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PEER REVIEWED PAPERS



No ordinary call: factors predicting fire communication officers' job strain and well-being

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ABSTRACT

Based on the Job Demands-Resource model (JD-R), the present study investigated the contributions of job demands and job resources to the mental health of emergency service workers. Eighty-one fire communication (FireCom) officers employed by Queensland Fire and Emergency Service, (52 females, 29 males; aged between 21 years and 55 years+) completed an online self-report questionnaire that assessed the contributions of job demands (including acute demands, chronic demands, and demands of shift work), age, and job resources (including social support and self-efficacy), as predictors of four indices of mental health (well-being, depression, anxiety, and stress). Four hierarchical multiple regression analyses were conducted. Higher social support, in particular family support, was found to significantly and positively predict well-being and negatively predict both depression and stress. The association between self-efficacy and overall well-being was not significant. Individuals with higher chronic job demands had higher levels of stress and anxiety but not depression, while those with higher acute job demands reported high levels of depression only. These findings have implications for the way FireCom officers can be best supported and educated to achieve positive mental health outcomes and continue to successfully provide that first link between the community and emergency services.



INTRODUCTION

The Queensland Fire and Emergency Service (QFES) is the primary provider of fire and rescue, emergency management and disaster mitigation activities in Queensland. The service includes Fire and Rescue, Emergency Management Queensland, Rural Fire Service (Queensland) (RFSQ), and the State Emergency Service (SES). This makes the QFES Fire Communication (FireCom) officers the vital first link between the Queensland community and fire and emergency incidents. When a triple Zero (000) call is made, it is re-routed from Telstra to the required emergency service (Ambulance, Fire or Police) and then to the communication centre nearest to the incident. It is the responsibility of the Fire Communication officer (FireCom) to gather information; co-ordinate and manage resources; dispatch an appropriate response; and maintain an accurate log of all communications. The roles performed by FireCom officers have expanded in recent times to include deployments to disasters such as extreme weather and wild fire incidents both within the state and interstate. While phone contact eliminates direct physical danger, there is still the need to judge situations based on ambiguous information, provide psychological support, and handle difficulties in communication (Dunford, 2002). Although, Fire Com officers are not exposed directly to trauma, they can experience secondary or vicarious trauma by listening to the primary victims' experiences (Figley, 1995) or by assisting people in highly stressful situations and traumatic events experienced by others (Miller, 1995).

FireCom officers are required to work under pressure in stressful situations and must have the ability to prioritise heavy workloads and multitask in a time-critical environment (QFES, 2016). These unique work stressors coupled with the problems associated with shift work (Petru, Wittmann, Nowak, Birkholz, & Angerer, 2005) all increase the job demands faced by FireCom officers. High job demands, such as high workload, emotional demands, and problems with work equipment or changes in the task have been identified in past research to be important predictors of health problems (Bakker, Demerouti, & Schaufeli, 2003).

However, as detailed in Shakespeare-Finch (2015), despite being regularly exposed to organisational and operational stressors and potentially traumatising events, there has been little research on the well-being of FireCom officers. The current study aimed to fill this gap. The study investigated both negative (job demands, shift work) and positive (self-efficacy, social support) as predictors of FireCom officers' well-being, depression, anxiety, and stress based on the Job Demands-Resources (JD-R) model (Bakker & Demerouti, 2007; Demerouti, Bakker, Nachreiner, & Schaufeli, 2001). As such, the study helps gain a broader picture of the factors affecting the general population of emergency services personnel. Investigating the influence of self-efficacy and social support is useful as, unlike other work context variables, these factors can be changed and adapted with consequent benefits for worker well-being (LeBlanc, Regehr, Birze, King, Scott, & MacDonald, 2011). Thus, by investigating both positive and negative predictors, the study may contribute to the amelioration of mental health problems in the emergency services workforce.



BACKGROUND

The background is organised as follows. First, the dependent variables (well-being, depression, anxiety and stress) in this study are defined. Second, background is given on the job demands-resources (JD-R) model (Bakker & Demerouti, 2007; Demerouti et al, 2001). It then discusses job demands, including the demands associated with QFES Greater alarm response system (GARS) and perceived work demands (PWD). The influence of shift work and age as predictors of health and well-being is also examined. Potential benefits of job resources such as self-efficacy and different levels of social support are also discussed. The background concludes with a justification for this study and presentation of relevant hypotheses. Figure 1 provides an overview of the study variables.

WELLBEING

The nature of emergency services work means Firecom officers are likely to be regularly exposed to potentially traumatic events, which may or may not impact their mental health and well-being. Like other workers, they may also experience common workplace stressors, such as excessive workloads, insufficient support and workplace bullying or discrimination (Tennant, Hiller, Fishwick, Platt, Joseph, Weich, & Stewart-Brown, 2007). The current study examined the relationships between job factors such as these and workers mental well-being, where mental well-being is understood to relate to a person's psychological functioning, life-satisfaction and ability to develop and maintain mutually benefiting relationships (Deci & Ryan, 2008). Well-being includes both short and long term mental functioning and incorporates both positive and negative health (e.g. anxiety, depression and fatigue; Brough, 2005). Therefore, the current study included measurement of depression, anxiety and stress so as to provide a reasonably comprehensive evaluation of psychological well-being.

DEPRESSION, ANXIETY AND STRESS

Several studies have shown the negative consequences of depression, anxiety and stress in the workplace (Cavanaugh, Boswell, Roehling & Boudreau, 2000; Greenberg, 1999), in particular, emergency service personnel, such as police (Husain, 2014), professional firefighters (Heinrichs, Wagner, Schoch, Soravia, Hellhammer, & Ehlert, 2005), and in other aspects of life, including social interactions (Alden & Phillips, 1990; Davies et al., 1995). Negative emotions such as depression or anxiety may also be experienced by some individuals following exposure to trauma (Grant et al., 2008). Broadbent (1985) found particular features of jobs are associated with different types of strain indices. He concluded that job demands (work load and pacing) primarily affect anxiety, and social isolation (lack of social support) primarily affects depression, that satisfaction and anxiety have different correlates, and that depression correlates with factors that have no effect on anxiety. Given this, the current study investigates whether different job demands and resources predict different mental health indices.



THEORETICAL FRAMEWORK

The job demands-resources (JD-R) model (Bakker & Demerouti, 2007; Demerouti et al, 2001) proposes that every occupation may have its own causes of employee well-being that can be organised into two broad categories, job demands and job resources. High job demands, such as emotional demands and work pressure exhaust employee's mental health and physical resources. Job resources are aspects of the job that reduce job demands, stimulate personal growth or are functional in achieving work goals (Bakker et al., 2005). Good examples of job resources that have the potential to buffer job demands are performance feedback and social support (Haines, Hurlbert, & Zimmer, 1991). The JD-R model assumes that job strain and burnout develop when job demands are high and when job resources are limited.


JOB DEMANDS

Firecom officers are faced with unique communication demands, including the need to make decisions and dispatch resources based on ambiguous information, provide advice and reassurance to the Queensland public, and communicate with other stakeholders from a wide range of different organisations. Forslund, Kihlgren, and Kihlgren (2004) found that the emergency dispatch role was stressful, as decisions need to be made quickly and assessing information over the phone is difficult. The unpredictable nature of most incidents and situations where poor or ambiguous information was provided adds to operator stress.

Job demands have been identified as one of the most common sources of work-related stress and can be characterised in a variety of different ways. One means of conceptualising job demands is in terms of the frequency with which workers are required to respond to critical or extreme events. The most commonly researched job demands are considered chronic, as they are thought of as constant for an employee (Beehr, Jex, Stacy & Murray, 2000). However, there have also been studies of short-term job demands or acute job demands involving emergency personnel such as police officers (Caplan & Jones, 1975), and ambulance personnel (Van der Ploeg, 2003). Previous research has shown that acute and chronic stressors, may differ in the impact they have on worker stress and performance (Beehr & Franz, 1987). Several studies (Bennett, Williams, Page, Hood, Woollard & Vetter, 2005; Halpern, Maunder, Schwartz, & Gurevich, 2011) have attributed the development of depression and anxiety to either acute or chronic stressors. Therefore, for the purpose of the current study job demands were conceptualised and measured in terms of both Greater alarm response system (GARS; acute job demands) and perceived work demands (PWD; chronic job demands).

GARS – ACUTE JOB DEMANDS

The level of response to an emergency incident in the QFES is termed the Greater Alarm Response System (GARS). The GARS is structured to facilitate resources for emergency incidents and allows provision of an automated response with specialised support to the officer in charge. A significant part of GARS is the alarm response level. As the size or the complexity of the incident increases there is a corresponding increase in the alarm level (QFES, 2016). The officer in charge of an incident will request a certain alarm level that



will provide a certain level of core firefighting resources, specialist support resources and command officer. A higher level of alarm and response places a higher level of job demand (and potentially higher level of stress) on FireCom officers.

Appendix 1 gives details of the number of fire trucks and other resources responded with each level of GARS or alarm level. A first alarm response usually involves one fire truck and limited other resources, as well as low-level job demands on FireCom officers, whereas a second alarm requires significantly more resources and places significantly more job demands and emotional stress on FireCom officers. Van der Ploeg & Kleber (2003) found employees working in medium or high-risk professions, such as firefighters and emergency workers, are often confronted with acute stressors or critical incidents in the workplace that reduce well-being and increase workplace stress, depression and anxiety. In the current study, the GARS was used as a measure of worker exposure to acute stress.

PWD – CHRONIC JOB DEMANDS


Perceived work demands (PWD) is a perception regarding demand levels within the work place (Boyar, Carr, Mosley & Carson, 2007). A number of studies (Michie & Williams, 2003; Roelen, Schreuder, Koopmans & Groothof, 2008) have shown associations between long working hours, high job demands, and psychological strain. There are indications that perceived workload is more important in determining health than the actual workload (Hobson & Beach, 2000). Therefore the current study also measured what FireCom operators perceive as their regular, daily or chronic experience of job demands in the workplace.

Specific job demands have been repeatedly found to predict exhaustion (feelings of severe fatigue) among various occupational groups (Bakker, Demerouti, & Schaufeli, 2003). Given that exhaustion has been recognised as a main indicator of negative strain (Karasek, 1979), and that shift work may contribute to worker exhaustion, the present study investigated the effects of shift work on overall FireCom officer's positive and negative well-being.

JOB DEMANDS – SHIFT WORK

Sleep is essential for normal life and very important for overall health and well-being. Shift work is defined as “a system of employment where an individual's normal hours of work are, in part, outside the period of normal day working and may follow a different pattern in consecutive periods of weeks” (Collins English Dictionary, 2009, p.p. 420). Research has shown documented that working shift work can have a negative impact on a person's daily health habits (Clendon & Walker, 2013) and night shift work in particular presents significant problems with regard to well-being, health, and occupational safety (Harma, 1998).

FireCom officers' are required to do shift work, which has been identified as a potential negative influence on well-being and health (Costa, 1996). Night shift in the QFES is between 6pm to 8am with permanent FireCom officers work a rotating four days on, four days off “10/14 roster” (2 x 10 hour days followed by 2 x 14 hour nights, then four days off). As well as the reduction in the quality and amount of sleep, shift work may cause



difficulties maintaining usual relationships both with family and outside social ties (Costa, 1996) and maintaining a healthy work-life balance (Camerino, Sandri, Sartori, Conway, Campanini & Costa, 2010). Shift work in general, but especially night shift work, presents a significant problem with regard to well-being, health, and occupational safety (Harma, 1998).

The JD-R model proposes that job demands such as shift work are predictive of feelings of exhaustion and contribute to physical and social aspects of a job that require effort and may have physical and mental costs (Bakker, Demerouti, & Euwema, 2005). Almondes & Araújo (2009) found working shift-work caused higher levels of situational and dispositional anxiety, when compared to fixed daytime work. Another study found 10% of Melbourne paramedics working the same four on, four rosters as the fulltime QFES FireCom officers, were suffering from severe or extremely severe depression, and above normal levels of anxiety. Nearly 40% reported higher than normal levels of stress (Courtney, Francis, & Paxton, 2010). Given this evidence, the higher the average of number of night shift hours FireCom officers reported over a two-week period, was expected to be predictive of higher levels of psychological strain in the current study.

AGE

Ageing may also be a factor increasing the adverse effects of shiftwork on well-being and health. As age is associated with increase vulnerability to several influences that effect overall well-being (Harma, 1998) such as poorer sleep quality, less healthy lifestyles, fatigue and cognitive impairment (Clendon & Walker, 2013), it was also investigated in the present study. Findings from previous studies on the effects of age have been shown inconsistent, with age bringing experience and increased ability to cope but also showing a decrease in well-being and ability to cope (Foret, Bensimon, Benoit, & Vieux, 1981). Research suggests that older people may be less able to adjust to abrupt changes in sleep timing occasioned by shift work (Harma, Hakola, Kerstedt, & Laitinen 1994), although other studies have failed to confirm this (e.g., Monk, 2005). Adaptation to shift work depends partly on circadian type and on changes in daily rhythm (Griefahn, Kunemund, Golka, Thier, & Degen. 2002; Roenneberg & Merrow, 2003). Age is an important factor, since the circadian rhythm of people older than 40 years seems to be less adaptable (Reid & Dawson 2001). Gershon, Lin & Li (2002) study investigated the well-being of aging emergency service personnel (police) doing shiftwork. A key finding of this study is that older officers with higher levels of work stress are at significant risk of serious physical, mental, and health risk problems. In this study, three of four officers reporting stress also reported symptoms of depression and perceived work demands was significantly associated with anxiety.

Looking at job demands is not enough when it comes to the well-being and health of FireCom officers. The presence of resources is also important, as they will help employees to handle their job and life stressors. Therefore, the present study investigated the positive influences of resources two job resources on well-being.



JOB RESOURCES – SOCIAL SUPPORT

Social support is defined, alternatively, as having friends and other people, including family, to turn to in times of need or crisis so as to provide a broader focus and positive self-image (Salovey, Rothman, Detweiler, & Steward, 2000), or as information from others that one is loved and cared for (Cobb, 1976). Social support enhances quality of life and provides a buffer against adverse life events. Warner, Gutierrez, Villegas & Schwarner (2015) found receiving social support shortly after a traumatic event was an important coping resource and was in turn associated with more adaptive adjustments. Social support has been significantly and positively linked to well-being and according to Cohen and Willis (1985), it protects against the adverse impacts of stress. Studies with emergency medical dispatch operators found that receiving social support from others helps protect against the harmful effect of job stress (Cohen & Willis, 1985) and is related to lower levels of posttraumatic stress disorder (PTSD) in other emergency services (Stephens, Long, & Miller, 1997). Therefore, it was predicted that social support will have a direct positive effect on well-being and negatively predict depression, anxiety and stress.

