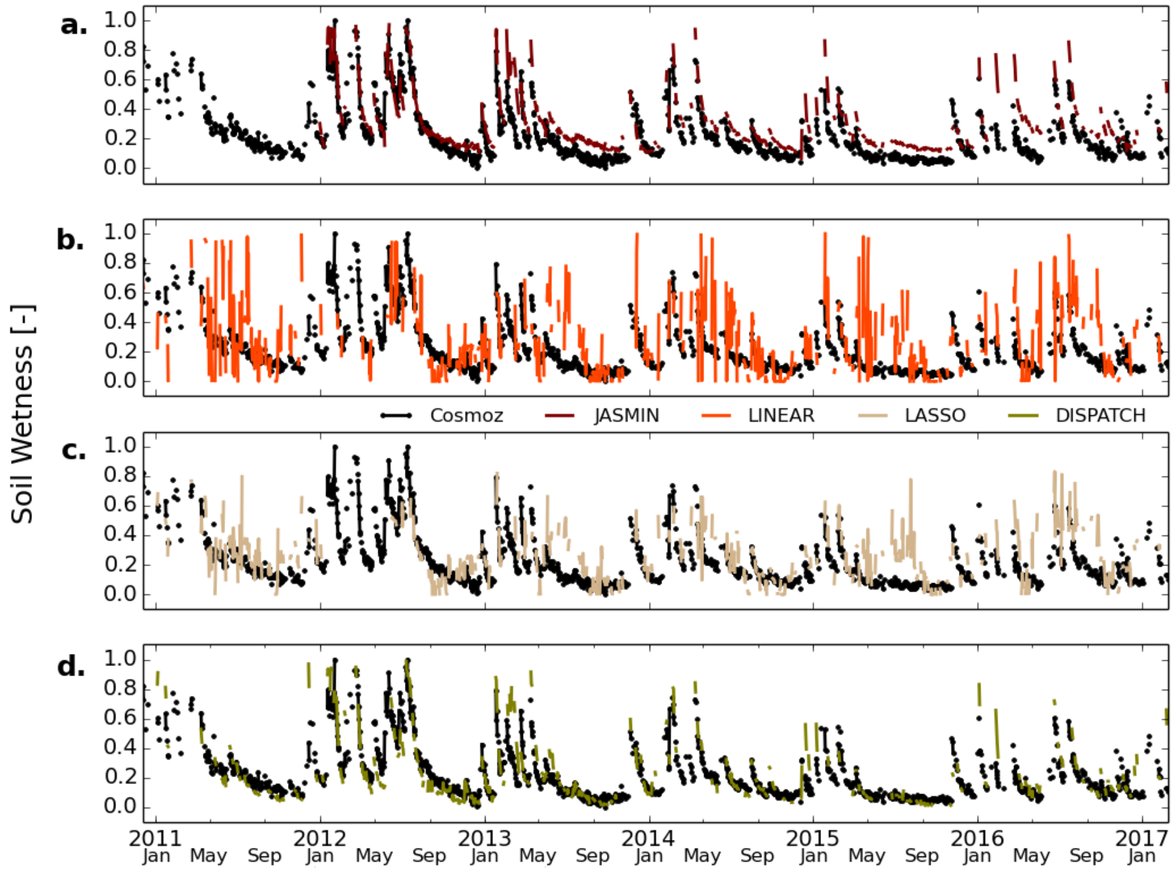


**Figure 3: Soil wetness time-series at the Weany Creek site in Queensland, part of the CosmOz network. The brown lines show JASMIN analyses at 5 km resolution, orange lines represent multiple linear regression method, light khaki depict LASSO method and the green line represents DisPATCh. The black dotted lines show the in-situ observations.**

## Summary

The present study underlines some of the limitations of traditional soil dryness indices in producing accurate soil moisture estimates, particularly for a shallow soil layer. One limitation of the traditional indices is that they use a single soil horizon to represent variations in both surface and root zone layers. The new JASMIN system can address gaps in the present operational methods by providing accurate soil moisture information in different layers. JASMIN has been shown to provide good skill in estimating soil moisture at both surface and root zone layers.

Results from the downscaling study indicate that it is feasible to improve the spatial resolution of JASMIN using all three disaggregating algorithms and preserve the general large-scale spatial structure seen in JASMIN soil moisture estimates. However, the seasonal means obtained at 1 km shows that each product displays characteristic soil moisture spatial variability at fine scales. Results from comparison with ground-based soil moisture measurements indicate that the regression methods degrade the temporal correlations and the ubRMSD scores. The DisPATCh method produces the best skill among the three algorithms tested here, and the skill scores from DisPATCh are comparable to those of the original JASMIN timeseries.

The low skill observed in regression methods possibly resulted from the large random errors attributable to the methods or uncertainties in the feature variables. It is worth noting that even the minimum and maximum limits applied to calculate the normalized LST and NDVI datasets (feature variables in the regression method) can introduce uncertainties in the downscaled soil moisture output. Further research is required to identify and minimize some of the uncertainties associated with both MODIS LST and NDVI datasets and to provide robust quality control.

Uncertainties in the MODIS input datasets have an important influence on the DisPATCh results as well, in addition to the uncertainties arising from the model assumptions and calibrations. It is found that calibration has a significant influence on the DisPATCh model behaviour. One aspect of DisPATCh that needs to be revisited is the modelling of soil moisture sensitivity to the soil evaporative efficiency. It is important to note that the DisPATCh algorithm is evolving and will continue to do so. Further work is required to test and evaluate the new ideas that will be developed in relation to DisPATCh and will be a focus of future research.

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# Pyrocumulonimbus Firepower Threshold: a pyrocumulonimbus prediction tool

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Pyrocumulonimbus (fire-induced thunderstorms, pyroCb) are associated with unpredictable changes in fire intensity, spread rates and direction, enhanced ember transport and lightning ignitions. Conventional thunderstorm threats such as downbursts, hail, lightning, and tornadoes may also be present. This paper introduces a pyroCb prediction tool and its application is demonstrated.

In favourable atmospheric conditions, suitably large and hot fires can produce pyroCb cloud in the form of deep convective columns with many similarities to conventional thunderstorms. They may be accompanied by strong inflow, dangerous downbursts and lightning strikes, which may enhance fire spread rates and fire intensity, cause sudden changes in fire spread direction, and the lightning may ignite additional fires. Dangerous pyroCb conditions are not well understood and can be very difficult to forecast.

In recent Bushfire and Natural Hazards CRC (BNHCRC) research, a method for determining how favourable the atmospheric environment is for pyroCb development was developed. This method is combined with a plume-rise model (originally developed for pollutant dispersion prediction) to determine how much heat a fire must produce for pyroCb to develop in a given atmospheric environment. More specifically, this fire heat is the rate at which heat enters the fire plume (which has units of power), often termed the 'power of the fire' or 'firepower'. A theoretical minimum firepower required for pyroCb to develop in a given atmospheric environment is calculated, termed the Pyrocumulonimbus Firepower Threshold (PFT).

Forecast spatial plots of PFT are being trialled that provide an indication of how the favourability of the atmosphere for pyroCb development varies in space and time over typical weather forecast periods. It is anticipated that such plots will provide useful guidance for fire weather forecasters and fire agencies. Preliminary studies have shown that the PFT can vary substantially from day to day, and that days that favour pyroCb formation do not necessarily favour large-hot fires. A PFT-flag is also under development that identifies when both pyroCb and large-hot fires are favourable.

## Background - previous BNHCRC research

In previous BNHCRC research an idealized theoretical plume model was introduced (Tory et al. 2018, Tory & Kepert 2018) that can identify at what temperature and pressure (or height) condensation will begin to form in a fire plume. These condensation properties vary according to how much warmer the plume is than the environment (i.e., how buoyant the plume is). Plotted on a thermodynamic diagram, the condensation properties are represented by a single point, termed the Saturation Point (SP), and the SPs for a range of plume buoyancies form a SP curve (Fig. 1, solid blue curve). Each SP curve is unique to an assumed mixed-layer environment comprising constant mixed-layer potential temperature ($\theta_{ML}$, Fig. 1 thick red line) and specific humidity ($q_{ML}$, Fig. 1 thick pale-blue line), and an assumed fire moisture to heat production ratio ($\varphi$). Fortunately, the SP curves are not sensitive to a range of realistic values of $\varphi$, and neither is the PFT.

The SP curve defines where a hypothetical ascending plume parcel begins to follow a moist adiabat on a thermodynamic diagram. For pyroCb formation any moist ascending parcel needs to remain buoyant (warmer than the environment, rightmost thin red line in Fig. 1) until it reaches some designated height at which pyroCb is deemed to have been achieved. Here, that height is the so-called electrification level, -20 ℃ (Fig. 1, pale-blue dashed line). The coolest moist adiabat that satisfies these criteria represents the coolest possible pyroCb plume-element pathway, and thus defines the pyroCb moist-adiabat limit (Fig. 1, yellow curve).

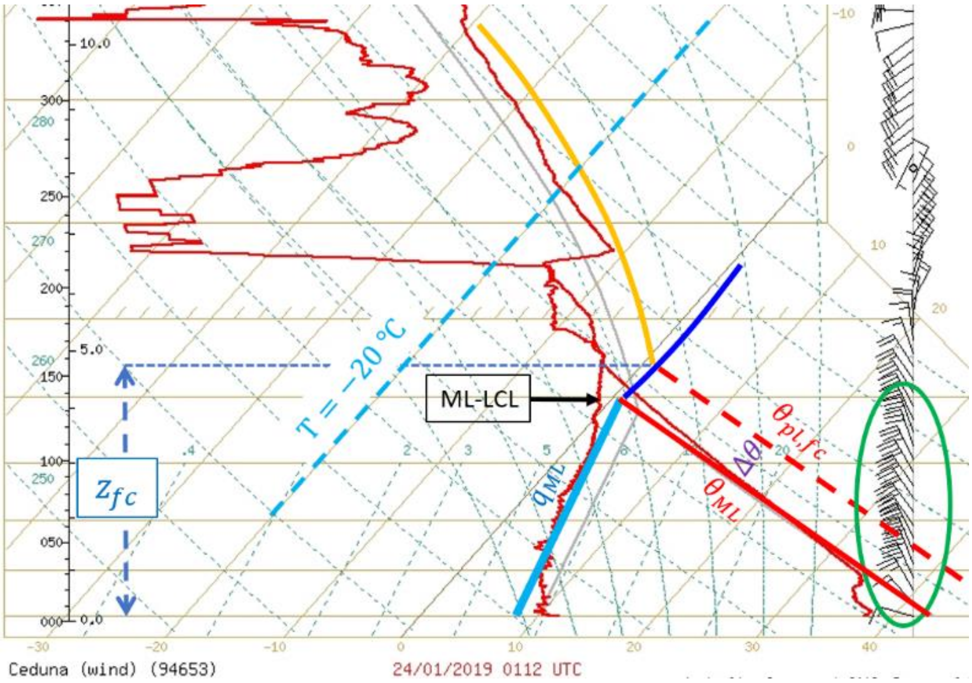


**Figure 1: A sample atmospheric sounding (thin red lines and wind barbs) applied to an F-160 thermodynamic diagram, with quantities required for the PFT calculation overlaid: Mixed Layer potential temperature ($\theta_{ML}$, thick red line); Mixed-Layer specific humidity ($q_{ML}$, thick pale-blue line); Mixed-layer lifting condensation level (ML-LCL, apex of the $\theta_{ML}$ and $q_{ML}$ lines); Saturation Point curve (SP curve, blue curve emanating from the ML-LCL); Free-convection moist adiabat (yellow curve); Electrification level ($T = -20$℃, pale-blue dashed line); Free-convection height ($z_{fc}$, blue dotted line corresponding to the intersection of the SP curve and free-convection moist adiabat); Free-convection plume potential temperature ($\theta_{pl,fc}$, red dashed line); Plume excess potential temperature ($\Delta\theta$, difference between $\theta_{pl,fc}$ and $\theta_{ML}$); and the winds used to calculate the mixed-layer wind speed ($U$, green ellipse).**

Where this moist adiabat and the SP curve meet is the free-convection height limit. Any buoyant plume element that reaches or exceeds this height will, in theory, freely convect to the electrification level. The intersection of these two curves defines the free-convection height ($z_{fc}$, Fig. 1, fine blue dashed line), which is one of the key inputs to the PFT (see below). Another key PFT input is a measure of the plume-element buoyancy at this height. Specifically, it is the potential temperature difference ($\Delta\theta$) between the plume element at $z_{fc}$ ($\theta_{pl,fc}$) and $\theta_{ML}$, which can easily be read off the thermodynamic diagram (Fig. 1). $\Delta\theta$ is a proxy for the plume buoyancy, and represents the buoyancy required for the plume to overcome any stable layers (inversions) that might inhibit the plume from reaching the electrification level. The third key PFT input is the average mixed-layer windspeed, which can be determined directly from the wind data available or estimated from the winds barbs on the edge of a thermodynamic diagram (Fig. 1, highlighted in the green ellipse).

## PFT equations

The PFT is derived from an equation that describes the buoyancy flux distribution along the plume centerline for a Briggs plume (Briggs 1975, 1984) in a constant horizontal wind crossflow ($U$) and neutrally stable environment (Tory & Kepert 2018, Tory 2018). A schematic representation of a Briggs plume is shown in Fig. 2. The plume geometry is described by two equations, an equation for the plume centreline height (Fig. 2, yellow line) with downwind distance ($x$),

$$z_c = \left[\left(\frac{3}{2\beta^2}\right)\frac{B_{flux}}{\pi}\right]^{\frac{1}{3}}\frac{x^{\frac{2}{3}}}{U},$$

1.

and an equation that describes an upright circular plume cross-section,

$$R = \beta z_c.$$

2.

Here $B_{flux}$ is the buoyancy flux at the plume source, which is proportional to the heatflux or firepower entering the plume. $\beta$ is a constant entrainment coefficient and $\pi$ is the circle constant. Eq. 2 describes the radius of the dynamic plume (pale blue lines, Fig. 2), which includes the plume gases (internal plume) plus the surrounding environment lifted by the rising plume. The internal plume (dark blue lines, Fig. 2) radius is smaller and is given by,

$$R' = \beta' z_c.$$

3.

Both entrainment parameters ($\beta$ and $\beta'$) have been measured in numerous observational and laboratory studies yielding $\beta = 0.6$ and $\beta' = 0.4$ (e.g., Briggs 1975, 1984). The PFT equation is based on buoyancy flux conservation within the internal plume, and thus $\beta'$ is the appropriate entrainment parameter in the following equations.

Assuming only some fraction of the plume area ($\alpha$) needs to reach the free-convection height, represented by a fraction of the plume radius, $\alpha'$ (Fig. 2, red arrow), then the plume centreline expressed as a function of the free-convection height becomes,

$$z_c = \frac{z_{fc}}{1+\alpha'\beta'}, \quad 4.$$

and the PyroCb Firepower Threshold becomes,

$$PFT = \left\{\frac{\pi C_p}{R_d}\left[\frac{\beta'}{1+\alpha'\beta'}\right]^2\right\}\left(\frac{P_c}{\theta_{pl,fc}}\right) z_{fc}{}^2 U \Delta\theta_{fc}. \quad 5.$$

Here $C_p$ and $R_d$ are the Specific heat at constant pressure and gas constant for dry air. $P_c$ is the pressure at the plume centreline corresponding to the free-convection height, and $\theta_{pl,fc}$ is the plume potential temperature at the free-convection height (by definition $\theta_{pl,fc} = \theta_{ML} + \Delta\theta$). Equation 5 is a slightly more accurate PFT formulation than that provided in Tory & Kepert (2018). (Note, this work is still under development, and further tuning and changes are likely in the future.)

## PFT equation insights

Since the entrainment coefficients ($\beta$ and $\beta'$) are constant, the plume centreline height (Eq. 1) at any given downstream distance $x$ is a function of only two variables, the buoyancy flux ($B_{flux}$), and the background cross-flow wind ($U$). Considering these variables independently, it is clear that the plume centreline height is much more sensitive to changes in the wind than the firepower. For example, to double the plume height at a given $x$ would require the windspeed to be halved, whereas it would require the firepower to be increased eight times. This result suggests that observed temporal changes in plume height and slope are more likely to be associated with variations in windspeed than fuel type and/or fuel loads.

The curly bracket term in Eq. 5 is constant, and the curved bracket term typically varies by 10% or less, which means the majority of PFT variation comes from the remaining terms: the free convection height, the background wind speed and the plume excess potential temperature (the buoyancy proxy). The relationship between the PFT and each of these three terms makes sense intuitively. The larger the free convection height, the more firepower required for the plume to rise to that height. The greater the windspeed, the more firepower is required to counter the tendency for the plume to be tilted over by the wind. The greater the buoyancy required for the plume to penetrate stable layers or inversions above $z_{fc}$, the more firepower that is required. The real insight provided by Eq. 5, however, is the relative power of each term and how they combine to determine an overall pyroCb formation threat. For example, if $z_{fc}$ decreases while $\Delta\theta_{fc}$ increases, perhaps with the passage of a cold front or sea breeze, Eq. 5 will determine if the net effect is more or less favourable for pyroCb formation.

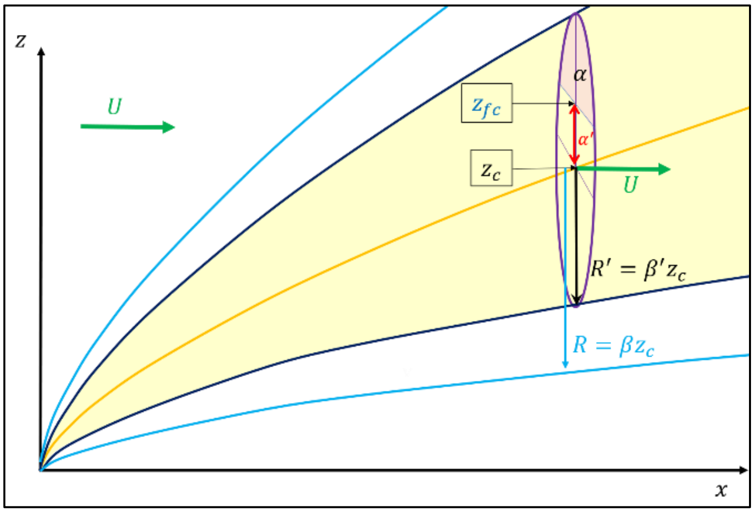


**Figure 2: Schematic representation of a Briggs plume, bent-over in the downwind direction ($x$) by a constant crossflow ($U$). The internal plume (yellow shading) has a vertical circular cross-section about the plume centreline height ($z_c$, yellow line) of radius $R'$, which is linearly proportional to the plume centreline height via the constant internal plume entrainment parameter ($\beta'$). Similarly, the dynamic plume (inside the pale blue lines) is defined by the dynamic plume radius and entrainment rate, $R$ and $\beta$. Only a fraction of the plume area ($\alpha$) is required to reach the free-convection height ($z_{fc}$), which can be expressed as a fraction of $R'$ ($\alpha'$).**

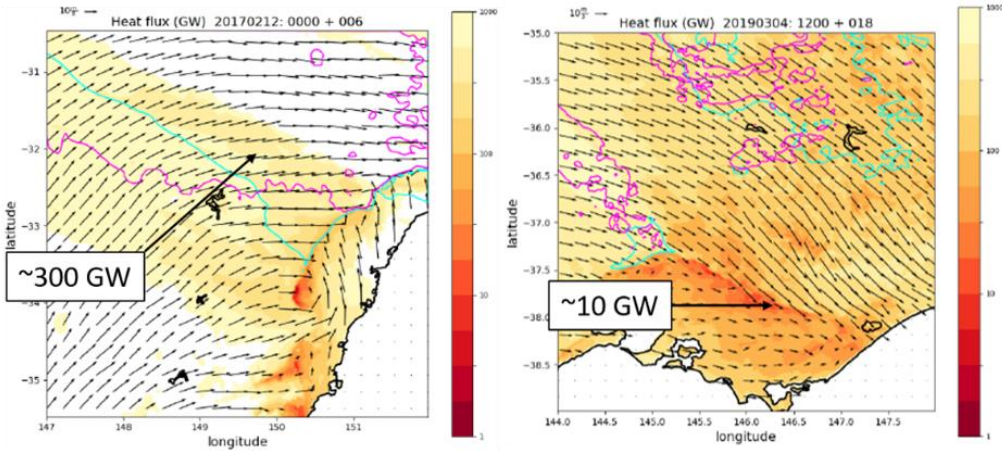


**Figure 3: PFT forecasts for two pyroCb events, Sir Ivan (5 PM, 12 February 2017, left) and Licola (5 PM, 5 March 2019, right). The PFT scale is logarithmic (units GW). The wind barbs represent the mixed-layer wind velocity. The PFT label for Sir Ivan points to the fire site, whereas for Licola it points to a minimum value on the wind change that is about to impact Licola.**

# Results

## PFT spatial distributions

Spatial plots of PFT generated from computer forecast models can provide valuable insight into how the pyroCb threat varies in space and time (Fig. 3). The PFT colour scale in Fig. 3 is logarithmic in order to capture the substantial PFT variability at any given time across the landscape. Both cases presented show increased threat near a wind change. This is a very common result. Ahead of the wind change the winds are often very hot and dry (contributing to large $z_{fc}$) and the windspeeds are often very high (large $U$), which together contribute to large PFT (Eq. 5) corresponding to highly unfavourable conditions for pyroCb formation. If the wind change brings cooler and moister air to the fire ground (reduced $z_{fc}$), and a short-term (or longer) lull in the winds (reduced $U$), conditions become much more favourable for pyroCb formation. Furthermore, a shift in wind direction can lead to increased firepower as long flank fires become head fires.

The two PFT plots in Fig. 3 also demonstrate very large differences in PFT in the vicinity of the fires at the time the pyroCb were observed (about 300 GW for Sir Ivan and 10 GW approaching Licola). This suggests pyroCb formation conditions are much less favourable for the Sir Ivan fire than the Licola fire, since 30 times the firepower would be required in the former than the latter. Indeed, conditions that highly favour pyroCb plume development (high humidity and light winds) do not favour large, hot fires, and vice-versa.

Fire-weather forecasters and fire-behaviour analysts using the PFT diagnostic would require some knowledge of the size and intensity of any going fires to be able to assess pyroCb formation potential. This knowledge is rarely available and will never exist for fires that have yet to be ignited. Without such knowledge they can only identify a relative threat, and the PFT forecast performance cannot be verified.

It may be many years before sufficiently reliable observations of firepower become available to enable a rigorous verification program to be undertaken. In the short term, a dataset of past events could be constructed, to identify fire-types that will produce pyroCb for a specific PFT forecast (eg, a Sir Ivan-scale fire is required for pyroCb to form when the PFT = 300 GW). However, this approach is not ideal because it assumes the yet to be verified PFT is stable and performs consistently across the full breadth of fire weather conditions.

An unverifiable forecast tool such as the PFT has limited prediction value. It must be combined with other information to have value. Ideally, the pyroCb prediction tool would allow forecasters to know that a fire burning in a specific location at a specific time will or will not produce pyroCb.

Returning to Fig. 3 one clear difference between the Sir Ivan and Licola fires is the fire-danger conditions. Sir Ivan had catastrophic fire conditions, which would support a much hotter fire than the very-high fire danger conditions present in Licola. Combining some measure of the fire danger conditions with the PFT could produce a verifiable prediction tool.

## PFT-flag formulation

The PFT-flag is designed to represent a ratio of pyroCb plume-development potential (PFT) to fire-intensity potential, to identify when a favourable combination of plume and fire potential is present. For simplicity, the PFT-flag uses only atmospheric variables readily available in Numerical Weather Prediction (NWP) models. The atmospheric components of a variety of fire-weather indices were tested, with the best performing being the product of the Project Vesta (Cheney et al. 2012) and the near-surface windspeed. The main test was for the PFT-flag to produce a similar value for the two extreme cases introduced above, Sir Ivan and Licola. Despite this very rudimentary testing regime the only changes required, after application to more than twenty cases, were the addition of low-wind and low fire-danger limits.

In order to separate the atmospheric component from the fuel components in the Vesta function, two assumptions need to be made. The near-surface windspeed is greater than $5\ km\ hr^{-1}$ (1.39 $m\ s^{-1}$), and a constant term in the rate-of-spread equation is small compared to the windspeed/fuel term and can be ignored. The latter assumption is good for moderate to high fuel loads. Such fuel loads may be necessary to support deep flaming, observed in pyroCb producing fires (McRae and Sharples 2014). The resulting Vesta atmosphere-only equation can be expressed as,

$$V = 18.35{V_M}^{-1.495}.V_U, \quad 6.$$

where,

$$V_M = \begin{cases} 2.76 + 0.124RH - 0.0187T, \text{Period 1} \\ 3.60 + 0.169RH - 0.0450T, \text{Period 2} \\ 3.08 + 0.198RH - 0.0483T, \text{ Period 3} \end{cases} \quad 7.$$

$$V_U = 1.531(\max(U_{10}, 3.0) - 1.39)^{0.858}. \quad 8.$$

Here $V_M$ and $V_U$ are the fuel moisture and wind speed contributions to the Vesta function ($V$). The wind speed term uses the near surface or 10 m wind ($U_{10}$, units $m\ s^{-1}$). The fuel moisture term is a function of relative humidity ($RH$, units %) and air temperature ($T$, units °C), which varies with time of day and time of year, expressed as three distinct periods (Eq. 7). Period 1 extends from midday to 5 PM from October to March. Period 2 is used otherwise for daylight hours, and Period 3 for night hours. Note, these periods are valid for southern hemisphere low- to mid-latitude regions. Application to the northern hemisphere, high latitudes requires additional consideration about when best to apply Period 1. (Experiments in the mid-summer Arctic, suggest Period 1 should apply continuously.)

For comparison with the better-known McArthur Forest Fire Danger Index (FFDI, McArthur 1967, Noble et al. 1980), $V = 15$ is roughly equivalent to an FFDI of 50, and $V = 30$ is similar to an FFDI of 100.

The PFT-flag is given by,

$$PFTflag = \frac{PFT}{V.U_{10}}. \quad 9.$$

To avoid divide by zero errors and to eliminate the PFT-flag triggering in light-wind conditions, or low fire danger conditions the PFT-flag is set to a very large number (to indicate pyroCb is impossible) whenever $V \leq 2.0$ or $U_{10} \leq 2.0$. The smaller the PFT-flag value, the more favourable the combined plume and fire conditions are for pyroCb formation. When calculating PFT-flag, PFT in units of GW is used in Eq. 9 to generate manageable PFT-flag units for plotting (e.g., Fig. 4).

Like the PFT, the PFT-flag is still in development and will undergo further tuning and editing in the future.

## PFT-Flag results

A rigorous assessment of the PFT-flag is yet to be undertaken. At present a prediction of favourable pyroCb formation is based on a somewhat arbitrary choice of colour-scale in the PFT-flag plots. Both Sir Ivan and Licola yielded PFT-flag values between about 1 and 3 (Fig. 4), which led to the choice of a colour-scale between 0 and 5. Initial interpretation of these values is as follows: less than 1 is highly favourable for pyroCb formation; between 1 and 3 is favourable; between 3 and 5 is possible; and greater than 5 is unlikely. This is very preliminary and is likely to change in the future.

As mentioned above many cases have since been examined, with very promising results. A good example is the dual fires that produced pyroCb in view of the Mt. Hotham webcam on 4 March 2019: The Mayford-Tuckalong Track fire and the Mount Darling-Cynthia Range Track fire. Early in the day, while impressive pyroCu developed, there was no indication of pyroCb, and the PFT-flag indicated pyroCb was unlikely in the immediate vicinity of the fires (although favourable conditions were indicated nearby, Fig. 5). Throughout the afternoon, the PFT flag showed a steady southward progression of favourability, with the shading becoming increasingly darker (c.f., Figs 5 and 6). Both fires produced pyroCb, with the northern fire (Mayford-Tuckalong Track closest to the camera) triggering about an hour earlier than the southern fire.

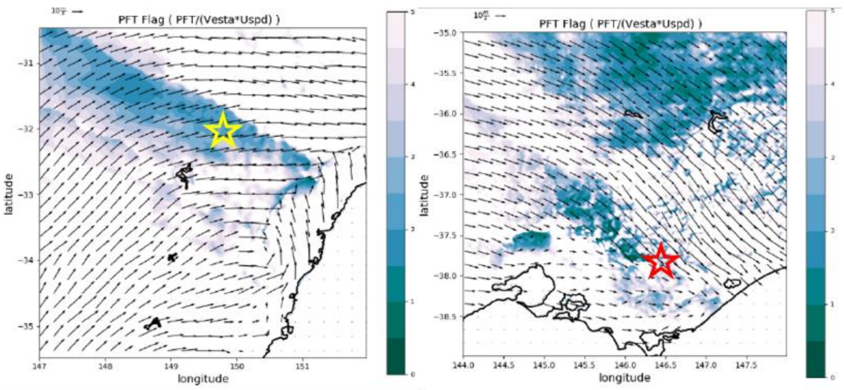


**Figure 4: Same as Fig. 3 but PFT-flag forecasts. The stars indicate the fire locations.**

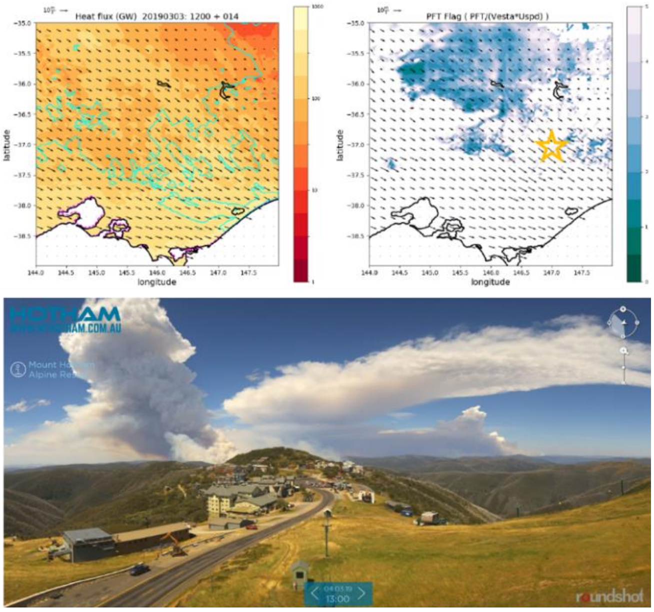


**Figure 5: The PFT (top left), PFT-flag (top right) and below an image from the Mt. Hotham webcam of the Mayford-Tuckalong Track fire (left, mid-ground) and the Mount Darling-Cynthia Range Track fire (right, distant) at 1 PM, 4 March 2019. The star marks the location of the two fires.**

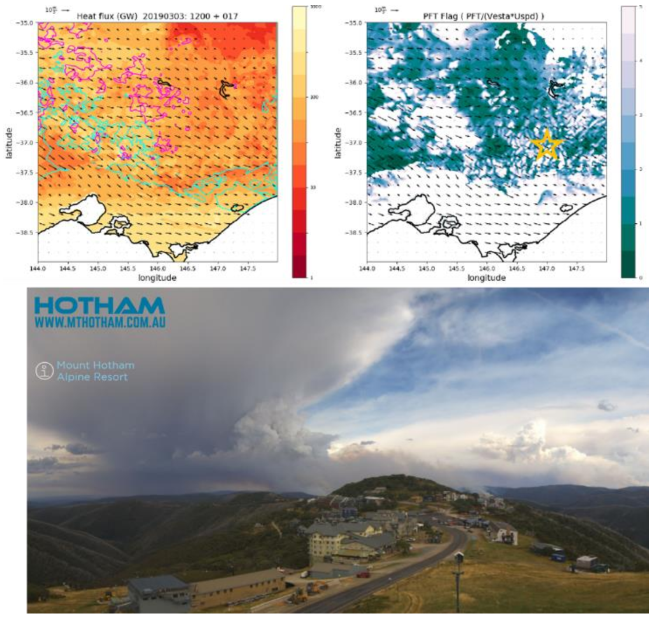


**Figure 6: As in Fig. 5, but three hours later (4 PM).**

The sequence of 10-minute images (not shown) showed the two plumes produced multiple bursts of deep convection throughout the afternoon, progressively becoming larger and more energetic, with clear evidence of rain falling from the nearby fire plume, and a mature anvil in the more remote fire plume. This behaviour was well-matched by the ever darkening and southward progression of the PFT-flag shading. As a forecast tool the PFT-flag would have provided excellent guidance for pyroCb prediction on these two fires.

