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Cover:
Dr Mark Finney from the US Forest Service delivers the opening keynote his new fire behaviour research at the 2015 Research Forum.
Photo by the Bushfire and Natural Hazards CRC.

TABLE OF CONTENTS

PEER REVIEWED PAPERS

NON-PEER REVIEWED EXTENDED ABSTRACTS

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PEER REVIEWED PAPERS

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THE FUTURE OF 'NON-TRADITIONAL' EMERGENCY VOLUNTEERING: WHAT WILL IT LOOK LIKE AND HOW CAN IT WORK?

Research proceedings from the Bushfire and Natural Hazards CRC & AFAC conference
Adelaide, 1-3 September 2015

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ABSTRACT

THE FUTURE OF 'NON-TRADITIONAL' EMERGENCY VOLUNTEERING: WHAT WILL IT LOOK LIKE AND HOW CAN IT WORK?

The future landscape of emergency volunteering and volunteer management in Australia is not going to be the same as the landscape of the past. Overlapping and interacting developments taking place both within the emergency management sector and external to it are likely to lead to forms of volunteering, and volunteer management and engagement, that are 'non-traditional' for the established emergency management sector becoming much more prominent in the future alongside more traditional emergency management volunteering. This paper considers the questions of what this non-traditional volunteering is likely to look like in the future and how EMOs can successfully engage with it. It outlines seven types of non-traditional emergency volunteering that are likely to feature more prominently in the future ('what will it look like?'). It then considers how EMOs can engage with it. It suggests in particular that the idea of 'coproduction' is a p owerful way for EMOs to think about engagement with non-traditional volunteers that is aligned to a resilience-based approach in emergency management. It illustrates how coproduction can work, and the utility of the concept in this area, using the example of a community-led bushfire preparedness project in Victoria, Be Ready Warrandyte.

INTRODUCTION

The future landscape of emergency volunteering and volunteer management in Australia is not going to be the same as the landscape of the past. The traditional model of emergency volunteering employed in Australia is based on formal, accredited volunteers who are affiliated with emergency management organisations, and are mostly involved in response and recovery roles (e.g. Commonwealth of Australia 2012). This form of volunteering is crucial to Australia's emergency management capacity and it will remain central to any model of emergency volunteering into the future. However, overlapping and interacting developments taking place both within the emergency management sector and external to it are likely to lead to forms of volunteering, and volunteer management and engagement, that are 'non-traditional' for the established emergency management sector becoming much more prominent in the future alongside more traditional emergency management volunteering.

Developments within the emergency management sector include the policy focus on building community resilience to disasters before events occur, and fostering greater shared responsibility across government sectors and between governments and citizens (including NGOs, communities and businesses) (COAG 2011). This has spurred greater government attention to volunteering beyond the traditional emergency management volunteer workforce (Rafter 2013). This focus is certainly not restricted to Australia. At an international level also, there is growing emphasis on building "resilience to disasters through a 'bottom-up' process in the form of volunteer initiatives rooted in the community" (UNV 2011, p.xxiii).

Beyond the emergency management sector, broader socioeconomic, cultural and political shifts are reshaping people's choices about how, when, where and why to volunteer compared to the past. A recent review of key volunteering trends identified four key large-scale changes that are likely to impact on future emergency volunteering (McLennan *et al.* 2015b): 1) transformation in the way people live and work in the 21st Century, which includes increasing time demands of paid employment, cultural globalisation, rising aspirations, and shifting values (Hustinx et al. 2010; Rochester et al. 2010); 2) the revolution in communication technology (UNV 2011, p.26); 3) growth of private sector involvement in volunteering through employee volunteer programs and partnerships with non-profits (Haski-Leventhal et al. 2010); and 4) rising government expectations (and regulation) of volunteering, connected to greater outsourcing of public service delivery to volunteer-involving organisations (Rochester et al. 2010; Warburton et al. 2013; Hustinx 2014). These trends are evident both within Australia and internationally.

In light of these developments, this paper broadly examines what 'non-traditional' emergency volunteering is likely to look like in the future under these shifting conditions and begins to consider how EMOs can engage with it. It suggests in particular that the idea of 'coproduction' is a powerful way for EMOs to think about engagement with non-traditional volunteers that is aligned to a resilience-based approach in emergency management. It then illustrates how coproduction can work, and the utility of the concept in this area, using the example of a community-led bushfire preparedness project in Victoria, Be Ready Warrandyte (McLennan *et al.* 2015a).

WHAT WILL IT LOOK LIKE?

Exactly what shapes non-traditional emergency volunteering will take in the future will depend on the way that EMOs, volunteer managers, and volunteers themselves respond and adapt to the developments taking place within the sector and more broadly. However, research suggests that seven key categories of non-traditional emergency volunteering are likely to feature more prominently. Each presents potential benefits for emergency management but also particular challenges and risks. While not all of these are new in the context of emergencies and disasters, they all fall outside of the more traditional model of emergency volunteering and therefore have not been formally factored into emergency planning in the past in a comprehensive way.

1. *Emergent volunteerism,* including 'spontaneous' volunteering, occurs in the context of emergent collective behaviour where people work together towards shared goals (Drabek and McEntire 2003) but in less formal ways that "typically lack formal elements of organisation" (Whittaker *et al.* 2015). It is increasingly recognised as an important component of community resilience, but is also difficult to integrate with formal emergency management.

2. *Extending volunteerism* involves groups and organisations that do not have regular emergency or disaster functions that extend their activities into this area to volunteer before, during or after a crisis (Whittaker *et al.* 2015). Like emergent volunteers, these volunteers often have intimate understandings of local needs and can draw on existing networks and resources to meet them. However, they are often unaware of the broader emergency management context.

3. *Digital volunteerism* can be thought of as a form of telecommuting (Cravens and Ellis 2014, p.1). It represents a new mode of volunteerism enabled by the increased accessibility of sophisticated yet simple information technology. Digital volunteering is likely to become increasingly prevalent in emergency and disaster management worldwide, with particular potential as brokers of crowdsourced disaster information (Hughes and Palen 2009).

4. A rapid growth of shorter-term, *episodic volunteering* and an associated decline in longer-term, high-commitment volunteering is one of the most widespread changes in volunteering styles reported in recent times (Cnaan and Handy 2005; Rochester *et al.* 2010). Although usually viewed in negative terms, episodic volunteering also has benefits that are well-suiterd to disaster conditions, with volunteers tending to exhibit greater flexibility, adaptability and pragmatism compared to more traditional volunteers, for example (Macduff *et al.* 2009).

5. *Employer-supported volunteering* is often referred to as corporate volunteering, but is not limited to big corporates. This form of volunteering is on the rise (Haski-Leventhal *et al.* 2010). It increasingly overlaps with and reinforces a related trend towards *skills-based volunteering,* where the skills, training and experience of potential volunteers are purposefully matched with the specific needs of recipient organisations (Points of Light Foundation and Hands On Network n.d.).Benefits to recipient

organisations from engaging with corporate volunteers are greater when ongoing relationships are established between them (Cavallaro 2006).

6. *Government outsourcing to, and regulation of, volunteers* through contracts with non-profit organisations and community groups has increased in the last decade (Warburton et al. 2013; Hustinx 2014). While not constituting a new type of volunteering per se, it does constitute a significant shift in the positioning of volunteers in relation to government with respect to the delivery of public services as well as in the organisational and regulatory contexts in which emergency volunteering takes place.
7. *Community-based emergency preparedness and planning* - is becoming an increasingly important component of emergency and disaster management internationally, replacing the top-down, interventionist approaches that dominated in the past (Allen 2006). Community-based initiatives rely on the involvement of volunteers that are able to represent their community in formal preparedness and planning activities. There is a nascent but growing interest in community-based approaches in Australian emergency management.

Each of these categorisations reflects a current focus in research, and each adds to our understanding of non-traditional emergency volunteering. To varying degrees, each of the categories emphasize a particular dimension of volunteering over others, such as duration (episodic volunteering), mode of delivery (digital), organisational context (emergent, extending and employer-supported), and positioning in relation to community and government (outsourcing and community-based preparedness and planning). Hence there is overlap between them and care should be taken not to rely on single dimension criteria to characterize volunteering per se. Indeed, this is a criticism of the growing focus on episodic volunteering that unduly emphasizes the duration of volunteer engagements above other dimensions (Cnaan and Handy 2005, p.31).

HOW CAN IT WORK?

It is clear that, with the growing prominence of these non-traditional forms and modes of volunteering, the future emergency volunteering landscape is going to be populated by a much wider and more diverse range of players than in the past. In this Internet age, these players are also going to be more interconnected and less centrally-controlled. Increasing numbers of them are likely to be from outside the established emergency management system. Many of them will not be affiliated with formal organisations, at least not in an ongoing way. Many will volunteer for shorter durations, possibly off-site (and on-line), and many will not have specific emergency management training. However, the large majority will also bring important resources to emergency management that can strengthen community resilience such as local knowledge, social networks, adaptability, innovation, and professional skills.

THE COPRODUCTION OF COMMUNITY RESILIENCE

How can EMOs engage with these diverse non-traditional forms of volunteering in ways that contribute to building community resilience and increasing shared responsibility while managing associated risks?

A key part of the answer to this question may lie in the concept and processes of coproduction. In general terms, coproduction is "the process through which inputs used to produce a good or service are contributed by individuals who are not "in" the same organization" (Ostrom 1996, p.1073). In the context of public services, coproduction involves "engagement of citizen-clients in the actual provision of public services, in complex, informal interactions with state agencies" (Joshi and Moore 2004). Coproduction is by no means a new idea, but it has received renewed interest since the 1990s (Bovaird 2007; Alford 2009). In disaster management, coproduction is particularly evident in citizen involvement in producing disaster-related information via social media (e.g. Rafter 2013), as well as the generation of new disaster knowledge across the science-policy interface (Scolobig and Pelling 2015). Indeed, volunteer-based, state government emergency services constitute a form of coproduction in themselves.

Using coproduction of emergency management as a conceptual framework for understanding and pursuing engagement between EMOs and non-traditional volunteers strongly reflects the principles and aspirations of a resilience-based approach to Australian disaster management. Coproduction "essentially redefines the relationship between public service professionals and citizens from one of dependency to mutuality and reciprocity" (Holmes 2011, p.22). In this sense, it is an expression of shared responsibility (McLennan and Handmer 2013). It is also potentially very confronting to EMO organizational culture and processes, as through coproduction "power, authority and control of resources are likely to be divided (not necessarily equally) between the state and groups of citizens" (Joshi and Moore 2004).

As a process, coproduction faces some considerable challenges that stem from the fact that it requires very different relationships between public sector staff and citizen volunteers than have occurred in the past (Holmes 2011, p.25). There are issues of representation, accountability, and authority: who from a community gets to participate and who is excluded? There is also a risk of conflict or protracted negotiation that could undermine the process. It also requires public sector staff to adopt the role of motivating, advising, facilitating and enabling "citizen-client" contribution to service production rather than producing services directly. This calls for very different kinds of skills, for example in communication, negotiation and advice (Alford 2009, p.221-2).

In order to illustrate what coproduction of emergency management and community resilience between EMOs and 'non-traditional volunteers can look like in practice, as well as what it can achieve and how the challenges identified above can be addressed, the following section describes a case of coproduction in action, Be Ready Warrandyte (McLennan *et al.* 2015a). This example is not given with the intention of demonstrating how coproduction ought to be done, as coproduction can take many forms (Bovaird 2007). Rather, it is meant to illustrate key aspects of coproduction in an emergency management context, and to demonstrate the utility of the concept in this area.

THE EXAMPLE OF BE READY WARRANDYTE

Be Ready Warrandyte ('Be Ready') was a community-led bushfire preparedness project undertaken by the Warrandyte Community Association (WCA) in this area between May 2012 and June 2015. Its primary goal was "to have more Warrandyte households with effective bushfire plans" (WCA n.d.). Be Ready is notable for being an award-winning, community-led preparedness project. It is an example of two of the categories of non-traditional volunteerism identified above: extending volunteerism (by the WCA volunteers) and community-based emergency preparedness and planning.

Be Ready is a good example of the coproduction of community bushfire safety. The initial impetus for the project came from local Community Fireguard leaders and a local CFA brigade captain who were concerned about the low level of bushfire planning amongst residents following the community's near miss on Black Saturday. It was chaired by the President of the Warrandyte Community Association. Members on its committee of management included community volunteers from the WCA, Community Fireguard leaders, local CFA fire brigade captains, paid staff from the emergency management departments of two Councils, community safety personnel from two CFA Districts and representatives from its initial funders, the Department of Planning and Community Development (DPCD). The committee also contracted a local project management business – The Good Work Group – to help coordinate the project.

The Be Ready committee designed and delivered a diverse range of locally-targeted activities including: a community survey, a localised web page, a humorous video on bushfire planning, localised communication materials, interactive Bushfire Scenario Planning workshops, interactive sample fire plans, a public forum on fire bunkers and a tour of local bunkers, and a project on heat wave messaging.

Interviews with participants highlighted how it was able to adapt government communications, connect further into the community, devise and test more innovative approaches, lead discussion on topics that need independence from perceptions of government bias or agenda, and bring local contexts, priorities, goals and knowledge into emergency management dialogues and planning.

The coproduced nature of Be Ready was also evident in participant interviews. One community volunteer described a "*foundational perspective*" on which the project was built as being "*We're in this together. None of us can do it on our own*." A professional EMO participant highlighted it thus:

> *"Prior to Be Ready Warrandyte the responsibility of fire safety for the Warrandyte community was the CFA. Now the CFA is just a player. They're just one of the participants."*

In line with the definition of coproduction, professional EMO representatives and volunteers from the WCA and the local CFA brigades all input considerable resources and skills to the project to produce a service that was widely recognized would not have been possible otherwise:

> *"I think it's actually made the emergency management community realise that the community have a great amount of power. That something that's born from right at the community level has the capacity to be fantastic and to really take off. And it works sometimes a lot better than trying to push the message down from the top."* (Professional EMO representative)

The Be Ready experience also reflected aspects of the challenges to coproduction. The challenge of representation and community authority identified in coproduction literature was recognized by some participants in this type of community-based project in general. It was largely addressed in Be Ready through the longevity and good standing of the Warrandyte Community Association in the local community and its close and respectful relationship with local governments. The potential for conflict and protracted negotiation, also identified in the coproduction literature, was also reasonably well overcome in the Be Ready project due to good governance processes, skilled leadership from the Chair, a commitment amongst the volunteers to "work with" the established emergency management system, and good working relationships amongst the committee members. This enabled professional EMO representatives to 'agree to disagree' with WCA and CFA volunteers over the appropriateness of conducting tours of local, private fire bunkers, for example.

The different roles needed of public sector staff in coproduction processes, as enablers, motivators and advisors, was also reflected in the Be Ready process. Professional EMO staff on the committee (from both the CFA and local government) actively contributed to the project and strongly represented it within their own organisations without trying to direct it. One explained their role thus: "*be open, be supportive and sit back. Do not dictate*", while another emphasized that there still "*needs to be some advice*".

Related to this different role, the EMO participants in the project suggested changes that their organisations needed to make to support both paid and volunteer representatives in this type of process. These included longer-term planning, providing structures for their representatives to work confidently within, recruiting and training volunteers specifically for their community engagement skills, and developing organisational cultures that are more supportive of community engagement. In some respects, they reflected elements of a key dilemma in coproduction of public services, which is the capacity of public sector agencies to recognize, reward, and develop the appropriate skills amongst their staff (Holmes 2011). Notably, EMO participants in Be Read y indicated that these types of internal changes had already begun, while participants overall felt that the 'time was right' to pursue closer engagement between EMOs and community groups. One EMO representative summed this view up thus:

> *"The previous Chief Officer said at a forum years ago he said "the day will come when how we engage with the community will be as important as how we suppress fires." I think we're there now. I think the community is willing."*

CONCLUSIONS

The research reported here is beginning to answer the questions of what non-traditional emergency volunteering is going to look like in the future and how emergency management organisations can successfully engage with it. The seven categories of volunteering described, while adding to our understanding of current and emerging forms of non-traditional volunteering, tend to prioritise a particular dimension of volunteering over others. Some care should be taken not to rely too heavily on single dimension criteria to characterise volunteering out of context. Future work will extend on this to develop a multi-dimensional typology for characterising non-traditional emergency volunteering.

Answering the question of how emergency managers can support non-traditional forms of volunteering while assessing and managing the risks they present is an emerging research area where more work is needed. This paper suggested that a key part of the answer lies in the concept and processes of coproduction.

The Be R eady example shows that substantial benefits can flow from the coproduction of community safety and resilience by non-traditional volunteer groups and EMO representatives. It also showed that the challenges of coproduction may not be as difficult to overcome in this context as they might first appear.

Importantly, this paper does not argue that coproduction is a panacea for EMO engagement with non-traditional volunteers, nor that it is suitable for all such engagement, indeed it is not. However, it does hold that coproduction has considerable potential and power as a way for EMOs to think about engagement with the diverse and growing base of non-traditional emergency volunteers that is well-aligned with a resilience-based approach.

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CULTURALLY APPROPRIATE MAPPING TOOLS FOR INFORMING TWO-WAY FIRE MANAGEMENT PLANNING IN REMOTE INDIGENOUS NORTH AUSTRALIAN COMMUNITIES

Research proceedings from the Bushfire and Natural Hazards CRC & AFAC conference
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ABSTRACT

Remote northern indigenous communities are prone to annual flood, cyclonic events, and severe fire danger periods lasting weeks, that frequently result in environmentally destructive wildfires. Although effective responses to such events are typically hindered by inadequate infrastructural resources, of equal concern is the paucity of culturally appropriate ‘two-way’ planning aids which can help inform both non-indigenous and indigenous governance institutions, and build local community resilience. Based on extensive savanna fire management research describing fire impacts on a variety of ecosystem services and values, here we describe the development and testing of mapping tools to assist community-based fire management planning in two remote Arnhem Land communities.

INTRODUCTION

This project aims to build upon the suite of map-based tools describing the effects of fire on the environment, and develop their utility in a collaborative approach with remote indigenous communities in north Australia. Current map tools, available through the North Australia Fire Information (NAFI) web portal, are used in day-to-day, annual and long-term fire management and planning activities across north Australia. NAFI was developed by Bushfires NT (Research) with the Tropical Savannas CRC in response to and, most importantly, **with** land managers. The intent in this project is to develop a slightly more sophisticated suite of maps incorporating modelling of key ecological attributes from empirical models. An important lesson from the development of NAFI is collaboration with land managers [1]. A strong user-participation framework has been key to the development of NAFI and is seen as an essential component of this project.

Simple analyses of fire mapping histories clearly identify that fire management in remote indigenous lands can benefit from access to the information available from satellite mapping. These satellite derived data provide the basis through exisitng and future payment for ecosystem services opportunities, such as the Australian Government's Carbon Farming Initiative (CFI): Savanna Burning, Greenhouse Gas Emissions Abatement program (http://www.environment.gov.au/climate-change/emissions-reduction-fund/cfi/methodologies/determinations/savanna-burning). These remote communities with large tracts of relatively intact landscapes, although subjected to high intensity fire regimes [2] and declines in biodiversity [3], need to be in a position to benefit from their land management activities [4, 5].

RESILIENCE

Cultural resilience is dependent upon mental and emotional well-being [6]. Social vulnerability, the inverse of resilience, is the exposure of social communities to stress as a result of change [7]. A recent report by colleagues in the Northern Hub [8] defines resilience and vulnerability as two contrasting perspectives of the same issue, but that the concept of resilience is seen as more empowering. This Northern Hub group of research projects is attempting to scope Indigenous community resilience and governance, and to develop opportunities for building more resilient remote Indigenous communities in northern Australia. NAILSMA [8] report that there is a growing body of literature relating to indigenous livelihoods which supports the importance of diversified and local economies in aiding resilience [9].

The expected life span of Aboriginal Australians is much less than non-Aboriginals, "the gap" in health is recognised by the Australian Government as an issue of national significance [10]. Studies demostrate a positive correlation describing the connectivity between land management involvement and the health of remote aboriginal people [11], particularly through the outstation movement [12] and the formation of indigenous ranger groups [13]. It is also suggesed that any level of involvement in land management is important in addressing some factors affecting aboriginal health and therefore their vulnerability/resilience [14].

The main hazard for indigenous communities is their dependence on welfare which has been subject to a top-down approach in government policy. For example the impact of the NT Emergency Response Intervention, humiliated and demoralised indigenous communities, undermined the existing functional governance structures, instantly, and without warning nor consultation, a large suite of employment activities were removed through the cessation of the CDEP program [15]. The "intervention", by name and by nature, demonstrates a one-way, non-collaborative, government approach. Fundamentally Australian Aboriginal people, like many other indigenous people around the world [16], require a far greater level of independence to improve their community resilience.

CONTEXT

The NT Police, Fire and Emergency Services (NTPFES) have developed communications and support services in those communities where they have a presence; hence there are many hundreds of small communities and outstations with no direct emergency management support. However, with respect to fire management and planning, the Northern Land Council have been developing Indigenous ranger programs (http://www.nlc.org.au/articles/info/ranger-programs). The rangers have been actively working with traditional land owners, living on country or in towns, to develop over-arching fire management plans; they then coordinate and often undertake prescribed burning.

The literature review undertaken by NAILSMA [8] describes national, Territory and State emergency management with respect to Indigenous communities. They provide specific examples published in the peer reviewed literature demonstrating the paucity of infrastructure, training and, importantly, lack of communication and understanding of community knowledge. A noted example is given by [17] and also described at http://www.em.gov.au/ under Remote Indigenous communities.

The "Keeping Our Mob Safe: A National Emergency Management Strategy for Remote Indigenous Communities" report [18] undertook a community consultation approach to determine Indigenous community needs. The report emphasises the need for collaboration between agencies and communities as a means of self-empowerment and to provide a strategic direction for emergency management. These policies stem from the original COAG review of natural disasters in Australia [19] that highlighted special consideration for remote indigenous communities in the areas of capacity building, as well as relief, and emphasised community participation for effective delivery of disaster management outcomes. In another COAG report [20] from the EMA web site, an additional recommendation is to focus on actions that build economic and social self-reliance.

To this end, this project will provide information to, and in consultation with, Indigenous land managers that will assist in wildfire mitigation planning, thus reducing the area affected by fire generally and late dry season fires particularly. The improved fire management, already demonstrated on the west Arnhem Land plateau [3], offers opportunities to develop payment for ecosystem services projects and provide a level of economic independence.

METHODS

STUDY AREA

Two regions, **Kunbalanja** (*Goon-bar-larn-ya*, aka Oenpelli) and **Ngukurr** (*Ngoo-koo-rr*, with rolling rr's) managed in part by indigenous ranger groups, the **Adjumarllal** (*Ar-jew-marl-larl*) **and Yugul Mangi** (Y*oo-gool Marn-ji*) respectively, have been initially selected to co-develop the mapping due to our contacts through the Aboriginal Research Practitioners Network (ARPNet), Figure 1.

ARPNet have been active in these areas, they have established trust with the communities, many of the researchers are from these communities. Their unique survey techniques involve participatory and other research tools. ARPNet have demonstrated a clear advantage in collecting valuable information from remote Indigenous people [21, 22] that is not accessible through standard assessments. End-user, the NT Fire and Rescue Service Director, Steve Rothwell has shown a keen interest in using the ARPNet to promote remote indigenous community aspirations.

The NAILSMA "Assett Mapping" document [23] provides details of the location, history, geography, climate, natural and cultural assetts, infrastructure, governance and a history of the effects of floods, cyclones and bushfires to the two communities. In summary, both communities are within the Arnhem Land Aboriginal Land Trust, an area of aprroximately 95,000 km^2. Cyclones are periodic, floods quasi-annual and bushfires are certainly annual, occurring throughout the late dry season. Approximately 45% of Arnhem Land has experienced greater than biennial wildfires in the 15 years since 2000.

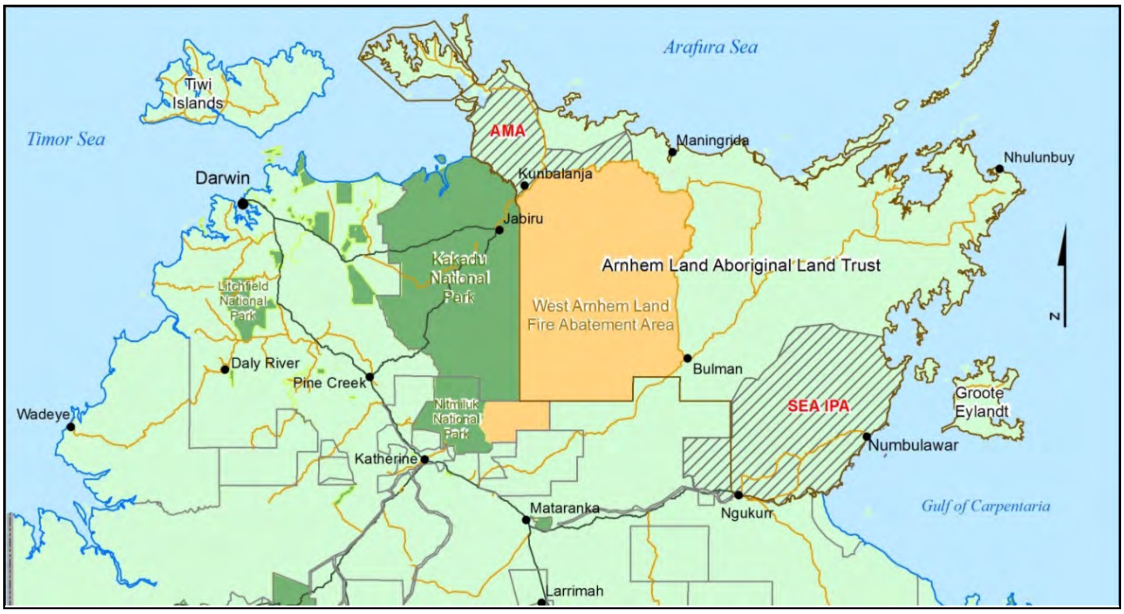

FIGURE1. THE LOCATION OF THE TWO STUDY AREAS (CROSS HATCHED) IN THE TOP END OF THE NORTHERN TERRITORY. AMA = THE "ADJMARLAL MANAGEMENT AREA; SEA IPA = THE SOUTH EAST ARNHEM LAND INDIGENOUS PROTECTED AREA

MODELLING

In these analyses empirically derived ecological models applying fire effect metrics were sourced from the literature quantifying fuel accumulation, greenhouse gas emissions [24, 25], carbon sequestration [26, 27], fire effects on soil erosion and transport, and water quality [28, 29], and counts of key biodiversity elements such as adult stems of the long lived obligate seeder native conifer *Callitris intratropica* (R.T. Baker and H.G. Smith) and long maturing obligate seeder shrub taxa [30, 31].

SPATIAL DATA

The primary dataset for derivation of spatially explicit fire metrics was the mapping of fire affected (burnt) areas. Mapping used difference-image techniques of red and near infrared bands from 30m pixel Landsat imagery, following mapping methods outlined in [32]. Spatially explicit and multi-temporal datasets describing annual fire frequency, and frequency of early dry season (EDS—before 1 August) and late dry season (LDS—post 31 July) fires, and time since last fire affected (in years since last fire) were derived from the database.

Fire severity mapping was derived from Landsat 30 m pixel imagery by calibrating a model derived from the proportional pre- to post- fire change in reflectance in the near infrared [33]. Three mapped fire severity classes are applied here: *low, moderate and high severity*. These three classes accord generally with fire severity and fire intensity classes as described by Russell-Smith and Edwards [34], based on regional long-term monitoring plot observations.

Vegetation fuel classes follow the classification used by Australia's National Greenhouse Gas Inventory (NGGI) given in DCCEE [24], based essentially on dominant overstorey genera, vegetation structure and grass form [35]. Four broad eligible classes are distinguished: (1) eucalypt open-forest (EOF) with 30-70% upper canopy foliage cover (FC; *sensu* Specht 1981[36][36][36]); (2) eucalypt woodland (EW) with 10-30% FC; (3) sandstone woodland (SW) with 10-30% FC; (4) sandstone heath (SH) with <10-30% shrub FC.

A global digital elevation model (3" pixels) derived from the Shuttle Radar Topography Mission (SRTM) (http://www2.jpl.nasa.gov/srtm/) was clipped for the regions. Slope was calculated in degrees of rise (0-90^{o}) in a 3 x 3 pixel window, and a topographic index (TI; *[37]*), derived for surface roughness.
Spatial analyses were undertaken with raster layers using the Spatial Analyst extension of ESRI® Arcmap TM 10.0 [38]. Spatial data were transformed into the Australian Albers equal area projection [EPSG: 3577] (central meridian: 132^{o}, 1st standard parallel: -18^{o}, 2nd standard parallel: -36^{o}, false easting: 0.0, false northing: 0.0, latitude of origin: 0.0, linear unit: metre, datum: GDA94) with 30 m pixels being the maximum pixel size of all non-categorical data.

ASSESSMENTS

The assessment of the utility of the maps to fire management planning comes from three sources: 1. Feedback from the ARPNet survey. This required a re-interpretation of a simple set of survey questions posed by the Practitioners to the different cohorts in the community. The cohorts represent the spectrum of the community many of whom are not involved in land management or land management decisions; 2. Workshops with various ranger groups; 3. Consultation by fire managers with traditional land owners.

RESULTS

MAPPING TOOLS

This project has developed a set of satellite image derived mapping tools with simple yet sophisticated interpretations of the fire mapping from NAFI representing spatially explicit fire effects on processes representing land management and improvements to land management. Ecosystem functions such as fuel accumulation have been interpreted through empirical modelling into greenhouse gas emissions and bio-carbon sequestration that provide accounting of fire effects for the income from land management in current internationally accepted carbon accounting terms. Other models illustrate fire effects on key biodiversity elements distributed across the landscape; and water quality at appropriate catchment scales. The utility of these maps has been and will continue to be tested using social surveys, workshops and a consultation process involving traditional owners.

SURVEYS

To date, two workshops with indigenous ranger groups servicing remote areas have been undertaken. The indigenous rangers use the NAFI (North Australia Fire Information) fire mapping web site to undertake their planned burns. The NAFI data are served through WMS onto Google Earth providing. Layers illustrating areas burnt in the current fire season and older fuels (> 2 years since last burnt) are overlaid with tenure boundaries and topographic information, with areas depicting sacred sites and the overall strategy developed at the planning meetings and subsequently after consultation with traditional owners. Rangers saw the benefit of inclusion of the biodiversity, emissions and sequestration information in the strategic planning of prescribed burning. It was suggested to provide these map data to the broader regional strategic planning meetings.

The ARPNet researchers reported the preliminary results to the Northern Hub research group at a workshop in Ngukurr in May 2015. Less than half of both communities feel “safe” with respect to flood and cyclone. Most cohorts outside of the ranger groups were not aware of, and might only have had limited access to, any of the on-line mapping including NAFI. People involved in land management responded positively to the benefits of the on-line mapping and suggested that more maps would be beneficial. However they stated that further explanation of their derivation and application is required.

DISCUSSION

The potential for payment for ecosystem services has already been realised through Savanna Burning. In January 2015 the West Arnhem Land Fire Abatement (WALFA) projects were credited with 600,000 Australian Carbon Credit Units (ACCUs) - worth around $A10,000,000 - for GHG emissions abatement in 2011-2013. This project is only one of many undertaken on Indigenous owned land. As of February 2015 there were 34 approved projects with a combined 1.33 million ACCUs, the equivalent of approximately $A24, million. The new Methodology about to become Commonwealth law has found an increase of approximately 1 ACCU for every tonne of emissions abated, and covers an extra 715,000 km^2 of northern Australia. Other Savanna Burning methodologies for bio-carbon sequestration will be available in the next few years, with an expected five-fold increase in annual ACCUs over greenhouse gas emissions methodologies [39].

The potential for many of the fire maps and other derived map products to be used to guide wildfire mitigation has been realized across many sectors of the north Australian community. The added potential of financial biodiversity benefits, although not yet a reality methodologically, can be assessed through our mapped models and traditional knowledge through a two-way consultation process benefited markedly by the ARPNet.

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HOW WILL THE NEW SATELLITE NAVIGATION SYSTEMS HELP WITH THE PROVISION OF INFORMATION AND WARNINGS?

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ABSTRACT

HOW WILL THE NEW SATELLITE NAVIGATION SYSTEMS HELP WITH THE PROVISION OF INFORMATION AND WARNINGS?

This paper introduces the concept and benefits of using next generation Global Navigation Satellite Systems (GNSS) such as the Japanese Quasi-Zenith Satellite System (QZSS) for the provision of emergency information and warnings. The Japanese GNSS-based warning system can be tailored to transmit context-sensitive messages according to people's location and situation through GNSS receiver terminal embedded in mobile phones and in-car navigation units. The key advantage of satellite based communication is its high resilience to communication network overload and failure of ground systems and network infrastructure during a d isaster. This enables people to obtain necessary information anywhere (outdoor) and anytime during times of disaster. A satellite-based warning system could also be integrated with existing warning services and be used as a complementary technology. This paper describes a collaborative project with Japan on the potential utilisation of QZSS for emergency alerting and warnings in Australia.

INTRODUCTION

A ‘warning system’ is a means of getting information about an impending emergency, the nature of the threat, communicating that information to those who are likely to be affected by it, and facilitating informed decisions and timely response by people in danger (Mileti and Sorensen 1990). Several studies have shown that functional warning systems can be a highly effective tool for saving lives and reducing property losses (Golnaraghi et al., 2009). The range of Information Communication Technologies (ICT) used by the state and national emergency authorities to disseminate warnings has conventionally involved one-way, top-down communication flows. However, a r ecent re-examination of hazard warning systems owing to increased global climate variations enhancing natural disaster risk demonstrates a steady progression toward incorporating two-way participatory approaches leveraging new technologies and collaborative information sharing such as the powerful combination of the Internet, mobile, crowd-sourcing and social networking technologies (Keim and Noji 2011; White 2011; Crowe 2012). This marked shift from command to dialogue communication functions reflects the remarkable pace of change within contemporary communication patterns and information sharing systems.

Utilisation of satellite navigation systems for emergency warning and alerting is a relatively new and emerging technology. There has been little research to investigate its feasibility and application. The value of such capabilities could be foreseen in the case of critical situations where ground-based communication channels are limited or unavailable; and the coordination of emergency procedures with location-awareness activities is paramount. In mid-2014, the Japanese and Australian Governments formally agreed to cooperate to promote utilisation of ICT as well as strengthen cooperation for the promotion of geospatial information projects using the Japanese satellite navigation system (Prime Minister of Australia 2014). The Japanese Quasi-Zenith Satellite System or (QZSS) is an example of a satellite-based navigation system. While primarily built for users in Japan, the satellite trajectory design offers significant advantages to neighbouring East Asian countries as well as Australia. This paper introduces the concept of utilising a satellite navigation system in the domain of emergency warning and alerting. The proposed system is capable of providing real-time alerts enhanced with location-based information enabling users to take appropriate risk mitigation actions during events of disaster.

NAVIGATION SATELLITE WARNING SYSTEM

Satellite-based communication is another mode of communication that is used by various countries and organisations around the world to disseminate emergency messages. The Japanese nationwide warning system called J-Alert is an example using Superbird-B2 communication satellite to broadcast warning messages. The International COSPAS-SARSAT[1] Programme is another well-established satellite-based search and rescue (SAR), distress alert detection and information distribution system. It is best known as the system that detects and locates emergency beacons activated by aircraft, ships and backcountry hikers in distress (COSPAS-SARSAT 2014). Satellite communication services are generally robust and can be enhanced with geographical information to specify for which locations the information is relevant. However the use of a satellite phone is not as common as compared to mobile phones. Furthermore, maintenance of satellite communication service and operation are costly for both service providers and users.

Navigation satellites emergency system combines the strengths of both mobile telecommunication services and satellite-based communication. Global Navigation Satellite System (GNSS) is a s tandard term for satellite-based navigation systems, which include the U.S. GPS, Russia's GLONASS, and several other new and emerging constellations such as Europe's Galileo and China's BeiDou systems. These systems provide precise position in three dimensions, timing, and velocity using radio navigation signals. GNSS is generally a one-way system: the receivers receive the signals and there is no interaction from the receiver to the satellites. There are also regional navigation satellite systems and Satellite Based Augmentation Systems (SBAS) like the U.S. WAAS, Europe's European Geostationary Navigation Overlay Service (EGNOS) and India's GAGAN, which aim to augment GNSS.

The GNSS receiver embedded in smartphones providing information of the users' position could be used to correlate messages sent from the satellite based on the message geographical criteria. This makes the information relevant to intended users at a specific point in time and within the defined geographical area. GNSS could be used to supplement and enhance exiting warning systems. Europe has been working on emergency message services since 2005 using the EGNOS and Galileo satellite navigation systems with the introduction of the ALIVE (Alert interface via EGNOS) Concept (Mathur et al. 2005). Since then there were follow on projects investigating technical and non-technical benefits as well as advantages of utilising GNSS satellites for disaster alerting (Dixon and Haas 2008; Wallner 2011; Domínguez et al. 2013).

1 SARSAT is an acronym for Search and Rescue Satellite-Aided Tracking. COSPAS is an acronym for the Russian words "Cosmicheskaya Sistyema Poiska Avariynich Sudov", which means "Space System for the Search of Vessels in Distress".

The Japanese Quasi-Zenith Satellite System (QZSS) is another example of an SBAS developed by Japan Aerospace Exploration Agency (JAXA). When fully deployed in 2018, it will consist of three QZSS satellites placed in Highly Inclined Elliptical Orbits (HEO) and one geostationary satellite providing 24 hours coverage. The orbit configuration of these QZSS satellites provides continuous coverage at a high elevation angle, providing improved satellite navigation in areas of Japan that challenge traditional GNSS satellite positioning capabilities, such as central city areas. While intended primarily for users in Japan, the orbit design offers significant advantages to neighbouring East Asia countries and Australia. Figure 1 shows the footprint of QZSS satellite. The first QZSS satellite was launched on 11 September 2010.

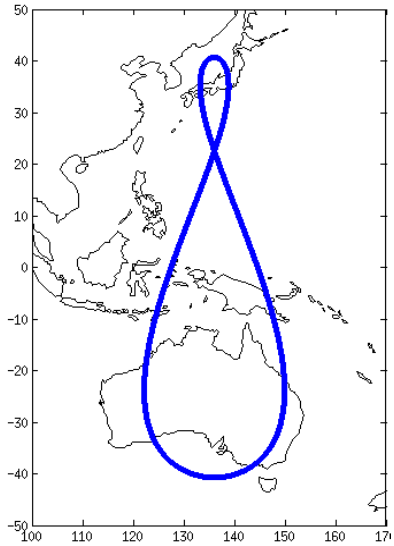

FIGURE 1: GROUND TRACK OF QZS-1 ORBIT.

One unique feature of QZSS is that in addition to the standard GNSS navigation signals used for Position, Navigation and Timing (PNT), QZSS also has the capability of sending short emergency messages. The messages can be received directly from the satellite by a GNSS/GPS receiver embedded in mobile phone or in in-car navigation systems. An application software or app would interpret and display the information. Given that mobile phones use and in-car navigation systems are becoming near-universal, with almost everyone involved, the potential coverage and reach of warnings sent to these personal devices is likely to be much greater than the current approaches could achieve.

Another feature of the QZSS provision for alert messaging is that in addition to the wide area coverage provided by the satellite system, the receivers also provide, through their embedded GNSS/GPS capabilities, precise position information. In this way, alert messages can be sent to a specific area depending on the type and content of the disaster information, and only those receivers within the specific area will be activated. Knowing the area of the possible disaster location, the intended users could then be warned, while those outside the disaster area would not be alerted.

The satellite based system offers a number of advantages for real-time disaster alerts over current approaches to sending warnings via personal devices. A disadvantage is that at present the signal is not generally received indoors due to the low signal strength (GPS signals do not typically pass through solid objects). Advantages include:

1) GNSS with location-based information can be used during an emergency. This provides the ability to indicate high priority and targeted messages for specific areas and groups;

2) The service can cover a wide area simultaneously – e.g. the whole of Australia – because of its wide area broadcast footprint, and within the broadcast area, there is no limit to the number of people who can be warned simultaneously;

3) The messages can still be received even when terrestrial communications infrastructure is damaged or not available. This allows for redundancy; and

4) As the system is independent of mobile phone coverage it would reach people wherever they are, regardless of the existence of mobile phone coverage.

QZSS RED RESCUE PROJECT

The Red Rescue Project (for real-time disaster response using small-capacity data packets from the ubiquitous environment) was funded by the Japanese Ministry of Education, Culture, Sports, Science and Technology. It is a real-time disaster response solution, which sends emergency messages through the L1-SAIF signal from QZSS satellites to government, relevant authorities as well as the general public through smartphone equipped with GNSS chips during times of emergencies. The project commenced in 2009 as a three-year project and has recently run trials in Japan, Thailand and Malaysia for tsunami warnings. The core members of the project consist of system design specialists from Graduate School of System Design and Management in Keio University, Asia Air Survey on panoramic navigation, Pasco on disaster management and NTTDATA on disaster information systems. NTTDATA Corporation (a Japanese system integration and data company) has developed several governmental IT infrastructures for disaster management (Buist et al. 2013; Iwaizumi and Kohtake 2013; Iwaizumi et al. 2014).

The emergency message is sent to the user from the QZSS satellite using the L1-SAIF (Submetre-class Augmentation with Integrity Function) signal. This signal is broadcasted on the L1 frequency band (1575.42 MHz). The advantage of the L1 signal is that it is the most widely used signal by the mass-market GNSS/GPS receivers. All GNSS/GPS receivers are able to track and acquire this signal for positioning. The L1-SAIF signal, as the name implies, is designed to transmit precise navigation messages and integrity data with the intention to augment positioning accuracy to decimetre-level and transmit integrity information for mission critical applications. The L1-SAIF signal has a data rate of 250 bits per second (bps) and the 212 bits data area in between the navigation message could be used to deliver emergency messages. At 212 bits, each emergency message is very short, but a number of messages can be combined to produce a longer message. Figure 2 shows a schematic diagram of the QZSS alert messaging transmission system. The system consists of three parts: the Transmission, Satellite and User Segments (Iwaizumi et al. 2014).

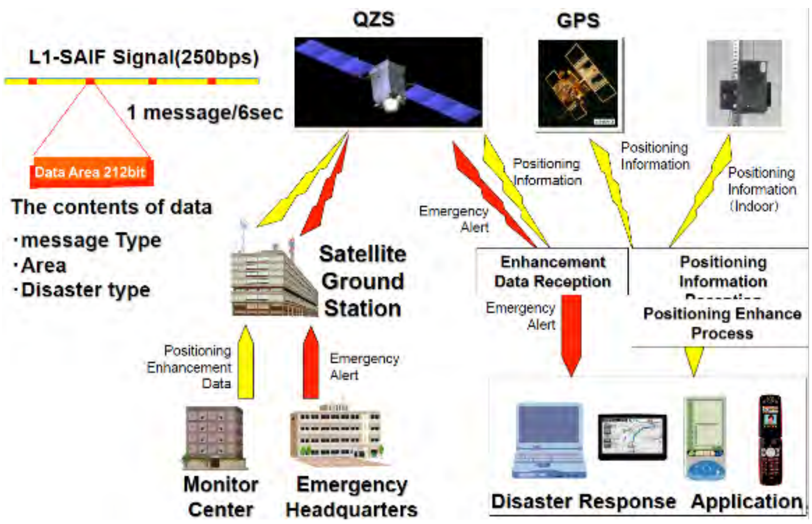

FIGURE 2: QZSS ALERT MESSAGING TRANSMISSION SYSTEM.

The Transmission Segment consists of the Disaster Management Centre, the Monitor Centre, and the Satellite Ground Control Station. The transmission segment transmits disaster messages to the satellite segment in the following order: First, the Disaster Management Centre gathers the relevant information. Second, the Disaster Management Centre converts the information into an emergency message for transmission by QZSS. The Disaster Management Centre decides the distribution schedule for providing the information and transmits the emergency message to the Satellite Ground Control Station. Third, the Ground Control Station collects the Monitor Centre's results and generates (enhanced) navigation messages for broadcast on the L1-SAIF signal, which will be used by the user to derive precise position information The Ground Control Station uplinks both the navigation message and the emergency message to the QZSS satellites.

The *Satellite Segment* consists of both the QZSS and other GNSS satellites like GPS and QZSS. The L1-SAIF signal with the enhanced navigation message and the superimposed emergency message are transmitted to the users.

The *User Segment* (or receiving segment) receives the L1-SAIF signal and position information from QZSS as well as position information from other GNSS satellites on their GNSS receivers. The enhanced navigation message is used to provide an accurate position of the users. The L1-SAIF signal contains the emergency messages that are decoded by the users' device in order to acquire the disaster information. Once these messages are received, it triggers the app, which then provides guidance to users to take appropriate risk aversive actions, for example an evacuation route for the user at a s pecific location and other relevant information. Here we assume the use of smartphones with GNSS/GPS capability and other geospatial tools such as maps for evacuation guidance.

For the QZSS alert messaging system, two receiving modes are being developed: One is the wide-area broadcast mode, which can send emergency messages simultaneously over a large area; the other is the area-selected broadcast mode, which can send messages to a specified area (Iwaizumi et al. 2014). The area-selected mode delivers several emergency messages to provide disaster information for all areas depending on the type and content of the disaster information. Therefore, the user segment of this system provides the disaster information to the users by selecting the information of the area corresponding to the location of the user from the received emergency messages (Iwaizumi et al. 2014).

CONCLUSION

Australia's vast landmass presents a significant operational and practical challenge for the government to provide an emergency warning mechanism that can disseminate time critical safety information 'wherever to whomever it is necessary' during events of disaster. It would require massive investment in establishing the network and underlying infrastructure, which may not be economically viable. The provision of safety information through a GNSS-based system is feasible as it combines the strengths of both mobile telephone-based service and satellite communications, while it overcomes their weaknesses. The key advantage of satellite based communication is its high resilience to communication network overload and failure of ground systems and network infrastructure during a disaster. It also provides scalability of coverage for mass public warning and its operation is potentially more cost effective compared to other warning systems.

In spite of pervasive presence of GNSS based technologies, application of GNSS in emergency warning and alerting in Australia is still in its infancy. To a large extent, research into the viability and implications of GNSS technology within the national emergency warning apparatus is scarcely limited. This boils down to the partial immaturity of the satellite-based warning technology which soon will change with the advent of new GNSS satellites and augmentation systems. The challenge remains in thinking beyond the immediate barriers, identifying technical and non-technical requirements and understanding operational context in which the technology can be used as 'added value' to existing warning systems.

The Japanese satellite system or QZSS has the capabilities of delivering warning messages to people's personal mobile devices. The devices could be tailored to receive location-based emergency warnings at a specific point in time and within a defined geographical area. It has the potential to therefore address some of the shortcomings of the traditional warning services. A GNSS-based warning system is not likely to replace existing systems, but it can augment and strengthen them by providing an independent means of sending location-based warnings. There is a constant need to build effective warning systems that evolve over time by embracing newer technologies. As other GNSS systems such as Galileo and BeiDou continue to mature and be equipped with emergency alert capability, Australia will have an opportunity, by virtue of the geographical location of the continent relative to all of these global navigation satellite systems, to be an excellent test ground for GNSS-based emergency services and be first to innovate with new tools and products.

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THE ROLE OF EXTREME VALUE ANALYSIS TO ENHANCE DEFENDABLE SPACE FOR CONSTRUCTION PRACTICE AND PLANNING IN BUSHFIRE PRONE ENVIRONMENTS

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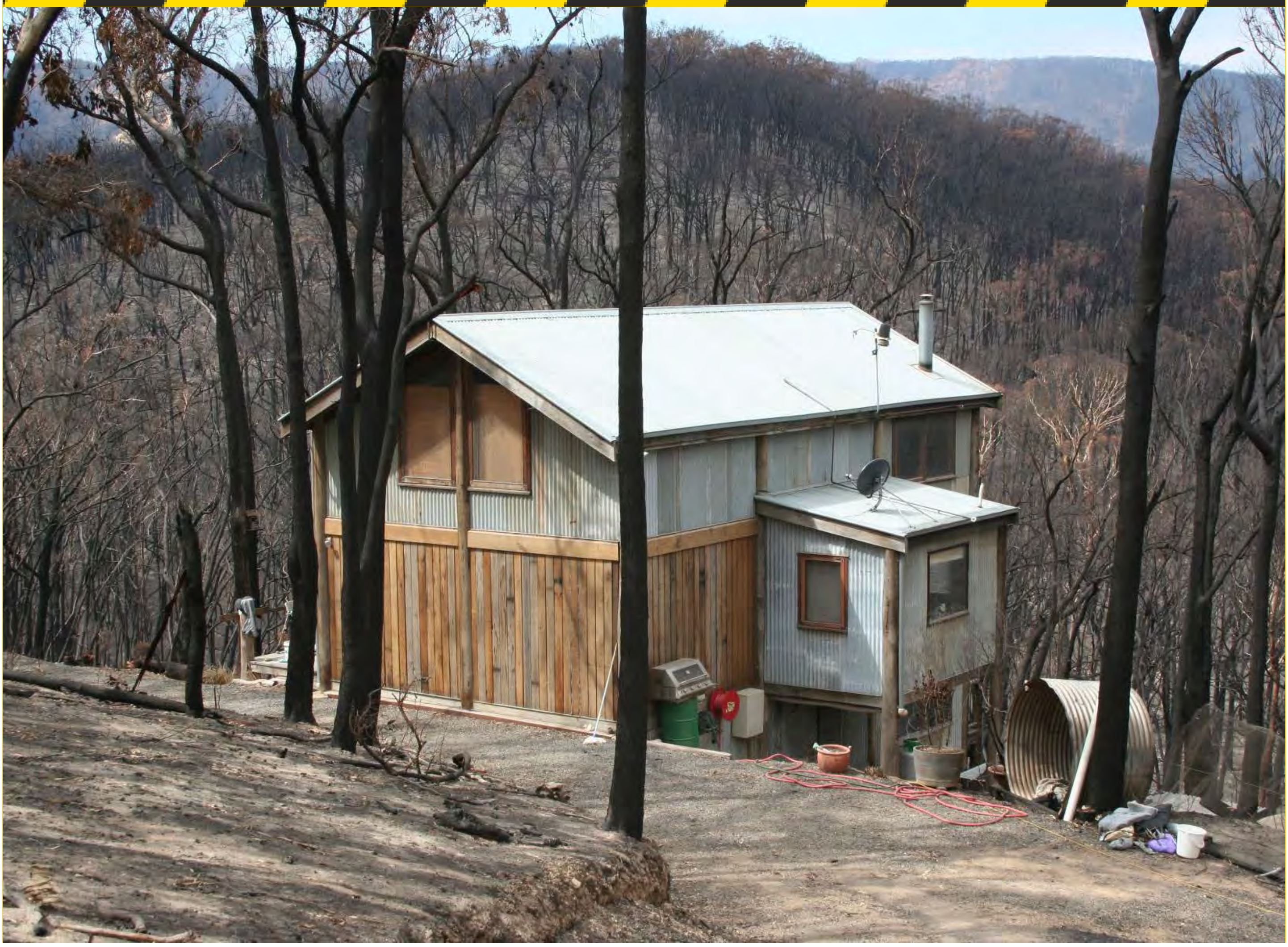


ABSTRACT

Preparation of defendable space for buildings of both existing and planned urban development in bushfire prone areas relies on critical assessment of potential fire conditions. This paper offers new insights into the application of three extreme value assessment methods to the input parameters of both MacArthur and Project Vesta fire behaviour models for the determination of the defendable space and other fire safety measures. Weather data for various durations from 21 New South Wales fire weather districts are processed to derive the fire behaviour model input parameters such as the forest fire danger index and the fuel moisture content. These parameters are then subjected to probabilistic and recurrence modellings using three extreme value analysis methods. The results are evaluated to determine the most appropriate approach. It is found that the recurrence trends can be modelled with log functions with good correlation coefficients. The models are used to predict 1:50 year recurrence values of forest fire danger index which are compared with the existing policy settings. The results indicate the need to revise the policy settings for some of the weather districts.

KEYWORDS: fire weather, planning, probability, recurrence, risk assessment, wildfire.

Nomenclature

A_{max}	annual maxima
a	coefficient in the regression modelling
BAL	bushfire attach level (kW/m^2)
BoM	bureau of meteorology
b	constant in in the regression modelling
DF	draught factor
FFDI	Forest fire danger index
Fm	Fuel moisture content (%)
GCM	global climatic modelling
GEV	general extreme value
GFDI	grassland fire danger index
GPD	generalised Prato distribution
KBDI	Keetch-Byram Drought Index
NSWRFS	New South Wales Rural Fire Services
H	relative humidity (%)
T	air temperature (°C)
T_{max}	maximum daily temperature (°C)
U_{10}	average wind speed (kph) at 10 m above the ground
x	Independent parameter in probability density distribution, recurrence interval (year)
y	FFDI in the recurrence regression modelling
$\alpha, \beta, \mu, \sigma, \xi$	constants in various probability density distribution functions.

INTRODUCTION

Bushfires are frequent phenomena but variable in severity and landscape. Bushfires can occur with some regularity with season, however, extreme bushfire events are less likely and hard to quantify. These events are dependent on the antecedent weather conditions which give rise to severe bushfire conditions (Sullivan, 2004).

The determination of the severity of a potential bushfire for construction practice and land-use planning purposes is crucial in any assessment process. Property protection measures are therefore related to the concept of a 'design bushfire' (Douglas et al, 2014).

Building constructions in Australia are governed by the Building Code of Australia (BCA) and the relevant standards (ABCB, 2014). BCA is a performance based code which prescribes the performance requirement as well as the deemed-to-satisfy provisions. For performance based fire safety design, design fires provide a design reference (ABCB, 2005, Ramsay et al, 2006). Building fires are predominantly influenced by the combustible materials, ventilation conditions and the fire safety measures installed within a confined area and the selection of the design fire in building fire safety engineering is principally based on the consideration of these parameters (ABCB, 2005, SFS, 2012). Bushfire intensity, on the other hand, depends on topography, fuel loads and weather conditions and the development of design bushfires must consider these parameters. The determination of weather conditions for design bushfires is the focus of the current study.

Since weather conditions are more or less random phenomena, the selection of the design condition is usually guided by risk base principles. The quantification of extreme weather events based on a risk profile and recurrence analysis has been regularly used in areas of storm, flood and wind protection. However, similar approaches have not found wide application in bushfire protection. The application of fire weather data for planning and construction practice in bushfire prone areas has been empirically inferred from past events and relied on assumed FFDI values (NSWRFS, 2006). In some cases the selection of the reference FFDI has been supported by subsequent work although only indirectly (Hennessey et al, 2005).

Based on the assumption that the forest fire danger index follows the Weibull distribution, Douglas et al (2014) presented a g eneralised extreme value approach to the modelling of the recurrence of forest fire danger index (FFDI). This approach sets the selection of design bushfire on a more rigorous basis than the existing method used in the existing standard (AS 3959, 2009). The application of the method to the recorded weather data from a limited number of weather districts in NSW, where complete or continuous weather data was available, has shown good correlations between the regression lines and the FFDI recurrence data. However, in view of the existence of a number of the extreme value analysis methods, there remains a q uestion as to whether the generalised extreme value approach is the most appropriate approach available.

Further review of the weather data record revealed that not all weather districts in New South Wales state have the complete weather data due to historical development of the weather stations. It is still unknown if the available assessment methods are robust enough to deal with incomplete weather datasets.

The objective of the current study is to test multiple extreme value assessment methods and apply them to the data obtained from all NSW weather districts. The methods will be compared against the criteria of accuracy and robustness. The study will result not only the evaluation of various extreme value analysis methods, but also the recommended design bushfire parameters for all NSW weather districts.

BACKGROUND

TOWARDS A DESIGN BUSHFIRE

A major assessment parameter for bushfire protection design is the bushfire attack level (BAL) which is expressed in heat flux exposure (AS3959, 2009). This parameter can be evaluated from flame dimensions, flame temperature and flame distance (Douglas and Tan, 2005). The latter can be a design input parameter for building design or an outcome parameter for design and planning. The former two are design input parameters and depend on bushfire intensity which in turn depends on fire weather conditions. Hence, the selection of design bushfires is reduced to the selection of design weather conditions which is characterised by the forest fire danger index (FFDI) (Noble et al, 1980).

The concept of annual occurrence of exceedance (or recurrence) for FFDI is used by the New South Wales Rural Fire Service (NSWRFS) as a major input for determining the design bushfire conditions where a solution that is alternative to deemed-to-satisfy provisions of the building code and the standard is proposed (NSWRFS, 2006).

The sensitivity of FFDI used to estimate fire danger throughout Australia has been considered by Williams et al (2001) and linked to increased recurrence of fires as measured in terms of very high and extreme events and may be linked to maximum daily temperature. However, the question remains as to the process of determining suitable risk criteria for the development of defendable space, not only for property protection for new developments, but also fire fighter safety and existing developments (Douglas, 2012).

A major difficulty therefore is in defining bushfire scenarios for design and assessment purposes. The failure to obtain the appropriate design fire can result in additional costs to the environment or construction for land holders or, alternatively, the failure of the building systems to withstand the likely fire event. For example, the environmental conditions for the Victorian bushfires in 1939 were deemed to have set the 'benchmark' of worst possible conditions for bushfires and the corresponding FFDI value was set at 100 to mark the presumed upper limit of the scale (Sullivan, 2004). However these conditions and the FFDI 100 limit have been exceeded on many occasions since. Table 1 lists recent examples of such fire events and their FFDI ratings. The exceeding of the benchmark FFDI value of 100 presents challenges as to what is the appropriate benchmark for design in bushfire prone areas and whether a unified benchmark value exists.

Table 1. Recent Australian major bushfire events exceeding FFDI 100.

Event	Year	FFDI	Source
Ash Wednesday	1983	>100	Sullivan (2004)
Mt Hall fire	2001	>100	NSW Rural Fire Service (2002)
ACT (Duffy, etc.)	2003	105	McLeod (2005)
Eyre Peninsula, South Australia	2005	200	Smith (2005)
Victoria's Black Sunday	2009	188	VRCB (2010)

These challenges are further complicated by the global warming. The overall impact of climate change is undertaken using global climatic modelling (GCM) to develop 'scenarios' arising from different emission patterns into the future (Hasson et al, 2008). However such models are not suited for infrequent extreme events at the small scale due to their limited spatial and temporal resolution.

Previous climatic assessments have largely focused on historical weather records and linear regression models (e.g. Andrews et al, 2003; Bradstock et al, 1998). Recent work by Cechet et al (2013) and Sanabria et al (2014) have illustrated the role of extreme value assessment to map fire weather return periods based on forest fire danger index (FFDI) across the landscape using GCM to incorporate the potential effects of climate change. Such mapping exercises are initially attractive but rely on complex models to translate a w eather and climatic scenario for events which are occurring in different time frames and conditions. Li and Heap (2011) identified the challenges of environmental mapping under such conditions, which include the needs for larger numbers of data-points (i.e. weather stations) within a landscape for model enhancement.

An alternate approach is to progressively build up weather station data within the landscape, based on BoM weather prediction districts, and increase the number of weather station data-points for comprehensive climatic model validation.

This paper provides an update of progress in the broader study of extreme value assessment techniques and their applications for land use planning and construction practice in NSW fire weather areas. The content covers weather related parameters only. Vegetation classes and fuel structure assessments are excluded, though they also form part of this broader investigation.

MCARTHUR AND PROJECT VESTA BUSHFIRE BEHAVIOUR MODELS

The determination of flame characteristics, including dimension, temperature and rate of spread, is central to consideration of land use planning and construction practice. Bushfire behaviour models therefore underpin the site assessment and construction measures used in bushfire prone areas and are sensitive to the underlying assumptions made as inputs to these models for the development of bushfire attack levels (BAL) and defendable space. In essence these assumptions relate primarily to weather and vegetation (Douglas and Tan, 2005).

The two key models for fire behaviour to be considered for forest fire in Australia are those of McArthur (Noble et al 1980) and Project Vesta (Gould et al, 2007).

In the McArthur fire behaviour model, the forest fire danger index (FFDI) has been recognized as the most indicative of forest fire behaviour. This index is mathematically formulated by Noble et al (1980) and has been applied to limited weather data as part of the National Fire Weather Data set (Lucas, 2010). FFDI is used to determine both the rate of spread and flame length (Noble et al, 1980), although the model is believed to be suited to low range of FFDI index or low intensity fires (Gould et al, 2007, McCaw et al, 2008Dowdy et al, 2009).

The more recent model developed in the Project Vesta is believed to more accurately reflect the rate of spread in higher intensity fires (Gould et al, 2007). However its fuel assessment approach differs from McArthur approach as does the use of weather parameters in deriving fire behaviour including El Nino Oscillation and Inter-decadal Pacific Ocean events (Verdon et al, 2004).

The two models require different fire weather inputs. The McArthur model relies on the forest fire danger index which incorporates a set of weather data including wind speed, relative humidity, temperature and draught factor, whereas the Project Vesta model uses primarily wind speed, fuel configuration and fuel moisture (Gould et al 2007, Cheney et al, 2012).

DATA COLLECTION AND ANALYSIS

DATA

The State of NSW has 21 Fire Weather Districts (NSWRFS, 2006) as shown in Figure 1. Each weather area has multiple weather stations. However, not all weather stations have a complete dataset to calculate FFDI. Data from at least one weather station in each NSW fire weather area were used in the present study. Some areas investigated for FFDI may be better associated with GFDI which is not included in the current study. The twenty-one (21) weather station locations in the 21 fire weather districts are listed in Table 2.

Figure 1 NSW fire weather districts (NSWRFS, 2006) and some weather station locations (Source: BoM).

For the current study, three weather datasets have been acquired from the Bureau of Meteorology (BoM) including:

- 1976/86-2009 data on FFDI/GFDI and associated data (Lucas, 2010) (16 stations);
- All 1950-2009 daily data available at 3:00pm including wind speed and direction, relative humidity (H), temperature (T), gusts and rainfall;
- 1994-2009 drought indices (DF and KBDI) with 3pm relative humidity, daily maximum temperature (T_{max}) and 24 hr rainfall (88 stations).