Previous investigations of workplace social support have focused on evaluating the impact of support received from various sources, typically supervisors and colleagues (Brough & Frame 2004; Pears 2004; Dollard & Winefield, 1995). Supervisor social support, in particular, has been identified as alleviating the negative consequences of occupational stress across a variety of job contexts (Bliese & Castro, 2000). In contrast studies involving emergency service workers found that fire fighters in particular favoured partner and work support over supervisor support (Haslam & Mallon, 2003). Therefore, it is predicted that social support will have a direct positive effect on well-being and negatively predict depression, anxiety and stress.

JOB RESOURCES – SELF EFFICACY

As mentioned previously, job resources are those aspects of a work place that help with employees' achievement of work goals, reduce demands, and stimulate growth and development, and lead to organisational commitment (Bakker, Demerouti, & Euwema, 2005). One such job resource is self-efficacy, which, Bandura (1997) defined, as the level of confidence a person has to perform a specific task. It is the feeling of confidence (or lack thereof) about accomplishing job related goals and succeeding with a challenging project at work. More specifically, self-efficacy relates to our confidence in our own ability and in the likelihood of being able to succeed in a challenging work situation (Bandura, 1997; Paulhaus, 1983).

Bandura's social cognitive theory proposes that a reaction to stress depends on levels of self-efficacy. High self-efficacy predicts better adjustment to the environment, with lower levels of strain and burnout across various professions (Bandura, 2000). Self-efficacious employees are protected from burning out not only because they cope better with the negative emotions generated by the work itself, but also because they adjust to the work environment, and interact differently with it (Consiglio, Borgogni, Alessandri, & Schaufeli 2013). Therefore, it is predicted that FireCom operators who believe they are capable of handling job tasks effectively will experience greater well-being and lower job strain.



THE CURRENT STUDY

Despite the important role of QFES FireCom officers, there has been little research on their overall mental health. Therefore, the current study aimed to investigate the mental health of FireCom officers by utilising the JD-R theory. The study measured both positive (self-efficacy and social support) and negative (job demands and shiftwork) predictors of employee well-being, depression, anxiety, and stress. Job demands were further broken down into acute stressors (GARS) and chronic stressors (perceived work demands). Previous research on the effect of age and shift work has shown that older emergency service personnel have lower reported levels of well-being. Based on the previous literature, the following hypotheses are proposed;

H₁. Shift work, age, and two types of job demands (acute and chronic) will negatively predict well-being and positively predict depression, anxiety, and stress.

H₂. Self-efficacy and social support will positively predict psychological well-being and negatively predict depression, anxiety, and stress

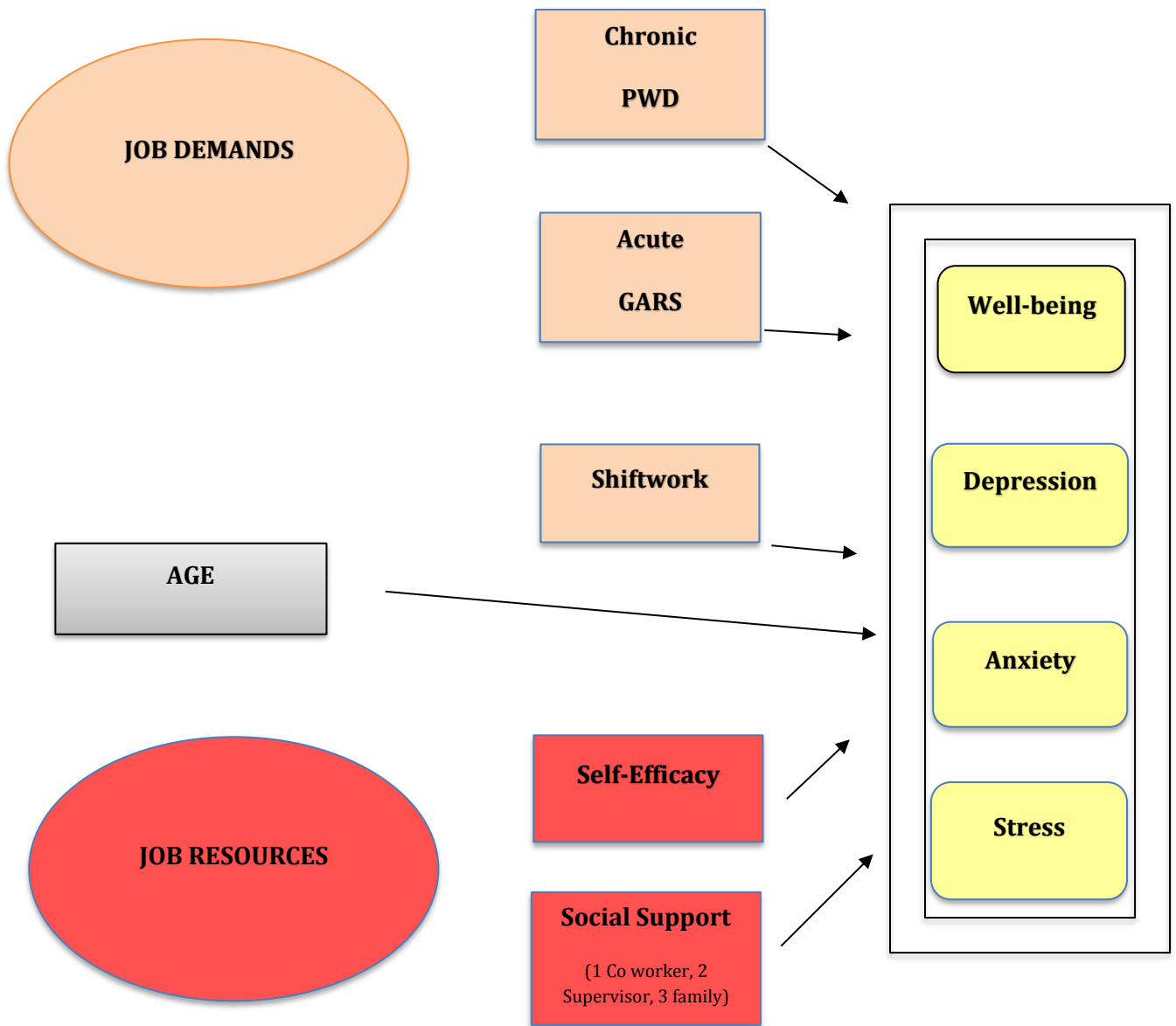


Figure 1. Overview of the research model showing effects of job resources (social support; self-efficacy), job demands (Acute GARS; Chronic PWD & shiftwork), and age on well-being, depression, anxiety, and stress.

METHOD

Eighty-one QFES Fire Com officers completed the questionnaire with one participant excluded because of incomplete data and another excluded because of potentially influential scores. The final sample consistent of 79 participants (29 male, 50 female). Their ages are given in Table 1.

Table 1

Age bracket groups showing number and percent of participants for each category

Age (years)	N	%
21 - 30	16	19.75
31 - 40	28	34.57
41 - 50	25	30.86
51 - 55+	12	14.81

Of these, 25.9% indicated having over 15 years of service with QFES, 6.2% had between 12-15 years service, 9.9% between >10 - 12 years; 13.6% between >8 - 10 years; 14.8% between >6 - 8 years; 9.9% between >4 - 6 years; 12.3% between >2- 4 years; 3.7% between >1 - 2 years and 3.7% between 3 months and 12 months service. Weekly shift rotation was identified by either, 1) Day work - 8am to 6pm, or 2) Night shift 6pm to 8am with nearly half of the sample (48.75%) indicated they worked more than 48 hours of night shift in a fortnight. Eighty one per cent of participants identified as employed full-time, with 10.1% part time and 8.7% identifying as casual. There were no incentives offered for completing the survey.

MEASURES

Warwick Edinburgh Mental Well-being Scale (WEMWBS; Tennant, Hiller, Fishwick, Platt, Joseph, Weich, & Stewart-Brown, 2007). The WEMWBS is a scale of 14 positively worded items, with five response categories, for assessing mental wellbeing. Participants were asked to rate the extent to which they have experienced each state *over the past 6 months*. Tenant et al. (2007) showed the WEMWBS is a short and psychometrically robust scale, and with a Cronbach's alpha score of $\alpha = 0.89$ and high correlations with other mental health and well-being scales.

Depression, Anxiety Stress Scale (DASS; Lovibond & Lovibond, 1995). The DASS 21 is a 21item self-report questionnaire designed to measure severity of symptoms of the negative emotional states of depression, anxiety, and stress. Subjects use 4-point scales to rate the extent to which they have experienced each state *over the past 6 months*, ranging from 1 (*Did not apply to me at all over the last 6 months*) to 4 (*Applied to me very much or most of the time over the past 6 months*). Scores are calculated by summing the responses to the relevant items, with high scores indicating higher levels of depression, anxiety, and stress. The DASS-21 has been shown to be psychometrically sound with good reliability

and validity (Oei, Sawang, Goh, & Mukhtar, 2013) with Cronbach Alpha scores for the depression scale at $\alpha = 0.91$, the anxiety scale at $\alpha = 0.84$, and the stress scale at $\alpha = 0.90$ (Lovibond & Lovibond, 1995).

Perceived Work Demands Scale (PWD; Boyar, Carr, Mosley, & Carson, 2007). This 5-item self-report questionnaire is designed to measure workers' perceptions of their experience in their place of work. Responses are given on a 5-point scale ranging from 1 (*strongly disagree*) to 5 (*strongly agree*) to rate their experiences *over the past 6 months*. Higher scores indicate higher levels of perceived work demands. The scale has a reliability coefficient of Cronbach alpha score of $\alpha = .83$ (Olowodunoye & Adebayo, 2015). The scale has a reliability coefficient of Cronbach alpha score of $\alpha = .83$ (Olowodunoye & Adebayo, 2015).

Greater Alarm Response System (GARS; QFES, 2016). This is the QFES response level to an emergency incident and is recorded in both QFES emergency services computer aided dispatch (ESCAD) and Operations Management (OMS) systems. A second alarm requires significantly more resources and places higher acute job demands on FireCom officers. Therefore, as a measure of acute demands, this study asked specifically the number of second alarm responses FireCom officers had experienced in the last 6 months. This information was self-reported and could be sourced from ESCAD records to ensure accuracy, with mean of 3.91 (SD 1.74).

Shift work Night shift in QFES is between 6pm and 8am, with fulltime FireCom officers' rostered two consecutive night shifts in a 4 day rotation, also known as a "tour". This study asked how many hours of night work (between 6pm and 8am) FireCom officers averaged in a two-week period and then categorised into over 48 hours (fulltime) or less than 48 hours (part-time).

The Occupational Self-Efficacy Scale (OCCSEFF; Schyns & von Collani, 2002) is a specific measure of self-efficacy in the occupational domain that has shown to be a reliable, one-dimensional scale that has acceptable construct and criterion validity (Schyns & von Collani, 2002). The OCCSEFF includes eight items and has been shown to have good validity when compared with general measures of general self-efficacy such as The Self-Efficacy Scale (Sherer, Maddux, Mercandante, Prentice-Dunn, Jacobs, & Rogers, 1982) and a Cronbach's alpha coefficient of $\alpha = .90$ (Rigotti, Schyns & Mohr, 2008).

Social support (Caplan, Cobb, French, Van Harrison, & Pinneau, 1980). This scale includes subscales that measured the support an employee perceives is available from their 1) co-workers, 2) supervisor, and 3) spouse and family/friends. It assesses the extent to which these three sources go out of their way to help an employee, are easy to talk to, can be relied on when things get tough on the job, and are willing to listen to an employee's personal problems. The present study, a 6 month time-frame was specified. Items are rated on 5-point scale from 4 (*Very much*) to 0 (*Don't have any such person*). Responses are averaged to form totals for each subscale, and then the three subscales are summed to give an overall social support score. High scores indicate high levels of received social support in each case. The 4-item scales have reported coefficient alpha of $\alpha = .86$ for co worker, $\alpha = .86$ for supervisor support, and $\alpha = .87$ for family and friends (Frese, 1999).



Age Previous research has shown that people older than 40 years seems to be less adaptable to shift work and experience lower overall well-being (Reid & Dawson 2001), therefore age was dummy coded into 1 = over 40 years and, 0 = under 40 years.

PROCEDURE

All QFES FireCom officers with a minimum of three months service were eligible to participate in this research. Participants were recruited via a web link emailed to their work intranet email address by the South East Region HR department. This approach was taken to ensure that participants remained anonymous to the researcher, who was also an employee of the QFES. Individuals who wanted to participate were asked to click on a link that took them to the online survey, hosted by the website 'SurveyMonkey'. Upon accessing the survey, participants viewed an information sheet that provided details about confidentiality, anonymity, the risks and benefits of the study, and the ability to withdraw without penalty. Subsequent completion of the questionnaire, which took approximately 15 minutes, indicated informed consent. A second email with the survey link was sent out to all Fire Com officers two weeks after the first email either thanking them for their participation or asking for completion. Responses were received from 81 of the approximately 110 FireCom officers originally contacted, a response rate of 73%.

RESULTS

All statistical procedures were conducted using SPSS Version 22. The data analyses that were conducted included missing data analyses, reliability analyses, bivariate correlations, and regression analyses. Descriptive statistics for each of the variables can be seen in Table 1, and correlations can be seen in Table 2.

Table 1

Descriptive Statistics for Study Variables (N = 79)

Variable	<i>M</i> (<i>SD</i>)	Actual Scores Range	Possible Range of Scores
GARS	3.91(1.74)	2.00 – 6.00	1.00 – 6.00
Job demands	4.07 (0.58)	1.28 – 5.00	1.00 – 5.00
Self-efficacy	2.91 (0.57)	1.73 – 4.56	1.00 – 6.00
Social support (total)	13.21(1.88)	8.00 –16.00	1.00 – 48.00
Well-being	3.06 (0.45)	1.75 – 4.37	1.00 – 6.00
Depression	1.47 (0.48)	1.00 – 3.57	1.00 – 4.00
Anxiety	1.28 (0.40)	1.00 – 3.14	1.00 – 4.00
Stress	1.73 (0.49)	1.00 – 3.28	1.00 – 4.00

Regression analysis. Four standard multiple regression analyses, one per dependent variable, were carried out to investigate the factors that predict the mental health of FireCom officers. All analyses included GARS, job demands, shift work, age, self-efficacy and total social support as predictors.