## Summary

A series of BNHCRC studies beginning with a little 'blue-sky' research into the thermodynamics of smoke plumes, led to the ability to identify potential condensation heights in plumes, and the minimum plume buoyancy required for plumes to freely convect to the electrification level. With this knowledge equations for a theoretical minimum firepower required for pyroCb formation were derived using the Briggs plume model (PyroCb Firepower Threshold, PFT).

The work has culminated in the development of a diagnostic that seeks to determine when the atmosphere is conducive to both deep plume development and large, hot fires (PFT-flag). Originally designed as a flag to alert users when to examine the PFT, the PFT-flag may prove to be a more valuable prediction tool than the PFT itself. It was developed and tuned to identify the atmospheric conditions corresponding to two pyroCb events at opposite ends of the pyroCb spectrum. The first (Sir Ivan) occurred in catastrophic fire weather conditions, when pyroCb formation conditions were not especially favourable. The second (Licola) occurred in much milder fire weather conditions, when plume formation conditions were considerably more favourable. The PFT-flag has now been applied to more than 20 cases covering multiple days and time periods. While no rigorous performance assessment has yet been made the tool appears to be working surprisingly well. It not only identifies days of pyroCb occurrence, but also reproduces the diurnal variation in pyroCb threat, plus variations in threat associated with atmospheric features such as troughs, fronts and sea-breezes.

Both the PFT and PFT-flag are under continued development and will undergo real-time testing this coming southern Australian fire season.


## Acknowledgements

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

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## 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.

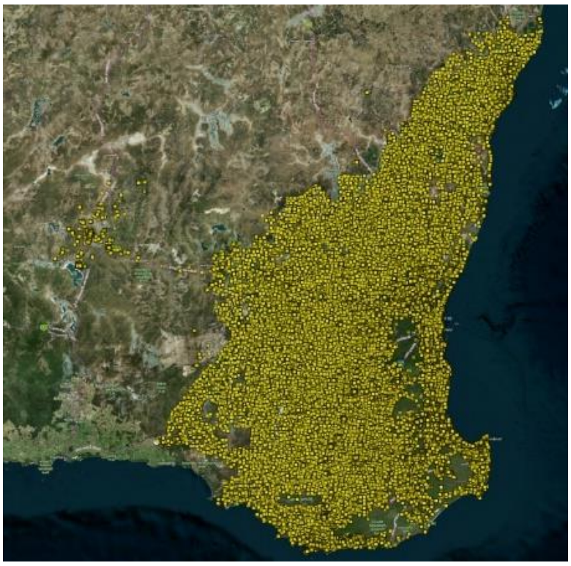

**Figure 2: Building location points dataset for the SW of WA**

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.

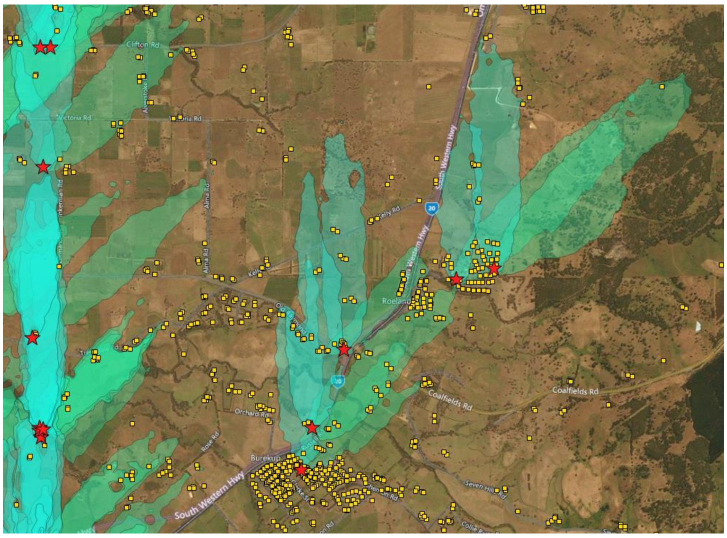


**Figure 3: 1-hour fire spread isochrones from northerly and south westerly wind directions from a sample of power pole ignition points and buildings likely to be impacted.**

**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.


### Acknowledgements

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# Transforming through diversity and inclusion capability – the pathway to achieving diversity benefits

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## Abstract

A key driver for building diversity and inclusion (D&I) in emergency management organisations (EMOs) is to better represent diverse cohorts and ensure EMOs and their communities become more resilient to natural hazards. While EMOs have made some progress, dynamic transformation is required to effectively manage the rapidly changing contexts they and their communities face. Central to this is the need to expand the current service–client relationship to become a more inclusive partnership model that builds resilience.

This paper reports on Phase 2 of the Bushfire and Natural Hazards Cooperative Research Centre project *Diversity and inclusion: Building strength and capability*, which aimed to develop a D&I framework for the emergency management sector (EMS). Key aspects are: [1] A process framework to guide organisations by linking strategic objectives to day-to-day decision making and integrates D&I practice into organisational systems; [2] Identification and development of specific strategic and people-based capabilities and skills; [3] Management of risks arising as a result of D&I shocks; and [4] A process to measure and manage progress and assess the benefits derived from investment.

## Introduction

> *If only senior managers dealt with this situation in the same way they deal with an emergency incident - by giving it their full attention.*
>
> Ex-firefighter, Dr Dave Baigent

Over the past decade, D&I has become a major focus for the EMS. Organisations such as Women and Firefighting Australasia (WAFA), and initiatives such as AFAC's Male Champions of Change have been intrinsic in broadening awareness and providing focus in this area. Evidence shows that D&I is being integrated into many organisations, but this agenda is still vulnerable (Young, Taylor & Cramer 2019). Diversity concerns more than diversity of people in the workforce (paid and unpaid) and in the community, but includes diversity of thought, roles and tasks, and relationships. These are all required for EMOs to negotiate the changing risk profile and the increasingly diverse communities they work with.

> *Like driving a car with a standard transmission for the first time, changing a hardwired organisational habit can be nerve-wracking.*
>
> Rock & Swartz (2007, p.4)

The D&I agenda is a key part of the transformation of the EMS – from one that has a focus on response during and immediately after emergency events, to one that improves community health and safety during the entire risk cycle, while expanding to embrace a multi-hazard approach.

A key characteristic of the EMO workforce is the 'fit in and fix it' culture that is highly skilled in tactical, command and control decision making (Baigent 2001, Young 2018). The mental maps required for effective D&I are different, and require changing organisational structures, and developing thinking pathways that require different 'mental muscles' to be exercised. Discomfort is to be expected in organisations with strong, inbuilt traditional and hierarchical cultures, and this needs to be managed throughout the process. Organisations also need to develop solution-focused approaches that encourage people to 'go through the process of making connections themselves' (Rock & Swartz 2007, p.4).

This paper presents a process-based framework that can be used to develop implementation plans capable of supporting the D&I-led component of the transformation process.

## Project background

The project (2017–2020) aims to develop a practical framework for the implementation of D&I that builds on and leverages current strengths and expertise within EMOs and their communities. Its purpose is to support better management and measurement of D&I by using evidence-based decision making. The project has three phases:

- understanding how D&I operates within emergency services systems
- developing a suitable D&I framework for the EMS
- testing and using the framework.

The first phase surveyed the D&I literature to determine what constituted effective D&I, and surveyed the sector through interviews, group discussions and feedback from practitioners (especially those on the end-user working group), in relation to barriers, needs, challenges and opportunities. Case studies and a community survey examined what the sector and D&I within the sector looked like from the community's point of view. An economic component collected the broad D&I benefits in preparation to identify those most relevant to emergency services. These were combined to present a draft Diversity and Inclusion Framework for development in Phase 2.

## Phase 2 activities

Phase 2 included the following activities:

- A workshop 'Into the future: Building skills and capabilities for inclusive and diverse organisations' (December 2018)
- Six semi-structured focus groups with members of agency brigades and units
- Testing processes developed for the framework with stakeholders
- An economic assessment of the Indigenous Fire Indigenous Fire and Rescue Employment Strategy (IFARES) program.

The workshop aimed to improve understanding to support effective D&I practice within EMOs and throughout the sector, and how it related to specific tasks. The workshop was attended by 20 people representing 10 EMS agencies, representatives from industry and not-for-profit (NFP) organisations and researchers. There was a varied representation of gender, ethnicity and a mixture of executive, management and officer level in attendance. The participants were active in areas of D&I practice and were invited due to their expertise.

The key questions were:

- What skills and capabilities are needed for inclusive practice in EMOs?
- Do these skills and capabilities change during specific aspects of the transformation process? If so, how?
- What specific skills and capabilities are needed to solve D&I issues that people and organisations may encounter?

Participants worked through a structured process, where three groups were presented with a scenario containing D&I shocks, and which required specific D&I management:

- Scenario one involved a large influx if climate refugees from different cultures into a high-risk environment.
- Scenario two outlined a social media storm due to a lack of cultural awareness in a local brigade, and
- Scenario three outlined a policy reversal on D&I that required a sector wide response in relation to the benefits.

Participants were asked to propose their interventions, list their benefits and the most important attributes, capabilities and skills needed to support this intervention.

The workshop was synthesised by categorising data using a grounded-theory approach to extract key themes and identify synergies and patterns of decision making across the three groups. The data was coded and basic statistical analysis was undertaken. The key themes to emerge were D&I risk, capabilities and skills, and D&I benefits.

Data was also collected through six semi-structured interviews with focus groups comprised of people from brigades and units to determine how D&I is understood and linked to day-to-day tasks. These groups were diverse in age, race, gender and disability, and included paid and unpaid workforce members. Key tasks relating to D&I activities were then extracted and coded.

These tasks were then mapped using the following categories:

- Risk category
- Type of risk
- Primary capitals at risk
- Risks
- Impact and consequences
- Treatment
- Benefits
- Key tasks
- Attributes
- Skills
- Capabilities.

Key phases of successful programs were mapped to identify the steps needed to support the framework's development. This was then synthesised with findings from Phase 1 to refine the draft framework, and follow-up consultations were undertaken with project end-users. Key findings were presented to end-user organisations to verify key findings, and to test the processes for salience and usefulness.

The economic case study estimated the benefits of the IFARES program by modelling different benefit and cost components (see 'Summary economic case study').

## Workshop findings: D&I risk

Our focus was to explore which D&I attributes, skills and capabilities were most salient to EMOs, and how these related to day-to-day functions and tasks. The most prominent theme that emerged was the risk associated with poor, or lack of, management of D&I. Responses indicated that these risks were not uncommon or unexpected, with participants having a collective, almost visceral, reaction to the scenarios recognising aspects such as:

- how easily such shocks could occur
- the degree of damage they could produce, and
- the extent of time and resources required to recover.

Out of the 32 responses in relation to consequences, 65% of these were directly related to risk. The scenario related to political shock was identified as the most risk to organisations.

Common themes that arose were:

- increased conflict
- competing agendas
- increased risk
- erosion of trust in between the community and EMS, and
- reduction in effective responses.

Twenty-one perceived consequences for the community were broad-ranging, but all three scenarios were felt to increase risk to the community and negatively impact public safety. Eighty percent of all consequences were directly related to risk. Themes that were common to all three scenarios were:

- Increase/amplification of community risk and impacts, particularly psychosocial impacts
- Decreased public safety, community cohesion
- Loss of trust, reputational damage to EMS
- Increased conflict, community tensions, factions
- Program failure
- Negative effect on regional sustainability.

Twenty-four consequences were also identified in relation to a specific activity each group selected. Challenges identified pertained to social licence, loss of trust, technology, external factors and behaviours. Positive actions included championing and sustaining impetus for improvement and broader community acceptance.

## What is at risk?

Social and human capital are the areas most at risk from direct impacts caused by D&I shocks, and the following section summarises findings from Young & Jones (2019).

Human capital can be defined as:

> *The knowledge, skills, competencies and attributes embodied in individuals that facilitate the creation of personal, social and economic wellbeing.*
>
> OECD (2016a, p.29)

This encompasses skills that support D&I and the growth of new knowledge. For most organisations, human capital is usually an internal consideration, but EMOs need to extend that notion to the community. This is important due to the substantial role volunteers play in service delivery, and the role the community plays in partnering with EMOs to build resilience and exercise risk ownership.

Social capital is described by Woolcock (2002) as:

> *One's friends, family and associates constitute an important asset, one that can be called on in a crisis, enjoyed for its own sake or leveraged for material gain.*
>
> Woolcock (p.20)

Social capital is seen as pivotal to social cohesion and equity. It is also defined as:

> *Networks together with shared norms, values and understandings that facilitate cooperation within or among groups.*
>
> OECD (2016b, p.103)

Effective relationships generated by interactions are central – manifesting between different networks and groups within and between organisations and communities. The quality of these interactions can be a key determinant in whether there is a positive or negative outcome. In particular, they determine the level of trust generated by the building of social capital that is critical for the delivery of effective services and organisational development. The development of human capital is critical to being able to manage this effectively. Of particular importance is the need to understand and proactively manage the difficult and, at times, destructive behaviours that can occur in response to the supportive changes EMOs need to make.

The need for organisations to address D&I from a risk perspective is not a new concept. Holzmann and Jorgensen (1999) presented a set of conceptual components making up social protection and applied them to social risk management – making particular reference to equity and measurement of risk through a welfare lens. The Opening up on Diversity report

(Price Waterhouse Coopers 2017) also explored reputational risk, stating:

> *Your record on diversity and inclusion is now a key, though generally under-managed, source of reputational risk as it comes to play an increasingly powerful role in shaping stakeholder perceptions.*
>
> Price Waterhouse Coopers (2017)

The focus on wellbeing (where inclusion plays a role in ensuring the wellbeing of workers), covers their physical and psychological workplace safety (Worksafe Victoria, 2017), thereby creating new responsibilities and liabilities for EMOs.

These risks can be direct and indirect. Table 1 outlines the major categories of risk identified from the workshop, and subsequent interviews and end-user feedback.

Direct risks to the organisation are the result of specific action(s) from within the organisation or external parties. An example of direct risk would be due to an act of a directed, destructive action that impacts an organisation, such as behaviour with a cultural or gendered bias resulting in damage to a specific individual or cohort.

Indirect risks result from flow-on effects from a direct impact that reacts within the organisation and community and creates new risks. The impact of indirect risks can be just as severe as those from direct risks. An example is breakage of trust, which can reduce the ability of EMOs to take part in and encourage collective behaviour. This can reduce community safety and effectiveness of service delivery.

D&I risk can also affect multiple areas through risk contagion. This is when a risk 'infects' another area beyond the initial impact. This type of risk contagion can result in compound risk (the combination of two or more risks). For example, a lack of inclusive practice can result in vulnerable community fragmentation, and in longer term impacts such as a negative image of a community, which can have economic impacts for local businesses.

Pre-existing risks can also become amplified as a result of a diversity shock. For example, resistance to an increase of diverse cohorts in organisations or communities can increase their vulnerability.

## Workshop findings: capabilities and skills

A key aspect of transformation is the development of new attributes, skills and organisational capabilities to support D&I implementation beyond the usual technical skills needed for risk and natural hazards management. The focus for D&I is on people within organisations and the community, understanding and managing their behaviours and responses to difference and change. This suggests that D&I itself is a key organisational capability.

**Table 1: Risks where the origin is predominantly related to D&I (Young & Jones 2019).**

| Risk category | Impact type | Primary capital at risk | Risk example |
|---|---|---|---|
| **OHS** | Direct | Human | Decreased wellbeing |
| **Reputational** | Indirect | Social | Poor public perception, loss of social licence with community |
| **Operational (service delivery)** | Direct | Human | Reduced service/response capability |
| **Regulatory and legal** | Direct and indirect | Human | Legal action for discrimination |
| **Innovation** | Direct | Human | Reputational damage and disengagement due to perverse outcomes |
| **Programmatic risk (D&I program implementation)** | Direct | Social | Inability to fulfil future community needs due to resistance |
| **Strategic** | Direct | Human | Inability to transform and secure organisational sustainability due to lack of vision |
| **Political** | Direct and indirect | Social | Disruption of D&I programs and strategies due to changing agenda |
| **Social (community livelihoods)** | Indirect | Social | Reduction in safety, increased vulnerability in diverse cohorts |
| **Economic** | Indirect | Financial | Unforeseen liabilities (e.g. increased premiums due to discrimination claims) |
| **Cultural** | Indirect | Social | Breakage of trust, cultural values at risk |
| **Environmental** | Indirect | Natural | Community risk increases due to loss and degraded natural environment |

Table 2 provides a snapshot of the attributes, skills and capabilities that were most allocated and given the greatest importance by workshop participants. They are relational rather than functional, showing that relationships rather than things such as program delivery are considered the highest priority. Of particular interest is the listing of empathy as an attribute, which is not a feature of many current D&I frameworks.

## D&I benefits

The 35 benefits identified fell across three categories (Table 3), and built upon previous work:

- benefits for the organisations
- benefits for the community, and
- mutual benefits for both.

The highest level of benefits were for the community, and included social benefits such as reduction of risk, increases in resilience, ability to recover and social cohesion. Economic benefits, such as increased investment, a more integrated and healthier economy and increased business were also identified. In terms of organisations, trusted economic benefits were also identified.

Our research has shown that there is little, if any, measurement of D&I-related community benefits, and that measurement is mostly focused on diversity aspects within organisations. It also reinforces previous findings identifying the need for development of understanding and better measurement of D&I benefits, particularly at the community level.

## Joining the dots

Risk identification can help provide a pathway that joins the dots between D&I principles and day-to-day organisational tasks with the benefits that can be derived. It also helps pinpoint the specific nature of the skills, capabilities and attributes needed to support practice and build future capability. An example of this mapping is shown in Table 4.

Summary economic case study: IFARES (Maharaj & Rasmussen 2019 forthcoming)

IFARES was initiated in 2013 by the Fire and Rescue New South Wales (FRNSW) to help breakdown longstanding barriers to Indigenous recruitment. IFARES data demonstrates the program's success, with registrations increasing from 18 in 2014 to 235 in 2016. Overall, 49 fire fighters have been employed from the program and 1 into administration.

The program also promotes greater engagement with Indigenous communities, improving fire safety and learning from traditional knowledge about fire management.

This study modelled the program's benefits by considering the reduced unemployment benefits, working life returns after leaving the program, health benefits to the recruited fire fighters and the community, health benefits arising from graduates bringing increased awareness of health issues and making healthier choices. The study also estimated the cost-benefit ratio.

The economic assessment found an estimated $8 million benefit to the community, with a cost-benefit ratio of 20, and a range of invaluable intangible benefits, such as building community pride and strengthening social cohesion.

**Table 2: Most allocated and prioritised attributes, skills and capabilities (Young & Jones 2019).**

| | Attributes | Skills | Capabilities |
|---|---|---|---|
| **Most allocated** | Empathy<br>Emotional intelligence<br>Integrity<br>Trustworthy | Communication<br>Listening | Agility, adaptiveness<br>Collaborative |
| **Greatest importance** | Empathy<br>Emotional intelligence<br>Inquisitive | Listening<br>Reflective | Agility, adaptiveness<br>Cultural competency |

**Table 3: Identified benefits from specific workshop activities (Young & Jones 2019).**

| Organisations | Community | Mutual benefits |
|---|---|---|
| Better targeting of resources to risks | Ability for individuals to manage their own risks better | Clearer mutual understanding and increased trust |
| Expanded capabilities across sector | Better engagement | Shared responsibilities |
| Continuous improvement through assessment | Inclusive communities | Empowerment |
| Engaged workforce | Increased resilience | Non-political |
| Trusted economic benefits | Community cohesion, capital, connectedness, engagement | Self-sustaining |
| Gaps identified | Increase business | Threat proof |
| Better engagement and understanding of community values to steer activities | More integrated economy | EMS part of the social fabric of the community |
| Effective relationships | Sustainability | Safe by design |
| Social licence | Social cohesion | |
| Increased trust in government agencies | Harmony | |
| | Increased investment | |
| | Greater capacity to recover | |
| | Healthier economy | |
| | Attractive place to live | |
| | Community agency | |
| | Increased community resilience, connectedness | |
| | Confidence in public safety | |

**Table 4: Pathway from risk to benefit (Young & Jones 2019)**

| Risk category | OHS |
|---|---|
| **Risk** | Exclusion or discrimination due to difference |
| **Consequences** | Low morale, disengagement, WorkCover/liability claims |
| **Treatment** | Develop inclusive culture program, education, measurement of wellbeing |
| **Benefit** | Decrease in insurance premiums, increase in trust, wellbeing and community safety |
| **Key tasks** | Monitoring/evaluation, engagement/communication, program development, project and risk management, innovation, education |
| **Attributes** | Cultural and emotional intelligence, sensitivity, trustworthy, empathy |
| **Skills** | Engagement, communication, educational, strategic, innovation, project and risk management |
| **Capability** | Risk management, self-care, cultural and emotional capability |

## D&I framework: supporting management and measurement

In addition to D&I risks, the innovation required to undertake transformation and build capital carries its own risk. Innovation risk is associated with the uncertainty of the unfamiliar, as new strategies and actions are tried and tested. Social and innovation risks can increase if D&I is poorly managed and/or implemented.

Aspects of risk can be managed using a process-based framework that links bottom-up and top-down processes, undertakes monitoring and assessment to feed information on progress back into the strategic planning component, and builds trust amongst the people undertaking the work. The key areas of organisational activity  are shown in Figure 1:

- Strategic – process of transformation and change
- Programmatic – continuous improvement models using monitoring and assessment
- Organic growth – bottom-up engagement and relationships.

The strategic process of change provides the overarching framework for the programmatic actions and organic growth needed to support change and innovation. This framework will be supported by four practice documents across the areas of managing behaviours, change and innovation, engagement and communication, and measurement.

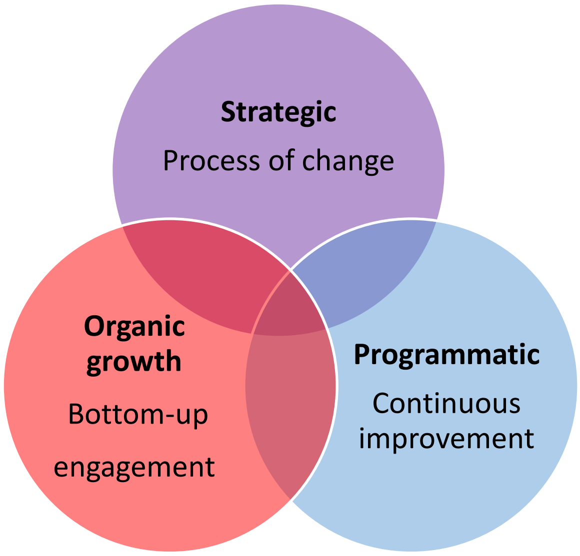


**Figure 1: Conceptual D&I management and measurement model.**

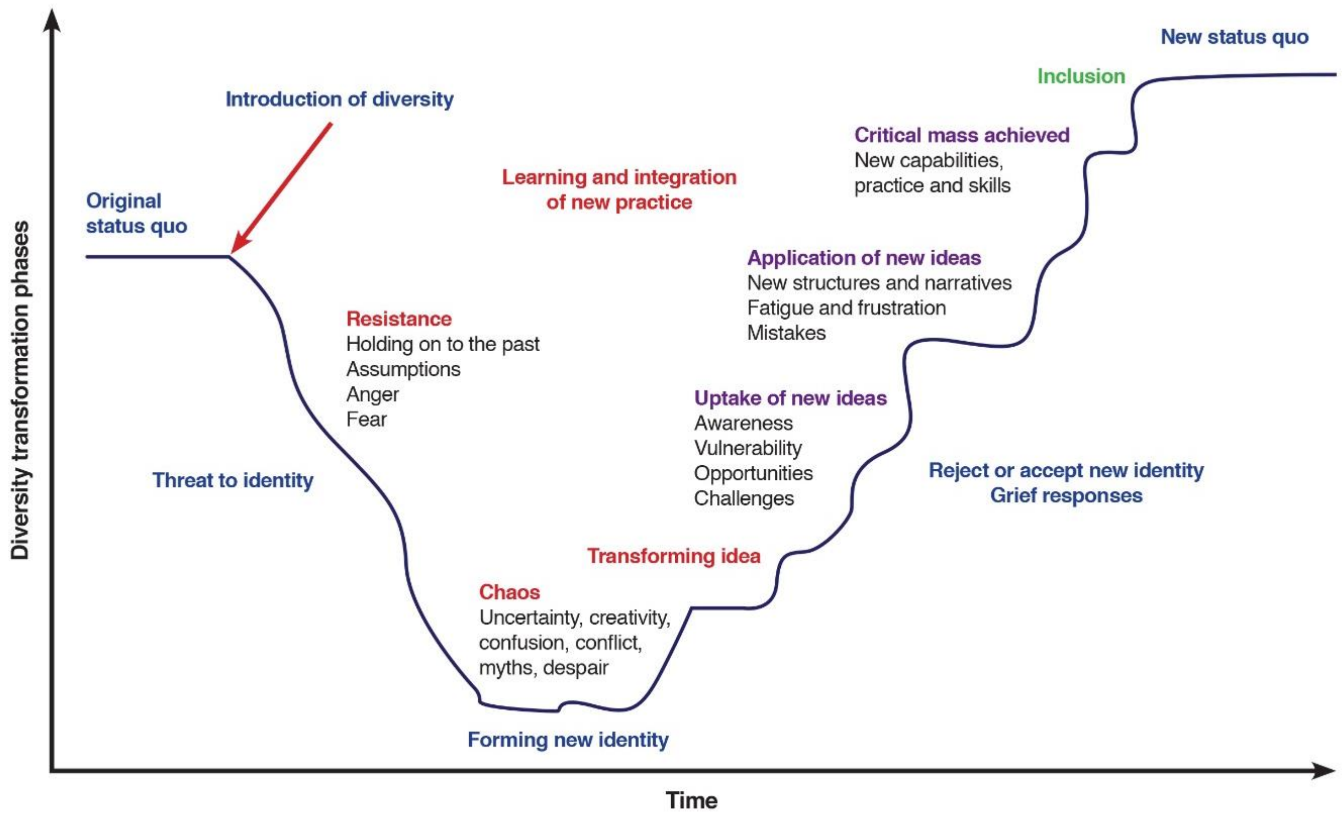


**Figure 2: D&I transformation process phases. Young et al 2018 (Adapted from Satir et al. 1991; Kübler-Ross 1993; Gardenswartz & Rowe 2003; Rogers 2010).**

## The strategic transformation process

EMOs need to transform to provide cultures and structures that support diversity of people, thought, roles and tasks. This requires a systemic and strategic approach using a complex change process that includes management of innovation, changing identity, establishing a new status quo and grief (Figure 2)

This process can help organisations understand the potential responses that might be encountered, and can also be used to plan long-term resourcing needs. A critical component is the development of a future vision of what the organisation wishes to become. That will determine the types of programs, structures, capabilities needed to provide the basis for monitoring and measurement. It also provides the forward focus that is needed to shape expectations and support meaningful engagement.

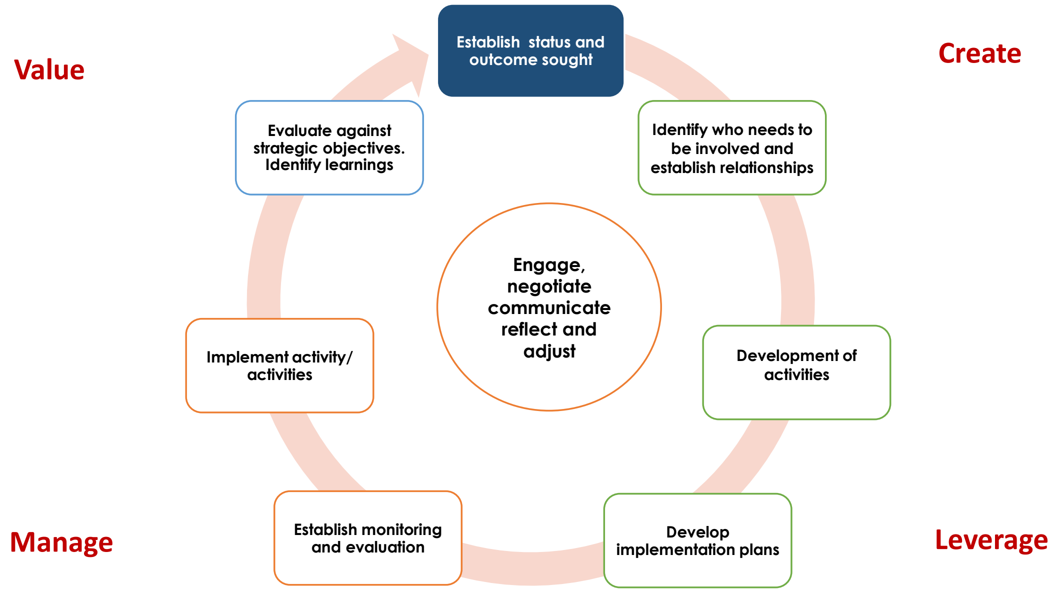


**Figure 3: Programmatic continuous improvement process.**

**Table 5: Key actions and supporting tasks for creating an inclusive culture supporting D&I led change.**

| Key action | Supporting tasks |
|---|---|
| **Connect and understand** | • Observe, listen<br>• Seek out ideas |
| **Developing relationships** | • Welcome difference<br>• Enable ideas, trust<br>• Build common language, purpose<br>• Establish boundaries<br>• Build on existing values, strengths<br>• Be reflective, flexible |
| **Collaborate and empower action** | • Enable leadership, ownership of actions<br>• Leverage capabilities, skills<br>• Create pathways for two-way dialogue/feedback<br>• Acknowledge, respect contributions<br>• Watch, listen, learn, reflect, adjust |
| **Celebrate and share** | • Evaluate, celebrate, share achievements/learnings<br>• Acknowledge, reward achievements/contributions |

## Programmatic – continuous improvement

Due to the evolving nature of D&I, a continuous improvement model is best suited for implementation (Figure 3). This iterative process connects long-term strategic change with transitional activities that provide feedback on progress, providing a management and evaluation structure as part of an ongoing process. Creating, leveraging, managing and valuing activities and evaluation outcomes are activities needed throughout the process. Implementation starts late in this process due to the need for bottom-up-based activities that require managers to [1] engage and socialise new ideas and activities to support acceptance and success; and [2] manage the innovative nature and risk associated with program implementation.