The datasets have been consolidated and 30 location datasets have been produced covering all 21 fire weather districts (see Figure 1). These include FFDI (and GFDI in western NSW), 3:00pm wind speed and directions, relative humidity and the daily maximum temperature. For each area, forest fuel moisture was also calculated on a daily basis using models described by Gould et al (2007). The data obtained from the Lucas (2010) datasets cover the period from 1976 to 2009 and the data derived from BoM covers the period of 1994-2009. Due to significant data gaps and geographical spread, not all weather datasets by Lucas (2010) have been used (see Sanabria et al, 2014).

Table 2. Fire Weather Areas (Districts), and associated weather stations used in the study (BoM after Lucas 2010, NSWRFS, 2006).

Fire Weather Districts No.	Fire Weather Area Name	Weather Station
1	Far North Coast	Grafton
2	North Coast	Coffs Harbour
3	Greater Hunter	Williamtown
4	Greater Sydney	Sydney
5	Illawarra/Shoalhaven	Nowra
6	Far South Coast	Batemans Bay
7	Monaro-Alpine	Cooma
8	Australian Capital Territory	Canberra
9	Southern Ranges	Goulburn
10	Central Ranges	Bathurst
11	New England	Armidale
12	Northern Ranges	Tamworth
13	North-Western	Moree
14	Upper Central West Plains	Coonamble
15	Lower Central West Plains	Dubbo
16	Southern Slopes	Young
17	Eastern Riverina	Wagga Wagga
18	Southern Riverina	Deniliquin
19	Northern Riverina	Hay
20	South Western	Mildura
21	Far Western	Cobar

METHOD OF ANALYSIS

Overview

In the past, practice has been to consider the limited data available for a site and determine whether any of the following policy decision should be based on:

a) FFDI has been exceeded on more than one recorded occasion;
b) FFDI which is a frequency percentile value of the dataset (e.g. 95% value of FFDI>12); or
c) derived FFDI from maximum values of wind speed, (lowest) relative humidity, maximum temperature and drought factor for summer data.

Each of these methods has significant shortfalls and does not necessarily represent a valid risk based approach to the assessment of fire weather. They have been used in the absence of a clear methodological and statistically appropriate approach (e.g. Douglas and Tan, 2005). In particular, they are all based on the past records which may not give true representation or prediction of the likely and the extreme scenarios. The exceedance of traditional limiting value of 100 for FFDI is a typical example of the limitation of this kind of approaches.

In the current study, a number of probability distribution functions have been hypothesised to describe various parameters namely FFDI and fuel moisture content (F_m) in the two identified bushfire behaviour models. The corresponding recurrence models are then established to predict the parameter recurrence values for a specified recurrence interval. These methods are applied to the derived fire weather index data for all 21 NSW fire weather districts. The results are compared with the current policy or standard settings in bushfire protection practice.

Derived parameters for bushfire behaviour modelling

Historically extreme value analysis has been used for directly measurable weather parameters such as rainfall, floods, temperature, relative humidity and wind, however, such analysis has not been routinely undertaken for fire weather. The reason may be attributed to fire weather being described by a composite of differing parameters as explained in Eq. (1) below (Noble et al, 1980):

$$F = 2\exp\left[-0.45 + 0.987\ln(D) - 0.0345H + 0.0338T + 0.0234U_{10}\right] \quad (1)$$

where F denotes FFDI, D is drought factor derived from Keetch-Byram Drought Index (Griffith, 1999), H is relative humidity (%), U_{10} is wind speed at 10 m above ground (kph) and T is air temperature (°C).

Similarly, the fuel moisture correlation used in the Project Vesta model is dependent on relative humidity and air temperature in the following equation:

$$F_m = 5.658 + 0.04651H + 3.151 \times 10^{-4}H^3/T - 0.1854T^{0.77} \quad (2)$$

where F_m is fuel moisture.

It is unlikely at any given time that all individual independent parameters could attain their extreme values simultaneously to yield an 'extreme' value of the derived or dependent variables such as forest fire danger index F or the fuel moisture F_m. Therefore, one cannot rely on the results of the extreme value analysis of individual weather parameters to deduce the extreme value of F or

F_m. It is nevertheless possible to extend extreme value to the dependent parameters themselves.

Probabilistic description of the derived parameters

As discussed earlier, the derived parameters F and F_m are random parameters because of the random nature of the weather parameters on which they depend on. Extreme value assessment provides a useful tool for the determination of risk associated with the occurrence of extreme events (Coles, 2004). Although some work has been undertaken using extreme value techniques on large fires, only limited work has been done in relation to assessing fire weather parameters. For example, Andrews et al (2003) and Douglas et al (2014) employed the generalised extreme value (GEV) method, whereas, the use of generalised Pareto distribution (GPD) was reported by Cechet et al (2013) and Sanabria et al (2013). There remains a question as to which method is more suitable. Furthermore, it is hypothesised that a Gumbel type distribution may be an alternative description of the random characteristics of F. Hence, this study uses the following three extreme value assessment techniques:

a) Generalised Extreme Value (Weibull) distribution (GEV);
b) Annual Maxima (Gumbel) distribution (Amax); and
c) Generalised Pareto distribution (GPD).

The Weibull probability density function is expressed by the following equation:

$$f(x) = \frac{\alpha}{\beta}\left(\frac{x}{\beta}\right)^{\alpha-1} e^{-\left(\frac{x}{\beta}\right)^{\alpha}} \tag{3}$$

where α and β are constants and the domain of x is (0, ∞).

The distribution governing the annual maxima is believed to be Gumbel distribution of the form:

$$f(x) = \frac{1}{\beta}\exp\left(-\frac{x-\mu}{\beta}\right)\exp\left[-\exp\left(-\frac{x-\mu}{\beta}\right)\right] \tag{4}$$

where β and μ are distribution parameters, and the domain for x is (0, ∞).

The probability density function for the generalised Pareto distribution (GPD) takes the form:

$$f(x) = \frac{1}{\sigma}\left[1 + \frac{\xi}{\sigma}(x-\mu)\right]^{-\left(1+\frac{1}{\xi}\right)} \tag{5}$$

For $x \geq \mu$ when $\xi \geq 0$ and $\mu \leq x \leq (\mu - \sigma/\xi)$ when $\xi < 0$. In all of the above three probability density distribution functions, variable x represent FFDI.

Recurrence modelling

The application of the GEV method to obtain the regression fit and estimate of recurrence values of FFDI is explained in Douglas et al (2014). Detailed descriptions of GEV method can be found in Makkonen (2006).

In the annual maxima approach, the annual maximum FFDI value for each calendar year is selected and ranked in a similar way as in the GEV approach.

Unlike other GEV approaches, the plot of recurrence trend based on GPD approach relies on determining the proportion of exceedance values above a threshold. This is often referred to as a peaks over threshold approach where FFDI values are ranked and the proportion of values being exceeded are then plotted in a similar way to GEV (Makkonen, 2006). To calculate average return intervals a partial duration series dataset (as opposed to annual maximum) was constructed, using:

$$ARI_y = \frac{\text{Total number of data points}}{\text{Number of data points where FFDI} > y} \quad (6)$$

where ARI_y is the average return (or recurrence) interval with the condition of FFDI>y. The advantage of the GPD approach is that it is not reliant on seasonal or calendar considerations. The disadvantage however, is that it has stringent requirement on the continuity of data string. Any gap in the data string will have a greater influence on the output than in either GEV or A_{max} approaches.

The recurrence trends based on the three methods are fitted with log functions of the form:

$$y = a\ln(x) + b \quad (7)$$

where a and b are the constants of best fit to the recurrence trends. Variable x in the above equation represents the recurrence interval and y the corresponding forest fire danger index. From the established correlations the forest fire danger index for any specified recurrence interval can be predicted. It is noted that the prediction can be extrapolated beyond the period of the data collection.

These three approaches have been used and compared to maximum recorded values in the dataset. For illustrative purposes, 1:50 year return using GEV only for fuel moisture has also been determined.

RESULTS AND DISCUSSION

RESULTS

Probability density distribution analysis

A software package EasyFit (Mathwave, 2015) was used to obtain the probability density distribution functions described earlier. An example of the histogram and the fitted distribution functions for the FFDI values obtained from the Sydney Airport weather station are shown in Figure 2. It can be seen from this figure that Weibull distribution curve produces a monotonously decreasing trend that gives the best fit to the histogram. Both the fitted GPD and Gumbel have a peak that is not observed in the histogram.

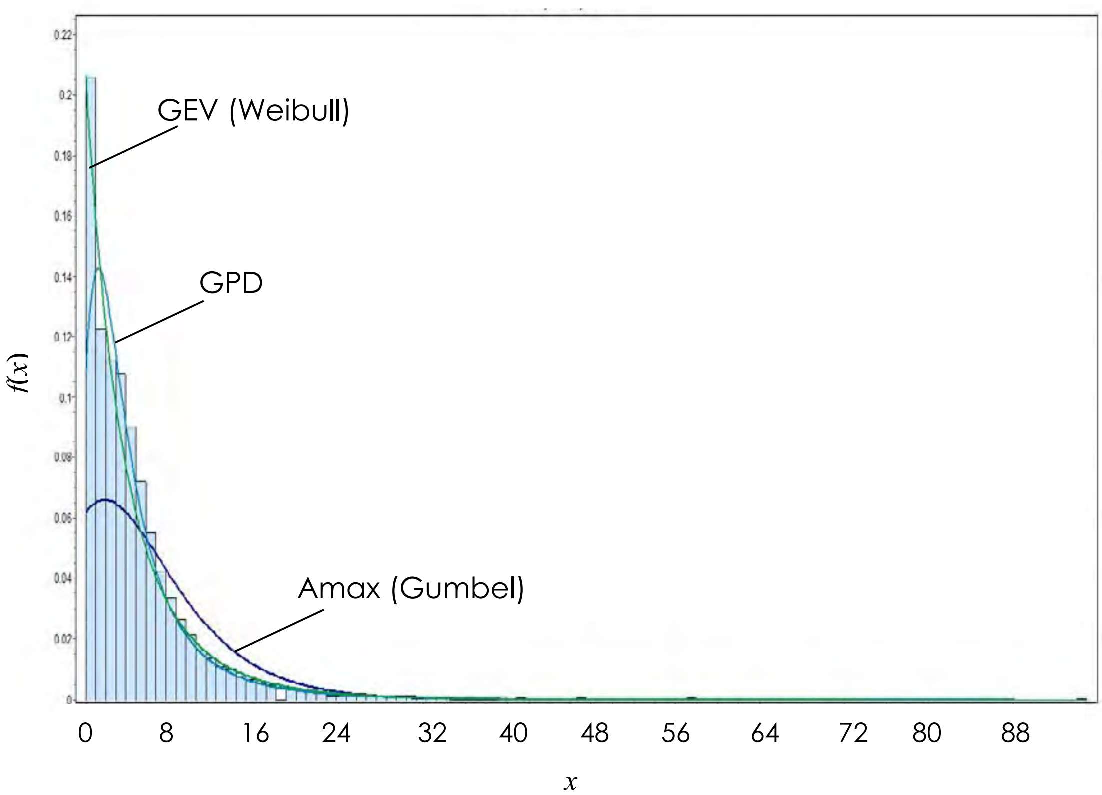


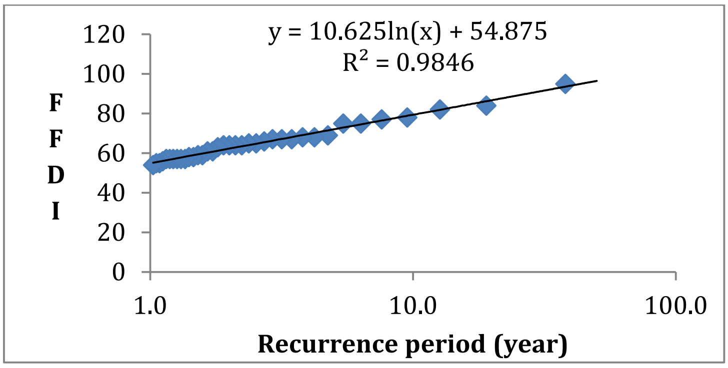
Figure 2. Histogram of FFDI and fitted probability density distribution functions.

The fitted distribution functions underwent Kolmogorov-Smirnov (K-S) test (Corder and Foreman, 2014) and, not surprisingly, the results indicated that the Gumbel distribution attains the lowest ranking among the three and the Weibull distribution the highest ranking. Therefore, the Weibull distribution is the most suitable description of the probabilistic characteristics of FFDI obtained from the Sydney Airport weather station. Similar outcomes were found for the majority of the stations listed in Table 2.

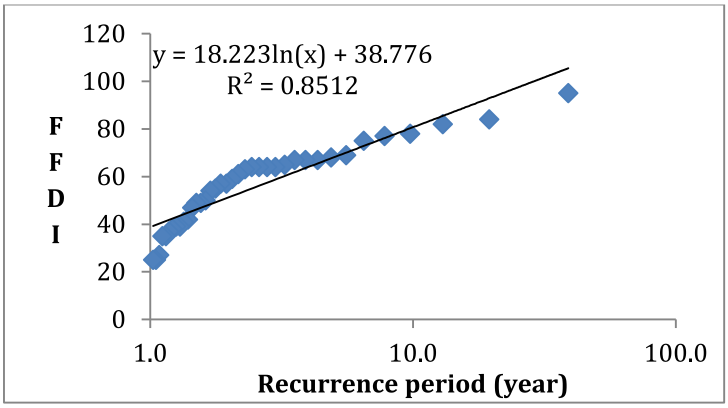
Recurrence analysis

Recurrence analyses were conducted over the FFDI values of all 21 fire weather districts using the GEV, Amax and GPD approaches. An example of the graphical representations of the recurrence plot based on three techniques is shown in

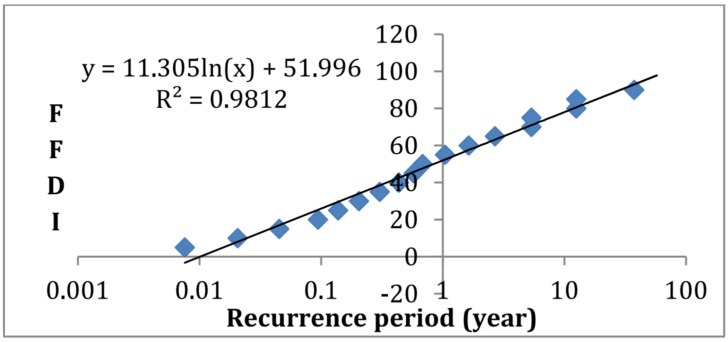
Figure 3 for the Sydney Airport district. It can be discerned that GEV [Figure 3(a)] resulted in the best log regression model over that of Amax [Figure 3(b)] (which has the lowest correlation coefficient, or the R^2 value) or GPD [Figure 3(c)].



(a) Results of GEV method.



(b) Results of Amax method.



(c) Results of GPD method.

Figure 3. Graphical representation of FFDI recurrence plots with regression models for Sydney Airport.

The three methods of recurrence analyses were applied to the FFID data of all 21 NSW fire weather districts. The GEV method, which yields the best fit among all three methods, was also applied to fuel moisture data. The predicted results of 1:50 year recurrence are presented in Table 3 and are compared to the existing policy settings that are prescribed in the New South Wales *Planning for Bush Fire Protection* (NSWRFS, 2006) and Australian Standard *Construction in bushfire prone areas* (AS3959, 2009). Also included in Table 3 are the recorded maximum FFDI at 3:00 pm for all fire weather districts.

Table 3. Evaluated recurrence, standard setting and maximum recorded FFDI, and recurrence fuel moisture content for 21 weather stations.

District No.	$FFDI_{1:50}$			FFDI		$Fm_{1:50}$ (%)
	GEV	A_{max}	GPD	AS3959	3:00pm Max	GEV
1	101	120	94	80	93	2.64
2	96	94	82	80	95	2.86
3	106	121	101	100	99	1.84*
4	98	110	96	100	95	2.47
5	112	122	104	100	120	3.55
6	97	112	90	100	74	3.07
7	83	96	84	80	68	2.28
8	100	115	96	100	99	2.48
9	105	121	104	100	91	2.00
10	83	100	82	80	91	2.93
11	46	52	46	80	46	3.07
12	100	101	100	80	105	2.44
13	115	104	103	80	125	2.41
14	123	163	121	80	121	2.29
15	107	121	101	80	99	2.60
16	79	97	89	80	71	2.35
17	122	144	121	80	138	2.26
18	131	146	125	80	121	2.42
19	108	125	106	80	125	1.55*
20	136	150	130	80	132	2.40
21	116	128	113	80	117	2.22

* The predicted value is less than the limit of 2% (McArthur, 1967) and hence practically unlikely.

DISCUSSION

The application of extreme value techniques to forest fire danger index allows the interrogation of multiple weather parameters for the determination of appropriate design bushfire conditions for bushfire protection. Table 3 shows that there can be significant variation between techniques though the GEV and GPD approaches align more closely with the processed data than Amax. The latter generally produce higher estimate of the 50 year recurrence FFDI values that the former two. Higher estimate of recurrence FFDI value for planning and design purposes will lead to conservative or safer protection outcome.

What is also apparent in Table 3 is that the current policy and standard settings of reference or design FFDI for a number of districts in the North Coast (Districts 1 and 2) and inland areas (Districts 10, 13 - 17) are lower than 1:50 year return period FFDIs. In other areas (notably District 12) policy settings are higher than the evaluated 1:50 year recurrence FFDI. Although not all stations can be said to be representative for the whole of the fire weather districts, the data from these stations and the subsequent analyses do provide references of recurrence values for those areas. It, however, should be borne in mind that because of the nature of the vegetation cover, far western NSW would be better represented with GFDI than FFDI.

It is noted that in the Project Vesta model, the fuel moisture correlation as given by Eq. (2) has a lower mathematical limit of 2.66% corresponding to the limiting case of 5% relative humidity and 41°C temperature. Anecdotally, temperatures higher than 41 °C have been observed in many parts of NSW. Therefore, it may be possible that the limit is even lower. In the literature, a limit of 3% was cited by Gould et al (2007) and Cheney et al (2012). The physical limit identified by McArthur (1967) is 2%. The predictions of the 1:50 year recurrence values for some fire weather districts (No. 3 Greater Hunter and No. 19 Northern Riverina, see Table 2 and Table 3) are found to be below this limit. Care should be taken when apply these recurrence values for design bushfire selection, bearing in mind that lower fuel moisture value would result in higher risk assessment outcome. It is recommended that the minimum threshold value of 2% be used.

This study has found that *prima facie*, the north coast and inland areas of NSW should be brought up from FFDI=80 to a more appropriate FFDI=100. The major exceptions to this are the Central West (Bathurst), Southern Slopes (Young) and Cooma-Monaro (Cooma) fire weather areas which should retain FFDI=80. In the case of New England (Armidale), the fire weather area comprises areas of higher and lower elevations which could affect the FFDI return value. While an FFDI=80 value currently exists, the reduction of the weather area to FFDI=50 may be appropriate unless fire services seek further investigation and confirmation with other weather station data. Areas of western NSW, which do not exhibit forest vegetation should also be included in FFDI=100, although there FFDI values are found to exceed 100.

CONCLUSION

Three extreme value analysis methods have been used in the current study to obtain probabilistic descriptions and recurrence modellings of forest fire danger index and fuel moisture content from the weather data records for the 21 fire weather districts in New South Wales state.

The current study illustrates that the extreme value techniques can be used when determining FFDI and fuel moisture for bushfire behaviour modelling. For planning and design purposes, GEV (Weibull) method appears more suitable than Amax (Gumbel) and GPD methods because of its generally high ranking by the Kolmogorov-Smirnov test and high correlation coefficient of the recurrence regression. Although Amax method is the least accurate approach, it may give a more conservative (safer) design reference FFDI value over the other two methods. GPD method produced reasonable description of FFDI. It is, however, sensitive to the continuity or the period length of data.

The extreme value analysis and recurrence modelling allow us to predict the recurrence values at recurrence period longer than the length of the data collection period from which the model is developed. However, care should be taken when extrapolating the recurrence values. The results should be subjected to the physical constraints based on field experiment and studies. Notably the modelled 1:50 year recurrence fuel moisture value based on GEV method was observed to fall below the 2% threshold in some weather districts of NSW.

The existing approaches to mapping of the forest fire danger index in the regulatory policy area may be problematic in that they deviated significantly from the estimates based on rigorous methods. Adjustments of the policy mapping are recommended to reflect the local weather district conditions presented in this paper.

The data processed in the current study was selected from one typical station in each of the 21 NSW fire weather districts. Multiple weather stations in different locations exist in most districts. The application of the extreme value analysis to additional weather station data within a district will assist in establishing design reference FFDI and fuel moisture with better ore more appropriate spatial resolution within the landscape.

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IMPROVED ASSESSMENT OF GRASSLAND FUELS IN MULTIPLE JURISDICTIONS ACROSS AUSTRALIA

Research proceedings from the Bushfire and Natural Hazards CRC & AFAC conference
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ABSTRACT

IMPROVED ASSESSMENT OF GRASSLAND FUELS IN MULTIPLE JURISDICTIONS ACROSS AUSTRALIA

The degree of grassland curing (senescence) is an essential component in Australian fire behaviour models and Grassland Fire Danger Index (GFDI) calculations. Throughout Australia, techniques used to assess grassland curing and fire behaviour vary between states and territories. The variations in techniques may cause inconsistent GFDI values across the continent, and may inhibit the continuity of GFDI values at state/territory borders. Additionally, inaccurate assessments and poor spatial coverage of curing measurements provide imprecise information for modelling fire behaviour and determining fire danger ratings.

From 2010 to 2014, the Victorian Country Fire Authority (CFA) improved and automated methods to more accurately assess grassland curing. A network of over 200 observers was established and supported by online training to produce accurate ground-based curing observations. A new satellite-based model and an automated online system were developed and deployed. The system combines satellite and ground-based data to produce weekly curing maps used operationally during the fire season. Finally, experimental grassland burns were conducted to improve the understanding of the curing function for grassland fire behaviour models.

Since 2014, CFA has collaborated with fire agencies from multiple jurisdictions, supported by the Commonwealth Attorney General's Department National Emergency Management Projects (NEMP), to improve techniques for grassland fuel assessment across Australia. As a trial to improve GFDI calculations, grassland curing datasets have been produced for multiple states and territories, and will be accompanied with a pilot trial of the online system. In collaboration with the Commonwealth Scientific and Industrial Research Organisation (CSIRO), further experimental burns have been conducted to improve assessments of fire behaviour at different levels of curing.

The combined efforts of the project will improve the accuracy and continuity of GFDI calculations across Australia, and will result in more accurate and spatially representative grass fuel information being used in fire behaviour prediction and fire danger indices.

INTRODUCTION

In Australia, the Grassland Fire Danger Index (GFDI) is determined from a number of inputs including fuel load and the degree of grassland curing (senescence), which is also an essential component in many grassfire behaviour models (McArthur, 1977a, McArthur, 1977b, Cheney *et al*., 1998). Methods used to assess grassland curing, fuel load and fire behaviour vary between states and territories. Such variation may cause inconsistent GFDI values across the continent, and may inhibit the continuity of GFDI values at state/territory borders. Additionally, inaccurate assessments and poor spatial coverage of curing and fuel load provide imprecise information for modelling fire behaviour and determining fire danger ratings.

From 2010 to 2014, the Victorian Country Fire Authority (CFA) developed and deployed an automated technique for operational curing assessment that entails the amalgamation of satellite and ground-based observations. The automated technique has since been trialled for other jurisdictions to improve the assessment of grassland curing across Australia. To also improve the understanding of the curing function for grassland fire behaviour models, CFA has collaborated with the Commonwealth Scientific and Industrial Research Organisation (CSIRO) to conduct experimental grassland burns in Victoria. Further experimental burns are being conducted in other states and territories to develop a robust curing function to be used in Australian grasslands.

BACKGROUND

CURING ASSESSMENT

Previous Methods

Fire management agencies across Australia have historically used either ground-based visual observations or satellite observations for operational curing assessment. These techniques alone have inherent limitations providing imprecise information for modelling fire behaviour and determining fire danger ratings. From the ground, visual observations are subjective, and therefore have high variability in accuracy. As indicated by Anderson et al. (2011), Levy rod observations (Levy and Madden, 1933) are more accurate than visual observations however the Levy rod technique is not operationally feasible for weekly estimates by volunteer observers. Regardless of which ground-based method is used, ground-based observations do not capture variation in curing levels across the whole landscape (Anderson et al., 2011). Satellite observations provide a curing value for every pixel across a state or territory; however, changes in curing may not be captured entirely by satellite in the event of consecutive days of cloud cover. Satellite models, developed through research supported by the Bushfire Cooperative Research Centre (named Maps A, B, C and D) (Newnham et al., 2010), provide observations every eight days, which is not a feasible time-frame for operational use. Satellite models may underestimate curing owing to woody vegetation and secondary grass growth, and may overestimate curing owing to water-bodies, urban areas, sand dunes, bare soil and even landscapes covered by yellow flowers which result in inaccurate curing estimates (Newnham et al., 2010, Martin, 2009).

Current Methods in Victoria

In Victoria, from 2010 to 2014, an improved automated technique for grassland curing assessment was developed. The inherent limitations of previous practices were lessened by merging ground-based observations with 'MODerate resolution Imaging Spectroradiometer' (MODIS) satellite data. To collate accurate ground-based observations, CFA established a n etwork of 200+ observers supported by online training and field-based products including a field card and a revised grassland curing field guide (CFA, 2014). To collate accurate satellite observations, two products were developed: (i) a satellite model, named MapVictoria, based on historical MODIS satellite data and ground-based visual observations, and (ii) the application of the MapVictoria model in an integrated model named the Victorian Improved Satellite Curing Algorithm (VISCA), combining near real-time MODIS satellite data (provided by the Bureau of Meteorology) with weekly observations of curing from the ground (Martin *et al*. 2015). In contrast with the eight-day window of previous satellite models (Maps A, B, C and D), satellite observations are now provided in near real-time. Also, the VISCA model allows ground-based observations to minimise any under- or over-estimation of curing derived from satellite. The integration of data from the ground and satellite has been automated using a newly developed online system. The online system collates ground based observations and runs the VISCA model to produce operational curing maps on a weekly basis during the fire season. In 2013, the MapVictoria and VISCA models, delivered by the online system, were deployed in operations in Victoria. See Figure 1 for an example of VISCA curing data. The MapVictoria model (alone) has also been deployed operationally in Queensland (A. Sturgess, pers. comm.), New South Wales (S. Heemstra, pers. comm.), Australian Capital Territory (M. Gale, pers. comm.) and Tasmania (M. Chladil, pers. comm.).

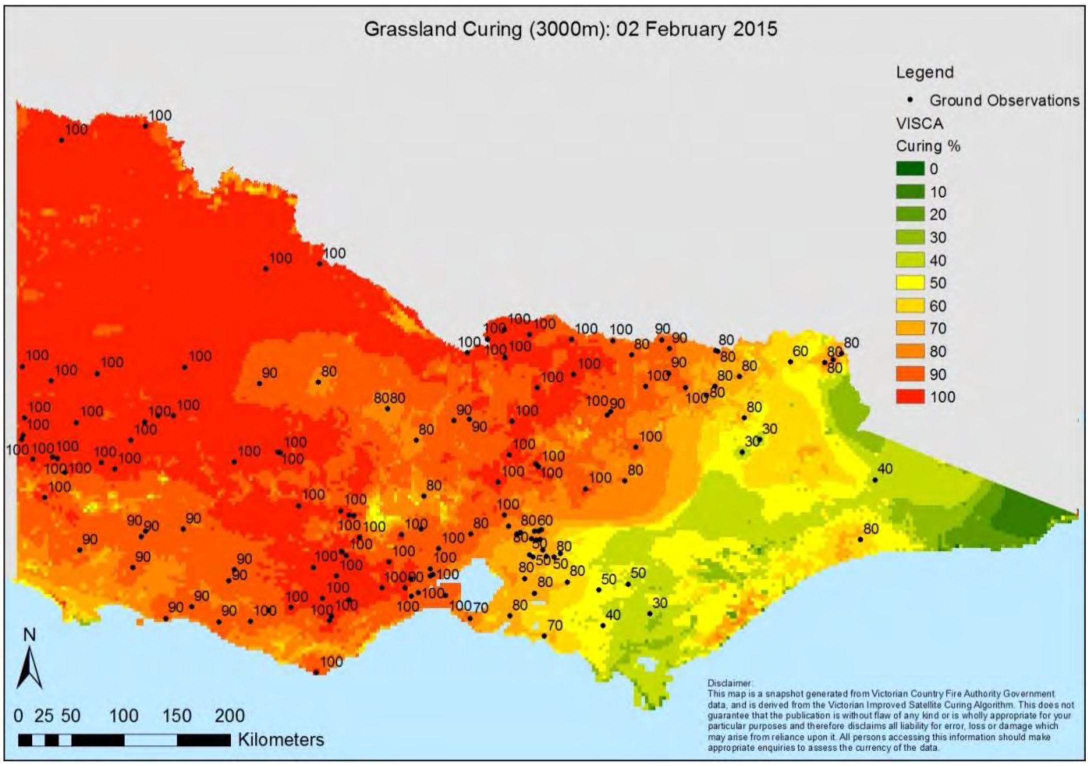

FIGURE 1 VICTORIA GROUND OBSERVATIONS AND VISCA CURING DATA 02/02/2015

VISCA Trial in Multiple Jurisdictions

Since 2014, with support from the Commonwealth Attorney General's Department NEMP, CFA has collaborated with multiple fire management agencies to improve assessment of grassland curing across the continent. Participating agencies include the Bureau, CSIRO, the University of Melbourne, Queensland Fire and Emergency Services (QFES), Australian Capital Territory Rural Fire Service (ACT RFS), ACT Parks and Conservation Service, New South Wales Rural Fire Service (NSW RFS), Tasmania Fire Service (TFS) and the South Australia Country Fire Service (CFS). In the first phase of the trial, VISCA curing datasets have been produced for Queensland, ACT and NSW. See Figure 2, Figure 3 and Figure 4 for examples of VISCA data for Queensland, the ACT and NSW respectively. During the 2014/2015 fire season, the ACT also utilised VISCA for operational curing assessment (M. Gale, pers. comm.).

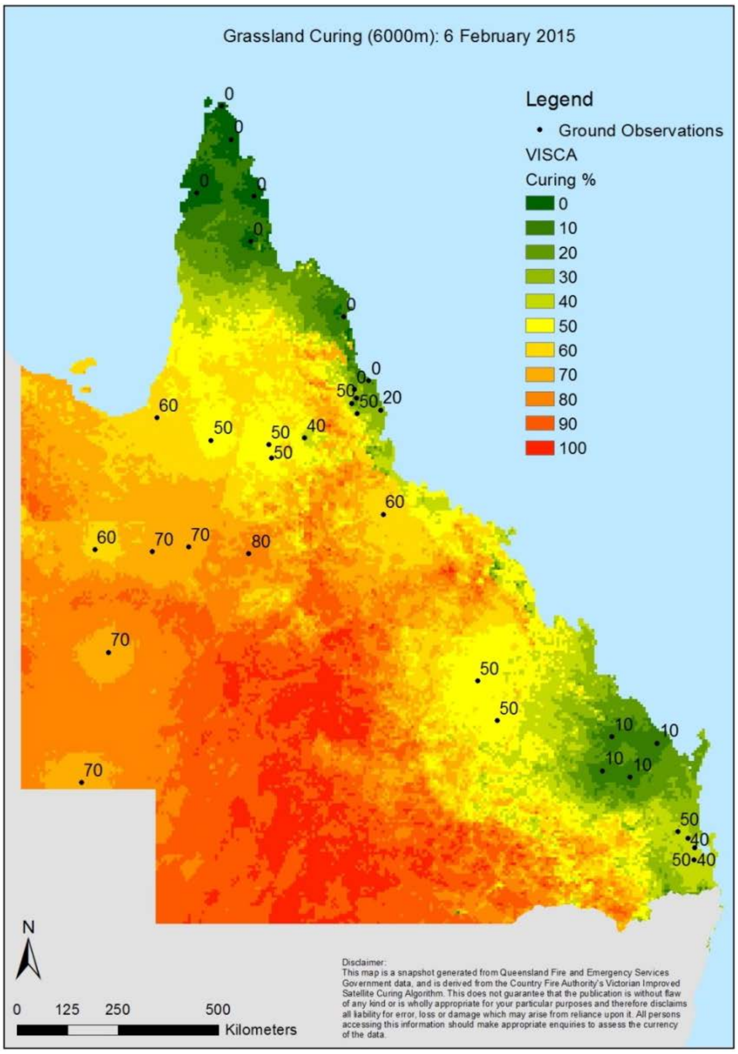

FIGURE 2 QUEENSLAND GROUND OBSERVATIONS (SOURCE: QFES) AND VISCA CURING DATA 06/02/2015

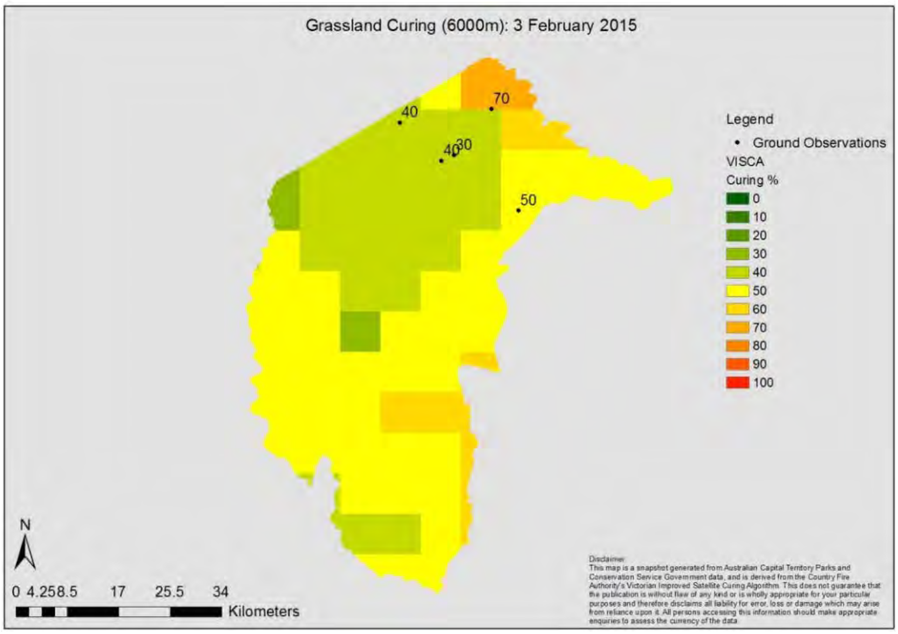

FIGURE 3 ACT GROUND OBSERVATIONS (SOURCE: ACT PARKS AND CONSERVATION SERVICE) AND VISCA CURING DATA 03/02/2015

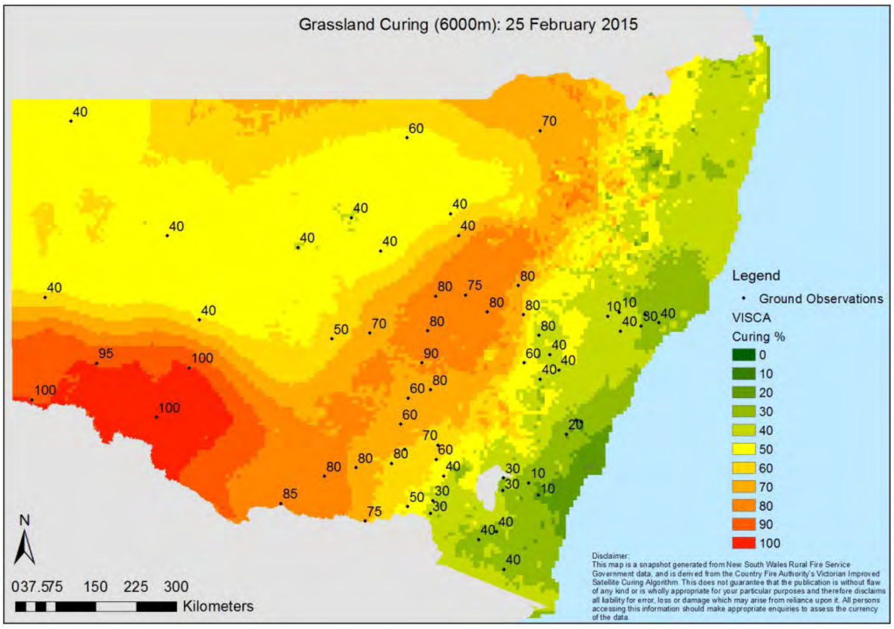

FIGURE 4 NSW GROUND OBSERVATIONS (SOURCE: NSW RFS) AND VISCA CURING DATA 25/02/2015

DEVELOPMENT OF THE AUTOMATED ONLINE SYSTEM

In 2013, the online system was developed and deployed to Victoria's CFA website to facilitate an automated operational workflow for VISCA curing map production. The system's workflow progresses from signing up new observers, to capturing and collating field observations, to producing a VISCA curing map of Victorian grasslands. The system can be accessed using various web browsers on different platforms including personal computers, tablets and smartphones. As part of the National NEMP project, CFA will trial the automated online system for data entry and automated VISCA map production for all participating states and territories for 2015/2016. A prototype of the online system comprises a web application, cloud-based database and a geo-processing service, residing in a low-cost, low maintenance, and scalable cloud computing platform.

Like the Victorian online system, the prototype for other jurisdictions provides a role-based login for users to access the system. Each role is given a different level of access to various functions of the system.

- Observers collecting ground observations can add and access their associated observation site(s) and can report weekly observation data.
- Validators can validate all curing values reported by observers.
- Administrators have full access to all system functions such as data validation, site and user access management, executing the VISCA model and managing data delivery.

It is envisaged that for 2016 onwards, QFES, NSW RFS, ACT Parks and Conservation Service, ACT RFS, TFS and CFS will deploy the online system and VISCA model into operations for weekly assessment of curing.

GRASSLAND FIRE BEHAVIOUR MODELLING

From 2013 to 2014, CFA collaborated with CSIRO to test the relationship between grassland curing and fire behaviour through a series of experimental grassland burns at two improved pasture sites in Victoria (Cruz *et al*., 2015; Kidnie *et al*., 2015). Simultaneous burns of (i) treated, fully cured plots and (ii) natural, partially cured plots meant the effect of curing on spread rate could be isolated. The techniques used in the experimental burns are a world first and will ultimately improve fire behaviour prediction in partially cured grasslands. CFA and CSIRO researchers investigated: (i) the degree of curing threshold above which sustained fire propagation is expected to occur and (ii) the damping effect of live grass fuels on the relative rate of fire spread. To measure curing and fuel moisture content, a modified destructive sampling technique was used. Rather than categorising grass fuels as live or dead, the grass fuels were partitioned into four categories; green, senescing, new dead and old dead (thatch) (Kidnie *et al*., 2015). This method allowed for detailed analysis of curing dynamics throughout the curing season as well as insight into how to better visually estimate curing.

Findings from the experimental burns suggest that the curing function used in fire behaviour prediction in Australia under-predicts rate of spread in partially cured grasslands, and fire spread can be sustained at a lower degree of curing than previously believed (Cruz *et al*., 2015). A new curing function has been proposed, but further research is required to implement the function operationally. CFA and CSIRO have recently collaborated with QFES and NSW RFS to conduct further experimental grassland burns in Queensland and NSW using the same experimental design as the burns in Victoria.

FUEL LOAD ASSESSMENT

In addition to accurate assessment of grassland curing, GFDI calculations and fire behaviour models require accurate estimates of fuel load. In Australia, a modified version of the Mk IV meter is used which incorporates fuel load into the prediction of grass fire spread and Fire Danger Ratings (FDRs) (Purton, 1982). In Victoria, a constant fuel load of 4.5 t/ha is used throughout the entire state, but in other states, variable fuel loads are incorporated into FDR calculations. Like curing, methods used to estimate fuel load vary from one jurisdiction to the next. As part of the NEMP national project, CFA and the University of Melbourne are trialling non-destructive methodologies for fuel load assessment in Victoria and are planning to expand fuel load testing in other states and territories in 2015/2016. Methods to incorporate point fuel load observations and satellite data or pasture growth models are also being explored. Improved estimates of fuel load will provide more accurate GFDI calculations and fire behaviour predictions.

CONCLUSIONS

In Victoria, CFA has contributed to improved GFDI calculations through the development and deployment of an effective automated technique (that is, VISCA) for operational curing assessment. In conjunction with CSIRO, a series of experimental burns have resulted in an enhanced prediction of fire behaviour in improved pastures. Further improvements of GFDI calculations and fire behaviour predictions will also be supported by more accurate assessments of fuel load. Across Australia, methods used to assess grassland curing, fuel load and fire behaviour vary between states and territories. Inconsistent methods can result in inconsistent GFDI values at state/territory borders. Inaccurate assessment of grassland fuels result in inaccurate FDRs and fire behaviour prediction. To support the standardisation of these grass fuel measures, multiple state fire and land management agencies are participating in the NEMP project. By trialling the VISCA model and the online system in multiple jurisdictions, the project will provide accurate and consistent GFDI calculations across multiple states and territories. Thus far, in the 2014/2015 fire season, consistency with curing has improved across the Queensland/NSW, NSW/ACT and NSW/Victoria borders with all four jurisdictions using curing data derived from MapVictoria. Access to near real-time satellite data has also improved the temporal accuracy of curing. Further experimental burns in NSW and Queensland will further progress the curing function and its applicability to various grass types and climatic conditions. The combined efforts of the NEMP project will result in more accurate and spatially representative grass fuel information being used in fire behaviour prediction and fire danger indices across the country.

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IMPROVEMENTS AND DIFFICULTIES ASSOCIATED WITH THE SEISMIC ASSESSMENT OF INFRASTRUCTURE IN AUSTRALIA

Research proceedings from the Bushfire and Natural Hazards CRC & AFAC conference
Adelaide, 1-3 September 2015

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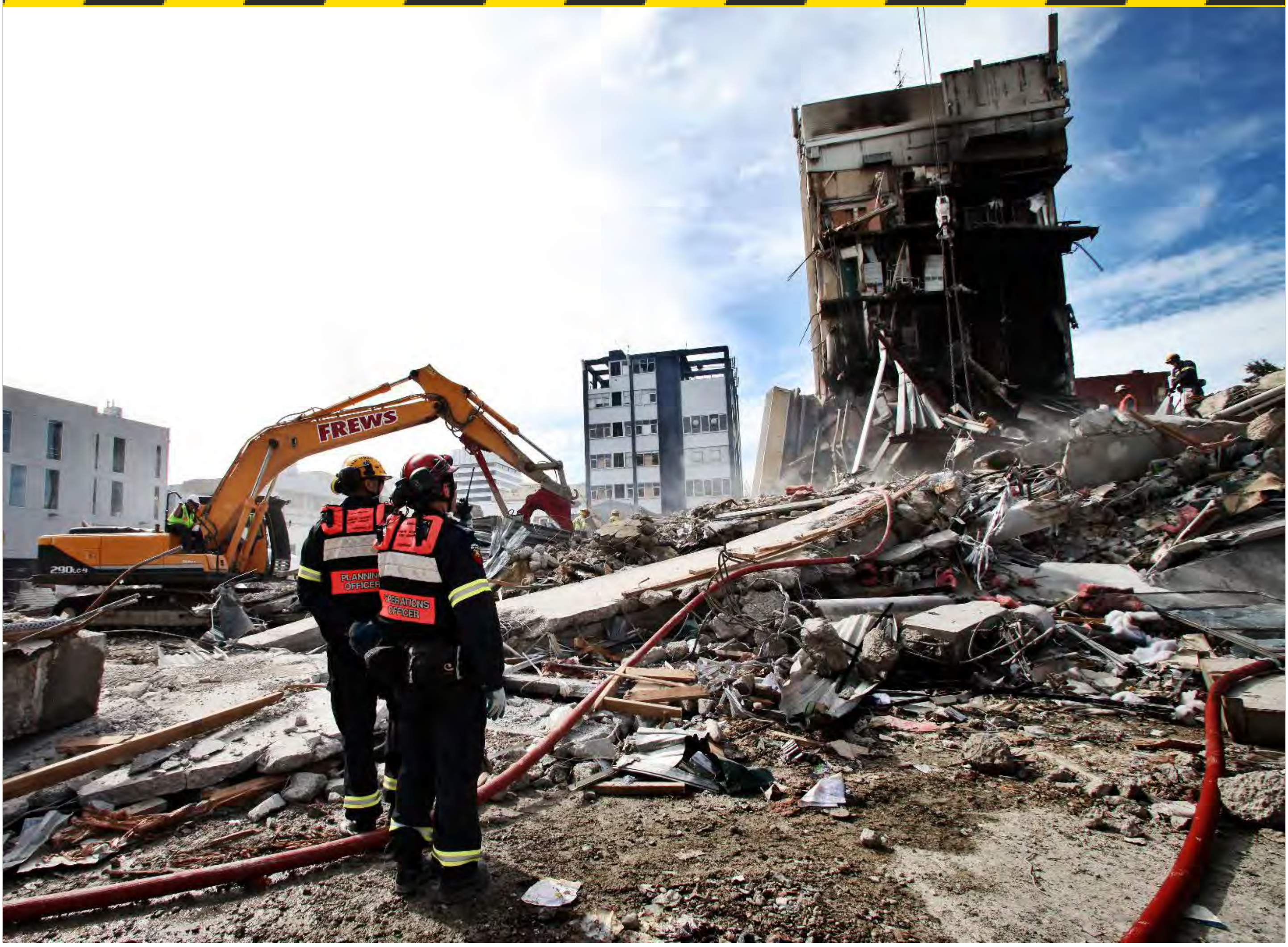

ABSTRACT

Australia is in a region of low-to-moderate seismicity, but experiences a higher level of seismic activity than other active intra-plate regions around the world. Because of the low earthquake return period that is typically used in design, coupled with the poor quality of reinforcement detailing that is required by current Standards, it is anticipated that many of the typical reinforced concrete (RC) structures in the Australian building stock have limited ductility. Moreover, it has only been the last couple of decades that structural engineers have been required to consider the forces that are associated with a low return period earthquake event. This paper aims at providing some of the latest research and modelling that can be incorporated in the seismic assessment of a structure in Australia. The seismic demand for a region in Australia is primarily dependent on the models used for the earthquake recurrence, attenuation and the site response. A building's capacity can be found using a displacement-based assessment, where the building can be modelled as an equivalent single-degree-of-freedom (SDOF) structure. Some of the assumptions and parameters involved in the modelling processes for seismic demand and a building's capacity are scrutinized for their validity in places of low-to-moderate seismic regions, such as Australia. Potential vulnerabilities within the building stock of Australia, primarily associated with reinforced concrete wall and core buildings, are discussed.

INTRODUCTION

On average Australia experiences two earthquakes that are over magnitude 5 per year (Leonard, 2008) and a magnitude 6 every five years (Wilson *et al.*, 2008a). This corresponds to a higher level of seismic activity than other active, intra-plate regions around the world. Earthquake events such as the M6.8 Meckering in 1968, M5.4 Adelaide in 1954 and three M>6 occurring within a twelve hour period at Tennant Creek in 1988 clearly demonstrate that moderate to large size earthquakes can occur and have the potential to tragically affect Australian communities. The most damaging and costly earthquake in Australia was a moderate magnitude 5.6 earthquake that struck the New South Wales city of Newcastle in 1989. The earthquake caused widespread damage as illustrated in Figure 1. Damages and losses cost up to $4 billion if the event and damage were to recur today, with the earthquake ultimately taking the lives of 13 people (Walker, 2011). Standards Australia delivered an earthquake actions loading provision AS 1170.4-1993 (Standards Australia, 1993) after the Tennant Creek and Newcastle earthquake events. This subsequently required earthquake loading to be part of the general design for structures in all areas of Australia (Wilson *et al.*, 2008a). This means that the older building stock can be more vulnerable to seismic loading in Australia compared to building stock that has been designed in the last couple of decades. It is therefore imperative to understand the seismic performance of the Australian building stock under different levels of earthquake loading. This paper aims to provide some of the latest research and modelling that can be incorporated in the seismic assessment of a structure in Australia.

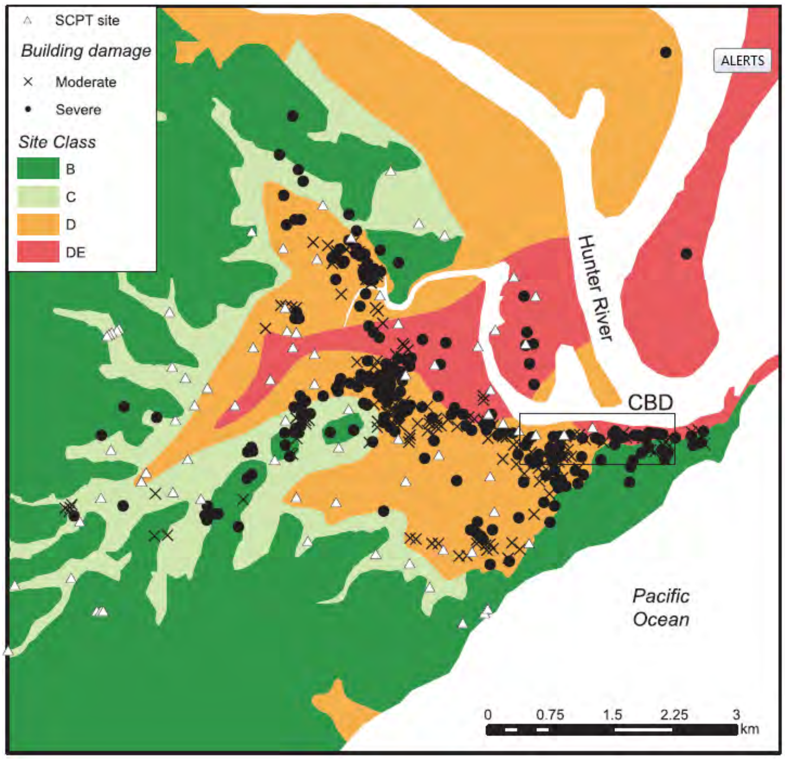

FIGURE 1 SITE CLASSIFICATION MAP FOR THE NEWSCASTLE AREA SHOWING SURVEYED LOCATIONS OF BUILDING DAMAGE FROM THE 1989 NEWCATSLE EARTHQUAKE (MCPHERSON & HALL, 2013)

BACKGROUND

SEISMIC HAZARD IN AUSTRALIA

The seismic demand is primarily dependent on the models used for the earthquake recurrence, attenuation and site response. There have been some improvements over the past decade or so in attempting to quantify the seismic hazard of the different regions in Australia.

Earthquake recurrence modelling

The recurrence model which was developed by Geoscience Australia (GA) was subsequently used in creating the recently released 2012 Australian Earthquake Hazard Map (Burbidge, 2012; Leonard *et al.*, 2013a). The new map offers updated seismic hazard values throughout the country and is thought to be an improvement of the current map developed in 1993 by McCue *et al.* (1993), that is still used in the current AS 1170.4 (Standards Australia, 2007). The new hazard values, equivalent to the peak ground acceleration (PGA) on rock for a 500-year return period, have decreased for most capital cities in Australia. Interestingly, the 2500-year return period PGA is generally higher for the capital cities, with the probability factor (k_p) differing significantly for each capital city in Australia from what is currently given in AS 1170.4 (Standards Australia, 2007). However, it should be noted that although the 2500-year return period hazard value (or PGA) from GA is slightly higher than what is currently stipulated by the Australian Standards, the resulting spectrum for the period range is much lower. Figure 2 gives the resulting 500 and 2500 year return period spectra for Melbourne from AS 1170.4 (Standards Australia, 2007), GA (Leonard *et al.*, 2013a) and AUS5 (Hoult, 2014) out to a period of 1.0s.

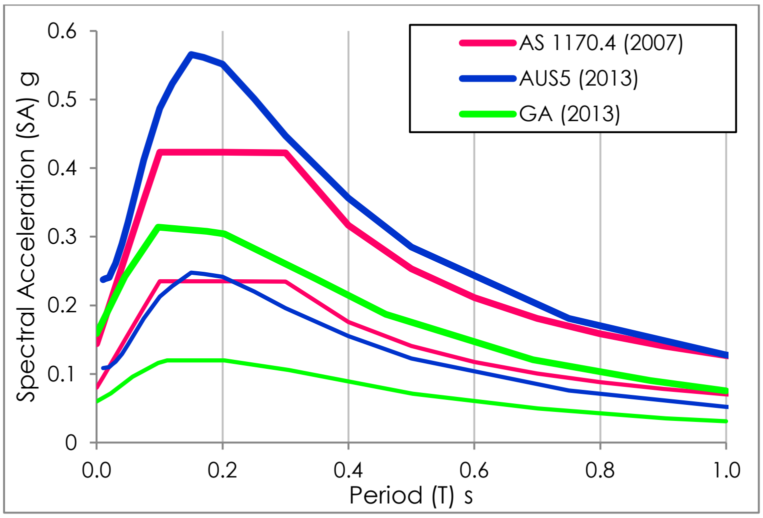

FIGURE 2 COMPARISON OF THE 500 YEAR (THIN LINES) AND 2500 YEAR (THICK LINES) RETURN PERIOD SPECTRA

The AUS5 recurrence model developed by Brown and Gibson (2004) is another seismotectonic model for Australia that is based on numerous layers of geological, geophysical and seismological information, and assumes a relationship between the current seismicity, with geology and the past and present tectonics. Many other earthquake recurrence models assume widely uniform seismicity, which tend to give a much lower hazard for "active" regions, while models that are based on known seismicity tend to give higher values. The AUS5 model, with smoothed seismicity, lie in between the two extremes (Gibson & Dimas, 2009). Hoult (2014) undertook a study using the AUS5 model to determine the seismic hazard for most capital cities in Australia. One of the outcomes of the study resulted in higher k_p values for all cities in Australia for the 2500-year return period event, similar to the findings from GA (Leonard *et al.*, 2013a). These values are compared for each city in Table 1. This has also been found by other researchers (Bull, 2008; Nordenson & Bell, 2000; Tsang, 2006). Overall, there is recognition of the larger ratio of seismic ground motions experienced in a very rare earthquake return period event (e.g. 2500-years) to that experienced in a 5 00-year return period event for places of low-to-moderate seismicity in comparison to places of high seismicity. The current Building Code of Australia (ABCB, 2015) specifies a 500-year return period for buildings of importance level 2, which is the standard design return period for earthquake actions in Australia for ordinary buildings. The implications of this could result in higher probabilities of structural collapse in low-to-moderate seismic regions, such as Australia, compared to high seismic regions when subjected to the very rare earthquake event.

	Probability Factor (k_p)		
Location	**AS 1170.4 (Standards Australia, 2007)**	**GA (Leonard *et al.*, 2013a)**	**AUS5 (Hoult, 2014)**
Adelaide	1.80	2.69	2.18
Brisbane	1.80	3.05	3.31
Melbourne	1.80	2.62	2.36
Perth	1.80	2.67	2.09
Sydney	1.80	2.83	2.08
Canberra	1.80	2.77	2.14
Hobart	1.80	3.01	3.09

TABLE 1 PROBABILITY FACTOR (K_P) COMPARISONS FOR A 2500-YEAR RETURN PERIOD

The National Earthquake Hazards Reduction Program (NEHRP) 1997 provisions recognised the margin against collapse integrated in design procedures represented by the hazard values for 2500-year return period levels multiplied by two-thirds (Nordenson & Bell, 2000). This resulted in a similar hazard value to the 500-year return period in areas of high seismicity, but an increase 'as much as 100 to 200 % greater in areas of low to moderate seismicity' (Nordenson & Bell, 2000). Increasing the design return period from 500-years to a 2500-year return period has already been a note of consideration for Standards Australia and the ABCB with the next revision of the earthquake loading standard (Wilson *et al.*, 2008b). Furthermore, when the 2012 Australian Earthquake Hazard Map was first introduced at the Australian Earthquake Engineering Society meeting, there was a general consensus to increase the reference hazard return period (or probability of exceedance) given in the Building Code of Australia (BCA) for buildings of normal importance to 2500 years (Leonard *et al.*, 2013b).

A recent study by Leonard *et al.* (2014) compared the different earthquake recurrence models for Australia; the GA and AUS5 models give quite different seismic hazard values of 0.059 and 0.109 respectively for a 500-year return period earthquake event in Adelaide. The variation of seismic hazard using the different recurrence models was shown to be primarily a f unction of the different recurrence estimations and how faults are included. Another important parameter that can affect seismic hazard studies is the choice of ground motion prediction equations (GMPEs).

Seismic attenuation in Australia

The attenuation of the seismic ground motions through the crust can be estimated using GMPEs, where typical input parameters include the magnitude of the earthquake and the distance of the site from the epicentre. The number of high-quality ground motion recorders in Australia is limited and the catalogue of recorded earthquake events in Australia is sparse, which make it particularly difficult to develop accurate attenuation models for Australian conditions (Burbidge, 2012). There have been some attempts in deriving GMPEs for the different regions of Australia, but the lack of strong motion data for Australia makes it difficult to validate these models and forces seismologists and earthquake engineers to also adopt GMPEs from other regions around the world with similar geology (Hoult *et al.*, 2013). Adopting GMPEs is an inviting approach, as some functions that have been derived using an abundance of data (high seismic regions) with similar geology may be applicable to some regions of Australia. Brown and Gibson (2004) believe that the GMPEs developed in western North America, such as the Next Generation Attenuation (NGA-West 2) functions, are more applicable to eastern Australia compared to the models developed for eastern North America (stable, intra-plate region). Depending on the function there can be quite a large variability in estimated attenuation and resulting acceleration (and displacement) response, as shown in Figure 3 for various GMPEs used by GA (Burbidge, 2012) for the 2012 Australian Earthquake Hazard Map.

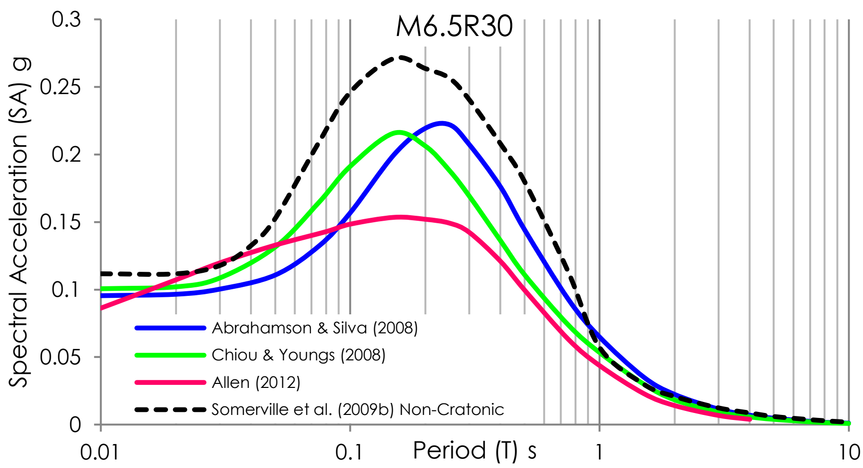

FIGURE 3 THE RESULTING ACCELERATION RESPONSE SPECTRA FOR A MAGNITUDE 6 AT A SITE 30KM FROM THE EPICENTRE USING VARIOUS GMPEs

The 2012 Moe earthquake event (M5.4) and main aftershock (M4.4) in Victoria provided many recordings of the events at close and varying distances from the epicentre. Using the Moe earthquake data, Hoult *et al.* (2014a) used the predictions from potentially applicable GMPEs for eastern Australia to try and validate their use for the region. 'This can be particularly important for hazard studies that utilise Probabilistic Seismic Hazard Analyses (PSHAs), in which there is a high dependency on the type of ground motion models used' (Hoult *et al.*, 2014a). The results tend to show some agreement with the earlier observations made by Allen and Atkinson (2007), that the attenuation of seismic motions of south eastern Australia attenuates in a similar way to regions of eastern North America within short distances from the epicentre. However, some of the results also infer that the functions developed in western North America are more applicable for eastern Australia. The study was inconclusive and further research is necessary to either develop or assess applicable GMPEs for different regions in Australia, since a larger dataset is needed for a statistically meaningful study. This will ultimately improve the accuracy of earthquake hazard studies in Australia.

Site response

Site response also plays an important role in estimating the earthquake demand for a building. It has widely been accepted in the engineering community that the seismic motions at the surface of a soil deposit can be significantly different to the seismic motions of the underlying rock. The general view, which is consistent with the current AS 1170.4 (Standards Australia, 2007), is that the harder the rock the less amplification of the ground motion at the surface compared with bedrock motion. Conversely, the softer the soil deposit the greater the amplification of the ground motion at the ground surface. However, recent studies have shown results that contradict this generally accepted representation of site response. A parametric study of different soil profiles by Dhakal *et al.* (2013) revealed that two variables significantly affected the seismic excitations at the surface: the shear-wave velocity of the soil (stiffness of the soil) and the intensity of the bedrock motions. The latter of these findings is of most interest, with Figure 4 indicating that lower intensity bedrock motions cause greater amplifications of the response at the surface.

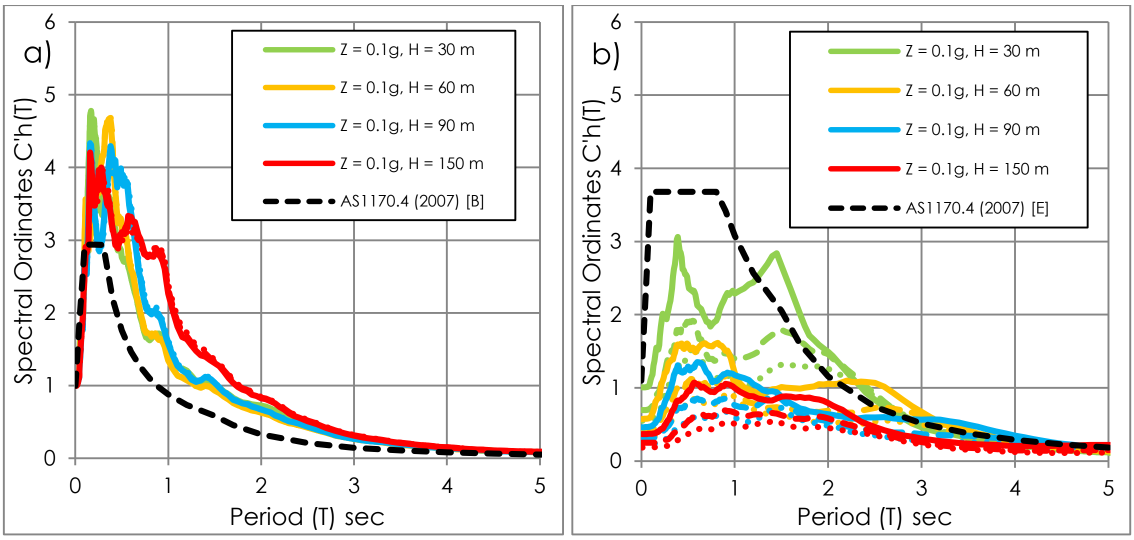

FIGURE 4 THE EFEFCT OF BEDROCK MOTION (Z) INTENISTY OF 0.1g (SOLID LINE), 0.2g (DASHED LINE) AND 0.3g (SQUARE DOT LINE) ON (a) ROCK AND (b) SOFT SOIL

Research conducted at the University of Melbourne (UoM) by the authors, with a primary focus on places of low-to-moderate seismicity such as Australia, found the same intensity dependent amplification. This could be crucial for estimating the earthquake demand in Australia, as the majority of the seismic events in the region are considered to be of low intensity and thus higher amplification of response at the surface would be possible. For example, it is possible to draw correlations between the areas of maximum damage from the Newcastle earthquake in 1989 and the geographical extent of Quaternary sediments (Jones *et al.*, 1996), shown in Figure 1. However, other researchers have argued that the observed damage distribution is mainly controlled by the age and construction type of the building, rather than the correlation between site class and damage (McPherson & Hall, 2013).