Well-being. GARS, job demands, shift work, age, self-efficacy and social support together explained 32.4% of the variance in well-being, $F(6, 72) = 5.74, p < .005$. Significant unique contributions to the explanation were made by age ($\beta = -.25, p = .016$) and social support ($\beta = .43, p < .005$) but not GARS, job demands, shift work or self efficacy. Thus, better wellbeing in Firecom officers can be explained by being younger (under 40 years) and receiving higher social support.

Depression. The predictors together explained 29.2% of the variance in depression, $F(6, 72) = 4.95, p = .000$. Significant unique contributions to the explanation were made by GARS ($\beta = .27, p = .015$) and social support ($\beta = -.47, p = .000$) but not job demands, self efficacy, age or shift work.

Anxiety. The predictors together explained 17.3% of the variance in anxiety, $F(6, 72) = 2.50, p = .029$. Significant unique contributions to the explanation were made by job demands ($\beta = -.24, p = .041$) but not GARS age, self efficacy, shift work or social support.

Stress. The predictors together explained 29.1% of the variance in stress $F(6, 72) = 4.93, p = .000$. Significant unique contributions to the explanation were made by job demands ($\beta = .25, p = .020$) and social support ($\beta = -.37, p = .003$) but not GARS, shift work, age or self efficacy.

SUMMARY OF FINDINGS

Results provide partial support for the both hypotheses; however all four models were found to be significant with differing amounts of the variance in outcomes explained. As expected, and consistent with findings from JD-R theory and previous job demands research, higher acute job demands (GARS) was associated with higher levels of anxiety and stress. Higher chronic job demands was also found to be a significant predictor of stress. The current study found older age (>40 years) FireCom officers reported lower well-being than their younger counterparts. However, contrary to previous research, no support was found for the negative effects of shift work on overall well-being.

Partial support was also found for the second hypothesis, with FireCom officers with higher total social support reporting higher levels of well-being and lower levels of depression and stress. Further analyses showed that support from family in particular, predicted higher wellbeing and lower levels of stress, depression and anxiety. Again, contrary to previous research self efficacy did not negatively predict lower levels of depression, anxiety, and stress. It did however, positively predict well-being.

Table 2

Bivariate Correlational Matrix for All Variables Used in Analyses (N = 79)

	Well-Being	Depression	Anxiety	Stress
GARS	-.14	.26*	.20	.26*
PWD	-.01	.16	.27*	.35**
Shiftwork	-.07	.00	.08	.12
Age	-.22*	.21	.24*	.15
Self-efficacy	.26*	.04	.16	.02
Social support	.46**	-.37**	-.09	-.34**

Note. Age was dummy coded into 1= over 40 years; 0 = under 40 years. Shift work was dummy coded into 1 = full time; 0 = part time. Job demands and self-efficacy have been square root transformed and reflection. Depression, anxiety and stress has been square root transformed.

* $p < .05$. ** $p < .01$. *** $p < .001$.

It was hypothesised that higher job demand both acute (GARS) and chronic (PWD) would negativity predict well-being and positively predict depression, anxiety and stress. A significant positive moderate correlation was found between job demands (chronic) and anxiety and stress. A significant positive moderate correlation was also found between GARS (acute) and depression and stress. Consistent with the JD-R model, the current study



found higher job demands lead to higher levels of depression, anxiety, and stress. Previous research has shown that chronic job demands and acute job demands have been found to differ on the impact they have on workers performance and to the development depression and anxiety (Beehr & Franz, 1987). The current study also found support for the association between job specific demands and negative outcomes, with acute job demands (GARS) negatively predicting stress and chronic job demands negatively predicting both anxiety and depression.



DISCUSSION

While there has been much research on frontline emergency service workers, the current study aimed to fill the gap in the literature by assessing factors that affect overall well-being of FireCom officers. Despite the stressful nature of their role, there has been little published research investigating psychological well-being or depression, anxiety and stress among this population. The Queensland Fire and Emergency Services is the primary provider of fire and emergency activities in Queensland. Given that FireCom officers provide an important service to the community and are the first link between the public and emergency services, it is important that the overall well-being of Fire Com officers be monitored and enhanced where needed.

Despite many well-documented studies showing the negative effects of shift work on daily health (Clendon & Walker, 2013), cognitive (Folkard, 1996), biological, psychological and social (Rouch, Wild, Ansiau & Marquie, 2005) factors, the current study found no link between shift work and FireCom officers well-being, depression, anxiety or stress. During a 14 hour night shift, up to 4 hours of “fatigue management” or short naps can be utilised by FireCom officers, which may account for the inconsistent results with previous negative reports on effects of shift work. Saksvik, Bjorvatn, Hetland, Sandal & Pallesen (2011), study found that there are a variety of individual factors that determine a individuals ability to cope with shiftwork, suggesting that some individuals are less affected by shift-work than others. As the majority of the participants in the current study are female, Sheilds, 2002 study found that females have a greater ability to cope with night work and are more likely than males to work these schedules to care for family.

Contrary to the hypothesis and previous finding the current study, self-efficacy was not a significant predictor of well-being or depression, anxiety or stress. A significant moderate positive correlation was found between self-efficacy and well-being. A low mean score was also found suggesting FireCom officers overall reported low levels of self-efficacy. A literature review by Smith, Fuqua, Choi, & Newman, (2007), showed that role ambiguity can have a negative impact on employees and their general self-efficacy, as well as their satisfaction in their position and with the organisation. With recent introduction of the new government wireless network (GWN) digital communication system, FireCom officers’ routine tasks have become more complex and challenging. Stajkovic and Luthans (1998) found that task complexity moderated the relationship between self-efficacy and work-related performance, perhaps offering another reason why self-efficacy was not a significant predictor in overall well-being.

Consistent with the hypothesis and previous research social support was found to positively predict well-being, indicating that the more social support FireCom officers reported the higher their overall well-being and lower reported levels of depression and stress.

STRENGTHS AND LIMITATIONS

An acknowledged limitation of the present research is the relatively small sample size on which the results are based ($N = 79$). Due to this low sample size and the number of



predictors, no interaction effects were carried out for the current study. Another limitation of this research is due to the problems associated with response-bias and common-method variance; common problems with questionnaire-based research. However, self-report was the most feasible and precise way to measure the constructs in this study, and having the QFES Human Resources Department distributed the survey ensuring the privacy of the respondents, which was expected to reduce the potential for self-report bias. Another consideration is the dependent variable measures were not context specific, which may influence the way Firecom Officers reported levels of overall well-being.

One of the strengths of the study was the high response rate therefore, the respondent characteristics were considered to represent the general characteristics of this organisation. However, it is acknowledged that the inclusion of a larger initial sampling pool would also improve the reliability and generalisability of the reported results to include all other emergency dispatch agencies. The ability to be able to access a normally difficult to reach sample would also be considered a unique strength for the current study. Another strength is the use of both positive and negative dependent variables to gain an overall and comprehensive measure of overall well-being of FireCom officers. Finally, another strength is the deaggregation of job demands to include a measure of both chronic and acute job demands expanding on previous JD-R research. Social support was also expanded to include family, colleague and supervisor support giving more specific categories.



CONCLUSION

The Queensland community needs the skilled support of every first responder it can get – and we need them to be mentally healthy and well. QFES Fire Com officers need to be flexible, compassionate, efficient and knowledgeable to deal with their tasks. Their challenging job requires a responsible attitude, the ability to cope with stress, patience and a wide range of personal and professional knowledge. Like any other workers, they may also experience workplace stressors, such as excessive and challenging workloads, inadequate support and changes to work systems and policies. Individual qualities and abilities also play a role in how people respond to stressful situations at work (Judge & Bono, 2001). Most first responders manage the challenges of the job well, and have the ability to endure, adjust and recover from the stress and adversity associated with their role. Promoting well-being and investing in mental health also makes good business and operational sense - low absenteeism, increased productivity and improved worker engagement (Hobson & Beach, 2000). Workers with high levels of mental health and wellbeing are not only happier and healthier, but also more productive and likelier to stay in the workforce despite any challenges life may throw at them (Deci & Ryan, 2008). This research demonstrated that social support had a greater impact on overall well-being, particularly support from family. It also highlights the importance of considering training and education in self-efficacy as well as providing support and more training around the introduction of new technology and organisational change.

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APPENDIX A

Shows the resources associated with each alarm level for the different emergency incidents

GARS South East Queensland Model (BR, SER)						
Incident type	1 st Alarm	2 nd Alarm	3 rd Alarm	4 th Alarm	5 th Alarm	4 th Alarm or higher
Structure Fire	First alarm response is as regional mobilisation protocols	4 x pumpers 1 x control vehicle 1 x Command Officer	6 x pumpers 1 x control vehicle 1x aerial 1 x BAHazmat 2 x Command Officer	8 x pumpers 1 x control vehicle 1 x rescue 1x aerial 1 x BA Hazmat 1 x scientific 3 x Command Officer	10 x pumpers 1 x control vehicle 1 x rescue 1x aerial 1 x BA Hazmat 1 x scientific 4 x Command Officer	2 x additional pumpers per alarm
Non-Structure fire (e.g. wildfire)		4 x pumpers or 4 x RFB 1 x control vehicle 1 x Command Officer	6 x pumpers or 6 x RFB 1 x control vehicle 2 x Command Officer	8 x pumpers or 8 x RFB 1 x control vehicle (or ICC) 3 x Command Officer RFCC – watching brief state air desk notified	10 x pumpers or 10 x RFB 1 x control vehicle (or ICC) 4 x Command Officer RFCC – watching brief SOCC state air desk notified	2 x additional pumpers per alarm
Rescue		3 x pumpers + 1 rescue 1 x control vehicle 1 x Command Officer	4 x pumpers + 2 rescue 1 x control vehicle 2 x Command Officer	6 x pumpers + 2 rescue 1 x control vehicle 3 x Command officer RFCC – watching brief	8 x pumpers + 2 rescue 1 x control vehicle (ICC) 4 x Command officer RFCC – watching brief SOCC – watching brief	2 x additional pumpers per alarm
Hazmat		3 x pumpers + 1 BAHazmat 1 x control vehicle 1 x scientific` 1 x Command Officer	5 x pumpers + 1 BAHazmat 1 x control vehicle 1 x scientific` 1 x decon unit 2 x Command Officer	6 x pumpers + 2 BAHazmat 1 x control vehicle 1 x decon unit 1 x scientific` 3 x Command Officer	8 x pumpers + 2 BAHazmat 1 x control vehicle (or ICC) 1 x decon unit 2 x scientific` 4 x Command Officer	2 x additional pumpers per alarm



INCLUDING THE INTANGIBLE BENEFITS OF BUSHFIRE MITIGATION IN ECONOMIC ANALYSES: A 'VALUE TOOL' FOR INFORMED DECISION MAKING

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ABSTRACT

Understanding the costs and benefits of bushfire mitigation is imperative for governments to be able to prioritise the strategies that provide the best value for money. The economic damages caused by bushfires and the costs of mitigation are relatively well documented and can be large. But the social and environmental benefits of bushfire mitigation, which can potentially be even larger, have not been well documented. As a result, these types of intangible benefits are often neglected in decision making. We have created a 'value tool' that makes information about these intangible benefits accessible to decision makers for use in economic studies such as benefit-cost analyses.

The value tool identifies the types of intangible values that might be affected by bushfires or their mitigation, in terms of health, environmental and social effects. We have compiled a database of different studies that have measured these values in dollar terms reflecting how much they are worth to the community. This means they can be directly compared with other monetary estimates of costs and benefits related to bushfire mitigation. The database comes with a set of user-friendly guidelines that illustrate how the intangible values can be used to make decisions and prioritise bushfire mitigation strategies. For example, a bushfire manager will be able to use the value tool to identify the types of intangible values that might be affected by a prescribed burning plan, such as protecting wildlife and minimising distress to local communities, and find dollar estimates for each of these values. The value tool also provides estimates of intangible values relevant to other types of natural hazards.



INTRODUCTION

Bushfires and other natural hazards can cause large economic damages and governments recognise the importance of mitigation to avoid these costs (Penman et al. 2011). Limited financial resources makes it critical to be able to prioritise mitigation actions efficiently. The use of economic frameworks such as benefit-cost analyses enables the efficient allocation of funds by weighing up the financial benefits and costs of different mitigation programs (Ganewatta and Handmer 2006). Milne et al. (2015) point out that economic studies of bushfire risk mitigation tend to focus on financial costs, as opposed to the intangible benefits and costs associated with mitigation which includes the effects on social values, the environment and human health. These types of intangible or non-market values are relatively more difficult to quantify than other financial costs and benefits because they are not traded in markets. However, the intangible impacts of bushfire events and mitigation efforts can be significant. For example, in two of Australia's high impact fires the environmental losses accounted for 9% (1983 Ash Wednesday Fires) and 71% (2005/06 Grampians Fires) of the total losses resulting from the fires (Stephenson et al. 2012).

Non-market values can be used in policy and decision making instrumentally by directly influencing decisions, for example, through inclusion in benefit-cost analyses, or conceptually by improving the understanding of policy issues (Pandit et al. 2015). Benefit-cost analyses are able to incorporate intangible, non-market values provided they are quantified in financial-equivalent terms to other market costs and benefits. Non-market valuation is an economic approach that enables non-market values to be measured in this manner. Specifically, non-market valuation estimates how much people are willing to pay for a change in the quantity or quality of a non-market good, service or benefit (Bateman et al. 2002).

Original (new) studies applying non-market valuation are generally the preferred approach for providing non-market values for use in policy and decision making, as they offer the most accurate representation of values in a specific context. However, for various reasons, an original study is sometimes not justified or feasible (Rogers et al. 2015). For example, the project or policy timeframe might not allow for the collection of new data, the budget for analysis may be too small, or the decision to be made may be a relatively minor one. In such cases, benefit transfer offers an alternative to conducting an original study.

Benefit transfer is, put simply, the "transfer" or application of data collected from one location to a new location of policy interest. As such benefit transfer relies on the use of non-market valuation results from pre-existing studies at one or more sites or policy contexts (often called study sites) to predict willingness to pay (WTP) estimates or related information for other, typically unstudied sites or policy contexts (Rolfe et al. 2015). Benefit transfer is advocated for use in policy making, particularly for non-market values, because usually it is cheaper, takes less time and is more straightforward than conducting original studies.