## Organic growth

Relationships and trust building are critical for leading and managing change, providing the safe environment needed for innovation and effective action where people can take risks to create opportunity. A key aspect of this is the adoption of solution-focused approaches that support people to 'go through the process of making connections themselves' (Rock & Swartz 2007, p.4). The four areas of activity help define how this can be achieved through specific actions and tasks that support the growth of safe and inclusive practice and work environments (Table 5). A key component is the development of healthy feedback and communication pathways that enable learning, promote the growth of innovative ideas and effective management of risk. It also helps organisations determine specific approaches, attributes and skills best suited to these types of programs and implementation.

## Conclusion

Building D&I in the EMS is not an end to itself, but part of the required transformation as the risks they manage and the society they work in, are also transforming. The goal of Phase 2 of the project was to further develop the draft D&I framework (devised in Phase 1) for implementation. The framework builds on a strategic process of change, a continuous improvement model and a bottom-up organic model of engagement, building an organisational culture through relationships, trust and collaboration.

A key part of that framework is the management of the systemic and pervasive D&I-related risks that can manifest in many different ways. The workshop highlighted the potential, substantial impacts of these – the most serious potentially leading to a loss of social licence that can affect the ability of an organisation to function effectively, potentially reducing community safety and security. D&I risk can also be associated with innovation and transformation if the change process is considered to threaten existing culture, identify or function, leading to resistance.

To date, D&I risk has been poorly defined, and further research is required, particularly in relation to the sort of impacts they can have for organisations and communities.

More importantly, risk provides a rationale for how D&I can be connected to the core function and tasks that EMOs undertake and connects it to community safety, which is central to mitigating and managing natural hazard risk. One of the key benefits of D&I is safer and healthier communities and organisations. The IFARES economic case study has also shown the substantial community benefits and return on investment.

In terms of attributes, skills and capabilities, the workshop and interviews reinforced previous findings in relation to the need to build specific strategic, people-based skills and capabilities that enhance the EMO workforce's existing technical and generic skills. The need to identify, develop and grow D&I skills and capabilities that exist in organisations and communities and build on existing strengths was also identified. The framework also provides the key processes and activities for D&I to support management and measurement.

Often lost in the dialogue surrounding the D&I agenda is how it connects to core business functions of the EMS and why it is so important to their communities. D&I risk has been implicit for a long time, but has generally not been formally recognised or managed by EMOs. Effective D&I provides a tangible mechanism to address this. Our research strongly suggests developing inclusive cultures that embrace diversity is no longer an 'add-on' activity, but a critical capability that EMOs need to develop.

### Acknowledgements

The project relies on the generosity and willingness of our end-users to open their organisations and give their time to explore difficult and potentially contentious issues. D&I research requires the same environment that implementing D&I needs – mutual trust and safe spaces where open and honest conversations can be had, and a willingness to be candid about the challenges. We are grateful to the D&I practitioners who have shared their invaluable experience and knowledge with us.

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# Emergency volunteer retention: can a culture of inclusiveness help?

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## Abstract

Given increasingly diversified communities and the importance of attracting and retaining all volunteers irrespective of their demographic background, it is important to increase the representativeness of volunteers by promoting diversity. We surveyed emergency services volunteers from Western Australia to examine (a) whether and why culture of inclusiveness plays an important role for volunteer retention and (b) whether and why female volunteers have different perceptions of inclusivity culture in their units. Our findings demonstrated that climate for inclusion played a vital role for volunteer retention because in such climates they felt connected and related to others, and felt freedom to express themselves professionally. Despite the importance of climate for inclusion, male and female volunteers viewed this climate differently and experienced different outcomes. Female volunteers perceived marginally lower levels of climate of inclusion than men. As hypothesised, female volunteers felt more connected to their teammates in inclusive climates integrative of differences. Unexpectedly, female volunteers' relatedness needs were less likely to be fulfilled in inclusive climates where they were included into decision-making.

Keywords: volunteer retention; climate for inclusion; psychological needs; female volunteers

## Introduction

Australian volunteers – people who willingly give time for the common good and without financial gain (PWC 2016) – contribute over 743 million hours of essential services a year (Australian Bureau of Statistics 2014). Volunteer-involving organisations, however, struggle to attract and retain volunteers (PWC 2016). Additionally, the Australian workforce is one of the most culturally and demographically diverse labour forces in the world with 50.6 per cent women and nearly 30 per cent foreign-born employees. Yet, the profile of emergency services volunteer is far less diverse with the majority of volunteers being White older men (Batty & Burchielli 2011). Coupling this with the fact that technology has made physically demanding tasks easier, the female population remains an untapped resource for emergency services.

Indeed, attracting and retaining women to emergency services remains a challenge for Australian emergency organisations (Huynh, Xanthopoulou & Winefield 2014). Stereotypes about how a prototypical emergency services volunteer should look like (Batty & Burchielli 2011), including the ability to engage in physically demanding tasks (Silk, Lenton, Savage & Aisbett 2018), and a lack of awareness of how technology could make it possible for them to partake in physically demanding tasks (e.g., using drones for search-and-rescue in hazardous areas; Camara 2014; Karaca et al. 2018), might stop women from considering involvement in emergency services. Women might also not be aware of the breadth of roles they can perform in emergency services, not all of which require the same level of physical strength. Furthermore, because women are typically described in communal terms (such as nice, accommodating), they may be deprived of tasks by men in their unit that are associated with agentic behaviours (e.g., risk-taking). Finally, stereotypes about emergency services culture, described by some female volunteers in our survey as being 'old boys' military,' may make prospective female volunteers feel unwelcomed in a group mostly constituted of men.

### Climate for inclusion and female volunteers

One way of attracting and retaining more female volunteers to emergency services is to create a culture of inclusiveness wherein all volunteers, irrespective of their background, feel valued and respected. Researchers have argued that "to reduce problems associated with demographic diversity […], organisations need to proactively create inclusive environments that make it possible to leverage diversity's potential benefits" (Nishii 2013, p. 1754). In an inclusive climate, all members are fairly treated, valued for who they are, and included in decision-making (Nishii 2013). In the context of our research of emergency services units run by volunteers, the last two aspects are particularly important. Firstly, the integration of differences describes workplaces where people feel valued, comfortable being themselves, and free to express what they need. The second is inclusion in decision-making, which portrays a work setting where everyone's inputs are actively sought and considered. The third, fairness, focuses on recruitment, selection, performance appraisal, and remuneration practices for which we could not get usable information. Thus, in our research we examined (1) how and why male and female volunteers may perceive the two aspects of climate for inclusiveness – integration of differences and inclusion in decision-making – differently; and (2) whether and why volunteer retention will be higher as a result of such inclusive climates (Figure 1). We expect that emergency service units that have a climate of inclusiveness will retain more female volunteers because women will feel valued and included in all volunteer activities. Such climates are helpful for minimizing conflicts, stereotypes, and misunderstandings that may arise in gender-diverse groups, which in turn results in lower turnover rates (Nishii 2013; Nishii & Mayer 2009).

For reasons mentioned in the previous section, we expect that emergency services female volunteers will perceive lower levels of climate of inclusion.

> Hypothesis 1: Female volunteers perceive lower levels of climate of inclusion than men.

## Psychological needs and volunteer retention

To better understand how and why a climate of inclusion would influence perceptions of fit in an emergency service unit, we appeal to self-determination theory (SDT; Ryan & Deci 2017). SDT proposes that people will have higher quality motivation (meaning and enjoyment) when they feel competent, autonomous, and related to others with whom they volunteer. Competence refers to the extent to which volunteers perceive they can have an effect on the environment and attain valued outcomes. Autonomy captures feelings of volition and authenticity. Relatedness refers to having meaningful connections to others, and to care for others and be cared for (Deci & Ryan 2000). For volunteers, the satisfaction of these needs will be important for their desire to continue their involvement. Research supports our assertions by showing the links between these needs and performance, retention, and wellbeing in the workplace (Van den Broeck, Ferris, Chang, & Rosen 2016) and volunteer work (Gagné 2003). Given the centrality of these needs for all employees irrespective of their background, the satisfaction of these needs would influence both men and women's intentions to continue volunteering.

> Hypothesis 2: Psychological needs of (a) relatedness, (b) competence, and (c) autonomy are positively related to retention.

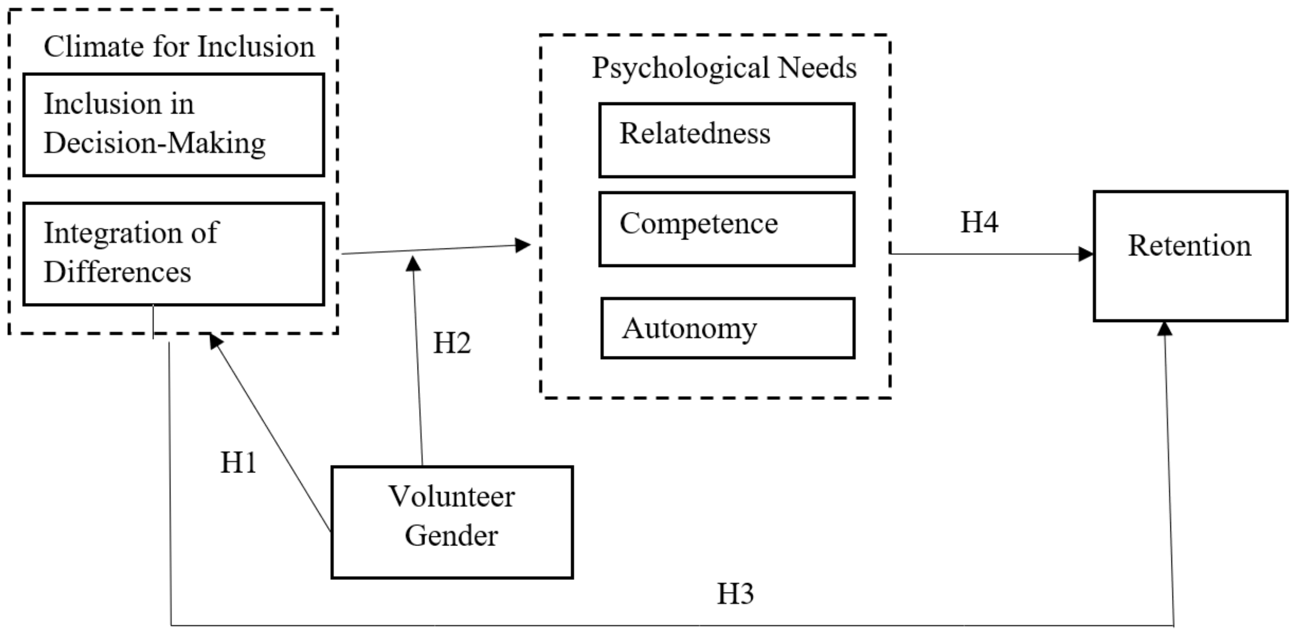


**Figure 1: Conceptual model.**

**Table 1: Means, standard deviations, and correlations among all variables.**

| Variable | Mean | SD | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|---|---|
| Gender[a] | .38 | .49 | -- | | | | | | |
| Volunteer age | 46.08 | 15.40 | -.15** | -- | | | | | |
| Integration of differences | 4.25 | .85 | -.09 | .08 | -- | | | | |
| Inclusion in decision-making | 4.03 | 1.00 | -.07 | .09 | .82** | -- | | | |
| Relatedness needs | 4.06 | .80 | .00 | .06 | .46** | .37** | -- | | |
| Competence needs | 4.09 | .69 | -.15** | .08 | .27** | .18** | .41** | -- | |
| Autonomy needs | 3.11 | .84 | -.00 | .08 | .57** | .58** | .41** | .26** | -- |
| Retention | 4.11 | .94 | -.04 | .07 | .55** | .49** | .46** | .28** | .57** |

*Note.* $N$ = 437; [a]0 = male, 1 = female; $^{*}p < .05$; $^{**}p < .01$.

There are reasons why a climate of inclusiveness would promote the satisfaction of these needs, and consequently intent to remain in the unit. The integration of differences will influence the satisfaction of all three needs by making gender differences less salient or more embraced as valuable to the unit. This will make people feel safe to try things (competence), be authentic (autonomy), and feel valued and cared for (relatedness). Inclusion in decision-making will influence the needs by valuing what each volunteer can bring to the performance of the unit and by giving them voice. Need satisfaction would therefore explain why a climate of inclusiveness would favourably influence retention.

> Hypothesis 3: Psychological needs of (a) relatedness, (b) competence, and (c) autonomy mediate the relationship between inclusion climate and retention.

## Volunteer gender, psychological needs and volunteer retention

We also propose that the beneficial role of climate for inclusion for the three psychological needs will be stronger for female than male volunteers. Female volunteers often face invisible barriers in emergency services, a typically male-dominated industry. They may be denied challenging tasks (e.g., cliff rescue, roof repair) due to benevolent sexism – wherein women receive less challenging tasks because they “deserve protection” or such decisions were made “in the women’s best interests” (Hoobler, Lemmon & Wayne 2014). This effect was observed with female employees, who did not get developmental opportunities because managers perceived them as having lower career aspirations (Hoobler et al., 2014). Manifestations of benevolent sexism may be minimised in an inclusive culture, wherein everyone is included, irrespective of gender. When female volunteers are included into decision-making and their input is considered, they feel competent, autonomous, and part of the group. Thus, the beneficial effects of climate for inclusion on these needs will be stronger for women than for men when they are not shielded away from challenging tasks.

> Hypothesis 4: Volunteer gender will moderate the positive relationship between inclusion climate and (a) relatedness, (b) competence, and (c) autonomy

# Method

## Procedure and participants

We invited emergency services volunteers from rural and urban units in Western Australia to participate in an on-line survey (N = 512); 50 per cent were men; 31 per cent were women and 19 per cent did not indicate gender (excluded from analyses); the mean age was 46 years (SD = 15.40). They came from both metropolitan (59 per cent) and rural (29 per cent) units with 12 per cent not revealing their unit. They have been volunteering with their organisation for nine years on average (SD = 9.72), seven years with their current unit (SD = 8.27).

## Measures

All measures, if not indicated otherwise below, used a 5-point Likert scale ranging from 1 (*strongly disagree*) to 5 (*strongly agree*).

**Culture of inclusiveness.** We measured culture of inclusiveness with a measure (Nishii 2013) with two dimensions. We selected seven items for each dimension with the highest factor loadings that were relevant for volunteering. They were: (a) integration of differences (e.g., "Volunteers in this unit are valued for who they are as people, not just for the roles that they fill;" α = .93) and (b) inclusion in decision-making (e.g., "Volunteers in this unit engage in productive debates in an effort to improve decision making;" α = .95).

**Psychological needs**. We measured psychological needs with a measure of need satisfaction (Van den Broeck, Vansteenkiste, De Witte, Soenens & Lens 2010). For each of the three psychological needs, we chose four items most relevant to volunteering: (a) relatedness (e.g., "At [organisation name] I feel part of the group;" α = .72); (b) competence (e.g., "I am good at the things I do in my volunteer role at [organisation name];" α = .82); and (c) autonomy (e.g., "I feel free to do my volunteer work the way I think it could best be done;" α = .67).

**Retention.** We measured retention with four items of intention to remain (Meyer, Allen, & Smith 1993). Participants responded to three items (e.g., "How likely are you to be volunteering at your current unit in two years?") using a 5-point scale ranging from 1 = *very unlikely* to 5 = *very likely*. They also indicated "how frequently they think about leaving [organisation name]" using a 5-point frequency scale (1 = *never* to 5 = *everyday*). We reverse-coded this item and created a composite of four items (α = .85). Higher values indicated the greater volunteers' intention to remain at their organisation.

**Volunteer gender.** We asked participants whether they are men (coded as '0') or women (coded as '1').

# Results

Table 1 contains descriptive statistics and correlations. Although we hypothesised the relationships between individual-level variables, participants were naturally assembled into workgroups because they volunteered in different units. Due to the nested nature of the data, we used an analysis of variance to calculate the intraclass correlation coefficient (ICC (1)) to determine whether this clustering would affect the results. The ICC (1) was .04 ($\sigma$ = .84, $p$ < .001; $\tau_{00}$ = .03, $p$ = .19), suggesting that 4 per cent of variance in individual retention is explained by the unit membership. Thus, we used multilevel modelling to test the hypotheses.

Although women reported lower levels on both dimensions of inclusion climate – integration of differences ($M_{female}$ = 4.21 vs $M_{male}$ = 4.35, $p$ = .10) and inclusion in decision-making ($M_{female}$ = 4.00 vs $M_{male}$ = 4.14, $p$ = .13), these differences were not significant. Thus, Hypothesis 1 was not supported.

We tested Hypotheses 2-3 (mediation) with SPSS PROCESS macro (Model 4) which allows multiple simultaneous mediators (in our case three psychological needs). As shown in Table 2 and Figure 2, integration of differences and inclusion in decision-making were positively related to retention ($B$ = .29, $SE$ = .05, $t$ = 5.55, $p$ < .001; $B$ = .18, $SE$ = .04, $t$ = 4.05, $p$ < .001) and to all three needs, relatedness ($B$ = .43, $SE$ = .04, $t$ = 10.63, $p$ < .001; $B$ = .29, $SE$ = .04, $t$ = 8.09, $p$ < .001), competence ($B$ = .21, $SE$ = .04, $t$ = 5.63, $p$ < .001; $B$ = .13, $SE$ = .03, $t$ = 3.88, $p$ < .001), and autonomy ($B$ = .58, $SE$ = .04, $t$ = 14.50, $p$ < .001; $B$ = .49, $SE$ = .03, $t$ = 14.53, $p$ < .001) respectively. In turn, both relatedness ($B$ = .22, $SE$ = .05, $t$ = 4.13, $p$ < .001; $B$ = .26, $SE$ = .05, $t$ = 4.85, $p$ < .001) and autonomy ($B$ = .37, $SE$ = .05, $t$ = 7.25, $p$ < .001; $B$ = .40, $SE$ = .05, $t$ = 7.48, $p$ < .001) needs were positively related to retention (as predicted by Hypothesis 2); whereas, competence needs were not related to retention ($B$ = .06, $SE$ = .06, $t$ = 1.06, $p$ = .29; $B$ = .08, $SE$ = .06, $t$ = 1.33, $p$ = .18). Indirect effects were significant for both relatedness (.10, 95 per cent CI [.04; .15]; .07, 95 per cent CI [.04; .12]) and autonomy (.21, 95 per cent CI [.14; .30]; .20, 95 per cent CI [.13; .27]) needs as mediators, supporting Hypotheses 3a and 3c.

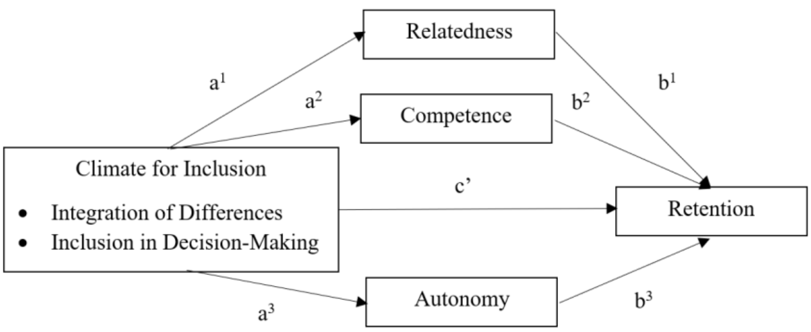


**Figure 2: The relationships between variables in the mediation analysis.**

Consistent with Hypothesis 4a (Table 3), gender moderated the relationship between both dimensions of inclusion climate and relatedness needs, namely, inclusion in decision-making ($B = -.30$, $SE = .12$, $t = -2.53$, $p = .01$) and integration of differences ($B = .41$, $SE = .14$, $t = 2.88$, $p < .01$). We plotted simple slope regression lines of inclusion in decision-making regressed on relatedness needs for male and female volunteers (Figure 3). The relationship between inclusion in decision-making and relatedness needs was unexpectedly negative and significant for women ($B = -.21$, $p = .02$; Figure 3); it was non-significant for men ($B = .09$, $p = .26$). The simple slope (Figure 4) between integration of differences and relatedness needs was stronger for women ($B = .70$, $p < .001$) then for men ($B = .29$, $p < .001$), as expected. Thus, Hypothesis 4a received mixed support.

Gender did not moderate the relationship between either dimension of inclusion climate and competence needs, namely, inclusion in decision-making ($B = -.18$, $SE = .11$, $t = -1.63$, $p = .11$) and integration of differences ($B = .12$, $SE = .13$, $t = .91$, $p = .36$). Likewise, gender did not moderate the linkages between inclusion in decision-making ($B = .06$, $SE = .12$, $t = .51$, $p = .61$) or integration of differences ($B = -.01$, $SE = .14$, $t = -.08$, $p = .93$) and autonomy needs. Hence, Hypothesis 4b-c did not receive support.

# Discussion

Given the importance of retaining all volunteers irrespective of their gender, emergency services strive to promote diversity (Batty & Burchielli 2011). We examined climate for inclusiveness as one such means of achieving this goal. As predicted, climate for inclusion was beneficial for volunteer retention because it made volunteers feel more competent, autonomous, and connected to others. Although female volunteers reported lower levels of inclusion climate, these differences were not statistically significant. Finally, female volunteers felt more connected with others than men when their differences were embraced. Yet, surprisingly, female volunteers also felt their relatedness needs were less fulfilled when there was a climate of involving them into decision-making.

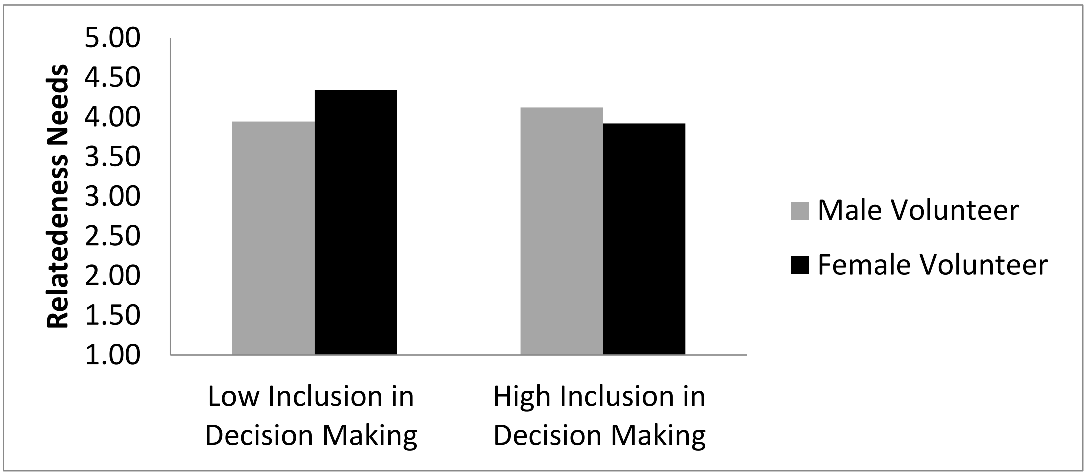


**Figure 3: The interactive effects of inclusion climate (inclusion in decision-making) and relatedness needs for male and female volunteers.**

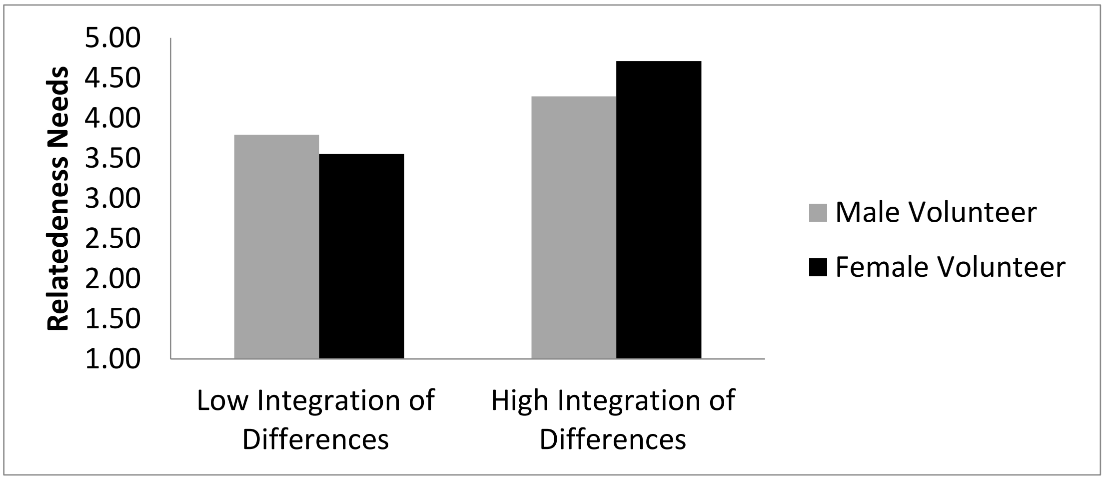


**Figure 4: The interactive effects of inclusion climate (integration of differences) and relatedness needs for male and female volunteers.**

**Table 2: Total, direct, and indirect effects, and 95 per cent confidence interval predicting retention (N=422).**

| Variables | Effect | LLCI | ULCI | SE | t | *P*-value |
|---|---|---|---|---|---|---|
| IV: Integration of Differences | | | | | | |
| Total effect (c) | .61 | .52 | .70 | .05 | 13.57 | .00 |
| Direct effect (c′) | .29 | .19 | .39 | .05 | 5.55 | .00 |
| $a^1$ | .43 | .35 | .51 | .04 | 10.63 | .00 |
| $a^2$ | .21 | .14 | .29 | .04 | 5.63 | .00 |
| $a^3$ | .58 | .50 | .66 | .04 | 14.50 | .00 |
| $b^1$ | .22 | .11 | .32 | .05 | 4.13 | .00 |
| $b^2$ | .06 | -.05 | .17 | .06 | 1.06 | .29 |
| $b^3$ | .37 | .27 | .47 | .05 | 7.25 | .00 |
| Indirect effects | | | | | | |
| Total indirect effect* | .32 | .24 | .41 | .04 | - | - |
| $a^1 b^1$ | .10 | .04 | .15 | .03 | - | - |
| $a^2 b^2$ | .01 | -.01 | .04 | .01 | - | - |
| $a^3 b^3$ | .21 | .14 | .30 | .04 | - | - |
| IV: Inclusion in Decision-Making | | | | | | |
| Total effect (c) | .46 | .38 | .54 | .04 | 11.42 | .00 |
| Direct effect (c′) | .18 | .09 | .27 | .04 | 4.05 | .00 |
| $a^1$ | .29 | .22 | .36 | .04 | 8.09 | .00 |
| $a^2$ | .13 | .06 | .19 | .03 | 3.88 | .00 |
| $a^3$ | .49 | .43 | .56 | .03 | 14.53 | .00 |
| $b^1$ | .26 | .15 | .36 | .05 | 4.85 | .00 |
| $b^2$ | .08 | -.04 | .19 | .06 | 1.33 | .18 |
| $b^3$ | .40 | .29 | .50 | .05 | 7.48 | .00 |
| Indirect effects | | | | | | |
| Total indirect effect* | .28 | .21 | .35 | .04 | - | - |
| $a^1 b^1$ | .07 | .04 | .12 | .02 | - | - |
| $a^2 b^2$ | .01 | -.00 | .03 | .01 | - | - |
| $a^3 b^3$ | .20 | .13 | .27 | .03 | - | - |

*Abbreviations: IV, independent variable; LLCI, lower limit confidence interval; ULCI, upper limit confidence interval; SE, standard error.*

**Note. A bootstrapped analysis (sample of N =5000) were conducted for the indirect effects shown in the table.*

## Theoretical implications

Our research has expanded the diversity literature by demonstrating the importance of climate for inclusion beyond employees (Nishii 2013; Nishii & Mayer 2009) to volunteers. Consistent with the general pattern of results found in the work context (Dwertmann, Nishii & van Knippenberg 2016), female volunteers perceived marginally lower levels of climate for inclusion than their male counterparts. This suggests that invisible barriers, stereotyping, glass ceiling effects, benevolent sexism that plague the work experiences of employed women (Heilman 2012) have similar detrimental effects for female volunteers. Given that both dimensions of inclusion climate were associated with feeling more competent, autonomous, and related to others, it is important to address this in female volunteers.

Results also showed, however, that involvement in decision-making made females feel less related to others in their units, relative to males. It is possible that inclusion into decision-making meant to voice one's ideas and engage in productive debates. Such behaviours are stereotypically associated with men but not women, who, by engaging in these behaviours, may violate behavioural gender norms (e.g., Luksyte, Unsworth & Avery 2018; Proudfoot, Kay & Koval 2015). This, ironically, could result in them feeling less connected to their teammates, who might feel that such behaviours are incongruent with stereotypical gender behavioural norms. For example, one female volunteer shared with us that "Complaints to manager result in being targeted". Consequently, some women felt that they cannot raise issues [about not being invited to call-outs] because "this results in me not getting any call-outs at all".

Our findings also have implications for SDT by testing it in the volunteering context. Though prior research has examined how need satisfaction is related to volunteer retention (Gagné 2003), no research to date had examined how each need uniquely contributes to retention. We found that being connected and feeling volitional were crucial factors for volunteer retention. Feeling competent, however, was not as important in this context. This could be because emergency volunteers are typically very well-trained for their role (the mean for competence was 4 out of 5), and those who are unable to "pass the test" would be naturally sorted out. No research on SDT to date had examined how diversity and inclusion influence need satisfaction. This is thus a new application of SDT.