The output of the seismic demand typically result in an acceleration or displacement response spectrum format, which can then be used by engineers to compare with the capacity of a building in resisting the predicted ground motions.

ASSESSMENT OF THE CAPACITY

Accurately assessing a structure using a force-based approach can be challenging. The standard force-based assessment is typically based on a simple comparison of the base shear capacity and the base shear demand, where there is no assessment of the actual displacement or ductility capacity and no consideration of risk levels (Priestley *et al.*, 2007). The displacement-based approach can be used to determine the displacement capacity of the structure and to compare it directly with the displacement demand, leading to an estimate of the risk. This approach is far more transparent than force-based methods because damage can be directly related to displacement. The aim is to assess the structure as to whether it has achieved a specified deformation state under a specific design-level earthquake event. However, there are many assumptions made in this approach that may not be applicable to typical building stock in low-to-moderate seismic regions like Australia.

Performance objectives and strain limits

Moment-curvature analysis of sections is a simple tool that can be used in determining the force-displacement relationship of RC structures. Curvatures ($\emptyset$), which are rotation per unit length, can be calculated from the analysis and can be used to find the overall deformation of the structure; this is shown in Equation 1 for calculating the displacement (Δ_i) at level *i* as a function of the yield (Δ_y) and plastic (Δ_p) displacement of an RC cantilever wall section, as taken from Priestley *et al.* (2007).

$$\Delta_i = \Delta_y + \Delta_p = \frac{\emptyset_y H_i^2}{2}\left(1 - \frac{H_i}{H_n}\right) + (\emptyset_{ls} - \emptyset_y) L_p H_i \qquad (1)$$

where H_i is the height of the wall at level *i*, H_n is the height at roof level, $\emptyset_{ls}$ is the limit state curvature and L_p is the plastic hinge length.

Using Equation 1, it is possible to determine different limit state displacements for a range of performance objectives; namely, Serviceability, Damage Control and

Collapse Prevention. This is done by either limiting the interstory drifts which cause damage to non-structural components or by limiting the curvature at the base of the wall which ensures that compressive and tensile strains in the reinforced concrete section are limited to values approximate to the given limit state. Ultimately, this can be used to produce a capacity curve that can be used in an acceleration-displacement response spectrum (ADRS) format (by dividing the base shear by the mass of the structure). The ADRS format can be used to predict if a building will reach or exceed any of the performance objectives for a given return period earthquake event, illustrated in Figure 5.

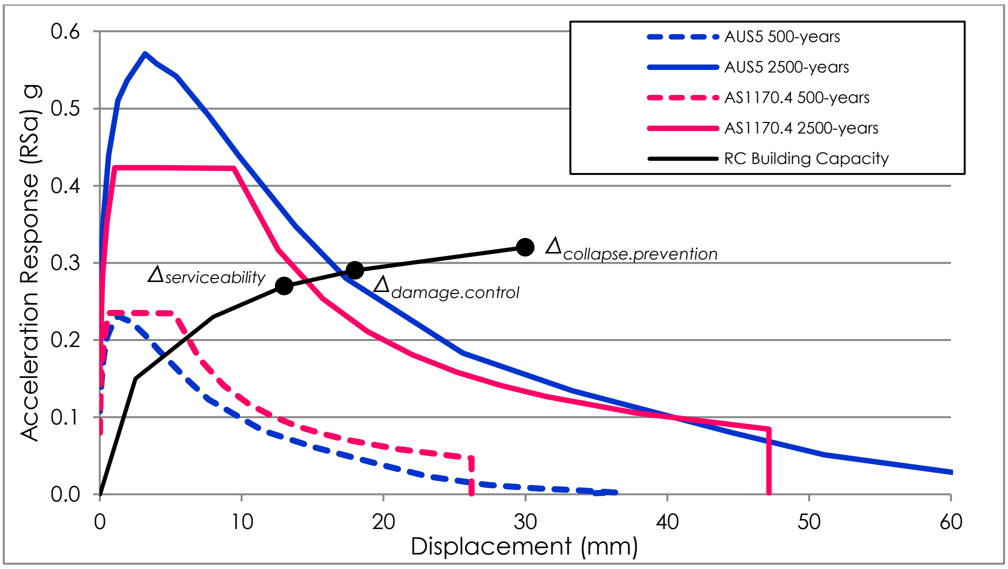

FIGURE 5 CAPACITY CURVE IN ADRS FORMAT WITH PREDICTED 500 AND 2500-YEAR RETURN PERIOD EARTHQUAKE EVENTS FROM AS 1170.4 (2007) AND AUS5 FOR MELBOURNE ON SITE CLASS B

Limiting material strain values need to be determined which correspond to the onset of the different performance objectives. The critical strain values given in Priestley *et al.* (2007) for the different performance objectives assume that the RC sections are well-confined (transverse ties) and have a higher amount of longitudinal reinforcement in comparison to typical RC sections in Australia. Not only would this allow a higher concrete axial strain, but the longitudinal bars are also well restraint by the transverse ties and less likely to buckle once the outer concrete has spalled off. Due to these considerations, Hoult *et al.* (2014b) attempted to define limiting strain values for the different performance objectives for unconfined RC sections, given in Table 2.

The material strain limits presented in Table 2 will ultimately determine the displacement capacity of the structure. However, as Equation 1 shows, the plastic displacement of the structure is also highly dependent on the plastic hinge length (L_p) value.

Structure Performance Limit State (Unconfined Concrete)	Concrete Strain (ε_c)	Steel Strain (ε_s)	Drift Limits (%)
Serviceability: The concrete stress-strain curve is close to linear and steel strains limited to twice the nominal yield value so that residual crack widths are small.	0.0010	0.005	0.5
Damage Control: Concrete is now in non-linear range but there is a low expectation of spalling. Steel strains are sufficiently low so that repair is inexpensive; Also, there is low likelihood of low cycle fatigue or out-of-plane buckling on load reversal.	0.0015	0.010	1.5
Collapse Prevention: Ultimate limit state of concrete at spalling due to the very brittle nature of the potential failure (crushing and longitudinal bar buckling). Steel strains are limited to prevent collapse due to low cycle fatigue (due to inelastic cycles in main event plus aftershocks) and out-of-plane buckling on reversal of load.	0.0030	0.015	-

TABLE 2 LIMITING STRAIN AND DRIFT VALUES FOR UNCONFINED CONCRETE SECTIONS

Plastic hinge length

Some RC walls with a light amount of longitudinal reinforcement detailing have been observed to perform poorly in past earthquake events (CERC, 2012; Henry, 2013; Wood *et al.*, 1991; Wood, 1989). There were several cases of a single crack forming at the base in the plastic hinge region after the Christchurch earthquake in 2011, with some of the longitudinal reinforcing bars prematurely fracturing that crossed this crack. This was due to the large concentration of inelastic behaviour over such a small height of the wall (CERC, 2012). Research which focused on one of these walls in the Gallery Apartments building in Christchurch concluded that there was an insufficient amount of longitudinal reinforcement (ρ_{wv}) to initiate secondary cracking (Henry, 2013; Henry *et al.*, 2014; Sritharan *et al.*, 2014). This could be a major issue for low-to-moderate seismic regions, such as Australia, where it is expected that a great percentage of the RC building stock typically incorporates a low amount of longitudinal reinforcement (Hoult *et al.*, 2014b; Wibowo *et al.*, 2013). The minimum longitudinal reinforcement ratio in the current concrete materials standards AS 3600 (Standards Australia, 2009) in Australia is 0.15%, which is similar to the 0.16% detailed in the failed wall of the Gallery Apartments building. In light of the recent observations, research has been conducted at the University of Melbourne by the authors to investigate if the current minimum reinforcement ratio employed in provisions for low-to-moderate seismic regions was adequate in ensuring that some ductility would be achieved.

A simple mathematical model was developed to estimate the amount of longitudinal reinforcement (ρ_{wv}) necessary to allow secondary cracking. This was derived by calculating the amount of reinforcement required to produce a tensile force in the steel large enough to exceed the tensile strength of the concrete that surrounds the bars. This would allow secondary cracking to occur above the primary crack at the base and thus allow the wall to behave in a ductile manner. A validated finite element modelling (FEM) program complimented the mathematical model, with numerical analysis being conducted on a number of different walls with a range of ρ_{wv}. Figure 6 shows the cracking distribution results from the FEM program VecTor2 (Wong & Vecchio, 2002) for the same wall with ρ_{wv} of 0.7% and 0.75%. This conforms to the mathematical model, which estimated that the wall needed a ρ_{wv} of 0.76% to initiate secondary cracking in the plastic hinge region close to the base where the inelastic rotations occur.

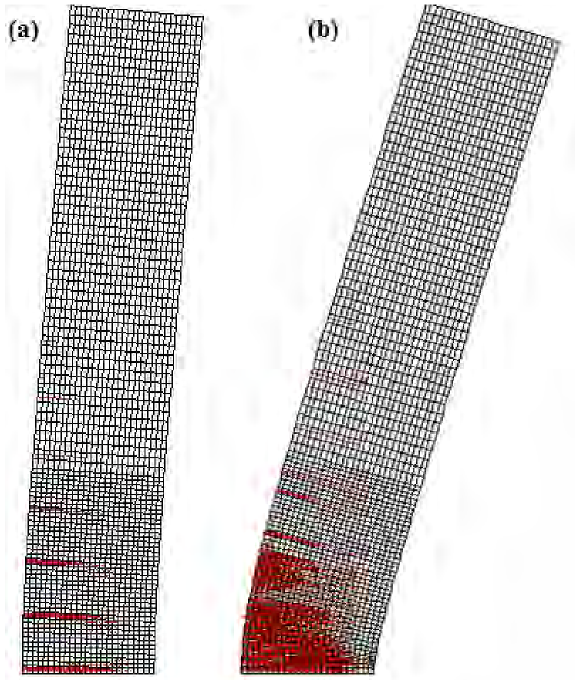

FIGURE 6 CRACKING DISTRIBUTION RESULTS FROM VECTOR2 AT ULTIMATE DISPLACEMENT WITH (a) ρ_{wv}=0.70 % AND (b) ρ_{wv}=0.75 %

The FEM results confirmed that a minimum ρ_{wv} was necessary to initiate secondary cracking in the concrete. This limit has been found to be much higher than the current minimum stipulated in some codified provisions, including AS 3600 (Standards Australia, 2009). Using the mathematical model, a minimum longitudinal reinforcement ratio ($\rho_{wv.min}$) is derived in Equation 2.

$$\rho_{wv.min} = \frac{0.54\sqrt{\kappa f_c'}}{f_u} \qquad (2)$$

where f'_c is the characteristic concrete strength and f_u is the ultimate tensile strength of the steel. The κ value is used to increase the concrete strength due to the initial variability in the concrete and increase of the strength with age.

The Structural Engineering Society of New Zealand (SESOC, 2011) recommended a $\rho_{wv.min}$ for RC walls following the observations from the Christchurch Earthquake (Equation 3).

$$\rho_{wv.min} = \frac{0.4\sqrt{f_c'}}{f_y} \qquad (3)$$

where f_y is the yield strength of the steel.

Many empirical plastic hinge length equations (Bohl & Adebar, 2011; Kowalsky, 2001; Priestley *et al.*, 2007; Thomsen & Wallace, 2004) have been shown to be unsuitable for lightly reinforced walls that do not exhibit secondary cracking. This has rather large implications for assessing lightly reinforced walls, as the ultimate displacement capacity (Equation 1) is highly dependent on the plastic hinge length (L_p) and can be grossly overestimated by using the existing equations. In the case of the wall from Figure 6, the L_p was effectively zero for ρ_{wv}=0.70%, while the L_p was 2600mm for ρ_{wv}=0.75%. Moreover, the current earthquake loading provision AS 1170.4 (Standards Australia, 2007) assumes that 'limited-ductile' RC walls have a ductility value (μ) of 2, equivalent to the ratio of ultimate to yield displacement. However, this research shows that many of these typical RC walls are likely to have very little ductility, requiring a reassessment.

CONCLUSION

In 1995 it became mandatory for buildings throughout Australia to be designed with some consideration of earthquake loading. Since then there have been many improvements in the general understanding of the earthquake hazard in Australia. However, this paper has highlighted some of the uncertainties that are still involved with predicting the earthquake hazard in a low-to-moderate seismic region such as Australia.

In addition a study has been conducted to determine the likely ductility of RC walls in Australia. The minimum reinforcement required by AS 3600 (Standards Australia, 2009) has been found to be too low and as a result some RC wall and core buildings have been found to be in danger of a non-ductile failure. Building codes in Australia may need to be improved in order to create a more robust building stock and retrofitting of some older buildings may be needed. Further research is being conducted at the University of Melbourne to assess the performance of a range of structures against a "very rare" earthquake event, and it is hoped that this work will provide a basis for some code recommendations.

ACKNOWLEDGEMENTS

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BRINGING HAZARD AND ECONOMIC MODELLERS TOGETHER: A SPATIAL PLATFORM FOR DAMAGE AND LOSSES VISUALISATION

Research proceedings from the Bushfire and Natural Hazards CRC & AFAC conference
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ABSTRACT

Estimating potential damage and losses as a r esult of natural disasters is challenging, as it entails a multi-disciplinary approach. Since the estimation of potential damage broadly initiates with the identification of the source as well as determination of the probability of the occurrence of disasters, hazard-modellers along with civil engineers generally lead the whole process to estimate the potential destruction—either fully or partially—of infrastructures against a set of scenarios. When it comes to the estimation of losses from natural disasters, economists step in mainly using an empirical econometric approach. However, to the best of our knowledge, no acceptable method has been devised to combine these two disciplines to estimate potential damage and losses coherently. In this paper, a methodology to connect the multi-hazard disaster damage assessment approach with an empirical econometric strategy of estimating disaster losses in one spatial platform is proposed. Enabling the visualisation of potential damage and losses of natural disasters through this approach acts as a crucial decision support tool for both the federal and state governments to prioritize budget allocation across different economic sectors.

1. INTRODUCTION

Rapid economic growth along with complex urban planning and development processes tend to accelerate economic vulnerabilities highlighting the ever-growing need for disaster risk reduction (DRR) interventions. In this vein, judging the potential damage and losses from natural disasters remains crucial in designing pre-disaster mitigation plans and formulating post-disaster recovery strategies. In practice, civil engineers—who mainly focus on the infrastructure sector—and hazard modellers assess the potential damage of physical assets using mapping tools. Economists, on the other hand, concentrate on estimating losses in economic flows due to natural disasters either at the state or national level using econometric methodologies. This divergence in approach makes it particularly challenging to provide a spatially enabled DSS in the DRR field, that can visualise not only damage of physical assets but also map overall economic effects of natural disasters. This paper bridges the gap between hazard modellers and economists by proposing a spatial platform which provides inputs to the economic model at a finer geographic unit level at the initial stage and then displays the estimated damages and losses from the economic model on interactive maps at the final stage. Precisely, this paper provides a n ovel methodology on estimating and visualizing disaster-specific losses at a spatial level which would be beneficial to the end users and policy makers in making informed decisions.

Another important contribution of this paper is that it provides a method on how to map the overall effects of natural disasters by economic sector and by smaller geographical unit. This will be of particular relevance to the economic policymakers in that they can prioritize budget allocation across the economic sectors as well as geographical areas in terms of their relative disaster risks. Moreover, the proposed method is helpful in identifying appropriate public policy and development programmes to mitigate detrimental effects on economic performance and public well-being due to catastrophic events.

It is worthwhile mentioning that the main objective of this paper is to provide a spatial method for estimating and visualising damage and losses of natural disasters. The rest of the paper is structured as follows. Section 2 presents overall methodology of assessing potential damage and losses of natural disasters through a spatial framework. Section 3 describes the data and some measurement issues related to the variables required for our proposed estimation process. Section 4 describes our visualisation tool of presenting damage and losses estimation. Section 5 emphasises on how our spatially enabled damage and losses estimation would be beneficial for decision-makers. Finally, section 6 concludes.

2. METHODOLOGY OF RESEARCH

The fundamental aim of this paper is to provide a method for estimating the localised economic effects of a disaster event as they propagate through economic sectors. In order to do this, the following methodology is proposed as articulated in Figure 1. The methodology consists of five steps: defining the geographic zone (i.e., the destination zone) that would be used as a cross-sectional unit in both spatial and economic analyses; disaggregating sector-specific gross state product (GSP) at DZN level; categorizing the sector-specific GSP into four broader groups—i.e., production, infrastructure, social, and cross-cutting, and finally, estimating disaster losses for 19 disaggregated economic sectors as well as four broader groups.

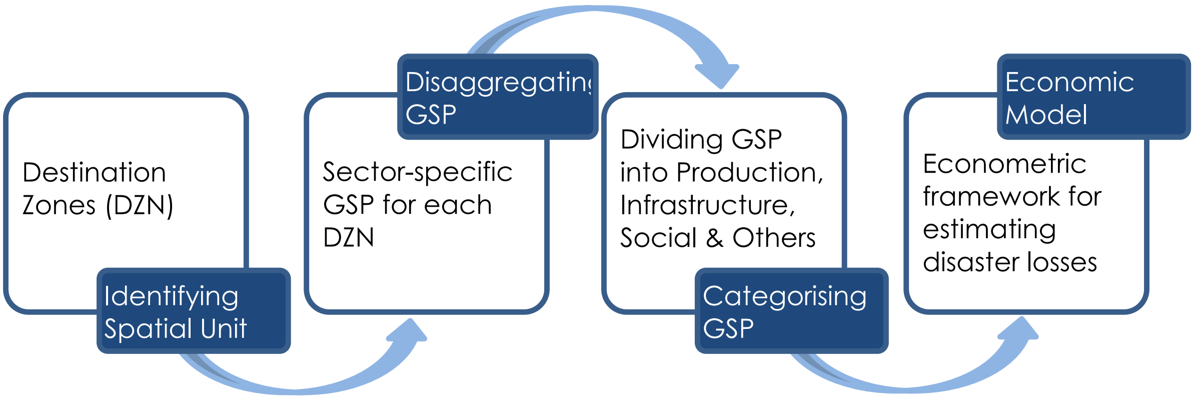

FIGURE 1: SPATIALLY ENABLED ECONOMIC MODELLING PROCESS

2.1. DEFINING THE SPATIAL UNIT OF ANALYSIS

To have a better understanding of where jobs in different sectors are located, the Place of Work (POWP 2011) dataset collected by ABS is utilised as one of the key inputs. Replacing the erstwhile Journey to Work (JTW) 2006 database, POWP provides information on the actual work location of employed people (15+ years old) of each sector in the week prior to Census Night. Generated from written responses to the 'Business name' and 'Workplace address' questionaire about the main place of work last week, the POWP is coded to geographic areas known as Destination Zones (DZNs), which are defined by the relevant State Transport Authority (STAs) from each state or territory, in conjunction with the ABS. POWP is a hierarchical field and for 2011 c an be broken into State, SA2 and DZN. Currently, DZN is the smallest spatial unit for POWP.

In POWP 2011, a total of 3157 DZNs are defined for Victoria. However, not all of them are spatial and therefore, cannot be represented geographically. In particular, as illustrated in Figure 2, there are 2755 DZNs, each of which provides the total number of employees by sector.

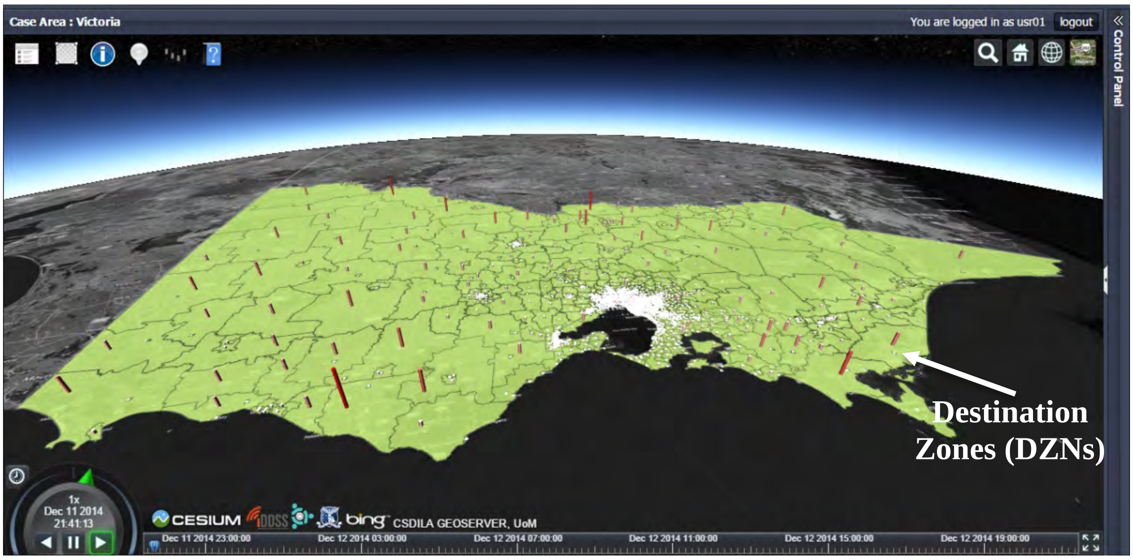

FIGURE 2: NUMBER OF EMPLOYEES IN AGRICULTURE BY DESTINATION ZONES, VICTORIA, 2011

2.2. DISAGGREGATING GSP AT DZN LEVEL

Since GSP data is not available at the spatial level, we devise an approach to disaggregate sector-specific GSP for Victoria. In particular, we have GSP data for each of the 19 economic sectors, which are decomposed into DZN level using the following formula:

$$TP_{ist} = \frac{TP_{st} \times Employment_{ist}}{Employment_{st}}$$

where *i* stands for DZN unit, *s* economic sector, and *t* year. *TP* denotes total production and *Employment* shows the total number of jobs available in the respective sector. That is, we use sector-specific employment size in each DZN as a weighting scale to disaggregate sector-specific GSP at DZN level. This approach imposes an assumption that all employees in a sector produce, on an average, the same quantity of goods and services in a given year. This is a reasonable assumption as it is highly likely to have similar pattern in the average productivity of employees in a sector across DZNs. Further, instead of using employment size, as a robustness check, we try other variables— such as night lights data (see Henderson et al., 2012; Keola et al., 2015)—as a proxy to measure the size of each economic sector at DZN level.

2.3. CATEGORIZING ECONOMIC SECTORS AT DZN LEVEL

According to the Australian national accounting system, there are 19 economic sectors that comprises the whole economy. Australian Bureau of Statistics (ABS) provides total annual production of each sector at state level from 1990 onwards.

Following damage and losses assessment (DaLA) approach as indicated in ECLAC (2012), one can categorise these 19 economic sectors in Australia and Victoria (as per ABS) into four broader groups such as production, infrastructure, social and cross-cutting sectors, as highlighted in Figure 3. Such categorisation provides several advantages in designing risk mitigation interventions. For example, the policymakers may not require designing risk mitigation strategies for all 19 economic sectors separately; rather, they can focus on the social sector for emergency responses, infrastructure sector for post-disaster reconstruction phase, and finally production and cross-cutting sectors for longrun recovery phase. That is, the policymakers are enabled to design economic policies in accordance with the heterogeneous effects of disasters across production, infrastructure, social and cross-cutting sectors.

There underlies a potential caveat with such aggregation of sectors. This also reduces visibility of capturing disaster impacts on different economic sectors and their interactions between each other. These interactions are a key aspect for understanding and ascertaining the potential damage associated with these sorts of systemic hazards. Therefore, we suggest that one should perform loss estimation analysis based on both approaches—i.e., by considering 19 sectors and 4 broader sectoral groups—that can provide more freedom to the policymakers to design risk reduction strategies.

Production	Infrastructure	Social	Cross-cutting
Agriculture Mining Manufacturing Wholesale Trade Retail Trade Accommodation and Food Services Rental, Hiring and Real Estate Services Professional, Scientific and Technical Services Arts and Recreation Services	Electricity, Gas, Water and Waste Services Construction Transport, Postal and Warehousing Information Media & Telecommunication	Education and Training Health Care and Social Assistance Public Administration and Safety	Financial and Insurance Services Administrative and Support Services Other Services

FIGURE 3: NATIONAL ACCOUNTING SYSTEM OF AUSTRALIA: ECONOMIC SECTORS

2.4. ESTIMATING ECONOMIC IMPACTS OF DISASTERS

Generally, two criteria are widely used for macroeconomic policy simulations under the simultaneous equation modelling approach. First, a macroeconomic system can be simulated under a well-specified *structural model* involving all economic sectors where feedback from one sector on another sectors output is not specified. Second, the *vector-autoregressive model* (VAR) is the vector-generalization of autoregressive models and can be regarded as an unrestricted reduced form of a structural model, where the specification is capable of addressing inter-sectoral linkages between economic activities. In regards to the policy simulation, both of the above approaches suffer from misspecification issues as they either do not incorporate inter-sectoral feedback of economic activities or do not address possible correlation of residuals in presence of the same disaster shocks across different sectors. To circumvent these problems, the newly proposed econometric techniques in the field work through pinning down the causal relationships over estimating statistical correlation, and hence, exogenous shocks such as natural disasters are modelled using single-equation estimators (e.g., IV-2SLS) instead of the earlier used system settings (see Cavallo et al 2010, Dell, Jones, and Olken, 2014). In accordance, the single-equation reduced form approach is employed which incorporates both inter-sectoral feedback as well as cross-equation correlation of residuals in presence of the same disaster shocks traversing to all sectors of the economy. The proposed economic model is estimated using the Seemingly Unrelated Regression (SUR)[1] estimation technique to decipher the effect of natural disasters on sector-specific GSP at DZN level (see Wooldridge, 2010). Our economic model has the following specification:

$$\boldsymbol{TP_{it}^{s1} = \alpha_0 + \beta_1 X_{it} + \beta_2 TP_{it}^{s2} + \beta_3 TP_{it}^{s3} + \cdots + \beta_{19} TP_{it}^{s19} + \varepsilon_{it}}$$

$$\boldsymbol{TP_{it}^{s2} = \alpha_0 + \gamma_1 X_{it} + \gamma_2 TP_{it}^{s1} + \gamma_3 TP_{it}^{s3} + \gamma_4 TP_{it}^{s4} + \cdots + \gamma_{19} TP_{it}^{s19} + \epsilon_{it}}$$

$$\boldsymbol{TP_{it}^{s3} = \alpha_0 + \delta_1 X_{it} + \delta_2 TP_{it}^{s1} + \delta_3 TP_{it}^{s2} + \delta_4 TP_{it}^{s4} + \delta_5 TP_{it}^{s5} + \cdots + \delta_{19} TP_{it}^{s19} + \vartheta_{it}}$$

$$\vdots$$

$$\boldsymbol{TP_{it}^{s19} = \alpha_0 + \mu_1 X_{it} + \mu_2 TP_{it}^{s1} + \mu_3 TP_{it}^{s2} + \cdots + \mu_{18} TP_{it}^{s18} + \omega_{it}}$$

where the script *i* denotes DZN units; *s* represents broad sectors such as production, infrastructure, social and cross-cutting denoted by Arabic numerals; and *t* depicts year. *TP* stands for total production and *X* denotes a set of variables measuring disaster shocks. In particular, one can measure disaster shocks in at least four ways. In econometric modelling, the best measure of disasters is gauging them by its physical attributes. For instance, the height of water during a flood event is a very close proxy to measure its intensity. However such data for each historical disaster events are rarely available. The second best available

[1] See Wooldridge (2010) for technical details about this approach.

measure of disasters is its bearing on human dimension (e.g., number of people killed, injured, homeless and affected). This measure needs to be used with caution in that one has to normalise the data by considering population size of each DZN. The next best measure of disasters is an account of physical damages in monetary terms, provided that such calculation generally suffers with exaggeration in most of the occasions. Finally, the crudest way of measuring disasters is counting them in terms of its occurrence only. There is a potential caveat with this later measure, as it does not capture the intensity of disasters.

The coefficients of interests are β, γ, δ and μ which provide the estimates of disaster impacts on total production at the sector level. Finally, $\varepsilon, \epsilon, \vartheta$ and ω denote error or disturbance terms which are stochastic in nature but guided by well-founded theoretical assumptions in order to minimize their possible confounding effects. The inter-sectoral feedbacks are captured by total productions of different sectors (say, 2, 3, ………, 19 as in the first line) as explanatory variables for a particular sector (say, 1 as in the first line).

Estimation method using historical data is unlikely to capture the effect of any future event that has not been experienced before. However, this caveat prevails in every economic model that is based on 'regression' analysis, and hence we leave this issue for further studies.

3. DATA AND MEASUREMENT

Given its multi-disciplinary scope, a wide range of datasets are used in this paper. To estimate the econometric model as indicated in section 2.4, data on the occurrence and location of historical disaster events is required, in addition to climatic variables, GDP data and total number of employment in each sector. These data were sourced from various sources. First, annual data on sector-specific Gross State Product (GSP) for the period 1990-2013 is taken from the Australian Bureau of Statistics (ABS, 2014). Second, for disaggregating these sector-wise GSP to a smaller geographic level, the total number of employment in each sector at a finer spatial unit—Destination zones (DZNs) —is taken from the Place of Work database (POWP, 2011).

This historical series of natural disaster events are sourced from Australian Emergency Management Knowledge Hub (AEM, 2014) that provides data on the location of incidence and its intensity in terms of human mortality and casualties (see Figure 4). Finally, to identify the exogenous sources of natural disasters, time-series gridded data on various climatic features such as monthly rainfall, temperature, and wind speed were collected from the Bureau of Meteorology, Australia (BOM, 2015).

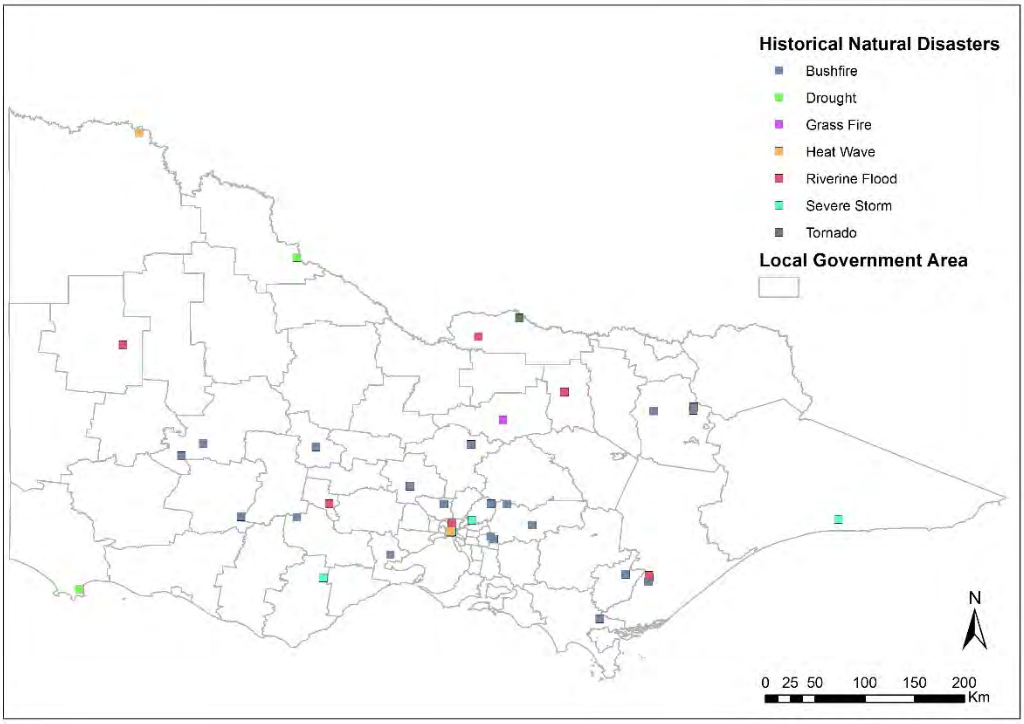

FIGURE 4: LOCATION OF HISTORICAL NATURAL DISASTER EVENTS IN VICTORIA

4. PHILEP: A SPATIALLY ENABLED DECISION SUPPORT SYSTEM

The platform developed and utilised for this work is the Pre-disaster Hazard Loss Estimation Platform (PHiLEP). The PHiLEP platform is particularly suitable for this specific research purpose since it is devised to facilitate the decision making process in Disaster Risk Reduction (DRR) field by utilising a combination of spatial data management, disaster modelling, optimisation technologies a nd visualisation. The PHiLEP conceptual model is shown in Figure 5 and a short description is provided below.

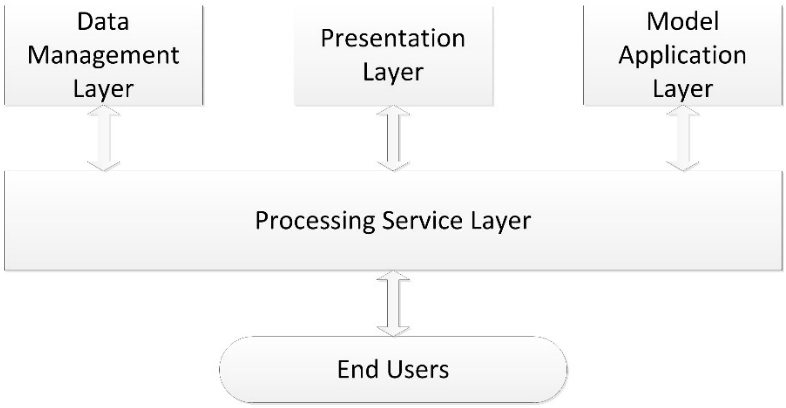

FIGURE 5: CONCEPTUAL MODEL OF PHILEP

One of the most important issues in the disaster decision making process is extracting effective information from heterogeneous data sources to enhance decision makers' situational awareness. The PHiLEP has the capability of aggregating and analysing related data from multiple channels simultaneously from participants as diverse as the authority agencies (e.g. ABS, BOM, VicRoads, DEPI), sensor networks (e.g. river meters, pedestrian counters), Volunteered Geographic Information (VGI) platforms (e.g., Ushahidi, Warnwave) as well as social media (e.g. Twitter). The aggregated data then can be populated into the processing chain to develop a series of time-based scenarios to increase the cognitive abilities of decision makers when facing with disasters of large magnitude and uncertainty. This part of work is abstracted as "Data Management Layer" as shown in Figure 5.

The core of most disaster decision support systems (DDSS) has built-in modelling capabilities such as flood, bushfire propagation and traffic simulation. The PHiLEP platform has been enabled to plug-in with any existing models easily by implementing a universal interface for model integration. This design provides the flexibility to bring in new information and makes the system loose-coupled with these models. In other word, it means the PHiLEP and its models could run as separate applications but still communicate with each other using data exchange protocols. This is particularly important for enhancing system extendibility and fits perfectly well in the cross-agency collaboration framework during disasters. The part is denoted as "Model Application Layer" in the conceptual model diagram.

The "Presentation Layer" provides decision makers with a user-friendly interface to interact with data and models outputs. The PHiLEP offers multiple rendering capabilities to adapt with various data sources and can easily be accessed in a multiuser environment. The system has been built upon a mature web mapping technologies to support data presentations from diverse perspectives, for example, real-time volunteered geographic information (VGI) and sensor network data, live video streams, charts and diagrams of analysis results, disaster propagation animations, etc., to enrich situational-awareness of decision makers. In particular, as the outcome of our economic analysis will be the estimation of overall effects of disasters on each economic sector by DZN, we can plug and present such estimated losses in a DZN based map.

Typically, a disaster event happens within a specific time and location; hence, we ascertain particular data extents and modelling methodologies for a scenario-based decision making process in disaster management contexts. The centre of the PHiLEP conceptual model sits the "Processing Service Layer", which serves as a middleware among the other layers. Its main function is to manage the life cycle of a scenario-based decision making process by preparing related data sets for the processing chain, communicating with designated model applications and aggregating the modelling outputs and analysis results for the presentation layer.

5. UTILITY OF RESEARCH

The proposed loss estimation method as outlined in this paper would have usefulness to a cross-agency collaborative team during emergency, recovery and mitigation. Consequently, a decision support system has been designed to contain the analysis, which is based on a web-based open source model that allows multiple agencies to simultaneously access and interact with the system, and to enable better communication across agencies through a single platform for data exchange and visualisation. For example, the proposed *spatial platform* can assist end users in estimating localised economic costs of natural disasters in the state of Victoria. To be specific, our proposed method is the first of its kind to deliver the following outcomes at the state level:

a) Estimation of the effects of natural disasters on local economic growth of Victoria by economic sectors
b) Identification of the economic sectors at the local level that are vulnerable to natural disasters
c) Identification of the economic sectors at the local level that experience natural disasters positively (in that economic incentives increase in these sectors as a consequence of the disaster)
d) Identification of the economic sectors at the local level that are unlikely to get affected by natural disasters
e) A ranked list of the economic sectors at the local level that seek more attention for policy intervention to minimise potential negative effects of natural disasters

Precisely, this approach is novel in that it provides the effects of natural disasters on each economic sector by DZN. This enables us to embed the disaster losses in a DZN based map in our proposed spatial platform, which can act as a decision support system by identifying vulnerable economic sectors followed by economic policy intervention (e.g., budgeting and resource allocation) for minimising potential disaster losses.

6. CONCLUSION

Disaster risk reduction remains a key focus for policy makers in presence of the continuing and often recurring natural disasters of various magnitudes. Apart from the pertinent physical damage to infrastructure, natural disasters wreak widespread havoc in economic activities. To date, hazard modellers and economists simulate and estimate differential effects of disasters which do not necessarily help the end users in the sense that an overarching impact of the disasters cannot be fully integrated within a single framework which can be used to formulate effective disaster mitigation strategies.

The main contribution of this paper is that the empirical strategy for predicting sectorial productivity declines from disaster events is connected with a novel spatial platform that can be used to display the sectoral effects of natural disasters on a map at the DZN level once they are estimated. This would be of utmost importance to end users for formulating effective preparedness and mitigation policies. Enabling the visualisation of potential damage and losses in natural disasters through this approach acts as a crucial decision support tool for both the federal and state governments to prioritize budget allocation across different economic sectors.

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VICTORIA FIRE WEATHER CLIMATOLOGY DATASET

Research proceedings from the Bushfire and Natural Hazards CRC & AFAC conference
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ABSTRACT

Weather and climate are essential elements in understanding the risk of bushfire and managing the landscape to reduce risks. Spatially and temporally homogenous climate data are essential for optimising planned burning and land management strategies, and scenario planning for major fire events. This paper summarises the development of a homogeneous 41-year (1972–2012) hourly 4-km gridded climate dataset for the fire-prone state of Victoria, Australia. This dataset has been generated using a combination of mesoscale modelling, global reanalysis data, surface observations, and historic observed rainfall analyses. Outputs include surface weather variables such as hourly temperature, relative humidity, wind speed and wind direction. The output data are created using the Weather Research and Forecast (WRF) model. Outputs provide an almost limitless opportunity for hitherto unavailable analyses – such as identifying the frequency of extremes and identifying trends over the 41-year period. Furthermore, the hourly mesoscale wind fields provide a homogeneous long-period data set with which to drive fire spread models such as Phoenix. This paper describes generation of the dataset, evaluation of the outputs and highlights its use and relevance for fire management.

INTRODUCTION

Southeast Australia has had many socially disastrous fires (Gill et al. 2013). Bushfires in the state of Victoria have contributed to over 67% of all bushfire-related deaths that have occurred in Australia over the last 110 years (Blanchi *et al*. 2014). The list of destructive fires includes Black Friday in 1939, Ash Wednesday in 1983 and, more recently, Black Saturday in 2009 which resulted in the loss of 173 human lives (Teague *et al*. 2010). There is a need for a detailed understanding of the climatology of fire weather across the Australian landscape if strategic decisions to ameliorate the sometimes-extreme impacts of bushfires on the socio-economic wellbeing of the community are to be based on sound scientific evidence, and if variability and trends in this climatology are to be correctly interpreted.

In situ observation networks are rarely homogenous in time and space. Consequently, there are some considerable barriers to basing climatology on long-term meteorological observations, as shown by the relatively low number of reliable, long-term observation records available for such analyses (see Lucas *et al*. 2007). This has significant implications for fire weather applications. The bulk of observations are based near population centers and do not necessarily reflect the conditions in the forests where most of the major bushfires occur—in the slopes and valleys of the ranges through central and eastern Victoria. To fulfill the needs of fire management agencies, an ideal climatology would be based on a homogeneous high-resolution temporal (i.e. hourly) and spatially-gridded fire weather and fire danger dataset.

It is logistically possible to spatially interpolate between observing stations to obtain a regular grid of data using distance-weighted averages. However, ensuring physical consistency when interpolating across regions of varying elevation or land surface type requires additional statistical assumptions that rapidly lead to excessive complication. Furthermore, observations may not be available at hourly intervals so some form of interpolation in time is necessary if hourly fields are required. This also adds complication, as any assumptions regarding diurnal cycles of variables would generally ignore differences through the synoptic weather cycle.

An alternative approach is to use mesoscale Numerical Weather Prediction (NWP) model outputs as these outputs are physically constrained by the equations of motion and thermodynamics in the model, they include realistic topography for the grid resolution of the model and provide outputs for regular time and space intervals. Operational NWP outputs, while archived by most national weather services, suffer as these models are upgraded every few years, and so have major inhomogeneities if they are to be used for climatological studies. However, the emergence of global reanalysis data sets, such as the National Center for Environemental Protection/National Center (NCEP)/National Center for Atmospheric Research (NCAR) Reanalysis (NNR) data set from (Kalnay *et al*. 1996), provide large-scale homogeneous data-sets that can be used as initial and boundary conditions for mesoscale NWP model integrations, with multiple nests to achieve high spatial detail in the inner nests.

A model that has become increasingly popular for producing such outputs is the Weather Research and Forecasting (WRF) model (Skamarock *et al*. 2008). The use of this model is well established in simulations conducted globally (Andrys *et al*. 2015). Furthermore, the WRF model is now being used for similar purposes in forestry, fire and agriculture, albeit with varying results. For example, a recent study by Andrys *et al*. (2015) covering south western Australia over a 30-year period produced a gridded observational dataset of daily rainfall, minimum temperature and maximum temperature. They found the WRF model was able to simulate daily, seasonal and annual variations in temperature and precipitation including extreme events. They also found significant performance gains in modeling precipitation with higher grid resolution. A study by Simpson *et al*. (2013) used the WRF model to simulate fire weather conditions for one fire season (2009–2010) in New Zealand. The study simulated 12-hourly temperature, relative humidity, wind speed and direction along with daily rainfall, fire weather index and the continuous Haines index. They found that temperature and relative humidity were under-predicted and wind speed and rainfall were over-predicted. Unfortunately, they also found issues around under-prediction of extremes which limited the operational use of the dataset. Another study that used the WRF model to produce fire weather outputs simulated fire weather for south eastern Australia from 1985–2009 (Clarke *et al*. 2013). The authors compared their results to station-based observations of Forest Fire Danger Index (FFDI) and found the WRF model simulated the main features of the FFDI distribution and its spatial variation with an overall positive bias. They concluded that the errors in average FFDI were mostly caused by relative humidity whereas the errors in extreme FFDI were mostly driven by wind speed. In general they found better performance of the model when the grid spacing was reduced from 50 to 10 km.

While these studies have made major advancements using the WRF model to produce simulations useful for fire studies the fire weather climatology, the dataset produced in this study is the first of its kind to provide hourly values of meteorological variables on a regular, high spatial resolution grid for Victoria based on WRF model outputs. In this paper we will describe and evaluate the performance of WRF model outputs in simulating fire weather variables. This evaluation will be presented through statistics, meteorological case studies and climatological characteristics of the region. We will show that this unique dataset can provide baseline climatology information for risk management assessments and climate change adaptation planning.

METHODS

DEVELOPING THE DATA SET

The mesoscale model used to develop the dataset was the WRF model (Skamarock *et al*. 2008). It is a well-supported and widely used non-hydrostatic model that includes a wide range of choices of physical parameterisation schemes. Three integration domains are used in our configuration with grid spacings of 36 km (outer mesh), 12 km (middle mesh), and 4 km (inner mesh). Each nest has 33 vertical model levels. Initial state and lateral boundary conditions for the outer mesh are provided by 6-hourly interval global reanalyses.

Three global reanalyses were utilised for initial state and lateral boundary conditions to start integrations using the WRF model and to nudge fields through a 1 5-day process, discarding the first day (Mills *et al*. 2013). The National Centers for Environmental Prediction (NCEP) FNL (Final) Operational Global Analysis (NCEP 2000) data, based on 1-degree by 1-degree grids prepared operationally every 6 hours, were used for the 2000–2012 period. The ERA-Interim (Dee *et al*. 2011) reanalysis dataset was used for 1979–1999 and the ERA40 reanalyses (Uppala *et al*. 2005) was used for 1972–1978. A list of the physical parameterisations used in this configuration of the WRF model is provided in Brown *et al*. (2015).

Observed data

The observed data used to assess the accuracy of the modelled output were the Automatic Weather Station (AWS) data from the Bureau of Meteorology. These data range temporally from 1-minute observations to daily observations and spatially with more stations located around populated regions and fewer stations in remote regions. The density of the network and the frequency of reporting have increased through the 1972–2012 period.

Qualitative and statistical evaluation of the dataset

There is no defined performance standard for a dataset such as the one developed in this project. It can be assumed that (1) the climate information in the dataset should reflect the temporal and spatial variability of the actual climate, and (2) the meteorology of actual (fire) weather events should be sufficiently realistic such that scenario investigations of these events using, for example, fire behaviour models should produce sensible outcomes. Subjective assessments were used to validate the meteorological integrity of the data for significant weather events and to identify any possible model deficiencies that could be mitigated by tuning the various parameters of the model. Objective statistics were used to further inform the meteorological integrity and to validate the fortnightly integration strategy to demonstrate stable characteristics of outputs from the WRF model across these periods. This was done as it is undesirable for the WRF model to show any drift in accuracy or variability through days 2–15 of a 15-day integration period.

In addition to the subjective assessment, root mean square (RMS)errors were calculated between model output and observed data (AWS) for each hour along with field variance of these quantities for each hour. Following this, cumulative distribution functions (CDFs) were calculated and compared for a combined 30-observation dataset and the corresponding model grid points for a 10-year period which includes all hours and days during this period.

RESULTS

CHARACTERISTICS OF THE DATASET

The surface data of primary interest generated by the WRF model included 4-km grid hourly temperature, relative humidity, wind speed and wind direction. All variables extended from January 1972–December 2012. Rainfall data were also generated but were not assessed in this study. Additionally, outputs from the WRF model include hourly three-dimensional fields of all atmospheric variables. This enables opportunities to assess the effect of climatology of above-surface weather on fire activity. It should be noted that this has never been possible at this scale for Victoria before. The upper levels had a horizontal spatial resolution of 4 x 4 km, hourly temporal resolution and 32 atmospheric pressure levels (hPa). A list of the upper level variables included are provided in Brown *et al*. (2015) and are not assessed in this paper.

EVALUATION OF THE DATASET

Temperature, relative humidity and wind speed

To inform the final model configuration and 15-day integration, the RMS error (RMSE) between observations and outputs from the WRF model for wind speed, temperature and relative humidity were calculated for each hour throughout the summer period for 2008–2009, together with WRF field variance of these quantities for each hour. There was no trend in error through the 14 days of integration. This was investigated further for each integration period with the bias and RMSE for all stations for each hour for the same summer period for 2008–2009. A subjective conclusion from these comparisons is that the integration gaps should have relatively little impact on the utility of the data set for climatological analyses. However, if a fire spread model is to be run across these periods, it is recommended that care should be taken to carefully assess the impacts of any possible inconsistencies.

The 15-day integrations and model field nudging produced remarkably small biases. Figure 1 shows CDFs for a combined 30-observation dataset and the corresponding model grid point for each station for the 10-year period from 2004–2013. This includes all hours and days during this period. Further analyses are being undertaken to assess diurnal, seasonal and elevation biases.

The WRF model produced simulations with slight under-prediction of wind speed during the day, slight over-prediction of temperature and a slight under-prediction of relative humidity during the day with opposite biases at night. The ability of these outputs to simulate extreme values has yet to be statistically analysed.

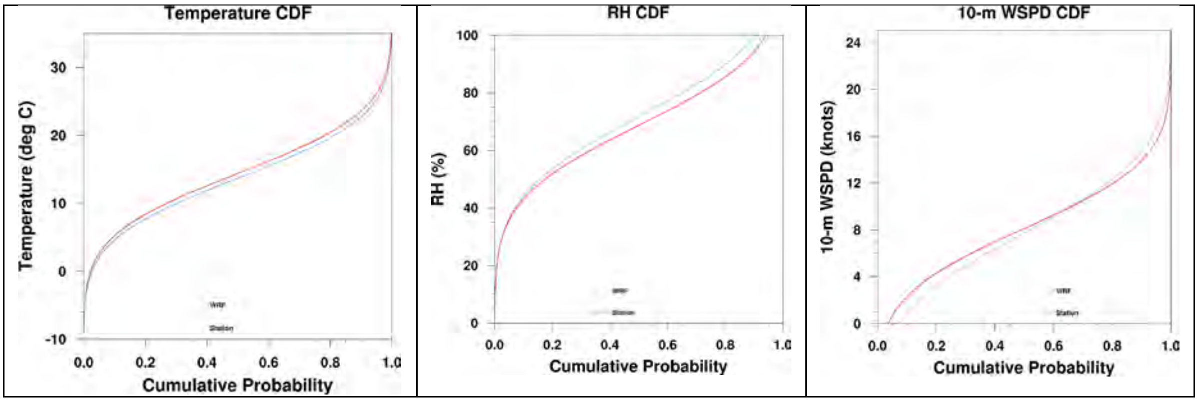


FIGURE 1: CUMULATIVE DISTRIBUTION FUNCTIONS FOR 30 STATIONS (RED LINE) AND CORRESPONDING MODEL GRID POINTS (BLUE LINE) FOR ALL HOURS AND DAYS 2004–2013 FOR TEMPERATURE, RELATIVE HUMIDITY AND WIND SPEED.

Synoptic evaluation

A large number of hourly charts were examined, both for random periods and major fire weather events. Overall, many interesting or notable events and mesoscale circulation systems were very well simulated, including foehn wind events, wind changes, major fire weather events and land-sea circulations. Two fire weather case studies are presented below and additional examples are presented in Brown *et al*. (2015).

METEOROLOGICAL INTEGRITY: CASE STUDIES

Major fire events: observed versus modelled

A number of fire events were examined as case studies, both subjectively in terms of synoptic pattern and evolution throughout the fire, and using comparison of point values at observation sites. Table 1 lists these events, together with the date, time and observation location used for these point comparisons. A subjective comment based on inspection of the simulated state-wide patterns of wind, temperature and humidity on these days is also included. Data for these variables can be found in Brown *et al*. (2015).

Subjectively, the simulations appear to be excellent, with well matched patterns of extreme fire weather simulated for most of the days examined, albeit with a tendency for slightly lower quality early in the period. This is likely due to changes in the global observing system over 41 years affecting the quality of the initialisation grids.

Point-by-point comparisons show that the temperatures are almost unbiased for this comparison, whereas relative humidity is over-predicted (too humid) by an average of approximately 5%. Wind speeds were lower by some 14 km hr^{-1}, but there are some reservations regarding the values for cases for Streatham and East Gippsland as these are quoted values rather than observations from the Bureau of Meteorology. A more realistic estimate of wind speed would be an under-prediction of around 9 km hr^{-1}. More detailed evaluations of simulations of extremes in individual elements will be conducted in further work.

TABLE 1. DETAILS OF FIRE WEATHER EVENTS, REPRESENTATIVE VALUES FROM THE WRF MODEL (WRF) AND COMPARISONS WITH OBSERVATION (OBS) AND BRIEF SUBJECTIVE COMMENTS. 'UTC' INDICATES XXX.

EVENT	DATE (YEAR, MONTH, DAY)	TIME (UTC)	LOCATION	WRF/OBS TEMPERATURE (°C)	WRF/OBS RELATIVE HUMIDITY (%)	WRF/OBS WIND S PEED (KM HR^{-1})	COMMENTS
BLACK SATURDAY	2009 02-07	0200	MELBOURNE AIRPORT	42.6/44.1	12/7	51/48	EXCELLENT SIMULATION. WIND CHANGE GENERALLY WITHIN 1 HOUR AT MOST OBSERVATION STATIONS.
BRISBANE RANGES	2006 01-22	0400	SHEOAKS	41.0/40.3	18/22	38/48	OBSERVED COOL CHANGE AT SHEOAKS BETWEEN 0800 AND 0830 UTC - WRF AN HOUR EARLY AT AROUND 0700 UTC. TEMPERATURE, HUMIDITY AND WIND APPEAR EXCELLENT FOR MAJOR FIRE PERIOD.
ALPINE BREAKOUT	2003 01-30	0100	MT HOTHAM	28.2/20.2	29/34	46/59	WRF SIMULATED OVERNIGHT STRONG WINDS, DAYTIME STRONG WINDS OVER THE MT HOTHAM AREA. ALSO EXCELLENT SIMULATIONS OF COOL CHANGE STRUCTURE AND TIMING BOTH NORTH AND SOUTH OF THE RANGES.
CANBERRA	2003 01-18	0400	CANBERRA AIRPORT	36.8/36.9	16/8	32/48	SOUND SIMULATION OF MAJOR FIRE WEATHER PERIOD AROUND MIDDLE OF THE DAY. EXCELLENT SIMULATION OF EVENING EASTERLY COOL CHANGE IN TERMS OF TIMING AND STRUCTURE. ALSO SHOWED EFFECTS OF MID-TROPOSPHERIC DRY BAND MIXING TO THE SURFACE.
KING ISLAND SMOKE	2001 01-11	0300	GROVEDALE	38.3/39.4	16/12	30/41	FIRE WEATHER SIMULATED WELL IN TERMS OF PATTERN, BUT SLIGHTLY LOW FOR TEMPERATURE, RELATIVE HUMIDITY AND WIND SPEED IN UNCORRECTED WRF. WIND CHANGE TIMING AT GROVEDALE AND MOORABBIN EXCELLENT.
LINTON	1998 12-02	0300	LINTON	26.5/28.0	39/24	36/44	METEOROLOGICAL PARAMETERS WELL SIMULATED DURING AFTERNOON FIRE RUN. OUTSTANDING TIMING FOR WIND CHANGE SIMULATION.
DANDENONG RANGES	1997 01-27	0300	SCORESBY	33.7/36.2	29/17	25/33	EXCELLENT SIMULATION, PARTICULARLY FOR STRUCTURE AND TIMING OF WIND CHANGE.
BERRINGA	1995 02-25	0400	BERRINGA	36.1/37.0	15/5	18/30	GOOD SIMULATION OVERALL AND EXCELLENT SIMULATION OF TIMING AND STRUCTURE OF MESOSCALE WIND CHANGE.
STRATHBOGIE	1990 12-27	0400	BENALLA	38.0/35.0	12/15	46/65	EXCELLENT SIMULATION OF EXTREME FIRE WEATHER, INCLUDING INVERSION BREAKING AND RAPID CHANGES IN WIND SPEED AND RELATIVE HUMIDITY.
BEMM RIVER	1988 10-14	0200	ORBOST	28.8/30.0	28/27	40/95	INTERESTING FOEHN CIRCULATIONS LEADING TO ENHANCED FIRE WEATHER.
ASH WEDNESDAY	1983 02-16	0500	MELBOURNE AIRPORT	41.1/42.0	13/5	36/44	GOOD SIMULATIONS OF TEMPERATURE AND WIND SPEED DURING THE AFTERNOON. WINS SPEED BIASED LOW LATER IN THE DAY. EXCELLENT WIND CHANGE TIMING AND STRUCTURE ACROSS THE STATE, PARTICULARLY IN WEST AND ON SURF COAST.
MELBOURNE DUST STORM	1983 02-08	0400	MELBOURNE AIRPORT	42.4/41.0	10/3	34/42	GOOD SIMULATION OF TEMPERATURE AND WIND SPEED DURING THE AFTERNOON. WIND SPEED BIASED LOW LATER IN THE DAY. EXCELLENT WIND CHANGE TIMING AND STRUCTURE ACROSS THE STATE.
WESTERN DISTRICT FIRES	1977 02-12	0500	STREATHAM	37.4/38.0	19/15	42/55	GOOD SIMULATION OF EXTREME FIRE WEATHER AHEAD OF COOL CHANGE, BUT TIMING OF COOL CHANGE WAS POOR.

Black Saturday – 7th February 2009

Black Saturday was a devastating fire that led to the loss of 173 lives in Victoria on 7th February 2009. On this day many parts of the state experienced record breaking maximum temperatures and strong winds that grew as the day progressed and with the cool change came a w ind change that greatly intensified the fires and the danger (Teague *et al.* 2010). The temperature and relative humidity at 0400 UTC (3pm local time) is shown in Figure 2 when the cool change was just inland from the coastline in western Victoria, and temperatures above 42°C and relative humidities below 15% are simulated over much of western and central Victoria ahead of the cool change. Figure 2 also shows the wind direction and speed. The timing and structure of the change is excellent, with the faster movement of the southern portion of the change, and the areas of stronger post-change winds, well represented.

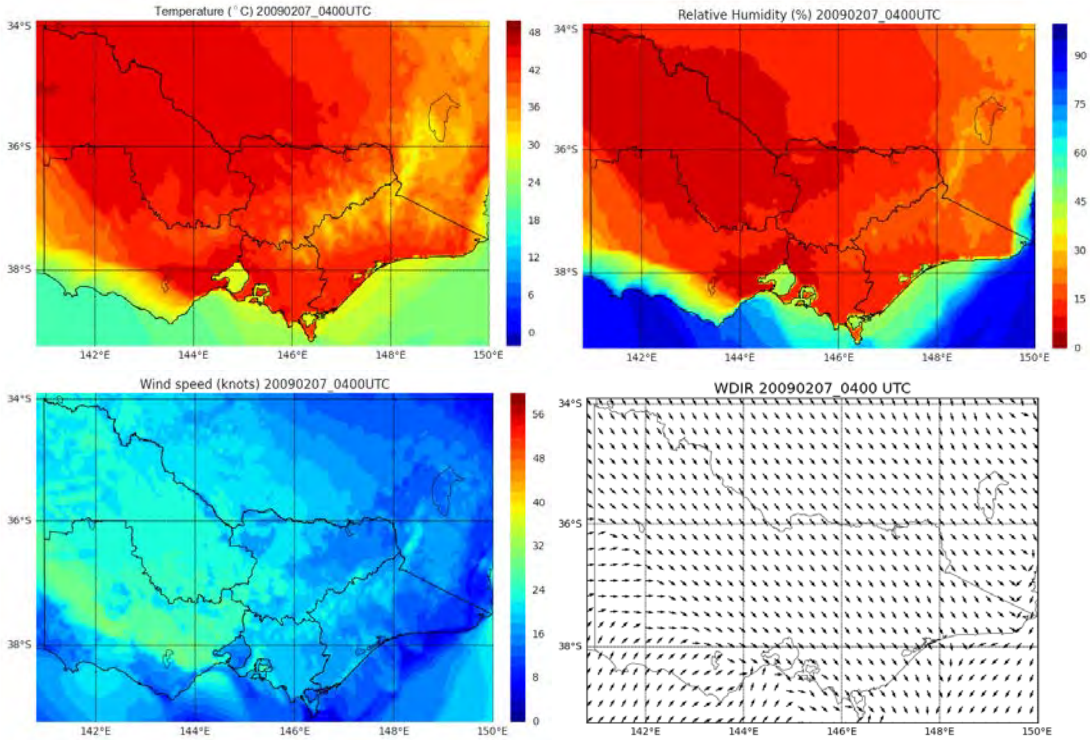


FIGURE 2: TEMPERATURE, RELATIVE HUMIDITY, WIND SPEED AND WIND DIRECTION AT 0400 UTC ON 7TH FEBRUARY 2009 (3 PM LOCAL TIME).

Ash Wednesday – 16th February 1983

The Ash Wednesday fires were a series of fires that occurred in south eastern Australia in which 75 people across Victoria and South Australia lost their lives (Pyne, 1991). Figure 3 shows very high temperatures and low relative humidity across Victoria, apart from the far east, on the afternoon of Ash Wednesday (4pm local time - 0500 UTC). In addition, very strong winds are developing in the west of state, with only weak backing in far west at this time (10pm local time - 1100 UTC). Importantly, the incipient development of a coastal change between Portland and Warrnambool is simulated in the fields from the WRF model. This was not resolvable with the 3-hourly observations available at the time.

Furthermore promising results were found in regards to wind direction. The simulation of wind change timing at a large number of stations across the state using the WRF model were very good on Ash Wednesday (see Table 2).