We have created a look-up database, hereafter called the 'Value Tool', that provides a compilation of intangible values from existing studies that are suitable for use in benefit transfer for bushfire mitigation decision making, as well as for other natural hazards. The tool has been created in order to improve the capacity of bushfire managers to consider and include non-market benefits and costs in prioritising decisions. This paper provides a concise introduction to the economic approaches of



non-market valuation and benefit transfer, before describing the design of the Value Tool. An example of how to apply the Value Tool is then provided before discussing its advantages and limitations.



NON-MARKET VALUATION AND BENEFIT TRANSFER

Non-market valuation includes a set of economic methodologies that are based on the concept that people make choices to maximise their utility (or well-being), and in doing so they make trade-offs between the attributes of different goods and services, including the costs involved in purchasing those goods and services (Hanley and Barbier 2009). That is, it is assumed that consumers purchase products to maximise their utility subject to their individual budget constraint.

There are two main forms of non-market valuation: revealed and stated preference techniques. Revealed preference techniques use information about behaviour and data from markets related to non-market goods to infer WTP for those goods. For example, the travel costs of a trip can be used to infer the minimum that an individual is willing to pay to visit a particular recreational location, or we could analyse how housing prices change in proximity to a recreation facility to determine the premium people would pay to live nearby. These approaches can estimate lower bound estimates of WTP for the use of non-market resources (see Hanley and Barbier 2009 for more information on revealed preference techniques). Stated preference techniques are able to estimate maximum WTP for both the use and non-use (e.g. existence values that people might hold for protecting the environment) of non-market resources. Surveys are used to define a hypothetical scenario where the respondent makes a trade-off between how much they are willing to pay for some improvement, or set of improvements, in the non-market good that is being valued (see Bateman et al. 2002 for more information on stated preference techniques).

Benefit transfer uses the WTP estimates that are derived from original non-market valuation studies and applies them to new policy or decision contexts. There are a number of ways to conduct a benefit transfer, which vary according to the accuracy and expertise required. The main approaches include unit-value transfer and benefit-function transfer.

Unit-value transfers involve the transfer of a single number or a set of numbers from study sites to the policy sites (Johnston et al. 2015). The number(s) can be adjusted to account for differences in, for example, currency value across different time periods and differences in average income of the sampled population in the study and the population affected at the policy site. These adjustments are imposed *ex post* by the practitioner based on their knowledge of the policy site's characteristics, such as the sociodemographic profile of the population.

Benefit-function transfers use a "transfer function" to estimate and transfer values from study sites to policy sites (Johnston et al. 2015). The transfer function includes variables from the original study such as socio-demographic characteristics or the number of substitute sites available. That is, the transfer function can account for observable differences between the study and policy sites using adjustments based on information provided by the original study. The approach could be a parametric function, a meta-analysis (typically meta-regression analysis), or a preference calibration based on a structural utility model.

In cases where the study and policy sites are dissimilar in some respects, benefit-function transfers are generally more accurate than unit-value transfers (Bateman et al. 2011). Any mismatch between the study and policy sites will generate errors in the transferred values (Johnston et al. 2015). The ability to account for differences between the sites in the benefit-function transfers means that there is less error associated with



the transferred value. However, a degree of error is likely to be present in any transfer approach and function-based approaches are more difficult to implement than unit-value approaches, generally requiring an experienced analyst to conduct the transfer. Thus, there is a trade-off between accuracy and practicality. The Value Tool relies on the simpler unit-value transfer approach given its focus on making non-market values more accessible for use in decision making, though the tool emphasises the importance of transparency in the assumptions that are made for each decision and informs users about the degree of accuracy in the transfers they might make.



VALUE TOOL DESIGN

The first step in generating a database of WTP estimates for use in natural hazard decision making was to determine what types of intangible values could possibly be affected by natural hazard events or their mitigation. We identified 11 different value types via consultation with natural hazard decision makers and through reviews of the natural hazard management literature and the outcomes from risk assessment workshops run by the WA State Emergency Management Committee. The value types were divided into three categories (Table 1):

- Health – physical and mental health;
- Environment – ecosystems and water quality;
- Social – recreation, amenity, safety, cultural heritage, social disruption, memorabilia and animal welfare.

We identified a set of measurable processes and outcomes associated with each value type, as examples of the ways in which a value might be affected by a natural hazard event or its mitigation. The changes in final outcomes are typically what is 'valued', and where these changes can be measured they can be used to establish the marginal or physical change that people are willing to pay for (or require compensation for, in the case of a negative change) (see column 3, Table 1). However, it can sometimes be easier to quantitatively measure the physical changes related to intermediate processes, which subsequently produce a desired outcome (see column 2, Table 1). As such, the Value Tool database provides estimates related to changes in the processes and outcomes of the different value types. To avoid double counting it is important to be clear in the distinction between values for processes and outcomes, and not to combine WTP estimates for both in relation to the same value type. For example, for ecosystems, you would not use a WTP estimate for reducing the number of invasive species in an area – which is a process that leads to adverse impacts on native flora – along with a WTP estimate for improving the health of native flora – the desired outcome (Table 1).

With the value types and descriptions of likely processes and outcomes identified, we conducted a review of the non-market valuation literature to identify studies with appropriate WTP estimates for inclusion in the Value Tool database. There is a vast literature on non-market values related to the health, environmental and social categories; however, few studies have been conducted in a natural hazard decision making context. The policy or decision context in which a WTP study is conducted has implications for how appropriate it is to use in benefit transfer (Carlsson et al. 2010): while different decision contexts might lead to the same outcome (e.g. destruction of native forest), the cause of the change (e.g. clearing for a mining project versus an intense wildfire) can affect the magnitude of how much people are willing to pay for that particular outcome. Accordingly, we followed a search protocol where we selected the most relevant studies that were available for natural hazard decision making for each value type. In some cases, certain value types are not well represented in the literature, and the studies included in the database require caution when using for benefit transfer. We were able to identify studies to include in the database for all value types except memorabilia.

The search protocol prioritised studies for inclusion in the database as follows:

- 1) Studies measuring the value type in a natural hazard context, in Australia
- 2) Studies measuring the value type in a different context, in Australia



- 3) Studies measuring the value type in a natural hazard context, internationally
- 4) Studies measuring the value type in a different context, internationally
- 5) Studies measuring costs associated with a value type, where WTP studies can't be identified

The database includes over 40 studies, some of which have multiple WTP estimates reported for the various marginal changes measured within the study. For each study, the database records:

- which value type is being measured;
- which types of natural hazards the study provides suitable WTP estimates for;
- what specific marginal (physical) change is being measured;
- the WTP estimate(s) for the change, converted to Australian \$ where relevant;
- information about study location, sample demographics, study methodology and supporting statistics (e.g. confidence intervals for WTP estimates) where provided; and
- recommendations on appropriateness for benefit transfer.

In addition to the database, the Value Tool also includes a set of guidelines on how to use WTP estimates listed in the database for the purpose of benefit transfer. The guidelines present a review of existing non-market valuation literature for each value type to establish how well the available literature, and corresponding WTP estimates, match natural hazard decision contexts. This provides an understanding of the accuracy with which values can be transferred from the database to a new decision. With this understanding in mind, the guidelines provide recommendations on how to undertake the benefit transfer, including suggested adjustments (e.g. income adjustments between study samples and the relevant population affected by the present decision) that can be made to transferred values and sensitivity testing.



VALUE TOOL APPLICATION

Here we demonstrate a hypothetical example of how to apply the Value Tool. The first requirement is to follow instruction in the guidelines on defining the policy context. A checklist of questions must be answered to establish what type of value(s) the decision maker is looking for in the database. The checklist should be applied separately for each value type being considered.

We provide an example in the context of managing bushfire risk. The geographical area and mitigation strategy will help to determine exactly which value types from Table 1 are relevant in this context, but values that are likely to be relevant include physical health, mental health, ecosystems, recreation, amenity, safety and animal welfare. Focusing on the value type 'physical health', we show how to work through the checklist below:

- 1) What is the natural hazard type?
Bushfire
- 2) Which value type is affected by the hazard or its mitigation?
Physical health
- 3) How is this value affected, in terms of the physical changes that are likely to occur?
A prescribed burning regime is expected to prevent loss of life due to wildfire
- 4) What is the scale of the proposed change?
5 lives saved
- 5) Who is the affected population?
Victorian population

We acknowledge that answering the checklist of questions is not always a straightforward task, particularly in relation to clearly establishing the physical change and the scale of that change. Answering these questions will often depend on the availability of information such as bio-physical data. In the absence of such data, expert judgement can play a valuable role.

With the policy context defined, decision makers are then advised to consult the literature review provided in the guidelines relevant to the value type they are measuring. The review provides a summary about the state of the existing literature and how relevant it is for decision making in a natural hazard context. In the case of physical health, the review concludes that:

- There is a large literature on value of statistical life which includes Australian studies, meta-analyses and study contexts relevant to natural hazards.
- Physical health values are well documented and readily applicable to benefit transfer.

With this contextual understanding in mind, the database can be consulted to extract relevant values. The database can be searched by hazard type, value type, and the specific marginal or physical change that is being measured (Figure 1). For our prescribed burning example, a study exists that provides a review of the international literature on the 'value of a statistical life', with the objective of identifying an



appropriate value for Australia (Abelson 2008). The value of a statistical life can be measured through a range of revealed and stated preference techniques. It is generally a measurement of the trade-off an individual is willing to make between their income and the probability of death, or their WTP to reduce the risk of death.

Relative to our example, this study is not conducted specifically within the context of a natural hazard decision, but is based on a meta-analysis of studies providing a dollar estimate averaged over a variety of different contexts which means that it is broadly applicable to most situations. It does provide an estimate specifically relevant to the Australian population which means that the cultural and socio-demographic differences between the study site and our decision context are minimised. Accordingly, income and other population-based adjustments are not essential.

The database provides an estimate of \$3,500,000 per Australian life saved, in 2007 AUS\$ (Figure 2).

To make the estimate applicable to the prescribed burning plan, some adjustments are required:

- 1) The number must account for price changes or inflation over time using an index like the CPI (see <http://www.rba.gov.au/calculator/>):

CPI adjusted AUS\$ from 2007 to 2016 = \$4,340,915.55

- 2) The number must then be aggregated over the number of lives saved:

$\$4,340,915.55 \times 5 \text{ lives saved} = \$21,704,578$

This number can then be inserted into a benefit-cost analysis comparing the full range of benefits and costs associated with the prescribed burning plan over a specified time period.



DISCUSSION

The Value Tool provides a practical means of finding non-market values for inclusion in natural hazard decision making, through the use of benefit transfer. The Value Tool can be used to improve decision making through a number of ways. First, it can provide quantitative, financial estimates of intangible values that can be used instrumentally in benefit-cost analyses or other prioritisation metrics, to ensure that the effects of non-market values are directly accounted for along with the market costs and benefits of proposed mitigation actions. Second, it can provide specific WTP estimates that can be used conceptually or qualitatively to make judgements about decisions, for example, by supporting or justifying an existing policy. Third, in addition to providing specific WTP estimates, it can provide information about the relative magnitudes of people's preferences for different types of values that can be used to judge how people might behave under a proposed decision. Finally, it provides a platform to improve understanding about the importance of including non-market values in decision making, as well as where the knowledge gaps and uncertainty exists in relation to these values, and different approaches for dealing with uncertainty.

A limitation of the Value Tool is the uncertainty of how accurate the information within the tool is given its reliance on benefit transfer and the probable errors that occur when using this approach to transfer WTP estimates between different decision contexts. This is particularly the case given the limited literature available to provide non-market values in the context of natural hazard decision making. Many of the WTP estimates in the Value Tool database are set in a different decision context to the specific types of decisions made by natural hazard managers. In addition, valuation of non-market benefits in quantitative terms is difficult and economists are well aware that non-market valuation and its associated techniques, such as benefit transfer, are not perfect (Hausman 2012; Kling et al. 2012). However, these techniques offer a structured and transparent framework by which policy makers can include non-market values in decisions. We are of the view that it is preferable to include some information about non-market values in the decision process, than none at all. The error, and decision bias, resulting from the latter is likely to be far greater than the error from using an inaccurate number.

Indeed, Pannell and Gibson (2016) simulated millions of decisions about environmental project prioritisation, and used the results to test whether it was preferable to omit poor-quality information or to include it despite its shortcomings. They evaluated the long-term environmental outcomes from the two approaches and found that it is clearly better to include information about a particular variable, such as a non-market value, than to ignore it, even if there is high uncertainty about the accuracy of the information.

Reinforcing our view that 'some number is better than no number', it should be recognised that omitting information about non-market values does constitute making an implicit assumption – that there are no differences in non-market values between the decision options – and this implicit assumption is highly likely to be wrong.

Provided the policy maker is aware of the potential for transfer errors when applying the Value Tool, and they use a conservative and transparent approach for transferring values, including appropriate sensitivity testing in analyses that use those values, then the values can provide useful, quantitative information for decision making. In some cases, where a value transfer is too unreliable, we do not recommend using the values



in a quantitative analysis, but suggest using them in a qualitative manner to inform thinking about particular policies. Further, for major projects or decisions where time and budget permits, we recommend original non-market valuation studies are conducted to provide the most robust non-market value estimates for sound decision making.

The Value Tool will be publicly available for decision makers to utilise by the end of 2017. A custodian will maintain the tool to ensure its currency for decision making in the future. The Value Tool guidelines identify key gaps in the non-market valuation literature with respect to provision of WTP estimates suited for natural hazard decision making, particularly for the value types of mental health, ecosystems, cultural heritage and memorabilia (see Table 1). A future research focus will be to address these gaps by conducting original non-market valuation studies to provide suitable estimates for inclusion in the database. Further research is also recommended on the benefit transfer approach to establish the magnitude of transfer errors that occur under different natural hazard decision scenarios. This could enable rules-of-thumb to be established in setting the bounds of sensitivity tests for transfers made between well-matched study and policy sites, and those that are poorly matched.



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Table 1. Value types affected by natural hazard events and their mitigation.