## Implications for practice

Our findings provide guidance for organisations that are looking for ways to attract and retain more culturally and demographically diverse volunteers. First, our results highlighted the importance of promoting climate for inclusion, wherein volunteers of all backgrounds feel valued and respected. Given that female volunteers felt that ideas were judged based not on their qualities but who expressed them, units could use a system of anonymous suggestions and anonymous voting for ideas. Managers also need to encourage the submission of ideas from diverse people, and convey that differences are valued.

Second, organisations could emphasise how volunteering for emergency services fulfils people's relatedness needs. Volunteer recruitment messages could include examples of how volunteering for emergency services offer opportunities to "form friendships" and "find second family", and how it helps build deeper connections with one's community.

We note some potential limitations. First, all our measures were self-reported at one point in time, suggesting that common method variance could have influenced our results. Longitudinal research will be needed in the future. Second, we only examined volunteer gender; yet, other demographic factors may be of equal importance such as volunteer age, racioethnic background, and immigrant status. Our finding about the importance of climate of inclusion are likely to be applicable to these other demographic factors as well. Finally, we did not examine the demographic composition of each unit, and only looked at gender of individual volunteers. Theoretically, it is possible that in more gender-balanced units, female volunteers feel more integrated and included.

**Table 3: Moderating effects of gender on the relationship between inclusion climate and psychological needs (i.e., relatedness, competence, and autonomy).**

| Variables | *B* | LLCI | ULCI | SE | t | *P*-value |
|---|---|---|---|---|---|---|
| Dependent variable: Relatedness needs | | | | | | |
| Inclusion in decision-making (INC_DMC) | .09 | -.07 | .25 | .08 | 1.13 | .26 |
| Integration of differences (INC_DIFC) | .29 | .10 | .48 | .09 | 3.05 | .00 |
| Gender | .10 | -.04 | .24 | .07 | 1.38 | .17 |
| INC_DMC * Gender | -.30 | -.54 | -.07 | .12 | -2.53 | .01 |
| INC_DIFC * Gender | .41 | .13 | .69 | .14 | 2.88 | .00 |
| Dependent variable: Competence needs | | | | | | |
| Inclusion in decision-making (INC_DMC) | .01 | -.14 | .15 | .07 | .10 | .92 |
| Integration of differences (INC_DIFC) | .23 | .06 | .41 | .09 | 2.66 | .01 |
| Gender | -.19 | -.32 | -.05 | .07 | -2.79 | .00 |
| INC_DMC * Gender | -.18 | -.41 | .04 | .11 | -1.63 | .11 |
| INC_DIFC * Gender | .12 | -.14 | .38 | .13 | .91 | .36 |
| Dependent variable: Autonomy needs | | | | | | |
| Inclusion in decision-making (INC_DMC) | .23 | .08 | .39 | .08 | 2.98 | .00 |
| Integration of differences (INC_DIFC) | .34 | .16 | .52 | .09 | 3.64 | .00 |
| Gender | .09 | -.05 | .22 | .07 | 1.22 | .22 |
| INC_DMC * Gender | .06 | -.18 | .30 | .12 | .51 | .61 |
| INC_DIFC * Gender | -.01 | -.29 | .27 | .14 | -.08 | .93 |

## Limitations and future research

We note some potential limitations. First, all our measures were self-reported at one point in time, suggesting that common method variance could have influenced our results. Longitudinal research will be needed in the future. Second, we only examined volunteer gender; yet, other demographic factors may be of equal importance such as volunteer age, racioethnic background, and immigrant status. Our finding about the importance of climate of inclusion are likely to be applicable to these other demographic factors as well. Finally, we did not examine the demographic composition of each unit, and only looked at gender of individual volunteers. Theoretically, it is possible that in more gender-balanced units, female volunteers feel more integrated and included.

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# Research activities within European Union research program for improving preparedness and resilience

Kaare Harald Drager and Thomas Robertson, International Emergency Management Society.

## Introduction

The International Emergency Management Society (TIEMS) is an international not for profit non-profit organisation, registered in Belgium, operating in its 26th year. TIEMS has chapters in 14 countries around the world and is in the process of establishing three new chapters this year. TIEMS activities comprise international conferences and workshops; research and development activities; and education, training and certification programs. TIEMS's slogan is: Preparedness saves lives.

Since 2006 TIEMS has participated as a consortium partner in European Union (EU) Research and Technology Development (RTD) programs to improve emergency preparedness. In addition, TIEMS experts have been members of user groups and advisory boards for a variety of other EU projects focusing on preparedness in Europe and worldwide. The present running EU program is Horizon 2020, which will have invested more than 100 billion Euro in RTD by the end of 2020, by EU RTD funding and private investment.

Four EU projects where TIEMS has been a consortium partner are: NARTUS (addressing important public safety communication issues); ASSET (improving trust between authorities and the public for pandemics and epidemics); HERACLES (protecting cultural heritage sites towards climate change), and DG ECHO Wildfire HUB (establishing an expert HUB in Europe to support wildfire fighting and to serve as a prototype for additional expert HUB's for other disasters in Europe). This paper summarizes the approaches developed by these programs to improve emergency preparedness.

TIEMS has also launched its own internal RTD project to develop a curriculum and on-line system for TIEMS International Certification – TQC, which aims to become an internationally recognised certification of qualifications in international emergency management. This paper describes the structure and operational aspects of TQC.

## Horizon 2020

Horizon 2020 is the biggest EU Research and Innovation program ever in EU with nearly €80 billion of funding available from EU over 7 years (2014 to 2020) – in addition to the private investment that this money will attract. It promises more breakthroughs, discoveries and world-firsts by taking great ideas from the lab to the market. Seen as means to drive economic growth and create jobs, Horizon 2020 has the political backing of Europe's leaders and the Members of the European Parliament. They agreed that research is an investment in our future and so put it at the heart of the EU's blueprint for smart, sustainable and inclusive growth and jobs.

By coupling research and innovation, Horizon 2020 is helping to achieve this with its emphasis on excellent science, industrial leadership and tackling societal challenges. The goal is to ensure Europe produces world-class science, removes barriers to innovation and makes it easier for the public and private sectors to work together in delivering innovation.

Horizon 2020 is open to everyone, with a simple structure that reduces red tape and time so participants can focus on what is really important. This approach makes sure new projects get off the ground quickly – and achieve results faster (EU RTD program, Horizon 2020).

## NARTUS

The first EU RTD project TIEMS participated in as a partner was the NARTUS project, in the period 2006 - 2009. It was financed within the FP 6 framework EU program.

The NARTUS project was focused on creating a European Public Safety Communication Forum with the aim of establishing a European platform and roadmap for future public safety communication to help to facilitate European integration in the area of Public Safety with particular focus on public safety communications and information systems. The European Public Safety Communication Forum was to include Conferences and other activities between the Conferences, designed to be interactive and consultative with public safety users, system providers and operators in as many European nations as possible.

Through the Forum Conferences and other consultative mechanisms, NARTUS should not only establish consultation processes and build consensus, but also disseminate information, best practice and establish protocols through which it would be able to provide advice to policy makers and influence the development of standards for the benefit of public safety in Europe (NARTUS project Facts, 2009).

The project result was establishment of the Public safety Communication Europe Forum, or PSCE. Since its establishment, PSCE has evolved into an independent forum, where representatives of public safety user organisations, industry and research institutes can meet to discuss and exchange ideas and best practices, develop roadmaps and improve the future of public safety communications.

PSCE is a permanent autonomous organisation, working to foster excellence in the development and use of public safety communication and information management systems by consensus building (Public Safety Communication organization, 2019)

## HERACLES

The HERACLES (2016 - 2019) project's main objective were to design, validate and promote responsive systems/solutions for effective resilience of CH (Climate Change) against climate change effects, considering as a mandatory premise an holistic, multidisciplinary approach through the involvement of different expertise's (end-users, industry/SMEs, scientists, conservators/restorers and social experts, decision, and policy makers). To this end, the project developed an ICT platform able to collect and integrate multisource information in order to effectively provide complete and updated situational awareness and support risk assessment and decisions on building CH resilience by developing new solutions for mitigation actions.

The HERACLES solutions are flexible and can be changed and tailored to the specific CH assets needs, guaranteeing in that way a general applicability. A fundamental role was to be played by end-users, which actively contributed to the project activities: the state institution that takes care of Greek CH in Crete, the Minoan Knossos Palace and the Venetian coastal monuments and municipality of Gubbio, a medieval city in Italy, taking care of historical monumental in the town (palace and walls). The locations were carefully selected in order to represent the monuments, which are evidently under influence of the effects of climate change that would endanger their safeguard.

The solution is based on comprehensive diagnostic and analytical protocols and risk assessment methodology (HERACLES project, 2019).

Diagnostic and analytical protocols have been developed and are at the basis of the HERACLES best practices. These protocols cover three types of activities:

- Comprehensive site strategies;
- Quick assessment strategies;
- Laboratory Analysis.

This strategy exploits sensors and techniques/methodologies that investigate the CH assets also by looking to the surrounding areas, as well as the building structures and their constituting materials. This comprehensive vision is carried out by means of satellites and airborne sensors, in-situ sensors and material characterization methods by using a multi-scale multi-resolution strategy. A large set of sensors (satellite, airborne and in-situ) are employed to assess the risk context, the structural state and the environmental factors affecting the test-beds. These sensors acquire information on the structural and environmental conditions around the asset, which represent the input to the ICT platform as well as to the models developed in the HERACLES project. At the same time, specific information on the physico-chemical properties of the involved materials are acquired through a number of portable (in-situ) and laboratory analytical techniques (ex-situ).

Risk assessment methodology is conceptually presented with the following basic expression:

Risk = Vulnerability X Exposure

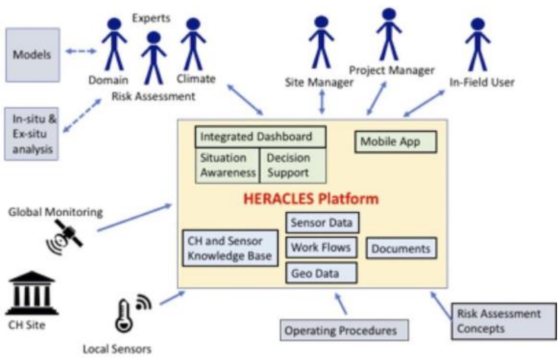


**Figure 1: Pictorial view of the HERACLES Platform (HERACLES project, 2019).**

The methodology supports multi-hazard evaluation and values of both vulnerability and exposure are assessed based on five categories: Very Low, Low, Medium, High and Very High. Vulnerability is estimated as the probability of risk, while the socioeconomic impact functions as the exposure variable. The methodology considers long-term risk assessment that is based on impacts calculated using models and future climate change conditions (winds, precipitations, etc.), thus leaving enough time for mitigation actions.

The HERACLES users interact with the ICT platform through the Integrated Dashboard and the Mobile App (Figure 1). The functions performed by users through interaction with the ICT platform include:

- Visualisation of data collected at CH sites from various sensors;
- Visualisation of results produced by models and other analysis (modelling and analysis are carried out external to the ICT platform, whereas the corresponding results feed the platform);
- Generation and review of alerts and other messages and communication with mobile devices;
- Generation and tracking of workflows representing the steps, work requests, and information flows associated with HERACLES Operational Procedures;
- Creation, management and retrieval of reports requested by Site Managers and produced by Domain, Climate, and Risk Assessment Experts through their analyses;
- Creation, management and retrieval of a Knowledge Base of information about CH sites and information about them created through HERACLES Operational Procedures.

The HERACLES operational procedures' framework for disaster prevention, risk mitigation and management is developed to help end-users to operate the relevant functionalities of the HERACLES Platform in terms of situation assessment as well as information and decision support. The procedures are designed to be generic, so whoever will use the HERACLES Platform's functionalities may use them and additionally customize to a particular CH asset.

The HERACLES operational procedures' framework is organised according to the following actions:

- Monitoring and management – monitor and document the preservation state of the site, factors affecting the site, and develop procedures for CH risk management;
- Threat identification – identify potential climate change induced threats/hazards that may impact CH site health;
- Threat assessment – perform in-situ or ex-situ analysis, or run CH health related models as required and determine if there is a need for a risk assessment;
- Vulnerability as a part of risk assessment – assess vulnerabilities for individual hazards and overall vulnerability of CH site in a multi-hazard scenario;
- Exposure assessment as part of risk assessment – assess exposure based on socio-economic impacts including economic and non-market factors;
- Risk assessment – assess risk based on vulnerability and exposure;
- Mitigation – develop and carry out a mitigation plan through a cooperation among Site Manager, Domain Experts and Project Manager.

Figure 2 shows how HERACLES solutions: Diagnostic and Analytical Protocols, Operational Procedures and ICT platform are mutually connected.

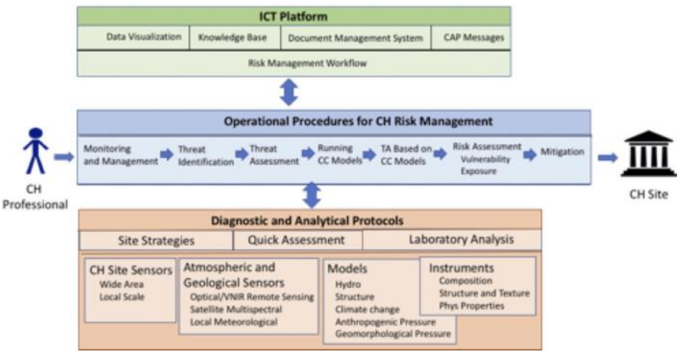


**Figure 2: Unified framework of Diagnostic and Analytical Protocols, Operational Procedures and ICT platform (HERACLES project, 2019).**

# Network of European hubs for civil protection and crisis management

The objective of this on-going project (February 2019 - to February 2020) is to formulate a concept and a model for European hubs for civil protection and disaster management. The idea is to build a generic concept of civil protection hub, which will ensure an optimum use of the disaster management knowledge and expertise that exists in Europe, through its further integration into existing practice. Within the scope of the project, a series of concrete activities will be designed to test the feasibility and adequacy of the proposed concept. The activities will result in a pilot hub on wildfire risk management. Based on the experiences of the wildfire pilot hub, a generic hub-model will be proposed to provide guidance for a potential future initiative of the UCPM participating states (European Union Civil Protection Mechanism, 2019).

The project is a part of the Preparatory Action 'European Hubs for Civil Protection and Crisis Management', and was adopted by the European Parliament to support the disaster preparedness in the Union and its Member States in the framework of the Union Civil Protection Mechanism (UCPM) and to better tackle the new challenges posed by the changing risk landscape in Europe. Preparatory actions and pilot projects are initiatives of an experimental nature designed to test the feasibility and usefulness of actions and to prepare new actions like EU policies, legislation, and programs. They are meant to try different approaches, develop evidence-based strategies to address a problem, identify good practices, and provide guidance for possible future initiatives. As such, the preparatory action 'European Hubs for Civil Protection and Crisis Management' is an opportunity to explore the concept of hubs for civil protection and to propose a theoretical model for the development and setting up of such hubs. The Commission, in close cooperation with the participating states, will then decide whether and how to implement this theoretical model. For this reason, the project will help the Commission to assess the feasibility and relevance of the creation of hubs for civil protection (EU DG ECHO Tender, 2018).

So far, the research shows that there is a long-list of potential hub activities may be clustered along the hub's specific objectives:

- Implement and coordinate training and exercises;
- Enhance exchange of knowledge;
- Promote interoperability;
- Policy advice, advocacy and awareness raising.

The hub shall be a neutral body with no own (strategic, political or commercial) interest. It shall be independent, open and accessible to all stakeholders that might have an interest to be connected to it. The hub shall (through a high-level Governing board) support, stimulate, promote and connect existing initiatives (for example national initiatives as, non-profit initiatives as or for example training centres and school and research institutes and the actual civil protection agencies). It shall not duplicate or compete with what is currently there and being developed. As such, the hub shall provide support to bottom-up initiatives and activities, as well as strengthening the EU Civil Protection Mechanism programmes.

In order to meet the above-mentioned objectives and to implement the suggested activities the hub will have virtual components (in particular related to exchange of knowledge objectives) as well as 'non-virtual' components.

The project will also provide training courses and recommendations for a common command and coordination framework.

# ASSET

The 2009 H1N1 influenza pandemic revealed a breakdown in the communication between decision makers, their scientific institutions, and the European public. This communication failure led to unwanted effects, such as the failure of a large part of the population to adopt adequate preventive measures, and the scientific sector not taking into account important information coming from the population. The objective of ASSET (Action plan in Science in Society in Epidemics and Total pandemics) was to create a blueprint for a better response to pandemics, through improved forms of dialogue and better cooperation between science and society at various stages of the research and innovation process. ASSET was a four-year, European Commission funded Mobilization and Mutual Learning Action Plan (MMLAP) project, which started 1st January 2014 and ended on 31st December 2017. ASSET was funded through the European Union's Seventh Framework Program, the predecessor to the Horizon 2020 program (ASSET project, 2017).

The ASSET project objectives were to:

- Forge a partnership with complementary perspectives, knowledge and experiences to address scientific and societal challenges raised by pandemics and epidemics, and associated crisis management;
- Explore and map SiS (Science in Society) related issues in pandemics and epidemics;
- Define and test a participatory and inclusive strategy to improve bi-lateral communication aimed to succeed with crisis management;
- Identify necessary resources to make sustainable the actions after the project completion.

## ASSET activities

ASSET activities are summarised in Figure 3.

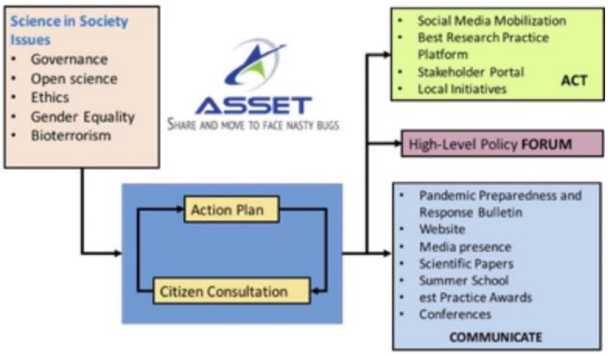


**Figure 3: ASSET Activities (ASSET project, 2017).**

The project began with an examination of five key issues at the interfaces between officials, experts, and the general public:

- Governance - the roles of national and international health organizations in the 2009 pandemic were reviewed, with a particular focus on causes of lack of trust, and perceived conflicts of interest. Experience with participatory governance, state-sanctioned institutional processes that allow citizens to exercise voice and vote, was reviewed and analyzed for applicability to pandemics;
- Open Science - unsolved scientific questions related to pandemics were reviewed, and a roadmap was developed for responsible, open, citizen-driven research related to pandemics;
- Ethics - ethics, law, and fundamental rights implications of pandemics were examined, including issues such as protection of personal autonomy versus public good, informed consent under emergency circumstances, stigmatization, resource allocation, preventions versus treatment, and human rights;
- Gender Equality - gender difference implications were examined with respect to infectious disease exposure, access to information on and use of vaccinations, and research protocols;
- Bioterrorism - governance problems associated with intentionally caused outbreaks were reviewed, with a focus on the tension between secrecy and transparency, freedom of research and security, and citizen involvement in expert's decisions.

From this research, an action plan was developed in conjunction with citizen consultation. Elements of this plan were developed and exercised during the rest of the project, with the intent that they would inform future pandemic response after the project was completed. Plan elements were developed and carried out during the project included

- Prototype initiatives to support preparedness and response to pandemics, including social media mobilization, a Best Research Practice Platform, a Stakeholder Portal, and Local Initiatives to experiment with various forms of multi-way communications between officials, experts, and the public;
- A High-Level Policy Forum that brought together selected European health policy/decision makers from 12 different countries (Bulgaria, Denmark, France, Greece, Ireland, Israel, Italy, Luxembourg, Norway, Romania, Sweden and United Kingdom) in a continuing dialogue to promote on-going reflection on European strategic priorities and challenges for tackling pandemics;
- A wide variety of communications mechanisms to connect and inform pandemic stakeholders, including electronic and traditional publications, a media presence, summer schools, conferences, and a Best Practice award to focus attention on the key role played by general practitioners in pandemic response.

## ASSET handbook and toolbox

The ASSET Handbook and Toolbox were developed as a project legacy to support practical implementation of the project's findings, as shown in Figure 4.

The intended Handbook audience includes the full range of stakeholders concerned with pandemic preparation and response: authorities, healthcare professionals, scientists, industrialists, media, and of course the general public. The handbook describes the instruments developed by ASSET to support all stakeholders in establishing a trusting, collaborative, effective response to pandemics.

The ASSET Toolbox supports the application of the Handbook instruments by providing ready access to reference information, guides, templates, and training materials.

## Key recommendations from ASSET citizen consultations

ASSET convened eight Citizens' Consultations in as many European countries (Bulgaria, Denmark, France, Ireland, Italy, Norway, Romania, Switzerland), simultaneously, carried out on 24th September 2016, asking 425 citizens questions relevant to preparedness and response during epidemics, pandemics or in general PHEIC (Public health Emergency of International Concern). A comprehensive report of the results of the citizen consultations cited the following main conclusions:

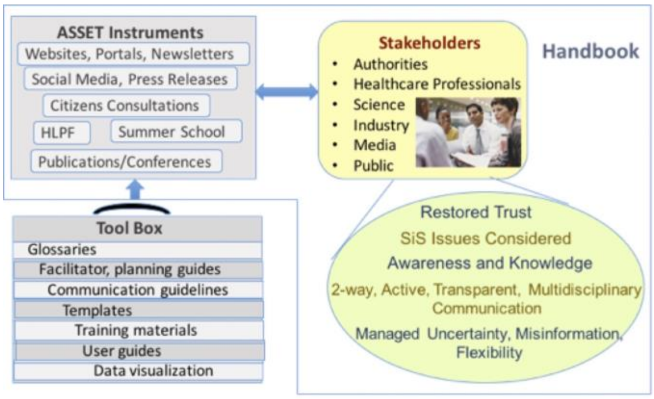


**Figure 4: ASSET Handbook and Toolbox support project legacy (ASSET project, 2017).**

- Risk Communication - Citizens believe that developing honest, clear and transparent communication can restore and further increase the public trust (no matter how bad the situation is). They think it is their right to know and understand occurrences;
- Trustable Sources - General practitioners and health professionals should be trained to adapt to changing society, and decision makers should be urged to be visible and present on the web, as the use of Internet is increasing;
- Ethics - In emergency situations, public health interest should take precedence over individual freedom;
- Vaccination - Informational materials for vaccination needs to be updated, clarified and standardised, especially considering particular target groups, such as pregnant women and the elderly;
- Participation - Public health authorities should devote more resources to collecting citizen input on policies for epidemic preparedness and response.

# TIEMS participation in other EU RTD projects

As TIEMS is an international organization with chapters in 14 countries, it has established an international Group of Experts, TIGE (TIEMS International Group of Experts 2018), comprising TIEMS Directors and Officers from TIEMS International Board and from each of the Chapter Boards, forming a group of more than 100 international experts from more than 25 countries, and with different background, education and experience. This unique expert group will be called upon, when TIEMS is invited to be a member of advisory boards and user groups or other refence groups in running EU RTD projects.

So far TIEMS has participated as referenced experts in the following EU projects: ACRIMAS, OPTI-Alert, Archimedes, CRISMA, DRIVER, DRIVER+, TAWARA_RTM, EDEN, PHAROS, RESCUER and TARGET (TIEMS RTD 2019).

# TIEMS international certification - TQC

TIEMS believes that Education, Training and International Certification in Emergency Management and Disaster Response is the key to improved resilience worldwide and TIEMS has therefore launched its own RTD project developing a comprehensive international education, training and certification program under the motto, Preparedness Saves Lives!

## What is TQC?

TIEMS international certification project has been called Certification of Qualifications in International Emergency and Disaster Management (QIEDM), or just TQC. The long-term goal is to become an internationally certification body officially accredited by a recognised accreditation body. The short- and medium-term goal is to set up the certification procedure, to implement the supporting certification platform, to get experience and to be recognised worldwide (TIEMS Education, 2019).

## Benefits of international certification

You may be asking yourself what the benefits of being internationally certified are. One reason is that by being internationally certified, you show that you are knowledgeable in the four core components of emergency management: preparedness, response, recovery and mitigation. TQC aims to be internationally recognised, for that it may be necessary to complement TQC with a national certification recognised by the specific country in which the applicant is operating. Another reason is to be professionally recognised by other professional emergency managers. By being internationally certified, you are more marketable in looking for another position, whether it is for a promotion or another position outside of the law enforcement profession. Many positions for managers in emergency management are seeking a certification as a prerequisite to employment.

With that in mind, TIEMS wish to fill the gap of an Internationally Recognised Certification Body, awarding an assessment-based certification based on the evaluation of Compliance Assessment Results and Test Examination Results, provided by two distinct Sections of TIEMS.

TQC Certification is reserved for individuals who have demonstrated their knowledge and experience in the risk management / emergency management / disaster response as certified by the TIEMS Certification Body based first on the results evaluation of TQC Compliance, and after on the results evaluation of TQC examination, with reference to International Standards and Best Practices. Prerequisite to apply for TQC Certification is to satisfy the Minimum CV Requirements.

TQC certification is a voluntary process by which individuals are evaluated against predetermined standards for knowledge, skills, or competencies, as well as test exam results. Participants who demonstrate they meet the certification requirements by successfully completing the assessment process are granted a time-limited credential. To retain the credential, participants must maintain continued competence and periodically re-evaluated. The importance of International Certification is recognised worldwide, as mentioned in the Report of World Bank Civil Protection (World Bank Desk Report, 2018)

## Why another certification scheme?

Although there are several higher qualifications and certification schemes in Emergency Management, they mainly focus on specific countries' requirements rather than an international focus. Looking throughout different certification schemes worldwide, we have found none which goes through an official internationally recognised accreditation for certification. They simply ”go through a generic and general endorsement from parts of the international community”. TIEMS long term plan is to go throughout an official accreditation path for TQC Certification.

## TQC certification concept

It is represented by the following picture and at this time is well supported by a documented functional requirements specification for all four sections (see Figure 5).

## TQC certification platform implementation

The supporting certification platform is going to be implemented for the beta testing activities as reported below (see Figure 6).

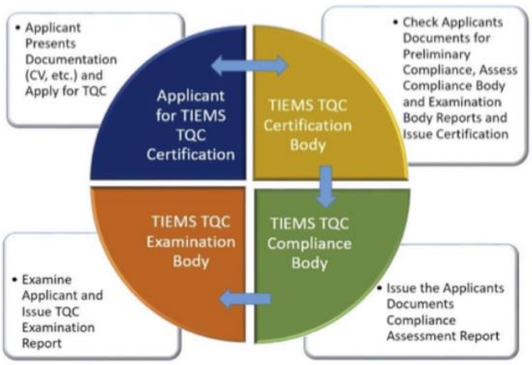


**Figure 5: TIEMS TQC Certification Concept (TIEMS Education 2019).**

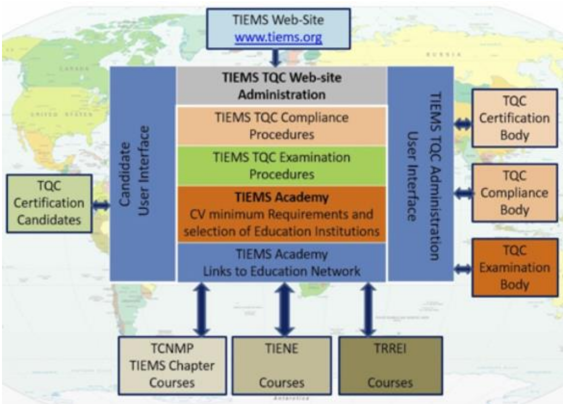


**Figure 6: TQC Certification Platform (TIEMS Education 2019).**

# Conclusion

TIEMS has through above described projects established itself as a valuable partner in EU RTD projects, contributing to improved resilience worldwide. The variety of projects also shows that emergency management is valuable methodology in different fields, above described for public safety communication, protection of cultural heritage towards climate change, building an expert HUB for wildfires in Europe, addressing epidemics and pandemics issues, and developing an international certification of qualifications in emergency and disaster management.

TIEMS International Group of Experts (TIGE) is also a unique international, multicultural and multi-disciplinary group of experts to be used as an international expert reference group in emergency and disaster management.

TIEMS continuous to be a partner in EU RTD projects, and TIEMS is at the moment invited to be a partner in four proposals addressing different EU Calls for proposals in the security field.

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# Climate Ready Communities: empowering communities to spread climate preparedness messaging and take local action

Nick Banks and Dani Austin, Australian Red Cross.

The United Nations Intergovernmental Panel on Climate Change has articulated an urgent need to address climate change in its recent report on the impacts of global warming of 1.5°C. Even the most optimistic projections indicate the inevitability of some increase in global temperatures, even if emissions were to be significantly reduced today. With the most vulnerable likely to be the hardest hit by changing weather patterns driving natural hazards of increased severity and frequency, it is essential that communities have access to resources and support to adapt.

## Introduction

The Climate Ready Communities project equipped and supported community members to take self-organised action to spread the climate preparedness and adaptation message by engaging their networks and the wider community. 61 Climate Ready Champions from four local government areas were trained and supported between July 2017 and June 2019. The project was facilitated by Australian Red Cross in partnership with Resilient South (Cities of Holdfast Bay, Marion, Mitcham, and Onkaparinga) and funded by the Commonwealth Department of Home Affairs and the Government of South Australia through the Natural Disaster Resilience Program (NDRP).

Following a training day, Champions were supported as self-organising volunteers, leading their own projects both individually and as collectives. Champions were supported by a project officer who assisted with ideas and helped them make connections with other people and organisations. Champion-led projects included a Climate Ready Forum event, public Facebook page, heat mapping displays at community events, and creating Climate Ready Packs. Champions were successful in securing community grants to support several projects.

Evaluation of the project highlighted the benefits and constraints of supporting self-organising volunteers, the advantages of not-for-profit organisations working with local government, and varied reactions to the message of getting prepared for climate change.

This paper will present the learnings, challenges and successes of this important grassroots change project.

The Resilient South: Aware and Adapt (Climate Ready Communities) project, funded by the Commonwealth Department of Home Affairs and the Government of South Australia through the Natural Disaster Resilience Program, was a two-year pilot project which sought to empower self-organising community volunteers to spread climate preparedness and adaptation messaging and take local action.

The project, facilitated by Australian Red Cross in partnership with four Adelaide councils, engaged community members who were provided with training and then supported to take self-organising action, both individually and as collectives, in their community to increase climate preparedness and resilience.

Community members engaged in the Southern Adelaide region (City of Holdfast Bay, City of Marion, City of Mitcham, and City of Onkaparinga) were equipped to understand natural hazard risks, how these are changing and are expected to shift with a changing climate, and how they can build emergency resilience in their community. The project took an integrated approach, embedding risk communication within a broader conversation about climate change, and in particular, with a particular focus on the actions individuals and communities can take for themselves.