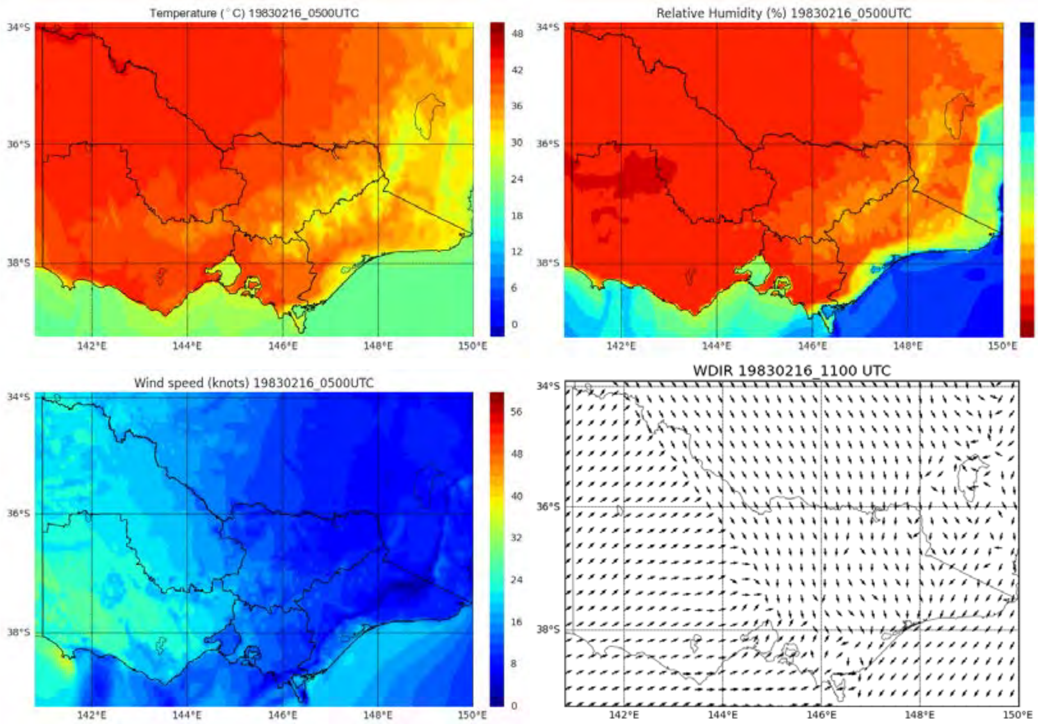


FIGURE 3: TEMPERATURE, RELATIVE HUMIDITY AND WIND SPEED AT 0500 UTC ON 16 FEBRUARY 1983 (4 PM LOCAL TIME) AND WIND DIRECTION AT 1100 UTC (10 PM LOCAL TIME).

TABLE 2. OBSERVED (BUREAU OF METEOROLOGY 1984) AND INTERPOLATED WRF CHANGE TIMES

STATION	CHANGE TIME (EDST)	CHANGE TIME (UTC)	WRF TIME (UTC)
HAMILTON	1800	0700	0700
NHILL	1800	0700	0700
CAPE OTWAY	1810	0710	0600
HORSHAM	1823	0723	0730
LORNE	1900	0800	0700–0800
ANGLESEA	1924	0824	0800–0900
AVALON	1958	0858	0930
MELBOURNE AIRPORT	2040	0940	1030
EAST SALE	2230	1130	1200
MANGALORE	2230	1130	1130
ORBOST	2400	1300	1500
MILDURA	2035	0935	1115

CLIMATOLOGY OUTPUTS – APPLICATIONS OF THE DATASET

Diurnal cycle

Figures 4 and 5 show mean temperature and relative humidity at midday (12 pm) and midnight (12 am) in January. There is a clear contrast between day and night with higher temperature and lower humidity during the day with the largest contrast between day and night occurring closer to the coast for the period. For both day and night, the mean temperature increases with distance inland, ranging at night from 10–15°C near the coast to 25–30°C inland and, during the day, ranging from 15–20°C near the coast to 30–35°C inland. Relative humidity decreases from the coast to inland with night time humidity at 100% near the coast decreasing to 30–40% inland. During the day the mean relative humidity was as high as 60–70% in some small regions near the coast and decreased to 20–30% inland.

Information on the diurnal cycle can inform when the fire weather peaks (when the hottest, windiest and driest conditions occur), and when and for how many hours temperatures are high and humidity is low. Furthermore, the diurnal cycle is also important for understanding the weather conditions in the shoulder periods, when conditions are less extreme, and also overnight, as these conditions also contribute to the fire danger.

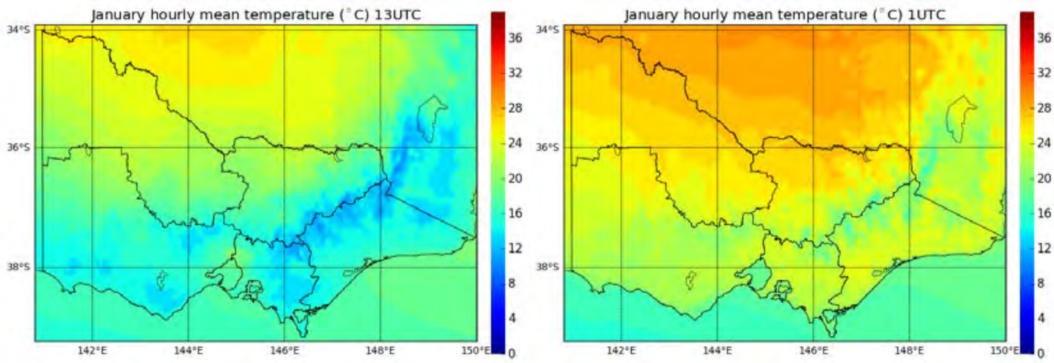


FIGURE 4: MEAN JANUARY TEMPERATURE AT 12 AM AND 12 PM (LOCAL TIME) (1972-2012)

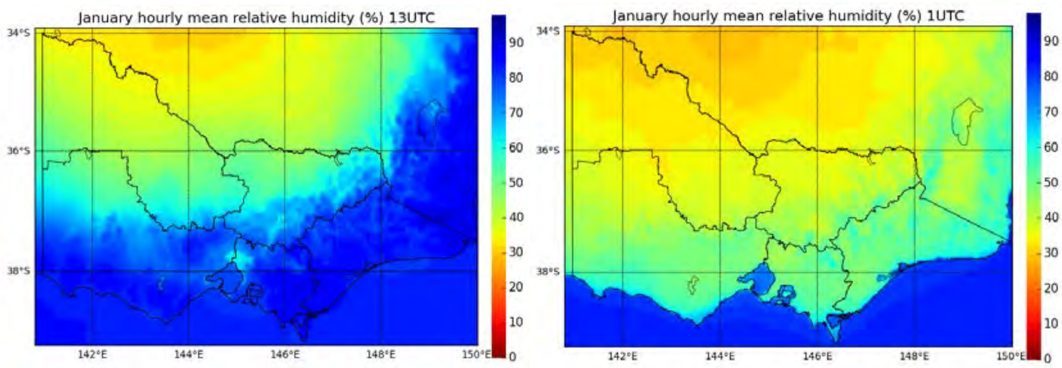


FIGURE 5: MEAN JANUARY RELATIVE HUMIDITY AT 12 AM AND 12 PM (LOCAL TIME) (1972-2012)

Interannual variability

Time series analyses are useful for identifying changes between months, seasons and years and to identify any longer term climate patterns and relationships with other features such as climate oscillations. For example, time series plots for Victoria (Figure 6) reveal the interannual variability in monthly maximum temperatures. Over the last 41 years, the mean monthly maximum for Victoria is 26.5°C for the study area (study area range can be viewed in Figure 5 and included areas of ocean and other states outside Victoria) with a s tandard deviation of 6.5°C. The hottest monthly maximum of 39°C was experienced in 2009. The average monthly minimum relative humidity is 32.5% with a standard deviation of 8% (Figure 7). The lowest average minimum relative humidity across the study area was 18% in 2009.

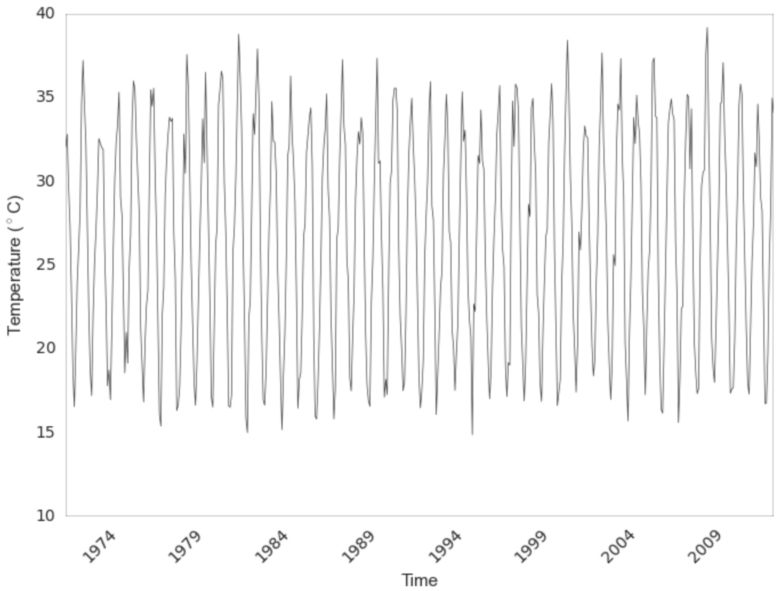


FIGURE 6: MONTHLY MAXIMUM TEMPERATURE (°C) AVERAGED ACROSS STUDY AREA 1972-2012.

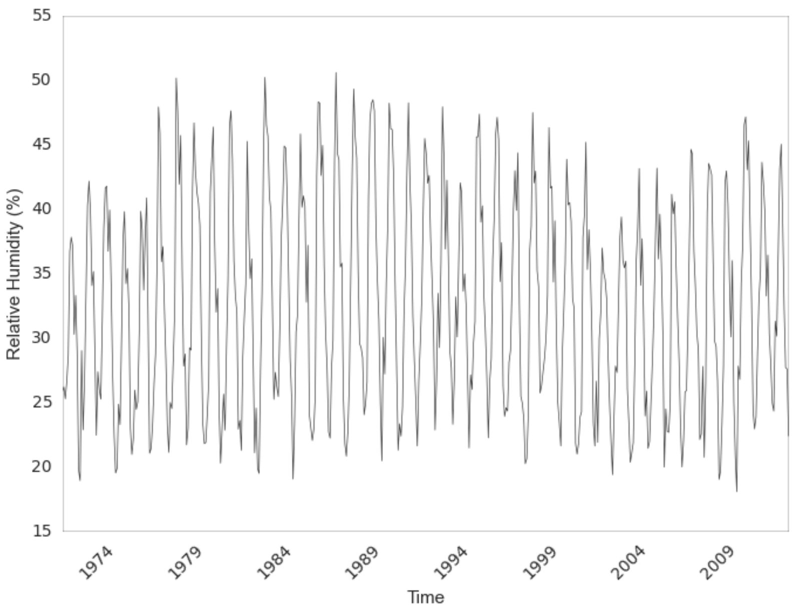


FIGURE 7: MONTHLY MINIMUM RELATIVE HUMIDITY (%) AVERAGED ACROSS STUDY AREA 1972-2012.

Extremes

Contour plots of extremes allows for assessment of the spatially variability of the extreme values. Across Victoria, the lowest maximum temperature reached in December, January or February (DJF) for the period 1972–2012 was 30°C (Figure 8). However, there was large spatial variability—in mountainous regions the maximum temperature range was 30–35°C, in coastal regions the range was 35–40°C, and in inland areas temperatures were up to 45°C. In contrast, the minimum relative humidity for some parts of inland Victoria was less than 5%, with most of Victoria experiencing less than 15% at some stage in the summer months over the 41-year period (Figure 8). Further work will assess these extremes in comparison to AWS data and other gridded weather products such as the Australian Water Availability Project (AWAP) dataset.

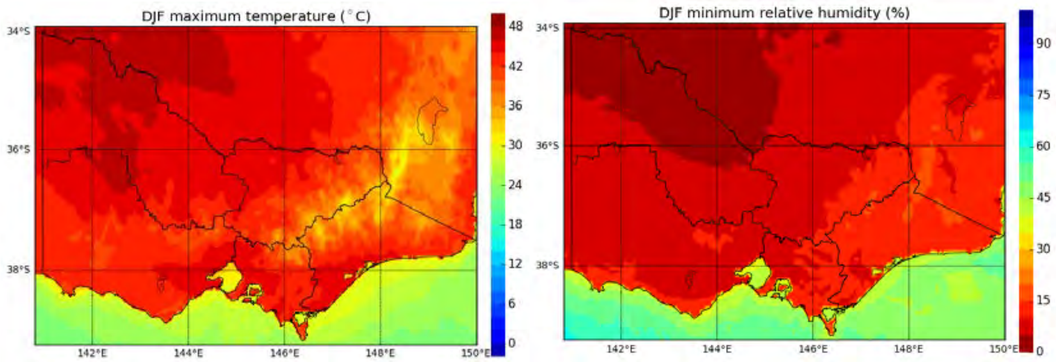
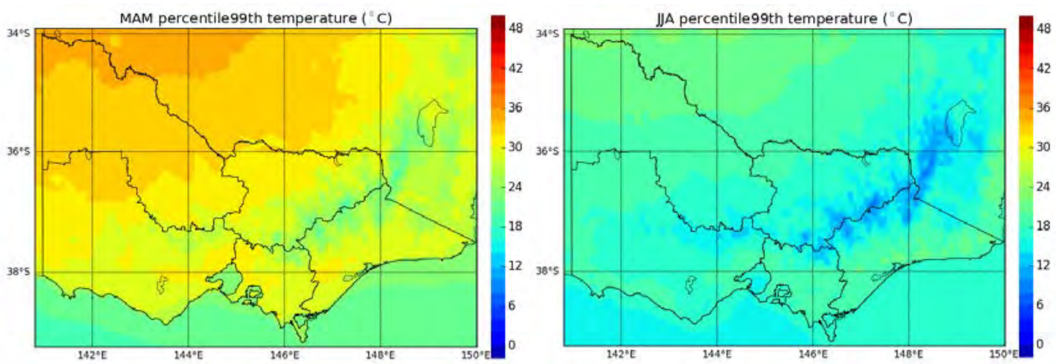


FIGURE 8: MAXIMUM TEMPERATURE AND MINIMUM RELATIVE HUMIDITY FOR DECEMBER, JANUARY OR FEBRUARY (1972–2012)

Knowledge of maximum and minimum conditions is important for preparing for worst-case situations. However, using percentiles may be more useful for planning and preparedness and working with different scenarios. As an example, Figure 9 shows the 99th percentile of temperature for 1972–2012 for each season. Temperatures are obviously higher in the DJF period and cooler in the June, July, August (JJA) period and the spatial variability is evident for all seasons. This type of information could also be included in optimising planned burning schedules by identifying periods where conditions are most favourable for burning.



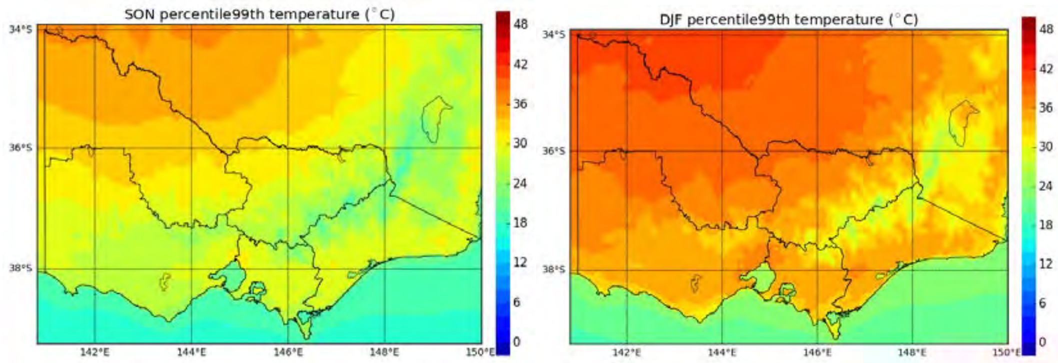


FIGURE 9: THE 99TH PERCENTILE OF TEMPERATURE FOR EACH SEASON 1972–2012 – MARCH, APRIL, MAY (MAM), JUNE, JULY, AUGUST (JJA), SEPTEMBER, OCTOBER, NOVEMBER (SON) AND DECEMBER, JANUARY, FEBRUARY (DJF)

DISCUSSION AND CONCLUSION

The Victoria fire weather climatology dataset described here is the only hourly long-term 4-km dataset containing temperature, relative humidity, wind speed and wind direction that is currently available. This paper summarises the development and potential applications of this spatially- and temporally-homogenous dataset. The results of evaluations, observation-fitting statistics, application of case-studies and climatological assessments show that the quality of the data set is such that there is great potential with a number of applications and analyses to which this data set might be usefully applied.

This study found that the simulations using the WRF model slightly under-predicted wind speed during the day. Temperature was slightly over-predicted and relative humidity was slightly under-predicted during the day, with opposite biases at night. The ability of the WRF model to simulate extremes have yet to be fully evaluated, however, case studies indicated promising results. Overall, these results are impressive for such high temporal and spatial resolution. Other models can only simulating daily outputs, often for shorter periods and coarser spatial resolutions. Further assessment will be done to review any diurnal, seasonal and elevation biases.

In planned future work, a bias correction will be applied to address any anomalies identified in the dataset. In addition, we will assess outputs from the WRF model in relation to precipitation. From this, a d ataset containing daily drought factors, the Keetch-Byram drought index and a h ighly-anticipated hourly Forest Fire Danger Index will be constructed. The opportunities to use this dataset for research purposes and for fire management are immense, with the outputs providing an almost limitless opportunity for analyses. Furthermore, as the WRF model can produce hourly 3-dimensional fields of all atmospheric variables, there is the opportunity to assess the climatology of above-surface weather on fire activity at a scale and resolution that has not been possible for Victoria before.

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SHARED RESPONSIBILITY – SHADES OF GREY

Research proceedings from the Bushfire and Natural Hazards CRC & AFAC conference
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ABSTRACT

A university, NGO and local council partnership was formed to map the Blue Mountains community in relation to vulnerable people in daily life and in times of emergency. Soon after the project launch the October 2013 fires broke out in Yellow Rock, Winmalee and Mt Victoria, directly affecting hundreds of households.

The Community Connections research involved a survey sent to all ratepayers in the Blue Mountains, and interviews and focus groups with community members in 2014. Over 1100 surveys were completed and returned. Findings, including accounts of meetings with newly developed committees formed as a result of the 2013 f ires, indicate that in some areas 'shared responsibility' actually becomes 'shades of grey' as vulnerable community members become confused between the 'community engagement' activities of the emergency services and the lack of individual assistance when disaster strikes. Vulnerable community members include the aged, financially disadvantaged, single parent families, households without a car, people living alone and people with chronic illnesses, who lack connections to assist them in emergencies.

The pressing question is – who is responsible for appropriately identifying and assisting the vulnerable in a crisis situation? Community organisations are recognised in the National Strategy for Disaster Resilience 2011 and are seen as sharing responsibility for disaster resilience. This sector, however, is not often invited to the table of disaster committees and bodies. In particular, community organisations could play a part in strengthening community resilience through their work with the most vulnerable members of the community. This paper explores the Blue Mountains experience.

INTRODUCTION

Building the community resilience of identified vulnerable individuals, and the community as a whole, needs to occur in a way that strengthens existing wider community resilience and recognises the social capital of the local area.

The project drew together information from various sources on the needs of vulnerable populations within the Blue Mountains. This information is being used to develop strategies for increasing community resilience, community connection and planning for the needs of vulnerable community members broadly and when impacted by natural disaster or public emergency.

The National Strategy for Disaster Resilience sets out the agenda for shared responsibility in disasters and the need to draw on all sectors of society to take responsibility in times of disaster -including all levels of government, business, the non-government sector and individuals. For individuals this involves 'taking their share of responsibility for preventing, preparing for, responding to and recovering from disasters'[1]. The ability of the individual to do this is enhanced by drawing on guidance, resources and policies of government and other sources such as community organisations. It is further stated that:

> The disaster resilience of people and households is significantly increased by active planning and preparation for protecting life and property, based on an awareness of the threats relevant to their locality. It is also increased by knowing and being involved in local community disaster or emergency management arrangements, and for many being involved as a volunteer.[1]

The community sector, including non-government organisations (NGOs), is recognised as having a valuable part to play in strengthening disaster resilience through the support they are able to offer in helping communities to cope with, and recover from, a disaster[2]. Community organisations often have a pool of volunteers to draw on and are typically aware of and working with some of the most vulnerable members of the community. As Fitzpatrick & Molloy (2014) write:

> NGOs … are ideally placed for promoting the messages of disaster management and building resilience as they exist to support the communities they service, and they are already embedded and connected at a grassroots level. Furthermore, NGOs have an enduring and trusted presence in and with the community and already engage a large majority of those communities that are commonly considered to be most vulnerable to disasters.[3]

The Bushfire and Natural Hazards CRC consider the lack of prescriptive approaches to sharing responsibility as an opportunity for communities to develop their own approaches[4]. We contend that as communities begin to work out ways to determine their strengths and vulnerabilities and the key factors in community resilience they can work with, they are also confronted with the need to recognise those who are unable to adequately support themselves in a disaster[5]. The Community Connections project set out to examine these issues in the context of the Blue Mountains.

BACKGROUND

COMMUNITY CONNECTIONS: RESILIENCE AND VULNERABILITIES RESEARCH

The City of Blue Mountains consists of a population of 78,691, living in 33,348 dwellings scattered across 25 separate hamlets, within a 75 kilometre stretch. The City straddles the mountain ridge in a ribbon development serviced by one major arterial road and one main railway corridor. The Blue Mountains are located on the rim of the Sydney basin in the region identified as Greater Western Sydney, NSW. There are specific challenges for older, vulnerable and at risk members of the Blue Mountains community due to the topography of the region, the known natural disaster risk (bushfire, earthquake, severe weather storms), problems created by the ribbon development of hamlets, demographic profile, and variable public infrastructure. The Community Connections research project involved investigating the fabric of social connectedness, organisational links and knowledge of the community, in addition to mapping social support and planning for the vulnerable in the event of disaster.

The impetus for the research stemmed from initial investigations revealing that the vulnerable residents of the Blue Mountains are not actively engaged or consulted by relevant authorities prior to or during, emergency situations. There is some concern that in the context of shared responsibility there is a lack of appreciation for the needs of the vulnerable and at risk and their needs during potential extended periods of isolation (such as caused by electricity outages, road closures and the halt of public transport). Knowledge of individuals and their needs is fragmented across the community and across multiple agencies and service providers.

There are a number of contributors to vulnerability recognised in existing models and literature including living alone, low income and unemployment[5]. Other factors are ageing, living with dementia, disability or chronic debilitating illness, and chronic mental health issues. In addition social vulnerability or lack of social support increases overall vulnerability[6]. The Community Connections research aimed to consider how to determine the resilience of the Blue Mountains community and to identify the needs of vulnerable community members in order to inform strategies to address these needs. The results of the research are presented in detail in the project report, Community Connections: Vulnerability and Resilience in the Blue Mountains[7].

METHOD

The Community Connections survey was sent to all ratepayers with properties in the Blue Mountains with the council rates notice in July 2014. The survey was closed at the end of August 2014 and analysed using SPSS. In addition to the survey a purposeful sample of community members were interviewed and the perspective of vulnerable community members was captured through focus groups and individual interviews. Ten interviews were held with 11 participants (one couple were interviewed together) and three focus groups with a total of 12 people were held in Katoomba. Eleven interviews were also held with community leaders in work locations in Springwood, Katoomba and Blackheath. Interviews and focus groups occurred between August 2014 and January 2015 and were recorded, transcribed and analysed using NVivo. Major themes were identified and coded. This paper draws on the research findings.

RESULTS AND FINDINGS

A total of 1103 surveys were returned from across the Blue Mountains region of 27 hamlets and included many of the vulnerable in the area. Fifty four per cent of survey respondents were over 65 years of age, 19 per cent stated they had a chronic illness (compared with 4.5% needing assistance for severe or profound disability in the 2011 census[8]), and 36 per cent lived alone (24.5% lone person households according to the 2011 census[7]). Of all respondents 9.8 per cent stated they required assistance with household tasks such as putting bins out, while 38 per cent who responded to the question said that they provided assistance to others in the neighbourhood requiring assistance[7].

Not all those over 65 years are vulnerable and many have assistance provided to them. It was clear from statistical analysis using SPSS and applying weightings for age and gender, that those who said they had a c hronic condition or disability were less likely to feel connected to their neighbourhood. It was also clear that neighbours of participants help each other or received formal support from community organisations for help with daily activities. People aged less than 65 years with a chronic condition are less likely to feel supported or to feel very safe.

When asked who would assist them if they needed help, the majority of respondents, 44 percent, indicated family. Interviews and focus groups revealed that for many, family lived out of the area and in many cases out of the region. Thirty three percent responded that neighbours would help them and 17 percent friends. The actual extent of the help neighbours could provide was unclear as many did not know their neighbours well and mentioned that they would not want to unduly impose on them.

In some cases it was evident that neighbours could be put at risk if they were required to assist those less able in their neighbourhood. One woman in her 60s had delayed leaving the mountains during the October 2013 fires because her neighbour could not leave until the next day and most other people in the area had left already. Another interviewee was helping to care for three people in their 90s in her street, one of whom had animals and was difficult to deal with. If it was up to neighbours to help the vulnerable to leave and to deal with their animals it could place an unreasonable burden on them.

Six percent of survey respondents said they had no one to help them. One woman interviewed who had a chronic condition had no family and no car. She had a n umber of pets and said that when everyone was told to leave the mountains she had nowhere to go and no means of getting there as she would not be allowed to take her pets on the train, even if she could get to the station.

Emergency services, such as the Rural Fire Service (RFS) and police, are in a position where they cannot provide the same level of support to vulnerable people that they have in the past, while there remain expectations in the community that previous levels of support would continue. In the Winmalee fires of October 2013 there were stories of elderly couples who packed their bags and waited for the police to collect them. In other areas interviewees reported being contacted by RFS members and reassured that they would be safe or rescued if necessary.

During briefings at RFS stations in the mountains in 2013 people flocked to hear the latest from the local authorities. Interviewees, some of whom identified themselves as vulnerable, reported being unable to attend these meetings because of the volume of people attending, often extending out into the surrounding streets. People in community housing who had disabilities reported having no means to actually get to the meetings.

COMMUNITY ORGANISATIONS AND RECOVERY

Prior to 2013, community organisations within the Blue Mountains were not participants in disaster management or represented on committees dealing with disaster management. The fires of 2013 brought about the greater involvement of the community sector as neighbourhood centres and other community organsations found themselves having to deal with recovery issues, particularly in providing information to those affected concerning the services and assistance available to them.

None of the community sector organisations had a plan for their role in disaster and recovery prior to the fires of 2013. A key community organisation, Mountains Community Resource Network (MCRN), which represents a n umber of local community organisations including neighbourhood centres, has informational and advocacy roles, develops networks and convenes interagency meetings in order to put organisations in touch with each other for cooperation and collaboration. MCRN and Blue Mountains City Council (BMCC) convene all the networks and inter-agencies within the Blue Mountains concerning a range of issues from housing and homelessness, disability and aging, through to the generalist interagency Blue Mountains Community Interagency (BCMI), as well as mental health, youth, families and households.

The Blue Mountains is one of the first areas in New South Wales to have economic and community recovery dealt with jointly. This came about with the involvement of community organisations, such as the MCRN and various neighbourhood centres, in the recovery process. A combined inter-agencies meeting was called by MCRN within 10 days of the October 2013 fires, attracting 55-60 people, including a r epresentative from the Ministry for Policing and Emergency Services (MPES). The initial meeting set up a work plan and created a number of sub-committees. Short, medium and long term planning was blocked in, starting with the coordination of immediate relief and recovery work on the ground. Each participating organisation outlined their work sphere and this avoided duplication and determined where the gaps in service were.

PROBLEMS EXPERIENCED BY COMMUNITY ORGANISATIONS

The involvement of community organisations in the recovery process presented a major burden for staff involved for quite some time with various sub-committee meetings requiring attendance for a couple of hours once or twice a week, and Recovery Committee meetings two or three hours twice a week. Additionally there was the process of getting the rest of the community sector geared up and connected.

In general, community sector organisations have their own sphere of influence, which might be the issues they deal with or the local community that they serve. The bigger problem however, was the lack of any connection between the so called non-traditional community sector organisations, and the 'BINGOs', the big international non-government organisations such as Anglicare and Catholic Care and others. Red Cross had made connections straight away with community organisations and their staff, being local, helped with making relevant community connections. As a result of this process and experience Blue Mountains community organisations are now intimately connected with the recovery process.

The community sector had not had any connections with the Local Emergency Management Committee (LEMC) prior to recent events. Formal systems are now being put in place within both Council and the community sector to formalise, role to role, the kind of triggers that need to be recognised, who should respond to them, what roles should be involved and who should be chairing. The newly created role of Recovery Manager in the Blue Mountains LGA is a separate role in Council from the LEMO role (Local Emergency Management Officer).

Enormous difficulties were experienced by the community organisations in communicating with the general public. Although there were many sources of information and assistance available, only messages with a s tructural and operational focus were being pushed through. The messages the community sector proposed were put aside by those controlling public communications and a road-block was placed in the way of getting messages to people in need.

CONCLUSION

Shared responsibility requires the involvement of a community-level response through local organisations, as these organisations are in contact with the most vulnerable people. Community disaster resilience requires the involvement of organisations who are linked in with community members and local networks (such as support groups), especially regarding vulnerable community members. Within the Blue Mountains the lack of inclusion in disaster infrastructure and coordination hampered the 2013 response by not for profit organisations and volunteer agencies[9]. The structures and processes for including community organisations, previously non-existent in the Blue Mountains, are now evolving as communities find ways to take on a greater share of the responsibility for disaster planning, response and recovery.

Where services, such as the Rural Fire Service, are endeavouring to increase their level of community engagement, they are at the same time having to pull back from providing community assistance in evacuation or rescue, creating many shades of grey in their connections with their communities. There have been no formal structures whereby they could work with community organisations on these issues.

There is great value in local emergency services and committees working with local community organisations to connect with community. Within the Blue Mountains the potential for greater community engagement in formal emergency management processes is now being developed. This involves the need to clarify differences in roles in order to develop effective means for increasing disaster resilience within communities at the community level. While shades of grey might remain there will be greater clarity as resources are focused on where the best connections have been forged within the community.

As more responsibility is being placed on communities themselves to manage in times of disaster, it is becoming increasingly evident that community resilience must involve the ability to care for and manage the most vulnerable in the community. In most cases individual households are able to manage their own situations, but there are a number who lack resources and could be in danger in times of disaster. Neighbourhood centres in the Blue Mountains, as in other areas, are often dealing with the most vulnerable members of the community, such as those with disability, mental illness, the homeless, socio-economically disadvantaged and the socially isolated. These organisations should be included in planning and preparedness as well as recovery. At present statutory requirements for emergency management exclude such organisations.

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FRAMEWORK TO INSPECT FLOODWAYS TOWARDS ESTIMATING DAMAGE

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ABSTRACT

Floodways provide economic and environmental friendly alternative solution over bridges and culverts for roads with low traffic volumes in rural road networks. They connect regional communities, farmlands and agricultural areas to city centers and hence play a vital role in the economy of a country. Design and operational condition of floodways differ from major road infrastructures because the floodway design process allows a certain degree of submergence for floods with high annual exceedance probability (AEP). Nevertheless, natural hazards can cause damage to floodways as evident from the 2011 and 2013 Queensland flood events. 58% of floodway structures in the Lockyer Valley Regional Council area in Queensland, Australia, were damaged during the 2013 Queensland flood event leading to operational failures in rural road networks and isolating regional communities. Damage assessment during the post-disaster event is a difficult but significant step to enhance the resilience of regional communities. A lack of a proper method to estimate the extent of damage can cause significant delays to repair/reconstruction activities and also can lead to errors in the decision-making process on prioritizing the repair/reconstruction works. Such delays can have a detrimental effect on the resilience of the regional communities. In general, floodways are infrequently being inspected or assessed its capacity only after a natural disaster. This irregularity can cause difficulties during the inspection and assessment process, as information on the previous state of the floodway can easily be unknown. Unavailability of a widely accepted inspection framework is the main cause of this problem. Having identified this gap in knowledge, this paper aims to develop a floodway inspection framework. This framework is designed to extend its capability to help the decision makers to quantify the damage and estimate the repair/reconstruction needs. This framework, therefore, contributes to enhancing the resilience of regional communities who are served by floodways.

INTRODUCTION

Bridges, culverts, and floodways are vital road infrastructures for the operation of a road network. Their application may vary based on geographic and demographic features of the territory. Floodways are common in rural road networks as they provide economic and environmental friendly solutions over bridges and culverts. Floodways play a significant role in the economy of a country by connecting regional communities, farmlands and agricultural areas to city centers. For an example, 48% of total agricultural production in Australia in 2006 had been produced from regional council areas, those covering only about 6.9% of Australia's population, 11% of total Australian land mass and 24% of roads in length [1]. Floodways are common in most of these rural road networks and, hence, play a vital role to distribute agricultural and farming products to highly populated city centers. Therefore, healthy operational levels of floodways are of paramount importance to maintain the continuous supply of essential commodities and the economic balance of Australia.

Floodways are different from bridges and culverts in the design and operational aspects. By definition, floodways are sections of roads which have been designed to be overtopped by floodwater during relatively low average recurrence interval (ARI) floods and are expected to return to fully serviceable level after the flood water recedes [2]. They are also known as causeways in some regions [3]. Although, floodways are designed to withstand at low flood levels, extreme natural disasters can damage these vital road infrastructures as evident from the 2011 and 2013 Queensland flood events. 58% of floodway structures in the Lockyer Valley Regional Council (LVRC) area in Queensland, Australia, were damaged during the 2013 Queensland flood event leading to operational failures in rural road networks. Floodway damage leads to isolating regional communities and hindering the supply of agricultural products to other regions. In a post-disaster period, the long-term impacts on the community and the economy of the country depend on the speed of re-establishing the fully operational level of those floodways.

BACKGROUND

The rehabilitation process of floodways during the post-disaster period includes several steps such as preliminary assessment, detailed evaluation, design and tendering process and reconstruction activities, similar to any other infrastructure. It is obvious that the preliminary and detailed assessment steps can cause an enormous impact on the subsequent operations. Underestimation of the extent of the damage often leads to subsequent failures of floodways during floods with lower recurrence intervals than that they are designed for. This situation can result in frequent repair and/or reconstruction activities causing operational failures in terms of extended travel times and/or distances. On the other hand, overestimation of damage results in overdesigning the structure and hence higher repair/reconstruction costs. In these situations, financial constraints should be thoroughly investigated, particularly in case of widespread natural disasters such as in the 2011 and 2013 Queensland flood events. In such cases, regional councils and government bodies can extend the time frame for the repair/reconstruction period, after prioritization of all activities through a detailed budget evaluation. Correct identification of the extent of the damage will avoid both situations highlighted above and will lead to right decision making in terms of prioritization and reconstruction of damaged floodways. Development of a method to estimate the extent of damage in terms of monetary requirements will assist the regional councils by enhancing the decision making and prioritization processes, considering both short term and long term benefits. Damage index method defined below evaluates repair and reconstruction needs in monetary terms.

DAMAGE INDEX

Nishijima and Faber [4] presented a damage index that is the ratio of the repair cost to the estimated replacement cost. This index measures the severity of damage in terms of the cost for the repair/reconstruction activities. Wahalathantri et al. [5] extended this method to quantify the extent of floodway damage. They divided the reconstruction work of a floodway into eight gross activities, namely: construction of temporary road; demolishing and removing existing structures; reconstruction of concrete roadway crossing; reconstruction of apron; placing geotextile fabric in conjunction with rock fill; construction of rock protection; replacing sign posts and clearing debris material. This categorization is based on the inspections reports for damaged floodways in Lockyer Valley region during 2013 flood event. For each of above eight activities, contribution factors were defined using Equation 1, in which, 'i' represents the i^{th} category from the above list.

$$\text{Contributing Factor for item 'i'} = \frac{\text{Repair Cost for item 'i'}}{\text{Estimated replacement cost}} \qquad \text{Equation (1)}$$

The damage index is then calculated using Equation 2 as given below.

$$\text{DI} = \sum \text{Contributing Factors for items 'i'} \qquad \text{Equation (2)}$$

Wahalathantri et al. [5] defined maximum contributing factors for these eight elements based on cost estimations for 27 floodways across the Left Hand Branch

Road in the LVRC. The extent of the damage is classified into five categories based on the calculated damage indices as below.

1. Complete damage – when the calculated damage index becomes 1 or above. Full replacement can be warranted based on site investigations.
2. Extreme damage – when the damage index is between 0.8 and 1. It is advisable to consider the long-term benefits of the full replacement, rather considering repair works only.
3. Major damage – when the damage index is between 0.5-0.8. It is advisable to assess the vulnerability of areas that are severely damaged against possible extreme flood event in near future.
4. Moderate damage – when the damage index is between 0.1 and 0.5. Floodways with moderate damage can be easily rectified.
5. Minor damage – when the damage index is less than 0.1. Such incidents may have an insignificant impact on the operational level of the floodway.

The above method estimates the maximum damage index using maximum contributing factors. However, actual damage index can vary if the floodway components are not fully damaged. This discrepancy often leads to overestimation of the repair cost that may result in an extended time frame for reconstruction of damaged floodways. Extended time will cause partial operation for long periods of times, which will reduce the resilience of the community. Therefore, an accurate method to estimate the extent of the damage is an important field of study. Such a detailed method should include a detail inspection report to improve the quality of the assessment.

Although bridges do have an inspection framework/protocol to follow, same is not applicable for floodways. For an example, Queensland Transport and Main Roads do have the bridge inspection manual [6] which outlines inspection procedures, key components of bridges and general format of inspection forms for Queensland. Floodway inspection details received from the LVRC for the 2011 and 2013 flood events do not indicate the existence of such a detailed inspection report or framework for floodways. Similarly, other regional councils may also do not utilize standard forms to inspect floodways. If any regional council has a standard framework to assess damage, it is worthwhile to bring this matter into a common discussion forum so that regional councils who own floodways can further discuss and improve the framework towards developing a locally, regionally and nationally accepted framework. Therefore, developing a floodway inspection framework is a timely topic for investigation.

FLOODWAY INSPECTION FRAMEWORK

The proposed floodway inspection framework consists of following key elements:

A. Basic information about floodway
B. Notes from previous inspection or repair/maintenance work
C. Basic details of current inspection
D. Inspection records
E. Condition report

A. BASIC INFORMATION

Contrasts to the other major road infrastructures, floodways do not require regular inspections, and, hence, they are often inspected infrequently or only after a major natural disaster. This inspection practice leads towards making assumptions about the floodway performance prior to a natural disaster. Also, it makes it difficult to distinguish between deterioration due to aging and damage due to a natural disaster. These factors can lead to more uncertainties in judgement or may require re-inspection after referring to the previous condition. The inclusion of basic information minimizes those uncertainties and any needs for re-inspections.

Basic information should facilitate asset identification, location, some design and construction details with suitable sketches or drawings as shown in Table 1. A01-A03 supports floodway identification in terms of asset number, suburb and road name. Type of floodway should be specified under A04. It is recommended to adopt the Austroads Guide [7] to define the floodway type. Austroads guide defines five types of floodways [7]. However, alternative floodway types or slightly modified versions from above five types have been attempted and constructed by regional councils in Australia. For an example, Allen and Rickards [8] presented alternative floodway types with the utilization of soil stabilization methods. Some of those types are being constructed and tested in the Central Local Government Region of South Australia. In such situations, a clear explanation should be given to the type of floodway with the correct reference. Alternatively, a comprehensive study should be performed to include those floodway types in a nationally accepted guideline such as Austroads guide [7]. A05-A11 provides design details of the floodway.

A. **Basic Information**	
A01. ID	
A02. Suburb & Road Name	
A03. Local Authority	
A04. Type	
A05. Constructed year	

A06. Design Life				
A07. Number of lanes and load limit				
A08. Construction material				
A09. Design Flood (AEP)	Trafficable		Maximum	
A10. Chainages/Coordinates	Start chainage (Latitude, Longitude)		End chainage (Latitude, Longitude)	
A11. Drawings & Details (dimensions, material)				

Table 1: Section A of the Floodway Inspection Framework

B. NOTES FROM PREVIOUS INSPECTION, REPAIR OR MAINTENANCE WORK

Summary of previous inspection reports, repair/reconstruction work will also be important in the decision-making process. This section can include pictures from last inspection to demonstrate the latest status of the floodway. Table 2 shows a general format for this task.

B. **Notes from previous inspection, repair or maintenance work**	
B01. Date of last inspection	
B02. Inspected by	
B03. Reason	
B04. Recommendations	
B05. Repair/reconstruction work	
B06. Pictures/sketches	

Table 2: Section B of the Floodway Inspection Framework

C. BASIC DETAILS OF CURRENT INSPECTION

Section C is to record current inspection records such as date, time, person/s inspecting and the reason for the inspection. The reason for the inspection can be due to regular inspection procedures, maintenance work or to assess the structure due to the damage caused by a natural disaster or an accident. In the latter case, the nature of the incident should also be included. For an example, flood level, period and annual exceedance probability can be included in the event of a flood event. Table 3 shows the general format for the element C.

C. Basic details of current inspection	
C01. Date of current inspection	
C02. Time	
C03. Inspected by	
C04. Reason	
C05. Nature of the incident (E.g., flood level, period, AEP in case of flood)	
C06. Pictures/sketches	

Table 3: Section C of the Floodway Inspection Framework

D. INSPECTION RECORDS

This section should include a detailed and methodological approach outlining each component of a floodway, failure mechanisms and extent of the damage. This step is the most important step to estimate the magnitude of the damage and hence decisions on repair/reconstruction needs. Therefore, attempts should be made to quantify the damage at all possible instances. A qualitative assessment can be performed if it is hard to undertake a quantitative evaluation.

Table 4 presents the framework to record inspection details according to floodway zones and elements in each of the four zones. Four floodway zones proposed by Allen and Rickards [8] are used in this table. Wahalathantri et al. [5] presented common floodway failure mechanisms and elements based on the inspection records from the LVRC area following the 2013 QLD flood event. These floodway zones and elements are therefore listed in Table 4.

D. Inspection records					
Element		Quantitative Assessement[1]		Qualitative assessment (See notes below)[2]	Notes (such as failure mode, source of damage, etc..) & reference to photos/sketches
		Location/ Dimension	Damage extent (%)	Quality Index	Notes
D01. Upstream Zone					
	Apron				
	Rock Protection				

	Cut-off Wall					
	Culvert entry					
	Stream banks					
D02. Downstream Zone						
	Apron					
	Rock Protection					
	Cut-off Wall					
	Culvert exit					
	Stream banks					
D03. Roadway Zone						
	Road crossing					
	Sub-base					
	Sub-grade					
	Culvert					
	Road signs					
	Flood level indicators					
D04. Peripheral Zone						
	Approaches					
	Approach signs					
	Flooded area beyond floodway extent					
	Vegetation - upstream					
	Vegetation - downstream					
	Evidence on creek changes					
D05. Photos						
Notes:	[1] Report extent and dimension, if the damage extent significantly varies at different sections for a given element					
	[2] Qualitative Assessment					
	Value	5	4	3	2	1
	Condition	Critical	Poor	Fair	Satisfactory	Good

Table 4: Section D of the Floodway Inspection Framework

Table 4 has a provision for both quantitative and qualitative assessments and a column to record any other notes or sketches or reference for photos. The qualitative assessment assigns a value to each element based on the state of the floodway at the time of inspection [9]. The value of 1 indicates that the element is In excellent condition with no significant damage or deficiency. Satisfactory condition means that the floodway is only subjected to minor damage, deterioration and/or misalignment with insignificant effect on the performance. Moderate damage/deterioration levels can be classified as the fair condition. Elements with major or multiple defects that can cause significant impact on the serviceability or the integrity of the floodway should be rated as poor condition. Any element that has failed or failure is imminent should be rated as in critical condition.

E. CONDITION REPORT

Last section includes a condition report prepared and signed by the person/s who inspect the floodway. Judgement on the extent of damage, repair/reconstruction needs should be outlined here. The method developed by Wahalathantri et al. [5] can be used to rank the repair/reconstruction needs. Maximum contributing factors defined by Wahalathantri et al. [5] should be modified based on the estimated percentage damage for each component.

E. Condition Report					
E01. Damage Index			Repair need as a fraction	Maximum factor for item	Adjusted Contribution factor
Need for temporary access				0.05	
Demolishing existing structures				0.10	
Reconstruction of roadway crossing				0.25	
Reconstruction of apron				0.50	
Placing Geo-textile				0.01	
Reconstruction of Rock Protection				0.05	
Replacing sign posts				0.02	
Cleaning and debris removal				0.02	
DI = Σ(Adjusted contribution factors)					
E02. Level of Damage	Complete DI =1	Extreme DI: 0.8 -1.0	Major DI: 0.5 – 0.8	Moderate DI: 0.1 – 0.5	Minor DI < 0.1
E03. Recommendation based on DI	Replace the structure	Perform a detail analysis considering design life	Critically assess components subject to major damage	Repair activities should perform as quickly as possible	Rectify the problem at the earliest possible time
E04. Other recommendations					
E05. Asset Number:					
E06. Date of inspection:					
E07. Prepared by (Name, Signature and Date):					

Table 5: Section E of the Floodway Inspection Framework

CONCLUSION

Damage assessment during the post-disaster event is a difficult but significant step to enhance the resilience of regional communities. A lack of proper method to inspect floodways and quantify the extent of damage can cause huge delays to repair/reconstruction activities and also can lead to errors in making correct decisions and prioritizing the repair/reconstruction works. Such delays can have a detrimental effect on the resilience of the regional communities. This paper, therefore, developed a f loodway inspection framework that can be easily extended to estimate the extent of the damage using a damage index method. Hence, this framework will enable making correct decisions in terms of repair/reconstruction activities and prioritizing them. This approach, therefore, contributes to enhancing the resilience of regional communities who are served by floodways.

The developed floodway inspection framework consists of five key elements, labelled as A-E: A -basic information; B - details of previous inspection report and recommendation; C - basic details of current inspection; D - inspection report and E - condition report. Elements A and B provide the basic information about the floodway and its last known condition to assess the damage or the state of the floodway at the current state. Element C and D provide the details of the person/s inspecting the floodway, reason for inspection and the inspection records. The last element, E, provides the condition of the floodway based on the current inspection and state of the structure in terms of repair/reconstruction needs.

WAY FORWARD

Although every effort has made to include all the aspects with respect to floodway inspection process, this framework should be attempted by councils who own floodways towards developing a nationally accepted framework. Future studies should also be conducted to derive contributing factors for each element of the floodway based on the extent of the damage or the qualitative assessment. Department of Transport and Main Roads has observed approach damage as another failure mechanisms. This failure mechanism should be further studied to identify associated cost components. Such studies require details from multiple case studies across Australia. Also, it is identified that new floodway types are being attempted by some regional councils in Australia. A detailed study on those new floodways is recommended to update floodway types given in the Austroads Guide.

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RISK OWNERSHIP AND NATURAL HAZARDS: ACROSS SYSTEMS AND ACROSS VALUES

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ABSTRACT

Severe natural hazards can propagate through systems, creating the potential for disasters. The strategic management of such disasters through risk mitigation, resilience and recovery requires the clear identification of who owns the assets at risk and who has responsibility for the relevant aspects of risk management. Most of the existing literature on risk ownership addresses risk to a single entity such as a household, business or organisation. However, disasters affect many entities, crossing institutional boundaries, changing ownership as they do so, potentially leading to some risks being unowned. A framework for assessing risk ownership at this scale needs to cover the institutions affected by disasters and those involved in disaster management, the different values at risk and current institutional arrangements that constitute risk ownership. This is being addressed in the Australian context through the construction of an economic geography of disaster risk and ownership arrangements. A desktop study of existing risk ownership arrangements suggests that the most complete coverage is for relief and recovery, with limited arrangements for risk mitigation affecting property and infrastructure. Intangible values affecting society and the environment are not well covered, suggesting a need to develop methods for addressing these values. This paper discusses some of the basic building blocks for doing so.

INTRODUCTION

This paper examines the concept of risk ownership for natural hazard risk management, what happens to risk ownership when natural hazard impacts, responses and responsibilities cross domains, and existing arrangements in Australia that pertain to these concepts. It uses risk ownership as a vehicle for risk governance, suggesting that if a risk is adequately 'owned', then it will be managed appropriately, whereas if it is not, then values at risk from natural hazards will be exposed to damage and loss that is potentially avoidable.

This work contributes to the BNHCRC project "Mapping and understanding bushfire and natural hazard vulnerability and risks at the institutional scale". We address risk ownership with respect to strategic risk management before and after events but not emergency response during events, which requires quite a different type of ownership relating to operational matters.

Natural disasters needs to be understood as a type of systemic risk, where severe hazards have the potential to harm people, property and natural systems resulting in disasters. In doing so, risks will cross domains that are geographic, institutional or a combination of both, transferring between different levels of government or the private and public spheres. A wide variety of values, both market and non-market-based, will be affected. As such, risk ownership is an important contributor to the governance of such risks (Jones et al., 2013).

Currently in Australia, identified spending for risk recovery at the Federal and State Government level outweighs spending on risk mitigation by greater than 20 to 1 (Productivity Commission, 2014a). As most of this recovery spending is spent on roads and bridges, we can reasonably assume that similar deficits may exist in other important areas of value, particularly 'softer' social and environmental areas. Especially public values shared in common, where risk ownership may be shared and unclear.

Two questions are addressed:

1. What general forms of risk ownership are associated with the different types of values at risk?
2. What current ownership arrangements are in place for managing natural hazard risks?

RISK OWNERSHIP AND NATURAL HAZARD RISK

The concept of risk ownership stems from two traditions: from economics (especially capitalism) and from risk management. Within economics the main emphasis is on the asset or resource owner, where the ownership of resources and the potential for substantial loss is linked to control of those resources (Robertson, 1923). Under risk management, a risk owner is a person or entity with the accountability and authority to manage a risk (ISO, 2009), placing the emphasis more on managing the risk itself, rather than the asset, although it can be one and the same thing.

With respect to capital risk, Robertson (1923) maintained that (1) those who stand to lose most heavily should have the power of decisions and (2) that those who are taking risks by using their resources should not have their authority handed to others. This describes the 'normal' aspect of risk ownership in a market-based economy, covering the interests that an owner has in an asset or enterprise, extending to areas such as property rights. This is because the capitalist is expected to risk their assets to produce future income. The degree to which natural hazards are managed will depend on the owner's willingness to assess the conditions under which they may 'lose most heavily' from natural hazard risk. Governments are keen to see citizens and business manage as much of their asset risk as possible to minimise demands on public funds for relief and recovery (Productivity Commission, 2014a).

The recent Productivity Commission review on Natural Disaster Funding Arrangements (2014a) considers risk owners primarily through asset ownership, which emphasises the economic rather than the risk-management tradition. Although they address aspects of accountability and responsibility for risk separate to ownership, we take the view that this is too limiting, and that the identification of shared and changing accountabilities and responsibilities under natural disasters requires a broader approach consistent with the risk standard (Young et al., 2015).

The risk standard invests the risk owner with the accountability and authority for risk management, which are quite different roles. We prefer to substitute responsibility for authority because it is better suited to both formal and informal roles (Young et al., 2015). Accountability is an audit task to ensure that an action has been carried out, whereas responsibility is the duty to carry out an action. Both accountability and responsibility are needed to manage systemic risk that concerns both tangible (economic) and intangible (social and environmental) values.

Natural hazard risks range from those that can be considered as being acceptable and within the limits of existing capacity to those that exceed a critical threshold, requiring external resources for effective recovery. Lack of awareness or incomplete knowledge may mean that a risk is unowned , in the sense that the resource owner may be accountable but not responsible, or neither accountable nor responsible (Young et al., 2015). In such cases, responsibility for post event damage and loss will be unallocated.

Generally, risk ownership is addressed at an organisational or enterprise scale. Standard risk ownership guidance addresses these types of ownership from a broad range of business perspectives, natural hazard risk being one (Buehler et al., 2008; Gerken et al., 2010). At an event or multi-event scale, risk ownership at the institutional level becomes important, where the formal and informal rules and arrangements matter most.

Ownership also varies according to the broad range of values, assets and otherwise, that are at risk. These are divided into five value clusters based on Jones et al. (2013). Three clusters cover built, social and environmental assets and infrastructure under both public and private ownership. The other two represent goods and services produced by those assets. These clusters provide a wide range of benefits measured in both monetary and non-monetary terms. The latter includes intrinsic values associated with human lives, cultural values and areas of natural value.

For social and environmental assets and infrastructure, and the benefits that flow from these, the issue of risk ownership becomes much more dispersed. This includes the commons and non-exclusive goods such as air and water. Where the crown acts as custodian for the public, values are held in trust. Other assets such as forests, which provide a broad range of values may be in both private and public hands.

FRAMEWORKS AND METHODS

The project applies two linked frameworks: Ostrom's Institutional Analysis and Development Framework (Ostrom, 2007; McGinnis, 2011; Ostrom, 2011; Eiser et al., 2012) and the more conventional risk management framework (ISO, 2009), to assess ownership in three phases: (1) ownership of values at risk in the pre-risk or normal phase; (2) ownership of mitigating severe risks associated with events likely to cross domains resulting in disasters and allocation between normal and exceptional; (3) ownership in the post event(s) phase of recovery from damage and loss (Young et al., 2015).

The first phase of the project is creating an economic geography that is mapping the five main areas of value: built, social and natural assets and infrastructure and the goods and services provided by these. These are being overlain onto hazard data such as frequency, magnitude and location of the hazard to construct values at risk. These values include:

- dollar values (e.g., property values, household income),
- assets valued in their own right (e.g., sites of cultural importance), and
- proxy values that represent natural and human values (e.g., ecological health and vulnerable people and groups).

The mapping is being carried out using a web-based open-source map-based system that links natural hazard and risk data with a wide variety of value-based data, which will allow users to compare and contrast very different types of values within a single platform. Its aim is also to make a variety of values at risk more visible, especially intangible values and those in public ownership. The current domain covers Victoria and will be expended to other states over time.

A tiered approach starts with high level values such as household income, industry income, employment, demographics, high value conservation land and agricultural production. Under these are more derived variables allocating specific risks (e.g., population vulnerability to heat) associated with each hazard. Broad groups of ownership of these values at risk that account for public, private (individuals, business and industry), government (local, state and federal) and community are being created.

These will also inform which values represent key vulnerabilities or the potential for loss that are clearly owned, partially owned or are unowned. Having a broad understanding of this aspect of ownership then opens the way to investigating accountabilities and responsibilities for managing risk on two fronts: pre-event mitigation and post-event response and recovery.

CURRENT FUNDING AND OWNERSHIP ARRANGEMENTS

A recent study by the project outlines publicly available information on natural hazard risk ownership within Australian jurisdictions (Young et al., 2015). Risk ownership is explored through three questions:

- Who pays for the risk?
- Who manages (is responsible) for the risk?
- Who is accountable for the risk?

Ownership was examined within a matrix of broad institutions (federal, state/territory and local government, business and industry and civil society) and values (built, social and environment assets and infrastructure). Ownership across this matrix was allocated according to individual hazards, ownership of assets, tasks associated with the risk management process and policy/legislative instruments (Young et al., 2015). Many of these arrangements are tiered and are designed to formalise ownership between different levels of government, between the public and private domains and between the government and the individual.

Funding to address natural disasters is provided by all levels of government, community groups and charities, as well as individuals and business sectors (Biggs, 2012). Funding arrangements are divided into pre- and post-disaster categories (Table 1). Pre-disaster funding addresses disaster mitigation and post-disaster funding concerns relief and recovery. The Australian Government has a role in providing financial assistance to other levels of government and the broader community for natural disaster recovery and relief due to its greater ability to raise revenue (Williams, 2012; Productivity Commission, 2014a).

Relief funding refers to short term assistance to households affected by natural disasters and recovery funding mainly concerns reconstruction efforts to repair or replace damaged infrastructure provided via the Natural Disaster Relief and Recovery Arrangements (NDRRA). The Australian Government Disaster Recovery Payment (AGDRP) is a one-off, non means-tested payment of $1000 for adults and $400 for children who are adversely affected by a major disaster.

Commonwealth funding to states for mitigation from 2009–10 to 2012–13 totalled $296 million. The main mechanism for this funding is the National Partnership Agreement on Natural Disaster Resilience (NPANDR; $115 million from the Commonwealth and $110 million from the states over the same period). Mitigation spending was about 3% of total Commonwealth expenditure on natural hazards in recent years (Productivity Commission, 2014a). In comparison, during 2002–03 and 2012–13 total recovery expenditure was at least $13,400 million from all levels of government (Productivity Commission, 2014a). $71 million was contributed through the National Emergency Management Program (NEMP), which contributes to both mitigation and recovery.

Role	Responsibility	Current arrangements
Risk mitigation	All governments	Mitigation activities General infrastructure spending Risk transfer via insurance
	Private/Industry	Risk transfer via insurance Property improvements OH&S measures
	Community	Risk transfer via insurance Development of hazard management plans Property improvements
	Australian Government	Provide funding through NPANDR and NEMP
	State and local governments	Land use planning Building regulations
Relief and recovery arrangements	Australian Government	Provide recovery funding through the NDRRA Provide relief funding through the AGDRP Other relief and recovery funding policies
	State and local governments	Funding and financing of recovery Utilise Australian Government recovery funding
	Private/Industry	Provision of essential items, food, water, energy, support services
	Community	Donations and volunteers and support services through local community organisations

TABLE 1. EXISTING HIGH LEVEL RESPONSIBILITIES FOR NATURAL HAZARD RISK OWNERSHIP (ADAPTED FROM PRODUCTIVITY COMMISSION (2014B, P. 271)).

Commonwealth reimbursement for recovery is based on state government spending on eligible measures each financial year, counting only events where state government expenditure exceeds the 'small disaster criterion' (currently $240,000), however this has resulted in Commonwealth contributions to cost-sharing of up to 75% (Productivity Commission, 2014a). To be eligible, state and local governments must have adequate insurance (Department of Finance and Deregulation, 2012). Of $975 million of declared state assets Australia-wide 32% are insured (Productivity Commission, 2014b).

The Productivity Commission (2014a) criticises the entry level for reimbursement via the NDRRA as being too low, discouraging insurance and mitigation measures being undertaken by state and local government. Although the benefits of mitigation cannot be reliably quantified at present, the imbalance between mitigation and recovery payments leads the PC to recommend in an increase in Commonwealth funding to $200 million pa with equal contributions from the states.

Insurers play an important role in natural disaster management by providing households, businesses and governments with products that help to manage residual risk and finance the cost of a natural disaster. Over 1970 to 2013, nominal losses totalled $21 billion, with the bulk of that being attributed to increased exposure (Productivity Commission, 2014a), although this attribution is heavily debated (Crompton et al., 2010; Nicholls, 2011). Insurance provides a signal to policyholders about the level of risk they face, encouraging them to undertake risk reduction measures such as mitigation (Australian Treasury, 2011).

Not all public and private mitigation is currently being captured by the above estimates. State and local governments also undertake a significant amount of mitigation and resilience activities as part of broader infrastructure and service delivery activities. The range of mitigation and resilience works are diverse including: fire trail maintenance and fire hazard mitigation; identification of levees and infrastructure at risk; and studies and reviews on land planning, emergency planning and capability assessment, and flood water movements. The Victorian Government noted that '[a]cross its State Departments and Agencies, Victoria spent in excess of $3.583 billion over the period from 2002–03 to 2013–14 (an average of $298.6 million per year)' (Victorian Govt 2014, sub. 113, p. 3). Other key policy areas, such as adaptation and resilience programs, are generally not included in such estimates but do contribute to levels of risk ownership (Young et al., 2015).

Damages and loss was identified by the Productivity Commission (2014a) as being direct, indirect and intangible. However, the overwhelming majority of finance provided is for direct loss. Currently, hidden losses cannot be reliably assessed. Social and natural infrastructure and assets that fail during a natural disaster have the potential to result in significant negative externalities for society. These forms of infrastructure are not eligible for funding under the NDRRA (AG, 2012) as they are not defined as essential public assets, despite the fact these forms of infrastructure being vital to the functioning of society (e.g., Frankenberg et al., 2013).

Households and businesses are responsible for protecting their property and assets from natural disasters by either formally or informally identifying risks, undertaking mitigation actions and obtaining appropriate levels of insurance (AG, 2009). However, there is widespread agreement that under-insurance and lack of awareness about exposure to natural hazards is a significant issue. Important aspects of human welfare are unowned; for example, recent events suggest the need for greater investments in mitigation strategies for community mental health (Morrissey and Reser, 2007).

Volunteers and not-for-profit agencies contribute to pre and post natural disaster funding by reducing fiscal costs of disaster response and recovery. They also lead to higher community awareness of risks and to community resilience. The role of the community in mitigating risk to public and private assets can also be considerable by contributing to ecological resilience in landscapes through activities such as Landcare.

However, the level of donations for natural disasters is highly variable. For example, the Cyclone Larry appeal raised about $20 million compared to the Black Saturday appeal, which raised about $400 million (Latham et al., 2010). The varying success of different appeals is due to reasons such as the level of media attention, the speed of onset, the scale of the tragedy (e.g., the number of lives lost) and the type of disaster. Relief appeals also require a large injection of resources, especially if collecting donated goods (Young et al., 2015).

Recent events and potential losses of natural infrastructure, e.g., forest losses in bushfire putting a water supply out of action for an extended period, have more recently become evident, but have not been formally identified (Young et al., 2015). High value natural heritage, such as Australia's World Heritage properties, also lack comprehensive plans that can mitigate changing risks despite being very exposed (Australian National University, 2009).

The Institutional Analysis and Development Framework Laying out risk ownership a more detailed way than currently is the case, has the potential to better delineate where current arrangements are comprehensive, partial and/or disconnected (Young et al., 2015). It can also help outline imbalances between mitigation and response and recovery and potentially identify where ‘unowned’ loss and damage is occurring or may occur in the future. The differences between capital risk ownership and that defined via risk management arrangements, if reconciled, can also help to better define the rights and responsibilities between public and private institutions.

CONCLUSIONS AND NEXT STEPS

Review of pre- and post-event policies and strategies revealed ownership strengths in these areas (Young et al., 2015):

- Widespread and well-developed early and medium-term response plans for impacts on built assets and infrastructure and to a lesser extent on social assets and infrastructure.
- Growing ownership in risk planning and preparation at the state and local level, and for civil society and business and industry in designated high-risk areas for specific hazards.
- Broad ownership by civil society of overall hazard risk in terms of insurance coverage, although growing exposure increases the risk of under-insurance.