Value type	Intermediate processes	Final outcomes	Availability of literature & recommendations
<i>Health values</i>			
Physical health	Cause emergency/ health services to be overwhelmed, resulting in further deaths directly attributable to the hazard event.	Change in number of deaths Change in number of injuries, serious illness and/or pain	There is a large literature on VSL which includes Australian studies, meta-analyses, and study contexts relevant to natural hazards. Physical health values are well documented and readily applicable to benefit transfer.
Mental health		Change in reported cases of grief, stress and anxiety	The approaches used in the literature to measure changes in mental health do not capture WTP with respect to the non-market <i>benefits</i> of avoiding/improving mental health problems. New, original stated preference studies would be required to measure WTP for mental health changes, in the context of natural hazards, to provide estimates appropriate for use in benefit transfer. The available literature can be used to assess the <i>costs</i> of mental health related treatment, which provide a partial indication of the benefits of avoiding mental health problems.
<i>Environmental values</i>			
Ecosystems	Change in spread of invasive species Change in amount of debris and pollutants to enter marine or estuarine/riverine environments Change in carbon stored in vegetation and soils Change in occurrence of algal blooms in rivers and estuaries	Change in the number of flora and fauna species Change in the status of vulnerable environmental ecosystems and/or identified critically endangered species. Change in ocean surges and wave activity resulting in marine inundation and erosion of sandy coastlines/dune systems.	There are very few cases where non-market valuation studies have estimated the value of protecting ecosystems directly. These are typically not in the context of natural hazards, nor directly relevant to Australian policy. More stated-preference studies are required to provide better estimates of these values for benefit transfer. Use of available estimates of ecosystem values for benefit transfer in the natural hazard context is limited.



Value type	Intermediate processes	Final outcomes	Availability of literature & recommendations
Water quality	<p>Change in turbidity in water bodies</p> <p>Change in occurrence of algal blooms in rivers and estuaries</p> <p>Change in debris and pollutants to enter marine or estuarine/riverine environments</p>	<p>Change in vulnerable environmental ecosystems and/or identified critically endangered species.</p> <p>Change in ocean surges and wave activity resulting in marine inundation and erosion of sandy coastlines/dune systems.</p> <p>Change in the aesthetics in the area.</p>	<p>There are few cases where non-market valuation efforts have estimated the value of water quality improvements in the context of natural hazards. However, there are numerous studies available for more general contexts.</p> <p>Use of available estimates of water quality values for benefit transfer in the natural hazard context is limited, but possible due to the availability meta-analyses which provide average WTP estimates for water quality improvements over a range of policy contexts.</p>
<i>Social values</i>			
Recreation	<p>Change in turbidity in water bodies</p> <p>Change in occurrence of algal blooms in rivers and estuaries</p> <p>Change in debris and pollutants to enter marine or estuarine/riverine environments</p> <p>Impact heritage buildings and cultural significant facilities</p> <p>Change in aesthetics in the area.</p> <p>Change in native vegetation communities</p>	<p>Change in recreation activity within the area</p>	<p>WTP estimates exist in the context of recreational values related to bushfires. There are numerous studies available for more general contexts.</p> <p>Use of available estimates for benefit transfer is possible but should be undertaken with caution, as these values are not in an Australian policy context, and do not encompass all natural hazard types.</p>
Amenity	<p>Change in turbidity in water bodies</p> <p>Change in algal blooms in rivers and estuaries</p> <p>Change in debris and pollutants to enter marine or estuarine/riverine environments</p> <p>Change in native vegetation communities</p>	<p>Change in aesthetics in the area.</p> <p>Change in amenity related recreation</p>	<p>There is a large literature on WTP estimates for amenity and safety values which includes Australian studies and study contexts relevant to natural hazards.</p> <p>Amenity and safety values are well documented and readily applicable to benefit transfer.</p>
Safety	<p>Impact to residential dwellings</p>	<p>Change in dwelling location</p> <p>Change in dwelling construction</p>	



Value type	Intermediate processes	Final outcomes	Availability of literature & recommendations
Cultural heritage	Impact to heritage buildings and cultural significant facilities	Change in cultural significance Change in heritage related recreation Impact sense of place	There are no cases where non-market valuation studies have estimated the value of protecting cultural heritage in the context of natural hazards. Use of available estimates of cultural heritage values for benefit transfer is limited: with so much uncertainty and many variables affecting the valuation of cultural heritage in general, determining the specific valuation of the impact of natural hazards on these resources may not be feasible. Available estimates can be used conceptually (qualitatively) to make judgements about decisions.
Social disruption	Evacuation to safe accommodation away from people's homes and work places Evacuation of indigenous communities away from their country, as well as being housed together in groups not aligned to their culture Change in existing social service providers (NGOs, Lions, Rotary, Salvation Army, CWA, other volunteer organisations), impacting community wellbeing. Change in day to day functionality of facilities for vulnerable people (aged, childcare, disability) Change in day to day functionality of facilities	Breakdown of existing family and support networks (including social community networks) Change in community services and wellbeing Change in availability of basic commercial products and services	There are very few cases where non-market valuation studies have estimated the value of avoiding social disruption. These are either not in the context of natural hazards, or are not Australian studies. Use of available estimates of social disruption for benefit transfer in the natural hazard context is limited.
Memorabilia		Impact to residential dwellings and contents	There are no estimates available to use for benefit transfer of memorabilia values. New, original stated-preference studies would be required to measure WTP for memorabilia values, in the context of natural hazards, to provide estimates appropriate for use in benefit transfer.



Value type	Intermediate processes	Final outcomes	Availability of literature & recommendations
Animal welfare		Displacement, death or injury to animals	<p>There are no cases where non-market valuation studies have estimated animal welfare values in the context of natural hazards.</p> <p>Use of available estimates of animal welfare values for benefit transfer is limited: the estimates are primarily in an agricultural and food-safety context, meaning there is difficulty in discerning the values for animal welfare separately from the intertwined values of food safety and environmental protection.</p> <p>Available estimates can be used conceptually (qualitatively) to make judgements about decisions.</p>



	A	B	C	D	E	F	G	H	I	J
1	STUDY IDENTIFICATION AND RELEVANCE									WILLINGNESS TO PAY
3	Observation ID (Identification number for this unique WTP)	Citation	Hazard types applicable	Value type applicabl	Brief summary of study objective(s)	Study conducted in the context of a natural hazard? (Yes/No)	Study quality (1=poor, 2=average, 3=high)	Benefits transfer applicability (1=rarely, 2=moderately, 3=highly)	Recommendations (Applicability for benefit transfer in natural hazard context)	Definition of marginal change (This is what is being measured - e.g. WTP for reduced loss of life)
4	18	Vlaev, et al. 2009	Fire, Flood, Storm, Earthquake, Tsunami	Physical health	WTP to relieve or avoid pain	No	1	1	Limited application; not NH specific, and be aware of/adjust for population differences	WTP to end a series of painful electrical shocks
5	19	Abelson 2008	Fire, Flood, Storm, Earthquake, Tsunami	Physical health	VSL for death by any means	No	2	3	Useful for BT in Australia; be aware of generalised context - not NH specific	Value of a statistical life
6	20	Abelson 2008	Fire, Flood, Storm, Earthquake, Tsunami	Physical health	VSL for death by any means	No	2	3	Useful for BT in Australia; be aware of generalised context - not NH specific	Value of a statistical life year
7	21	Knowlton, et al. 2011	Storm	Mental health	Quantify mental health costs associated hurricanes	Yes	3	2	Very limited application; provides partial assessment of benefits by assessing the costs of treatment.	Mental health cost per person per event
8										
9										

Figure 1. Screenshot of the Value Tool database showing study entries searchable by the 'Hazard types applicable', 'Value type applicable' and 'Definition of marginal change'.



	A	B	J	K	L	M	P	Q	R	S	T
1	STUDY IDENTIFICATION AND RELEVANCE		WILLINGNESS TO PAY								
3	Observation ID (identification number for by unique WTP	Citation	Definition of marginal change (This is what is being measured - e.g. WTP for reduced loss of life)	Hazard types identified	Specific value type measured	WTP estimate	WTP estimate (2016 \$AU)	Unit measurement (Quantitative units - e.g. life saved)	Model variables	Currency year	Currency
4	18	Vlaev, et al. 2009	WTP to end a series of painful electrical shocks	Physical pain	Physical Health	n/a		Quantity of shocks	price, quantity, pain level	2009	GBP
5	19	Abelson 2008	Value of a statistical life	Not specified	Physical Health	\$3,500,000	\$4,159,946	Life	n/a	2008	AUD
6	20	Abelson 2008	Value of a statistical life year	Not specified	Physical Health	\$151,000	\$179,472	Life	n/a	2008	AUD
7	21	Knowlton, et al. 2011	Mental health cost per person per event	Storm	Mental Health	\$17.38 per person per hurricane event	\$29.82	Hurricane event	Ethnicity, present for hurricane winds, property damage, amount of incurred damage, time displaced from home, social support	2008	USD
8											
9											

Figure 2. Screenshot of the Value Tool database showing the willingness to pay (WTP) data recorded for each study, including Abelson (2008) (highlighted) used in the Value Tool application example.

An assessment of the viability of prescribed burning as a management tool under a changing climate: a Tasmanian case study

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ABSTRACT

Fire danger is projected to increase across Tasmania under climate change, with the fire season starting earlier and lasting longer. Prescribed burning is currently the only effective method of managing bushfire risk at the landscape scale in Tasmania. It is generally carried out during autumn and spring, when weather conditions allow low intensity burns to be safely managed. We investigated the changing opportunities for prescribed burning in Tasmania in the near future (2021-2040) and towards the end of the century (2081-2100) under a high emissions scenario (SRES A2¹). We assessed monthly changes in the climate variables that determine when prescribed burning can be applied, including rainfall, temperature, fuel moisture and atmospheric stability. We found that in the future, weather conditions conducive to safe, low intensity burning may occur less frequently. Increased Drought Factor and Soil Dryness Index in spring and autumn, resulting from rising temperatures and reduced rainfall, may result in increased fuel availability. These trends become evident in the near future (2021-2040), followed by substantial changes by the end of the century (2081-2100). This suggests a significant reduction in the ability to safely conduct and contain prescribed burns in the coming decades. These findings have important consequences for the ability to manage bushfire risk using prescribed burning in the future. The timing and resourcing of prescribed burning may be affected, with a narrower window of suitable weather conditions for burning. Alternative methods to build resilience to bushfire risk may need to be considered.

¹ Scenario A2 described in the Special Report on Emissions Scenarios (SRES) by the Intergovernmental Panel on Climate Change (IPCC).



INTRODUCTION

Recent research suggests that fire danger may increase across much of Tasmania under ongoing climate change, with the fire season starting earlier in the year, and lasting for longer (Fox–Hughes et al. 2015). Changes to fire danger are projected to vary across Tasmania and in different seasons, most notably with an increase in high fire danger days projected to occur in spring. This has important consequences for the ability to manage bushfire risk using prescribed burning, which is currently the only effective method of managing bushfire risk at the landscape scale in Tasmania.

Prescribed burning is extensively used in Tasmania to reduce fuel loads and bushfire risk around human assets, particularly in the peri-urban fringe. It is also used to manage biodiversity and protect fire sensitive habitats in many National Parks and the Tasmanian Wilderness World Heritage Area (TWWHA). Prescribed burning is only carried out when weather conditions and soil moisture are conducive to safe, low intensity burning. These conditions are determined by wind speed and direction (both current and forecasted), fuel moisture, relative humidity, soil moisture and temperature (Marsden-Smedley, 2009).

Historically, most fires in Tasmania have occurred in mid- to late-summer and early-autumn, however significant bushfires can also occur in mid-spring, such as the 2006 Meehan Range fire that occurred on October 12th. The Autumn prescribed burning season therefore typically runs from late March to mid-May, and the Spring season can start as early as October and extend as late as the end of December. Winter burning can also be carried out in some of the drier and more accessible parts of the state, although daylight is a limiting factor in winter. The autumn periods are generally more stable and predictable, whereas spring usually has long periods of unsuitable weather between the ‘goldilocks’ days. The most appropriate conditions for burning, and thus the annual timing, varies with altitude, rainfall gradients, solar aspect and vegetation type. Both very wet and very dry years tend to curtail the amount of burning that can be done because of inappropriate moisture levels and wind and temperature patterns. During very wet years, moisture levels are too high for fire to carry, while in very dry years the fuel dryness can result in unacceptably high fire intensity even during periods of relatively benign fire danger weather.

If the stable autumn period during which suitable conditions occur becomes narrower under future climate conditions, the viability of prescribed burning as a management tool may be compromised. This study investigates the changing opportunities for prescribed burning in Tasmania under climate change. We use the Climate Futures for Tasmania (CFT) projections to assess changes in the magnitude and seasonality of weather variables that determine when prescribed burning can be applied (rainfall, temperature, fuel moisture and atmospheric stability).



METHODS

Climate projections from the CFT project (Corney et al. 2010) were used to provide fine-scaled (10 km) future climate data. The projections were dynamically downscaled using sea surface temperature from six atmosphere-ocean general circulation models from the Coupled Model Intercomparison Project archive (CMIP3) under the A2 emissions scenario as boundary conditions into the Commonwealth Scientific and Industrial Research Organisation (CSIRO) Cubic Conformal Atmospheric Model (CCAM) (McGregor 2005). The host models were ECHAM5/MPI-OM, GFDL-CM2.0, GFDL-CM2.1, MIROC3.2(medres), UKMO-HadCM3 and CSIRO-Mk3.5. These models give slightly different results because they are based on different configurations, but all provide plausible representations of the future climate. Dynamically downscaled climate models represent the climate processes that operate over small distances, so they have the potential to capture regional variation in the climate change signal. This is particularly relevant in Tasmania, which has a complex topography and coastline, and a range of regional climate influences.

The high emissions scenario (A2) is used because global emissions are currently tracking at the higher level of this scenario (Peters et al. 2013). If strong mitigation policies were to achieve reductions in global greenhouse emissions, the pattern of projected changes would be similar, but lower in magnitude.

The projected change in the monthly statistics (mean, and quantiles) for each variable were calculated between the baseline period (1961-1980) and two future time periods, near future (2021-2040) and the end of century (2081-2100). We use two-decade periods to reduce the effect of inter-annual variability and highlight longer-term climate trends.