## Climate change and emergency management

A 2014 United Nations Intergovernmental Panel on Climate Change (IPCC) report recognised the link between human induced climate change and the magnitude and frequency of extreme events such as heat waves, extreme precipitation and coastal flooding, as well as changing average climatic conditions and climate variables. These climatic changes will have a profound impact upon the experience of emergency risk in our communities, particularly for those who are already disadvantaged (IPCC 2014, p.12). In 2018 the IPCC Special Report on Global Warming of 1.5 °C brought to attention the severity of the situation to urgently and significantly curb greenhouse gas emissions. This report, which garnered significant media attention reinforced the urgency and reality of the need for adaptation at a household and community level (IPCC 2018). Even the most optimistic projections indicate the inevitability of some increase in global temperatures, even if emissions were to be significantly reduced today. With the most vulnerable likely to be the hardest hit by changing weather patterns driving natural hazards of increased severity and frequency, it is essential that communities have access to resources and support to adapt.

The connection between climate change and emergency management features strongly in contemporary emergency management sector planning and strategic documents, including in the Sendai Framework for Disaster Risk Reduction 2015-2030, which identifies the need to "update disaster preparedness and contingency policies, plans and programmes…considering climate change scenarios and their impact on disaster risk, and facilitating, as appropriate, the participation of all sectors and relevant stakeholders" (UNDRR 2015, p.21).

Furthermore, there is a natural connection between preparing for and dealing with the impacts of emergencies, including extreme weather events, and adapting to the impacts of climate change. Climate change adaptation efforts can benefit from emergency management tools that have proven to be effective in dealing with weather-related events which will be exacerbated by climate change, while emergency management is improved by incorporating information about new risks, or existing risks that will be exacerbated by climate change (Tearfund 2008).

## Climate change and risk communication

Communicating risk with communities remains a challenge for the emergency management sector. It is not easy to communicate risk in ways that are engaging for communities and develops the knowledge and skills that people need to take action, particularly when it comes to engaging people who have not experienced, or recently experienced, a disaster event.

The Australian Institute for Disaster Resilience Community Engagement Framework (Handbook 6) (AIDR, 2013, p.3) identifies that community engagement has traditionally been peripheral to the core business of emergency management organisations, and therefore "embedding engagement within the culture and practice of emergency management organisations is a key challenge for the future". A 2012 review of Australian Disaster Inquiries (Goode et al. 2012, p.17) identified that there is "scope for improvement in community engagement particularly with respect to clearly communicating risks and hazards".

The traditional approach to communicating risk with the community has largely been an information-action model that generally involves emergency management professionals providing information about risks, and encouraging people to do something in response. Too often, the communication process is one-off and one-way, and assumes that the audience is an indistinguishable group of individuals who have the same needs and values. The information-action model also assumes that people will actually take action based on the information provided (O'Neill 2004).

For these reasons and in response to a greater understanding about what motivates behaviour change, efforts to grow awareness of risk are increasingly moving towards two-way conversations that place greater emphasis on:

- the values and attitudes of the target audience
- community norms
- practical and local examples that model the desired behaviour
- developing and building upon the self-efficacy that already exists in individuals and communities
- 'bottom up' processes that encourage community members to be active participants in their own safety and in defining and implementing potential solutions.

Improving the way in which we engage with communities about disaster risk is particularly important given that our experience of emergencies and risk is changing because of climate change. We need to get better at building community awareness about disaster risk if we are to be successful in helping communities adapt to a changing climate.

The Climate Ready Communities project set out to build on existing information and advance a proven way of engaging communities around risk through empowering people to understand the risks they currently face, the way these are and will change in the future because of climate change, and what they can do to build their resilience.

The project methodology undertaken sought to support 'whole of community approach' to improving the wellbeing, knowledge, connection and security of people who are most at risk in emergencies as outlined in the People at Risk in Emergencies Framework for South Australia. Furthermore, the Framework acknowledges that education about emergencies occurs best in a community context and emphasises the need to 'lead action together', 'build on strengths' and to 'tailor approaches to individual capabilities'.

## Key learnings and outcomes

The key success of the project was the establishment of a network of 62 Climate Ready Champions in Southern Adelaide who were equipped and supported to spread climate preparedness and adaptation messaging both informally through conversation and more formally through talks and public engagement events.

Feedback from Champions and stakeholders as to the effectiveness of the project to engage people in truly community-led change was overwhelmingly positive. The project has been showcased at a number of conferences and events, and has been the subject of significant interest across Australia.

## Climate Ready Champions workshops

The first stage of the Resilient South: Aware and Adapt project was the Climate Ready Champions workshops. Four workshops were planned, however a fifth was run due to demand as the project grew and became more widely known within the region.

The workshops were held at Noarlunga Centre, Brighton Civic Centre, Woodcroft-Morphett Vale Neighbourhood Centre, Cooinda Neighbourhood Centre, and Tonsley Innovation District, with three conducted as one-day trainings, and two as two-evening split trainings. Training opportunities were primarily advertised through the four partner local governments (council newsletters, libraries, community centres), and through Red Cross communication channels (volunteer lists, social media, other organisation contacts).

The trainings were facilitated by the Red Cross Project Officer, and included guest speakers from local government, NGOs, and a previously trained Climate Ready Champion (from the third training onwards). The five training workshops were attended by 62 people aged between 16 and 75 years of age, with varying levels of existing understanding of extreme weather and climate change.

Although the general scope of the workshops was established, community member input was considered crucial to shaping the workshops in each location. As such, a pre-training survey was sent to champions in advance and the information collected was used to shape content and delivery. The responses from this survey indicated that there was greater interest from registrants in learning about taking action in their communities, than in detailed climate science information. The Red Cross Climate Ready Communities guide (available publically online), was utilised throughout the workshop as a supporting resource.

A survey of all workshop participants was conducted following the workshop. The results of this survey revealed that 100% of respondents agreed they have a role to play in taking action on climate change and climate readiness in their community. 62% of respondents reported experiencing an increase in confidence to share information on climate change and climate readiness with others as a direct result of the training. 84% of respondents indicated that they felt confident or very confident to share information following the training.

> *Training helped me develop some good ideas about what to do, who to approach, and a bit of an action plan which will evolve further I'm sure. (The training) also gave me some great insight and resources. Positive presentations and a positive friendly group of people makes me feel confident things will happen.*
>
> Climate Ready Champions workshop participant

## Ongoing engagement with champions

Following the training, Champions had ongoing engagement with the Project Officer who supported and encouraged them to continue climate preparedness and adaptation conversations within their networks, run climate-ready events, and take action to increase their own resilience and that of their community.

Ongoing engagement included monthly e-newsletters, the establishment of a Climate Ready Communities network (via Facebook), a Climate Ready Bus Tour daytrip, regular drop-in coffee catch-ups, periodical surveys, and phone calls with Champions. Further face-to-face support was provided to two main groups which formed organically – one based on location (Aldinga and Willunga), another based on a project (the Climate Ready Forum).

The project used online social media platforms and email to effectively and efficiently communicate with the large group of volunteers. Technology was further utilised with the purchase, following the suggestion of a group of Champions, of a thermal camera and laser thermometers which Champions could borrow to assess temperatures around their neighbourhoods and homes – particularly during extreme heat. This particular use of technology was popular with the Champions who could use the devices to engage others in their family and community to visually identify what they could do to create safer spaces during heatwaves.

## Climate Ready Champions' actions and community change

As a result of the project, community members were engaged by members of their own community in climate resilience conversations and action, including through a range of events. The changes in these communities as a result were captured informally during the project through story sharing, and more formally through surveys and focus groups with Champions. The surveys and focus groups included both the collection of quantitative data measuring a change in knowledge and action, as well as qualitative information and feedback such as the two examples below:

> *This program seems to be addressing an urgent and growing need to support communities in developing their own grass roots responses to climate change, not just relying on authorities, and to me this is the most powerful way to build true resilience.*
>
> Climate Ready Champion

> *It (the Resilient South: Aware & Adapt project) has provided me with opportunities to refresh or develop new skills such as grant writing, attending a public relations training and public speaking. I've also met other local*

*champions who are becoming close personal friends. I would highly recommend the program to continue in the Resilient South catchment area and be expanded into other areas as a way of helping us all be better prepared for future climactic related events and to develop resilient communities.*

Climate Ready Champion

Formal project evaluations included two focus groups (one with Champions, and another with project stakeholders) and a comprehensive Champions survey. 41 survey responses were received from the group of 62 Climate Ready Champions. The project officer was deliberate in ensuring that responses were received from a range of Champions including those with high, medium, and low levels of engagement in the project so as to avoid a positive skewing of consolidated data.

Results from the survey showed that a very high proportion of Champions took action following the training to spread the climate resilience message to the wider community with 97% saying they spoke to individuals about climate readiness, 68% spoke to groups, and 57% supported a Champion-led community event.

The 41 Champions who responded reported speaking to an average of 91 people each about climate preparedness which was a total of 3731 people. If this average were to be extrapolated to the total group of 62 Champions, the reach of Champion engagement can be estimated at approximately 5,600 people.

The survey of Champions captured actions undertaken by them specifically as a result of the project. The actions undertaken by the highest percentage of Champions was to "be informed e.g. read climate adaptation articles or attend events" (71%), to "get connected e.g. with their neighbours and local community" (49%), to "help others e.g. take care of those most at-risk" (44%), and to prepare themselves for specific extreme weather events (49% for heatwaves, 39% for drought, 29% for storms, 24% for bushfires, and 7% for floods). In addition to the percentages reflected above, some Champions said they were already doing these things before the project, and many planned to take these actions into the future.

Climate Ready Champions volunteered their time individually, and as small working groups, to run events including a Climate Ready Open House in September 2018, stalls at the Feeling Hot Hot Hot! event in February 2019 at Adelaide Town Hall and the Fleurieu Film Festival in McLaren Vale, the Climate Ready Forum Champion-led event in March 2019, and a number of presentations to community groups. A number of Champions were supported to write and submit applications for community grants to undertake specific projects. One Champion was successful in securing a grant of $5000 to develop Climate Ready Packs which were distributed through a range of avenues including other Champion-led events.

The Climate Ready Forum feedback form showed that the actions community members were most likely to take due to attending the training were to "prepare household action plan for extreme weather events" (76%) and "connect with other locals to make changes as a community" (64%). Additionally, 100% of attendees said they would recommend the event to a friend, were it to run again.

## Stakeholder review

An in-depth stakeholder review focus group (with two council representatives, one NGO representative, and two state government representatives) revealed a high level of satisfaction with the Resilient South Aware and Adapt project. All stakeholders present reflected that the project met or exceeded their expectations. It was felt that the model of supporting community members to run their own projects and spread the climate preparedness at a peer to peer level had been highly effective. Stakeholders were especially impressed with the Champion-led Climate Ready Forum. Council partners also indicated that the number of trained Champions exceeded their expectations.

In terms of the level of stakeholder involvement and engagement they felt that most aspects were "about right" and they did not desire less involvement with any aspects of the project. Some suggested they would have liked a little more engagement directly with the Climate Ready Champions.

The stakeholder group agreed that a particular aspect of the project that could be improved was the level of cultural diversity within the group of Champions, as well as even more focus on engaging the most at risk communities. There was an appreciation for the level of diversity in age and gender.

Stakeholders were pleased to personally hear about and see some of the outputs of the project in their community beyond communications with the Project Officer. Stakeholders reported seeing and hearing about the project and from Champions on social media, through colleagues, and at community events.

## Conclusion

The Resilient South Aware and Adapt Project provided a platform for engagement by community members, including those aware of and concerned about disaster resilience, particularly in the face of climate change. These Climate Ready Champions built resilience in their communities in a way that fit with their existing lifestyle, as self-organising volunteers with support from Red Cross and other partners.

This support was provided through the initial Climate Ready Champions training, subsequent engagement and motivation, and flexibly supporting the Champions with their projects and ideas. The Champions found the regular communication and encouragement extremely helpful, as well as the sharing of ideas and real life examples of climate and extreme weather preparedness.

Overall the Resilient South Aware and Adapt Project was able to engage communities in an important, and often daunting topic. The project delivery model was both community-facing and community-led.

The Climate Ready Champions engaged in a number of ways to get the message to their community. As a result, they were able to reach a wider and more diverse audience, with more genuine community and peer engagement, than the Project Officer could have ever achieved on their own.

The evaluation of the project with Champions and other stakeholders reinforced the success of the project and an enthusiasm to see more climate resilient communities into the future.

Following the success of Resilient South Aware and Adapt project, the delivery model developed and refined throughout the project term is set to continue and expand across South Australia in partnership with local government under the name 'Climate Ready Communities'.


### Acknowledgments

The Resilient South: Aware & Adapt project was funded by the Commonwealth Department of Home Affairs and the Government of South Australia through the Natural Disaster Resilience Program, with co-contributions from, and through the partnership of, Australian Red Cross, City of Holdfast Bay, City of Marion, City of Mitcham, and City of Onkaparinga.


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# Intelligent warnings: a twenty-first century approach to encouraging protective action in emergencies

Jacob Riley, Victoria State Emergency Service.

## Executive summary

The Victorian approach to the delivery of public information and warnings is robust and leads the country in many respects. Despite this, when at-risk individuals do receive warnings, existing research clearly highlights they are unlikely to immediately act, and instead, will seek out further information and take time to process the information to determine whether any action is required. This verification process may include talking with family, friends, neighbours or colleagues, resulting in a delay before protective action is taken. To counteract this problem and provide communities with as much time as possible to take action, we need to minimise the likelihood of delays infiltrating our decision-making and warnings dissemination process. Artificial Intelligence (AI) and automation can help us to achieve this.

To investigate this further, a desktop review of existing literature was undertaken, supported by informal discussions and semi-structured interviews with a diverse range of academics, emergency managers and other experts across Victoria, New South Wales, Queensland and the United States. The discussions and interviews highlighted exciting opportunities to enhance our current approach through the use of AI and automation, which could be particularly helpful in enhancing the effectiveness of warnings for rapid impact emergencies, such as flash flooding and severe thunderstorms. During these types of emergencies, where community consequences are often experienced very rapidly after initial onset of the event, AI and automation can support the tailoring of language and content in warning products according to affected communities and likely consequences, minimise warning issuance delay and maximise the effectiveness of decision-making.

The investigation found these technologies are not a replacement for human decision making, however, if leveraged effectively they will enable us to better understand risk in real-time and reduce the considerable time taken to manually process intelligence and apply our pre-determined triggers and business rules. For the Victorian emergency management sector, these results suggest there is a need to prioritise investment in innovative new approaches to support the dissemination of potentially life-saving public information and warnings, whilst also supporting researchers to further understand human behaviour and decision-making upon receipt of a warning. In summary, this investigation has identified opportunities to better support communities to take protective action in a timely manner, to ensure we achieve our shared vision of safer and more resilient communities.

## Introduction

The Victoria State Emergency Service (VICSES) is the control agency for flood, storm, earthquake, tsunami and landslide in Victoria. Victorian emergency management agencies, including VICSES, must issue timely, tailored and relevant warnings in response to emergencies, to inform communities and encourage protective action, in accordance with the Emergency Management Manual Victoria (EMMV), the State Emergency Response Plan (SERP), the Victorian Warnings Protocol and Joint Standard Operating Procedure (JSOP) J04.01 – Public Information and Warnings.

Following a number of significant emergencies in Victoria over the last decade, including the 2009 Black Saturday Bushfires and the 2010-11 Floods, the Victorian emergency management sector, including VICSES, has significantly enhanced the way it issues warnings to communities for a diverse range of hazards. Underpinning these changes has been the need to ensure warnings issued are in fact timely, tailored, relevant, accessible and consequence-based. Arguably, work undertaken to date has resulted in Victoria becoming a world leader in this space. Despite the significant progress made, there is considerable work required to ensure we remain at the forefront of global best practice.

## Discussion

In this complex and ever-changing global environment, where the quality and scale of data and information available to emergency management agencies continues to grow, we must be at the forefront of developing and implementing innovative new approaches that enable us to transform the data and information into actionable intelligence for the benefit of community safety. We must become smarter about making the most of all available intelligence in real-time, as well as the presence of new and emerging AI and automation technologies, to better inform, warn and support our diverse communities to take protective action in emergencies. Not doing so could have catastrophic impacts.

There is a clear requirement to move beyond dashboards and platforms that simply display information, or require warnings issuers to manually type information that in many cases is not genuinely tailored to specific communities. Instead, we must implement solutions that enhance our collective ability to leverage AI and automation to inform our warning decision making processes and products in an efficient and effective manner. Whilst information systems and warning platforms have begun to address these sorts of issues, there is still significant research and groundwork required to implement enhanced systems and processes incorporating these exciting technologies, in a complex, multi-hazard warnings environment.

Upon receiving a warning, research shows that community members may initially believe the emergency will not impact them. In some instances, emergency managers may falsely believe that if a warning is issued, it will be received and actioned upon by those at risk. Trusted research to date indicates it is not this straightforward. When at-risk individuals do receive warnings, the research clearly highlights they are unlikely to immediately act, and instead, will seek out further information and take time to process the information and determine whether any action is required (Mileti & Sorensen, 1990). This may include talking with family, friends, neighbours or colleagues, resulting in a delay before protective action is taken.

Furthermore, numerous post-disaster inquiries, Royal Commissions and official reviews internationally, and across Australia, have repeatedly identified unfortunate failures in the decision-making processes of emergency managers' responsible for warnings who may have been under immense pressure at the time, or may not have all available intelligence to support effective decisions (Victorian Bushfires Royal Commission, 2009). Recurring delays in the issuing of emergency information over disparate events have also been identified and in some cases, critical emergency information was never disseminated. AI and automation can enable the longest possible lead time for the issuing of warnings containing highly tailored information.

In order to issue warnings containing highly tailored information, and with as much lead time as possible, efficient methods of intelligence collection and analysis are required. Scientists at the Queensland University of Technology have developed an Australian-first device which can be placed into floodwater to map exactly where water is flowing (Hamilton-Smith, 2018), which can assist hydrologists and technical experts to make more accurate predictions about downstream impacts ahead of time. The projected impact area could then be 'pushed', using automation, to community warnings platforms for dissemination alongside calls to action specifically tailored to the community at-risk. For example, if the projected impact area covered areas of farmland, the warnings platform would recognise the need to automatically include action statements such as 'move stock to higher ground' or might include contact details for government agencies responsible for agriculture and farming, which would only be required for warnings being issued to those specific communities.

There is no doubt that an enhancement to the impact of community warnings can be achieved through the use of AI and automation given the success other sectors have seen in this space. The intent for emergency managers is to ensure emergency we issue more genuine timely, tailored, relevant, accessible and consequence-based warnings. Reflecting on the world of aviation, we can see that the industry has taken significant steps forward in enhancing the safety of passengers on commercial airlines by increasing the use of automation throughout flights (Vartabedian & Masunaga, 2019), which has minimised the potential for human error. For Victorian emergency management agencies, in a practical sense, this might mean using these technologies to simultaneously tailor language and content in warning products according to affected communities, whilst minimising warning issuance delay. In essence, we would transform the way we disseminate potentially life-saving, critical information in emergencies by applying our pre-determined business rules and language through automated platforms, or perhaps through development of a decision-support tools that guide our people when warning communities.

Despite the clear benefits of increased automation and the use of basic AI when issuing warnings, allowing computers to make independent decisions on content with little human oversight could evoke fears within both the emergency management sector and the general population. With the advent and rise of new technologies in people's homes, such as Google's Home and Amazon's Alexa, concerns around privacy and the role of technology in the lives of ordinary citizens are often raised. Experts have noted serious concerns about the potential for smart devices to be vulnerable to hacking (Butler, 2019), which could have all sorts of unintended consequences for individuals. This idea creates a sense of fear and distrust in technology, which could have a significant impact on the effectiveness of emergency warnings if communities become fearful that technology is directing them on how to stay safe in a flood, for example, rather than a human with intuition and years of experience. This is particularly relevant because of the importance of trust in promoting protective action when warnings are received by individuals (Victorian Bushfires Royal Commission, 2009). In this sense, it seems important to ensure that any enhancement to the technology we use to issue warnings and emergency information is focussed on augmenting and enhancing the current approach of human-led warnings, rather than replacing our people entirely.

The importance of a human or customer-centred approach to warnings is also essential when considering how to best engage with culturally and linguistically diverse (CALD) communities. In the health sector, the significance of nuance in language when conveying potentially life-saving medical information to diverse communities is well-understood and influences communications approaches, particularly in the United States, through bodies such as the Centers for Disease Control and Prevention (D. Daigle, personal communication, October 9, 2018). Interestingly, vaccine information is now available in more than 110 languages across the United States, which is crucial in empowering communities to make decisions by themselves in a bid to stay safe, which in some ways is similar to the intent of emergency management agencies when issuing warnings – to inform, empower and protect communities. However, much of this work in the health sector happens ahead of time and requires careful translation by people, rather than computers or robots. In rapid onset emergencies, for example, the time it might take a human translator to disseminate the content in 100 or more languages is unlikely to be available before impacts are felt. Nonetheless, technology does still provide opportunities to enhance our approach, whilst maintaining a focus on the individuals and communities at the other end.

The Victorian emergency management sector is already taking steps to integrate greater automation as part of the response to emergencies. In the flood context, the Victoria State Emergency Service, Department of Environment, Land Water and Planning, Melbourne Water, Bureau of Meteorology and Emergency Management Victoria are working to implement automatic Flash Flood Alerting which will not require human involvement. This project, due to progress to a trial in mid-2019, will see monitoring gauges aligned to specific triggers (determined ahead of time) push an automatic notification to community members who subscribe to the VicEmergency app, alerting them to the potential for flash flooding. Agencies, including the Victoria State Emergency Service can then expand on the initial automatic alert by disseminating a more formal warning product through human involvement, with specific calls to action based on the actual event. This, in some respects, is similar to the Victorian fire context where fire predictions from the Phoenix platform are automatically pushed across to the warnings platform (EM-COP), for warnings issuers to refer to when creating an impact area polygon to distribute alongside a warning product. Although simple, these examples demonstrate the positive steps already being undertaken in the emergency management sector to leverage technology for the benefit of community safety.

Internationally, other exciting work is taking place to enhance the way emergency management agencies and governments communicate, inform and warn communities during emergencies and disasters. In the United States, for example, the AWARN Alliance is working to explore opportunities for greater integration and automation across local emergency managers and television networks through the provision of a platform to enable warnings to be pushed directly to 'next generation' televisions (J. Lawson, personal communication, November 21, 2018). Additionally, in the research space, institutions such as the University of Georgia are partnering with service-delivery agencies including VICSES to better understand the psychological aspect of warning success, in encouraging behaviour change during emergencies. Additionally, VICSES has, for some time, partnered with the Queensland University of Technology through the Bushfire and Natural Hazards Cooperative Research Centre to develop our collective understanding of the role of trust, effective types of messaging and structures, and how alternative mediums (e.g.: video and other visuals) can aid or inhibit the success of warnings. All of these projects are, in some way, demonstrating the significant will of the sector to improve the way we operate and support communities to stay safe.

# Conclusion

Bearing in mind the work already underway across our sector, there is an abundancy of options available to VICSES, and partner agencies, to develop a smarter, technology-driven approach to support decision making and enable genuinely timely, tailored, relevant, accessible and consequence-based warnings. Ensuring our sector can learn from the considerable investment and research into artificial intelligence and automation across other industries is crucial in dealing with the community safety challenges we face. Now is the time to transform our approach to warnings in Victoria.

This investigation has enabled the researcher to develop an in-depth understanding of the issues and opportunities that exist and will act as a foundation for further discussions to ensure we can continue to provide the best information, with as much lead time as possible, to truly achieve safer and more resilient communities. This investigation has helped to ensure that we, as emergency managers, can truly meet the needs of all Victorians, supporting our desire to achieve safer and more resilient communities, through an innovative, twenty-first century approach.

## Recommendations

The author makes the following recommendations:

1. The Victorian emergency management sector should prioritise investment in real-time, automated data sharing between disparate platforms, such as the Emergency Management Common Operating Picture (EM-COP) and hazard-specific applications including FloodZoom and the Bureau of Meteorology (BOM) Warnings Entry Tool (WET), to support decision-making and minimise warning issuance delay. In a practical sense, this integration might include the ability for EM-COP to digest BOM warning polygons and FloodZoom flood extents in real-time for immediate dissemination to communities.

2. The Victorian Public Information Working Group and Victorian Intelligence Capability Group should investigate development of a decision support tool, which would digest real-time data, overlay it with hazard predictions and our pre-determined business rules/triggers, outputting a suggested warning (including warning level, polygon, and key safety messages), for publishing by the relevant issuer. This tool could also benefit other aspects of response.

3. VICSES, EMV and other agencies should scope opportunities to develop a multi-agency project that would seek to develop collaborative relationships with graduates, experts and relevant institutions focussed on data and analytics, AI and robotics, enabling the sector to better leverage opportunities that AI and automation are already presenting to other like-industries, such as aviation, policing and transport.

4. VICSES and the broader emergency management sector should continue to work in partnership with the Bureau of Meteorology as part of its long-term project to review, refine and enhance its service delivery arrangements for warnings at a national level, with a particular emphasis on shifting towards truly impact-based warnings.

5. VICSES should to continue to work with the University of Georgia (UGA) to conduct a cross-national research project (US – Italy – Australia) focussed on risk communication in the context of natural disasters and emergencies.

6. VICSES should continue to work with the Queensland University of Technology and the Bushfire and Natural Hazards Cooperative Research Centre across relevant research projects considering the effectiveness of warnings and risk communication more generally, whilst advocating for greater research into the role of AI and automation in relation to the dissemination of warnings and emergency information.


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# School-based bushfire education: advancing teaching and learning for risk reduction and resilience

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## Abstract

In response to Recommendation 6 of the 2009 Victorian Bushfires Royal Commission, the topic of bushfire has been incorporated into the Australian school curriculum. To support the implementation of this new curriculum content, fire agencies and education authorities have invested in a range of bushfire education programs and resources. Research in the field of school-based bushfire education has also intensified. Drawing on key findings from a suite of recent Australian studies, this paper outlines two key elements of effective school-based bushfire education that have the potential to advance teaching and learning for risk reduction and resilience. The first is a holistic risk framework that builds children's conceptual understanding of bushfire risk as a socio-environmental phenomenon that derives from the interaction a physical hazard, the vulnerability of exposed people and assets, and the capacities people possess for disaster risk reduction. The second is a place-based pedagogy of bushfire risk, which grounds teaching and learning in the socio-environmental contexts of children's lives. The paper concludes with some key recommendations for the continued development of good practice in this emergent field.

## Introduction

In the aftermath of the 2009 Black Saturday bushfires, the Victorian Bushfires Royal Commission conducted a full and detailed inquiry into the disaster (Teague et al. 2010). Over the course of the inquiry, the Commission heard ample evidence of communities who did not think they would be affected by bushfire and of people whose lack of bushfire knowledge and preparedness had left them highly vulnerable to disaster impacts (Teague et al. 2010). In its final report, the Commission explicitly identified bushfire education for children as the most effective means by which to rectify this fundamental lack of knowledge and preparedness in the community:

> *The Commission is of the view that educating children about the history of fire in Australia and about safety in the event of a bushfire will probably influence not only the children but also their parents, siblings and extended family and community. A concerted education program remains the most effective approach to instilling the necessary knowledge in Australian families.*
>
> Teague et al. (2010, p. 55)

Accompanying this sentiment was an official recommendation that bushfire education be incorporated into the formal school curriculum:

> *Recommendation 6: Victoria [should] lead an initiative of the Ministerial Council for Education, Early Childhood Development and Youth Affairs to ensure that the national curriculum incorporates the history of bushfire in Australia and that existing curriculum areas, such as geography, science and environmental studies include elements of bushfire education.*
>
> Teague et al. (2010, p. 2)

As a direct result of Recommendation 6, the Australian Curriculum for Grade 5 Geography now includes a content description pertaining to the "impacts of bushfires or floods on environments and communities and how people can respond" (ACARA 2019). To support the implementation of this new curriculum content, fire agencies and education authorities have developed a range of bushfire education programs and resources (e.g. DFES 2019, VCAA 2019). Research in the field of children's bushfire education has also intensified: prior to 2009, there were no published empirical studies on this topic. However, over the last 10 years, numerous studies, from both Australia and the United States, have explored the theory and practice of school-based bushfire education and its role in the development of fire adapted communities (e.g. Ballard et al. 2015; Gibbs et al. 2018; Monroe et al. 2016; Towers 2015; Towers et al. 2018a; Towers 2018b; Towers 2018c). In this paper, I draw together key findings from a suite of recent Australian studies to identify two key elements of effective bushfire education. The first is a holistic risk framework that builds children's conceptual understanding of bushfire risk as a socio-environmental phenomenon. The second is a place-based pedagogy of bushfire risk, which grounds teaching and learning in the socio-environmental contexts of children's lives. The paper concludes with some key recommendations for continued development of good practice in this emergent field.

# A holistic risk framework

Bushfire risk is a socio-environmental phenomenon (Eriksen 2014; Whittaker et al. 2012; Simon 2017). It derives from the interaction of bushfire hazards, the vulnerability of exposed people and assets, and the capacities people possess for disaster prevention, preparedness, response, and recovery (Cardona et al. 2012; Collins 2008; Whittaker et al. 2012; Gaillard et al. 2018). If children are to develop a coherent understanding of bushfire risk that is sufficient for identifying problems and solutions in their own local context, a holistic learning framework that incorporates the environmental and social dimensions is needed. This requires teaching and learning activities that systematically build children's knowledge and awareness of the various dimensions of risk – the physical hazard, exposure, vulnerability and capacities – and how those dimensions interact to cause hazard impacts and disasters.

Building children's knowledge of the physical hazard in the early stages of the education process is fundamentally important. Children often approach bushfire education with a wide range of misconceptions about the physical characteristics of bushfire hazards and these misconceptions exert a strong influence on their understandings of risk and risk reduction (Towers 2012; 2015). For example, children often understand bushfire spread solely in terms of direct flame contact, which leads them to assume that a non-flammable physical barrier (e.g. a river, a road or a brick wall) will prevent a bushfire from reaching their neighborhood or property, thereby eliminating any potential risk (Towers 2012). Children can also tend to underestimate the intensity, magnitude and speed of major bushfire conflagrations and thereby assume they will be able to safely escape on foot or by car, even after a bushfire has begun to impact on their property (Towers 2015; Towers & Ronan 2018c). It is also common for children to report that their family has an emergency bushfire plan, but when encouraged to share the details of that plan, they often describe the features of a house fire escape plan (e.g. get down low and go, go, go; climb out the window; meet the family at the letterbox), which suggests they don't readily differentiate between the physical characteristics of house fires and bushfires (Towers 2012; Towers 2015; Towers & Ronan 2018c). As these examples illustrate, children actively construct their perceptions of bushfire risk and formulate risk reduction strategies by drawing on their existing knowledge of the physical hazard. When that knowledge is characterised by gaps and misconceptions, their ability to accurately interpret and apply new information can be impeded (Towers 2012; Towers 2015).