And ownership gaps in these areas:

- Mitigating risk to environmental assets and infrastructure with gaps in coverage for both built and social assets and infrastructure.
- Despite a degree of existing resilience, the contribution of resilience to the risk management process and how it can be applied is not well defined. Accountabilities also extend beyond emergency management into broader social, economic and environmental policy.
- Long-term recovery in social and environmental assets and infrastructure.

The recent review by the Productivity Commission Productivity Commission (2014a) makes recommendations for government policy with respect to improved fiscal responsibility and better accountability and transparency, especially with regard to minimising recovery costs. However, allocations for what the PC called ‘shared risks’, require the clear identification of risk ownership at the institutional scale, especially those pertaining to indirect and intangible values.

Ostrom’s Institutional Analysis and Development Framework is being adapted to address how risk ownership is being applied at the institutional scale. This is identifying the stated and implicit rules governing institutional relationships pertaining to strategic management of natural hazard risk. This is being done on a multi-risk basis, because the combination of future hazards is essentially unpredictable. Ownership arrangements therefore need to be robust, capable of dealing with a wide range of outcomes. The expansion of the concept of risk ownership to take in a broader range of values at risk is an important part of preventing loss to intangible values. In the short term, these may not appear on balance sheets, but will in the longer term if not adequately managed.

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LARGE-EDDY SIMULATIONS OF PYRO-CONVECTION AND ITS SENSITIVITY TO ENVIRONMENTAL CONDITIONS

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ABSTRACT

LARGE-EDDY SIMULATIONS OF PYRO-CONVECTION AND ITS SENSITIVITY TO ENVIRONMENTAL CONDITIONS

Intense heating by a bushfire causes air to ascend, which if deep enough can cause the formation of cumulus or cumulonimbus clouds. This moist pyro-convection can potentially have a significant impact on fire behaviour by amplifying burn and spread rates, enhancing spotting through plume intensification and igniting new fires via pyrocumulonimbus lightning. Here we use large-eddy simulations to investigate the generation of pyro-convection by bushfire plumes and the sensitivity of this pyro-convection to fire intensity and environmental moisture. Moister background atmospheres produce larger, more intense pyro-convective clouds and if the background atmosphere is moist enough, intense fires can produce pyro-convection even in the absence of any moisture from the combustion. Updrafts within the simulated pyro-convection are well in excess of the fall velocities of typical firebrands and exceed those in the cases where pyro-convection does not occur. The formation of precipitation within the most intense pyro-convective clouds leads to the development of downbursts that cause strong and highly variable winds at the surface. These strong updrafts and downbursts can have significant impacts on fire behaviour.

INTRODUCTION

Intense heating of air in the vicinity of a bushfire leads to deep ascent. If this ascent is deep enough to lift air above the lifting condensation level, cumulus or cumulonimbus clouds form in a process known as moist pyro-convection. There is abundant anecdotal evidence to suggest that pyro-convective clouds may have a significant impact on fire behaviour by (i) amplifying burn and spread rates (Fromm et al., 2006; Trentmann et al., 2006; Rosenfeld et al., 2007; Fromm et al., 2012); (ii) enhancing spotting through plume intensification (Koo et al., 2010); and (iii) igniting new fires via pyrocumulonimbus lightning, noting that pyrocumulonimbus lightning conditions favour hotter and longer-lived lightning strikes (Rudlosky and Fuelberg, 2011). Pyro-convective clouds are also responsible for the transport of smoke and other aerosols into the stratosphere, resulting in hemisphere-scale smoke distribution and substantial climate impacts (Fromm et al., 2010). Therefore a knowledge of the processes that lead to the generation of moist pyro-convection is an important component of being able to understand and predict fire behaviour, as well as the potential climatic influences of large fires.

Ideal conditions for the formation of pyro-convection are similar to ideal thunderstorm conditions, but with a dry rather than moist lower troposphere (e.g. Goens and Andrews, 1998; Trentmann et al., 2006; Rosenfeld et al., 2007; Cunningham and Reeder, 2009; Fromm et al., 2012; Johnson et al., 2014). Meteorologists assess the potential of the atmosphere to generate thunderstorms in terms of its thermodynamic profile, specifically the vertical profile of air temperature and moisture. An adjustment from a thunderstorm-friendly thermodynamic profile to a fire-friendly thermodynamic profile yields the classic inverted-V profile on a thermodynamic diagram, which is also widely recognised to favour severe weather (e.g. Beebe, 1955; Wakimoto, 1985). This profile represents a dry well-mixed lower layer over-laid by a moist middle troposphere. Profiles representative of this are present in all studies of moist pyro-convection studies that we are aware of, which suggests it may be a necessary condition for pyro-convective cloud formation. Here the dry adiabatic temperature trace forms the right side of the inverted-V, while the moisture profile, relatively dry at the surface with decreasing dew-point depression to near-saturation in the middle troposphere, makes up the left side.

The inverted-V profile also favours downburst development, when precipitation from the moist middle-troposphere evaporates as it falls through the dry layer below, extracting latent heat from the air and cooling it. If precipitation does develop in pyro-convective clouds, downbursts should therefore be expected (Rothermel, 1991). These downbursts can be very hazardous to fire crews as the winds can be gusty and intense and come from a direction completely different from the ambient flow, and in complex terrain may further accelerate down valleys causing highly unpredictable changes in fire intensity and spread, as occurred in the Dude River (Arizona, USA) fire in which six fire fighters perished, (Goens and Andrews, 1998). Moreover, downburst winds are much more difficult to predict than other common causes of wind change, increasing the danger to fire crews.

It was noted above that the heat from the fire provides the lifting mechanism to initiate cumulus formation in pyro-convection. The other necessary ingredient is sufficient moisture, which when condensed produces latent heating that enhances the plume buoyancy. There are three potential sources of moisture in a bushfire plume: (i) environmental air drawn into the fire and entrained into the plume; (ii) moisture in the fuels evaporated by the intense heat of the fire; and (iii) the moisture released as the by-product of cellulose combustion (Potter, 2005). Although moisture is known to be important for the generation of pyro-convection, there is still considerable uncertainty about the relative importance of moisture from the environment versus moisture from the fire. For example, two recent case studies are at odds: Trentmann et al. (2006) find that moisture from the fire is not important for the generation of pyro-convection, whereas Cunningham and Reeder (2009) conclude that it is essential.

In this study we use large-eddy simulations to investigate the potential for the generation of moist pyro-convection by bushfire plumes. Simulations are performed for a range of (i) fire intensities and (ii) environmental moisture levels. In cases in which pyro-convective clouds are found to form, their sensitivity to the environmental conditions is explored.

METHODOLOGY

Idealised simulations of bushfire plumes are performed using a cloud-resolving model, the UK Met Office Large-Eddy Model (LEM) described by Gray et al. (2001). The model configuration used here for simulating bushfire plumes with the LEM is described in Thurston et al. (2013), with some modifications as follows. The main change made is the inclusion of moist processes within the model, necessary for the simulation of pyro-convection. The model includes a three-phase microphysics scheme (Swann, 1998), which calculates the phase changes between the vapour, liquid and frozen water species. The domain top is also raised to 12.7 km to allow the vertical growth of pyrocumulus, which may have been restricted in our previous simulations.

The model is initialised with a potential temperature profile consisting of a 4.0 km deep well-mixed layer, of a constant value of 310 K, and a stably stratified troposphere with a gradient of 3.0 K km^{-1} above the mixed layer. The initial water vapour mixing ratio profile is specified as a constant value throughout the 4.0 km deep well-mixed layer, and is then reduced above the mixed-layer top at a rate such that the relative humidity remains constant throughout the troposphere. These conditions are representative of those associated with high fire-danger conditions: there is a deep, well-mixed boundary layer and the temperature and dew point profiles plotted on a skew-T log-p diagram together form a classic inverted-V (Figure 1). The model is initialised with no background horizontal wind, allowing us to concentrate on the effects of the thermodynamics on pyro-convective cloud formation.

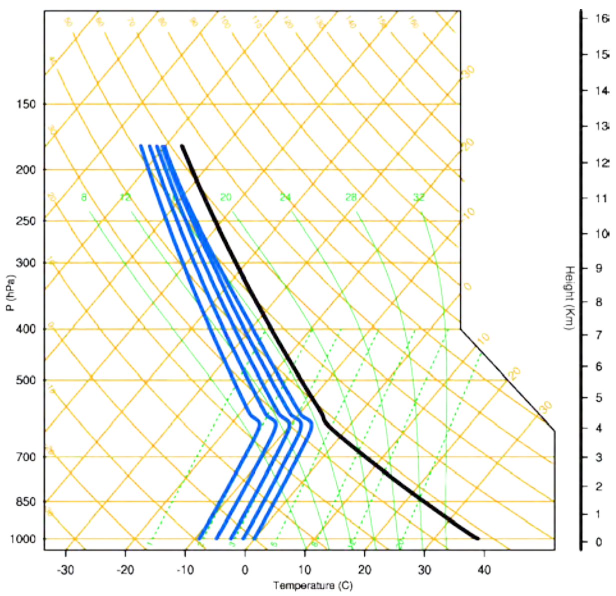

FIGURE 1: SKEW-T LOG-p DIAGRAM OF THE BACKGROUND ATMOSPHERIC CONDITIONS BEFORE THE INTENSE SURFACE HEATING IS RAMPED UP. ALL SIMULATIONS HAVE THE SAME TEMPERATURE PROFILE, SHOWN IN BLACK, AND THE FIVE DIFFERENT DEW-POINT PROFILES ARE SHOWN IN BLUE.

A range of simulations is performed here, in order to explore the sensitivity of the formation of pyro-convection to (i) the background moisture and (ii) fire intensity. Five sets of initial conditions for the simulation of bushfire plumes are created by initialising the model as described above, with five different values for the (constant) mixed-layer water vapour mixing ratio, q_v, of 2.0, 2.5, 3.0, 3.5 and 4.0 g kg^{-1}. The resultant five sets of initial conditions are shown in Figure 1. Bushfire plumes are then generated by imposing a localised intense heat flux at the model surface over a circular area of radius 250 m, centred at (x, y) = (0.0, 0.0) km. Four different fire intensities, Q, of 5, 10, 20 and 30 kW m^{-2} are simulated and in each case the heat flux is linearly ramped up from zero to its peak value over five minutes, then held constant for one hour, before being linearly ramped down back to zero over five minutes. The combination of five background moisture profiles and four bushfire intensities gives us twenty different simulations in total. In the simulations presented here there is no representation of the moisture flux from the fire, either from moisture within the fuels or from the combustion process itself.

RESULTS

Figure 2 shows a snapshot from the Q = 30 kW m^{-2} fire intensity and q_v = 4.0 g kg^{-1} boundary-layer water vapour mixing ratio simulation, 22 minutes after the fire has reached maximum intensity. This is the simulation with the moistest background conditions and the highest fire intensity. The bushfire plume has a strong updraft throughout most of the extent of the boundary layer, with a maximum vertical velocity in excess of 25 m s^{-1} (Figure 2 (a)). The plume decelerates as it penetrates into the stably stratified troposphere, but the ascent is deep enough to trigger the formation of a pyrocumulus cloud. The cloud base is located at 4.5 km above ground level (AGL) and the cloud extends to an altitude of 7.5 km AGL (Figure 2 (c)). Although the bushfire updraft core is relatively slender within the boundary layer, the horizontal extent of the pyrocumulus cloud is much greater, having a diameter in excess of 3 km (Figure 2 (d)). Extensive condensation within the cloud, notable in the liquid water mixing ratio field around (x,z) = (0.5,6.5) km, leads to the release of latent heat which is evident in the potential temperature perturbation field at the same location (Figure 2 (b)). There is a co-located updraft greater than 10 m s^{-1} within the pyrocumulus cloud, which is separated from the main plume updraft within the boundary layer. This resurgence of the updraft is due to latent heat release increasing the local plume buoyancy.

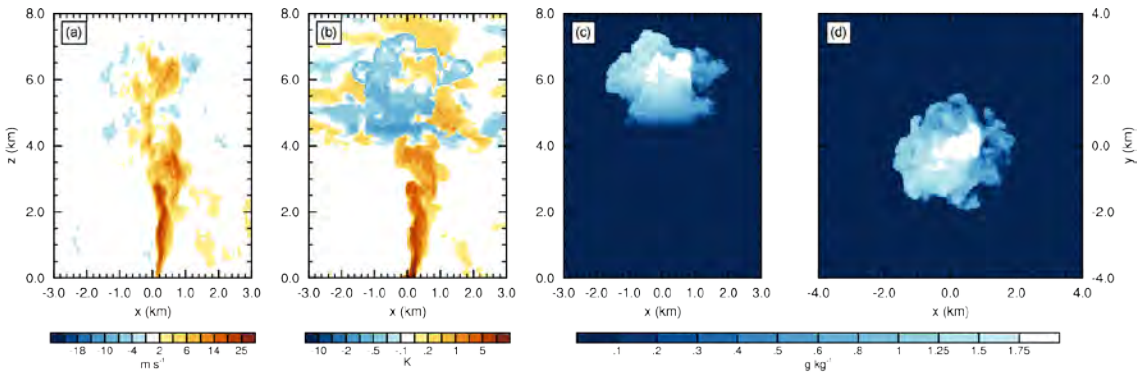

FIGURE 2: VERTICAL CROSS-SECTIONS OF THE INSTANTANEOUS (A) PLUME VERTICAL VELOCITY, M S^{-1}, AND (B) PLUME POTENTIAL TEMPERATURE PERTURBATION, K, BOTH IN THE *Y* = 0 PLANE. INSTANTANEOUS LIQUID WATER MIXING RATIO, G KG^{-1}, MAXIMUM VALUES IN THE (C) *Y*– AND (D) *Z*–DIRECTIONS. ALL PLOTS ARE SHOWN AT 22 MINUTES AFTER THE FIRE HAS REACHED FULL INTENSITY AND ARE FOR THE Q = 30 KW M^{-2} FIRE INTENSITY AND q_v = 4.0 G KG^{-1} BOUNDARY-LAYER WATER VAPOUR MIXING RATIO CASE.

The pyro-convection in this case is intense enough for substantial precipitation to begin forming approximately 22 minutes after the fire has reached maximum intensity. As the precipitation falls from the relatively moist troposphere through the warmer and drier lower levels of the atmosphere it evaporates, cooling the air. This negatively buoyant air then accelerates towards the surface in a downdraft. It should be noted that downdrafts are only found in this simulation and the Q = 30 kW m^{-2}, q_v = 3.5 g kg^{-1} simulation, in which the atmosphere is slightly drier.

Figure 3 shows vertical cross-sections at three stages of the downdraft development, positioned approximately through the centre of the downdraft and focused on the lowest 2 km of the atmosphere. When the downdraft has descended just far enough to touch the surface at 44.5 minutes after the fire has reached full intensity, Figure 3 (a), the main core of the downdraft is at about 1.2 km AGL, denoted by marker α, and has an intensity in excess of -8 m s^{-1}. A secondary, weaker, downdraft core closer to the surface is denoted by marker β at about 0.2 km AGL. At 53.5 minutes after the fire has reached full intensity, Figure 3 (b), the downburst has impacted on the surface and begun to spread out laterally in both directions as a gust front. The downdraft has split, with the core previously labelled α spreading to the left and the core previously labelled β spreading to the right. A vertical velocity couplet is visible at each leading edge of the gust front, with an updraft ahead of the leading edge and descending motion immediately behind it. These couplets are labelled γ in Figure 3 (b). At this time the downdraft core has become larger and less uniform, covering the region denoted by marker δ, with an intensity now in excess of -9 m s^{-1}. By 61.0 minutes after the fire has reached full intensity, Figure 3 (c), the downdraft is orientated slantwise and the intensity has decreased to approximately -6 m s^{-1}.

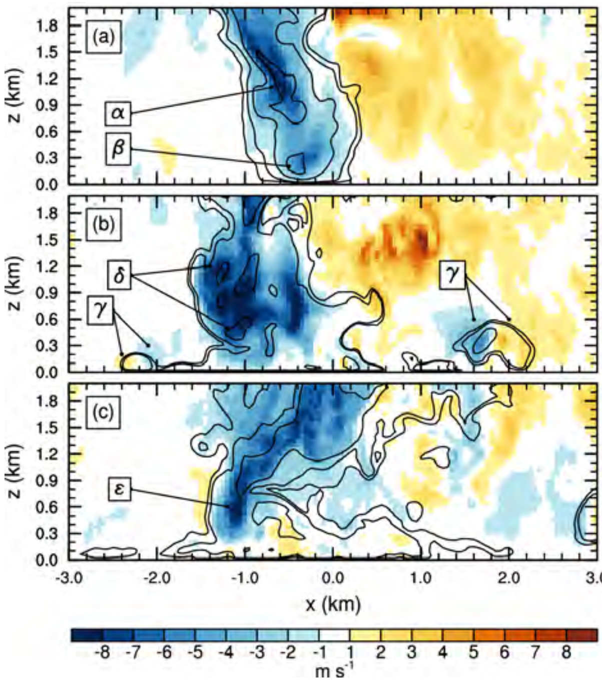

FIGURE 3: VERTICAL CROSS-SECTIONS OF THE PYRO-CONVECTIVELY GENERATED DOWNDRAFT IN THE *Y* = 0.65 KM PLANE AT (A) 44.5, (B) 53.5 AND (C) 61.0 MINUTES AFTER THE Q = 30 KW M^{-2} FIRE HAS REACHED FULL INTENSITY IN THE q_v = 4.0 G KG^{-1} BOUNDARY-LAYER WATER VAPOUR MIXING RATIO CASE. THE VERTICAL VELOCITY, M S^{-1}, IS SHOWN IN FILLED COLOUR AND THE POTENTIAL TEMPERATURE PERTURBATION CONTOUR LINES OF Θ = -0.1,-0.2,-0.5 AND -1.0 K ARE OVERLAID.

The near-surface effects of the downburst and associated gust front are illustrated by the plan views and time series of the 10-m wind speed shown in Figure 4. At 52.0 minutes after the fire has reached full intensity, Figure 4 (a), the gust front is expanding out laterally in all directions with the maximum 10-m wind speeds found in a ring around the leading edge. The gust front currently passing through the time-series location (denoted by the black diamond) originated from the core labelled by marker α in Figure 3 (a) at 44.5 minutes after the fire has reached full intensity. Four minutes later a s econd downdraft core has impacted upon the surface and begun to spread as a gust front laterally through the time-series location with a peak wind speed in excess of 11 m s^{-1} (40 km h^{-1}), Figure 4 (b), followed just two minutes later by a third gust front, Figure 4 (c). The origin of these two gust fronts is hard to separate and they both come from the region labelled by marker δ in Figure 3 (b). Gust fronts continue to pass through the time-series location (e.g. Figure 4 (d) but they begin to become less coherent. The time-series plot, Figure 4 (e), clearly illustrates the intensity and the large variability of the near-surface wind wind speeds as each gust front passes through the time-series location. Six gusts in excess of 8 m s^{-1} (29 km h^{-1}), separated by calmer conditions, occur in the space of about 15 minutes.

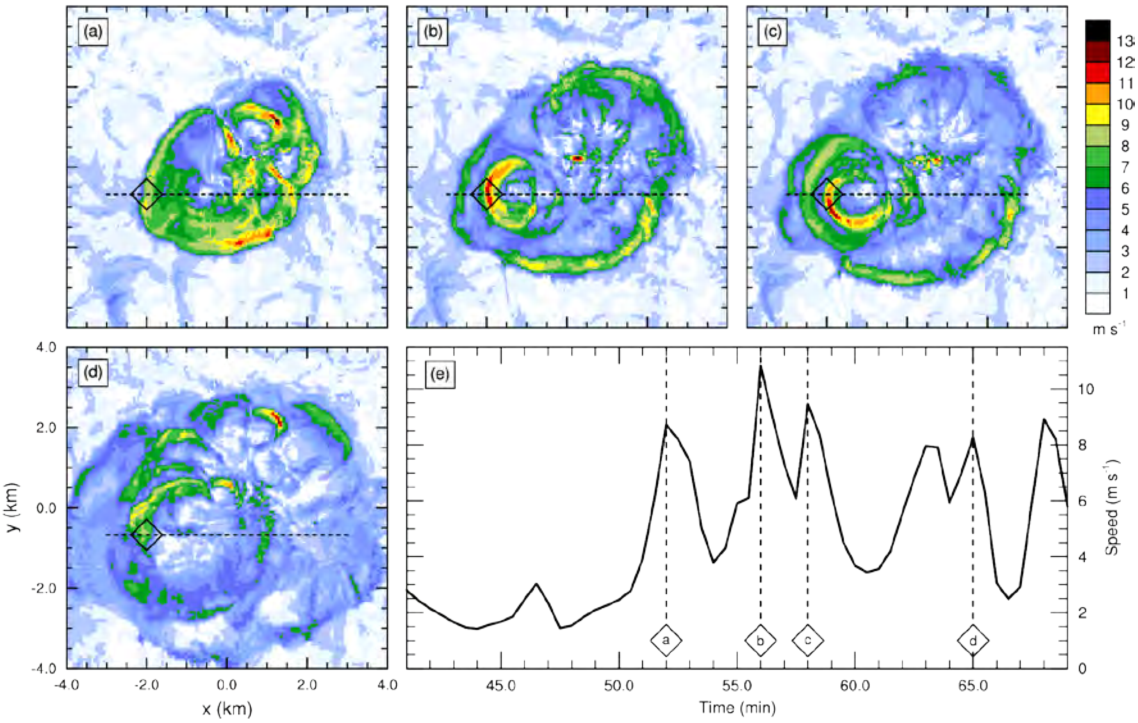

FIGURE 4: PLAN VIEWS OF THE INSTANTANEOUS 10-M WIND SPEED, M S^{-1}, AT (A) 52, (B) 56, (C) 58 AND (D) 65 MINUTES AFTER THE Q = 30 KW M^{-2} FIRE HAS REACHED FULL INTENSITY IN THE q_v = 4.0 G KG^{-1} BOUNDARY-LAYER WATER VAPOUR MIXING RATIO CASE. THE BLACK DIAMOND OVERLAID ON EACH OF THE PANELS (A)–(D) DENOTES THE LOCATION OF THE 10-M WIND SPEED TIME SERIES, M S^{-1}, SHOWN IN PANEL (E) AND THE HORIZONTAL DASHED LINE DENOTES THE LOCATION OF THE VERTICAL CROSS-SECTIONS SHOWN IN FIGURE 3.

Figure 5 shows a snapshot of the liquid water mixing ratio vertical cross-sections for all twenty combinations of Q and q_v, at 22 minutes after the fires have reached full intensity. The potential formation of a pyrocumulus cloud and the properties of that cloud are dependent on both the intensity of the fire and the environmental moisture. Pyrocumulus is more likely to form if the environment is moist and the fire intensity is high. The size of a pyrocumulus and its cloud top height both increase with environmental moisture and fire intensity. In the driest environment, with a boundary-layer water vapour mixing ratio of 2.0 g kg^{-1}, pyrocumulus only forms for the most intense fire and the cloud that does form is very small. As the environmental moisture increases, pyrocumulus forms for weaker and weaker fire intensity, and by the time the boundary-layer water vapour mixing ratio reaches the maximum value of 4.0 g kg^{-1}, pyrocumulus forms for all values of fire intensity. For a fixed fire intensity, increasing the boundary-layer water vapour mixing ratio lowers the cloud-base height, from 5.7 km AGL for the driest to 4.5 km AGL for the moistest. Conversely for a fixed boundary-layer water vapour mixing ratio, increasing the fire intensity does not substantially affect cloud-base height.

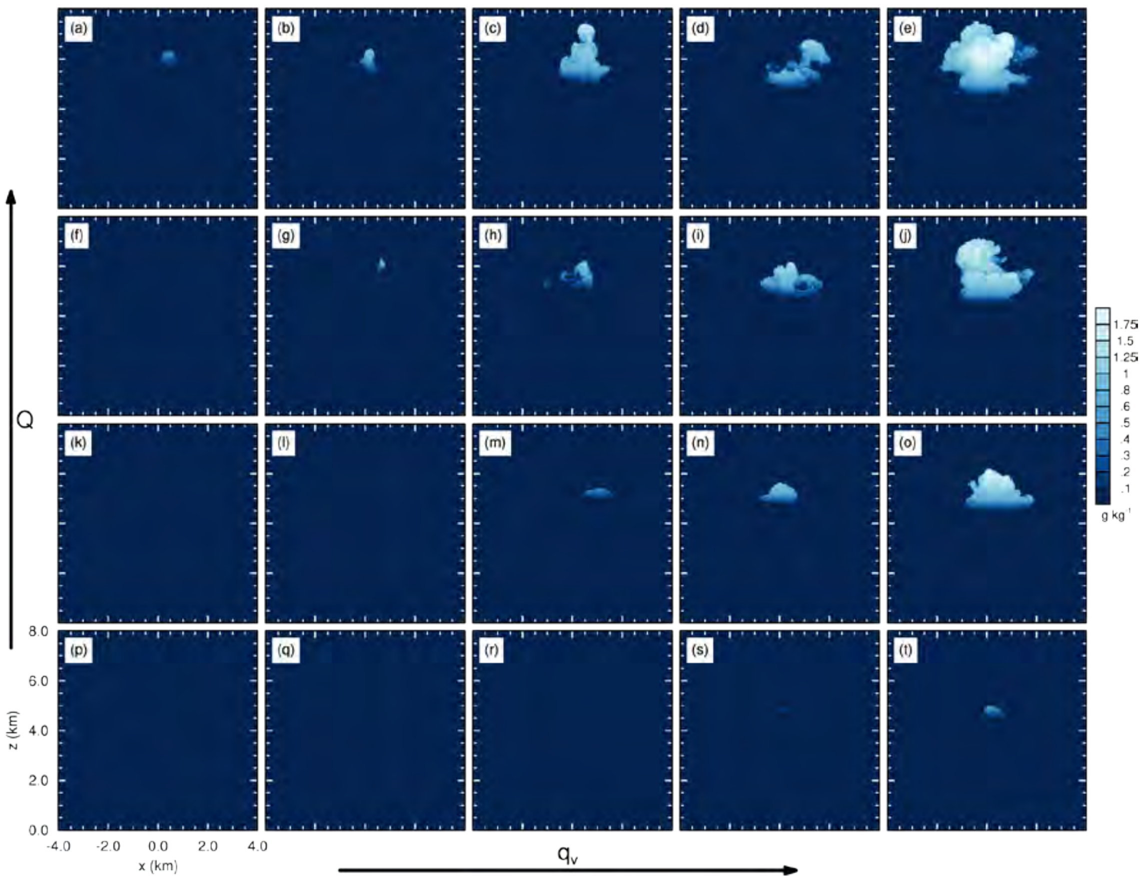

FIGURE 5: VERTICAL CROSS-SECTIONS OF THE MAXIMUM INSTANTANEOUS LIQUID WATER MIXING RATIO IN THE Y–DIRECTION, G KG^{-1}, AT 22 MINUTES AFTER THE FIRES HAVE REACHED FULL INTENSITY. PANELS SHOW ALL TWENTY COMBINATIONS OF FIRE INTENSITY, Q = (5,10,20,30) KW M^{-2}, ARRANGED VERTICALLY AND BOUNDARY-LAYER WATER VAPOUR MIXING RATIO, q_v = (2.0, 2.5, 3.0, 3.5, 4.0) G KG^{-1}, ARRANGED HORIZONTALLY. FIRE INTENSITY INCREASES FROM THE BOTTOM ROW OF PANELS TO THE TOP ROW OF PANELS AND BOUNDARY-LAYER WATER VAPOUR MIXING RATIO INCREASES FROM THE LEFT-HAND COLUMN OF PANELS TO THE RIGHT-HAND COLUMN OF PANELS, AS INDICATED BY THE ARROWS.

SUMMARY AND DISCUSSION

Large-eddy simulations of bushfire plumes have been performed in background atmospheric conditions representative of high fire-danger days. The potential for the formation of pyro-convection has been investigated by varying the environmental moisture and the fire intensity. Intense fires in moist atmospheres formed larger pyrocumulus than weak fires in dry atmospheres, which in some cases formed no pyrocumulus at all. Increasing the environmental moisture reduced the cloud-base height, whereas increasing the fire intensity had no discernible effect on cloud-base height. The pyro-convection generated by the most intense fire and in the moistest environmental conditions was strong enough for the formation of substantial precipitation, which subsequently led to the formation of evaporatively-cooled downdrafts. As the downdrafts impacted upon the surface they spread laterally as a series of concentric gust fronts, with peak 10-m wind speeds in excess of 11 m s^{-1} found in the strongest gust front.

There are two mechanisms identifiable in these simulations through which pyro-convection has potential to have a significant impact of fire behaviour. Firstly, the resurgence of the plume updraft due to the latent heat released within a pyrocumulus has the potential to increase the height to which firebrands are lofted, particularly as the pyrocumulus updrafts are in excess of 10 m s^{-1}, considerably greater than the fall velocity of typical firebrands of 4–6 m s^{-1} (e.g. Ellis, 2010). Lofting the firebrands higher into the atmosphere has the potential to then increase the distance they travel before landing, although detailed calculations similar to those performed by Thurston et al. (2014) would need to be performed to accurately assess the potential impact of pyro-convection on spotting distance. Secondly, the formation of downdrafts and their associated gust fronts has implications for the surface-based fire spread. The sudden increase in wind speed as the gust front passes will increase burn and spread rates, but there is also a l arge amount of speed and direction variability associated with the downburst. The downburst is seen to comprise multiple cores impacting the surface, resulting in many gust fronts spreading out in concentric rings. This variability is not captured within the traditional conceptual model of a pool of cold air descending then spreading out radially and means that if fire fighters on the ground experience the passage of a gust front, they should be prepared for gusty variable conditions to continue for some time. In the case presented here six surface gusts in excess of 8 m s^{-1}, all separated by calmer conditions, were experienced over the space of 15 minutes. Although we are currently unable to forecast the precise location and timing of an individual pyro-convective updraft or downburst, by performing studies such as this we are able to learn about the conditions under which they form, their dynamics and potential impact on fire behaviour. Future work will use a similar framework to systematically explore the relative importance of moisture from the environment and moisture released in the combustion process for the generation on pyro-convective clouds.

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We thank the UK Met Office for the provision of their Large Eddy Model code. Andrew Dowdy, Chris Lucas and two anonymous reviewers are thanked for their comments on an earlier version of this manuscript. This research was undertaken with the assistance of resources from the National Computational Infrastructure (NCI), which is supported by the Australian Government.

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AN EARTHQUAKE LOSS SCENARIO FOR ADELAIDE

Research proceedings from the Bushfire and Natural Hazards CRC & AFAC conference
Adelaide, 1-3 September 2015

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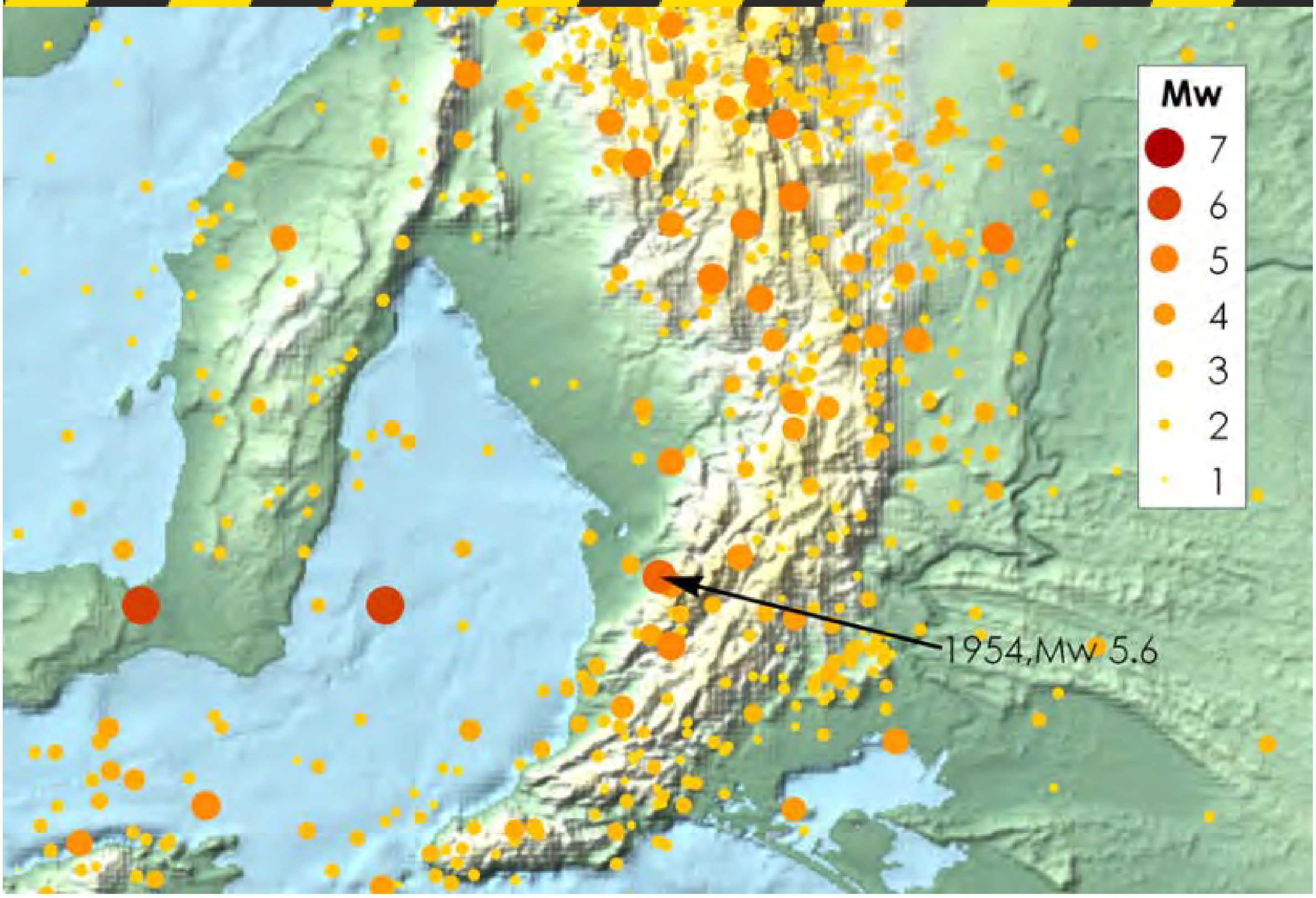
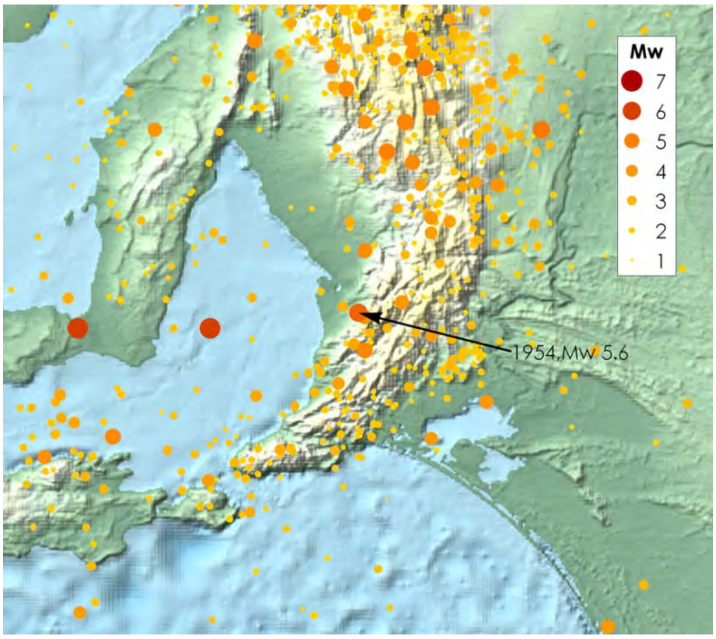
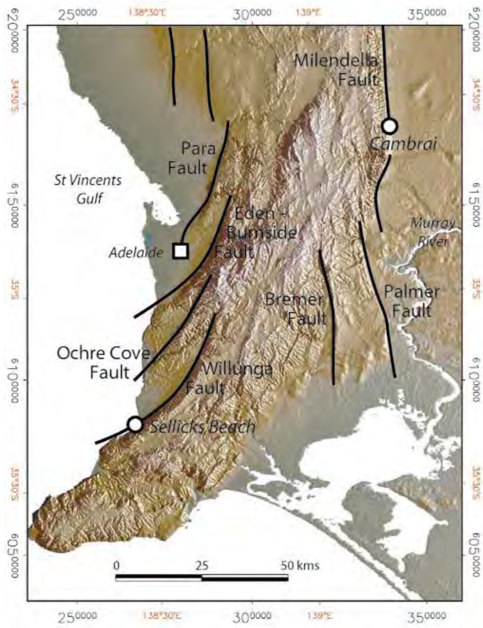


INTRODUCTION

Despite its low seismic activity, Australia is more vulnerable to earthquakes than one would expect due to the concentration of population and the large stock of buildings which are structurally unable to withstand even moderate seismic shaking. This was demonstrated by the 1989 M5.6 Newcastle earthquake, one of the costliest natural disasters in Australia, despite its low magnitude. One question elicited by these circumstances is: what would happen if one of Australia's main cities were hit by an earthquake similar to the Newcastle earthquake? An example of a near miss is the 1954 M5.6 Adelaide earthquake, whose epicentre, far from developed areas at the time, would lie in densely developed areas were it to occur today. Providing realistic estimates for natural disaster scenarios is essential for emergency managers. A systematic approach to developing such scenarios can reveal blind spots and vulnerabilities in planning.



(a) Historically recorded earthquakes (1840- present), source Geoscience Australia.



(b) Active faults, from Sandiford [2003]

Figure 1: Scenario's selection information.

The Adelaide region is undergoing active tectonic deformation caused by earthquakes occurring on a system of prominent active thrust faults that are oriented approximately north-south and are uplifting the Mount Lofty and Flinders Ranges. The earthquakes are caused by high horizontal compressional stresses oriented in the east-west direction. The largest historical earthquake to have occurred in Adelaide is the March 1, 1954 Mw 5.6 earthquake, which is thought to have occurred on the Eden-Burnside fault that lies just east of Adelaide (Figure 1a). The Para fault is located directly beneath the Adelaide CBD (Figure 1b). The largest earthquakes that can occur on these faults have magnitudes that are thought to lie in the range of 7.0 to 7.5, but earthquakes that large would have notional recurrence intervals of tens of thousands of years [Clark and McPherson, 2011]. Earthquakes as large as magnitude 6 are estimated to have recurrence intervals of about 1,000 years. Earthquakes with return intervals of 500 years, which form the basis of the seismic provisions for the building code [Standards Australia, 2007], have magnitudes of about 5.5. Smaller earthquakes also occur in a distributed manner throughout the region, not only on the identified active faults. Figure 1a shows the epicentres of the historically recorded earthquakes in the Adelaide region from 1840 until present days.

The event we consider is a M6 occurring on the Para Fault, with an epicentre about 7 km from Adelaide CBD, generating peak ground accelerations in the range 0.3 – 0.4 times the acceleration of gravity (0.3g-0.4g) in the CBD. Figure 2 shows the location of the epicentre.

Figure 2: Epicentre location.

METHODOLOGY

We estimate the probable ground motion level for the chosen event using the ground motion prediction equations developed by Somerville et al. [2013] and the soil condition maps from McPherson and Hall [2006].

The calculation of losses is performed with the methodology developed by the US Federal Emergency Management Agency (FEMA) through its model HAZUS [FEMA, 2004]. The HAZUS methodology provides functional relationships between physical earthquake parameters and probability distribution of building or infrastructure response to shaking and therefore damage. The HAZUS methodology also provides estimates of the number of casualties. These estimates take into consideration the probability that a structure will collapse, the spatial distribution of people at different times of the day, and the likelihood of a person being indoors or outdoors at the time of the earthquake.

The methodology provided by HAZUS entails a high degree of uncertainty since many factors determining the outcome of an earthquake cannot be modelled a priori. For example, the time of day plays an important role in determining human casualties: the 2007 Gisborne earthquake hit at 8:55pm resulting in no direct casualties, despite many parapets falling in footpaths across the town (see section 2 of AEE [2008]).

To estimate the damage (material, financial and casualties) caused by the earthquake we use the exposure datasets summarised in table 1.

Table 1: Datasets used in the modelling.

Population Distribution	We perform an analysis of the **2011 Census** and statistics provided by the **Department of Higher Education**. We estimate the population distribution at two different times of a mid-week day, 2.00 AM (Night time scenario) and 2.00 PM (Day time scenario). These scenarios are expected to generate the highest casualties for the population at home and the population at work/school, respectively. Figure 4 shows the estimated population density during the day and at night time.
General Building Stock	From the National Exposure Information System (**NEXIS**) database, aggregated at the SA2 level, and the Geocoded National Address File (**G-NAF**) database. Figure 3 shows the G-NAF addresses locations, the black dots, and the SA2 areas on which the NEXIS information is available, the coloured polygons.
Critical Infrastructure Inventory	From the **RoadNet** (Map Data Services) and **Features of Interest** (PSMA) databases.

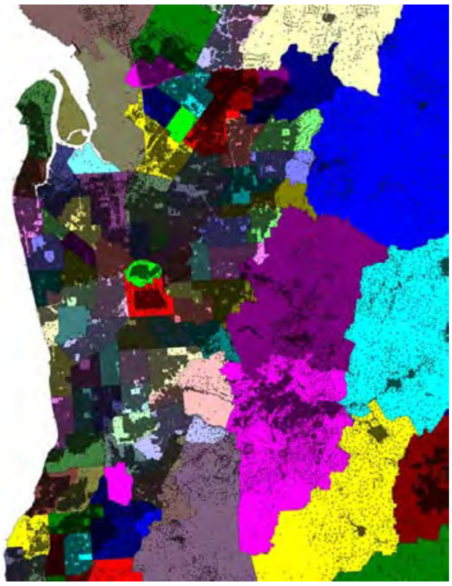
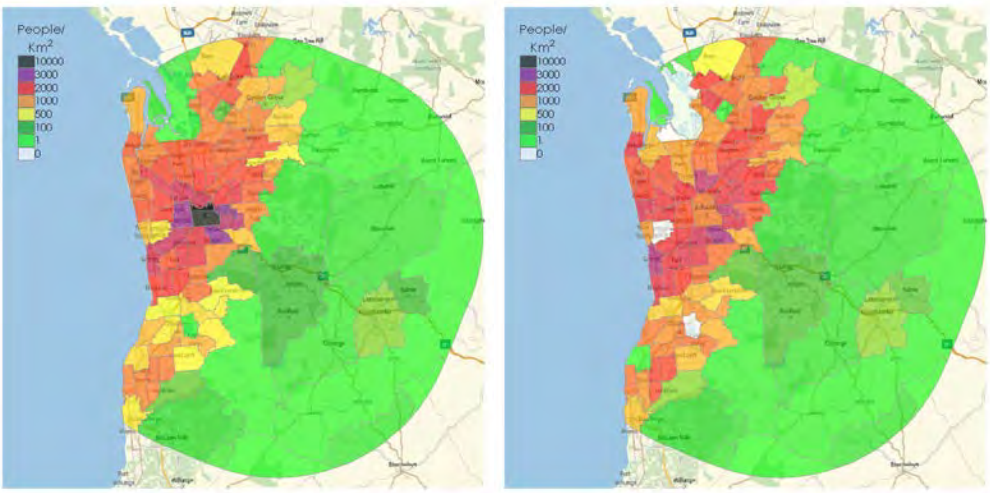


Figure 3: Buildings exposure data. Black dots: G-NAF addresses. Coloured polygons: SA2 areas.



(A) Day Time. (B) Night Time

Figure 4: Population Density within 25km from the epicentre

HAZARD MODELING

We model the event (Figure 2) as a rupturing fault plane. The top centre of the fault plane is placed 7 km ESE of the surface trace of the Para fault at a depth of 7 km on a 45 degrees fault dipping at 45 degrees to the ESE. Fault dimensions are consistent with Leonard [2010] and Somerville et al. [2013].

GROUND SHAKING

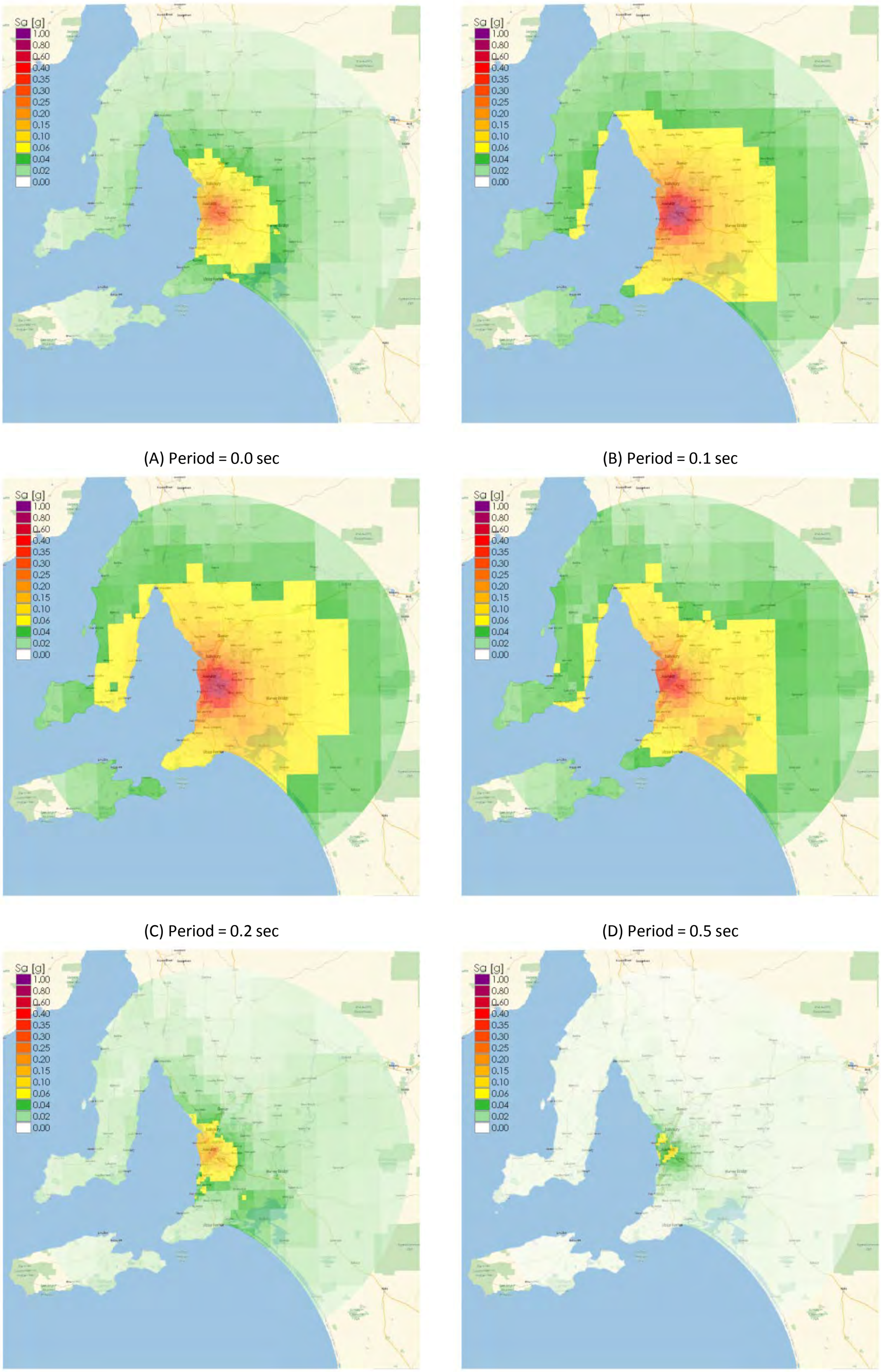
The probable (median) ground motion level for the chosen event is calculated using the ground motion prediction equations developed by Somerville et al. [2013] and the soil condition maps from McPherson and Hall [2006]. We calculate the full demand spectrum for each location.

Figure 5 shows spectral acceleration at all the affected locations for a range of periods.

GROUND DISPLACEMENT

The likelihood of experiencing ground displacement due to liquefaction at a specific location is primarily influenced by soil type, ground shaking intensity and duration, and depth of groundwater.

Liquefaction damage was one of the main causes of destruction in the Christchurch 2010 event, affecting transportation and water networks. We have produced a liquefaction potential map for Adelaide by using a statistical model that uses distance to water bodies, elevation, soil type and ground shaking to parameterize the probability that a site will liquefy, [Knudsen et al., 2009]. For this scenario, liquefaction would likely occur around the banks of the Torrens river and of the creeks on the south-east of the CBD, and could potentially destroy a number of bridges. Combined with shaking, liquefaction damage may render parts of Adelaide inaccessible for large extents of time and cause long term infrastructure damage. Figure 6 shows an overlay of the Adelaide road network and the liquefaction potential map.



(A) Period = 0.0 sec

(B) Period = 0.1 sec

(C) Period = 0.2 sec

(D) Period = 0.5 sec

(E) Period = 1.0 sec

(F) Period = 2.0 sec

Figure 5: spectral acceleration [g] at different periods.

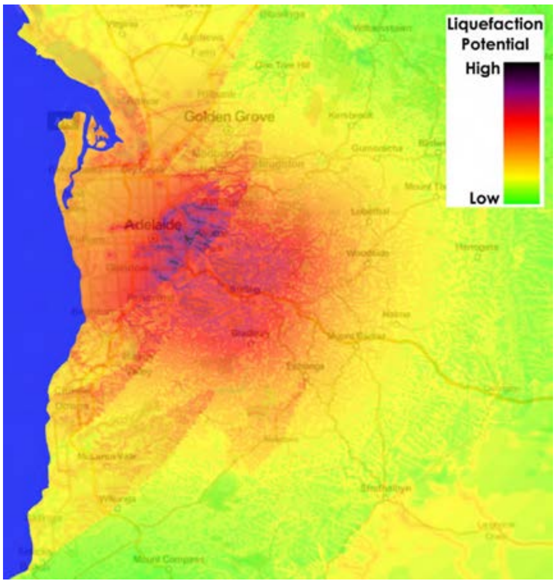


Figure 6: Liquefaction potential map for Adelaide. Hot colours represent areas with higher probability of liquefaction.

IMPACT MODELING

The estimate of the count of casualties and damage to buildings and infrastructure is performed following the HAZUS methodology, FEMA [2004]. It should be kept in mind that HAZUS results are subject to a high degree of uncertainty because of the large number of factors that cannot be modelled. Moreover, HAZUS does not take into account related costs, such as labour and demand surge, nor takes into consideration the inter-relationships between different infrastructures.

To create a realistic scenario, therefore, it is desirable to make also use of information from events that occurred in areas of similar demography, construction practices and cultural background. The modelled results are therefore compared and integrated with observation from recent similar events.

Australia has low seismic activity so our historical experience is limited. Christchurch (New Zealand) on the other hand, has recently been devastated by a series of earthquakes. Given the similarities between New Zealand and Australia, we can use observations from damage assessment field work done following the Christchurch event to hypothesize a realistic scenario for the Adelaide region. This experience also allows us to draw important conclusions, in particular for impacts not covered by models, such as damage to infrastructure, social impacts, unforeseen consequences and long term impacts. It should be kept in mind that the transferability from the Christchurch experience to a possible earthquake scenario in Adelaide is limited to the older Christchurch structures that have not been seismically retrofitted.

We also use the experience obtained from the 1989 Newcastle earthquake, which is third most expensive natural disaster in Australia, in terms of insured losses when normalised to current societal conditions, [Crompton, 2011].

The earthquake that hit Adelaide in 1954 occurred in the vicinity of the chosen scenario event. There is however little information we can gather from it as the available records of the sustained damage is limited and the socio-economic condition as well as the physical extent of the urban area have changed dramatically in the last 60 years.

BUILDING DAMAGE

The demand spectrum earlier described is applied, via the capacity spectrum method described in HAZUS, FEMA [2004], to each building category present in the location according to NEXIS. This allows the evaluation of the structural response of every particular building to each particular demand spectrum. We then use the vulnerability curves provided by HAZUS which best match the NEXIS building categories to estimate the probable damage to the buildings. Figures 7 and 8 show the extent of the damage to residential addresses. Table 2 summarise the Number of Equivalent Addresses Destroyed (Count of Replacement Values) for the whole area.

Table 2: Number of equivalent addresses destroyed.

Line of Business	Number of Addresses
Residential	88,440
Commercial	4,815
Industrial	1,650

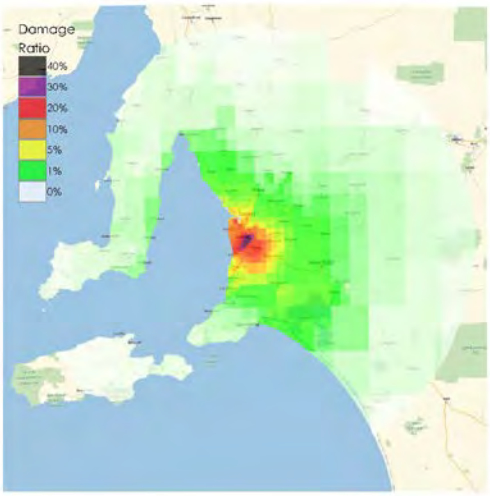


Figure 7: Residential Damage: Percentage of Replacement Value of the local Buildings' Stock.

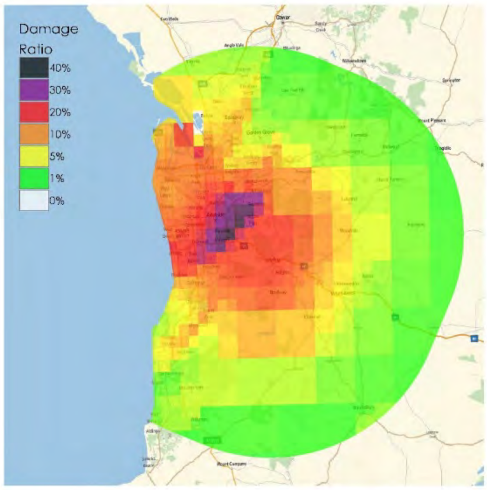


Figure 8: Residential Damage: Percentage of Replacement Value of the local Buildings' Stock. Within 30km of the Epicentre.

CASUALTIES

The damage states probabilities for the building stock are used in conjunction with the estimated population distribution to calculate casualties. The output from the HAZUS model is given on a four level injury severity scale, table 3.

Table 3: Injury severity scale

Severity	Description
1	Injuries requiring basic medical aid that could be administered by para-professionals. Injuries that could be self-treated are not considered.
2	Injuries requiring a greater degree of medical care and use of medical technology such as x-rays or surgery, but not expected to progress to a life threatening status.
3	Injuries that pose an immediate life threatening condition if not treated adequately and expeditiously.
4	Instantaneously killed or mortally injured.

Figure 9 shows the median spatial distribution of severe injuries and deaths (sum of severity 3 and 4) to be expected from the modelled event while table 4 summarises the total counts for all the severity levels.

Table 4: Median total casualties by severity level and time of the day (Number of People).

Severity	Day	Night
1	4,988	5,324
2	1,532	1,650
3	170	167
4	322	327

ESSENTIAL FACILITIES

Essential facilities comprise hospitals, fire and police stations, emergency operation centres and schools – all are essential to provide support in the event of an earthquake (schools provide evacuation centres). Such buildings are designed to withstand higher levels of shaking than ordinary buildings.

It is expected that hospitals should continue to operate even in the event of failures in the power and water networks. Using the appropriate HAZUS methodology, we have estimated a loss of capacity in the area near the epicentre of up to 22%, and up to 14% in the area encompassing the Adelaide CBD, which includes the Royal Adelaide Hospital. Figure 10 maps the loss of capacity overlaid with hospitals, police, fire and SES stations, and ambulance centres. It is estimated that the 7 hospitals nearest to the fault will experience a damage of 20% and around 80 will experience damage on the order of 5%. Some hospitals may have to interrupt their functioning for safety reasons; others may sustain extensive or even complete damage.

Schools are expected to experience similar rates of damage as hospitals, but these facilities are likely to lack the capacity to generate their own power; thus we expect that only those far from the epicentre will be usable as temporary shelter. In Table 5 we show the number of facilities expected to experience sufficient damage to hinder their operations (i.e. > 10%).

Table 5: Number of essential facilities expected to experience damage in excess of 10%

Facility	Number
Hospitals	46
Schools	167
Fire Stations	5
Police Stations	5
SES Stations	1
Ambulance Stations	3

INFRASTRUCTURE

Damage was estimated using ground motion parameters shown in Figure 5a and 5e, where areas referred to as “near the epicentre” correspond approximately to the Red-to-Yellow coloured region in Figure 5a. The methodology does not take into account work or replacement materials shortage and should be seen as an estimate of the amount of work without considering the inter-relationships between downtimes from different infrastructures. Tables 6 to 9 summarise the expected damage from modelling and review of past similar events.

Table 6: Transport Damage

Roads	• At this level of ground shaking (in the absence of liquefaction) roads are not directly considerably affected • Roads may be blocked as a consequence of debris from fallen buildings. • Roads may also be shut where there is the potential for surrounding building to fail during aftershocks, even if no debris have yet fallen. • As a result, and as observed in Christchurch, areas of the CBD may be cordoned off for a minimum of 7 days following the event.
Bridges and tunnels	• In the absence of liquefaction, bridges may be closed for a day to a week for inspection and repairs of moderate damage. • Near the epicentre, a small number of bridges could experience extensive to complete damage and take a minimum of 150 days to be completely restored. • Liquefaction may cause damage to bridges at locations indicated with hot colours in Figure 6.
Trams and trains	• At this ground shaking level (in the absence of liquefaction) there is no significant proportion of railway lines completely damaged. • However, some rail and light rail bridges close to the epicentre may be extensively damaged and take a minimum of 110 days to be repaired. • A greater proportion (40%) of railway and tram lines close to the epicentre will experience minor damage, which corresponds to a downtime of 2 to 7 days but may be longer depending on ground rupture patterns. • The fuel and maintenance facilities for this infrastructure located in the proximity of the epicentre will mostly suffer minor to moderate damage, which may add 2 to 7 days to the downtime. • The fuel and maintenance facilities in the neighbourhood of the epicentre will also have a 40% chance to suffer extensive damage, with associated downtimes of up to 4 months.
Airports	• Adelaide airport is situated around 10 km from the epicentre of this scenario and is situated on soft soil which is prone to liquefaction. • Airports are usually well built and are expected to perform reasonably well. However, as observed in Christchurch, airports are expected to be closed for a short period of time for damage assessment, Giovinazzi et al. [2011].

Table 7: Electricity Damage. The scenario described below is consistent with historical experience in Christchurch (2010), Giovinazzi et al. [2011], and Newcastle (1989), Caldwell [2009].

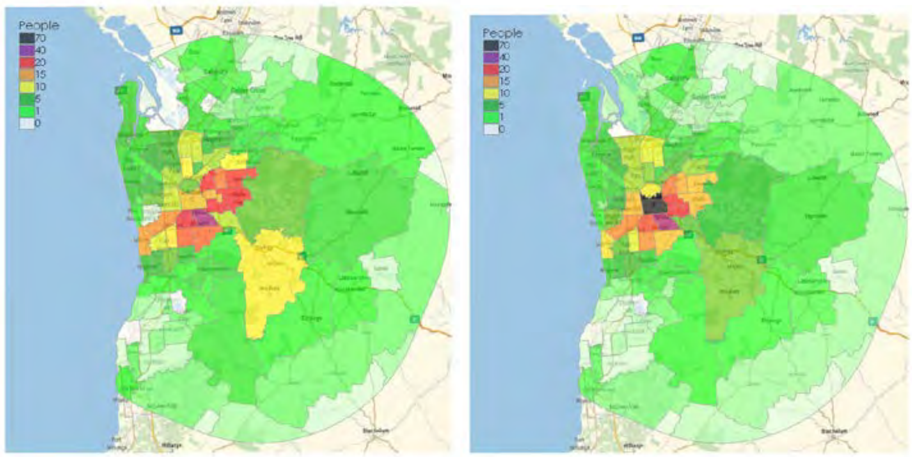
Transformers & Substations	• The complete failure of large power components, such as transformers or substations, may occur in the proximity of the epicentre with a probability of around 40%, and downtime of approximately two months. • According to the HAZUS model, almost all addresses close to the epicentre will experience at least minor power failures with downtimes of up to 3 days (if no nearby substation is completely damaged), see Figure 11.
Power Stations	• Some power stations, close enough to the epicentre to sustain some slight or moderate damage will take a month or longer to fully recover, see Figure 12.

Table 8: Fresh and Waste water. The modelling results are supported by the experience in Christchurch, Giovinazzi et al. [2011].

Water supply	• Major water facilities such as pumping stations and reservoirs may experience extensive damage with a probability of 15%, which implies a downtime of 40 days. • Minor damage may occur across the network, with a downtime of 3 days (if no major system was completely damaged). • In case of liquefaction, breakage of pipes is likely to be widespread in the hot coloured regions in Figure 6, and concerns over contamination may render the water not suitable to drinking.
Waste water	• Extensive damage is modelled to occur in 25% of waste water systems near the epicentre even without the occurrence of liquefaction; addresses within this zone may be without sewage services for up to 150 days.

Table 9: Communication Damage. For a description of the Christchurch experience see Fenwick [2011].

Disruption	• Most of the area near the epicentre will experience minor to moderate damage with downtimes ranging from less than 1 day to a week.
Major facilities	• About 30% of the major facilities (central offices and broadcast stations) located in the area near the epicentre will experience extensive damage with associated downtimes of up to a month.



(A) Day Time. (B) Night Time.

Figure 9: Severe Injuries and Deaths within 25km from the epicentre.

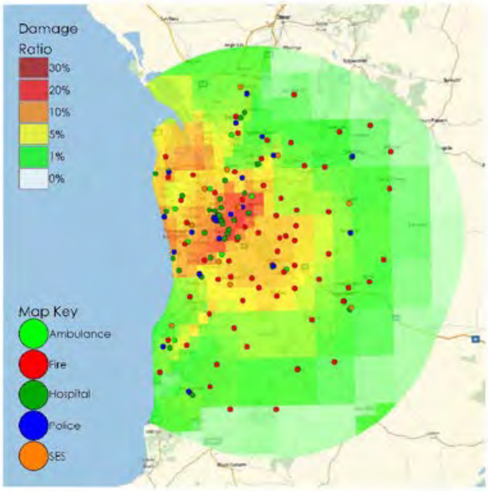


Figure 10: Damage Ratio to essential facilities.