In addition to daily minimum and maximum temperature and total daily rainfall, several indices were used to indicate weather conditions suitable for prescribed burning. These indices incorporate temperature, rainfall, wind and humidity. Firstly, the Drought Factor (DF, an index scaled between 0 and 10) represents the influence of recent temperatures and rainfall events on fuel availability. It is calculated by combining estimates of the effects of (a) direct wetting from recent 'significant' rainfall (> 2 mm); and (b) wetting from below, which is dependent on the soil moisture content. The latter is calculated as a soil moisture deficit, using the Soil Dryness Index (SDI) (Mount 1972). Secondly, the SDI is used independently as an index of fuel moisture. It is used operationally to help assess the relative flammability of different vegetation types, and therefore the ability to safely conduct a prescribed burn. An overview of the SDI and its strengths and weaknesses can be found in Marsden-Smedley (2009).

Finally, two indices of fire danger were calculated. The Forest Fire Danger Index (FFDI) is used operationally throughout the Tasmanian Fire Service (and other supporting emergency service organisations) to estimate fire danger at a particular location on any given day (initially described as equations by Noble et al. 1980). It incorporates antecedent rainfall conditions (DF), daily soil dryness (SDI), daily temperatures and wind speeds. The Moorland Fire Danger Index (MFDI) is a better representation of fire danger in Buttongrass Moorlands, where soil dryness is less important in determining fire danger



than in forests, and is also the most appropriate of the two indices for heathland vegetation types throughout Tasmania (Marsden-Smedley, et al. 1999).



DISCUSSION AND RESULTS

TEMPERATURE

Mean annual temperature increases of approximately 1°C in the near future (2021-2040) and 2.7°C by the end of the century (2081-2100) are projected to occur across Tasmania under the high emissions scenario considered here. This is a gradual acceleration of warming trends observed over recent decades. These increases are consistent across the seasons and are similar in both maximum and minimum daily temperatures (Figure 1A, 1B and 2A, 2B). Trends in the multi-model mean of annual temperature are similar in all regions of Tasmania, demonstrated in Figures 3A and 3B.

Over the next decades, monthly temperatures are projected to move towards temperatures currently experienced in warmer months. For example, by 2081-2100 September may exhibit temperatures more like those currently experienced in October. This effect is amplified in colder months, where July will be more similar to April. During summer, temperatures (both daily minimum and maximum) will exceed those currently experienced in any month.

By the end of the century, days exceeding the 25°C threshold above which prescribed burning cannot be applied (Marsden-Smedley, et al. 1999) are projected to occur regularly in November, becoming more similar to conditions in December, January and February.

RAINFALL

Annual mean rainfall is not projected to change substantially across Tasmania in the future, however, there are strong regional (Figure 3C) and seasonal (Figure 1C and 2C) differences. Summer rainfall is projected to decline in four of the six models, and winter rainfall is projected to increase substantially in all models. There is little change projected in the mean rainfall in autumn. Five of the six models project increased mean monthly rainfall in spring, while one projects reduced rainfall during this season.

The CFT spring rainfall projections should be considered in the context of other available climate projections. A comparison of the CFT projections with a range of CMIP3 models, CMIP5 models, and new downscaling using a more recent version of the CCAM model, suggested they “are at the wetter end of the plausible range of spring rainfall projections” (Grose et al. 2015a; 2015b). The results presented here are therefore likely to be conservative estimates of the drying trends in spring.

When averaged across Tasmania, there is little change projected to occur in monthly rainfall (Figure 1C), although this comes with low confidence due to low agreement between models on the direction of change (increase vs decreased rainfall) and high spatial variability, which is masked by the state-wide averaging (i.e. some districts get wetter, others drier). This degree of uncertainty is common in projections of rainfall (CSIRO and Bureau of Meteorology 2015), because the large-scale storm tracks in the projections are uncertain (Risbey and O’Kane 2011), and it is difficult to fully resolve the many physical processes involved in precipitation or the fine-scale spatial variability (Dowdy et al. 2015).



DROUGHT FACTOR

In the near future period (2021-2040), there is a large range in the annual DF across the climate models, reflecting the greater variation across rainfall projections in the short-term, particularly in summer and autumn (Figure 1E). By the end of the century, however, substantial increases in DF are projected across Tasmania (e.g. up to 100% increase in the monthly mean), with the greatest increases in summer. Large increases in the DF in spring are also projected. There is a wide range in the projections for autumn, reflecting the large range across the models in rainfall for this season.

The projections of DF across Tasmania show gradual drying trends in all months, with increases particularly during summer and early autumn (Figure 2E).

SOIL DRYNESS INDEX

Substantial increases in SDI are projected to occur across Tasmania in the future. In the near future (2021-2040), all models project an increase in SDI in summer, and all but one model project increased soil drying during spring and winter (Figure 1F). There is a greater range across the models in autumn. However, by the end of the century, substantial increases in the SDI are projected by all climate models in all seasons.

Increases in SDI are greatest in the summer and autumn months by the end of the century (2081-2100) (Figure 1F). Smaller increases are projected in late winter and spring months. Increases in the SDI values for both June and November are so substantial that the wettest period for SDI (June to November) is projected to be two months shorter (i.e. July to October) by the end of century (Figure 2F). These changes are projected to occur rapidly over the next decades.

FIRE DANGER INDICES

Substantial increases in annual values of the fire danger indices (FFDI, MFDI) are projected to occur across Tasmania by the end of the century (Figure 1G, 1H). However, the extent to which the indices change across the seasons differs slightly, reflecting the different emphasis on soil dryness and antecedent rainfall in each index. In the near future, increases in the Forest Fire Danger Index are projected by all climate models, for all seasons except autumn (Figure 2G). In contrast, the mean Moorland Forest Danger Index (MFDI) increases in spring and winter (Figure 2H) by the 2021-2040 period, and decreases in autumn and summer. However, this state-wide summary masks substantial regional patterns, with a strong west vs east difference (Figure 3H). Regional differences (for all variables) are outside of the current scope and will be presented in a future publication.

By the end of the century, increases in FFDI are projected for all seasons, with very dramatic increases in spring and summer (Figure 1G). The projected increases in FFDI are lowest during the months April to September (Figure 2G). In the warmer months, there is a shift in FFDI so that by the end of the century, November FFDI is higher than what is currently experienced in December, and future January FFDI values exceed any currently experienced in any month. The MFDI increases substantially in spring and winter, and declines slightly or maintains similar values in autumn (Figures 1H and 2H). The MFDI



shows a consistent shift in fire danger indicating higher fire danger values earlier in the year. From June through to December, monthly MFDI by mid-century exceeds the current value for the following (warmer) month. By the end of the century the differences are greatest in late winter and spring. To a large extent, the effects on MFDI of increases (decreases) in winds are offset by increases (decreases) in rainfall.

Wind speed is an important variable in the calculation of FFDI, however, the projections of wind speed for the near-term period are highly variable, with a large range in wind speed across the climate models. In the absence of a gridded wind observations product (see below), the wind output from the regional climate model has not been validated against observations. That said, the model appears to underestimate wind speed, which would contribute to the conservative estimates for FFDI reported here.

WIND SPEED AND DIRECTION

Similar trends in wind speed are projected for all districts (Figure 3D). The projections of wind speed for the near future period are highly variable, with a large range in wind speed across the climate models (Figure 1D). By the end of the century this very large range is reduced, but remains more variable than in the baseline period.

The modelled wind output has not been validated against observations or bias adjusted because gridded observations are not available. However, a comparison with available point observations suggests that the model underestimates wind speed. This would contribute to the conservative estimates for FFDI, since wind is an important component in that calculation. For this reason, we only consider the relative differences between time periods in these variables.

By the end of the century, increased maximum daily winds are projected across Tasmania for spring, and decreased daily winds are projected to occur in autumn. Reductions in maximum daily wind speed are projected for May and June by the end of the century (Figure 2D). From July through to November, maximum daily wind speed increases.

Changes in wind direction were projected and analysed, but these changes were minimal and are not discussed here.

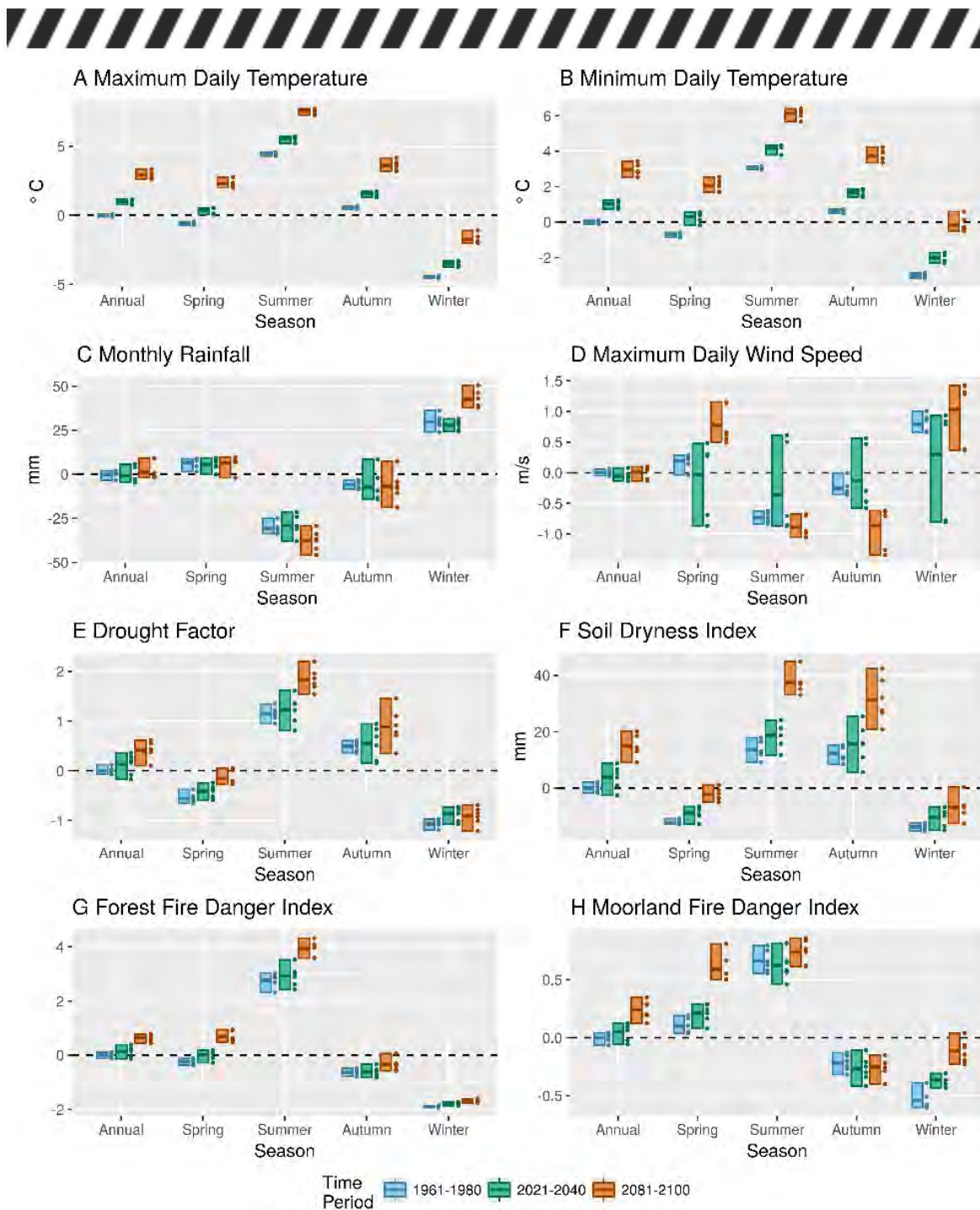


Figure 1: Projected changes in the annual and seasonal values for each variable across Tasmania under the A2 emission scenario. Each season is shown for the baseline (1961-1980), near future (2021-2040) and end of century periods (2081-2100). Values represent change from the multi-model mean annual value for the baseline period, to highlight the real differences of the seasons from the typical annual mean values. The box indicates the multi-model range, the bar shows the multi-model mean, and points indicate the mean for each of the six downscaled climate models, indicating the extent to which the models agree.

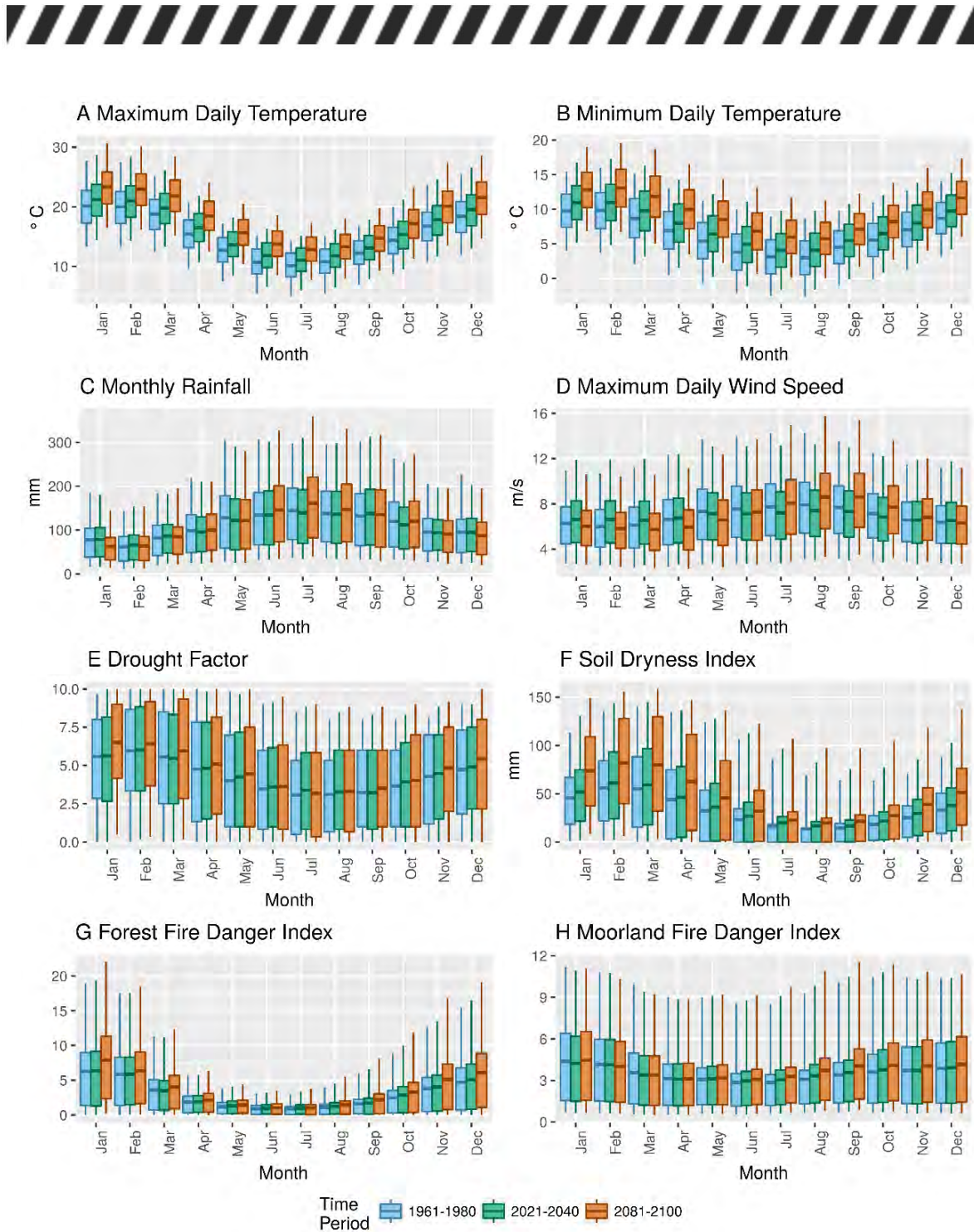


Figure 2: Annual cycle of each variable as projected by the six climate models under the A2 emission scenario for the baseline (1961-1980), near future (2021-2040) and end of century (2081-2100) periods. The box indicates the multi-model interquartile range, the bar shows the multi-model mean, and the whiskers extend from the 5th to the 95th percentile of the multi-model range.