When children have developed an adequate understanding of the hazard, they are able to explore how it interacts with the social dimensions of exposure and vulnerability to create the conditions for damage and loss. In the context of bushfire risk, exposure refers to the location of people and property relative to a potentially harmful bushfire event (Whittaker et al. 2012). As noted above, children often assume that some form of physical barrier will prevent fire spread, which has obvious implications for their understanding of exposure. However, there is often a broader misconception at play. While children might readily recognise exposure in the context of densely vegetated bushland environments, they often perceive more developed, built-up areas as being relatively immune to bushfire activity (Towers 2012, Towers & Ronan 2018). This stems from an underlying assumption that bushfires happen 'in the bush', not towns or suburbs, and this can prevent children who live in more built-up areas from viewing bushfires as something they need to be concerned about (Towers 2012, Towers and Ronan 2018). Importantly, post-fire research with adults in fire affected communities (Whittaker et al. 2013), as well as numerous formal commissions and inquiries conducted in the aftermath of bushfire disasters (Ellis et al. 2004, Miller et al. 1984, Teague et al. 2010), have found that residents living in more urbanised environments can tend to underestimate their potential exposure. As such, learning how processes like ember attack and house-to-house ignition can carry a bushfire into a built-up area is important, particularly for the increasing number of Australian children living on the wildland-urban interface.

At this point, children also need to understand that exposure to a bushfire event will only lead to damage and loss when it is coupled with vulnerability. Children are usually quick to grasp the concept of vulnerability and they can often identify the general conditions that increase the susceptibility of individuals, households and communities to bushfire impacts (e.g. a lack of public knowledge and awareness; low levels of planning and preparedness; limited financial resources for structural mitigation) (Towers 2012; Towers 2018a; Towers 2018b; Towers 2018c). However, more detailed knowledge of the specific conditions that lead to harm, damage and loss is often lacking. For example, children often advocate for a 'wait and see' approach to evacuation (Towers 2015; Towers 2018c), not realising that this is a major cause of bushfire fatalities and injuries (Haynes et al. 2010; Teague et al. 2010). It is also common for children to identify the bathroom as a safe place in which to shelter during a bushfire (Towers 2015), but this is where a large proportion of bushfire fatalities occur (Haynes et al. 2010; Teague et al. 2010). From the perspective of the learner, it is very difficult to identify and implement effective risk reduction strategies when the conditions that increase susceptibility to bushfire impacts are not clear. Over the past 15 years, scientific research on major bushfire disasters has provided essential insights into those conditions and the social, cultural, political, and economic factors and processes that drive them (Whittaker 2013; Whittaker 2019; Handmer & O'Neill 2016; Haynes et al. 2010). Unfortunately, little if any of that research has been translated into quality age-appropriate educational resources or activities for children. Hence, incorporating the concept of vulnerability as part of a holistic learning framework remains a challenge for educators, who may be reluctant to address this concept in the absence of trusted guidance and advice (Towers et al. 2018a; Towers et al. 2018b). There is a certainly a need for quality resources that can address this gap.

The final component in a holistic risk framework relates to capacities, which can be defined as "the set of diverse knowledge, skills and resources people can claim, access and resort to in dealing with hazards and disasters" (Gaillard et al. 2018, p 865). As Gaillard et al. (2018) point out, everyone possesses a unique set of knowledge, skills and resources that are often shared and combined with those of relatives, neighbours, friends etc who face the same hazards. While often overlooked, children also possess capacities that can be harnessed for reducing bushfire risk and building resilience (Towers 2015). Firstly, children have expert knowledge of their day-to-day activities, routines, movements, networks and interactions (James & Prout 2005). In this context, it is worth emphasising that disaster risk is constructed in the fabric of everyday life (Hewitt 1983, 1998), and the most knowledgeable informants on children's everyday lives are children themselves (Kellett 2011). Secondly, children are not a homogenous group: they have varied concerns, perspectives, interests, talents and strengths that, when applied to the problem of bushfire risk, can drive the development of innovative and creative solutions. While the last several years have seen a gradual shift toward more participatory community-based approaches to bushfire risk reduction that draw upon the endogenous capacities of local people (Muir et al. 2017), opportunities for children to participate have been limited. Incorporating capacities as part of a holistic risk framework for bushfire education provides a pathway for children's participation because it explicitly recognizes them as active citizens with knowledge, skills and resources that can be deployed to enhance and strengthen local risk reduction efforts (Pfefferbaum et al. 2018; Tanner et al. 2009; Mitchell et al. 2008).

## A place-based pedagogy of risk

Historically, bushfire education programs for children have tended to consist of standardised activities that decontextualize children's learning from the environmental, social, cultural and historical contexts of the places in which they live. While standardised activities may offer a useful introduction to general principles, processes and practices, it is becoming increasingly evident that for children to develop a accurate perceptions of local bushfire risks and make genuine contributions to risk reduction efforts, teaching and learning needs to be grounded in place (Towers et al. 2018a). In a place-based pedagogy of bushfire risk, the surrounding socio-environmental context serves as the learning ecosystem: abstracted environments are substituted with local landscapes; textbooks and worksheets are replaced by local experts and experiential activities in the field; and generic information about bushfire risk is augmented by local knowledge, data and predictions. While a holistic risk framework provides a robust structure for learning about bushfire risk as a socio-environmental phenomenon, place-based pedagogy makes that learning relevant and meaningful in the context of children's own households, schools and communities.

Place-based education is nothing new. Over a century ago, in 'The School and Society', John Dewey advocated for an experiential approach to student learning in the local environment, stating that "Experience [outside the school] has its geographical aspect, its artistic and its literary, its scientific and its historical sides. All studies arise from aspects of the one earth and the one life lived upon it" (2007, p. 91). Over the last two decades, however, a proliferation of research and practice, predominantly in the fields of outdoor education and environmental education, has demonstrated the benefits of place-based education for children's learning and development (Gruenewald & Smith 2013; Smith & Sobel 2010). These benefits include stronger connections between students, schools and their communities; the active participation of students in democratic processes, including problem-solving and decision-making; increased student understanding and appreciation of their natural and social environments; and enhanced ecological literacy (Gruenewald & Smith 2013). There is also growing evidence that place-based learning can have a positive impact on academic engagement and achievement across a range of domains, including reading, writing, mathematics, science and social studies (Smith 2013).

While documented examples of place-based bushfire education are relatively rare, two case studies from southeastern Australia serve to demonstrate the value of grounding children's learning in local phenomena. In the CFA's Survive and Thrive program at Anglesea Primary School (Taunt & Rankin 2017), children in grade 5/6 participate in a series of "Bushfire Behaviour and Resilience Sessions" with local CFA staff and volunteers, and other local fire and emergency management experts. They learn to calculate fire danger ratings using local weather data and the Macarthur Forest Fire Danger Index. They conduct local assessments of fuel type, moisture content and slope to map the rate of fire spread under different fire danger conditions. They explore the traditional use of fire with local Indigenous land managers and conduct interviews with veteran volunteer firefighters about past bushfire emergencies and disasters in the area. They also examine local emergency response plans and consider the shared roles of emergency management agencies and local residents in bushfire risk management. Once they have they gained an appreciation of their local bushfire risk and local emergency management arrangements, children identify what Anglesea residents would need to know in order to 'Survive & Thrive' before, during and after a bushfire (Taunt & Rankin 2017). They then develop 25-minute interactive child-led workshops to communicate that information to their families, children at other schools and the wider public (Taunt & Rankin 2017). Through these place-based learning activities, children not only gain a coherent understanding of the local bushfire risk, they also develop a sense of their individual and collective capacities to influence risk reduction and resilience at home, at school and in the local community (Gibbs et al. 2018; Taunt & Rankin 2017; Towers et al. 2018a).

At Strathewen Primary School, the Strathewen-Arthurs Creek Fire Education Partnership program for students in grade 5/6 commences with a fieldtrip to nearby Kinglake National Park, where the children are immersed in a full day of experiential learning activities (Hayward 2018). With guidance from fire management experts and local CFA volunteers, they explore the influence of fuel, weather and topography on local fire behavior, calculate fire danger ratings using the Macarthur Forest Fire Danger Index, and map fire spread using 6-digit grid refencing. They also explore the effect of fire on biodiversity with the local park ranger. Following this fieldtrip, the children work together with their local CFA brigade to explore how human-action and decision-making influence bushfire risk, and identify problems of concern in their local context. Ultimately, through production of educational books and films, they share solutions to those problems with their local community. In 2016, the children produced a claymation film that explains the fire danger rating system and how it can be used to inform household decision-making on high fire danger days. In 2017, they created a children's book about a family who have just moved to Strathewen from the city and need advice and support to prepare for bushfire season. In 2018, they produced a film that explores the fire history of the local area - from the Indigenous use of fire by traditional landowners, through to impacts of the 2009 Black Saturday bushfires and the lessons learned from that event. In a community that was so severely impacted by the Black Saturday fires, the impact of this placed-based approach on the children's learning and development has been profound (Hayward 2018). Not only have the they developed an accurate understanding of the physical hazard, they have also come to understand how exposure and vulnerability interact to cause bushfire disasters (Towers et al., 2018a). In doing so, they have learned that bushfire disasters are not inevitable and have recognised the important role they can play, as children, in preventing them (Hayward 2018; Towers et al. 2018a).

These examples from Anglesea and Strathewen serve to demonstrate how bushfire education that cultivates and values the use of local knowledge and local places can benefit children's conceptual understandings of bushfire risk and resilience. Importantly, the local knowledge children acquire through these programs often extends beyond what most community members would ordinarily gain access to. This positions the children as valuable sources of knowledge and information within their families, which in turn, facilitates their genuine involvement in household bushfire planning and preparedness (Towers et al. 2018a). The process through which children take ownership of that local knowledge - via the production of child-led workshops, books and films - is also an essential part of the equation. It is through that process, in which they exercise a high level of power in decision-making, that children gain a sense of agency and empowerment (Gibbs et al. 2018; Towers et al. 2018a). As demonstrated by findings from in-depth program evaluations undertaken in both Anglesea and Strathewen, the combination of local knowledge and a sense of empowerment leads to a range of highly valuable risk reduction outcomes, including increased levels of planning and preparedness within children's households (Towers et al. 2018a).

## Conclusion

The emerging evidence pertaining to holistic, place-based bushfire education provides policy makers and practitioners with a valuable foundation for the advancement of teaching and learning for bushfire risk reduction and resilience. However, it also presents some major challenges with regards to scaled, sustainable implementation. Existing programs and resources tend to adopt more standardised approaches that can be delivered over short time frames within the confines of the classroom. In this sense, programming that incorporates a holistic risk framework and a placed-based pedagogy represents a radical departure from current practice. Not only does it require a creative approach to program development that is driven by teachers, fire managers and other community partners at the local level, it also requires an extended period of program delivery. Building capacity and capability for this task would require sustained commitment and investment from the fire management and education sectors, at both the state and local level. However, in a context where climate change and rapid urbanisation are exacerbating Australia's bushfire risk and existing approaches to community bushfire education continue to fall short, that commitment and investment is both needed and justified.

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# The mitigation exercise: a long term mitigation planning process, with a coastal flooding case study in Adelaide

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The Bushfire and Natural Hazards Cooperative Research Centre (CRC) has had a cluster of research projects focused on economics and strategic decisions to improve mitigation since its commencement in 2013. A great deal of work (Bushfire and Natural Hazards CRC 2019a,c,d,e) has been done across the economic dimension looking at such issues as:

- risk ownership
- non-market value of losses
- tracking the impacts of disasters as they ripple through sectors of the economy
- land use planning policies for reducing losses

These projects seek to present end-users, emergency management agencies and organisations, as well as recovery agency and other relevant departments such as planning and treasury, with more accurate insights into the potential losses from disasters.

The mitigation argument remains a difficult one to sell. In its 2014 inquiry into natural disaster funding arrangements, the Australian Productivity Commission (2014, pp. 12-13) listed four impediments for effectively managing disaster risk, including:

- a lack of information, such as the future likelihood and impacts of some natural hazards
- difficulty understanding or treating risks because of cognitive and behavioural biases, such as myopia
- market failures, such as asymmetric information, externalities and public good characteristics
- regulatory barriers and distortionary taxes, such as insurance-specific taxes

More eloquently, in 1999 Kofi Annan described the mitigation challenge in terms of preventative costs needing to be paid now, which may potentially reduce invisible costs in an uncertain future.

> *Building a culture of prevention is not easy, however. While the costs of prevention have to be paid in the present, its benefits lie in the distant future. Moreover, the benefits are not tangible; they are the wars and disasters that do not happen. So, we should not be surprised that preventive policies receive support that is more often rhetorical than substantive.*
>
> Kofi Annan, Facing the Humanitarian Challenge: Towards a Culture of Prevention (1999).

For people working in the mitigation and prevention space, these arguments are not new. They were raised as part of the initial research questions to be addressed by the CRC in 2013, and 'Communicating risk and understanding the benefits of mitigation' is one of the four major issues described in the CRC in the May 2019 version of the 'National research priorities for natural hazards emergency management' (Bushfire and Natural Hazards CRC 2019f).

The CRC project, a partnership between the University of Adelaide and the Dutch Research Institute for Knowledge Systems (Bushfire and Natural Hazards CRCb), is playing a role in trying to understand future changes in disaster risk profiles and shift the thinking and priorities of practitioners towards quantifying future losses, and prioritising mitigation.

Since 2013, the project has been developing the platform known as UNHaRMED (Unified Natural Hazard Risk Mitigation Exploratory Decision support system). This is a platform that models and maps the change in land use of an area into the future, following different assumptions about zoning, transport infrastructure, population growth and incentives for land use change.

It has been applied as a case study to greater Adelaide, greater Melbourne, the state of Tasmania, and the south-west corner of Western Australia including Perth. The outputs of the UNHaRMED simulation includes an asset, or exposure layer, of the future area of interest with relationships that describe how they interact with natural hazards in region such as flooding or bushfires to consider how losses vary into the future.

These 'future scenarios' of the landscape or exposure are not intended to be a single 'truth' of the future from a black box. They can be adjusted based on different policy scenarios about land use zoning, population growth projections etc. A report on greater Adelaide (Bushfire and Natural Hazards CRC 2017) presents five possible future versions of Adelaide, each generated with different assumptions and allowed to grow over 30 years. They present the outcomes of current thinking and assumptions.

When these future states are coupled with potential hazard layers (such as earthquakes, flood maps, bushfire severity and extents etc.) it is possible to combine the hazard and exposure layers and describe a state of future risk. This is done using vulnerability functions relating the magnitude of a particular frequency of hazard event with the damage it causes to particular asset classes.

One benefit of the UNHaRMED platform is that it can be applied to almost any land use and hazard, provided there is sufficient geographic data to express them.

When describing how UNHaRMED can be utilised to BNHCRC end-users, there were times when the open and flexible nature of the platform could be daunting. The breadth of potential applications makes it difficult to imagine a case for utilisation. To assist end-users with this, a case study approach has been used to see UNHaRMED being applied to disaster scenarios, to illustrate how it can be applied in other settings.

The 'Mitigation Exercise' process was derived from the case study approach, in an emergency management context. It is a term used to describe an application of the UNHaRMED platform to assist practitioners, agencies and jurisdictions strategically plan the mitigation of future disasters.

This scenario-based approach an opportunity to contribute to the new National Disaster Risk Reduction Framework (Australian Government Department of Home Affairs 2018), the under National Priority 1: 'Understand Disaster Risk'.

**STRATEGY D: Integrate plausible future scenarios into planning**
Scenario-based risk and vulnerability assessment can provide a structured and rigorous method to factor future climate and disaster risks into decision making, in the context of a variety of social, environmental, demographic and economic changes. It is designed to inform both straightforward and complex decisions, including management of residual risk, and is a useful method for navigating future uncertainties.

The process of the Mitigation Exercise includes two phases.

In the first phase, the UNHaRMED platform is used produce a future state (e.g. 2050) of land use, assets and exposure. This future state is then exposed to one or more hazard scenarios. This becomes the scenario of a discussion exercise.

Exercising is a tried and tested approach by emergency services to understanding the potential impacts of hazards and emergencies and test current processes and create insights for learning.

The future scenario, either through extent or impact, is anticipated to be an amplification of current conditions, and challenge current thinking of how such events will be managed into the future. This increased severity can be from both socio-economic changes and the effects of climatic change.

The second Phase is a back-casting exercise to the present. Where potential future mitigation remedies are available, UNHaRMED can be used to simulate them. This can include changes to future exposure (e.g. changes in zoning rules, floor levels, removal of assets etc.) or future hazards (e.g. construction of mitigating infrastructure to change the impact footprint).

This second phase uses the benefit of time to allow a more comprehensive consideration of more significant changes that may need to be made to prevent the future losses predicted in the first Phase. For example, if the Phase 1 scenario is 20-30 years in the future, there may be 10-20 years to consider implementation of mitigation options, which presents a broader range of options. Evaluation of options can also be enhanced using UNHaRMED to test and visualise their effectiveness.

The Mitigation Exercise method is anticipated to have a broad application to many strategic disaster mitigation issues across Australia. It is also hoped that it will appeal to emergency management practitioners but also other related stakeholders, such as town planners, local councils and infrastructure authorities.

The first test of the Mitigation Exercise method is being performed in Adelaide, where the earliest case study model of UNHaRMED was developed.

The area of Port Adelaide was chosen for the exercise to reduce uncertainties in input data and focus on the mitigation exercise process. This is one of the oldest areas of European settlement in South Australia, and currently an area of recognised coastal flood risk. It is also an area of significant population, infrastructure and industrial development, and an identified area of growth for the State.

In 2005, there was a significant study undertaken that mapped coastal flood risk of the Port Adelaide area under current conditions, as well as under future sea level rise scenarios. These inundation coverages form the basis of the hazard layer.

The Port Adelaide Enfield Council:

- Spends over $9 million annually on stormwater management and coastal protection projects.
- Has invested in engineering studies to understand the exposure while ensuring that these findings make their way into the respective Development Plans that cater for land subsidence and sea level rise.

With this in mind, the local council is well aware of the vulnerabilities and is working with land holders and state government to treat this risk where reasonable and feasible.

The two phases are being executed as two one-day workshops about a month apart.

For Phase 1, the exercise will consider the same coastal storm surge event to a 2050 Port Adelaide under two different sea level rise scenarios. The projection into the future will consider population growth under current strategic planning arrangements, and also some subsidence of ground level that have been recorded in some areas. In May 2016, a significant storm surge caused significant losses across many coastal areas of South Australia, including Port Adelaide.

The first scenario will apply the May 2016 storm surge event, amplified with a 300mm sea level rise between 1990 and 2050, the currently agreed level for planning policies. Due to the non-linear relationship between sea level rise and coastal inundation, this significantly increases the projected inundation and damage to Port Adelaide. Looking ahead to 2050, there is also an influence of subsidence in the region, with also amplifies inundation extents.

The second scenario applies the same May 2016 storm but assumes that sea level has risen faster than currently anticipated due to accelerated polar ice melt. This is represented by using the 2100 sea level, or around 800mm of sea level rise from 1990, being experienced in 2050. This is an even more significant impact from flooding and presents a significant challenge to the emergency services.

Mitigation opportunities are being introduced at the end of the first workshop as a way of gaining some insight into the participants' priorities and desired discussion for Phase 2. It also allows UNHaRMED to be applied between Phases 1 and 2 to test assumptions made about mitigation options and provide feedback on their efficacy.

Part 2 will consider hypothetical options for mitigating losses due to sea level rise and storm surge. These include sea walls, rezoning, community resilience and education etc.

It is anticipated that a broader cross section of stakeholders than just the emergency services will be active participants in this stage. Mitigation of complex future disasters, and the processes that lead to future increased exposures, have a complexity of processes that contribute over a long period of time. Similarly, many mitigation strategies may have long implementation timeframes, and need to commence soon to be effective by 2050.

The aim at the end of Part 2 is to increase understanding and produce a structured planning method for considering future disasters, and the means to implement mitigation strategies now to prevent them.

An evaluation will be provided to participants seeking their advice not only on this particular scenario, but also on what other types of scenarios this planning method could be applied to, and how it could be improved.

Interstate observers have been invited to observe and participate in the exercise. It is anticipated, and hoped, that the end-users of the BNHCRC are interested enough by the Adelaide case study to plan and try further Mitigation Exercises using other hazards in other places.

The potential application for any jurisdiction to apply similar methods to their own hazards is significant. UNHaRMED has very few limits in what it can consider.

All states have some form of emergency exercise program to seek new insights and improvements to current practice. An expanded exercise program, with additional examinations of future scenarios involving a broader range of participants can look further towards mitigating the disasters of the future and assisting us all further the goals of shared responsibility and mitigation that we aspire to.

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# Future risk framework: understanding tomorrow's risk and what we can do to reduce it

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Unless appropriate mitigation action is taken, disaster risk is likely to increase into the future due to factors such as climate change, population growth, economic development and an ageing population. Consequently, there is a pressing need to think about plausible future risks and how to best mitigate them. This paper presents the future risk framework, which provides a structured, stepwise approach for relevant agencies to explore future risk and what it means for their organisation. The framework consists of four main steps, progressively increasing in levels of insight into future risk, as well as increasing the level of quantification of risk. A key feature of the framework is the incorporation of sense-making and its implementation consists of a combination of participatory approaches and the use of data, information, modelling and analysis. Application of the framework is illustrated for the case study of Greater Adelaide, South Australia, highlighting the approaches used and the level of insight into future risk obtained at each of the four stages. A discussion on the challenges associated with using this insight to mitigate future risk is also provided, suggesting that a collaborative, multi-disciplinary, multi-agency approach is needed to effectively mitigate all aspects of future risk, especially those associated with increases in exposure and vulnerability.

## Introduction

Disaster risk is considered to be a function of three factors: hazard, exposure and vulnerability (Figure 1) (Crichton 1999). Hazard refers to the magnitude and extent of the event (e.g. the magnitude of an earthquake, the extent of a flood), exposure refers to how many people, assets and other things we care about are affected by the event (e.g. how many people are affected by floods, how many houses are exposed to wildfires) and vulnerability refers to the attributes of the people and things exposed to the natural hazard event in relation to the degree of damage this event will cause (e.g. floor heights in relation to floods, ability of people to escape from wildfires). Consequently, risk only occurs if there is an intersection of hazard, exposure and vulnerability, where the people and things we value and care about are actually exposed to a hazard and the attributes of these exposed people and things are such that damage occurs. This is why hazards are natural, but disasters are not, as disasters only occur when we expose vulnerable people and assets to natural hazards.

As a result of drivers such as climate change, population growth, economic development and an ageing population, all of the factors contributing to risk are likely to increase in the future (Figure 1). However, many countries around the world, including Australia, are signatories to the Sendai agreement, in which it is stated that we will reduce global disaster mortality, reduce the number of people affected, reduce economic loss and reduce damage to critical infrastructure (UNISDR 2015). Consequently, there is an urgent need to think about future risk and what we can do to not only stop it from increasing, but to decrease it in order to meet our stated goals. The need to address future risk now is reinforced by the fact that it has been well established that investment in mitigation (i.e. prevention), as opposed to response and recovery (i.e. cure), is significantly more effective (Rose et al. 2007). In addition, there is a recognition that future risk is a function of decisions made today (Global Facility for Disaster Reduction and Recovery, 2016; Riddell et al. 2019). For example, allowing development in flood prone areas today will result in increased risk in the future.

However, understanding what specific future risks are and what can be done to reduce them is often difficult for organisations responsible for dealing with disaster risk reduction. This is because there is generally a disconnect between the various factors affecting future risk (e.g. climate change, population growth, economic development) and their impact on local risks, as well as a lack of evidence to justify investment in specific mitigation options. In order to assist such organisations with obtaining a better understanding of the future risks, we present our future risk framework, which consists of four successive steps, each of which assists with obtaining a better and more quantitative understanding of future risk. In addition, thoughts are provided on the challenges associated with reducing future risk.

## Future risk framework

The proposed framework for exploring, understanding and quantifying future risk is shown in Figure 2. As can be seen, the framework consists of four main steps, where each stage builds on the outputs from the previous one. Each stage has specific outcomes that enable a more detailed and quantitative understanding of future risk. Consequently, users can decide how many stages of the framework they would like to implement, depending on the desired outcomes.

The first stage corresponds to the exploration of drivers of future risk, which enables users to develop an understanding of how factors such as climate change and population growth can impact future risk in their particular decision context. The second stage corresponds to the development of plausible future scenarios based on integrating drivers of risk explored in the first stage. These scenarios enables users to develop an understanding of how different future developments can combine and how they can create futures of particular relevance to develop or test risk reduction strategies. As part of the third stage, the scenarios developed in the previous step are parameterised by determining the relative levels of common factors affecting future risk (e.g. population levels, community resilience, quality of housing stock) for each scenario. This enables users to develop an understanding of how different drivers of change can translate into different values of local risk factors affecting exposure and vulnerability, in particular. The final stage corresponds to the simulation of the impact of the different scenarios on future risk, which is achieved by quantifying the different parameters (risk factors) from the previous stage and quantifying their impact on hazard, exposure and vulnerability (and hence overall risk) over time using the Unified Natural Hazard Risk Mitigation Exploratory Decision support system (UNHaRMED). This enables quantitative information on the spatial and temporal distribution of risk under different plausible future scenarios to be obtained, increasing understanding of plausible future risk profiles and their contributing factors.

At the different stages, a combination of stakeholder input, data and modelling and analysis are used (Figure 2), although the degree of modelling and analysis increases in the latter stages. It should also be noted that although the four stages of the framework are sequential, there are feedback loops throughout the process via sense-making activities, where feedback is sought from stakeholders on whether the outputs from the previous stage make sense or need to be adjusted (Figure 2).

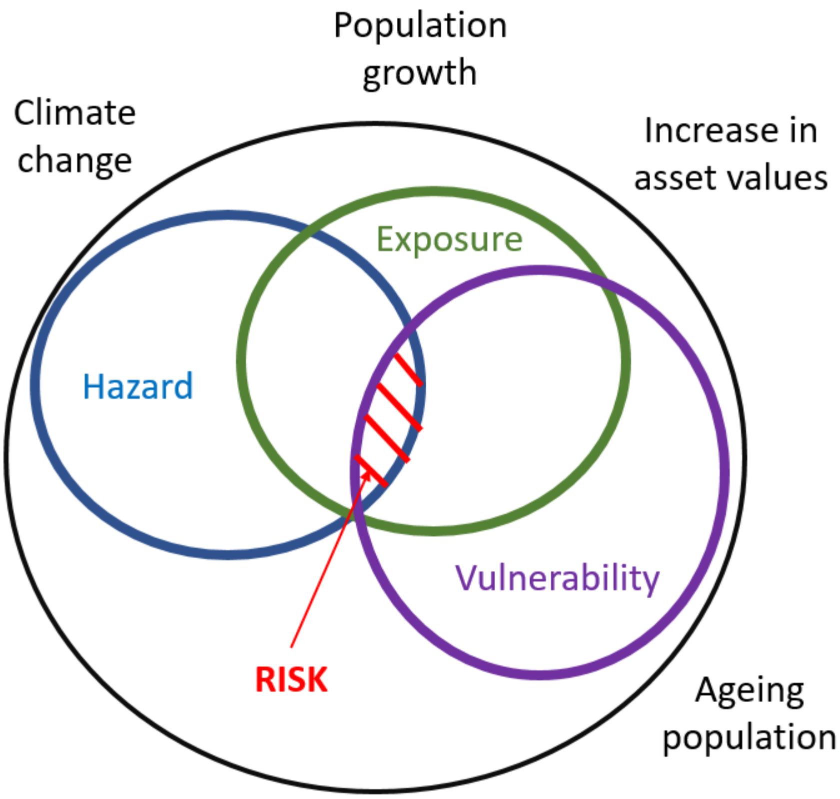



**Figure 1: Illustration of risk as the intersection between hazards, exposure and vulnerability and some of the factors that affect future values of these three components, and hence future risk.**

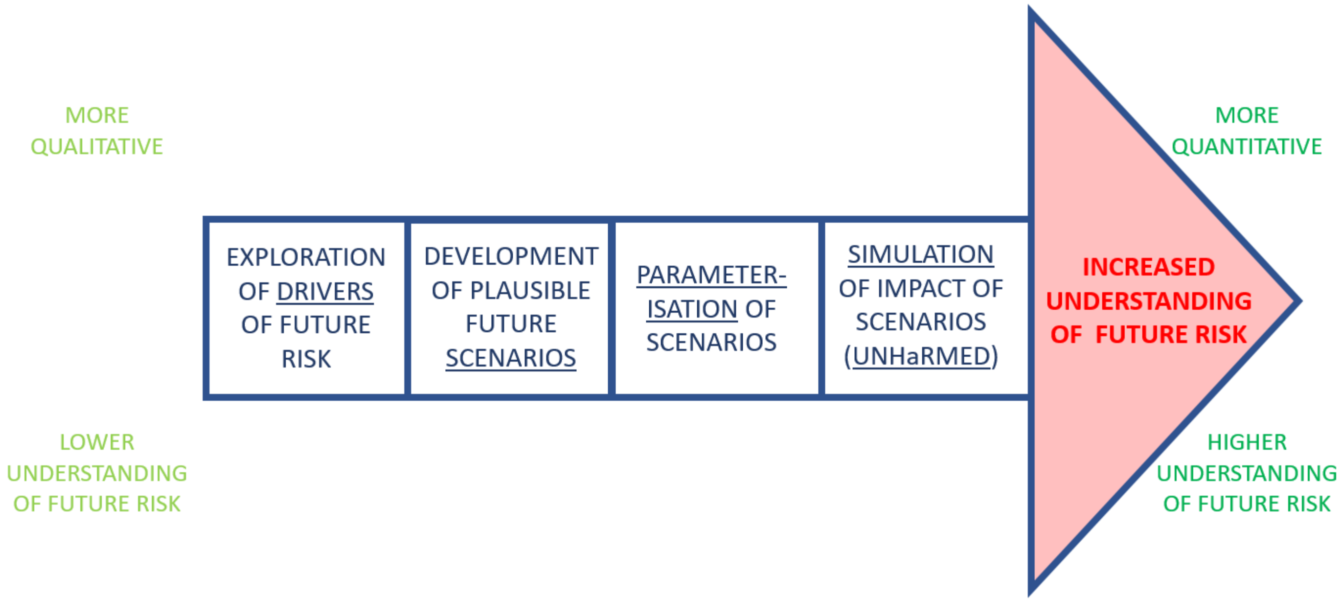



**Figure 2: Proposed future risk framework, consisting of four consecutive steps designed to develop an increasing understanding of future risk.**

In the subsequent sections, further details are provided on each of the four stages in the context of a case study application of Greater Adelaide. Adelaide is the capital of South Australia and has a population of approximately 1.3 million. It is prone to a number of natural hazards, including coastal flooding, riverine flooding, wildfires, earthquake, heatwaves and storms.