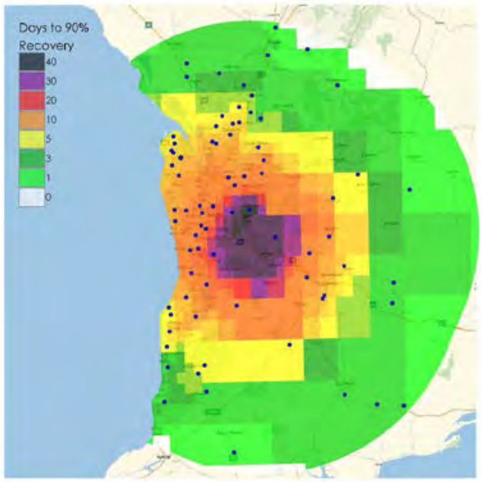


Figure 11: Estimated Number of Days to reach 90% of the Substations' functionality. The Blue Dots indicate the Substations' locations.

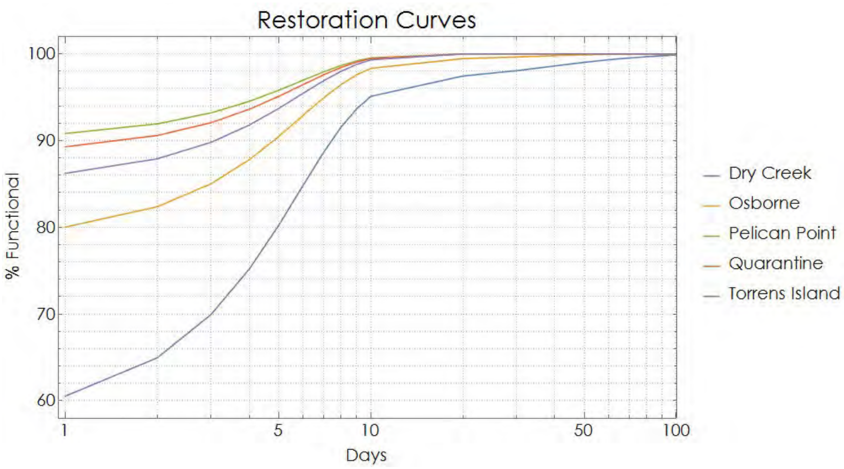


Figure 12: Restoration Curves for some of the power stations near the epicentre.

UNFORSEEN IMPACTS

There are a number of issues that we are not able to model but need to be taken into account when investigating a possible earthquake scenario. Table 10 summarizes the main aspects to consider.

Table 10: Unforeseen Impacts

Chemical and high risk industrial plants	• These are usually located away from residential zones. • High risk facilities should be designed for increased resilience to earthquake damage, thus the probability of an accident induced by an earthquake is classified as low. • If, however, there were damage, it would be such as in the 1998 Longford gas explosion in Victoria, Gippsland (Wikipedia [2015b]).
Hazardous material release	• Hazardous materials are not exclusive to heavy industry and may be released as a consequence of building collapse. • These may include carcinogenic or corrosive gases, poisonous liquids that contaminate the water table. • Asbestos was used in Australia from the 1950's until 2003 when it was banned and may be exposed as a result of earthquake building damage in an earthquake. • Irrespective of the risk, it will impose large clean-up costs and require the cordoning of many properties.
Fire following earthquake	• Fire following earthquake has caused extensive damage in the past (San Francisco, 1906 and Tokyo, 1923). • Extensive fire following earthquake damage is less common in present times, and will likely be localized to high risk sites as was the case for the Cosmo Oil Company fire following the 2011 Tohoku earthquake in Chiba, Japan.
Long series of strong aftershocks	• The Christchurch event was notable for its unusual frequency of aftershocks. The most damaging event (M6.3 Lyttelton) occurred as an aftershock of the original event (M7 Darfield) 4 months earlier. • An even more unusual earthquake sequence occurred in Australia: during the period 1883-1892 around 2000 earthquakes occurred off the NE coast of Tasmania (Marion [1987]). • The three largest events, in July 1884, May 1885 and January 1892, had estimated magnitudes of 6.3, 6.6 and 6.9. • The earthquake sequence in Christchurch moved away from the city only one year after the main event, and even its short duration compared with the 1883-1892 Tasmanian sequence has posed a serious challenge to the recovery of the Christchurch CBD. • If an earthquake sequence like the Tasmania sequence occurred near Adelaide it would probably result in a decrease in population and economic importance of the city as businesses migrated to safer areas. The results of such scenario would be devastating for Australia as has been the case for New Zealand.

CONCLUSIONS

Although the earthquake hazard in Australia is low compared to neighbouring countries, the risk to people and build environment is relatively high because of the concentration of population and the large stock of buildings structurally unable to withstand even moderate seismic shaking. The 1989 Newcastle earthquake, ranking as the third most expensive natural disaster in Australia, [Crompton, 2011], being a clear example.

In this report, we present a scenario of potential impacts of a magnitude 6.0 earthquake on the Para fault near Adelaide, SA, with the objective to help emergency managers to:

- visualise potential impacts before disasters happen
- better understand the implications of catastrophic events beyond recent experience, and
- reveal blind spots and vulnerabilities in strategic planning.

The hazard is represented by the response spectrum of a quake at a given location, and provides indication of building response to ground motion; it was simulated using the ground motion prediction equations developed by Somerville et al. [2013] and the soil condition maps from McPherson and Hall [2006]. Expected casualties and impact on buildings, essential facilities and critical infrastructures have been estimated using the HAZUS methodology, FEMA [2004]. We compared and complemented these results with experience from past similar events.

The analysis pictures a potentially devastating scenario for the population and the economy of Adelaide. It should serve as a tool for emergency managers to reason about an event that is beyond the recent experience but has a reasonable possibility to happen in the future and help them plan for such a dreadful occasion.

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NON-PEER REVIEWED EXTENDED ABSTRACTS

bushfire&natural HAZARDSCRC

"WE'VE GOT TROUBLE GETTING AROUND BUT WE'RE STILL ALRIGHT": DISABILITY IDENTITIES AND THE IMPLICATIONS FOR BUSHFIRE PLANNING

Research proceedings from the Bushfire and Natural Hazards CRC & AFAC conference
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ABSTRACT

Physical disability and illness are significant risk factors in natural disasters. In the 2009 Victorian bushfires, of those who died, 24 per cent had chronic health conditions and 5 per cent had acute disabilities (VCOSS 2014). Globally, mortality rates for people with a physical disability are up to four times higher than the able-bodied population (UNISDR, 2013). In the Great East Japan Earthquake the estimated mortality rate for people with disabilities was double that for the abled population (2.06%) and this was even higher in the provinces along the coast and for people with hearing disabilities (Fuji, 2012).

A physical disability can impact on both planning and preparation for natural disasters like bushfires. McLennan, Elliott & Beatson (2010), in a survey of 584 households at risk of bushfire, found that of 74 people who identified living in a household with a disabled member, 39 planned to leave before a bushfire begins to threaten where they live. However, 7 planned to stay and defend, and 28 planned to wait and see. Wait and see is the most dangerous option. Most people who plan to wait and see have in mind that they will evacuate. However, there are very few safe options to leave once a fire comes. The greatest number of fatalities occur when people leave their property at the last minute (Handmer, O'Neill & Killalea, 2010).

Kimpton (2012) found that 45 of the 55 people in the Yarra region of Victoria who identified as disabled or frail did not have a bushfire plan. They were concerned about their ability to maintain their property as bushfire ready, however most saw the cost of relocation on a fixed income as more of a burden than fire risk. Rosenbaum, Goodman & Rhodes (2008), in their qualitative study with 9 households with a physical disability affected by the 2007 fires in the Grampians, Victoria, found that five had a verbal plan to leave early or stay and defend, and four households had no plan.

The lack of, and limited, bushfire planning is similar to that found in international research on natural hazards. This research finds that people with a disability may be unprepared with limited or partial plans (UNISDR, 2013; Pines et al., 2009; Bethel, Foreman & Burke, 2011; Hogaboom et al., 2013). There is also relatively limited preparation at institutional levels (Rooney & White, 2007). For example, Boon, Brown & Pagliano (2014) found that in a survey of 80 Australian schools, that less than one third included disability in their natural hazard planning.

Changing these fatality rates and improving planning and preparation requires engaging, educating and communicating effectively with people with a disability in relation to bushfires and other natural hazards. Previous research has explored the mediums and formats of emergency messages in relation to different disabilities (e.g. disaster communication for the Deaf Community: Calgaro & Dominey-Howes, 2013; disaster communication for blind people: Crandall, Benson & Myers, 2010). This type of research differentiates types of disability and their different impacts, such as hearing or sight impairment, mobility impairment, and cognitive impairment. It then identifies the most effective formats and forums for emergency communication, e.g. TTY for hearing impairment (Stork-Finlay, 2014). Previous research has also looked at the content of emergency messages for people with a disability. For example, in relation to bushfires, whilst the common message prior to the 2009 fires was to 'stay or go', concerns were raised about this as a message for vulnerable groups, particularly people who are disabled. The report recommended that this message should be changed to an emphasis on early relocation (VCOSS 2014).

Although this research has provided valuable insights and changes to emergency management communication, it does not explain why people with a disability may choose not to have a bushfire plan, or to develop a plan to stay and defend or to wait and see, both of which are highly risky. Research with people with a disability outside of emergency management considers the impacts of

disability extend further than access to communication. Disability profoundly disrupts one's sense of self and can lead to a loss of a meaningful identity (Bury, 1982; Charmaz 1983). People who experience a disability may struggle to develop a new coherent narrative of the self, particularly in relation to independence and work (Galvin 2005). Developing a positive, balanced self-identity in response to disability requires "knowing oneself, accepting oneself with one's limitations, not being ashamed of the limitations but simply seeing them as part of the reality one is in, and perhaps as a boundary one is challenged to expand" (Murugami, 2009). However, the greatest challenge to developing a sense of self is the way others view and respond to disability as 'tragic' and 'abnormal' (Galvin 2005). This language shapes how people see themselves, and the feelings of inadequacy and inferiority that can come with the onset of disability are internalised and deeply affect how people engage with the world (Galvin, 2003).

Making a bushfire plan is arguably a time of reflecting on (and potentially exposing) one's personal, social and environmental abilities and limitations. It is a situation that makes physical limitations highly salient, even where the person may have adapted to these successfully in their daily lives. It is also a situation where people may be more exposed to other's views about normality. This paper draws on work in the disability field on self-identity and disability, and proposes that bushfire planning is an activity which potentially exposes people to negative self and community identities as 'not able', 'useless' or 'a burden'. These negative identities may be particularly salient for men in rural settings, where they are valued for their physical control of the environment, their independence and emotional stoicism. These potentially negative identities that are available for people with a disability may explain why they may choose not to identify as disabled, or to identify themselves as at risk. This paper suggests that disability identities, both external to the person and internalised by them, is likely to be part of how they approach bushfire risk.

Using a thematic analysis of interviews with 27 households after the January 2014 South Australian bushfires, three disability identities were observed: denial, ambivalence and balanced. Most people rejected the label of 'disabled', many only later revealing through the interview that they were experiencing illness or impaired functioning. Others were ambivalent, simultaneously identifying the impacts of disability on their ability to plan and prepare their properties, but also developing plans and strategies which relied on full physical functioning. These negating and rejecting disability identities were reflected in the absence of a plan, or an untenable plan to stay and defend or wait and see. Nine households balanced disability and ability in ways that enabled them to make a fire plan that included early evacuation.

For those for whom bushfire decision-making is implicated in preserving a valued identity as able-bodied, independent and productive, providing information about disability and bushfire planning may simply not be sufficient. In fact, where it reinforces the assumption that the only option in identifying is disabled is to be seen as vulnerable and incapable, then it is likely to have the opposite effect. Rather, the research presented here suggests that it is important to promote alternative identities in relation to disability and bushfire planning. These may include: championing new ways of being heroic and capable; basing education and planning on the principle that disability may close down some options but opens up others. These new images may be ones which champion community connection as well as independence or which show different images of heroism, such as being a support person at evacuation points. Further, making disability assessments a normal part of a fire risk evaluation, i.e. something that everyone is doing, not just 'disabled people' is also a potentially important way to decrease the stigma of identifying as disabled.

The language of emergency services, both textual and visual, has an important role to play in creating new, positive and balanced identities that support people's bushfire survival.

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VERIFICATION OF SOIL MOISTURE FROM LAND SURFACE MODELS AND TRADITIONAL SOIL DRYNESS INDICES

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Adelaide, 1-3 September 2015

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ABSTRACT

The McArthur Forest Fire Danger Index (FFDI) used in Australia has a component representing fuel availability called the Drought Factor, which inturn is partly based on soil moisture deficit, commonly calculated as either the Keetch–Byram Drought Index (KBDI) or Mount's Soil Dryness Index (SDI). The KBDI and SDI are essentially simplified water balance models to estimate soil moisture depletion in the upper soil levels, and are driven by precipitation and maximum temperature analyses. In this study, we compare these two old empirical models against an emerging new approach in soil moisture estimation in the form of land surface modelling. Validation of these models are carried against *in situ* observations of soil moisture from OzNet and CosmOz networks in Australia. The results indicate that soil moisture from land surface model employed within Bureau of Meteorology's operational numerical weather prediction (NWP) model produce a better skill than KBDI and SDI. The average correlations obtained over all sites are 0.77, 0.62 and 0.74 for NWP, KBDI and SDI respectively.

INTRODUCTION

The ignition, spread and temporal variations in fire danger depend heavily on fuel availability (FMC; Chandler *et al.*, 1983). Because fuel availability measures are not always readily available, fire danger rating systems include sub-models to estimate this quantity from weather observations. The McArthur Forest Fire Danger Index (FFDI; McArthur 1967) used in Australia for instance, has a component representing fuel availability called the Drought Factor, which inturn is partly based on soil moisture deficit which is commonly calculated in Australia as either the Keetch–Byram Drought Index (KBDI; Keetch and Byram, 1968) or Mount's Soil Dryness Index (SDI; Mount 1972). These two empirical water balance models are, however, over-simplified and may lead to large uncertainties in the estimated soil moisture deficit. With the advancement in the science of soil moisture estimation and prediction in the form of physically based land surface models, more comprehensive and systematic measures of soil moisture is now available. Research is already started to deliver a better provision of soil dryness products with greater accuracy at a much higher spatial and temporal resolution for use in fire danger ratings. This study intends to be of a preliminary nature to this research and describes the comparison between soil moisture from old empirical models (KBDI and SDI), a land surface model and *in situ* observations.

DATA AND METHODOLOGY

For the present study, KBDI and SDI are generated for the whole of Australia at 0.05o x 0.05o resolution using the Australian Water Availability Project (AWAP) daily rainfall and daily maximum temperature data (Jones *et al.*, 2007) for a period of 40 years, from 1974 – 2014. The two sources of *in situ* data used for this study are from the OzNet and Australian Cosmic Ray Sensor Network (CosmOz) soil moisture monitoring networks. OzNet data used in this study consists only observations from the Murrumbidgee Soil Moisture Monitoring Network (Smith *et al.*, 2012). CosmOz is the first national network of cosmic ray soil moisture probes and comprise of 13 sites situated at different locations over different climate zones in Australia (Hawdon *et al.*, 2014). The numerical weather prediction (NWP) soil moisture dataset used in this study are analyses from the old (called Australian Parallel Suite – 0; APS0) and current (Australian Parallel Suite – 1; APS1) versions of the Australian

Community Climate and Earth Simulator (ACCESS) global modelling system employed operationally by the Bureau of Meteorology. APS0 had a horizontal resolution of about 80 km and APS1 that of about 40 km.

Since the different soil moisture datasets mentioned above are represented in different forms and units, to enable a fair product comparison, all are scaled between [0, 1] using their own maximum and minimum values from the respective lengthy time series. In order to match the daily time steps of the KBDI and SDI fields, the NWP model and *in situ* data are averaged over each day. A spatially collocated sub-set using the nearest neighbour technique with respect to the *in situ* observation locations are then made from these daily averaged gridded model (NWP, KBDI and SDI) fields. For all stations, correlations, bias, and root mean square difference are calculated for the whole period in which the comparing data overlaps.

RESULTS AND DISCUSSIONS

COMPARISON WITH OZNET

In order to assess the accuracy of the soil moisture estimates from APS1, KBDI and SDI, an evaluation is made against the soil moisture observations from OzNet hydrological network. The verifications are made with datasets which span for a period of 21 months, i.e. from September 2009 to May 2011. OzNet provides soil moisture observation for the top 30 cm layer (0 – 30 cm deep) which is used in this study for comparisons.

The correlation, bias and RMSD calculated for APS0, KBDI and SDI with respect to the OzNet sites are given in Table 1. The values represent an average taken over 30 stations. The results show that, in general, the APS0 correlations are higher than that from both KBDI and SDI. The average correlation values across all OzNet sites for APS1, KBDI and SDI are 0.72, 0.60 and 0.71 respectively. The APS0 soil moisture usually correlates very well with the observations, where 90% of sites showing a correlation of 0.6 or more. Biases are in average of 0.02, -0.39 and -0.02 for APS0, KBDI and SDI respectively. KBDI in general display a large wet bias, which suggest that the evapotranspiration estimates in KBDI are rather under-estimated. Though SDI presents on an average a wet bias, it doesn't systematically exhibit any wet bias at all stations. Averaged RMSD for APS0, KBDI and SDI are 0.19, 0.43 and 0.23 respectively. The higher RMSD in KBDI signify that the errors in soil moisture are larger in KBDI compared to APS0 and SDI.

Table 1. Comparison of normalized soil moisture between OzNet *in situ* observations located at Murrumbidgee catchment area and ACCESS NWP model (APS0), KBDI and SDI. The values represent an average over 30 sites.

Correlation [-]			**Bias [-]**			**RMSD [-]**		
APS0	**KBDI**	**SDI**	**APS0**	**KBDI**	**SDI**	**APS0**	**KBDI**	**SDI**
0.72	<u>0.60</u>	0.71	0.02	-0.39	-0.02	0.19	0.43	0.23

COMPARISON WITH COSMOZ

The three modelled root-zone soil moisture estimates from APS1, KBDI and SDI are evaluated against daily average measurements from CosmOz cosmic ray probe sites across Australia. Since APS1 dataset had the shortest span among the four data types, a subset of CosmOz, KBDI and SDI data set were produced based on APS1 time period for sensible verification. This period spans about 31 months, from May 2012 to Dec 2014. The statistical scores of this verification is presented in Table 2. The verifications results using CosmOz data displays a similar pattern to that from the OzNet, where the NWP soil moisture product exhibit a good skill over the KBDI and SDI products. The mean correlations obtained for APS1, KBDI and SDI in this case are 0.8, 0.63 and 0.76 respectively. The average bias obtained for APS1, KBDI and SDI are 0.01, -0.35 and -0.07 respectively. KBDI again shows a rather large wet bias over all stations. Since the CosmOz observations are scattered all over Australia, this implies that KBDI under-predict the soil moisture deficit substantially, regardless of the climate zone. SDI doesn't exhibit any consistent wet or dry pattern spatially, similar to APS1. RMSD are in average of 0.15, 0.42 and 0.20 respectively for APS1, KBDI and SDI.

Table2. Comparison of normalized soil moisture between CosmOz observations and APS1, KBDI and SDI. The values represent an average over 13 sites.

Correlation [-]			Bias [-]			RMSD [-]		
APS1	**KBDI**	**SDI**	**APS1**	**KBDI**	**SDI**	**APS1**	**KBDI**	**SDI**
0.80	0.63	0.76	0.01	-0.35	-0.07	0.15	0.42	0.20

SUMMARY

The validation study done in this work use *in situ* observations from OzNet and CosmOz network to assess the reliability of NWP, KBDI and SDI soil moisture products. In general, the NWP soil moisture gives a better performance compared to KBDI and SDI, and as depicted by the correlation, bias and RMSD values. This is despite the fact that NWP soil moisture were calculated at a much coarser resolutions (~ 40 – 80 km) and use its own precipitation estimates - which are generally associated with lot of errors - to drive the soil moisture. As compared to this, KBDI and SDI soil moisture estimations use observation based precipitation analysis and are done at a much higher resolution (~5 km). Over most of the sites on which comparisons were made, KBDI soils are significantly wetter than other three datasets. This wet bias seen in KBDI could have its implication for fire danger ratings, where it is used, as this would potentially downgrade the fire potential. SDI, although displays a much better temporal soil moisture variation than KBDI, usually fail to catch the rapid drying / wetting phases seen in the observations.

It is worth noting that there is still a lot of scope to improve soil moisture products from land surface models used in NWP by using advanced data assimilation techniques (Dharssi *et al.*, 2013). As the next step, research will be performed to calculate soil dryness using satellite remote sensing measurements, land surface model simulations and data assimilation techniques. Consequently, this research is intended to lead to the provision of soil dryness products with greater accuracy at a much higher spatial and temporal resolution.

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DEVELOPING A TARGETED RESILIENCE INTERVENTION FOR THE PRIMARY PREVENTION OF PTSD

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INTRODUCTION

The current 'best practice' approach to trauma is to screen for pathology and provide treatment when required (Cloitre, 2009; Cornum, Matthews, & Seligman, 2011). This reactive paradigm is seen in the wealth of information and numerous studies regarding debriefing, early intervention responses following trauma and therapeutic approaches to stress and trauma pathologies. When Seligman (Seligman & Csikszentmihalyi, 2000) launched the Positive Psychology movement, academic interest in resilience increased. Positive Psychology literature abounds with research exploring components of resilience, comparing resilient individuals with less resilient individuals and, more recently, implementing resilience programs with children. Only in recent months have studies reflecting resilience training programs with adults appeared (Burton, Pakenham, & Brown, 2009, 2010; Cornum et al., 2011).

Given this backdrop of research in resilience building and PTSD prevention, future research is needed to explore whether a resilience training intervention can prevent or reduce PTSD and other post-trauma pathology following exposure to a PTE. Research has confirmed the effectiveness of resilience training in increasing protective factors in individuals in university (Steinhardt & Dolbier, 2008) and work (Burton et al., 2010) settings. There are also research claims that resilience training programs have decreased the incidence of pathology in a military setting (Cornum et al., 2011) and improved adjustment in military (Cohn and Pakenham, 2008) and police (Arnetz et al., 2009) settings. There is not currently sufficient evidence to support a claim that resilience training can be effective in the primary prevention of PTSD and this review of the research has identified a lack of experimental tests of theory-based, targeted, primary prevention interventions for PTSD.

Some professions, by their nature, will be exposed to trauma. Fire and emergency service work is widely recognised as a stressful occupation, with fire-fighters often exposed to potentially traumatic situations. This presentation will outline a PhD level program of research that aimed to explore the possibility of teaching resilience and psychological flexibility to adults in high-trauma professions. Phase 1 of this project was to develop a program aimed at the primary prevention of Post-Traumatic Stress Disorder (PTSD) and comprised a literature review, needs assessment and ongoing consultation with the target organisation (the Department of Fire and Emergency Services, DFES, in Western Australia). Phase 2 of this project was the implementation and evaluation of the program via a randomised control trial with a 12-month follow up.

OBJECTIVES

The objectives of this research project are as follows:

1. Determine the frequency of exposure to trauma and the presence (or absence) of symptoms of depression, anxiety, stress, problematic alcohol use and PTSD within the target profession.
2. Create an evidence-based, targeted intervention, grounded in literature and research and aimed at interrupting cognitive mechanisms that have been shown to contribute to symptoms of PTSD.
3. Refine the intervention in consultation with a target organisation, such that it becomes tailored to the needs and requirements of individuals working within the targeted high-risk profession.
4. Evaluate the intervention using a longitudinal, experimental design.

METHOD

The proposed research was conducted in two phases. The first phase comprised the development of a program aimed at the primary prevention of PTSD. The second phase comprised a longitudinal randomised control trial evaluation of the developed program. The developed program was a 4-hour intervention delivered during recruit training, aimed at the primary prevention of PTSD. The development of this program included a systematic review of the literature and prior intervention programs to distil the key points and inform preliminary program development in consultation with key members of (and stakeholders in) the target population for further refinement of the program. This also included a cross-sectional survey of 210 DFES career fire-fighters, to ensure that the population will be an appropriate target for the intervention.

The intervention aimed to target individuals who were at elevated risk of developing PTSD, given their membership to a profession with high incidence of exposure to potentially traumatic events. A traumatic experience is part of the diagnosis of PTSD by definition (APA, 2004) and increased exposure to PTEs has been identified as a risk factor for PTSD (Maguen et al., 2008; McCloskey & Walker, 2000; Ozer, Best, Lipsey, & Weiss, 2003; Stephens & Miller, 1998; Violanti, 2006). A minimum of 60 participants were recruited from the DFES recruit training school, with some recruit schools receiving training-as-usual (control condition) and other recruit schools receiving the 4-hour Mental Agility and Psychological Strength (MAPS) training program (intervention condition). All participants were tracked for their first 12-months as DFES career fire-fighters and measures of trauma exposure (TSS), PTSD symptoms (PCL-C), stress, depression, anxiety (DASS-21), perceived social support (SSQ) and preferred coping style (Brief COPE) were administered.

ANALYSIS

A pre-intervention/ post-intervention/ follow up control group design with clustered random allocation of participants to groups will be used. Recruits within DFES are naturally grouped into 'schools', where a school is a cohort that completes training together. For this reason, random allocation of single subjects to treatment or control groups was not feasible. Rather, 'schools' were randomly allocated to treatment or control.

The 'control' group is the 'Training as Usual' (TAU) group; this group was treated identically to the intervention group, proceeding through all components of DFES training, but did not participate in the intervention program. Due to the limited time and resources available within the DFES professional training program, an attention placebo control group was not a viable option. Both the intervention and TAU groups engaged in an equal number of overall professional training hours. All participants were measured on the outcome variables immediately prior to the intervention. Immediately following the intervention, all participants are measured once again on the outcome variables; and then again 6 months post-intervention, and for one final time 12 months post-intervention.

HYPOTHESIS TESTING

The hypotheses for this project (not listed due to space constraints) predict a Group x Time interaction for the T1 to T2 section of the T1 to T3 outcome trajectory. Specifically, each hypothesis predicts that this section of the trajectory will increase at a greater rate for the intervention group than the control group. This prediction is best tested with multi-level mixed effects linear regression (Bryk & Raudenbush, 1987; Dimitrov & Rumrill, 2003; Hofmann & Asmundson, 2008). GLMM will analyse the outcome data within the context of a hierarchical design in which Time (T1, T2, T3) is nested within Participants, Participants are nested within schools, and schools are nested within group (intervention, control).

GLMM has several advantages over traditional statistical procedures for analysing behavioural change. Firstly, GLMM does not rely on participants providing data at every assessment point; it uses all the data present at each assessment point thereby reducing the impact of subject attrition on statistical power. Moreover, GLMM can deal with unequally spaced data collection points, is robust to unequal group sizes, does not require equal variances at each measurement occasion, or an equal covariance between all pairs of time points, and is able to account for correlations that occur between repeated measurements. Relative to other techniques, GLMM is able to more accurately estimate group means when group sample sizes are small.

This project is currently in the final stages of data collection and so preliminary results cannot be included in this proposal. Full results will be available by the time of the proposed presentation in September 2015.

DISCUSSION

There is a clear need for prevention research of this nature however it is often limited by practical concerns and barriers, including organisational restrictions, time constraints within training programs and differing priorities across stakeholder groups. The barriers encountered during this program of research will be discussed, including recommendations for how to avoid similar barriers in the future.

The bulk of the discussion will be guided by the results, which are not yet available. Future directions for similar research and practice will be discussed in light of the current results.

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THE INTEGRATION OF INFORMAL VOLUNTEERS INTO ANIMAL EMERGENCY MANAGEMENT: EXPERIENCES FROM THE 2015 SOUTH AUSTRALIAN BUSHFIRES

Research proceedings from the Bushfire and Natural Hazards CRC & AFAC conference
Adelaide, 1-3 September 2015

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INTRODUCTION

Members of the public are often first on the scene in a disaster and are keen to assist. It is widely recognised that spontaneous and/or loosely organised groups from local communities play important roles during disaster response and recovery, and indeed, these 'informal volunteers' often provide extra capacity and skills that are highly valued in an emergency situation. It has been reported, however, that volunteers acting outside of the established emergency management system can be disruptive and put themselves and others at risk (see for example, Liath, 2004). Nevertheless the potential for negative outcomes, whether recognised or not, does not dampen the desire of people to help and the onus is on those in emergency management to harness this resource and provide flexible and novel ways to integrate it into the emergency management system.

In recent years there has been increasing recognition of the fact that animals need to be considered and integrated into emergency management and disaster response in Australia. Moreover, it is acknowledged that such consideration poses additional challenges for traditional responding, and therefore extra preparation, knowledge and skills are required to ensure the safety of animals, their owners, and responders (Leonard and Scammon 2007; Edmonds & Cutter 2008; Austin, 2013, White, 2014). Consideration of animals also requires the integration of a broader set of official response agencies, such as primary industries, and may also include a range of secondary responders, such as RSPCA, established animal rescue organisations, and veterinary clinics. Although inclusion of these secondary responders enhances the capacity to rescue and manage animals, resources may still be stretched. Members of the public with specific interests in animals may have skills in animal rescue and/or handling that are scarce or patchy in the formal response teams, and therefore provide an additional valued resource.

Recent research undertaken in Australia as part of the Bushfire and Natural Hazards CRC Managing Animals in Disasters (MAiD) project revealed that emergency response organisations and other stakeholders groups face challenges and uncertainty regarding their responsibilities and role in the management and rescue of animals and in their interactions and management of animal owners (Taylor et al, 2015). Clearly, with an extended set of organisations and agencies involved in the formal response, there is a more complex operating picture, a greater potential for ambiguity or confusion, and a greater need for inter-agency coordination.

The ambiguity surrounding official responsibilities for animals in disasters, a more distributed response system, and increasing media coverage of animals in the wake of recent disasters may have contributed to the public perception of a vacuum in emergency response in this area. Although an association is unproven, this may also have led to an increase in the number of 'emergent groups' forming to rescue, support, and assist in this area. In recent years social media have created additional platforms for response and volunteerism that have enabled people to offer support from afar; people can co-ordinate volunteer activity and disseminate information in unprecedented ways (Meier, 2013). Many of the informal volunteering groups that focus on animals in disasters have a prominent social media profile, which is their main avenue for disseminating information. These groups typically focus on providing disaster response for animals; coordinating informal volunteers to help rescue, move and temporarily re-house animals, providing animal owners with information and advice ahead of, or during, disasters, and encouraging the donation of supplies and funds to support veterinary care.

Despite their keen interests in the area, there have been reports that such groups may not have sufficient knowledge of the official emergency management policies and plans that are in place and the actions that are triggered in the event of an unfolding disaster. It is also reported that some groups have, on occasion, disseminated incorrect information and have issued their own warnings, and therefore may have been disruptive to the official response. Furthermore, emergent groups often have weak or evolving organisational structures and little or no integration into the official emergency management system. This lack of integration leads to poor situational awareness, with misunderstanding about the timing and intentions of official actions and a lack of accurate or timely information.

From the perspectives of these informal volunteering groups, the lack of integration can create frustration. In the context of animal emergency management, there is often a sense of urgency that action is needed, an enthusiasm to 'do something' and a rising concern for animal welfare. At such times decision-making can be adversely impacted and risky or emotionally-charged situations can arise.

PROJECT

This research presentation will discuss the initial findings of a project that aims to understand how these emergent informal volunteering groups integrate with established animal welfare and veterinary organisations, and the formal emergency response agencies.

The goal of the study is to identify the challenges for, and strengths and limitations of, informal volunteering in the context of animal emergency management. It is anticipated that the findings of this research will advance dialogue in this area, enabling solutions to be identified and improvements to be made to the integration of this potential resource in emergency management.

This research project aims to explore the following research questions:

- What are the issues and challenges for:
    - Official responders who interact with these informal volunteers?
    - Established animal welfare/rescue groups who interact with these informal volunteers?
    - Those who coordinate (facilitate) informal volunteer activity?
    - On-the-ground volunteers?
- What role do social media (Facebook and Twitter) play in the work of emergent informal volunteer groups?
- How do these emergent informal volunteer groups see their role?
- What are the perceptions and experiences of those in official response capacities?
- Are these groups filling a gap (perceived or otherwise) in the current official emergency response?
- How can we improve the interface between emergent groups and emergency responders to improve emergency management when animals are involved?

The January 2015 Sampson Flat bushfire in the Adelaide Hills, South Australia will be utilised as a case study to explore the research questions. The proposed research presentation will focus on the first two questions above, and will discuss the initial findings from in-depth semi-structured interviews that will be undertaken with participants from the following groups:

- Coordinators/administrators of emergent informal volunteer groups who were disseminating information and mobilising volunteers during the bushfire to assist with animals.
- Members of established animal organisations who were involved in the response, but who don't specialise in disaster response in their core business/activities, e.g. Animal Welfare League, RSPCA SA, local council shelters.
- Members of the volunteer group South Australian Veterinary Emergency Management (SAVEM), who are veterinary health professionals with a level of emergency management training and who were responding as part of the official emergency response.
- Trained emergency services personnel and personnel from key government agencies (CFS, PIRSA, DEWNR), including those in decision making roles and those who encountered informal volunteers 'on-the-ground'.

This research will be further strengthened by documentary research, including the analysis of online media/news articles, government reports, social media content, such as Facebook posts and Twitter feeds, and other relevant sources that will provide important context to this research presentation.

The study findings will be important in enabling an increased understanding of the role, position, motivation, skills and knowledge of emergent informal volunteer groups and the roles of these volunteers in disaster situations. Identifying areas where informal and formal volunteers and responders might assist each other could help save the lives of people and animals. Moreover, there is a dearth of knowledge on the specific needs of animals and their owners in a disaster situation, and this research will help to provide important insights into the skills required when dealing with animals in disasters, the scope for integration of informal volunteers in the emergency management system.

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SCIENCE IN MOTION: KNOWLEDGE PRACTICES AND PRESCRIBED BURNING IN SOUTHWEST VICTORIA

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ABSTRACT

The Scientific Diversity, Scientific Uncertainty and Risk Mitigation Policy and Planning BNHCRC project examines three case studies in which scientific knowledges and scientific uncertainties play a significant role in the mitigation of bushfire and/or flood risk. Through these case studies, the project examines how diverse knowledge practices—including scientific knowledge, professional experience, local knowledge, and Indigenous knowledge—and key scientific uncertainties are encountered, managed and utilised by practitioners and decision-makers involved in bushfire and/or flood risk mitigation. This paper suggests that a better understanding of the interaction and evaluation of different knowledges and forms of uncertainty in such mitigation practices will enable industry to better articulate decisions to stakeholders, inquiries, and other audiences.

Scientific uncertainties are those 'known unknowns' and 'unknown unknowns' that emerge from the development and utilisation of scientific knowledges. They are the things we have comparatively limited knowledge about, whether we know it or not, because of limits in available data or modelling methods. These uncertainties are an irreducible component in any practice that utilises scientific knowledges, and, as such, they play a significant role in bushfire and flood risk mitigation professionals' attempts to anticipate hazard behaviour within non-linear dynamical systems such as weather and climate. This is not to suggest these uncertainties are overwhelming, but that, as Moore et al. suggest (2005), risk mitigation professionals must 'embrace uncertainty' if they hope to comprehensively manage a given risk. This paper will survey both the key findings of the project's literature review of relevant scientific uncertainties and the initial results of interviews and a scenario exercise involving mitigation professionals from the project's first case study in the Barwon-Otway area of southwest Victoria. Over the past decade, this region has been the site of multi-agency efforts to reduce the residual bushfire risk using ensemble forecast modelling and fuel reduction burning.

EXTENDED ABSTRACT

The Scientific Diversity, Scientific Uncertainty and Risk Mitigation Policy and Planning (RMPP) BNHCRC project examines three case studies in which scientific knowledges and scientific uncertainties play a significant role in the mitigation of bushfire and/or flood risk. Through these case studies, the project examines how diverse knowledge practices—including scientific knowledge, professional experience, local knowledge, and Indigenous knowledge—and key scientific uncertainties are encountered, managed and utilised by practitioners and decision-makers involved in bushfire and/or flood risk mitigation. This paper suggests that a better understanding of the interaction and evaluation of different knowledges and forms of uncertainty in such mitigation practices will enable industry to better articulate decisions to stakeholders, inquiries, and other audiences (see also Neale and Weir 2015). To this end, this paper will survey both the key findings of the project's literature review of relevant scientific uncertainties and the initial results of interviews and a scenario exercise involving mitigation professionals from the project's first case study in the Barwon-Otway area of southwest Victoria.

All scientific knowledges are necessarily probabilistic and, therefore, absolute universal reliability is a false standard against which to judge scientific knowledges (see Latour 1999). The nature of scientific inquiry is to produce knowledge or facts verified by their reproducibility, a task that also involves attempts to falsify existing theories and to perfect the data and theories on which these verified and reproducible facts are based. Scientific uncertainties are, in turn, those 'known unknowns' and 'unknown unknowns' that emerge from the development and utilisation of scientific knowledges. They are the things we have comparatively limited knowledge about, whether we know it or not, because of limits in available data or modelling methods. These uncertainties are an irreducible component in any practice that utilises scientific knowledges, and, as such, they play a significant role in bushfire and flood risk mitigation professionals' attempts to anticipate hazard behaviour within non-linear dynamical systems such as weather and climate. This is not to suggest these uncertainties are overwhelming, but that, as Moore et al. suggest (2005), risk mitigation professionals must 'embrace uncertainty' if they hope to comprehensively manage a given risk.

Using geographer John Handmer's (2008) tripartite analysis of flood risk, we can think of bushfire and flood risk mitigation as an intermediary stage between risk creation and residual risk. Risk creation involves those processes, such as urban planning, through which populations, values and assets are placed in relation to a natural hazard. Consequences of various magnitudes are created in relation to events of various probabilities. Subsequently, risk mitigation involves those processes through which agencies, many of which are involved in risk creation, attempt to limit vulnerabilities to that hazard. Residual risk, in this schema, is therefore the processes though which remaining vulnerability is distributed to, and borne by, emergency management, citizens, insurance companies and others. Such a definition differs from broader definitions of risk management as, for example, 'the culture, processes and structures that are directed towards effective management of potential opportunities and adverse effects' (see Renn 2008, 145), but it is useful in the context of this paper for reasons of analytical clarity. Further, risk mitigation itself is divisible between processes aimed at likelihood reduction, consequence reduction or risk transference (e.g. Ellis et al., 2004). Given that risk transference involves distributing responsibility to non-state actors, this paper focuses on scientific practices related to likelihood reduction and consequence reduction.

Having staked out a field of inquiry in this way, this paper will proceed first by summarising the major uncertainties that are a necessary component of predicting and mitigating bushfire and flood risk. These major uncertainties are categorised as historicist, instrumental and interventionist uncertainties. Historicist uncertainties emerge from the reliance of scientific knowledges on archives of historical data, which can itself be scarce and variable in its reliability. As Lane et al. suggest (2011), in hazard prediction 'the futures imagined are tied to pasts experienced' and their availability in the present. Instrumental uncertainties emerge from the limitations of a given apparatus, heuristic or theory brought to bear to mitigate a risk. Each such 'instrument' brings with it inherent limits of confidence owing to its parameters, design and development. Interventionist uncertainties emerge from any effort to predict and/or calculate the effect of an intervention, such as legal reforms, policy changes, and engineering works, amongst others. All such interventions are themselves wellsprings of uncertainty with effects that can and should be scientifically quantified in advance but that nonetheless cannot be wholly predicted by scientific methods.

But how are such multiple uncertainties understood and managed by risk mitigation professionals? To answer this question, the second section of this paper will draw upon the project's first case study in the Barwon-Otway area of southwest Victoria. Like other comparable regions in Australia's southeast, the region is a high bushfire risk area because it is at risk of bushfires that are low probability but high consequence. More specifically, the region's abundance of old-growth eucalypts, the geographic proximity of resident and tourist populations to forested areas, and the prevailing weather pattern capable of creating intense firestorms that first burn in a narrow southerly direction through contiguous forest to create what, following a perpendicular 'cool change', can turn into a wide fire front along the coastline. Several of the disastrous post-settlement fires to affect the region followed this pattern, such as the Dean's Marsh (or Ash Wednesday) fire in February 1983, a firestorm that burnt through 41,000 hectares between Lorne and Anglesea (Bardsley et al., 1983; Mills, 2005).

Over the past decade, the Barwon-Otway area has been the site of multi-agency efforts to reduce this bushfire risk to assets and values using ensemble forecast modelling and fuel reduction burning. Drawing upon qualitative research, this paper asks how risk professionals utilising advanced scientific methods understand and prioritise knowledges in practice. What other knowledges—including professional experience, local knowledge, and Indigenous knowledge—are brought to bear in calculating and mitigating risk, and how are these knowledges ordered and judged as salient, credible and authoritative? Are the uncertainties they encounter historicist, heuristic or interventionist? The preliminary findings of this case study suggest that risk mitigation takes the form of cycles of self-reflexive pragmatic reasoning—cycles in which logical inferences from available data and knowledges are made self-reflexively to produce functioning hypotheses in light of known uncertainties. As such, while mitigation professionals' are generally alert to the limits of scientific confidence, they exhibit a variety of perspectives about how such limits can and should be communicated.

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DISASTER MANAGEMENT: BUILDING RESILIENT SYSTEMS TO AID RECOVERY

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INTRODUCTION

Developments in open innovation platforms, mobile phones and portable computers have enhanced communication, collaboration and location of people, places and resources, while facilitating societal transformation and self-organising capability on an unprecedented scale. Communities have been able to "self organise" like never before and have become major participants in, and facilitators of disaster recovery operations in the Haiti Earthquake (2010), Christchurch Earthquake (2010/11), Japanese Tsunami (2011) and the Queensland, NSW and Victorian Floods of (2011/12). Case studies of these incidents provide numerous examples where self-organizing groups of citizens supported and supplemented government efforts. While genuinely attempting to render assistance in the recovery process, these self-organising groups and the systems they have created, have sometimes been misguided, inappropriate and dangerous due to their lack of integration with coordinated government, NGO and community view of recovery activities and systems.

We examine how to best harness the principles of self-organising systems to augment traditional "command and control" pictures of disaster recovery in order to more effectively develop an integrated approach to: situational awareness, resource utilization and recovery outcome optimization. This is a very important, costly and complex problem for government and one that is currently significantly under-researched. In order for this problem to be effectively tackled in the current context of social transformation, the best of command and control approaches and structures must be considered and blended with the potential that is arising from emerging self-organising systems.

This study outlines the results of a 1-day Resilient Disaster Systems Symposium that was held with an experienced academic, agency and NGO audience where key issues in disaster recovery and suggested areas of focus were generated. These key issues were then examined utilising the theory of evolving organisations and systems archetypes, so as to better understand guiding principles for developing effective and resilient systems solutions.

BACKGROUND

Most emergency agencies use their own currently proven processes, technologies and information systems to optimize outcomes and get value for money. These processes, technologies and systems are utilized with varying degrees of success and effectiveness (Bunker & Smith, 1999, Betts, 2003, Levine & Woody, 2010) in the various phases of a disaster. For example, Bunker et al. (2013a) highlight lessons learned from the 9/11 Terrorist Attacks (2001), Hurricane Katrina (2005) and the Black Saturday Bushfires (2009) which show that all phases of disaster management suffer from: 1) incompatibility of local responses together with a lack of central global management; 2) a lack of centralized oversight and sense of common purpose at a local level resulting in poor resource management; 3) "paralysis" of government agencies not wanting to be seen as complicating and over-reacting to the disaster or wasting resources; and 4) little coordinated oversight of individual agency "command and control" structures, processes and systems which prohibited the effective sharing of situational awareness at a central or local level.

COMMAND AND CONTROL PICTURES IN DISASTER MANAGEMENT

During crises and disasters, traditional command and control processes and systems are used to develop situational awareness during a disaster. The Prevent, Prepare, Respond and Recover (PPRR)[1]

[1] As outlined in EMERGENCY MANAGEMENT IN AUSTRALIA CONCEPTS AND PRINCIPLES MANUAL NUMBER 1 © Commonwealth of Australia 2004 ISBN 0-9750474-6-9

protocol provides a common strategy and a backdrop for the development of this situational awareness.

We argue that in most disasters or crises, agencies need to supplement their command and control pictures with dynamic, local situational awareness as a command and control view of a disaster does not easily accommodate a range of representations of the disaster scenario or its dynamic nature. It also does not account for multiple stakeholders needing adequate information to collaborate at a central and/or local levels.

SELF ORGANISATION, OPEN INNOVATION AND THE RISE OF THE "SPONTANEOUS" VOLUNTEERS

We are seeing an emerging trend for individuals and groups (spontaneous volunteers) to "take matters into their own hands" to self-organize and assist in recovery efforts. Open innovation tools and social media platforms (Facebook and Twitter), mapping (Ushahidi and Google) and wiki and mash-up technologies; have enabled many-to-many communication for self-organisation, coordination and collaboration (Mingers 2002, 2004). For example we have seen the:

- Adoption of cloud-based, freely-available collaborative technologies by ENGOs, for ecocollaboration activities of ENGOs (Aoun et al., 2011). These collaboration technologies were used in a structurally dynamic manner depending on the NGO national context (Thai, Lebanese and Australian); and
- Adoption and use of open social media platforms for dynamic communication, co-ordination and collaboration activities during the civil uprising of the "Arab Spring" i.e. Iran 2009/10, Tunisia 2010/11 and Egypt 2011 (Bunker 2011) and the current uprising in the Ukraine and Crimea 2014.

As a general rule, emergency agencies have direct control, governance and assurance over the information within their internal operational "command and control" systems, throughout all phases of a disaster. They must now deal with the proliferation of information generated by individuals and groups using open innovation tools and platforms. Indeed, in order to ensure successful outcomes during disaster recovery, it is imperative that citizens are providing information to, and receiving information from, government agencies (Sydney Alliance, September 14, 2011). For example, during the 2011 Queensland Floods, there were reports of the difficulties engaging with local communities to incorporate local knowledge on floods, into the COP of government agency decision makers. This may have contributed to the loss of life and property for some communities (Campbell, 2011).

A CASE IN DISASTER RECOVERY

The SVA and their self-organised disaster recovery role in the wake of the Christchurch earthquakes, is one of many cases which motivate us to examine how to best augment the command and control picture of disaster recovery in order to more effectively: develop situational awareness, utilize resources and optimize recovery outcomes. The SVA was formed through the use of social media in the wake of the Christchurch earthquakes (September 2010 to June 2011). Bunker et al. (2013b) studied and analysed the first few weeks of Facebook and Twitter activity by the SVA after the February 2011 Christchurch Earthquake (the major disaster event in the earthquake series throughout 2010/2011). This analysis highlighted the power of harnessing community ethos, goodwill, motivation and momentum through the establishment of concepts, descriptions, rules and communications as the prime focus of interactions between the SVA and disaster management agencies. As is indicated by the findings of this case analysis, we argue that the best of command and control approaches must be supplemented with the potential that is arising from such emerging self-organising systems. A command and control picture enables a centralized view and the integration of agency and organisational systems, whilst individuals and groups (local and remote) are enabled by open innovation platforms to self-organize, coordinate and collaborate as never before.

CURRENT RESEARCH PROJECTS

We are aware that government agencies have been incorporating social media tools and platforms into general operations and the management of disasters and crises as diverse as floods, bushfires, earthquakes and terrorist bombings (Bunker, 2011, Ehnis & Bunker, 2012, 2013, Bunker et al. 2013b). This use of social media by government occurs across many portfolios: engineering, communications, agriculture, animal management, health, transport and defence at local, state and federal levels as well as internationally. Current examples include: NSW Police EyeWatch[2]; Australian National Security Website and Monitor Centre[3] and international cooperation in local disasters by Sahana Software Foundation and the IBM Disaster team[4], as well as within volunteer organisations attended by the UN and Red Cross.

In recent years Sahana has been somewhat effective in China, Pakistan, Philippines, Peru, NZ (Christchurch Earthquake 2010/11), and New York (Hurricane Sandy 2013) in collaborating efforts of volunteers, NGOs and government organisations. Within the open innovation platform and tool development space, there have also been many development activities, for example Ushahidi[5].

SETTING AN AGENDA

From our initial analysis we can see that command and control pictures and self-organising systems are at work in disaster recovery situations and as discussed, both can help and hinder recovery efforts, but both are still essential if we are to build resilient systems to aid in any recovery effort.

RESILIENT DISASTER SYSTEMS SYMPOSIUM

The symposium was conducted over one day and involved representatives of all of the major metropolitan Sydney universities as well as a cross section of government agencies and NGOs. The aim of the symposium was for agency and NGO representatives to present some major aspect of their disaster management operations and engage with the academic audience on identifying key issues in disaster recovery that required focus and problem solving. There were 35 participants in total as well as a facilitator who kept symposium presenters to time as well as managing the day's proceedings.

OUR RESEARCH METHODOLOGY AND APPROACH

Output from the Symposium was generated collaboratively by speakers and the audience and was documented and presented at the end of the day's activities. The data gathering followed 3 steps:

1. Presentation by each speaker followed by a general discussion (notes were taken by 3 of our research team while this occurred);

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[2] www.police.nsw.gov.au/about_us/structure/specialist_operations/operational_communications_and_information_group/project_eyewatch
[3] www.nationalsecurity.gov.au/
[4] http://sahanafoundation.org/
[5] http://www.ushahidi.com/

2. Generation of a list of discussion points identified by each presenter and the audience in the general discussion; and
3. Presentation of these discussion points to the presenters and audience for further comment.

In order to effectively interpret this output we have employed a traditional problem solving approach which includes: 1) a critical review of the practical body of knowledge and how this links to our current understanding of theory; 2) data gathering from primary sources (in this case the symposium participants); and 3) data analysis using thematic and pattern analysis.

THE RESULTS

Our analysis indicates that there are 5 major areas of concern for practitioners and academics that if better understood through joint research and development activities, would assist in the building of more resilient disaster recovery systems for use by agencies, NGO's and communities. As researchers and practitioners we should focus on the further development and integration of our knowledge about:

- The "system of systems" i.e what is available in formal command and control systems but also what is "at hand" in general consumer technologies and self-organizing systems and how can both of these be better integrated?
- How communities and societies behave in relation to resilient disaster recovery?
- Current government approaches and policy on disaster recovery and how this facilitates or impedes the integration of command and control and self-organizing systems to produce resilient disaster recovery systems?
- The impact of self-organizing systems (operations) on agency operations and what practical steps can be taken to integrate the two?
- What knowledge sharing and situational awareness mechanisms do both command and control and self-organizing systems have and how can we learn from these mechanisms to improve and optimise disaster recovery?

Our full paper examines these 5 areas in detail through the research focus of evolving organisations (Star and Levine, 2006) utilising the mechanism of systems archetypes (Novak and Levine 2010).

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A DECISION SUPPORT FRAMEWORK FOR MULTI-HAZARD MITIGATION PLANNING

Research proceedings from the Bushfire and Natural Hazards CRC & AFAC conference
Adelaide, 1-3 September 2015

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ABSTRACT

Hazard mitigation planning is multi-facetted. First, plans should be holistic, considering a number of community goals in addition to risk management. Secondly, plans should guide development over the long term, and need to consider how the frequency, magnitude and consequences of hazards change over time. To assess future changes, a large number of environmental and anthropogenic factors that affect hazard risk need to be estimated, yet strong uncertainty exists in estimating these factors. Thirdly, implemented plans have a wide social, environmental and economic impact; impacts across these systems need to be assessed. Finally, resources for mitigation are limited; benefits of mitigation need to be clear in order to make a business case to decision makers and the public. Due to these facets, decision support systems (DSSs) that include integrated models are invaluable when planning mitigation strategies.

This paper proposes a Natural Hazard Mitigation DSS framework that is designed to support the multi-facetted nature of mitigation planning, and demonstrates how it is being applied to the Greater Adelaide region.

INTEGRATED SPATIALLY EXPLICIT SIMULATION MODEL

The proposed DSS supports mitigation planning by simulating the effects of different mitigation options across the wider social, economic and environmental systems. In order to do this, the DSS contains an integrated model, shown schematically in Figure 1. The integrated model combines flood, bushfire, earthquake, and coastal surge models with social, natural and built environment models.

With regard to risk metrics, our framework allows two different ways for describing hazard. First exogenous maps may be used that give the likelihood of hazard occurrence at a given magnitude. Secondly, endogenous models included within the DSS may be used to calculate these hazard maps. The second option provides greater flexibility in assessing the impact of mitigation options, as these can be directly calculated by the model incorporated in the system. Furthermore, feedbacks between processes impacting on hazards can be included and simulated.

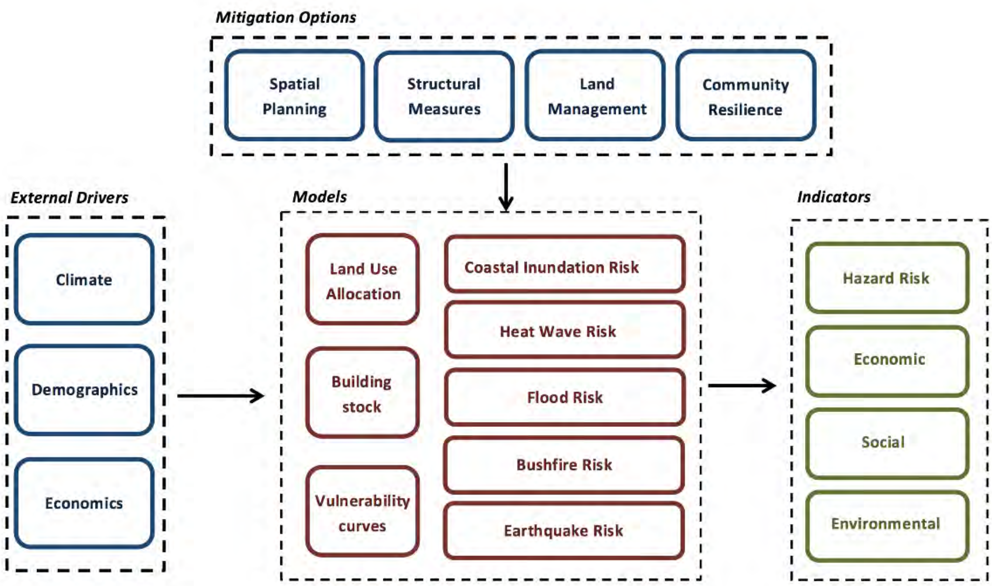


Figure 1. Modelling Components Within the Natural Hazard Mitigation DSS.

In order to assess risk, hazard — obtained by either of these two methods — is combined with dynamically calculated impact models. In our framework we define risk as the likelihood of a hazard occurring at a given magnitude multiplied by its consequence, summed across the magnitudes at which a hazard may occur at.

With regard to models of the social, natural and build environment, we have three separate, but related model components in the system:

1. A land use model that simulates changes in the social, natural and built environment as a result of socio-economic developments, spatial planning, physical characteristics of locations, accessibility and human behaviour.
2. A building stock component providing information on the mix of building types at the statistical area level 2 (SA2), as defined by the Australian Bureau of Statistics.
3. A component calculating the socio-economic impacts of hazards using the information provided by the land use model and the building stock component, together with hazard specific vulnerability curves indicating the damage based on the severity of the hazard and the building type.

The integrated model is used to estimate the values of multiple decision criteria, to enable holistic planning. In addition to risk indicators, the framework also includes indicators relating to social, environmental, and economic implications:

1. A land value component to calculate opportunity cost of mitigation options related to spatial planning based on locational characteristics;
2. Indicator models assessing the wider social implications, such as population density or accessibility to the city centre, places of employment, schools, recreational areas or (urban) green areas; and
3. Indicator models assessing the wider environmental implications, such as extent and quality of the green spaces, habitat fragmentation or (expected) urban development on natural or agricultural areas.

With regard to the temporal resolution at which these models run, most components operate at an annual resolution, in order to capture temporal dynamics well. With regard to spatial resolution, the land use model is set up using a resolution between 50 m and over 1 km square, to include sufficient spatial detail of the modelled area. Spatial indicators are calculated at the same resolution as the land use model or at the same resolution of the input data, such as the Bureau of Statistics SA1 or SA2 level.

MITIGATION ASSESSMENT CAPABILITY

The proposed DSS is designed to simulate the impact of a wide range of mitigation options. The mitigation options that the DSS is designed to simulate were identified through a participatory approach with end users, and include building code changes, land management practices, community based education, structural projects, land use planning, and legislative measures.

FORMAL OPTIMISATION TOOLS

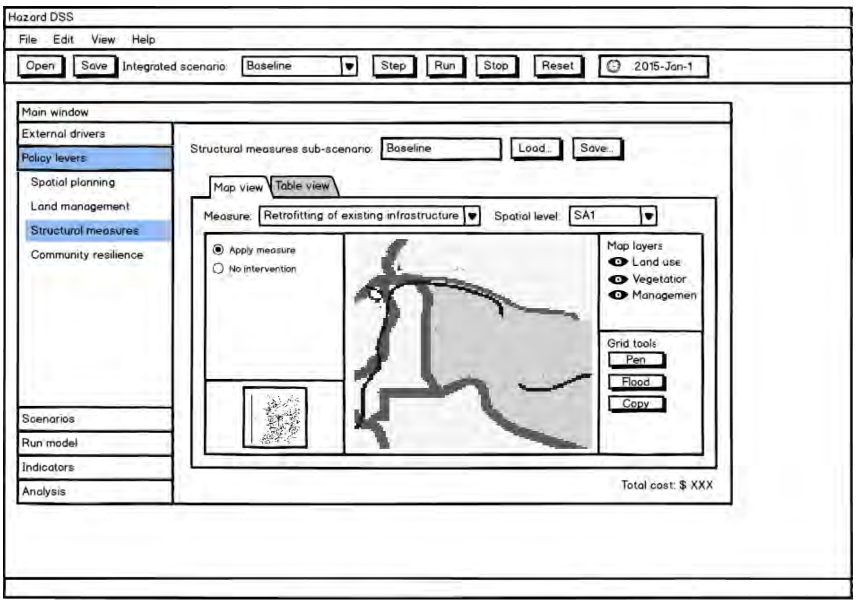
A novel component of the proposed DSS is the linkage of optimisation with the simulation model. The framework uses optimisation to screen through the available mitigation measures in order to identify near-to-optimal (Pareto efficient) mitigation portfolios, subject to budgetary constraints. In general, a large number of indicators are important for decision making, and therefore *multiobjective* optimisation methods are implemented within the software. Multiobjective methods generally find multiple (as opposed to a single) `optimal' designs that cannot be said to be better or worse than each other, but which display optimal trade-offs between the objective functions. It is important to identify these trade-offs so as to not waste scarce resources (for example, it is wasteful to implement a mitigation portfolio that has a higher cost and universally poorer indicator values than a Pareto efficient portfolio). Optimisation is used, as identifying these optimal trade-offs cannot be done manually, as there are too many possible combinations of mitigation measures to test.

Evolutionary algorithms (EAs) are used as the optimisation engine in the software, as they are robust artificial intelligence tools that can be used with any simulation model. Evolutionary algorithms work through an iterative process of constructing multiple mitigation portfolios, simulating the effect of implementing the portfolios, and using simulation outputs to evaluate their performance. This information is then used to create better portfolios, after which the process repeats until there is no further improvement in the constructed portfolios.

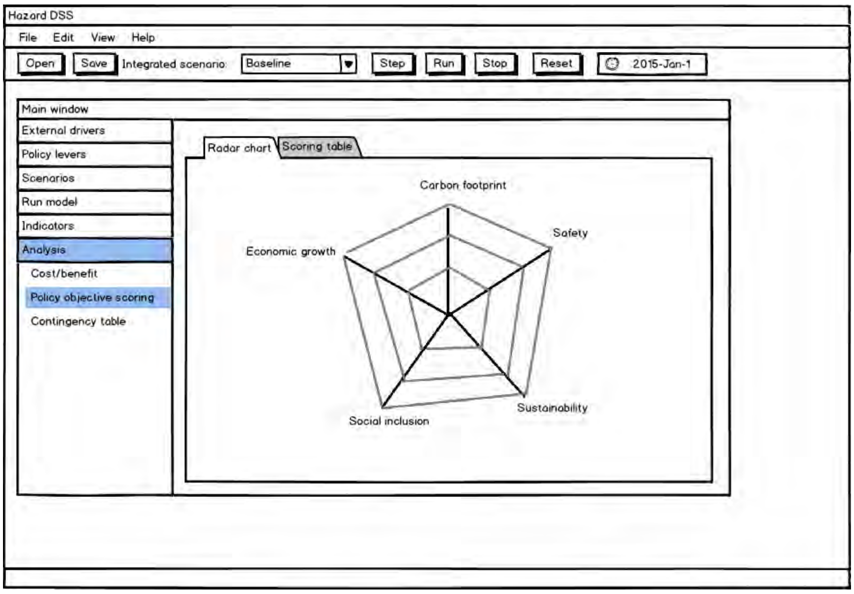
The construction of optimal mitigation portfolios is a very difficult optimisation problem, with an extremely large decision space, long simulation run times, and stochastic (probabilistic) objective functions. Consequently, parallel and cloud computing approaches are used to speed up simulation times, outputs from the landuse model are used to dynamically constrain the decision space, and multiple simulation runs are used to characterise the variability of objective values with respect to future uncertainties. This later feature also enables the optimisation of mitigation portfolios such that they are robust with respect to future pathways.

GUI DESIGN

The Natural Hazard Mitigation DSS makes use of a dual user interface to facilitate both the use of the system for scenario analysis and integrated assessment of mitigation options, and the updating of data and parameters. Only those settings relevant for the use of the model are included in the *policy interface*. The sub-models with all their adjustments are still accessible for model experts through the *modeller interface*. On a high level, access is organized by the steps that a user takes to carry out an impact assessment analysis: configure drivers, create integrated scenarios, run the simulation, review output through the indicators, and analysis.



(A)



(B)

Figure 2. Mock-up graphical user interface for the natural hazard mitigation DSS, showing (A) maps, and (B) spider diagram elements.