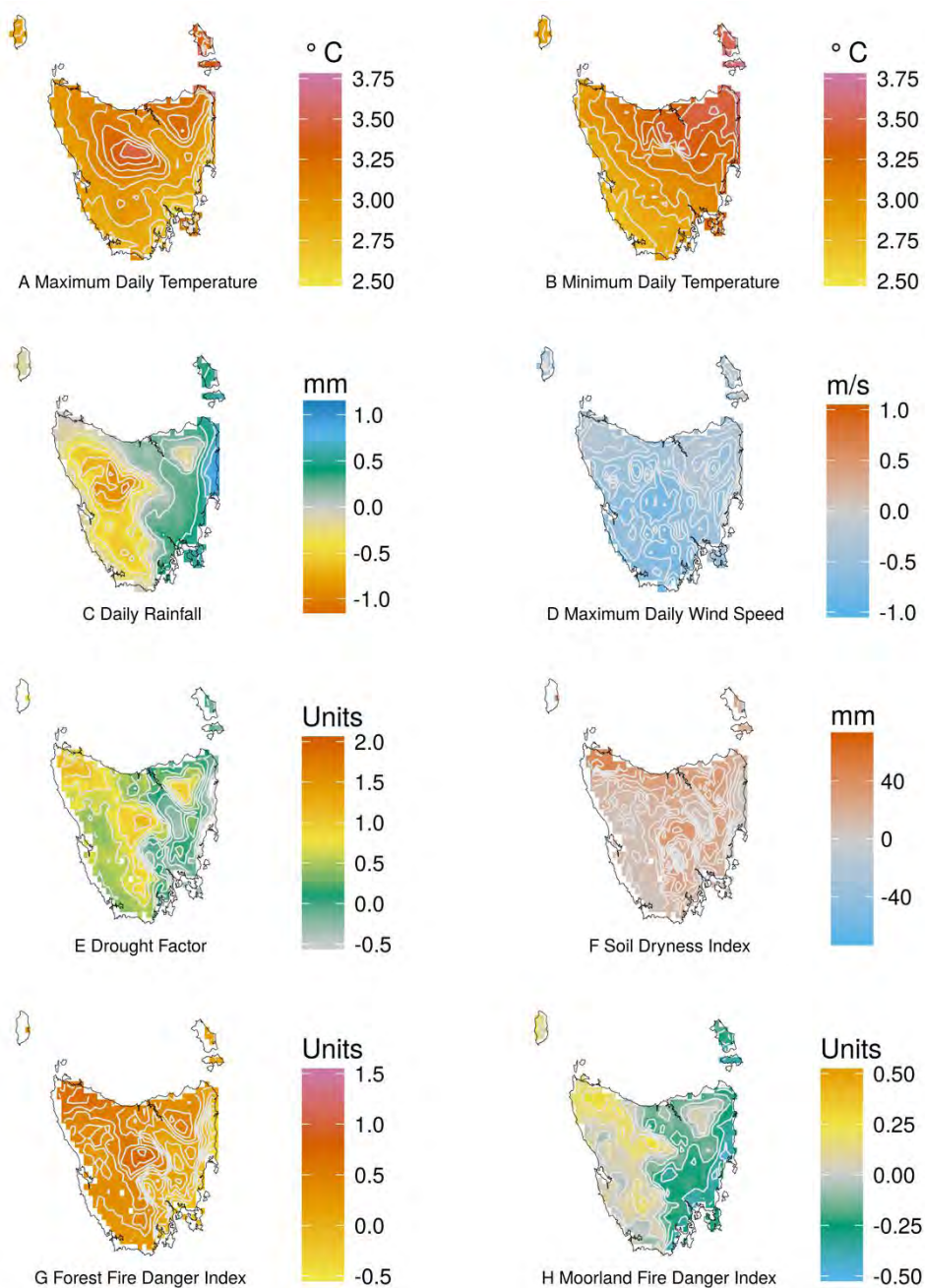


Figure 3: Change in climate variables for the autumn period (March, April, May) by 2081-2100, relative to the baseline period (1961-1980). These maps highlight the regional differences projected across the state, particularly the West to East gradient of moisture related variables (i.e. Daily Rainfall, DF, SDI, MFDI).



IMPLICATIONS FOR PRESCRIBED BURNING AS A MANAGEMENT TOOL IN THE FUTURE

The strong warming and drying trends projected for autumn and spring suggests that it will become more challenging to safely conduct and contain prescribed burns in these seasons. These trends become evident in the near future (2021-2040), and represent substantial changes (relative to the baseline) by the end of the century (2081-2100).

Wind speed and direction are not projected to change substantially in autumn and spring, but increased temperatures are projected to occur across Tasmania (up to 2.7°C by the end of century under the high emissions scenario), contributing to increases in Soil Dryness Index, Drought Factor and subsequently Forest Fire Danger Index and Moorland Fire Danger Index values. These changes are projected to occur rapidly over the next decades. In the near future (2021-2040), all models project an increase in SDI in summer, and there is high model agreement that there will be increased SDI during spring and winter. By the end of the century, substantial increases in the SDI are projected by all climate models in all seasons.

By the end of the century, very large increases in both FFDI and MFDI are projected for spring. The FFDI also increases dramatically in summer (discussed in detail in Fox-Hughes et al. 2014), while the MFDI increases substantially in winter. These changes have important implications for the ability to apply prescribed burns (following current protocols) in spring and winter to mitigate the increased fire danger that is projected to occur in summer. Over time, the burning period may move towards the winter and early spring months, as opportunities for safe burning decline in the autumn months.

There is general agreement across all models for increased SDI and DF as rainfall is projected to be less than evaporation as temperatures warm. However, as this ensemble of projections represents a slightly wetter future when compared to other available future model projections (Grose et al. 2015a), the results presented in this study may be a conservative estimate of the drying trends in spring. If so, spring may become drier and more prone to fire more quickly than shown here.

As the frequency of warmer and drier conditions increases in autumn and spring across Tasmania, the likelihood of all variables coinciding at their maximum values (e.g. maximum wind speed, lowest relative humidity, highest temperature, SDI and DF) can be expected to increase. This increases the likelihood that fires will burn with faster rates of spread, higher intensities and a higher risk of escape than under current conditions (Marsden-Smedley 2009). This higher risk will constrain the application of prescribed burning, as the number of available periods decreases, particularly in the autumn months, when the majority of prescribed burns are currently carried out. There are indications that these windows of opportunity for burning may move to the winter and early spring months.

Strategies that improve the capacity of fire agencies to take advantage of suitable conditions will always be of great value, and these projections support future research into a range of areas, such as improving the understanding of fire behavior during



prescribed burning (including the differences between vegetation types); investigating different prescribed burning practices, and utilizing finer scale weather forecasting to support operational activities.

Further to this, other tools for reducing fuel loads may need to be considered, such as mechanical removal of fuels and the maintenance of fire breaks by grazing. Research into the impacts of such approaches is still needed. Since these approaches are not yet widely accepted in the community, consultation and education will be an important aspect of the move to alternative fuel reduction techniques. Prescribed burning will always play an important role in fire management, but it is likely that it will need to be supplemented by other fuel reduction techniques under future climate conditions.



CONCLUSION

The results suggest that there will be a narrower window of suitable conditions for prescribed burning across Tasmania in the future. The trends become evident in the near future (2021-2040), and represent substantial changes (relative to the past) by the end of the century (2081-2100). This has important consequences for the ability to manage bushfire risk using prescribed burning in the coming decades. Fire managers will need to reconsider the timing and resourcing of prescribed burning and build capacity to mobilise rapidly when weather conditions are suitable during autumn and winter.

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SCIENCE IS CRITICAL BUT IT'S NOT EVERYTHING: OUR FINDINGS

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ABSTRACT

While scientific institutions and forms of scientific knowledge are critical for understanding and mitigating natural hazard risk, there is significant debate about their real utility to policy and practice. We ask: how are practitioners able to use scientific methods and evidence to make risk reduction decisions; how useful is this science for arguing for and defending these decisions; and, what other knowledge sources might we need to reduce our risk? In this paper we provide an end-of-project synthesis of our research regarding the use of science and scientific research by risk mitigation practitioners across three case studies of bushfire and flood risk.

Publics demand and politicians promise greater certainty when it comes to understanding and mitigating the risks of traumatic natural hazard events. It is often the scientific approaches and methods that are expected to produce all the evidence required to know, and prove, the right course of action. This is when the cracks appear in the assumed linear model of 'evidenced-based policy and practice'. In this paper we interrogate what is meant by 'scientific facts', how they are employed to mitigate risk, and what the consequences are for policy and practice. We find that instead of relying solely on scientific approaches, or assuring publics or governments that certainty can be found, we need to affirm the critical importance of scientific methods and results whilst also incorporating other ways of understanding. The rich learnings from the various kinds of scientific inquiry are essential for complex problem solving, but are not sufficient in isolation.



INTRODUCTION

It is a common assumption that natural hazard mitigation practitioners are heavily reliant on scientific methods and results to produce the information they need for decision-making. In order to provide as much certainty as possible, this information must: be able to be translated and used across locations; have a predictive capacity within both present conditions and into the future; and, be defensible – to some extent – with other agencies, senior staff, ministers, publics, possible inquiries, and to the practitioners themselves. However, these assumptions do not necessarily align with the realities that practitioners are faced with. While scientific institutions and forms of scientific knowledge are critical for understanding and mitigating natural hazard risk, there is significant debate about their real utility to policy and practice. In this paper, by 'science' we mean the legacy term that people are most familiar with – the research and methods of the natural and physical sciences.

Scientific methods and evidence are just one part of the risk management equation, interacting and intersecting with the politics and perceptions of natural hazards practitioners.¹ Whether in day-to-day operations or during major policy shifts, for practitioners the scientific evidence and methods are used alongside other sources of knowledge – such as professional expertise, experiential knowledge, and local knowledge. Indeed, practitioners face a similar spectrum of complexities and contradictions in their work as found in the at-risk community, although as risk mitigation decision-makers it is likely that their experience of this spectrum is much more acute. Here, we use the term practitioners to describe a broad group of people. They might be people doing hazard reduction burns or working with laptops in boardrooms – all are engaged in everyday practices of governance.²

Clearly, the work of practitioners goes beyond being automatons that implement regulations and policies. They are in a unique position to influence policy and practice outcomes, and scientific results and methods have a privileged position in influencing them. Practitioners find that, on the one hand, natural hazard risk mitigation is a very social and uncertain undertaking, full of value-laden, cultural and other 'non-rational' factors that cannot be reduced to data or modelled with algorithms; whilst, on the other, science is often used to end conversations about the how, why, what, where, when and/or who of risk mitigation. Within this complex context, practitioners must manage the authority of scientific data and methods as part of their pursuit of what they think is best-practice risk mitigation, and how they then present and defend this work to others.



BACKGROUND AND METHODS

The study of practitioners is a critical gap in natural hazard research. Most research on policy and practice focuses on the regulatory environment and policy influences. To address this, for three years we have investigated the cultural, political, legal, economic, ecological and other influences on practitioners' use of scientific data and methods – the 'social life of science'. This research project *Scientific diversity, scientific uncertainty in bushfire and flood risk mitigation* has been funded by the Bushfire and Natural Hazard Cooperative Research Centre (BNHCRC), and is co-located at Western Sydney University and The Australian National University.

We have pursued the following research questions:

1. How are practitioners able to use scientific methods and evidence to make risk mitigation decisions?
2. How useful is this science for arguing for and defending these decisions? and,
3. What other knowledge sources do practitioners use to reduce risk?

Between 2014-2016 we conducted three case studies with practitioners responsible for reducing bushfire risk in the Barwon-Otway area (Victoria) and the Greater Darwin area (Northern Territory), and flood risk in the Hawkesbury-Nepean valley (New South Wales):

- *Barwon-Otway area, Victoria*
A rugged coastal and rural region in which peak bushfire risk periods coincide with peak summer holiday seasons, with very constrained evacuation routes. Risk mitigation practitioners have successfully drawn on innovative scientific modelling (including the PHOENIX bushfire simulation model) to re-purpose prescribed burning around strategic approaches, as well as to raise bushfire awareness.³ The practitioners involved in our project were mainly from public land management agencies, as well as consultants and experts that collaborate closely with these agencies.
- *Greater Darwin area, Northern Territory*
The huge climactic flux between wet and dry seasons supports vigorous grass growth and curing in northern Australia's tropical savanna. Here, established bushfire risk mitigation techniques are proving no longer adequate to address the 'fire-weed' Gamba grass (*Andropogon gayanus*) that is spreading through the Greater Darwin area and its burgeoning peri-urban subdivisions. This management context is comparatively constrained in terms of environmental regulation, resourcing and research, though risk mitigation practitioners often have greater independent capacity for action.⁴ Here, the practitioners we collaborated with were mainly from public land management agencies, fire and weed agencies, as well as university and federal researchers.