## Stage 1: exploration of drivers of future risk

While the general drivers of disaster risk, such as climate change, population growth, economic development, changing demographics etc., are well understood, as mentioned above, there is often a disconnect between these generic drivers and how they affect the specific risks disaster risk management agencies have to manage. In order to address this, we have developed an approach that enables drivers of future risk to be explored in the context of the increased challenges to disaster risk reduction organisations could face as a result of the above drivers of change (Riddell et al. 2018) (Figure 3).

As shown in Figure 3, the main mechanisms for disaster risk reduction considered include top-down government intervention and bottom-up community resilience. Some of the factors enabling government intervention include access to adequate data and knowledge, appropriate governance structures, policies and culture and sufficient economic resources and some of the factors facilitating community resilience include access to sufficient resources, appropriate stakeholder knowledge and understanding of risk and sufficient levels of social cohesion.

For the Greater Adelaide case study, participatory processes were used to take stakeholders through a number of structured exercises exploring how various global drivers of change could challenge the factors enabling government intervention and community resilience over time (Figure 4) This enabled stakeholders to develop a better understanding of how drivers of change could affect future risk in the context of the decisions they have to make.

## Stage 2: development of plausible future scenarios

The outputs from the participatory processes from Stage 1 can be used to develop narrative scenarios that represent coherent storylines of how various drivers of change and their impact on the effectiveness of government intervention and community resilience can combine to represent different plausible futures. For the Greater Adelaide case study, such narrative scenarios were developed to represent five different futures (Figure 5):

- One in which there are low challenges to both the effectiveness of government and community resilience (Silicon Hills)
- One in which there are low challenges to community resilience and high challenges to the effectiveness of Government (Cynical Villagers)
- One in which there are high challenges to community resilience and low challenges to the effectiveness of Government (Ignorance of the Lambs)
- One in which there are intermediate challenges to both the effectiveness of government and community resilience (Appetite for Change)
- One in which there are high challenges to both the effectiveness of government and community resilience (Internet of Risk).

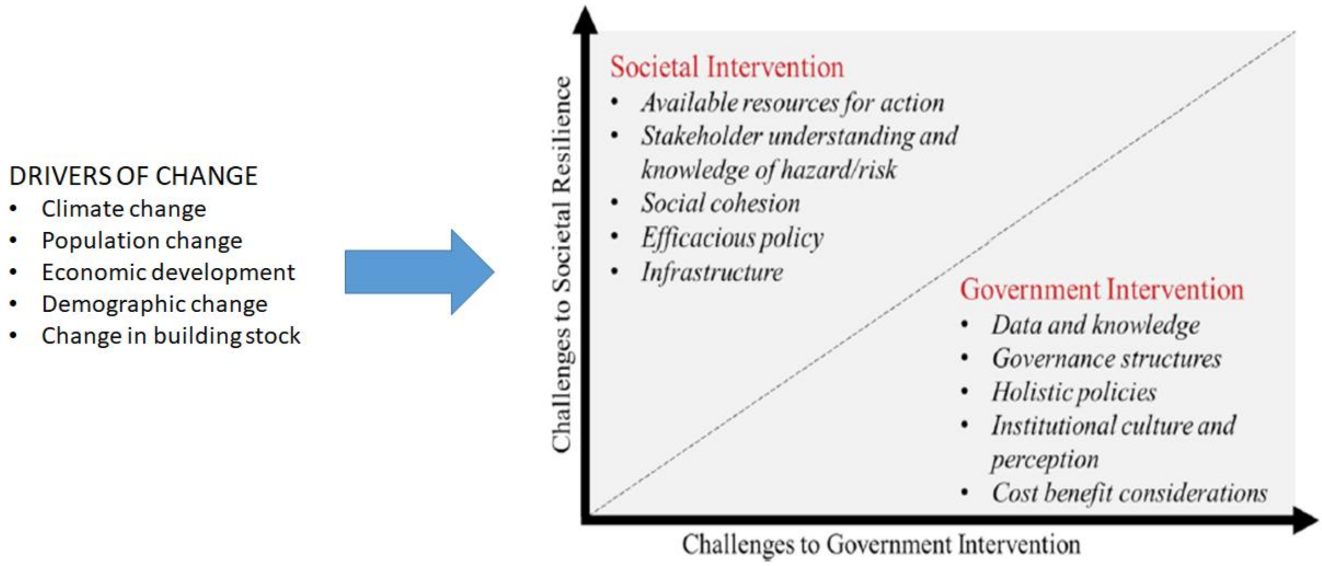



**Figure 3: Approach to exploring drivers of future risk in the context of the increased challenges to disaster risk reduction (adapted from Riddell et al. 2018).**


**Figure 4: Example of output from participatory process exploring how drivers of change impact on future risk in their specific decision context.**

By way of example, the coherent storyline associated with the Ignorance of the Lambs scenario is that there is significant population growth in Adelaide, underpinned by a large influx of refugees (e.g. from areas affected by sea level rise or from areas of unrest). Due to their relative poor economic circumstances, these refugees are likely to be settled on the outskirts of Adelaide in housing of relatively low quality and are reliant on government assistance. The resulting long commute times for work and differences in culture and language are likely to limit opportunities for the development of a strong sense of community. In addition, there is likely to be a lack of situational awareness of potential risk factors associated with natural hazards. Consequently, this scenario corresponds to challenges to community resilience and low challenges to government action. A brief summary of the other four scenarios is given in Table 1, with full descriptions of these narratives given in (Riddell et. al. 2018).

It should be noted that the scenarios are not designed to represent the most likely futures, but plausible futures that stress-test our ability to cope with future risk. In this sense, it is extremely unlikely that any of these scenarios will actually occur. However, they enable relevant government agencies to develop an understanding of how different future developments can combine to challenge / stress their ability to reduce future risk.

**Table 1: Summary of motivating factors underpinning each of the plausible future scenarios for the Greater Adelaide case study.**

| Scenario | Motivating Factor |
|---|---|
| **Silicon Hills**<br>*Low challenges to resilience and mitigation* | Growing valuation of nature and stimulation of tech industries see increase in skills for technology, innovation and R&D. |
| **Cynical Villagers**<br>*High challenges to mitigation* | Downturn in mining and ageing population, shift towards nature and high quality agricultural society. |
| **Ignorance of the Lambs**<br>*High challenges to resilience* | Large immigration to SA from various global areas of unrest. Increasing reliance on Federal Government for funding. |
| **Appetite for Change**<br>*Moderate challenges to resilience and mitigation* | Current projections hold steady, however mid-scenario a series of hazard events leads to increased community awareness. |
| **Internet of Risk**<br>*High challenges to resilience and mitigation* | Increasing reliance on the internet for social and work-related activities decreases community connectedness and resilience. |

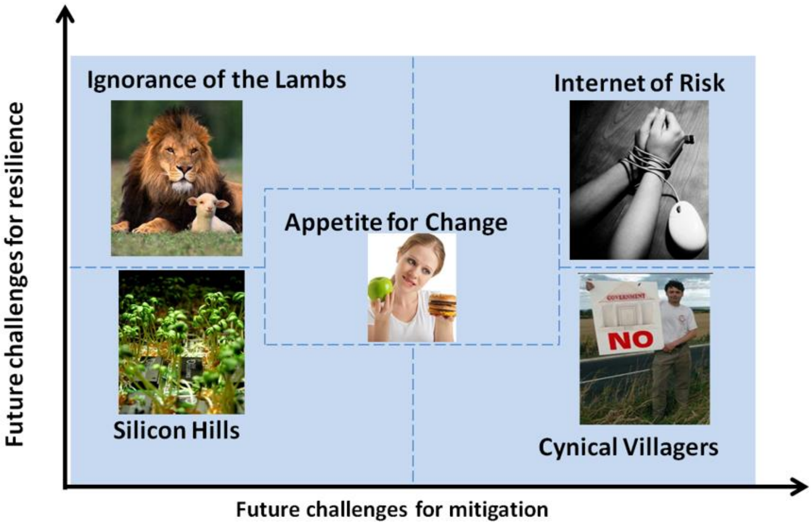
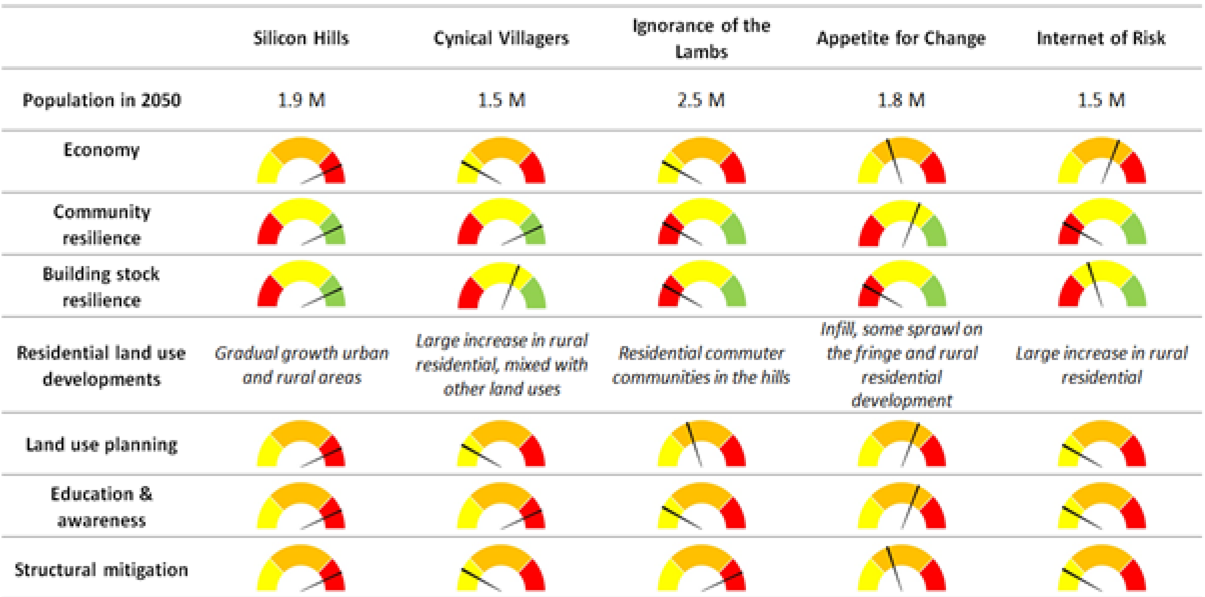



**Figure 5: Illustration of the five narrative scenarios / storylines developed corresponding to different levels of future challenges for societal resilience and mitigation (government intervention).**



| | Silicon Hills | Cynical Villagers | Ignorance of the Lambs | Appetite for Change | Internet of Risk |
|---|---|---|---|---|---|
| Population in 2050 | 1.9 M | 1.5 M | 2.5 M | 1.8 M | 1.5 M |
| Economy | | | | | |
| Community resilience | | | | | |
| Building stock resilience | | | | | |
| Residential land use developments | *Gradual growth urban and rural areas* | *Large increase in rural residential, mixed with other land uses* | *Residential commuter communities in the hills* | *Infill, some sprawl on the fringe and rural residential development* | *Large increase in rural residential* |
| Land use planning | | | | | |
| Education & awareness | | | | | |
| Structural mitigation | | | | | |

**Figure 6: Relative changes in parameters / factors affecting future exposure and vulnerability for the five scenarios developed for the Greater Adelaide case study.**

## Stage 3: parameterisation of scenarios

In this stage, the narrative storylines associated with each of the scenarios can be examined to extract the key parameters / factors that change in the different scenarios and the relative degree of change of each. The results of this analysis for the Greater Adelaide case study are shown in Figure 6, which shows the relative changes in population, the state of the economy, community and building stock resilience, the characteristics of residential land use developments, the effectiveness of land use planning, the level of education and awareness and the degree of structural mitigation for each of the five scenarios. This enables agencies responsible for disaster risk reduction to develop an understanding of how different drivers of change can translate into different values of local risk factors, especially those related to exposure and vulnerability.

## Stage 4: simulation of impact of scenarios (UNHaRMED)

In this final stage, the relative changes in parameters are converted to numerical values based on policy documents and other relevant information, and the resulting spatial and temporal impact is modelled using the Unified Natural Hazard Risk Mitigation Exploratory Decision support system (UNHaRMED) (https://lnkd.in/fhmcpgS). This will provide a range of quantitative dynamic risk outputs at a spatial resolution of 100mx100m and a temporal resolution of 1 year. For example, the change in residential land use, which is a component of exposure, between 2013 and 2050, is shown in Figure 7 for three of the five scenarios. The associated average annual loss from bushfires for building stock in 2050 is shown in Figure 8, and the associated change in social impact of bushfires from 2013 to 2050 is shown in Figure 9.

An understanding of the spatial and temporal distribution of different facets of risk under different plausible future pathways provides the first step towards developing appropriate mitigation strategies. It also provides much needed evidence for investment in long-term disaster risk reduction strategies.

## Sense-making

Sense-making is an important component of the overall process to ensure that the information provided on future risk is consistent with prior knowledge. For example, for the Greater Adelaide case study, stakeholders were asked whether the narrative scenarios developed (Stage 2) based on Stakeholder input in Stage 1 were (i) too extreme, (ii) not extreme enough, (iii) internally consistent storylines and (iv) representative of the input provided by stakeholders to ensure these narratives make sense and therefore provide useful insights into plausible future risks (Figure 10). In addition, stakeholders were asked to comment on the realism of the risk maps produced by using UNHaRMED (Stage 4) (Figure 11).

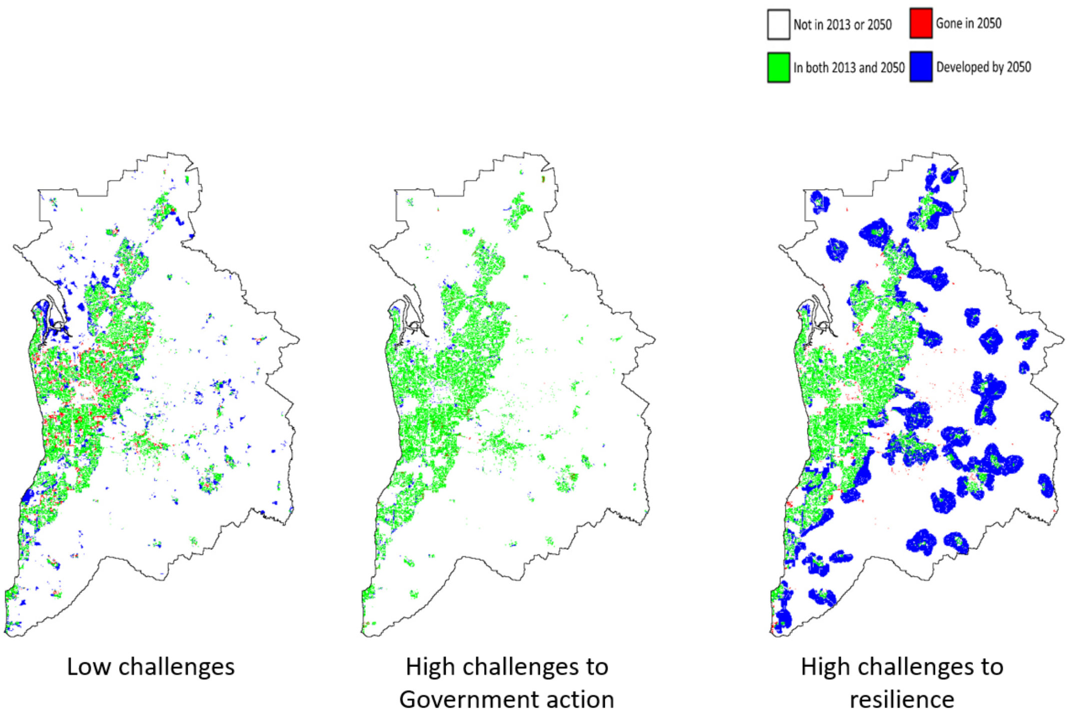



**Figure 7: Change in residential land use from 2013 to 2050 under three of the five scenarios considered for the Greater Adelaide case study (Silicon Hills, Cynical Villagers, and Ignorance of the Lambs).**

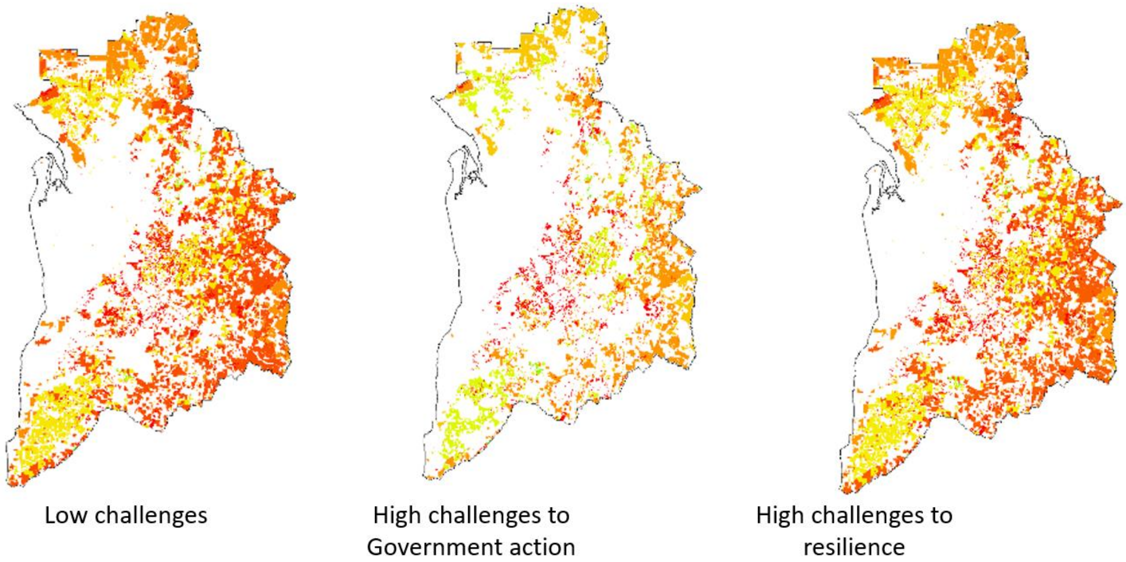



**Figure 8: Average annual loss for building stock due to bushfire in 2050 under three of the five scenarios considered for the Greater Adelaide case study (Silicon Hills, Cynical Villagers, and Ignorance of the Lambs).**

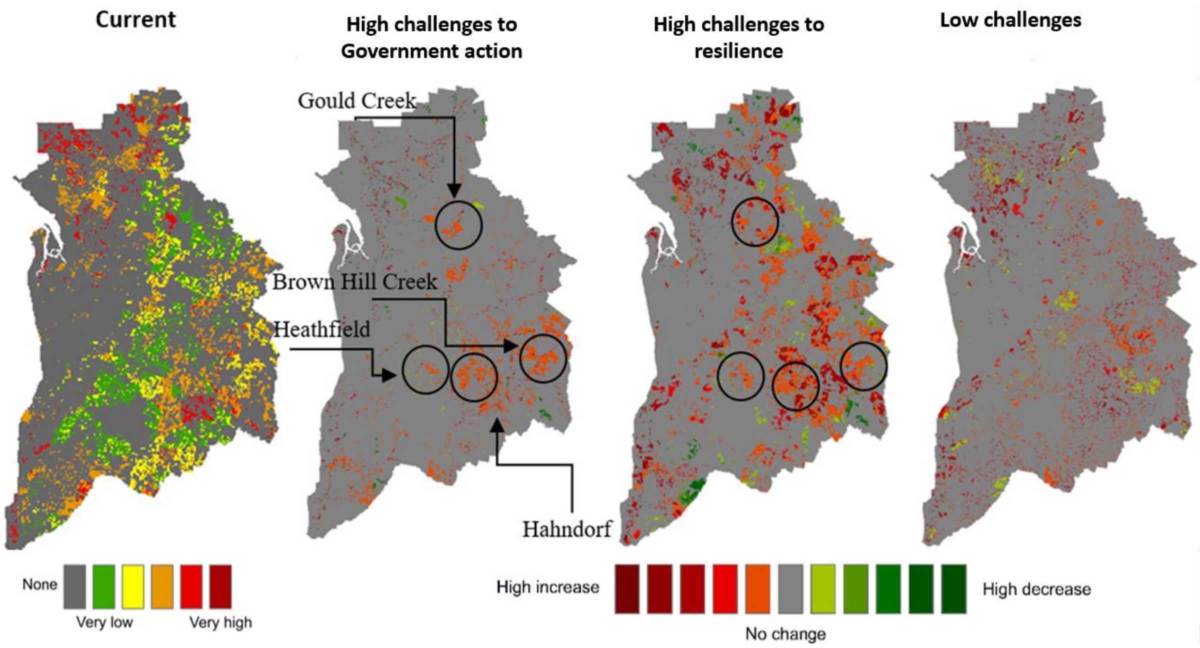



**Figure 9: Change in social impact due to bushfire from 2013 to 2050 under three of the five scenarios considered for the Greater Adelaide case study (Silicon Hills, Cynical Villagers, and Ignorance of the Lambs).**

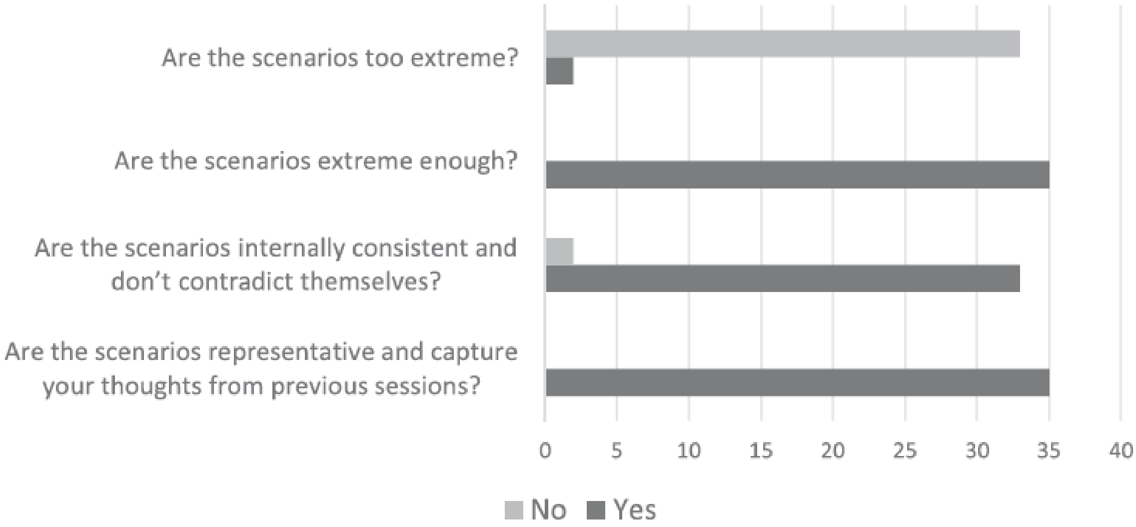



**Figure 10: Stakeholder feedback on narrative scenarios developed for the Greater Adelaide case study**

**Figure 11: Stakeholder feedback on risk outputs from UNHaRMED for the Greater Adelaide case study**

## Mitigating future risk

The biggest increases in future risk are likely to stem from increases in exposure and vulnerability, driven by population growth, urbanisation, urban sprawl, economic development and an ageing population. However, there is generally decreased awareness about the impact of these factors on disaster risk, compared with the influence of hazards (Figure 12). This is because these changes are driven by a range of community values, such as the desire for economic prosperity and living in locations with high amenity value (e.g. near the coast or in forested areas), rather than a desire to reduce disaster risk. Similarly, government organisations regulating such developments also have to accommodate this range of often competing objectives, where the desire to reduce future disaster risk often has a lower priority than objectives likely to result in more immediate benefits (e.g. economic development). As a result, future risk increases almost by stealth, as the increase in exposure and vulnerability over time occurs "naturally" as a by-product of other activities.

As exposure and vulnerability are likely to be the largest contributors to disaster risk, it follows that mitigating these risks by strategies such as land use planning is likely to result in the largest reduction in future risk. However, given that such strategies are not directly controlled by disaster risk reduction agencies (Figure 12), there is a need for a collaborative, multi-disciplinary, multi-agency approach to reducing future disaster risk. The first step in such an approach is the development of a shared understanding of future risk, which can be achieved via the future risk framework introduced in this paper.

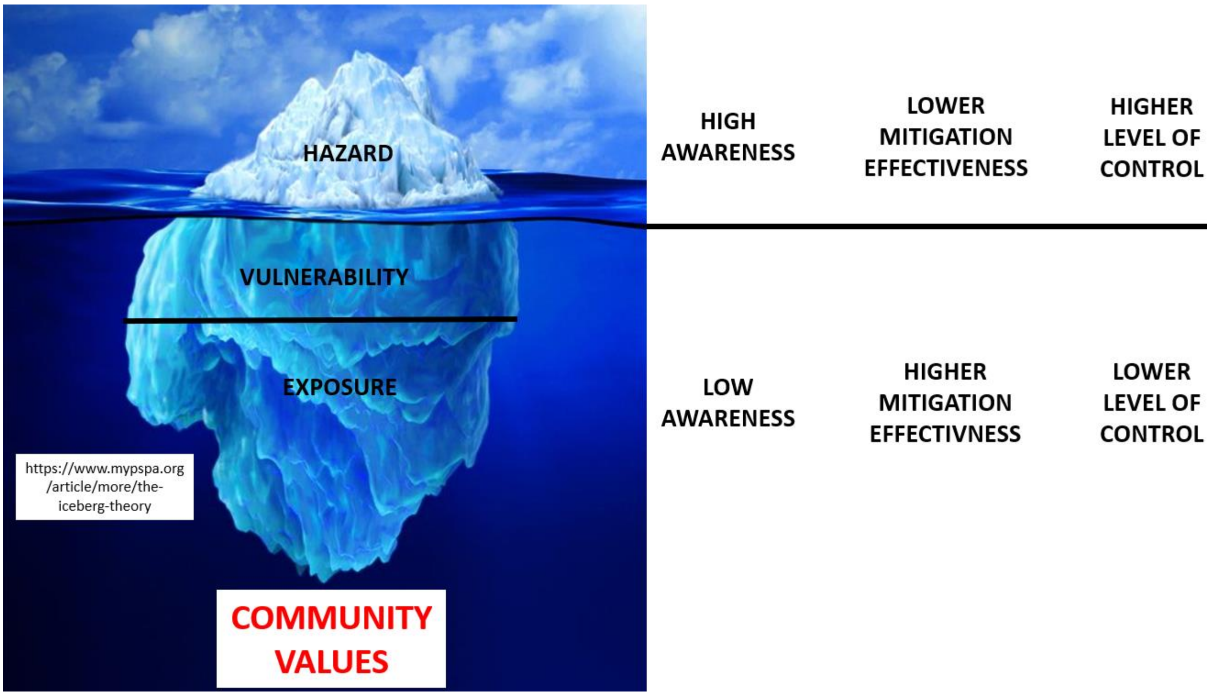



**Figure 12: The "risk iceberg", indicating that there is generally high awareness of the hazard aspect of disaster risk, while awareness of the influence of vulnerability and exposure on disaster risk is generally significantly less, although they are likely to have the biggest influence on future risk.**

## Conclusions

Future risk is a function of decisions made today, so we need to understand future risk now. The Future Risk Framework presented here provides a series of steps to achieve this, each increasing the level of insight into future risk, as well as the degree of its quantification. As much of our future risk is related to increases in exposure and vulnerability, which are driven by factors such as population growth, economic development and an ageing population, a collaborative, multi-disciplinary, multi-agency approach is needed to mitigate future risk. The framework presented here provides a means for facilitating this by enabling different stakeholder groups to achieve a shared understanding of future risk and its drivers, which is the first step in enabling such a collaborative approach to be successful.

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# A case study of South Australia's severe thunderstorm and tornado outbreak

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## Introduction

On September 28, 2016 one of the most significant thunderstorm outbreaks recorded in South Australia impacted central and eastern parts of the state. Multiple supercell thunderstorms were embedded in a Quasi-Linear Convective System (QLCS, Weisman & Trapp 2003) aligned with a strong cold front that was associated with an intense low-pressure system. The storms produced at least seven tornadoes, destructive wind gusts, large hail and intense rainfall. Transmission lines were brought down in four different locations, which contributed to a state-wide power outage.

Accurate prediction and understanding of tornadoes and other hazards associated with severe thunderstorms is very important, for timely preparation and announcement of warnings. By conducting high-resolution simulations, this study aims to offer a better understanding of the meteorology of the South Australian thunderstorm and tornado outbreak. It also contributes to improving knowledge of how to best predict similar severe weather events, which in turn enables better risk management and preparedness for such events. Updraft helicity (Kain et al. 2008), a severe storm surrogate that indicates the potential for updraft rotation in simulated storms, is used to investigate the ability of the model to predict supercell and tornado likelihood.

## Numerical model description and set up

Here, a case study of the September 28, 2016 event is conducted using version 10.6 of the UK Met Office Unified Model (UM), the atmospheric component of the Australian Community Climate and Earth-System Simulator (ACCESS) (Puri et al. 2013). The model consists of a global model run (17 km horizontal grid spacing) that is nested down to grid spacing of 4.0 km, 1.5 km and 400 m (Fig. **Error! Reference source not found.**), with the inner domain size chosen to capture the area where seven tornadoes were reported. Each domain has 80 vertical levels and the model top for the nested domains is 38.5 km.

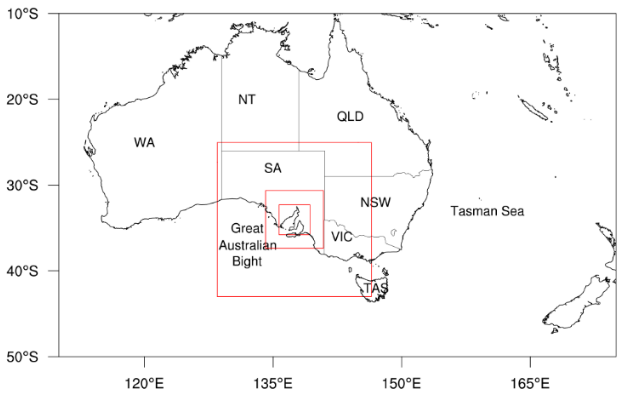


**Figure 1: Outline of model domains, with the larger domain having horizontal grid spacing of 4 km, and the smaller domains have horizontal grid spacing of 1.5 km and 400 m.**

In addition to the described deterministic simulations, convective-scale ensemble simulations of the same event were conducted to learn about the predictability of this event. For these simulations, version 11.1 of the UM ensemble nesting suite is used and consists of the Met Office global ensemble model (MOGREPS-G; Bowler et al. 2008) as a driving model, with a horizontal grid spacing of ~ 33 km, which is similarly nested down to 4 km, 1.5 km and 400 m regional domains.