The DSS allows the user to visualise drivers and indicators through a combination of maps, tables and graphs. Special attention will be given on appealing and understandable ways of entering information of drivers and providing results calculated by the model. Examples are the selection of census area units to which structural mitigation options can be applied through a map (Figure 2a) and the use of spider diagrams/radar charts, such as that shown in Figure 2b.

SUMMARY

Overall the proposed natural hazard DSS framework links simulation and optimisation, combines scientific and stakeholder knowledge in supporting hazard mitigation planning, and provides the potential to identify efficient combinations of mitigation measures for multiple hazards in a complex urban or regional system.

RISK AND PROTECTIVE FACTORS FOR BUSHFIRE RESILIENCE AND RECOVERY

Research proceedings from the Bushfire and Natural Hazards CRC & AFAC conference
Adelaide, 1-3 September 2015

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BACKGROUND

Building an understanding of resilience risk and protective factors is critical to the development and delivery of disaster response and recovery services. The impact of disasters on mental health and on social disruption has been demonstrated [1, 2]. However, there is limited understanding of the interplay between these factors because most of the research has tended to focus on either mental health *or* community impacts, in the short term period after a disaster. Individual capacity to adapt to the trauma event and the dislocating impacts of the disaster is likely to be dependent on the interrelationship between individual psychological functioning, community functioning and social cohesion. This will shift over time with different individual trauma recovery trajectories, changing community profiles, and social networks evolving through the recovery period. This interaction has not been well-captured in disaster research to date. In addition, there is a focus on outcomes for adults in disaster research, with a relative neglect of children and adolescents. This requires further examination because of the potential impact of trauma on the mental health, development, academic and social outcomes for children and young people, and opportunities to promote positive outcomes through community initiatives [3].

The Beyond Bushfires study aims to support the development of evidence-based strategies for promoting mental health, wellbeing and social inclusion of individuals and communities in regions affected by bushfires. The research achieves this by identifying social and community-level factors associated with individual recovery from the recent bushfire disaster in Victoria. This presentation will report on the findings of the Beyond Bushfires study on the impacts of the Black Saturday disaster experience and what made a difference to individual mental health and wellbeing afterwards.

'BLACK SATURDAY' FIRES

In February 2009, bushfires raged across the State of Victoria in southern Australia, with the worst occurring on Saturday 7 February, resulting in the 'Black Saturday' descriptor. This disaster represents one of Australia's worst with 173 fatalities, 3,500 buildings damaged or destroyed, significant impact on high value natural environments, and massive adverse impact on community infrastructure [4]. Two townships were completely destroyed, and others had significant damage.

BEYOND BUSHFIRES

The Beyond Bushfires: Community Resilience and Recovery study is a large-scale, multi-method longitudinal survey of community and individual health, wellbeing, and social connectedness in the wake of the 'Black Saturday' fires (www.beyondbushfires.org.au)[5]. It involves academic, community, government, emergency and service provider partners and recruited over 1,000 participants originating from 25 bushfire-affected communities in ten locations in rural and regional Victoria. The study explores the medium to long-term impacts of the Victorian 2009 bushfires on individuals and communities. A range of communities was selected to include high-impact (many houses lost plus fatalities), medium-impact (a small number of fatalities or no fatalities but significant property damage), and low-impact (no evidence of fires being present). Community diversity was also sought in terms of population sociodemographics, size of community, and distance from the capital city of Melbourne. The Beyond Bushfires study team commenced regular community visits in 2010 to ensure an understanding of local issues and contextual influences. A survey was administered in 2012 and followed up in 2014 (2014 results not available for this presentation), and in-depth interviews were conducted in 2013/14.

SURVEY

The Beyond Bushfires survey included the following domains, in addition to demographics: individual & organisational support networks; fire exposure; various mental health scales; resilience; attachment; general health; wellbeing; and community hope. The survey participants included 1016 adults (612 females, 404 males) living in the selected communities representing 16% of those eligible. Relative to census data, the sample was disproportionately older, female, and more educated than the general population, which is not unusual in research samples. For further information regarding the characteristics of this sample as a whole, including rates of mental health conditions, see Bryant et al [6]. Methods of analyses varied according to the issue being investigated. They included descriptive statistics, structural equation modelling and social network analysis.

QUALITATIVE INTERVIEWS

The in-depth interviews involved a sub-sample of the survey participants who indicated a willingness to be interviewed. They were purposively selected from high-impact communities with a variety of perspectives sought in terms of demographics and residential location. Interviews were conducted with 35 participants ranging in age from 4-66 years. Participant-guided mobile methods were used to explore participants' current sense of place and community. They involved an in-depth interview with the participant, combined with a walking or car driven tour around their property or local area, guided by the participant, to view and discuss places, things and events of importance to them. Detailed memos were recorded by the interviewers immediately after the interviews to capture initial impressions and learnings from the interview [7, 8]. This supported a subsequent thematic coding of the transcripts jointly by the three interviewers, with differing interpretations discussed until consensus was reached. Coding was conducted concurrently with data collection to allow for exploration of emerging themes through subsequent participant recruitment and interview discussions [9]. Categorized data were then compared and contrasted to develop a conceptual understanding of participant perspectives.

FINDINGS

Extensive findings are emerging from the Beyond Bushfires study relating to the impact of the bushfire experience and identification of factors influencing recovery. This presentation will provide an overview of the findings to reflect patterns of risk and protective factors likely to be relevant to emergency response and recovery services.

The study results show the disaster experience itself can have a direct and prolonged impact on mental health and wellbeing. Several years following the Black Saturday bushfires most people were not reporting severe psychological distress. However, a significant minority were showing symptoms of mental health disorders (25.6% in high-impact communities, 17.2% in the medium-impact and 11.7% in low- impact communities). Severe psychological distress was predicted by fear for one's life in the bushfires and death of someone close. Experiencing anger and major life stressors (e.g. change of income and/or accommodation) also contributed to the mental health impacts of fire experiences. Separation from close loved ones, during and immediately after the fires, was a risk factor for mental health problems, particularly for people who tend to feel anxious about their relationships. Age, gender and living circumstances influenced how the disaster and its aftermath were experienced. Importantly, this means that household and/or family members often differed in their responses to their bushfire experience.

A particularly strong finding in terms of recovery was that social ties matter. People with larger social networks were more likely to report loss of friends and extended family. However, close emotional ties, social networks and involvement in local community groups and organisations all contributed to resilience and recovery. People who were the most affected by the bushfires in terms of loss were more likely to move to a new community, with mixed experiences. For those who stayed in their community there was generally a stronger sense of community connection. For those who moved to a different community, the impact of subsequent financial and relationship difficulties was often lessened.

CONCLUSIONS

An overview of all of these findings will provide insights into the pattern of influences on resilience and recovery, with implications for future policy and service delivery.

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UNDERSTANDING PRESENT AND FUTURE BUSHFIRE HAZARD REDUCTION BURN WINDOWS IN NSW

Research proceedings from the Bushfire and Natural Hazards CRC & AFAC conference
Adelaide, 1-3 September 2015

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HAZARD REDUCTION BURNING AND THE NSW CONTEXT

Fuel management is the practice of maintaining vegetation at acceptable levels with respect to the risk posed to various assets by bushfires (Office of Environment and Heritage, 2013). A key aim of fuel management activities is to modify fuel characteristics in order to reduce fire behaviour, thus improving the ability to suppress bushfires. One method for managing fuel is hazard reduction (HR) burning, also known as prescribed burning: the planned use of fire, under specified weather conditions and in defined areas, to manage fuel. As part of its response to the 2009 Victorian Bushfires Royal Commission Final Report, the NSW Government committed to treating an average of 135,000 hectares per year of parks estate, largely through HR burning (NSW Government, 2010). The plan acknowledges that a narrow window of opportunity exists in NSW for burning safely and effectively, and that achieving burn targets depends on the presence of these windows of suitable weather conditions.

HR BURN WINDOWS IN PRACTICE

National Parks and Wildlife Service (NPWS) HR burn plans require preferred fire behaviour and weather to be specified. Fire behaviour properties include the planned fire intensity, the desired average flame height and the desired scorch height. Relevant weather elements include wind speed, wind direction, fuel moisture, relative humidity, soil moisture deficit and temperature. NPWS supplies some generic values of these quantities as a starting point, but staff are authorised to adapt these to local conditions (e.g. local vegetation) and the aims of the burn. An alternative to these generic guidelines stems from a pilot tool aimed at forecasting conditions suitable for HR burns (Rural Fire Service, 2013). However, despite recognition of the pivotal nature and relative infrequency of HR burn windows, there has been little quantification of just how frequently these windows occur, and other properties related to their spatiotemporal distribution in NSW. Moreover, it is unclear how closely the theoretical weather condition guidelines match those observed in practice i.e. during actual HR burns.

AN OBJECTIVE CLIMATOLOGY OF HR BURN WINDOWS

An aim of this research is to develop an objective climatology of HR burn windows in NSW, including their frequency, duration, variation and timing. In order to capture as many aspects of the phenomenon as possible, three measures of HR burn windows will be used: thresholds based on existing fire managers guidelines; thresholds based on extended burning seasons of autumn (March to June) and spring (July to October), during which the majority of burns take place; and reverse-engineered thresholds, based on prevailing weather conditions at the time that HR burns have taken place. This analysis required weather observations and records of prescribed burning from fire agencies. Because fire weather plays a key role in determining the suitability of weather conditions, observations of the McArthur Forest Fire Danger Index (FFDI; Luke and McArthur, 1978) are required. This limits the nature (point based rather than gridded), length (beginning 1973) and spatial coverage (a subset of the overall station network) of observations (Lucas, 2010). HR burn records are drawn from the Bushfire Risk Information Management System (BRIMS), in which high quality records commence around 2003.

PROJECTING THE IMPACT OF CLIMATE CHANGE ON HR BURN WINDOWS

Although multiple studies have investigated the impact of climate change on extreme and average fire weather conditions in Australia (Clarke et al., 2011; Fox-Hughes et al., 2014) and overseas (Yue et al., 2013; Lehtonen et al., 2014;), the authors are not aware of any studies projecting changes to fire weather conditions specifically conducive to prescribed burning. This study applies the HR burn window definitions discussed above to output from the NSW and ACT Regional Climate Modelling project (NARCliM; Evans et al., 2014). NARCliM utilises an objectively designed regional climate model (RCM) ensemble to project future changes in climate for NSW and the ACT. This ensemble is drawn from four global climate models and three RCMs, all selected for their skill in simulating the climate of NSW, their independence as models, and their ability to span the range of future climate change. Each RCM is based on the Weather and Regional Forecasting (WRF) regional climate modelling system (Skamarock et al., 2008). Model output has a horizontal resolution of 10 km. All models are supplied greenhouse gas concentrations corresponding to the A2 Special Report on Emissions Scenario (SRES) scenario (Nakicenovic et al., 2000).

WRF has previously been evaluated for its ability to simulate fire weather (Clarke et al., 2013) and the general climate (Evans and McCabe 2010) of southeast Australia. In general, WRF captures the broad distribution and spatial gradient in average and extreme FFDI well, but has an overall tendency towards overestimating FFDI. The evaluated simulations were forced by a reanalysis (also used in NARCliM), not a global climate model (GCM). This suggests that WRF does not introduce large biases to reasonable boundary conditions (i.e. reanalyses), but it does not address biases in the GCMs used to supply boundary conditions in this study.

SCOPE OF RESEARCH AND END USER FOCUS

There is already an active research community investigating the impacts of prescribed burning on bushfire risk (e.g. Price & Bradstock 2012; Cochrane et al., 2012; Burrows and McCaw, 2013). This study does not aim to critique current HR burning practices nor suggest solutions. Fire weather conditions are just one factor, albeit a very important one, that contributes to the decision to conduct HR burns. The aim of improving our understanding of present and future HR burn windows, in both theory and practice, is to give fire management agencies the best possible evidence for supporting decision making in this key area of bushfire risk management. To that end, fire managers have been involved in this project from conception to methodological design and are a critical part of ensuring the findings are useful and used by the fire management community in NSW.

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A BUSHFIRE EVACUATION PLANNING SERVICE UTILISING MULTIPLE SIMULATION SYSTEMS

Research proceedings from the Bushfire and Natural Hazards CRC & AFAC conference
Adelaide, 1-3 September 2015

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INTRODUCTION

Bushfires cause environmental destruction, property damage, and loss of life in many parts of the world. Examples include recent disasters in Australia, such as the 2009 bushfires in Victoria [1], and in the US with both the 2003 and 2007 fires in Southern California [2]. In addition, population growth and urban sprawl has given rise to communities where a large proportion of the population underestimate their risks. Therefore, enabling emergency services to better understand, plan, and prepare for such disasters is of great importance in mitigating the associated dangers. To this end, modelling the risk caused by bushfires on the population and environment has been a focus of research in recent years.

The behaviour of people during bushfires is a very important factor. People react differently as the emergency unfolds, and exhibit a variety of actions. Their awareness (e.g., the access to warning messages and danger reports), beliefs (e.g., on the defendability of their homes and the extent of the fire), evacuation behaviours and priorities (e.g., the need to save their pets and valuables), and consequently, their response to such events have a bearing on the overall outcomes of an evacuation within the affected region. This disparity in behaviours has a direct influence on the evacuee exposure risk.

MODELLING A BUSHFIRE EVACUATION

Multiple approaches have been proposed around modelling and simulation of bushfire evacuation scenarios aimed at better understanding the risks associated with them. However, many of the prior techniques are significantly simplified representations of reality.

In this talk we present a modelling and simulation approach that accounts for multiple dynamic factors affecting bushfire evacuation scenarios. A diagram of the core modelling components is shown in Figure 1. Our primary interest in this work is the safety of people. It follows that our modelling and risk assessment approach focusses on the movement of people and their proximity to threats.

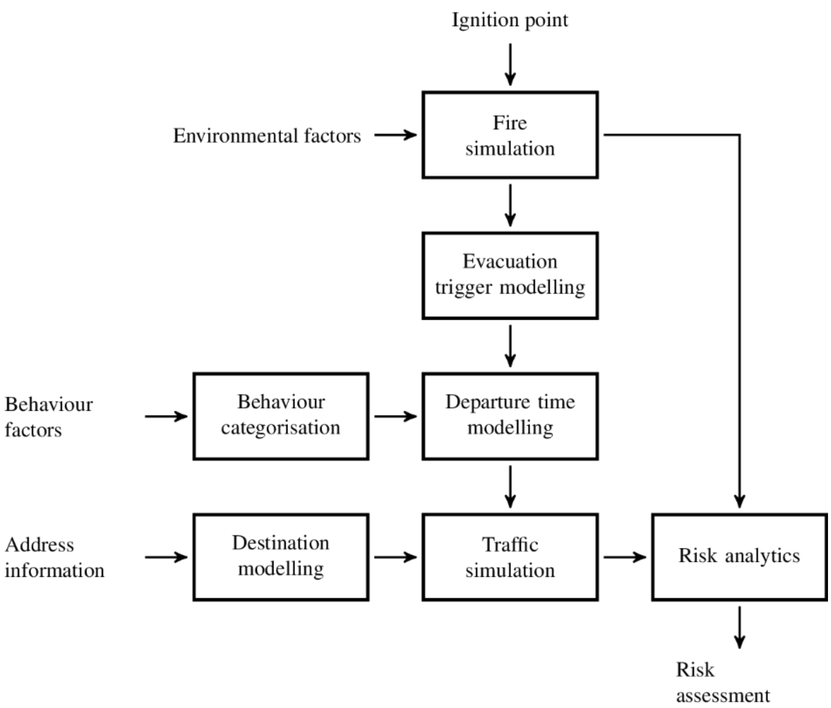

Figure 1: Modelling flow diagram

A *bushfire simulator* has been implemented following the cellular automata model for forest fire spread prediction proposed and validated by Alexandridis et al. [3]. In particular, our simulator captures the effects of the type and density of vegetation, wind speed and direction, ground elevation, and spot fires. In addition, the simulator includes models of the Fire Danger Index (FDI) and fire suppression efforts.

In response to the fire progression, several types of events are modelled and serve as evacuation triggers to the population. *Warnings* are sent out on a per-area basis, i.e., whenever the fire front is projected to impact an area the residents of that area are sent a warning of the estimated time-to-impact. There is also the *fire visible* event, which may trigger people to evacuate when they can see the fire.

Behaviour modelling captures the kinds of events people will respond to, i.e., what makes them leave, the timing of their departure, their vehicle use (people per vehicle) and destination selection (shelters, evacuation routes).

We use an agent-based *traffic simulator* to predict the movement of vehicles (and thus people) in each scenario. The particular simulator we use, SUMO, falls into the *microscopic* category in that individual vehicle dynamics are modelled explicitly. The simulator receives a set of *origin-destination-time* triples, one for each vehicle. It then computes a route for each vehicle before simulating their movements and interactions.

RISK EVALUATION

With the detailed results of the simulators we use, it is possible to derive more granular risk predictions. Specifically, we approximate the danger to a person by considering their proximity to the threat. We previously introduced a technique for computing the exposure count for an area or population. The basics of which follow.

We calculate the distance between a point $p \in \mathbf{R}^2$ and a threatened area $X_t \subset \mathbf{R}^2$ as $d(p, X_t) = \inf\{ f(p, a) : a \in X_t\}$, where f is the euclidean distance between two points. Both the threat and the position of each person will vary over time. We then define the *person-threat distance* (shown diagramatically in Figure 2) at time t as: $\xi_{it} = d(p_{it}, X_t)$ where p_{it} is the location of person i at time t. We obtain a minimum person-threat distance as $z_i = \min_t \xi_{it} T$. The *exposure count* for a population Q in a given scenario is the total number of people who were within some distance δ of the threat at some point in time, computed as:

$$E_Q = \Sigma H(\delta - z_i) \tag{1}$$

where $H(x) = 0$ if $x < 0$ otherwise $H(x) = 1$.

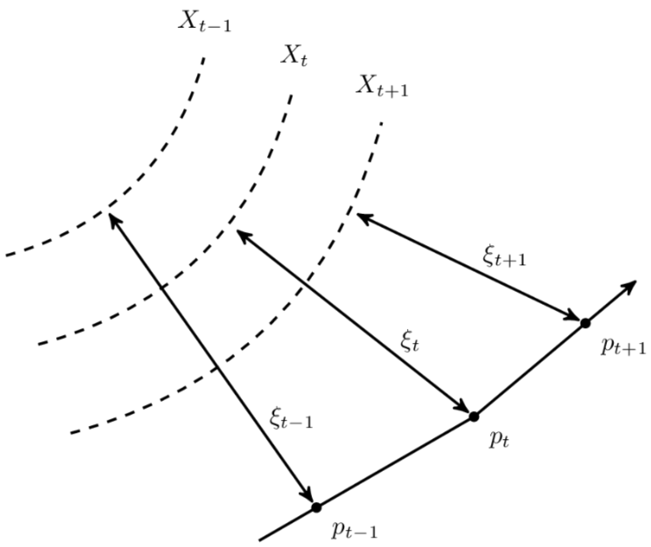

Figure 2: Person-threat distance. Note that in this figure we use $t - 1$ to denote 'the previous time-step' and omit the person index i for simplicity.

INTEGRATION PLATFORM

The internal design follows a Service Oriented Architecture (SOA) approach. The modelling, simulation and analytics components are each exposed as separate REST-based (Representational State Transfer) services. Data and execution flow is controlled by a workflow manager service, an orchestrator and a data-service. This separation into multiple web-services improves the ease and efficiency of development, testing, deployment, maintenance and scalability of the system.

An emphasis was placed on the composability and replaceability of services. To this end, all services are exposed through a standardized interconnect and designed around the abstract concept of a *job*. Also, a common framework was implemented and used across all services to handle job management, request processing and validation, data inputs and outputs.

New capabilities can be easily integrated into the system, and there is flexibility in the choice of modules (e.g., a different behaviour modeller service). More importantly, this is done with minimal impact to the REST interfaces of other services. We also achieve loose-coupling of components within the system by restricting links between components based on their data outputs and requirements, instead of pre-specified hard dependencies. This affords further flexibility and composition ease.

The workflow manager service is responsible for reactively driving the sequence of computations. It is charged with calling the various modelling, simulator and analytic services in the correct order, and ultimately informing the UI once computation is complete. An orchestrator manages a registry of services within the service composition system, and subscriptions to data-event notifications from other components. Finally, a data-service stores and serves all simulation outputs as they are generated.

USER INTERFACE

In order for this advanced modelling approach to be of practical value, it needs to be accessible to the people and organisations who must develop plans and make decisions to prepare for bushfire evacuations. Accordingly we have developed a web-based interface through which users can configure, execute and inspect evacuation scenarios. The user interface was built with the following objectives in mind:

- usable by a general audience with ten minutes of training,
- single click execution of full scenario simulation, and
- results should be returned within five minutes.

This interface is of value both during the planning activities carried out by emergency management organisations, and during community engagement campaigns. The use of dynamic visual scenario examples is a highly effective means of communicating the nature of the risk faced by residents. Accordingly, this tool helps to raise awareness and instigate greater responsibility among at-risk communities.

EXAMPLE USAGE

To further demonstrate the capabilities of our tool we now present a typical usage story.

1. User *A* opens the bushfire evacuation planning service in a standard web browser and sees the *scenario configuration* page. Here *A* can:
    - create and position one or more fire ignition points,

- create and position shelters, and adjust their radius of attraction (residents within the radius may then evacuate to the shelter),
- set environmental conditions (wind speed and direction, fire danger index), and
- inspect the local population distribution.

2. Once *A* has defined the initial conditions for a *scenario*, a simulation *job* can be submitted. This job enters a queue before the simulation begins under the guidance of the workflow manager service.

3. Upon completion of the job, a notification is delivered to *A* that the scenario results are ready for inspection

4. User *A* navigates to the results page for the newly completed scenario. Here *A* is presented with a regional break-down of the scenario outcomes. For each region there are estimates of the number of exposures and the time to evacuate for both local and through traffic.

5. On this page there is also time slider, which allows *A* to see the fire progression and the traffic conditions evolving over time. For the traffic, road segments are coloured according to the average speed of vehicle travelling over them within the current interval.

6. For each region more detailed statistics are also available. This includes a histogram of vehicle departures, and exposure counts. The histogram shows when people are leaving and often provides insight into the behaviour of evacuees. *A* can also see the number of shelter users originating from each region.

7. At any time *A* can configure alternate scenarios or variations on existing ones. In this way comparisons can be made and the impact of different factors can be assessed.

CONCLUSIONS

In this paper we have described a bushfire planning service for investigating the outcome of bushfire evacuation scenarios. The model builds on previous approaches by adding dynamic evacuation triggers (warnings and visibility) as determined by an evolving bushfire simulation.

The actions of evacuees have a dependency on their respective locations, relative to the threat, thereby enabling greater location sensitivity.

In addition, the combination of a microscopic traffic simulator with a dynamic fire spread simulator underpins the exposure count metric, which provides a direct estimate of the threat to a population in an evacuation scenario.

Finally, the approach we present is enabled by a model composition architecture. This architecture supports the seamless integration of modelling and simulation components in a way that is both efficient and scalable.

The work we have described is part of the *IBM Evacuation Planner* which is a decision support system targeted at emergency service personnel and community engagement groups. The system is currently designed for use in the planning stages of bushfire emergencies. Future work will consider the additional challenges of ingesting live data and generating real-time predictions.

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IMPROVED MODELING OF EXTREME STORM SURGES AND WAVES ALONG THE AUSTRALIAN COAST

Research proceedings from the Bushfire and Natural Hazards CRC & AFAC conference
Adelaide, 1-3 September 2015

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SUMMARY

More than 85% of Australians live near the coast resulting in a high density of coastal infrastructure and a population exposed to the destructive effects of extreme sea levels caused by storms. Successfully building resilience to, and planning for disasters when they occur requires accurate knowledge and prediction of extreme sea levels and areas susceptible to erosion and inundation. Recent advancements in numerical models now provide coastal planners and emergency managers with invaluable tools, such as inundation maps, to better prepare for and deal with disaster related to surges in sea level. Here we present results from state of the art storm surge modeling experiments and present a case study of a 'worst case scenario' storm, highlighting some modeling challenges and the improvements gained when waves are included in an advanced coupled storm surge model.

INTRODUCTION

Recent technological advances allow for realistic high-resolution numerical models capable of analysing dynamics to better understand how storms will impact the coastline through erosion and inundation and even predict such events. One of the most destructive storms in Western Australia was Cyclone Alby in 1978 that caused an estimated $50 million dollars in damage and killed five people. Large waves and extreme surges caused coastal erosion and inundation across the southwest of the state [1].

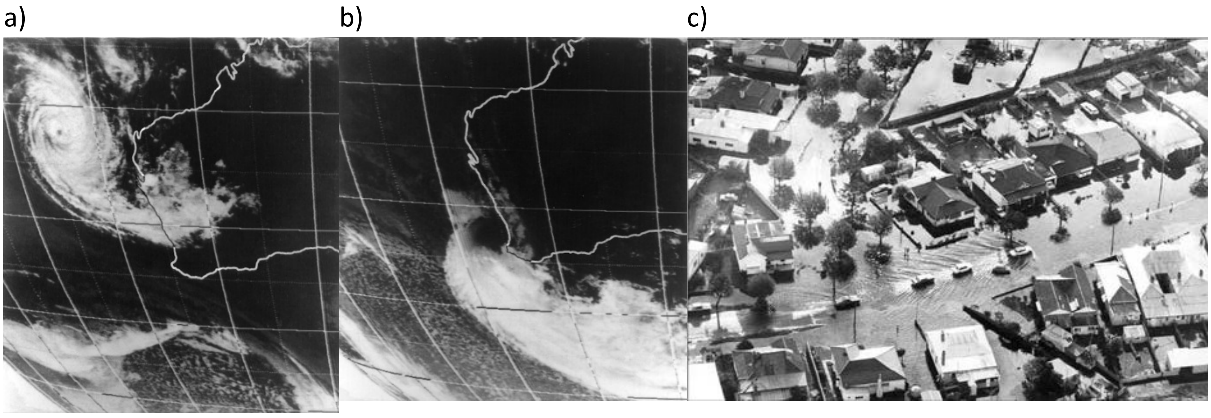

Figure 1. Satellite imagery of Cyclone Alby demonstrating the transition from tropical cyclone (a) to extratropical storm (b). Photograph of inundation in Bunbury, 200 km south of Perth caused by Alby (c). Source: http://www.bom.gov.au/cyclone/history/wa/alby.shtml#photos

Alby was not a typical tropical cyclone. As Alby moved south out of the tropics it violently interacted with an approaching cold front and became a hybrid storm transitioning from tropical to extra tropical in nature. The storm increased in speed, became spatially distorted with an extremely broad area of northerly winds along the coast, causing it to become a 'worst case scenario' for the southwest of the state due to the extreme waves and storm surge created [2]. Atmospheric models struggle to reproduce the dynamics of these transitioning storms [3] and historically simulations of the storm surge created by Alby and used to plan for future emergency situations have been limited to simplified wind models that treat Alby as a standard tropical storm. Here, we applied a recently released atmospheric hindcast dataset that has been shown to more accurately reproduce the dynamics of such storms than what has previously been available [4]. This in turn forced a state-of-the-art storm surge model.

METHODS

NUMERICAL MODEL SETUP

A realistic simulation of cyclone Alby was undertaken using the high resolution 3D finite element SELFE/SCHISM hydrodynamic modeling system that has successfully been applied to simulate storm surges in a broad range of coastal environments [5, 6, 7]. Model resolution increased toward the coast to as fine as 100 m. The model was forced with wind and pressure fields from the JRA-55 reanalysis (see below) and was two-way coupled with the WWMIII spectral wave model [8]. The coupled model better represented wind stress over the sea taking into account wave surface roughness and dynamics. Multiple model runs were undertaken with the coupling switched on/off to determine the effects of including waves. Model results were compared against measurements at available sites and the magnitude and timing of the surge matched well at Perth, Bunbury, and Busselton.

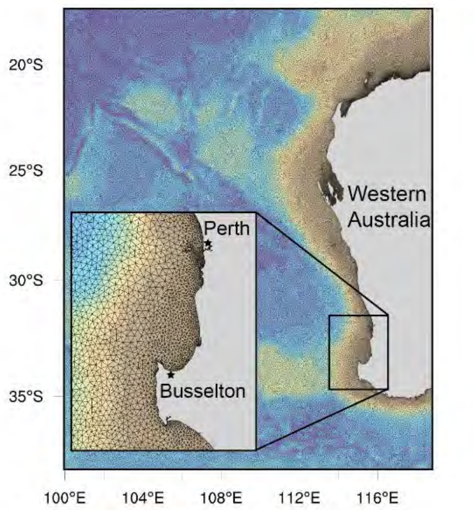

Figure 2. The model grid showing the study site and the unstructured mesh. Resolution increased from ~2000 m offshore to 100 m at the coastline.

The recently released Japanese Reanalysis JRA-55 reanalysis atmospheric model [9] provided wind and pressure fields on 1.25 degree resolution at 6 hourly intervals that were used to force the hydrodynamic model. This dataset has been shown to successfully capture the structure of storms transitioning from tropical to extratropical [4]. An advantage of the dataset is its vortex relocation algorithm that uses cyclone track data to ensure that the simulated storm follows an accurate trajectory.

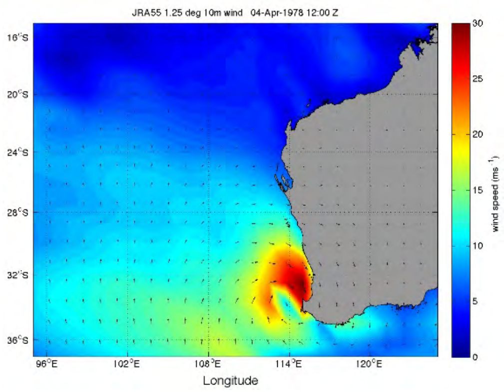

Figure 3. Snapshot of JRA-55 model wind speeds for cyclone Alby on 4 April 1978 used to force the hydrodynamic/surge model. Intense winds over a broad area created extreme surges along the SW Australian coastline.

RESULTS

Significant waves in the storm region were around 10m which agreed with ship observations (Fig. 4a). The two-way coupled modeling approach better represented wind stress over the sea taking into account wave surface roughness and dynamics. Including waves in the model also provided data on how waves acted to elevate water levels near the coast. The results revealed a closer fit with observed water levels compared with other commonly applied storm surge models. The predicted onset, magnitude, and duration of the surge event were similar to reported values. The surge from Alby peaked at 1.1 m in Busselton, with approximately 10% of the height resulting from wave effects included in the model (Fig 4b, 5). Highest water levels and the strongest currents occurred in Geographe Bay around Busselton in line with with observations during the night of 4 April 1978 (Fig 4b). In protected waters at Perth the storm surge created by model runs including wave effects reached 0.75 m whilst without waves the surge was only 0.44 m (Fig. 5). The difference here indicated that the wave effects could account for up to an astounding ~58% of the surge.

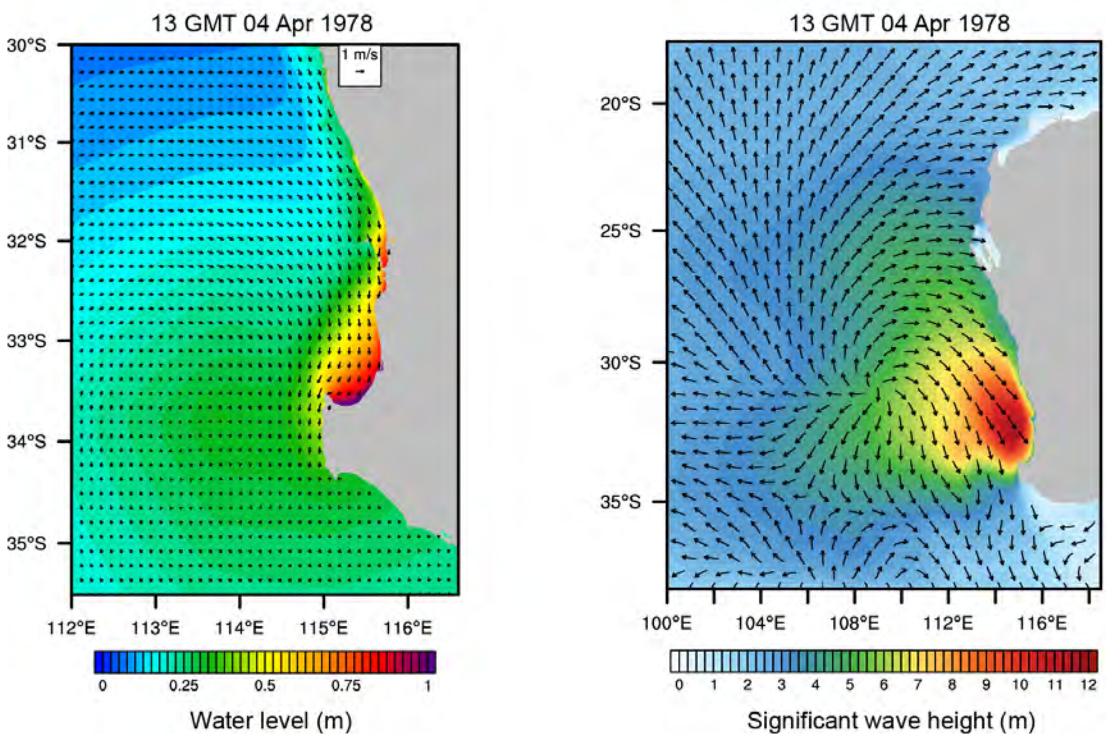

Figure 4. Model results from the coupled wave (a) and hydrodynamic (b) model. Colour background represents wave height in (a) and storm surge in (b). Vectors show wave direction and water transport respectively.

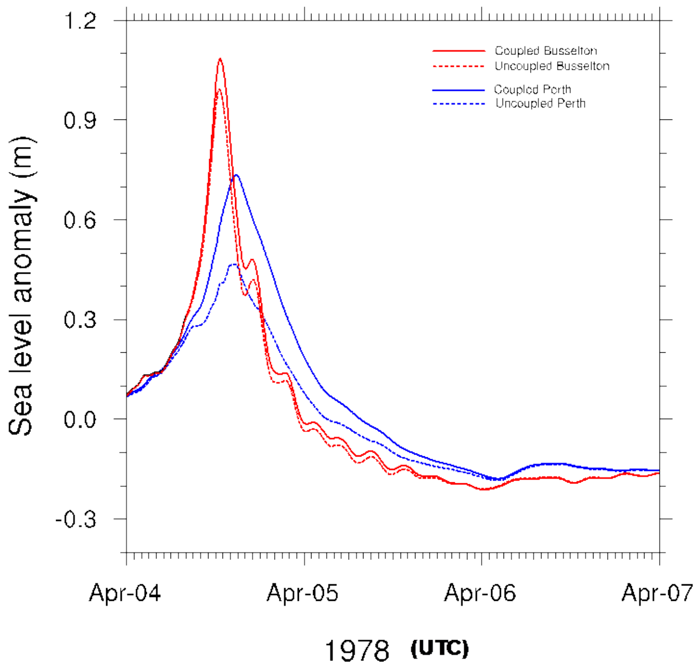

Figure 5. Modeled storm surge time series of water levels for the passage of Alby in Perth and Busselton for model runs with (solid line) and without (dashed line) the effects of waves included.

DISCUSSION

Cyclone Alby is presented here as a case study of a worst case scenario extreme event that is extremely challenging to model due to the nature of the storm and the lack of observations for this region and time period. In contrast to other comparable studies for cyclone Alby that used idealised cyclone wind fields we applied more realistic atmospheric forcing and modeled a storm surge comparable with observations at tide gauges. An additional benefit arising from the coupled hydrodynamic-wave modeling system was the ability to determine the relative contribution of waves to the surge. Storm surges are created by wind stress acting on the ocean surface allowing for setup at the coast and as a result the surge height is sensitive to the way that surface stress is quantified. The coupled model leads to a more realistic representation of stress causing an increased sea level response and higher storm surges. A secondary effect was an increase in water levels near the coast due to the presence of waves. In this case the increase in surge due to the inclusion of waves was between 10% and 58%. A benefit of the unstructured grid used here is the ability to simulate with extremely high resolution near the coastline, a requirement for inundation studies of land areas.

The successful application of this coupled model offers encouraging potential for improving predictions of a range of storm surge events along the coast. Ongoing work will expand to other parts of Australia to simulate other devastating storms and will also investigate inundation of land areas. The results will improve understanding of what conditions combine to produce damaging events and ultimately will contribute to improving preparedness for catastrophic storm events.

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LINKING LOCAL WILDFIRE DYNAMICS TO PYROCB DEVELOPMENT

Research proceedings from the Bushfire and Natural Hazards CRC & AFAC conference
Adelaide, 1-3 September 2015

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ABSTRACT

There has been a significant international collaboration studying the most extreme form of wildfire – pyroCbs (pyro-cumulonimbus or fire thunderstorm). Owing to their massive atmospheric impacts, the researchers include wildfire specialists, meteorologists and atmospheric scientists. There is a wide range of tools being used, including satellites, weather data, weather radar and fire ground observations. As a result, a comprehensive picture of these events is emerging.

One of the greatest challenges has been bridging the gap between what is seen on the fireground and what is seen in the middle layers of the atmosphere.

On November 22, 2006, two pyroCb events occurred in the Greater Blue Mountains, west and northwest of Sydney. These were in the Grose Valley in Blue Mountains National Park and near Mount Coricudgy in Wollemi National Park. These two case studies have been the subject of recent scientific studies aimed at addressing the gap.

The Wollemi Fire was the first extreme wildfire to be directly passed over by NASA's A-Train flotilla of earth observation satellites. Between them, these satellites recorded data from imagers, lidar, radar and UV backscaterring instruments. Useful data was collected for the Grose Valley Fire as well. This allowed confirmation that these were pyroCb events, and allowed detailed analysis of their structure and dynamics.

Later satellite data was used to track the downwind movement of the smoke at the upper troposphere – lower stratophere (UTLS). These elevated aerosol plumes are significant features on a global scale, and are studied in parallel with raised dust and volcanic plumes.

Satellite data was corroborated by radar data, which showed echotops up to nearly 12 km a.s.l. Radar data also showed that both fires had multiple pulses of convective intensity. Plume pulsing had been seen in satellite imagery previously in pyroCbs from Australia, Canada, the US and Russia, though the drivers of this pulsing were not clear. It was considered likely that variations in fireground energy release were involved.

The radar data also made it clear that both fires being studied escalated before noon but in association with a trough line, suggesting both the involvement of unusual surface weather and a role for atmospheric instability.

The NSW Rural Fire Service flew an airborne multispectral linescanner over the two fires a number of times. This permitted detailed assessments of changes in fire intensity with time, as well as assessment of the fire dynamics driving the fire's evolution.

The results for the Grose Valley Fire permitted a very detailed picture to be developed. Burning for some days over plateaux and in the incised Grose Valley, the fire exhibited expected behaviour in response to changes in surface weather. Fire spread was by means of a fireline of variable rate of spread and intensity.

Around noon on a dissected sandstone plateau, the fire exhibited atypical lateral spread. At a similar time much of the Blue Gum Forest area was consumed by dense mid-range spotting, with the spotfires rapidly coalescing. Radar data showed that this produced the first plume pulse that reached the UTLS.

Three hours later instance of atypical lateral spread occurred in the gorge of Govetts Creek. Radar data showed that this caused another plume pulse that reached the UTLS. Similar, events in the Wollemi Fire were also found to align with plume pulses that reached the UTLS.

The timing of the escalation of the fires was of interest. Weather records for the region indicated a foehn effect the night before. This caused significant deviations from the expected diurnal cycle for both temperature and relative humidity. The effects of these deviations would be to keep fuel moisture contents lower overnight, thereby priming the landscape for the occurrence of dangerous fire behaviour earlier in the day than would normally have been the case.

These studies clearly showed that the full information content of weather radar data is often underutilised, especially with respect to the characteristics of fire propagation. Radar allowed the bases of intense convection columns to be linked to places and times where distinctly dynamic modes of fire propagation were underway. The role of dense spotting was equally shown to be important.

In terms of the typical indices of surface fire activity, these case studies raised concerns. Fire danger indices on the blow-up day were not elevated, and were only slightly above those of the previous days when the fires burnt without any significant escalation. Australian fire danger indices only consider fuel flammability dynamics on hourly time scales (temperature and relative humidity) and on daily time scales (drought factor). The multi-hour time scale over which the foehn effects may persist on the landscape is not considered. There is an implication that this persistence involves fuel that is heavier than the normally-considered fine fuels.

Radar data showed that fire blow-up coincided with the passage over the fires of a trough-line. This developed normal thunderstorms in places, and new fire ignitions due to lightning were recorded in the region.

The studies also examined the Continuous Haines Index (C-Haines) for the fires. C-Haines peaked on the blow-up day, although only slightly above values for the preceding two days. The peak C-Haines values were reflected in both the stability and moisture components of C-Haines. It is thus evident that the fire danger and C-Haines indices, even when considered in combination, failed to unambiguously indicate that this day, and only this day, would exhibit blow-up fire behaviour.

These case studies have confirmed the significance of dynamic modes of fire spread (e.g. vorticity-driven lateral spread, aka: fire channelling) in fire escalation. Discovered only after the 2003 Canberra Fires, fire channelling has been confirmed or suspected in a number of key wildfire blow-ups in rugged landscapes. It is becoming clear that IMTs must be aware of the threat that dynamic fire spread poses as part of their dynamic risk assessments under AIIMS 4 doctrine.

These case studies have shown that blow-up fire events result from a combination of fire dynamics, fire weather and atmospheric instability. Consideration of one or two of these factors alone can provide an incomplete appraisal of the potential for blow-up fire behaviour. Similar case studies in the future will further aid our ability to anticipate pyroCb events, and the risks that they pose.

These case studies also indicate the value of detailed remote sensing data, whether it is from ground-based instruments (radar), airborne instruments (linescanners) or satellites. With the anticipated commissioning of the Himawari-8 weather satellite it is timely for us to improve our collective skill-levels in these respects.

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MAPPING IT OUT: A USER-CENTRED DESIGN FRAMEWORK FOR WEBGIS PUBLIC WARNINGS

Research proceedings from the Bushfire and Natural Hazards CRC & AFAC conference
Adelaide, 1-3 September 2015

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ABSTRACT

Hazard early warnings play a critical role in protecting lives and reducing property loss by providing information to citizens in a timely manner (Quarantelli, 1984). In recent decades, the way in which hazard related information is collected, managed and analysed has been revolutionised by geospatial technologies, such as Geographic Information Systems (GIS), Remote Sensing (RS) and Global Positioning Systems (GPS). Used in all phases of the disaster management cycle, GIS technologies allow for the integration and visualisation of a diverse range of spatial information (in the form of maps) during response and recovery as well as in the planning for and mitigation of hazards.

The effectiveness of maps has long been recognised for conveying the spatial and temporal dimensions of hazard conditions (Dymon, 1990, Hodgson and Cutter, 2001). In general, maps are demonstrated as essential tools for facilitating spatial cognition and aiding spatial reasoning (MacEachren, 1995). The contemporary interactive maps supported by either desktop- or web-based GIS technologies have experienced increasing attention for the ability to integrate a multitude of information whilst maintaining a suitable degree of complexity with ease of understanding (Dransch et al., 2010). The use of maps for decision support and communication however, occurs primarily within and between emergency management agencies. When it comes to communication with the public, hazard warning messages are still predominantly transmitted in textual or verbal forms and apply generically to large geographic regions. Recently, researchers have highlighted a need for map-mediated delivery of risk information to the public through WebGIS supported applications (Dransch et al., 2010). In addition to the inherent nature of maps for delineating spatial related risk information, WebGIS technologies also allow for location-based personalisation of maps, providing for a higher degree of contextualisation whilst overcoming the complex cognitive challenges of risk communication (Dransch et al., 2010). The applicability of such instruments is further supported by the advent of smart phones and wireless data communication technologies, which conjointly promise geographical targeting of at-risk population (Bennett et al., 2013) as well as real-time online dissemination of enriched content (e.g. images, videos, and mapping applications, etc.) (Dransch et al., 2010).

In addition to a clear need to increase the development of risk communication maps, researchers have stressed a growing necessity and importance of user-centred evaluation for designing usable and effective maps (Haynes et al., 2007, Dransch et al., 2010). This means that, rather than simple data fusion, effective hazard/risk mapping tools should be designed by assessing what is needed by the end-users (i.e. the public) to achieve the communication goals (Dransch et al., 2010, Lieske, 2012). It is underscored that such assessment is distinctive from the usability test in the sense of designing ordinary visual communication systems due to the profound psychological component of human perception and response to hazard/risk maps (Handmer, 1985, Lieske, 2012). However, a thorough search of literature only uncovered several general 'frames' for the development of user-centred risk maps, especially focusing on communicating *long-term* probabilistic risk (e.g. risk of climate change) (Haynes et al., 2007, Dransch et al., 2010, Lieske, 2012). There exists no precedent for the design of map-mediated *early warning* instruments to inform impending threats. In fact, the limited number of public warning maps that have been developed to date has generally been designed based on the subjective judgment of those creating the messages (i.e. cartographer, technician or emergency management personnel). For example, local authorities have recently started to release static or simplistic interactive maps over the Internet vaguely depicting incident locations to supplement the text warnings. The intention of such a mapping approach, although unsubstantiated, is potentially driven by a series of common emergency management myths, such as the public are not fluent map readers and may be overwhelmed with large amounts of highly accurate information (Sorensen,

2000). In addition, online mapping portals (e.g. Liu and Palen, 2010, USGS 2012) often focus on integrating and presenting an assortment of hazard and risk information (e.g. wind, topography) neglecting critical warning elements such as response guidance. What remains unknown is whether, and exactly how, the heterogeneous mapped information is understood and used by the recipients to understand risk and undertake appropriate actions (Haynes et al., 2007).

To address this void, this paper describes a user-centred framework utilised as the methodological foundation for designing an innovative WebGIS based bushfire early waring tool. The overall methodology draws upon the rich body of literature that investigates and illustrates user-centred design approaches for developing map-based visualisation tools in other domains (e.g. Robinson, 2005). Measurement of *effectiveness* of the bushfire mapping tool is defined based upon the cognitive objectives of public early warnings in general, which concerns three major aspects: 1) whether the (mapped) information is comprehended; 2) whether risk perception is facilitated; and 3) whether adaptive behaviours are stimulated (Mileti and Sorensen, 1990). The adapted research workflow is shown in figure 1. Initially, a conceptual model was conceived to facilitate individuals' risk perception and decision-making through location-based map presentation, and personal risk assessment and decision support. The following two critical design questions were then addressed: i) what information should be communicated, and ii) how can maps be designed to effectively present the information.

A two-phase user assessment approach was established to answer the design questions. First, a collection of hazard/risk information elements and associated cartographic representations were collated based on existing bushfire warnings and mapping schemes across Australia. A *users' needs assessment* was then conducted via an online survey with residents from bushfire prone areas, seeking to investigate the extent to which maps are more or less effective than texts in terms of understandability and promotion of risk perception. The survey also identified the most effective cartographic methods for representing and communicating a diverse range of hazard/risk related information elements. The survey findings showed a corroborated efficiency and effectiveness of maps (in contrast with texts) for communicating a majority of bushfire information. Based on the findings, a web-based bushfire information mapping tool was prototyped to integrate and deliver a range of information through texts, maps, or a combination of both. The second assessment phase, *usability and effectiveness evaluation*, was subsequently conducted using the prototyped web-based bushfire information mapping tool through 'think aloud' interviews with individual residents, to examine the ease-of-use of the tool and investigate how each bushfire information element is interpreted and used by residents in their cognitive procedure of perceiving risk and making decisions. In addition to illustrating a first user-centred approach to the development of a bushfire warning tool, the presented research framework can provide a general structure to guide user-centred design of map-mediated risk communication tools for a range of other hazards. More specifically, it demonstrates how design questions, evaluation attributes and assessment methods can be defined and formulated in a way that gives the user a central role.

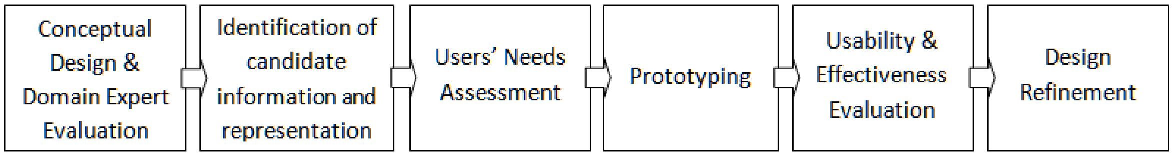

Figure 1. The user-centred research workflow for designing map-mediated public warning tools, adapted from Robinson (2005).

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COMBINING HYDROLOGIC AND HYDRAULIC MODELS FOR REAL TIME FLOOD FORECASTING

Research proceedings from the Bushfire and Natural Hazards CRC & AFAC conference
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ABSTRACT

Floods account for approximately 40-50% of all disasters and disaster-related deaths worldwide. Although improvements in mitigation and preparedness have reduced flood-related mortality, in the last decade of the 20th century, floods still caused an estimated 100,000 deaths and affected almost 1.4 billion people worldwide. In Australia, floods are the most common natural disasters and cause the most loss of lives.

Coupled hydrologic-hydraulic models have been widely used for the modelling of design flood events in order to reduce monetary damage and increase preparedness; nevertheless an accurate and reliable flood forecast in real time is vital for giving warnings and for emergency response to reduce flood-related mortality.

In this study, a continuous hydrologic model was combined with an event-based hydraulic model to build an integrated forecasting system. In particular, the conceptual hydrologic model GRKAL was adopted to continuously model streamflow into the river system. The forecasted hydrographs were then used as inputs for the hydraulic model, LISFLOOD. The latter solves the inertial approximation of the shallow water equations to assess the extent, depth, and velocity of the flood wave in each point of the tail valley.

In order to test this coupled hydrologic-hydraulic model, forecasting experiments have been completed in a “hindcasting” scenario using historical meteorological records in two Australian catchments. The results indicated reasonable accuracy. In the next step the potential of assimilating remote sensing data and ground measurements to constrain the coupled model will be tested for achieving improved real time predictions of the spatial and temporal development of floods. The final aim of the coupled model is the provision of accurate real time predictions of the extent, depth, and velocity of the flood wave for each point of the catchment. This information will benefit the emergency response teams.

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INVESTIGATION OF DAMAGE: BRISBANE 27 NOVEMBER 2014 SEVERE STORM EVENT

Research proceedings from the Bushfire and Natural Hazards CRC & AFAC conference
Adelaide, 1-3 September 2015

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INTRODUCTION

The city of Brisbane and other Australian cities are often subject to thunderstorms that can cause significant damage to houses by hail and strong winds. The severe thunderstorm of 27 November 2014 was an example of such an event. Two adjoining storm cells moving in a northerly direction (Figure 1) subjected Brisbane and neighbouring suburbs to severe hail, damaging winds and localized flooding.

Damage estimates for the event exceeded $1.3bn AUD (Insurance Council of Australia, 2015). The high cost of the event was mainly due to hail damage to motor vehicles and windows of buildings. Information from the Insurance Council of Australia suggests that up to 70% of claims were from hail damage to vehicles alone (Insurance Council of Australia, 2014).

Several cases of severe structural damage did occur due to wind loading. In response, the Cyclone Testing Station (CTS) conducted street and house surveys between the 28th of November and the 5th of December to estimate wind speeds in affected suburbs. Additionally, where structural damage was observed, the nature and likely causes of failure were determined. It was found that failures that occurred were due to defective construction details, degraded timbers and poor renovation and repair work.

It was frequently reported in the media that the storm brought winds of 140km/h. However it is believed that this gust was only an isolated occurrence due to the intensification of the storm's rear flank downdraft over Archerfield airport. From field surveys and analysis of Doppler radar it is estimated that high winds were up to 100 km/h in open terrain and 80km/h in suburban terrain within the affected areas.

This article will present an analysis of the wind field during the event and a summary of the damage investigation that was conducted. Further details can be found in Cyclone Testing Station's Technical Report 60 (Parackal et al., 2015).

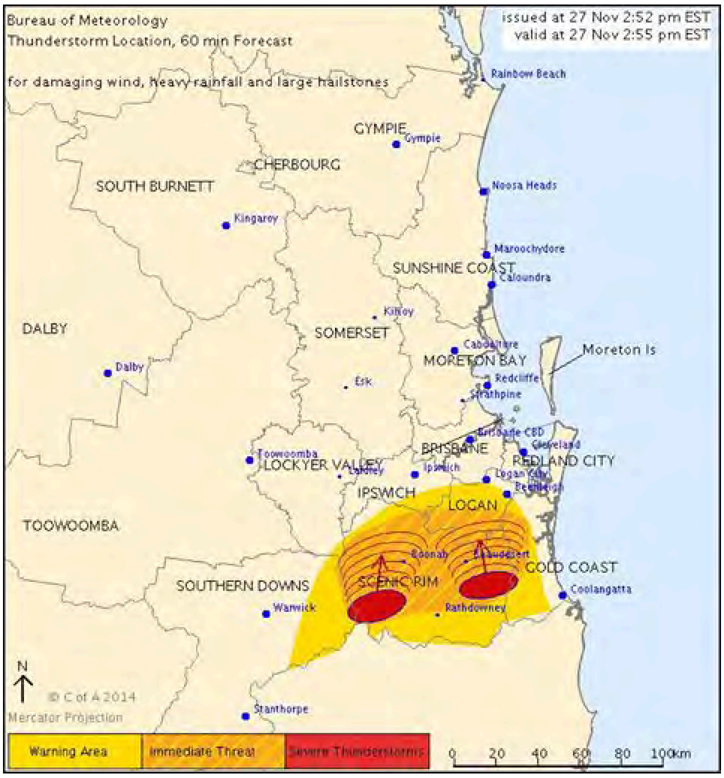

Figure 1: estimated storm track source*: bureau of meteorology*

ESTIMATED WIND SPEEDS

Based on field observations it is believed that the maximum surface wind speeds in most affected areas were below the 141km/h gust measured at Archerfield Airport. Indicators used were damage to street signs, buildings and defoliation of trees. It was found that in areas where complete roof failures occurred there was still considerable leaf cover including flowers and seedpods as well as relatively undamaged palm fronds. Unlike the widespread hail damage to windows, severe roof failures were localised, affecting individual houses with neighbouring houses relatively undamaged.

In addition to these damage indicators, a full surface wind field assessment was made using a combination of Bureau of Meteorology (BoM) 1-minute automatic weather station (AWS) measurements, radar scans (Mt Stapylton rain and Doppler winds), and amateur weather station information from the website WeatherUnderground.com. Figure 2 shows the broad area affected by winds greater than 90 km/h (at scan level), as observed by the Doppler radar. The majority of strong winds appear to have come from the southeast through southwest quadrant. Damage observations also suggest a strong southerly component to winds throughout this entire region.

The strongest winds for this event are believed to have occurred within the storm's rear flank downdraft (RFD). More specifically, they occurred during what appears to have been a re-intensification of the existing downdraft that occurred over Archerfield Airport as a result of intense rainfall and hail. Observations of damage to trees, buildings and road signs around the airport show evidence of diverging winds, suggesting downdraft impingement occurred near to the area. Given there was no intensification of wind speeds as the storm moved north of this point (as per Doppler imagery), and that winds would have been influenced by the rough suburban terrain, it is expected that lesser wind speeds would have been experienced throughout the suburbs north of the airport.

Considering these data it is believed that the storm's maximum wind speeds would have occurred in the vicinity of the Archerfield Airport AWS, and are unlikely to have been significantly higher than the 141 km/h recorded at that site. Given an observed gust of 84 km/h at the Brisbane AWS and similar, but less reliable, amateur weather station observations at Bardon, Ashgrove and Fig Tree Pocket, it is believed that wind gusts felt throughout much of the 'high wind region' (Figure 2) were up to 100 km/h in open terrain and 80km/h in suburban. These winds speeds are less than design wind speeds specified in the Australian wind-loading Standard AS/NZS1170.2. For a house in Brisbane this would be approximately 170km/h in suburban terrain (Standards Australia, 2011).

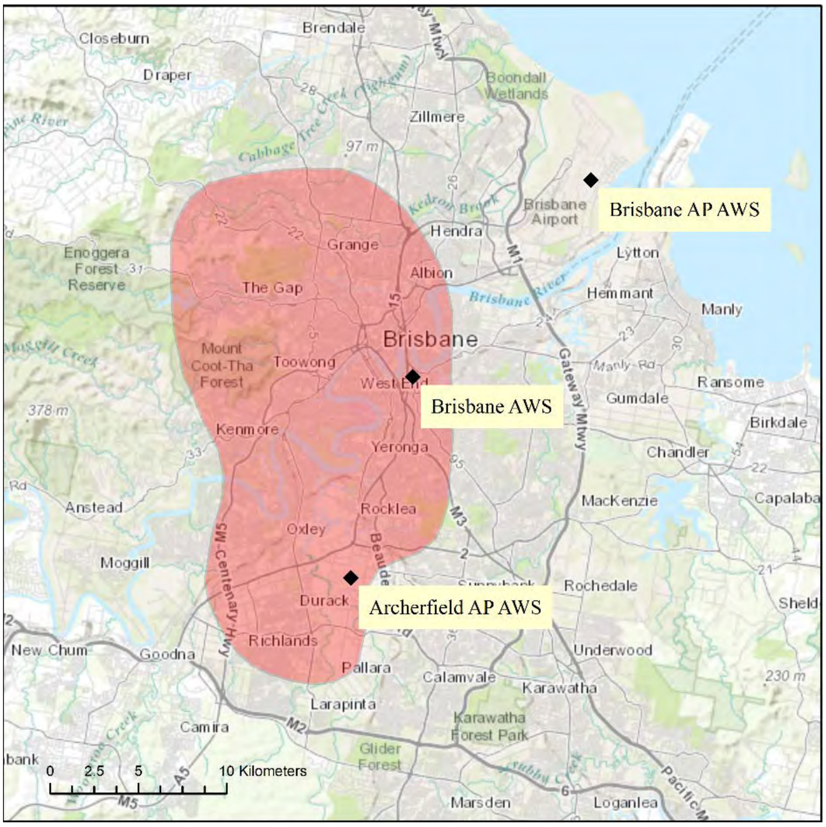

Figure 2: Envelope of areas with Doppler recorded wind speeds greater than 90 km/h.

Base image source: ESRI

Table 1: Maximum wind gusts measured by BOM weather stations as the storm moved in a northerly direction

Location	Maximum Gust (km/h)
Archerfield AP AWS	141
Brisbane AWS	84
Brisbane AP AWS	37

DAMAGE ASSESSMENT

As the storm moved in a northerly direction some impacted suburbs included: Archerfield, Moorooka, Annerley, West End, Brisbane CBD, Spring Hill and Herston. Locations of damaged properties were provided by the Queensland Fire and Emergency Services (QFES) through their Rapid Damage assessment (RDA) conducted within hours of the event occurring.

The RDA also provided an indication of the overall severity of damage from the storm. More than 2800 damaged properties were recorded with approximately 80% of these being houses. Of the damaged properties, approximately 92% of these were considered ‘minor’ damage, 7% ‘moderate’ and 1% ‘severe’. During this event most ‘minor’ damage was from broken windows due to hail, ‘moderate’ and ‘severe’ damage from debris or tree impact and in a few cases roof failure due to wind load.

Based on this information, teams from the CTS conducted street and house inspections between the 28th of November and the 5th of December to determine typical damage levels to the general building stock and causes of failure in the case of significant structural damage. Key observations from this survey include:

- The majority of damage to housing was window breakage due to hail, subsequently resulting in damage due to water ingress.
- There was a noticeable difference in performance of new vs. old window glass in this event.
- Structural damage due to wind was observed in several locations. Roof damage was observed mostly on older housing, on some occasions with complete roof loss. Often these were due to incorrect detailing after renovation works e.g. replacement of roof cladding.
- Generally little tile damage due to hail was observed, as most records of hail were smaller than the threshold for tile damage (50mm diameter) (Risk Management Solutions, 2009).

STRUCTURAL DAMAGE

Despite estimated winds being less than design wind speeds, several cases of significant roof failures were observed. These were typically older structures including houses, units and churches. Very often neighbouring houses had little or no roof damage at all, indicating that the area experienced low wind speeds.

Several failures of new roofs installed on old structures were observed. This was often the case for tile roof buildings that were replaced with newer metal cladding (Figure 3) Generally original battens were retained but the new cladding only fastened to a few battens. In one case this was to every 3rd batten and in another every 6th batten. This resulted in the overloading of batten to truss connections or cladding fasteners during the storm, causing the failure of large sections of the roof. In some cases, when metal clad roofs were replaced with new cladding, the older battens were not checked for rot or degradation. In one case this resulted in the loss cladding of the entire roof (Figure 4)

There were cases of complete roof loss of top floor units of some double brick apartments with timber roofs. For one site that was surveyed this had occurred due to window damage by hail, and a subsequent dramatic increase in internal pressure. The timber rafters of this apartment was observed to have insufficient tie down and resulted in the loss of the entire roof structure (Figure 5). Most cases were roof failures occurred resulted in debris damage to neighbouring properties otherwise undamaged by wind loading.

Damage from this event highlights the importance of reconstruction and repairs being carried out in accordance with relevant Standards and the regular inspection of structural elements within the roof space, to look for signs of deterioration such as corrosion and rot. For the rebuilding or upgrading of older housing, the complete load path from roofing to foundations must be considered, this is especially relevant when changing from a tile roof to metal roof cladding. Reference should be made to documents for the upgrading of older housing such as HB132.1 or AS1684 User guide no 3 (FWPRDC, 2002, Standards Australia, 1999).

Figure 3: Loss of metal cladding and battens of a church. Originally a tile roof, the new metal roof was only secured to every 6th timber batten.

Figure 4: Loss of cladding and battens of an older home. New cladding had been installed onto the original battens.

Figure 5: An example of complete roof loss of the top storey unit of a 3-storey apartment building (new roofing currently being installed). Original timber rafters had inadequate tie down to withstand internal pressure due to the breakage of a large southern facing window. The unit was also located on top of an escarpment (outlook shown in the lower photograph) and may have experienced slightly higher wind speeds.

HAIL DAMAGE AND WATER INGRESS

The level of damage to houses was especially high due to window breakage from hail and subsequent water ingress. The latter could be observed by damaged furniture and goods that were placed outside of homes for collection (Figure 6). Apart from the widespread damage to cars from hail, it is likely that water ingress would be a large contributor to insurance claims from this event.