The ensemble consists of 6 simulations (1 control + 5 perturbed) initialised at 1200 UTC 27 September 2016 (+ 9.5 hours for local time) and ran for 24 hours, with initial and boundary conditions for each member provided by the corresponding MOGREPS-G member. Like the deterministic model, all simulations use the RA1M science configuration and all domains have 80 vertical levels with the model top for nested domains of 38.5 km.All simulations use the Regional Atmosphere Mid-latitude first release (hereafter RA1M) science configuration (Bush et al. 2019), to assess model performance over the South Australia domain, and simulation results are compared to radar imagery. All simulations were initialised at 1500 UTC 27 September 2016 (+ 9.5 hours local time) and ran for 48 hours.

## Simulation results

### a) Deterministic simulations

To investigate how well the model represents severe thunderstorms, observed radar reflectivity (Fig. 2, left) is compared to simulated reflectivity (Fig. 2, right) from the 1.5 km model at 0600 UTC 28 September 2016. Figure 2a shows the line of thunderstorms that were associated with large hail and several reported tornadoes (Bureau of Meteorology 2016), and the overall timing and location of severe thunderstorms is captured well by the model (Fig. 2b). Individual supercells are not depicted by the model as grid lengths on order of 1 km are not able to fully resolve supercell or tornado-like signatures (e.g., Bryan, Wyngaard & Fritsch 2003; Hanley, Barrett & Lean 2016).

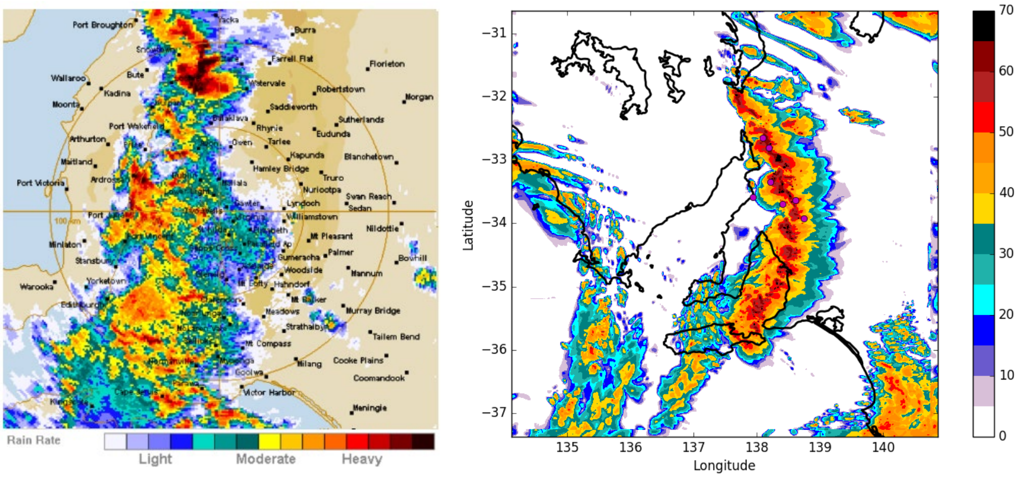


**Figure 2: (Left) Observed radar reflectivity and (right) simulated radar reflectivity at 0600 UTC 28 September 2016. The magenta dots in the right panel are the observed locations of the tornadoes.**

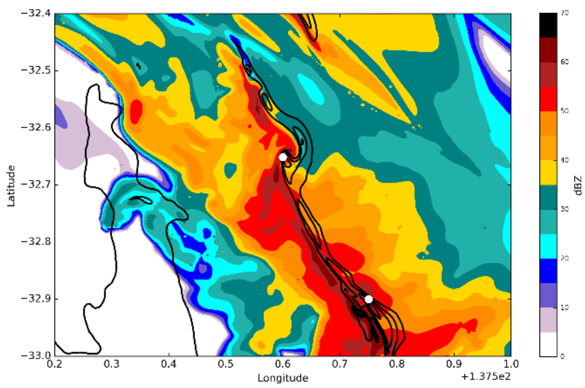


**Figure 3: 0600 UTC 28 September 2016 simulated radar reflectivity (dBZ) at 2 km height for the 400-m simulation. The white dots are the observed locations of the tornadoes and the black box denotes the area shown in Fig. 4.**

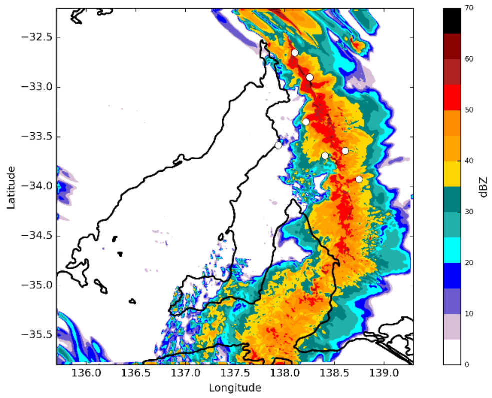


**Figure 3: As for Fig. 3, only for area denoted by the black box in Fig. 3.**

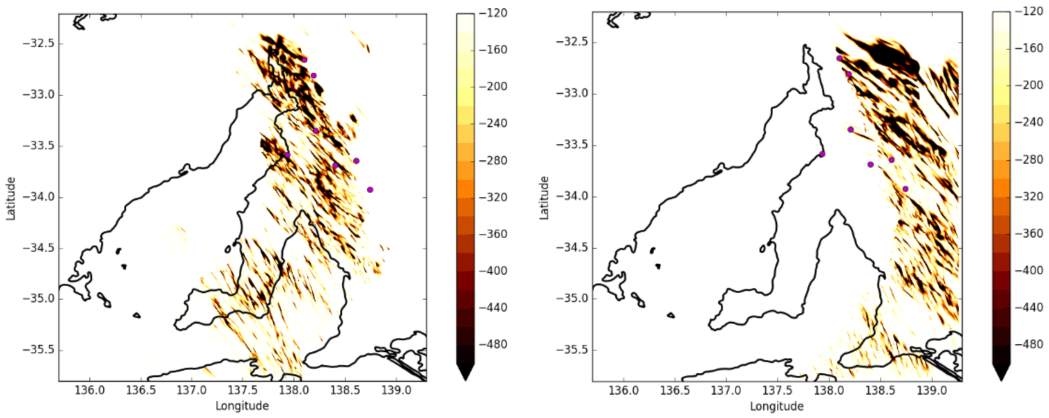


**Figure 4: Hourly minimum updraft helicity (UH, $m^2\ s^{-2}$) for the period (left) 0500-0600 UTC 28 September 2016 and (right) 0600-0700 UTC 28 September 2016. The magenta dots denote the approximate location of observed tornadoes.**

Figure 3 shows simulated reflectivity from the 400-m simulation, where the northern cells (black box in Fig. 3) are stronger and better defined than the southern part of the convective system, indicated by differences in the simulated reflectivity. A close-up view of the simulated reflectivity and vertical velocity (Fig. 4) in the northern part of the system (black box in Fig. 3) reveals a hook-echo feature and a curved updraft that coincide with the location of one of the reported tornadoes (northernmost white dot in Fig. 4). The hook echo indicates the presence of a mesocyclone (Davies-Jones 2015) at this location. The reported tornado is estimated to have started at approximately 0615 UTC, 28 September 2016 (Bureau of Meteorology 2016; Sgarbossa et al. 2018), which is about 15 min later than in the simulation. Therefore, the mesocyclone and features that indicate the possibility of a tornado are well captured with the 400-m simulation.

Based on (Kain et al. 2008), a model diagnostic field (updraft helicity) is used to investigate the ability of the model to identify the potential for supercell thunderstorms, within which tornadoes may form.

Updraft helicity (UH) is the product of vertical vorticity and vertical velocity, integrated vertically from 2 km to 5 km:

$$\boldsymbol{UH = \int_{2km}^{5km} w\left(\frac{\partial v}{\partial x} - \frac{\partial u}{\partial y}\right) dz},$$

where w is vertical velocity ($m\ s^{-1}$), $\left(\frac{\partial v}{\partial x} - \frac{\partial u}{\partial y}\right)$ is vertical vorticity ($s^{-1}$) and z is height (m). Relevant values of UH are negative in the Southern Hemisphere (SH). While UH can be computed as an instantaneous value at a single model output time, (Kain et al. 2010) developed hourly maximum UH that tracks the maximum (minimum in the SH) value of the diagnostic at every grid point at any model time step within the previous hour (e.g., Clark et al. 2012, 2013; Sobash et al. 2016). Here, UH is computed in this way as an output diagnostic in the Met Office UM model.

Figure 5 shows hourly minimum UH for the period between 0500-0600 UTC and 0600-0700 UTC 28 September 2016, which coincides with the time period of the reported tornadoes (Bureau of Meteorology 2016). It shows elongated swaths of hourly minimum UH exceeding -120 $m^2s^{-2}$ and reaching values < -400 $m^2s^{-2}$ in close proximity to the observed tornadoes (magenta dots in Fig. 5). A long and coherent, vortex-like swath of hourly minimum UH < -500 $m^2s^{-2}$ coincides with the location of the northernmost observed tornado, where the mesocyclone was identified in simulated reflectivity and vertical velocity (cf. Fig. 4). This indicates that the use of UH as a diagnostic field would have provided useful guidance for identifying the potential for tornado formation in this case. Another parameter that is worth investigating as a tornado proxy alongside UH is the Okubo-Weiss (OW) parameter, defined as

$$OW = \zeta^2 - (E^2 + F^2) = \left(\frac{\partial v}{\partial x} - \frac{\partial u}{\partial y}\right)^2 - \left\{\left(\frac{\partial u}{\partial x} - \frac{\partial v}{\partial y}\right)^2 + \left(\frac{\partial v}{\partial x} + \frac{\partial u}{\partial y}\right)^2\right\},$$

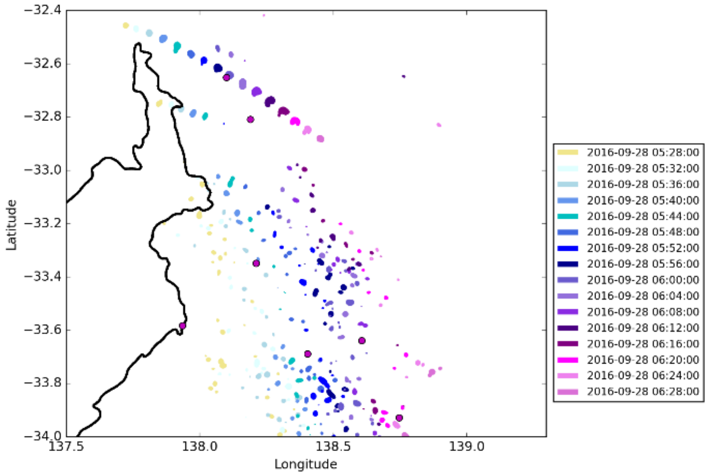


**Figure 5: The Okubo-Weiss parameter (OW; positive values only), calculated as a 1 km-4 km layer average for the time interval between 0528 UTC and 0628 UTC 28 September 2016. The magenta dots denote the approximate location of observed tornadoes.**

where $\zeta$ is the vertical vorticity, $E$ is the stretching deformation, and $F$ is the shearing deformation (Okubo 1970; Weiss 1991; Markowski et al. 2011). The OW parameter highlights flow regions where rotation dominates over strain, and therefore can be used to identify rotation (or vortices) associated with tornadic storms (e.g., Markowski et al. 2011; Coffer & Parker 2016).

Figure Figure 5 shows the OW parameter calculated as per the above equation, using layer averaging between 1 km and 4 km at 4-minute intervals during the time interval between 0528 UTC and 0628 UTC 28 September 2016. It shows a coherent track of positive OW parameter that coincides with the location of the northernmost reported tornado, thus clearly identifying the mesocyclone in this simulation. This analysis shows that the OW parameter identifies the rotation associated with the mesocyclone in these simulated storms and gives a clear indication of a tornado path. This suggests it can be used as an additional diagnostic alongside UH to assess tornado potential, thus potentially reducing false alarms.

## b) Ensemble simulations

shows the simulated radar reflectivity for each ensemble member and should be compared to Figure 2. The variation in the mode of convection is immediately apparent. While members 1, 2 and 5 display a QLCS structure quite similar to the deterministic forecast, member 0 is weaker to the north, member 4 is weaker throughout, member 3 has independent cells of convection rather than a QLCS.

The results from the convective diagnostic tools from these simulations possess a similarly wide range, although for reasons of space we show only the UH. Hourly minimum fields of UH for the six ensemble members are shown in Figure 7, with members 1 and 2 again being the most like the deterministic simulation. The four individual convective cells in member 3 each possess a strong band of intense UH, suggesting that these four cells are individual supercells, in contrast to the QLCS structure of members 1 and 2. The weaker UH in the remaining members is indicative of less

The analysis presented in the previous section is based on the deterministic, high-resolution simulations that enable the study of the dynamics and properties of tornadic storms, as well as highlighting how diagnostics such as UH and the OW parameter could be used as severe storm surrogates.

However, they do not provide information on the uncertainty associated with the timing, location and intensity of the tornadic storms or tornado pathlengths (e.g., Hanley, Barrett & Lean 2016; Snook, Xue & Jung 2019). Therefore, convection-allowing (i.e. grid lengths on the order of O(1km)) ensemble simulations are necessary to overcome these issues and to improve forecasting of severe storms and associated hazards, as tornado-resolving ensemble simulations are not very practical due to extreme computational costs involved (e.g., Zhang et al. 2015; Sobash, Schwartz, et al. 2016; Snook, Xue & Jung 2019).

The ensemble simulations showed some differences to the deterministic simulation described above. The most important of these is about a half-hour difference in timing of the event, likely due to the use of a different global initial condition.

favorable, but not impossible, conditions for tornadogenesis.

# Summary

The deterministic simulation, and two of the six ensemble members, produced simulated radar reflectivity plots whose structure, orientation, timing and intensity were in close agreement with the observations. In the remaining ensemble members, the convection was either weaker, or displayed a different structure, to that observed.

In the deterministic simulation, a strong mesovortex embedded in the main rainband closely agreed in position and timing with one of the observed tornadoes. Numerous diagnostics of mesovortex formation were examined, of which two demonstrated strong utility: the updraft helicity and the Okubo-Weiss parameter.

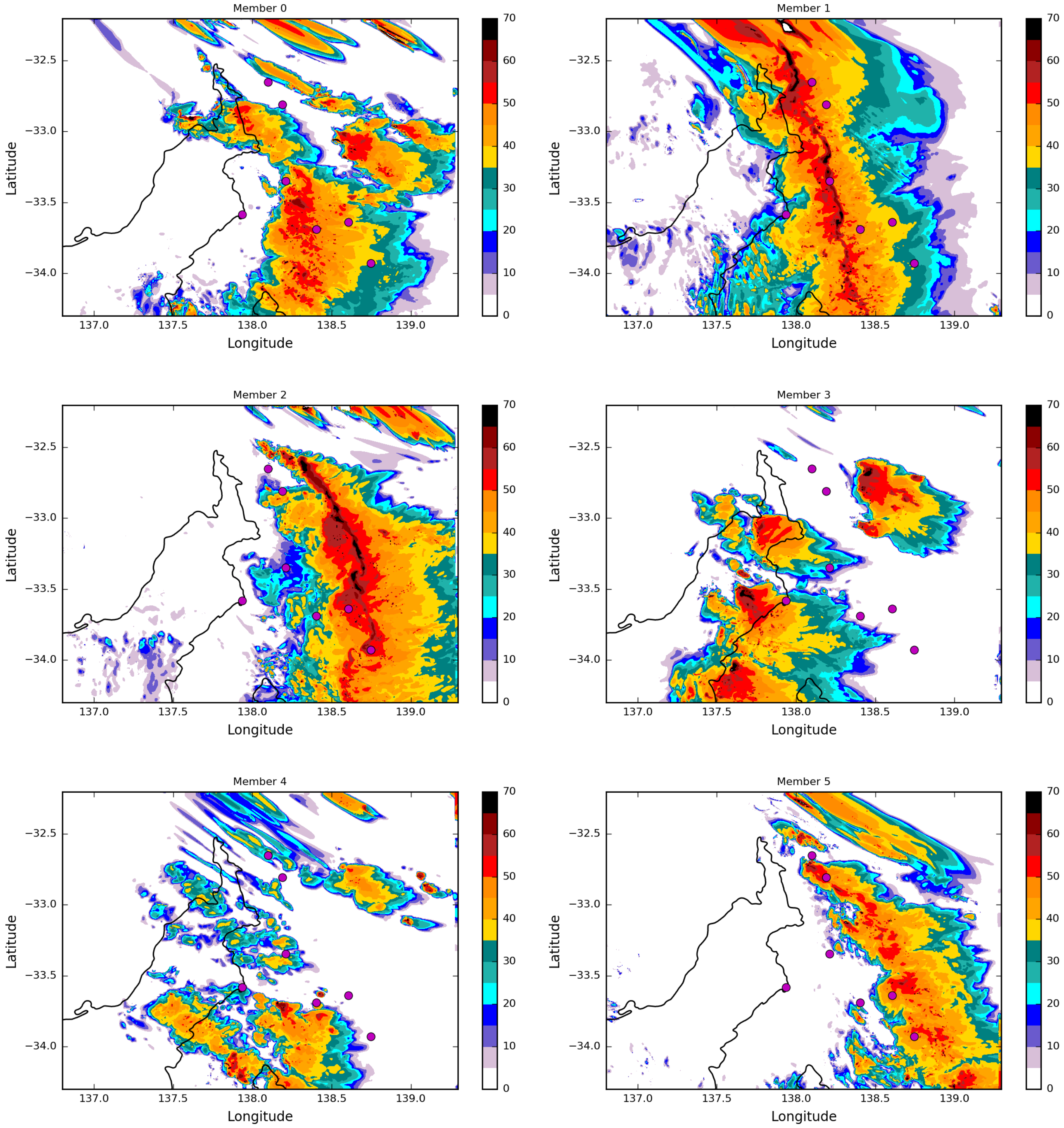


**Figure 6: Snapshots of simulated radar reflectivity from the ensemble simulation.**

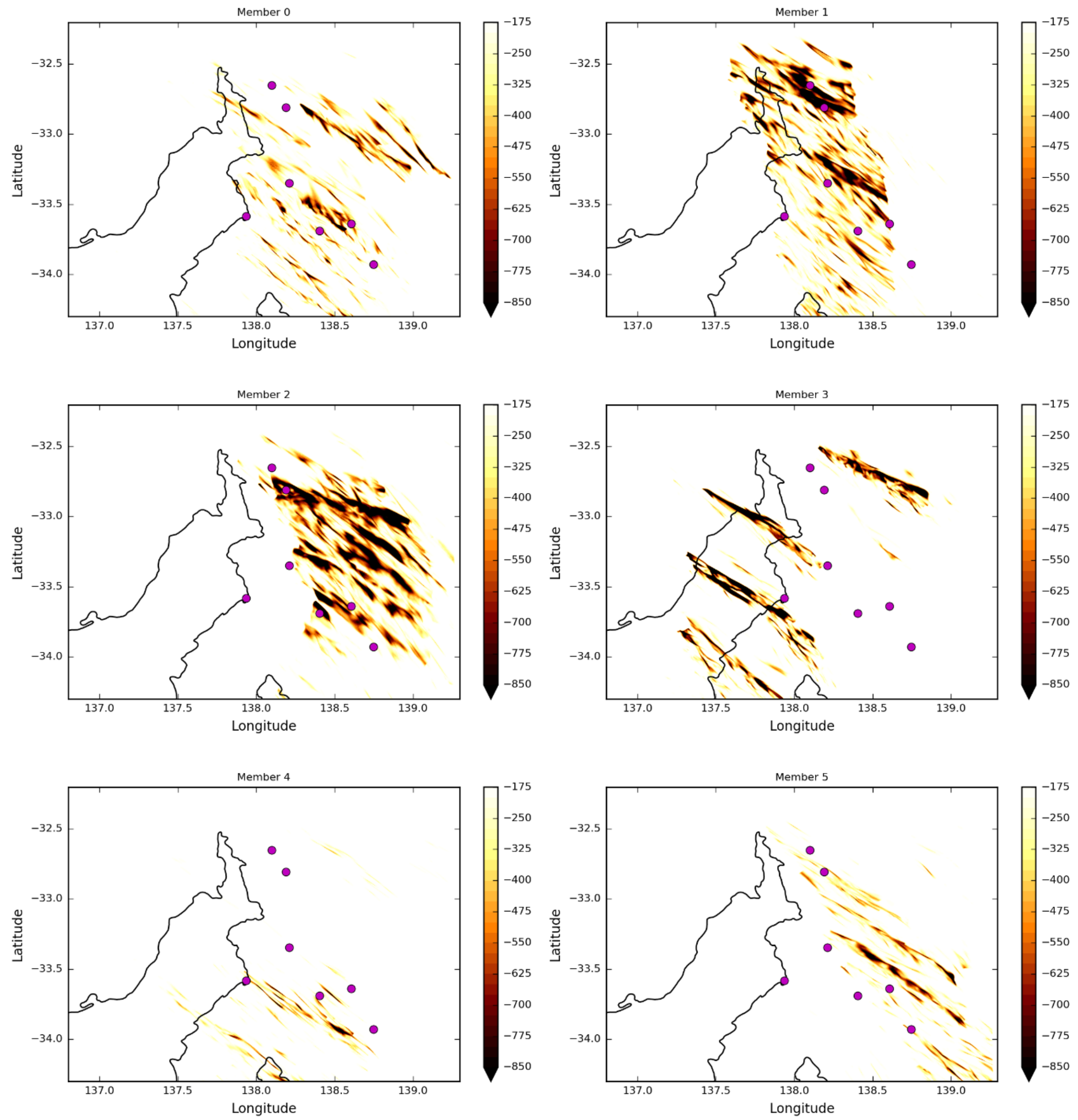


**Figure 7: Hourly minimum updraft helicity (UH, $m^2\ s^{-2}$) for the 6 ensemble members.**

The ensemble simulations highlight the uncertainty associated with timing, location and intensity of the convective systems that spawned the tornadoes. While each of the members indicated some potential for tornado formation, this potential varied in magnitude, timing and location between the members. It may not be appropriate to assign a numerical probability to tornado formation in this case, since the ensemble has not been calibrated for this purpose. Nevertheless, such an ensemble would have strongly supported a forecast of a high risk of tornado formation.

This ensemble simulation also presents a good example of an important advantage of ensembles over deterministic simulations. The control member of the ensemble (i.e. the unperturbed member 0) provided a more modest indication of tornadoes, especially to the north of the region of interest, as did two of the others. If any of these had been the sole deterministic member available, the forecasters would have not received as strong an indication of the potential for tornadoes. A single deterministic forecast can be regarded as a random choice from the set of all possible ensemble members. Although in this case the deterministic forecast happened to strongly indicate tornado risk, it could well have been weaker. The most extreme forms of severe weather are, almost by definition, rare events. Thus, the use of an ensemble reduces the chances the numerical guidance will unluckily miss the true magnitude of the event.

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# Climate change as an emerging disaster risk in Australia and Oceania

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## Introduction

Climate change is recurrently cited as the most important perceived challenge of this century (Intergovernmental Panel on Climate Change 2014; Watts et al. 2017). Yet, the perceptions of the risk of climate change, its societal impacts, ramifications and particularly the solutions needed to address it require further investigation.

This study profiles regional emergency and disaster management professional's perceptions of climate change as an emerging disaster risk in Australia and Oceania. We aimed to examine what evidence exists to support decision making and profile the nature, type and potential human impact of climate change as an emerging disaster risk in Australia and Oceania.

## Method

Thirty individual semi-structured interviews with participants from nine different countries were conducted. All of the participants were engaged in disaster management in the Oceania region as researchers, practitioners in emergency management or disaster healthcare, policy managers or academics. Participants were interviewed to discern their perceptions of current disaster risk in the Oceania region and emerging disaster risks in the next decade.

Data collection was conducted between April and November 2017. Thematic analysis was conducted using narrative inquiry to gather first hand insights on their perceptions of current and emerging threats and propose improvements in risk management practice to capture, monitor, anticipate and control disaster risk.

This study used The Sendai Framework for Disaster Risk Reduction as a conceptual framework to examine emerging disaster risk in Oceania.

## Results

The majority of interviewees viewed climate change as a risk or hazard. When this perception was explored further a breadth of impacts in Oceania related to climate change were described. Hazards identified included climate variability and climate related disasters; increasing infectious disease related to climate change; increasing heatwaves; climate issues in island areas and loss of land mass; and trans-nation migration and increased transportation risk due to rising sea levels. A participant from Timor-Leste related that:

> *"We have already seen some evidence of the impacts of climate change, personally noticed difference in seasons, have seen significant new drought impact in East Timor."*

An Australian participant described the effects of climate change on the natural environment and its relationship to disaster related to infectious disease; in particular,

> "Climate change is increasing vector prevalence;"

The impact of climate change on basic needs was identified by a Pacific resident who voiced concern of the sustainability of small island states to support the needs of populations impacted by climate change. A concern of access to food and fresh water was expressed:

> *"Climate change causes migration due to food and water insecurity"*

Moreover, a further respondent (Australian) described climate change as having an indirect, influencing affect across populations' vulnerability:

> *"Populations are vulnerable to emerging risks; overall vulnerability is increasing due to climate change with more hot days and less cool days."*

When participants described why they thought climate change was a risk, human impact on the natural environment featured strongly in participant responses. Descriptors included:

> *'human development and its imbalance with nature'; 'increasing global warming influencing natural disaster risk'; and, 'manmade causes/ manmade impacts on planetary health'.*

Insights on how climate change supported risk analysis and decision making varied between respondents. Geography, societal change and political will were key factors described:

> *'The location of Oceania lends itself to these risks. What's reported seems to indicate that they are escalating in size and*

*population numbers are increasing therefore the footprint is increasing'.*

This response is insightful in demonstrating that whilst Oceania has a natural disaster risk profile, the augmentation of natural disaster impact is related to both climate change and changes in population size and density.

Investigation of the relationship of society and governance in respect to disaster risk reduction and climate change produced findings that indicated challenges were perceived in upstream and downstream sections of communities. Whilst government inaction was voiced, it was also evident that there was a perceived lack of engagement at an individual level in some sectors of society:

> *"Government of the day not seeing them as a high priority in terms of mitigation due to cost, lack of government will to alter current human impact trajectory."*
>
> *"Society is becoming more modernised and therefore more vulnerable to a lack of technology when it fails.....heath systems are vulnerable in developed countries due to technology reliance and rapid/unsustainable urbanisation."*
>
> *"Weather, decreasing natural resources, affluent society have high expectations that may not be met post impact....the sense of community has reduced over years particularly in big cities, in condensed areas there is an increased risk of disruption to basic needs."*

When examining barriers to improvement in understanding disaster risk, interviewees identified challenges related to risk appreciation of slow impact events and inadequate measurement of the long term health effects of disaster:

> ***"The use of the word disaster is the Achilles heel in risk assessment as it has a connotation that infers a large event rather than a small event or slow burning/onset or series of small events - terminology is important in ensuring event capture."***
>
> ***"There is a lack of evidence to describe long term health effects associated with disasters and therefore investment in preventing or responding to these consequences. There is a lack of evidence for interventions and validation of them and little evaluation of determinants of risks associated with disasters – we need to look at determinants of an event not just the response."***

When examining solutions to improving disaster risk assessment a strong theme of community and individual engagement and responsibility emerged; particularly in reference to understanding and ownership of risk:

> *"Ensuring grassroots training on preparedness and response on the disaster risks that are relevant to those communities. Providing training to communities and ensuring plans are local and relevant."*
>
> *"Every community needs to own risk management strategy that is updated regularly with new and evolving knowledge. Urban planning needs disaster risk strategies built into them with detail. Then communicate these actions into the local population"*
>
> *"Improve connectedness in communities, and knowing people and groups within them – this should be a function of disaster practice that creates trusted networks."*

## Discussion

The Lancet Commission reported climate change as "the biggest global health threat of the 21st century" (Watts et al. 2017). This research investigated perceptions of current and emerging disaster risk in Oceania (Cuthbertson et al. 2019). The majority of respondents resided in Australia. They associated climate change as a primary current and emerging disaster risk that threatens the safety and security of communities. Climate change has been identified as future hazard in Australia (McAneney et al. 2009). The National Strategy for Disaster Resilience has included climate change within its scope following the 2008 Australian Prime Minister's National Security Statement (Rudd 2008, Council of Australian Governments 2011).

The Sendai Framework for Disaster Risk Reduction notes the importance of climate change, identifying it as a driver of disaster risk and articulates its relationship to disaster risk reduction and disaster risk assessment with a specific call for action on climate change and variability (UNISDR 2015). This policy tone indicates the relationship between the Sendai Framework for Disaster Risk Reduction and the United Nations Framework Convention on Climate Change Paris Agreement, and is demonstrative of the need for collaboration across disciplines and practice for comprehensive disaster risk reduction activities (UNISDR 2015, United Nations 2015). Moreover, and directly related to the Oceania region, The Sendai Framework for Disaster Risk Reduction specifically identifies the vulnerability and risk of small island states for particular attention (UNISDR 2015).

The findings of this study are consistent with previous research describing the health impacts of climate change. The fifth assessment report of the Intergovernmental Panel on Climate Change (IPPC) has identified injuries, hospitalisation and deaths due to intense heat waves, fires and other weather disasters and changes in patterns and impacts of infectious disease (International Panel on Climate Change 2014). Importantly the report notes that populations with low socio-economic status and pre-existing vulnerabilities are at greater risk of the impacts of climate change. Specific risks posed by climate change to populations in Oceania resulting in climate refugees have been previously reported by Weir et al who noted the intersection of climate change, conflict and disaster (Weir et al. 2011).

There is overlap between disaster risk reduction and adaption to climate change strategies. The increasing severity and intensity of natural disasters impacts many communities sensitive to changes in climate. Whilst disaster risk reduction embodies an 'all hazards' approach, focus on climate change adaptation strategies is required where socio-economic vulnerability is increased due to climate change.

# Conclusion

Climate change is perceived as a significant contemporary and future disaster risk in the Oceania region. Strategies for action identified by respondents include improved government and community engagement in risk understanding, ownership and mitigation; and improved understanding of the long term effects of disaster impact upon human health.

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