Estimates of hail intensity and size reported by the media varied greatly. The BoM reported that 40mm diameter hail (golf ball size) was observed in most locations and the CBD experienced up to 70-80mm diameter hail. Based on damage observed it is believed that the hail impacting buildings in the areas studied was indeed up to 40mm in diameter. Common hail damage to roofs observed during this event included, dented roof vents, broken skylights and damaged air conditioning units.

The strong winds created a significant horizontal component in the trajectory of the hail. Many streets were surveyed that had the majority of windows on the southern side broken, even those that were protected by awnings, while windows on other sides were undamaged (Figure 7).

It was observed that newer windows showed a better resistance than older thinner window glass. There were several examples of new homes or recently renovated homes with new windows experiencing little to no hail damage compared to older houses nearby (Figure 8). Thus, anecdotally, the installation of the new windows can reduce the vulnerability to water ingress and potential structural damage from internal pressures.

Figure 6: Broken windows on the southern facing wall as well as water damaged goods placed at the front for collection was commonly observed.

Figure 7: Hail damage to windows and vinyl cladding of an older house. The proximity of the neighbouring house on the right and the size of the window shades suggest hail being driven at a sharp angle by the wind.

Figure 8: A new apartment building in a storm-affected neighbourhood. All windows on the exposed southern side were undamaged, indicating the improved performance of new window glass.

CONCLUSIONS

The Brisbane thunderstorm of 27 November 2014 caused significant damage to properties as well as motor vehicles due to strong winds and wind driven hail. From field observations and the analysis of meteorological data, it is believed that wind speeds in most affected suburbs were significantly less than the 141km/h gust at Archerfield airport. It is estimated that winds of up to 100 km/h in open terrain and 80km/h in suburban terrain would have been felt in the affected suburbs.

Wind-driven hail extensively damaged windows (predominantly on older housing) leading to damage to building interiors from water ingress. There was a noted difference in the performance of new window glass compared with older windows.

Despite wind speeds being less than design level, several roof failures did occur. These were often caused by the deterioration of old connections or inadequate detailing of connections during renovations. This was especially the case when changing roof cladding from tiles to metal sheet. Such damage highlights the importance of repair and renovations being performed according to contemporary building Standards and the inspection of older structures for signs rot and corrosion.

ACKNOWLEDGEMENTS

The CTS appreciates the support and assistance of the Queensland Fire and Emergency Services, Bureau of Meteorology, Brisbane City Council and the Bushfire and Natural Hazards CRC (BNHCRC). Additionally, we are very grateful to the residents who generously assisted this survey by volunteering information, answering questions and on occasions inviting the authors into their houses to inspect damage.

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HOW DO WE REDUCE VEHICLE RELATED DEATHS: EXPLORING AUSTRALIAN FLOOD FATALITIES 1900-2015

Research proceedings from the Bushfire and Natural Hazards CRC & AFAC conference
Adelaide, 1-3 September 2015

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INTRODUCTION

Floods are the second highest cause of death from natural hazard events in Australia following extreme heat (Coates et al 2014)[1]. Research funded by the Bushfire and Natural Hazard CRC has so far uncovered 1874 flood fatalities between 1900-2015. This paper documents the initial findings and implications of research on flood fatalities. In particular, the growing number of fatalities associated with vehicles entering floodwaters will be discussed in relation to potential management strategies.

The analysis of flood fatalities is the first part of a wider project to examine human fatalities, injuries, rescues and building losses from natural disasters in Australia from 1900 to the present. The hazards of interest include: floods, cyclones, earthquakes, heatwaves, severe storms (gust, hail, lightning, tornado, flash flood) and bushfires. Measuring and understanding the impacts of natural hazards in terms of the toll on human life and building damage is a fundamental first step to enabling efficient and strategic risk reduction. The outcomes of this project will inform a wide-range of emergency management and government end users to advise on and update policy, practice and resource allocation.

RESEARCH PROCESS

Over the past 20 years researchers at Risk Frontiers have documented details of natural hazard events that have impacted Australia, from 1788. This information has been collected from publicly available documents, predominantly newspapers and government reports. Importantly, the information on fatalities contains, where possible, names of the deceased. This allows coronial files to be searched for further details on circumstances of the fatality. This information is crucial in order to meet the objectives of this project and conduct a comprehensive analysis for use by emergency services and government officials. The research is:

- Locating further names of the deceased
- Researching physical flood characteristics
- Adding details from coronial records.

Social and environmental factors of interest include:

- ***Social*** - Age, gender, occupation, preparation, risk reduction activities, knowledge / warnings received, activities / decisions leading up to and at the time of death, capacity to act, mode of transport, medical cause of death
- ***Environmental*** - Details of location and hazard: e.g. flood type, flood height and intensity (such as "a one in 100 event").

The statistical analysis will provide a longitudinal analysis of social and environmental circumstances that led to the fatalities in order to examine trends over time in terms of exposure and vulnerability. Trends will be interpreted in the context of emerging issues (e.g. ageing population and population shifts) and how these issues might influence vulnerability and exposure trends in a future changed climate.

[1] The numbers of flood fatalities have been updated since this publication. Flood fatalities are now higher than those from cyclones.

PRELIMINARY RESULTS[2]

OVERVIEW

- Total flood fatalities between 1900 and 2015 are currently 1874
- Of these 78% are male and 20% female (there are 50 fatalities of unknown gender)
- The majority of fatalities have occurred in Queensland, (39%) followed by NSW (37%) and Victoria (11%)
- In terms of age, children and young adults are the most vulnerable group
- The majority of both men and women die as they cross a watercourse or bridge in an attempt to maintain normal everyday activities. Other reasons include work, recreation and evacuation
- Of those infants who drown, many die whilst being evacuated and / or being taken across a watercourse or bridge
- Over the last 20 years to 2014, at least 81 people have died driving through floodwater in Australia, accounting for 43% of all flood fatalities over this period. 35% of these were driving 4WD vehicles: an increase in percentage over the previous two decades.

DISCUSSION ON THE VEHICLE RELATED FATALITIES

People entering floodwaters by vehicle constitutes a major cause of flood fatalities in Australia and globally (Haynes et al 2009). If water is fast-flowing, even thirty centimetres of floodwater can wash a car off the road. In addition, drivers may be unable to see what lies beneath flooded roads, with large sections of roads often washed away, creating hazardous conditions.

The problem is possibly easier to target than other flood deaths caused by walking or playing in floodwater, as motorist deaths occur largely in defined geographical areas where floodwater and roadways intersect.

[2] These results are preliminary and accurate as of July 21st 2015. Numbers will change as more data is gathered. Final flood results will be available in October 2015.

MANAGEMENT STRATEGIES

Typically, Australian management strategies have relied upon education and rescue interventions as the primary management tools. Figure 1 shows the four elements required for a more holistic strategy to change this behaviour: education and awareness, regulation and incentive, structural intervention and consequence management. The rest of this paper briefly explores each of these and identifies considerations for action.

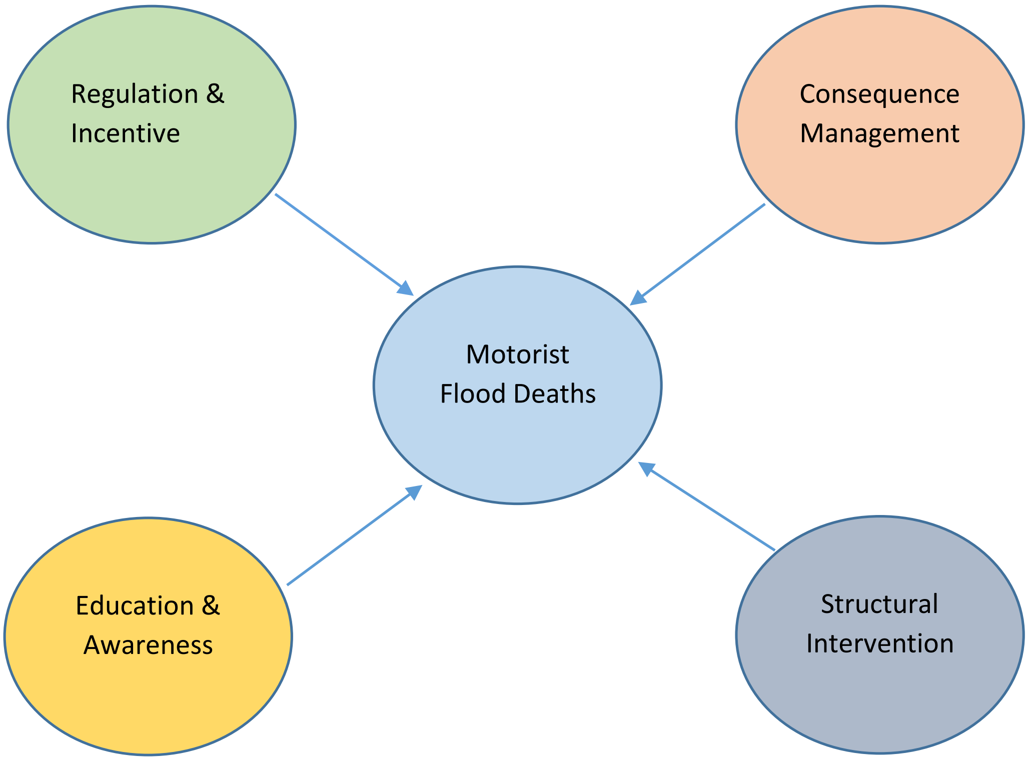

Figure 1 – Holistic Management Strategy elements

EDUCATION AND AWARENESS

Education and awareness, comprising both education campaigns and safety messages in public warnings, have been the primary strategies used to change behaviour. Some of the more prominent include:

- 'If it's flooded forget it' (Queensland Government)
- 'You don't know what you're getting into'(Victoria State Emergency Service)
- 'Turn around don't drown' (US National Weather Service).

Typically, campaigns have consisted of signage, TV commercials, social media and media engagement. Evaluation of Australian and international campaigns has been limited.

To be successful, campaigns must utilise messages and communications channels that target key risk groups, in particular males, and involve multiple partner agencies not just the emergency services e.g. road safety groups, peak motorist groups, water safety bodies, insurance companies and schools.

During flood events, variable message signs can be utilised to reinforce key messages about the dangers of floodwaters. Current roadside markers indicate depth of flooding, but leave motorists to interpret the risk. Provision of road information is also key so motorists are aware of flooded roads and less likely to travel routes which include traversing flooded roads. Today live traffic and road closure information is more widely available using online tools, radio broadcasts and broadcasting directly into car GPS units.

Some additional methods for consideration include:

- Inclusion of educational messages in driver training materials
- Altering road side depth markers to indicate level of risk rather than just depth of floodwater
- Implementation of a nationally consistent campaign as recommended by the Queensland Floods Commission (2012)
- Enhancement of flood warning systems, particularly in flash flood environments, enabling agencies to engage with communities, pre-deploy resources and close roads in a proactive manner
- Specific location-based warning systems in high risk locations. These may include lights and sirens, or locally based broadcasts through car radio systems.

REGULATION AND INCENTIVE

Regulation is an instrument frequently used to change behaviour: for example in enforcing speed limits and reducing the prevalence of smoking. Regulation, however, has not been used across Australia as a key strategy in stopping motorists from driving though floodwater. Queensland Police have utilised the enforcement of driving laws during flood episodes to change behaviour: drivers have been convicted of careless driving, resulting in fines and license disqualification. In 2012 a Queensland man was found guilty of manslaughter and jailed for driving into a flood. His action had caused a passenger's death.

In a similar vein, motorists who remove temporary barriers to allow their vehicle to pass could be prosecuted. In addition, a series of mobile cameras similar to speed cameras could be positioned at high-risk flooded roads to assist in enforcement.

The enforcement of regulation does require some discretion, however: for example, in the event of circumstances where motorists have travelled through floodwater due to emergency circumstances such as evacuation.

Incentives should also be considered and may include:

- Motorists requiring rescue being required to pay for the cost where behaviour is deemed reckless
- Insurance companies not being obliged to pay claims for vehicles damaged as a consequence of reckless driving through floodwater.

STRUCTURAL INTERVENTION

The erection of barricades and signage aims to physically prevent motorists from entering floodwater. However, due to the portable nature of barricades, motorists are able to move or drive around them. Often, flooding may occur before authorities can establish barriers.

To enhance the effectiveness of barriers we propose the following:

- Manning of barricades in high risk areas with personnel from emergency services or road authorities
- Establishment of automatic gates in high risk areas activated remotely or when triggered by a flood warning system.

Road design in flood-prone areas could have an important influence on survival outcomes of motorists once their vehicle becomes buoyant and should be an area of further research. The following road characteristics may influence the level of risk posed:

- Presence of roadside barriers to prevent vehicles being swept off
- Height of the road above surrounding terrain, determining the depth of floodwater a vehicle may be swept into
- Presence of vegetation as a natural barrier to prevent a vehicle being swept downstream
- Presence of road lighting to illuminate dangers at night.

If these factors were proved to have a significant impact, their consideration in road design and in prioritising emergency service resources could assist in reducing the death toll.

Vehicle design has proved to be a key factor in reducing the overall road death toll, with innovations such as seat belts and airbags becoming commonplace. Future innovations may be possible to reduce flood deaths through the production of autonomous vehicles programmed to avoid flooded roads.

CONSEQUENCE MANAGEMENT

Flood rescue is the primary consequence management strategy. Emergency services have long-standing flood rescue capabilities and significant investment has occurred recently in swift-water rescue capabilities. There is much still to learn about the overall influence of flood rescue in reducing the death toll of motorists. For example, do most flood fatalities occur before rescue resources arrive or bystanders can act? Do they occur after rescue resources arrive, indicating the overall ineffectiveness of the intervention? Further work on the detailed analysis of the most recent fatalities is needed to answer these questions. However, no matter what the answers are, it must be concluded from the death toll that preventative actions alongside rescue must be considered.

KEY CHALLENGES AND NEXT STEPS

The overall key challenge for policy makers in developing a holistic strategy is the lack of evidence regarding the effectiveness of the interventions outlined in this article. Evaluation of existing and potential new measures is critical to assess their influence on behaviour.

It must not be expected that the death toll can be reduced to zero, but ambitious targets need to be set and new holistic approaches considered to reduce the incidence of motorists travelling through floodwater.

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DEVELOPING ENTERPRISE OPPORTUNITIES AND RESILIENCE IN REMOTE NORTH AUSTRALIAN COMMUNITIES

Research proceedings from the Bushfire and Natural Hazards CRC & AFAC conference
Adelaide, 1-3 September 2015

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ABSTRACT

It is well recognised that local and indigenous communities face significant development challenges in remote regions of northern Australia. In this paper we contend that development of enterprise opportunities, especially through the fostering of land and sea management activities under culturally appropriate governance arrangements, can contribute substantially to the building of regional economies and community resilience with associated benefits for natural hazards management. We focus on recent experience with landscape fire management initiatives established as part of Australia's developing commitment to tackling climate change, and suggest that additional innovative incentives are available to help transform northern regional economies. In particular, we outline the case for promoting a range of economic benefits from CO_2-e emissions abatement that can be a source of income for Indigenous people and can improve savanna landscape values, thus supporting local and indigenous communities as well as government programs for developing healthy landscapes for healthy people.

INTRODUCTION

Tropical savannas occupy a vast area of 1.9 m km^2 in north Australia, about 1/3rd of the total continent area (Fig. 1). The region encompasses 22 bioregions including many endemic species and is internationally recognised for its biodiversity and cultural values. However, the region faces many challenges including economically marginal land management options, limited infrastructure, low population density (0.29 persons/km^2), low socio-economic status of local (especially Indigenous) people, and high socio-ecological risks for the local as well as for the broader Australian society. Additionally, there is an evident lack of understanding by all tiers of government concerning the inherent capacity of local institutions, the magnitude of the problems they face, and lack of culturally appropriate solutions that could better suit Indigenous and other regional stakeholders. These topics are well documented (e.g. Russell-Smith et al. 2014, Walsh et al. 2014, Whitehead et al. 2014, NAILSMA 2015, amongst others).

Many of the above-mentioned issues seriously impact upon the Indigenous population that comprises about 19% of the total region (Russell-Smith et al. 2014), and occupies ~50% of land under various title arrangements (e.g. Indigenous Protected Areas, freehold or leasehold land for pastoral and other purposes). Indigenous people's cultural, spiritual and subsistence living is still well connected to the landscape, unlike for many parts of Australia. Indigenous people practice fire management to 'clean' the country, for both cultural and ecological benefits (Altman 2009). However, cessation of fire as a management tool due to European influence over the last 100 years has compromised people's livelihoods, and led to major changes in landscape structure and function in terms of current extent of fires (Fig. 1), and loss of flora and fauna (Russell-Smith et al. 2003, Woinarski et al. 2011, Yates et al. 2008). This change (i.e. decline in fire management), over time has social, economic and ecological implications for the Indigenous people in region, especially for:

1. Increasing fuel loads that have exposed vast areas of land to severe, high intensity and frequent wildfires, thus increasing risk to community assets
2. Threatening many species of flora and fauna that are susceptible to resultant fire regimes which could be important as natural and cultural assets for community livelihoods
3. Increasing cultural vulnerability of Indigenous communities by not being able to use fire in customary ways

As a result of poor fire management, an average of ~20% of north Australian savannas are burnt annually, mostly under relatively severe late dry season conditions, and the region contributes annually ~2-4% to Australia's accountable Green House Gas (GHG; CH_4 and N_2O) emissions (CSIRO 2012, Walsh et al. 2014).

As part of the Bushfire & Natural Hazards CRC's (BNHCRC) community resilience research program, this paper serves to introduce research being conducted under the auspices of the 'northern hub' partnership (Charles Darwin University—CDU; Aboriginal Research Practitioners Network—ARPNET; North Australian Indigenous Land & Sea Management Alliance—NAILSMA) which aims to look at issues besetting, and solutions contributing to, resilience and natural hazards preparedness in remote north Australian Indigenous communities. In this contribution, we explore enterprise development opportunities for two large Northern Territory communities afforded through enhanced landscape fire management and associated marketable carbon emissions reductions. Together with an allied investigation of culturally appropriate community governance issues, our longer-term ambition is to consider a range of economic opportunities where ecosystem services can contribute to building resilience in remote north Australian communities (as suggested in Fig. 2).

CASE STUDIES: CO2-e EMISSIONS ABATEMENT BASED ENTERPRISES USING IMPROVED FIRE MANAGEMENT

The WALFA project was established in 2006 on 28,000 km^2 area in a voluntary agreement with Conoco Phillips (WAFMA report 2013). It currently abates an annual average (2007-2013) of 137,000 t of CO_2-e/year. These reductions in emissions are worth about \$2.74m/yr, assuming a C price of ~\$20/t CO_2-e. Based upon the success of the WALFA project, the Fish River Fire Project (FRFP) commenced in 2012-13 on a 1781 km^2 property to the south of Darwin. It was the first project to be set up under the Indigenous CFI (Carbon Farming Initiative). Currently, the project abates ~13,000 t CO_2-e/yr that are worth ~\$260,000/yr at the same C price as that used above. Details of these projects are provided in WALFA and ILC (Indigenous Land Council) annual reports.

Based on above initiatives, here we explore the potential of similar projects undertaken in two NT regional communities, based at Ngukurr and Gunbalanya, respectively. Salient details concerning these communities and current fire management are outlined in reports (NAILSMA 2015a,b) and an accompanying paper (Edwards et al., submitted for AFAC 2015).

1. Ngukurr community is located in the north-east of NT where 35% area is burnt every year with 26% burning in the LDS (Late Dry Season) and 8.5% in the EDS (Early Dry Season) (annual average from 1998-2012; Infonet – Fire Scars report). The average annual GHG emissions are about 118,000 t of CO_2-e (2003-2012). Under the ERF (Emissions Reduction Fund) initiative, fire management in this area can contribute to reduce these emissions to 45, 000 t/yr on average (based upon the data available through SavBAT2). Thus, the Indigenous managers can abate about 73,000 t of CO_2-e emissions per year. Keeping in mind the feasibility of future fire management, there are following abatement scenarios (Table 1):

Table 1. CO_2-e emissions (t/yr) abatement scenarios for fire management under EDS and LDS fire regimes (with realistic scenarios in bold) (Source: SavBAT2).

EDS →			
LDS ↓	20%	30%	40%
0%	69,290.80	**50,040.67**	30,790.54
10%	**33,573.47**	14,323.34	No good

Depending upon the fire management and the available C price, the monetary benefits are presented in Table 2.

Table 2. C benefits ($) for abating CO_2-e emissions applying fire management practices (with realistic scenarios in bold).

C price* **(**$/t of abatement)	Fire management				C benefits for 2013 reporting year
	EDS → LDS ↓	20%	30%	40%	CO_2-e abatement (74,604 t/yr, 2003-12 baseline)
$10/t	0%	692,908	**500,407**	307,905	$746,050
	10%	**335,735**	143,233	No good	
$15/t	0%	1,039,362	**750,610**	461,858	$1,119,075
	10%	**503,602**	214,850	No good	
$20/t	0%	1,385,816	**1,000,813**	615,811	$1,492,100
	10%	**671,469**	286,467	No good	

*We used $10, 15 and 20 per t of CO_2-e emissions abatement based upon our current knowledge.

The financial benefits for reducing the burnt area to 30% range from $500,000–$1 M/year that can contribute towards Indigenous employment, apart from many intangible benefits that are discussed later.

2. Gunbalanya: This community is located north of Darwin, NT where 56% of the total area is burnt each year (annual average from 2000-2014; Infonet – Fire Scars report), with 27% burnt in the EDS and 29% in the LDS. The average GHG emissions are about 104,000 t CO_2-e/yr, (2003-2014 data). Given the best performance years where these emissions were minimal, improved fire management can contribute to reduce CO_2-e emissions to 67,000t/yr. Thus, an abatement of 37,000 t CO_2-e/yr can help to generate C income. Given the fire history of this area, the following feasible scenarios are proposed (Table 3):

1. 50% of area burnt per year with 40% in EDS and 10% in LDS
2. 40% of area burnt per year with 30% in EDS and 10% in LDS
3. 40% of area burnt per year, all in EDS

Table 3. CO_2-e emissions (t/yr) abatement scenarios for future fire management (with realistic scenarios in bold) (Source: SavBAT2).

	60% area burnt/yr		50% area burnt/yr		40% area burnt/yr		30% area burnt/yr	
1. EDS	30%	No good	30%	15,151.70	**30%**	**40,849.86**	20%	52,911.73
LDS	30%		20%		**10%**		10%	
2. EDS	40%	3,089.83	**40%**	**28,787.99**	**40%**	**54,486.14**	30%	66,548.01
LDS	20%		**10%**		**0%**		0%	

The corresponding C benefits ($) are presented in Table 4. The realistic options are for fire management on 50% and 40% of the total area.

Table 4. C benefits ($) for abating CO_2-e emissions applying fire management practices (with realistic scenarios in bold).

C price* ($/t of abatement)	C value ($) for 50% and 40% of the total area burnt per year				C benefits for 2013 reporting yr
	50%: EDS: LDS 30: 20	**50%: EDS: LDS 40:10**	**40%: EDS: LDS 30:10**	**40%: EDS: LDS 40:0**	CO_2-e abatement (23,112 t/yr)
10	151,517	**287,879**	**408,498**	**544,861**	231,120
15	227,276	**431,820**	**612,748**	**817,292**	346,681
20	303,034	**575,759**	**816,997**	**1,089,722**	462,241

*We used $10, 15 and 20 per t of CO_2-e emissions abatement based upon our current knowledge.

Depending upon the C price and fire management, the benefits can range from $280,000–$1 M/yr. Given the current situation, it is possible to achieve 40% EDS burning in this area, suggesting that the total benefits could be $800,000–$1 M per year. These benefits will provide culturally appropriate employment opportunities for people, apart from many other benefits.

Both these projects are assessed based on the Savanna Burning Methodology (SBM), which is recognized for emissions abatement under the current ERF program established by the Australian Government. The amount of GHG emissions abated by changing the fire regime and its respective economic returns can be used as a surrogate for income in this new enterprise that is in line with the Indigenous customary sector. There are also C sequestration benefits that are not yet accounted in GHG accounting system. Indeed, the benefits that will flow from improved fire management are numerous, as mentioned below in discussion.

DISCUSSION

Improved fire management can provide significant enterprise opportunities for Indigenous people under the current CFI/ERF program, including personal/household income while improving land and the value of various natural and cultural assets. Currently, there are meager employment opportunities in the region. According to the Australian Bureau of Statistics (2011), 29% and 23% people (>15 years of age) are eligible for workforce in Ngukurr and Gunbalayna respectively, while only 4-8% people are employed full-time. The median weekly personal income in these communities is <$270 (*cf*. $362 of average Australian), thus many people depend upon welfare payments. Currently, the WALFA project employs over 200 Traditional Owners and rangers for 9500 hours per year for fire management related activities (WAFMA 2013). Based on that WALFA experience we consider that the proposed fire management projects, likewise, can provide culturally appropriate employment (especially part-time) opportunities for many Indigenous people in each of these communities.

Additionally, these projects are not only valuable in terms of C income but also for many co-benefits in terms of various socio-economic and cultural outcomes as outlined in Fig. 3. These co-benefits could further provide opportunities for biodiversity credits and related markets (e.g. stewardship arrangements). These projects will encourage people to live on and derive employment and other cultural benefits from their lands, including utilisation of their traditional knowledge systems. Ultimately, these fire management projects will contribute to improving natural and social capital, build capacity for dealing with natural hazards, and thus will contribute to enhancing community resilience.

Our present research project, on scoping resilience of Indigenous communities particularly through developing mechanisms for payments for ES, aims to explore and evaluate such opportunities that can support livelihoods and enhance well-being of Indigenous communities across the savanna region. Apart from co-benefits, such projects can contribute also to reducing Government expenditure on Indigenous welfare both through employment creation as well as enhanced health and well-being benefits. A tradeoff analysis of Government welfare expenditure for providing opportunities (such as these fire projects) may provide new insights into the range of benefits that these projects can offer. The critical aspects to consider for such future enterprises are:

1. Importance of partnerships between Indigenous (Land Councils, Indigenous Land Corporation, local Aboriginal corporations, etc.) and non-Indigenous institutions (R&D and Governmental organizations) in sharing of knowledge and building commitment
2. Recognition of Indigenous leadership
3. Need for consistent engagement of all the involved stakeholders
4. New arrangements for institutions to develop relevant policy frameworks, tool kits to monitor GHG emissions, and to share responsibilities/benefits

There is an evident need to develop relevant policy frameworks that can help establish these projects on the ground. It is anticipated that the suite of Northern Hub projects focusing on Indigenous community resilience will contribute to that development.

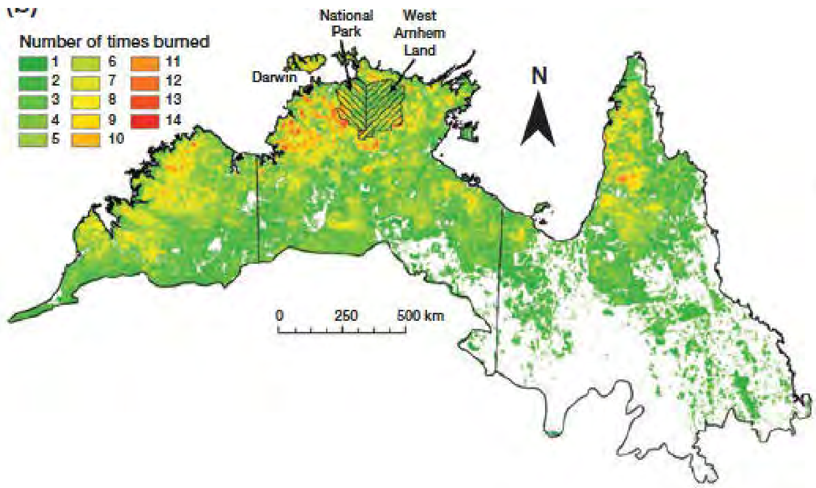

Fig. 1. Savanna region and fire frequency (no. of times burnt) from 1997-2010 (Source: Russell-Smith et al. 2013).

Improved Fire Management of Natural Resources

↓

Reduced risk of future severe fire events and natural hazards

↓

Improved ES (e.g. natural & cultural assets)

↓

Building/Utilizing People's Capabilities (e.g. Tradtional Knowledge on fire management)

↓

Improved Livelihoods and Well-being of people (e.g. good health, social network)

↓

Community Resilience

Fig. 2. The chain of benefits of ES-based enterprises for building community resilience.

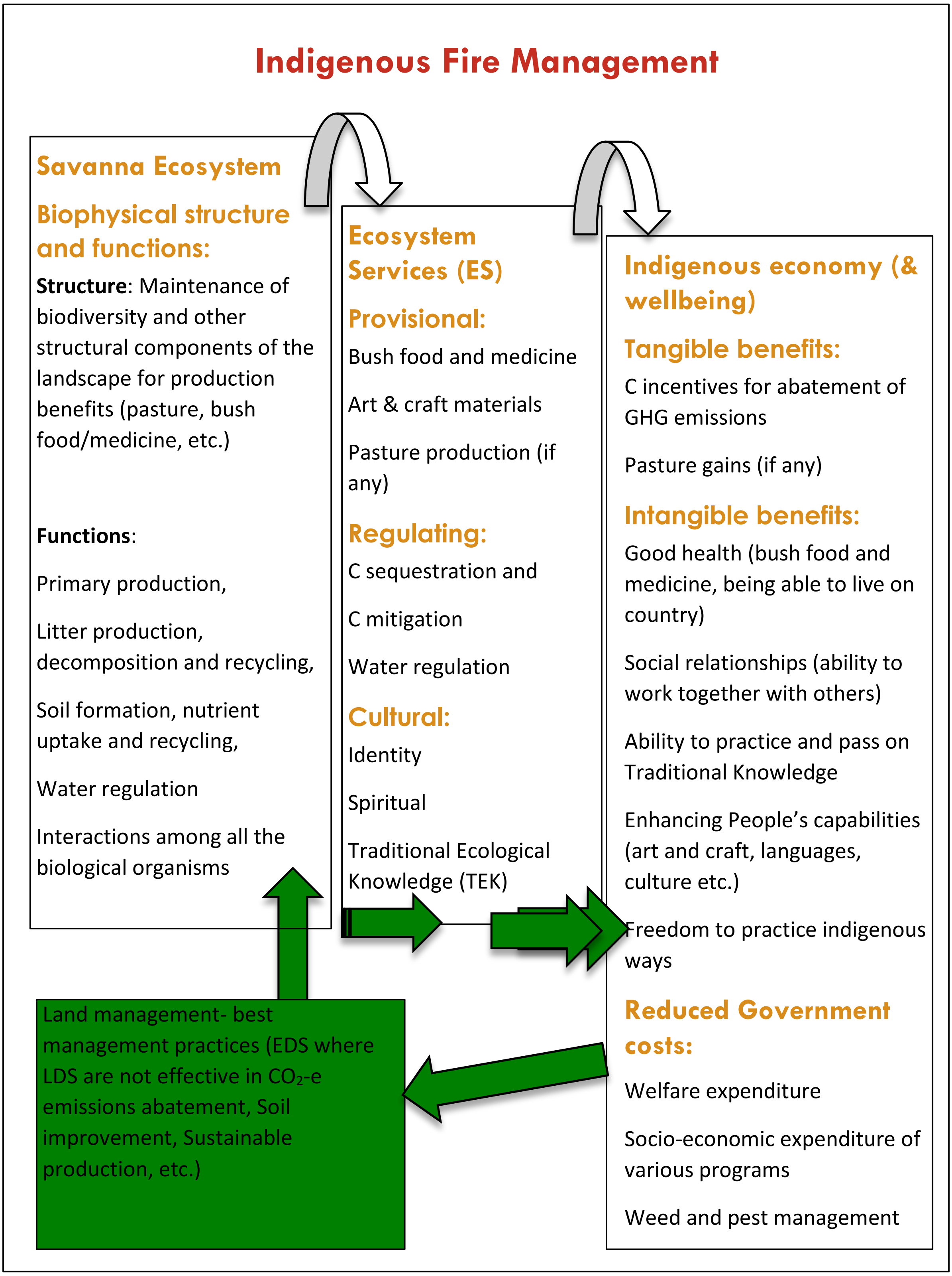

Fig. 3. Flow-on benefits from Indigenous fire management in savannas.

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THE SYDNEY 2014 FORECAST DEMONSTRATION PROJECT – A STEP FROM RESEARCH TO OPERATIONS

Research proceedings from the Bushfire and Natural Hazards CRC & AFAC conference
Adelaide, 1-3 September 2015

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INTRODUCTION

The tools available for predicting fire-weather conditions continue to evolve, due to recent advances in computer technology and greater scientific understanding of the meteorology surrounding and impacting fires. These have the potential to greatly benefit risk assessment at bushfires as well as predictions of how a bushfire will spread. This paper will discuss some of the recent advances in scientific understanding of meteorology influencing bushfires and the methods available to transition new knowledge into an operational framework, in particular through the use of Forecast Demonstration Projects (FDPs).

FDPs have provided valuable opportunities to expose recent research outcomes in a near-operational setting. During such exercises, operational forecasters and researchers work together each day over a period of weeks or months to trial new techniques and technologies in real-time forecasting situations. Researchers and new systems become better attuned to operational realities, and forecasters have an early look at, and a chance to shape, the tools that they will be using in the future. The Sydney 2014 FDP will be discussed here as an example of how new approaches to numerical weather prediction (NWP) modelling can be brought to bear on fire-weather services.

THE NEED FOR CHANGE

Fire-weather forecasts currently provided by the Bureau of Meteorology are underpinned by predictions of near-surface temperature and relative humidity and 10 m wind speed. These forecast values, combined with fuel information, provide the basis for fire danger ratings around the country and constitute the primary information in site-specific (spot) forecasts for planned and going fires. Importantly in an operational forecasting context, the near-surface parameters are quantifiable, easily extracted from NWP models and readily verified against observations from nearby weather stations.

Although official fire-weather forecasts are based on surface temperature, relative humidity and wind speed, there is (near-)universal acceptance by meteorologists and fire practitioners that this provides a limited description of the meteorology affecting a fire ground.

RECENT RESEARCH

Over the past decade, research into the meteorology surrounding bushfires has been active in Australia and much has been learnt about atmospheric processes with the potential to impact bushfires. The primary approach to fire-weather research has been case studies of significant events (e.g. Engel et al. (2013), Mills (2008a), Fawcett et al. (2013)). In particular, several studies examine the meteorology surrounding a fire in detail in order to identify dynamical atmospheric features that contributed to the observed fire activity. At many significant fires, three-dimensional and temporally evolving features of the atmosphere have been linked to the fire activity that occurred.

Examples include plume development processes and pyro-convective cloud (e.g. Fromm et al. (2006), McRae et al. (2013)), fire-modified winds (Coen et al. (2013)), mixing of dry slots (Mills 2008b), interactions between wind and topography (Sharples et al. (2013), Kepert et al. (2013)) and fire-atmosphere feedback processes (Peace et al. 2015). Broadly categorised, these studies relate the structure of the atmosphere in three dimensions and the dynamical interactions between the fire, atmosphere and terrain. They show that interactions between the different elements can be favourable for producing an environment that is conducive to non-steady-state fire activity.

The studies above identify phenomena that are distinctly different from the current focus in fire-weather forecasts in Australia.

FDP EXAMPLE – SYDNEY 2014

The Sydney FDP ran for 10 weeks from the end of September 2014 as a test bed for advances to the underlying science for extreme weather forecasting. It covered thunderstorm and rainfall prediction and fire-weather and air-quality services, and included forecasters outposted to the NSW Rural Fire Service as well as Regional-Office-based meteorologists. A centrepiece of the new techniques was a Rapid Update Cycle (RUC) NWP model, which produced a new forecast every hour at 1.5 km horizontal grid spacing, significantly finer than the most detailed operational predictions of around 4 km horizontal grid spacing.

Current operational NWP predictions update every 6 or 12 hours, and so in between model runs the predictions can be based on information about the state of the atmosphere which is at least 12 hours old. The hourly RUC predictions are able to incorporate the latest weather observations much more frequently (Dixon et al., 2009). The model run during the Sydney FDP, a version of the Australian Community Climate and Earth-System Simulator (ACCESS) NWP model (Puri et al., 2013), also incorporated rainfall and wind observations from Doppler weather radar, which are not currently used in operational NWP in Australia.

NWP models are crucial to forecasting dangerous fire-weather conditions. They provide input to the Graphical Forecast Editor (GFE), which is used by the Bureau of Meteorology to provide gridded and text forecast services including fire-weather products. The RUC guidance was a key aspect of the Sydney 2014 FDP and a particularly important aspect of the project was its use in the GFE, where forecasters had to manage the increased volume of information and apply the higher-resolution model to spot fire forecasts.

APPLICATION OF RUC GUIDANCE TO GRIDDED FIRE FORECASTS

Fire-weather forecasts in the operational GFE are initialised with NWP guidance. Forecasters then use manual editing tools to enhance the NWP and produce their gridded forecasts of near-surface temperature, humidity and wind. Tools are run which use these forecast inputs, together with gridded information on fuel state to calculate the traditional forest and grassland fire danger indices (Noble *et al.* 1980). The tools also produce a grid of 'fire-weather hazards' which indicate the grid cells which have met or exceeded the fire danger index thresholds for severe, extreme or catastrophic fire danger ratings at some time of the day.

An important aspect of the use of RUC in the Sydney FDP was bringing it into the GFE and using it as the input for automatic pre-calculation of forest and grassland fire danger indices and resulting fire-weather hazards in the GFE. The forecaster was supplied with a new hazard comparison tool, which enabled a rapid graphical overview (see **Figure 1**) of hazard outcomes for the day for different NWP runs or between NWP guidance and the existing GFE forecast. These comparisons were the basis for generating automated alerts for the forecaster on arrival of the latest RUC guidance. This enabled forecasters to assess changes from the previous forecast, without going through all the forecast steps to determine the implications for fire weather of each hourly RUC run.

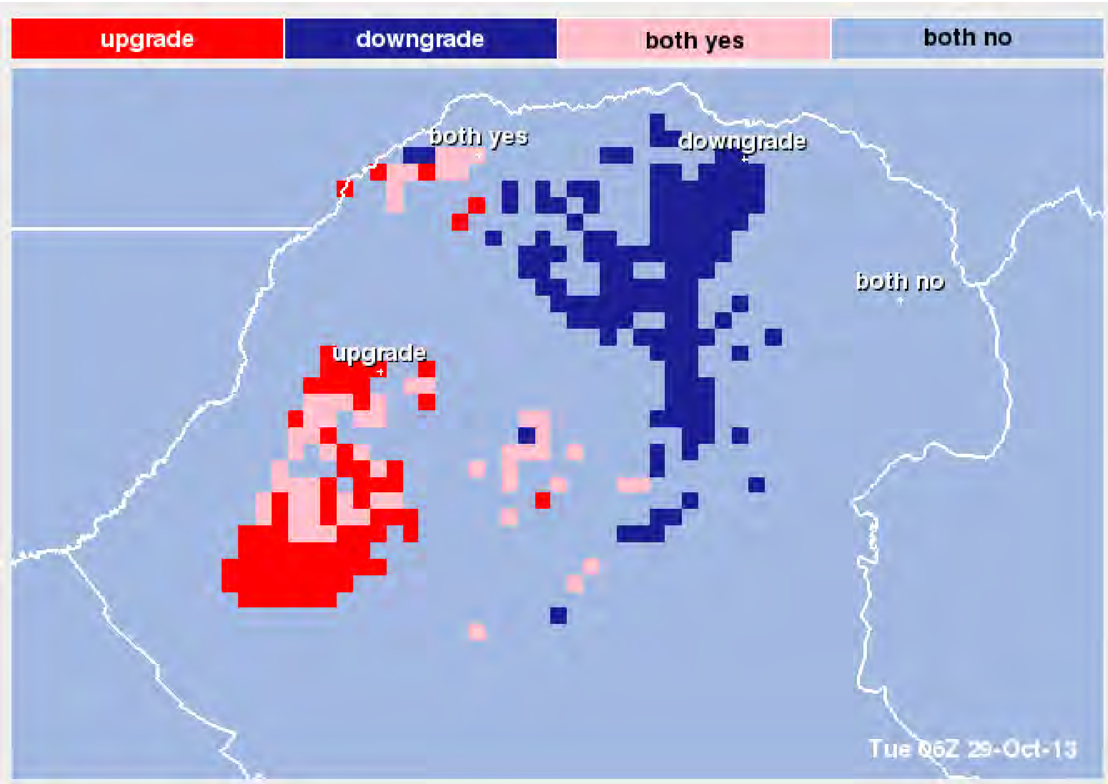

Figure 1. Comparison between the at-least-severe fire-weather hazard area for two NWP runs. Models agree where 'both yes' and 'both no'. Points labelled 'upgrade' show where the later model has the hazard while the earlier model does not, and vice versa for 'downgrade'.

OUTCOMES FROM THE FORECAST DEMONSTRATION PROJECT

During the Sydney FDP, the RUC guidance and new tools in the GFE were trialled on days of increased fire-weather risk by using the new guidance as the basis for gridded fire-weather products, as well as in production of 12-hour-long spot fire-weather forecasts. Automated alerts were then used for monitoring of the forecasts. **Figure 2** shows an example of a fire danger rating map produced with RUC guidance during the FDP, in which the extra detail provided by the high-resolution model can be seen.

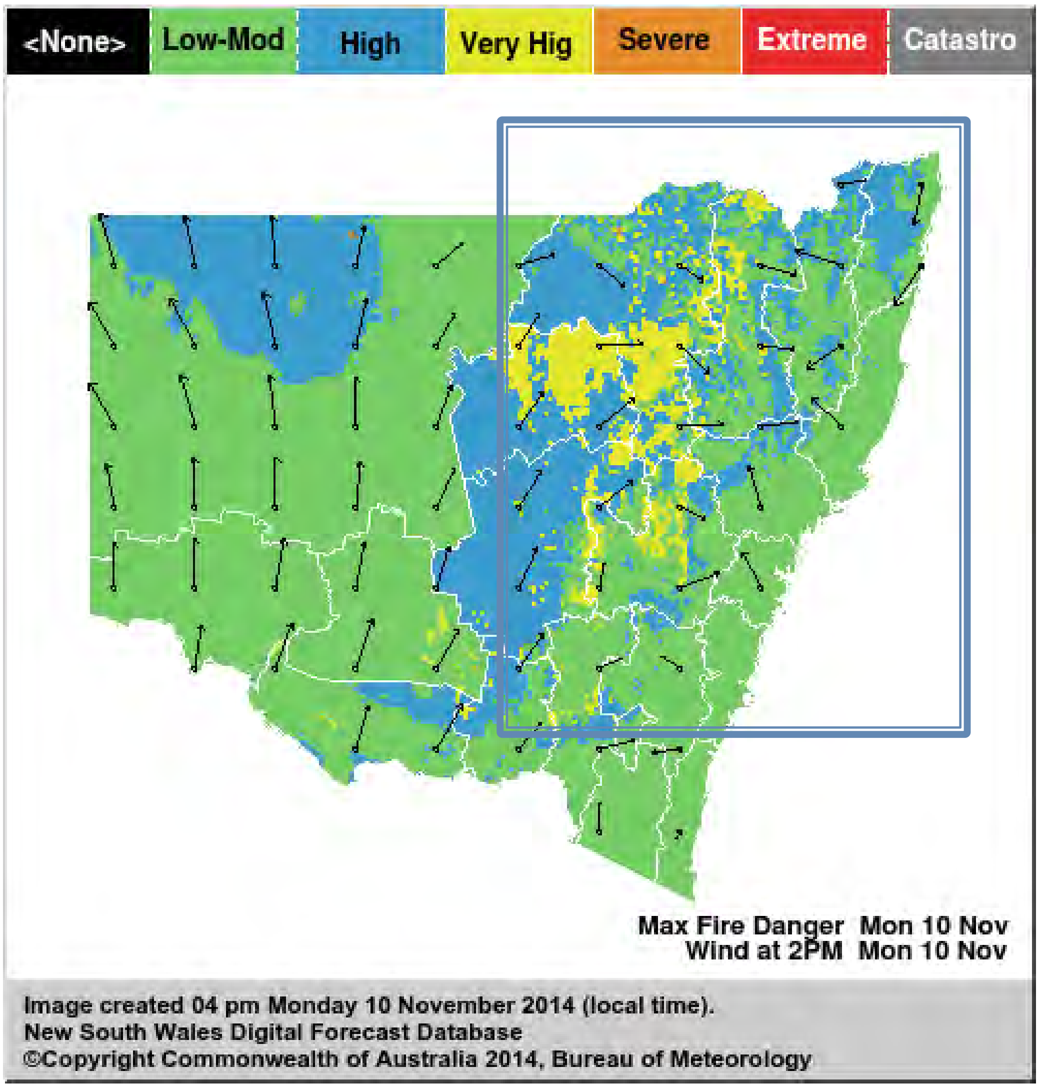

Figure 2. Fire danger rating (colour scale) and wind (arrows) prepared for the FDP using RUC data blended into lower resolution ACCESS-R data. The domain covered by the RUC data is indicated by the blue rectangle. Note that the spacing of the wind arrows does not reflect the spatial resolution of the wind data.

Subjective feedback was obtained from operational forecasters involved in the trial. The alerting and visualization of changes in hazard areas were considered to be useful for monitoring forecasts, in particular through comparing the latest version of guidance to that which had been used to prepare the forecast. The detailed depiction of wind features such as sea breezes interacting with topography at the 1.5 km grid spacing of the RUC helped forecasters build better understanding of meteorological processes significant for spot fire forecasts.

Limitations identified with the RUC guidance in its current form included problems with representation of late-afternoon surface dewpoint temperatures (a known problem with the ACCESS suite of models) and the lack of change in successive hourly runs of the model, except when the run of the 'parent' model supplying data at the edges of the model domain was updated. An area needing improvement in the model-based alerting in the GFE was accounting for the fact that the RUC runs were of various different lengths and could have different amounts of coverage of the peak fire-weather period of the day.

The Sydney 2014 FDP showed how new approaches to NWP modelling can be brought to bear on fire-weather services, but it stayed within the existing paradigm of fire-weather services, which focus on near-surface meteorological conditions. The past decade of research into the meteorology surrounding bushfires includes studies that have explored the structure of the atmosphere in three dimensions and the dynamical interactions between the fire, atmosphere and terrain. The challenge is how to formally incorporate what has been learnt in research into operational weather forecasts. Objective metrics are needed together with knowledge of significant thresholds, implying the need to extend case studies into more systematic research. A particular challenge is how to modify the current quantitative measures of fire risk, to include processes which are currently subjectively assessed. Future forecast demonstration projects would offer a vehicle by which researchers and operational practitioners could take up the challenge of transitioning such research outcomes into the operational sphere.

FIRE MODELS

A related challenge for the appropriate meteorological inputs in fire risk assessment lies in the increasing use of fire simulation models by fire agencies in Australia. The simulation models currently in operational use predict the evolution of a fire perimeter across a two-dimensional landscape in a particular fuel. The meteorological inputs of wind speed and direction are critical in these models, and small variations in wind inputs can produce substantial variation in simulation results. Fire models are generally run at grid spacings of tens of metres, whereas the highest resolution operational meteorological model in Australia runs at 4 km grid spacing. The variation in wind at the two spatial scales, particularly in mountainous areas, can be significant, and certainly affects the results from fire models. Compounding the complexity of the challenge of appropriate wind inputs is the knowledge that the energy released by the fire modifies the surrounding meteorological environment. It is the fire-modified winds, not the environmental winds, that propagate the fire front and in certain circumstances the difference between the two can be substantial (e.g. Peace et al. (2015)).

An additional challenge to establishing meteorological inputs to fire simulation models is that the near-surface winds only tell part of the story. Detailed, high-resolution gridded wind forecasts such as the RUC guidance from the Sydney FDP have the potential to improve wind inputs to fire simulation models. However, research shows that vertical structure of temperature and dewpoint, temperature inversions, atmospheric stability, as well as wind speed, direction and shear above the surface can all impact the evolution of a fire. Therefore, a simple wind-driven two-dimensional fire spread model will give a limited depiction of likely fire activity, and other meteorological processes need to be considered in order to anticipate how a fire will evolve.

FROM RESEARCH TO OPERATIONS

The Sydney 2015 Forecast Demonstration Project has already led to operational availability of higher-resolution NWP guidance in the GFE and is shaping plans for future meteorological guidance and models of operation for short-term forecasting.

The following questions have not yet been resolved: how do we best include the knowledge from recent research (which is mostly subjective), into a reasonably objective forecast process; and how do we establish the appropriate inputs to fire simulation models, with the aim of enabling safer, more effective and more efficient fire operations?

A forecast demonstration project bringing researchers together with fire-weather meteorologists, fire behaviour modellers and operational emergency services practitioners, in a near-operational context, would provide one way of exploring how new forecast guidance, conceptual models and service formats can connect in practice to allow better understanding and management of fire risks.

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IMPLEMENTING POLICY FOR ENABLING DISASTER RESILIENCE IN THE AUSTRALIAN FEDERATION: WHAT ROLE FOR GOVERNMENT?

Research proceedings from the Bushfire and Natural Hazards CRC & AFAC conference
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INTRODUCTION

This paper reports on work being done by the author at the ANU and funded, in part, by the Bushfire and Natural Hazards Co-operative Research Centre to investigate how disaster resilience policy can be enabled in the Australian federal system through implementation arrangements. It aims to contribute to the academic literature on disaster resilience and policy implementation and will also provide information about operationalising disaster resilience policy that can potentially be applied in policy and program development settings.

The central premise is that, while Australia's fundamental disaster resilience policy choices may be sound, policy goals cannot be achieved without effective implementation, which is constrained by a shortage of evidence-based information in this area.

This work will also contribute to discussion about the role of government in optimising disaster resilience, which is relevant to contemporary debate about the future of federalism in Australia.

BACKGROUND

In early 2011, all Australian governments adopted the National Strategy for Disaster Resilience (NSDR) (Commonwealth of Australia, 2011) which emphasises disaster prevention, preparedness and mitigation over the historical focus on relief and recovery. The NSDR, like many high level government policies, consists of broadly based principles designed to be picked up by state and territory governments with subsequent flow-on to local government and other sections of the community. While this approach provides flexibility, there is, at the same time, insufficient information and guidance about implementing disaster resilience policies and programs. This is a barrier to both the uptake and success of disaster resilience policy.

Learning more about how disaster resilience policy implementation occurs within and between the different tiers of government and the community, including downstream and upstream impacts of federalism will help understand the most appropriate approaches to implementing disaster resilience policy for strengthening Australia's disaster resilience.

Mainstream commentary tends to emphasise the limitations of resilience research and the effect this has on resilience policy efficacy, particularly policymakers' capacity to analyse and evaluate resilience policies and programs. This is not entirely accurate: The rise of resilience in public policy has seen the resilience evidence base grow substantially over the past decade, primarily in the areas of definitional, and conceptual model development and instruments for measuring resilience. It is also likely that this trend has contributed to research failing to keep pace in the area of policy implementation where gaps continue to be evident (Cork, 2010), with the possible exception of ecological resilience policy implementation (Walker and Salt, 2012; Alliance, 2010; Salt and Walker, 2006).

DEVELOPING A DISASTER RESILIENCE IMPLEMENTATION FRAMEWORK

Qualitative methods are being used to developing an analytical framework consisting, at one level, of factors that have been identified in the literature as essential for supporting community resilience and for operationalising these characteristics. On another level, the framework represents the three levels of government in Australia, which provide the platforms and the mechanisms for policy implementation. The framework, once tested and refined will become a product of the research that could potentially be used as a resource for guiding disaster resilience policy implementation.

Several evidentiary domains provide the structure and the data that is being used to populate the disaster resilience implementation framework: Theoretical concepts and characteristics of disaster resilience, theoretical and empirical evidence from policy implementation studies, qualitative and quantitative information from evaluation of Australian national strategic policies, and case studies that will be conducted specifically for this research.

THEORETICAL CONCEPTS AND CHARACTERISTICS

The work of Norris *et al.* (2008) has been chosen as the theoretical model because it links individual resilience to collective or community resilience in the context of disasters. Resilience is described by Norris as "a process linking a set of adaptive capacities to a positive trajectory of functioning and adaptation after a disturbance". This definition is disaster-appropriate because it explicitly refers to a shock or disturbance which is connected to, or triggers a dynamic process leading to an improvement in functioning. The four networked adaptive capacities of economic development, social capital, community competence and information and communication each have inherent qualities or attributes of robustness (strength), redundancy (substitutable), rapidity (timeliness) and resourcefulness. The validity of this theory was strengthened by the work of Kulig et al who expanded on Norris' model with the Index of Perceived Community Resilience (IPCR) which was tested in two fire-affected communities in Canada using interviews, community profiles and a household survey. The IPCR proposed additional characteristics of leadership and empowerment, community engagement, and non-adverse geography which align with Norris' social capital and community competence capacities (Kulig *et al.*, 2013).

ISSUES IN DISASTER RESILIENCE POLICY IMPLEMENTATION RESEARCH

In spite of the widespread take-up of disaster resilience and disaster risk reduction policy in Australia and overseas, academic studies on disaster resilience policy implementation are relatively scarce, with what there is to be found mainly in ecological and environmental policy literature. Some information is also available in the grey literature, including in various government and non-government reports (particularly relating to event-specific recovery initiatives).

Policy implementation research had its hey-day in the 1970s and 1980s and some of this early discussion remains relevant for disaster resilience today. For example, the debate about top-down vs bottom-up approaches and the view that, in a system of multi-level governance, a combination of these two approaches is a legitimate option (Sabatier, 1986), particularly for implementing disaster resilience policy (Buckle *et al.*, 2001).

Effective implementation at the very least needs to be legal and to have functional capability (can get the job done) with outcomes and actions that are consistent with the goal of building the four networked adaptive capacities for disaster resilience.

Evidence about implementing policy that enables the four adaptive capacities and their complementary sub-scales (community engagement, leadership and empowerment and non-adverse geography) informs normative outcomes at the broadest level of the disaster resilience policy implementation framework. It should be noted that there is overlap between these, as there is between their corresponding policy implementation mechanisms and actions at the lower level. This does not limit the usefulness of the implementation framework but rather, provides a comprehensive menu and awareness of the mutual dependencies within the system.

IMPLEMENTATION AND THE FOUR NETWORKED ADAPTIVE CAPACITIES: ROLE OF GOVERNMENT?

Social capital is enabled by implementing policies that build informal relationships, networks and stakeholder trust, by providing information to people relevant to their own roles and values, and by giving people the skills to socially engage and to deal with conflict (Productivity Commission, 2003). Ecological resilience is also linked to social capital, and is reflected in the non-adverse geography sub scale (Kulig et al., 2013). This highlights the importance of the physical environment in community well-being and provides evidence supporting the inclusion of environmental and natural resource management policy implementation within this resilience implementation framework.

A role for government in fostering community competence centres around engaging with communities to ensure that citizens are empowered to participate in policy development and implementation, including by facilitating local level leadership.

Normative policy outcomes of equity and diversity of economic assets (Norris et al., 2008) within communities can be influenced via government policies on taxation, social welfare and other redistributive strategies, employment, small business, regional development, foreign investment, competition, superannuation, energy to name a few.

In relation to information and communication, communities tend to look toward government for reliable and accurate information about issues of national public importance. Similarly, the importance of the role of government in formulating and leading effective strategic communications activities during and in the aftermath of disasters is well recognised (Conkey H, 2004). Governments are well placed to marshal the professional skills and substantial financial resources needed for conducting national public awareness and information campaigns using the mass media. Evidence supporting the effectiveness of this approach can also be found in national strategies relating to public health and road safety (Delaney A et al., 2004). On the other hand, a role for government in ensuring a responsible media, (another key element of information and communication adaptive capacity) is less clear.

IMPLEMENTATION CONTEXT - THE AUSTRALIAN FEDERATION

The context for policy implementation is critical for shaping its outcomes (Coffey, 2014). Analysis of the policy context informs decisions about allocation of responsibility, the role of different levels of government, and the mechanisms that are available to government for implementing government policy.

The notion of multi-level governance, the overarching theoretical model for the Australian federal system provides the context and the superstructure for the proposed framework. This translates into national, sub-national and local implementation platforms. The Australian Constitution, at the highest level, provides the legal framework for the system.

The federalism literature provides a number of reference points for developing a disaster resilience framework, including, but not limited to, the Australian Constitution, Federal financial arrangements, intergovernmental agreements and institutions (or lack thereof), political economy of Australian states and territories, the role of regional and local government, principle and practice of subsidiarity, and power sharing arrangements (Jordan, 1999; Fenna and Hollander, 2013; Galligan, 2002).

These reference points inform consideration of implementation approaches at the outset. For example, questions such as does a policy need to be whole-of-government i.e. initiated and/or overseen at federal government level through a body such as the Council of Australian Governments, and have corresponding implementation machinery within each state and territory government, then similarly be reconstituted at local government level down to households and individuals? The answer to this surely is, it depends. It depends on the nature of the policy – what it is seeking to achieve or change and the capability for achieving that change at each level of the system. These issues are fundamental to subsidiarity and the associated debate about centralism vs devolution. Therefore, in terms of a principle for successful policy implementation, subsidiarity is key and "a potentially powerful concept around which a debate about the optimal assignment of tasks across different administrative levels could be constructed" (Jordan, 1999).

Pathways to achieving outcomes that lie outside of government become increasingly less evident as the goal of implementation moves away from government toward the grass roots or community and household level. Reviewing the NSDR involves a renewed commitment by all levels of government to "an integrated approach for building disaster resilience through behaviour change and partnerships between governments, communities, businesses and individuals, and engagement with the private and not-for-profit sectors" (Law Crime and Community Safety Council, 2014). This means it has become even more critical to illuminate, within this structure, implementation mechanisms, currently obscure or non-existent, for supporting community empowerment through engagement, participation and partnerships for disaster resilience,.

The framework, therefore, needs to represent the system or machinery that gives rise to policy implementation. This policy implementation machine includes mechanisms such as sub-policies, laws and regulations, programs, and institutions and governance arrangements that operate at each level within the broader context of Australia's federal system, i.e. at national, sub-national (state and territory government), and local government levels. They have been incorporated into the framework because they offer relatively tangible units for analysis and provide structure that helps manage complexity. They can also help in identifying an appropriate role for government, including pinpointing the types of disaster resilience building activities that may be within its remit, or within the remit of other non-government actors.

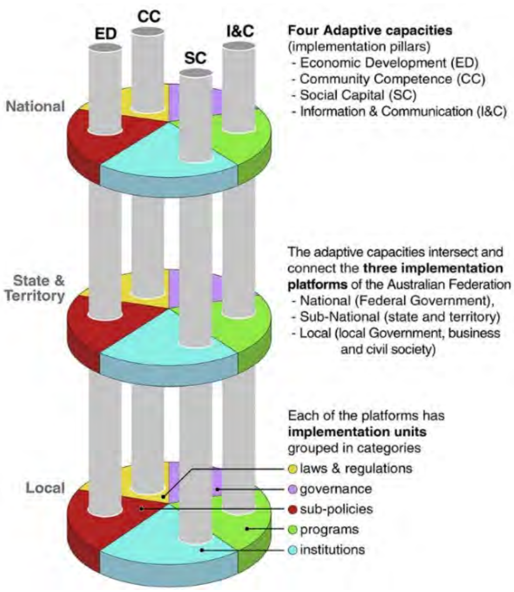

Figure 1 provides a concept for the disaster resilience implementation framework.

CASE STUDIES

Four case studies corresponding to each of the four adaptive capacities will be conducted to provide an empirical component to the research. Five programs or initiatives with explicit disaster resilience and/or natural hazard risk reduction/mitigation objectives have been selected for data collection, with one from each of the three levels of government and one each from the business and the not-for-profit sectors.

Data collection will involve initial document study, followed by structured interviews. The interview questions have been designed to draw out detailed contextual information about the way each of the disaster resilience initiatives are being implemented in relation to the actions/outcomes in Table 1. The interview responses will be analysed in terms of the actions/outcomes in Table 1 as well as in relation to the policy implementation information obtained from the document study. Particular regard will be given to whether or not, and how, approaches to implementation are a function of federalism. Consistent with the key principle of subsidiarity, the notion of centralism vs devolution and the direction of implementation (vertical, horizontal or multi-directional) will also be considered in the analysis.

Table 1 provides terms that will be used in the data analysis and form part of the framework. They have been adapted from Norris et al (2008) and Kulig et al (2013), the Productivity Commission (2003) and Australian Bureau of Statistics (2004) on social capital; Handmer and Dovers (2013) on information and communication as a "universal" policy instrument and the role of community participation; Richardson (2014) in relation to security as an outcome for economic development; Hussey el al (2013) regarding intra governmental and administrative policy mechanisms; links between stakeholder engagement and leadership and empowerment (Porteous, 2013); and Fenner and Hollander (2013), Jordan A (2013) and McAllister *et al.* (2003) on principles of co-operative federalism. In developing the methodology, guidance has been obtained from *Statutory frameworks, institutions and policy processes for climate adaptation: Final Report* (Hussey *et al.*, 2013).

Table 1

DISASTER RESILIENCE POLICY IMPLEMENTATION – NETWORKED ADAPTIVE CAPACITIES				
ADAPTIVE CAPACITY	Social Capital	Community Competence	Economic Development	Information & communication
Actions and outcomes	1.Networks 2.Non-adverse geography/place-based 3.Community engagement 4.Leadership (internally focused)	1.Political partnerships 2.Stakeholder engagement 3.Leadership (externally focused) & empowerment 4.Community participation	1.Security 2.Economic diversity 3.Equity of resource distribution 4.Sustainability 5.Shared (equitable) risk allocation	1.Narratives 2.Responsible media/access to trusted information 3.Skills and infrastructure 4.Information flow between sectors

CONCLUSION

If building disaster resilience requires long term commitment to action underpinned by attitudinal and behavioural change at all levels of government and the community, better and more detailed information and guidance is needed, not only on how to develop disaster resilience policy, but also on how to construct and design the apparatus of disaster resilience policy implementation i.e. the laws and regulations, sub-policies, programs, institutions and governance. At the very least there needs to be a greater level of knowledge and awareness about how to avoid undermining resilience, including as an unintended consequence of poorly designed and ill-conceived implementation practice.

This paper has outlined a concept, broad architecture and methodology for a framework to guide effective ways of implementing disaster resilience policy. The disaster resilience policy implementation framework will provide more clarity around actions and actors for achieving the four disaster resilience adaptive capacities of community competence, social capital, economic development and information and communication.

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