- *Hawkesbury-Nepean Valley, New South Wales*
The flood plains of Western Sydney – densely populated and under development pressure for more affordable and available housing – is also an area prone to very low-probability high-impact floods. Following extensive flooding in Brisbane and NSW in 2011 and 2013, the Hawkesbury-Nepean Valley Flood Management Taskforce was set up to consider flood risk and advise the NSW Government accordingly. The Taskforce is drawing on a diverse range of expertise (both scientific and technical) to develop a sophisticated range of mitigation, preparedness and response strategies. The Taskforce practitioners we have interviewed have been mostly state government officers supported by a range of consultant specialists, all of whom had varying combinations of scientific, practical and policy expertise.

The three case studies were undertaken consequentially as part of a multi-sited ethnography, using semi-structured interviews and scenario exercises,⁵ and thus the inquiry and methodology evolved as the research project progressed.

Through this research project, we consider not just what the practitioners are saying and doing, and how the socio-ecological context influences what is possible. We go further to consider the influence of different knowledge sources on this activity – their cultural traditions and the assumptions that carry through from that. We consider how these knowledge foundations are translated into risk mitigation decisions, and how shifting known or unknown assumptions behind these traditions might improve risk and resilience. This paper reports on the findings that are now arising out of our end-of-project synthesis.



RESULTS AND DISCUSSION

IS SCIENCE SCIENTIFIC?

In this project we have discussed 'science' as the legacy term that people are most familiar with – the research and methods of the natural and physical sciences. For example, the disciplines and inter-disciplines of maths, physics, chemistry, biology, hydrology, meteorology, climate science, agent modelling, and fire science, as well as the institutions, practices and values that have been created alongside. These disciplines employ diverse scientific methods to make **inferences from evidence so as to generate 'scientific facts'** – at least until disproven or confirmed by ongoing scientific inquiry. The intention is to uncover objective knowledge of the world. The rapid development of this knowledge tradition over 500 years is called the 'scientific revolution'. This expertise has fundamentally changed the knowledge basis for decision-making and governance, ostensibly replacing religion, intuition and emotion with science, reason and rationality.⁶ However, as social studies of science have shown, it is misguided to conceive of science as an objective universal knowledge, applied and valued the world over. All science, as sociologist Brian Turnbull states, is arguably a form of local knowledge – it is produced by, and circulates through, specific people in specific places shaped by their specific interests.⁷

Nevertheless, societal expectations of science as an objective universal knowledge, also known as the 'normal science paradigm', continues to be influential, and so it is important to examine how we define and use this science. A key assumption of the normal science paradigm is the expectation that uncertainty can be reduced for decision making; that decision makers can predict, manage and control outcomes in the environment, it is just a matter of getting enough information.⁸ It is this expectation that makes it so attractive and influential, including in the natural hazards sector. For example, being able to alter Bushfire Danger Ratings to both better reflect the fuel condition of changing landscapes and elicit greater fire suppression resources, as well as developing very basic risk mitigation tools such as flood and fire risk maps. In the Greater Darwin area case study, practitioners spoke about how the under-resourced over-stretched hazard management sector relied heavily on largely university-generated scientific research. In particular, scientific data on the fuel loads and invasiveness of Gamba Grass has been absolutely crucial to convincing policy makers to declare it a weed and fund containment activities.

The Northern Territory's less regulated and chronically underfunded governance context⁹ contrasts sharply with our other fire risk case study, the Barwon-Otway area. The Barwon-Otway practitioners have had very close access to the bushfire simulator PHOENIX, with an array of impressive results. Using simulation and Bayesian networks, practitioners provided advice on different prescribed burning strategies locally, and helped found a new state wide policy, moves that were framed in terms of being 'more scientific' than previous approaches. In addition to providing greater certainty for their own decision-making, this predictive work also helped with difficult conversations in policy and community contexts. And yet the science still fell short of a 'fix' because, in the process of generating new modelling methods, practitioners



found their answers actually created a host of other uncertainties – many of which require decisions about values. In short, more science did not resolve the **big tensions around what should ‘count’ most to agencies, what approaches they should take and how they should communicate their decisions.** Many of the practitioners were pragmatic about this, being very explicit about the scientific limitations of PHOENIX and their modelling in some contexts and omitting these limitations in others.

Across the case studies, it was shown that scientific evidence and scientists can have an important role in convincing *others*, whether they be individuals within the hazards sector, industry, the media, or in the public. This is critical because of the high-stakes high-accountability context that practitioners work in. However, while it may be expedient to rely on the authority of scientific knowledge when addressing concerned stakeholders or community members, it is clear from our research that there are downsides to mobilising this authority. In the Barwon-Otway case study, scientific tools and external scientific voices, such as university researchers, have been crucial to building trust in public land managers amongst sceptical communities; but having a deterministic colourful animated map which is a compelling communication device, is not the same as saying that it produces the right outcome for risk mitigation. In Greater Darwin, practitioners frustrated that their messages were not affecting policy **found greater ‘cut through’ when they translated scientific knowledge of Gamba grass into the dominant terms of Northern Territory politics: namely, a physical threat to politically influential suburbs and a financial threat to the government budgets.**

The Hawkesbury-Nepean case study was the most complex and risk-fraught context we studied. In this relatively highly populated area, very complex flood behaviour, tricky topography, climatic unpredictability and incredibly diverse stakeholder interests and knowledge, demanded a highly sophisticated and varied approach by the Hawkesbury-Nepean Valley Taskforce. The Taskforce not only combined researcher-practitioners from a broad range of disciplinary and practice backgrounds, it also placed a strong focus on a co-productive approach to generating new knowledge, with a highly collaborative and innovative approach to understanding. Seeking legitimacy with other stakeholders required careful thought and action. For example, the Taskforce has been meticulous in meeting governance and other review guidelines. The biggest challenge is currently unfolding, as the Taskforce engages with the broader range of stakeholders, including local communities, planning departments, developers etc., particularly with increasing pressure for new and affordable housing in the Greater Sydney area. The highly innovative and sophisticated modelling the Taskforce have generated will not decrease the uncertainty faced in this catchment, but rather highlights the uncertainty, ambiguity, complexity, intractability, instability and diversity of the situation.

It is thus clear that scientific methods and results do not always create the certainty that practitioners seek. Science is often very highly specialised, results are subject to numerous qualifications, and most scientists will tell you that science itself is inherently uncertain. Scientific uncertainties might be generated by historical gaps in the data, restrictions with adopting updated algorithms in new technology, socio-political interventions into which kinds of scientific research is funded, and so on.¹⁰ Degrees of certainty can be reached, with



some certainties more possible to reach than others, and this is work of immense value in risk mitigation. For example, that Gamba grass is a dangerous weed that can spread across the entire northern savannah; and, the modelling that shows where flood-risk is greatest, and where prescribed burning is best targeted. But to promulgate or expect certainty from science, and the linear translation of this into more certainty in risk-mitigation decision making, is completely unrealistic.

THE PROBLEM-KNOWLEDGE MATCH

In all the case studies there was a recognised need for engagement with a much broader range of expertise than just quantifiable 'physical' science. In the Barwon-Otway case study, the practitioners generated their own social science data on sense of place and community resilience. In the Hawkesbury-Nepean case study, more formal social science was recruited. However, the problems facing the practitioners require more than just adding social science to science. What is needed is an unsettling of our very understandings of these disciplines as part of re-thinking how we define and use knowledge. This re-think is already well underway in academia in response to the complexity of environmental issues arising out of the industrial revolution, and is work of high relevance to natural hazard risk mitigation. The re-think challenges us to move beyond expecting scientific information to produce a managerial solution, to **directly acknowledging that in many situations "facts are uncertain, values in dispute, stakes high and decisions urgent"**.¹¹ This includes acknowledging that there may be more than one solution to a problem, or no solution at all. Some have called this re-think 'post-normal science'. It begins by first looking to understanding, defining and formulating what we think the problem actually is, before considering how to respond to it.¹²

Critically, this re-working of our knowledge traditions reveals that there are always multiple perspectives about a given problem, context, and solution. Multiple perspectives, or subjectivities, are common territory for social science research into human values. What holds true for an individual, group or sector, may or may not be shared with others. Thus, there can be no single 'knowing' of anything, including natural hazard risk. There will be multiple perspectives from within and between diverse individuals and groups, including scientists, at-risk populations, practitioners, and so on. Indeed, human values have always been part of the natural and physical sciences themselves. For example, the influence of seventeenth century **Christian theology on the 'balance of nature'** assumption in biology and ecology, which in the twentieth-century was replaced with a dynamic focus on energy flow.¹³ Science has an internal logic, but it is also about trajectories and values.¹⁴ Across the diversity of normal science methods there will be decisions to be made about: which questions are pursued; which uncertainties are ruled in or out of the scope; what standards of proof are needed; and, which arguments are made more forcefully. We also see human values in the types of sciences that attract funding, the professions that are held to be the most prestigious, and, the scientific results that are most readily accepted by others.



The normal science paradigm strives for objectivity, but can only partially achieve this, because this knowledge creation has always been a very human activity. Post-normal science continues to conduct methodical, evidence-based research, but by also engaging with its inherent subjectivity, this research is more robust and rigorous. It can be argued that bringing multiple subjectivities together can only increase uncertainty, but what it does facilitate is a partial-objectivity that stands up better under interrogation. Our research shows that, and as many scientists will attest, even the most sophisticated scientific attempts to get closer to reality can just generate more uncertainties. If you try to avoid this complexity, or simplify it or gloss over it, the uncertainties will persist and present themselves again, possibly when least welcome.¹⁵ Unfortunately, there are risks associated with acknowledging uncertainty and subjectivity; chiefly the dismissal of scientific results and methods because they do not produce the anticipated hard evidence.

The influence of the re-think of our knowledge foundations has been profound, however technical-managerial approaches continue to dominate the decisions of experts and policy makers when addressing complex socio-ecological issues. To reiterate, in our research there were many examples of how practitioners understood that 'counting' through quantifiable methods produced 'hard data' that 'made things count', providing further opportunities for analysis – such as simulation models; and how these valuable options were not similarly possible through qualitative research results. It was also evident that the use of other sources of knowledge – such as intuition and local knowledge - was appreciated as being less legitimate than researched based knowledge. Whilst considered integral, essential, and indeed irreplaceable; at the same time it was apologised for, disparaged or marginalised for not carrying the authority of knowledge arising out of formalised methodologies. There were varying understandings across the case studies about how these attitudes were based in socio-cultural norms held more broadly in society.

The Hawkesbury-Nepean Taskforce is an example of both articulating a multi-world perspective and embracing it. They have understood that science is not enough on its own, and that they need to bring to bear multiple kinds of knowledge to deal with the complexity of flood hazard management in the Hawkesbury-Nepean catchment. They accept that all knowledge (scientific or otherwise) is partial and provisional and interpreted. They are now considering how to widen this discussion and the multi-world perspective to a broader range of stakeholders. However, this broader group has an even more diverse range of worldviews. This will provide many additional challenges as they work towards implementation of flood management adaptations. It will require embracing diversity at a new level.



CONCLUDING DISCUSSION

Natural hazard risk mitigation occurs within an intrinsically uncertain context. Practitioners work with multiple uncertainties that all interact with each other, including: the science, each unique natural hazard event, the identification of at-risk values, socio-political priorities, and climate change. These uncertainties are interlinked, and their interaction generates new uncertainties. Practitioners, scientists and many others appreciate this uncertain context. Politicians and other leaders in society need to help change societal expectations about what is possible through natural hazard risk mitigation. The assumption that natural hazard risk is 'governable' with the support of scientific methods should be made redundant – whether that is achieved through persuasive argument with or without the partially objective evidence. Otherwise, impossible expectations are placed on the science, whilst practitioners are left with gaps in what they also need. Perhaps the most invidious expression of societal expectations of certainty is the harsh treatment that practitioners receive in the cycles of blame and inquiry that follow catastrophic natural hazard events. Publics and policy makers who do not consider the many 'ungovernable' aspects of risk mitigation, subject practitioners to inquiries and media scrutiny based on their own unexamined expectations about certainty.

If scientific methods and evidence neatly provided straightforward risk mitigation answers, and we all lived in a world where decisions were then made based on this science, then we would be having a very different conversation. But we do not, never have and we never will live in such a tidily governable and knowable world. This is more than evident with what is happening up North. By not addressing Gamba grass today, it is highly certain that Australia will have a new catastrophic fire landscape in part of the northern savannah. The science is clear but the socio-political will to respond is missing.

Whilst the findings from our three case studies are still being synthesized, we have summarised the following conclusions:

- Automatic assumptions about the kind of expertise needed for risk mitigation are generally counterproductive. Privileging one area of expertise works against hazard management.
- Science is not just working with uncertainties, what actually *is* science is also permeable and unstable. In all the case studies, there were clear divergences in how practitioners identify where the science begins and ends, and where other types of knowledge are brought in.
- Uncertainty and complexity about expert knowledge and the world needs to be embraced (for example, in operations and in standards), but not exploited. Being upfront about scientific uncertainty decreases the risk that important scientific results and methods are dismissed or manipulated by other agendas.
- The world is not just more complex than we think, it is more complex than we can think.

So, what can we do?



1. We need to engage with broader perspectives to more fully understand the problem and then engage with multiple kinds of knowledge and expertise in developing solutions.
2. We need to keep interrogating how different knowledge sources are judged and evaluated in society, to ensure that we have the best information at hand.
3. Sector leaders need to keep critically reflecting on what is 'normal', and provide greater support for innovation. The influence and inertia of the status quo should not be underestimated.
4. We need to lose the emphasis on certainty in research, policy, practice, operations, inquiries, the media and so on; and, accept complexity instead of glossing over or avoiding it. New language and conceptual approaches such as 'resilience' are doing this.





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IMPLEMENTING DISASTER RESILIENCE POLICY IN THE AUSTRALIAN FEDERATION

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ABSTRACT

Australia committed to reorienting its disaster management system to emphasise disaster prevention, preparedness and risk mitigation when it adopted the National Strategy for Disaster Resilience (NSDR) (Commonwealth of Australia, 2011; 2013). Since then the notion of resilience has penetrated the Australian disaster management system to the extent that many, if not most, disaster management activities are now described in terms of resilience.

While there is broad consensus about the necessary elements of disaster resilience policy, these have generally been expressed in Australia as high level and principles-based. To build a more disaster resilient nation, it is therefore important to understand not only what needs to be done, but how to do it within the context of Australia's federal system and its disaster management arrangements.

This research investigated implementation of disaster resilience policy in Australia from the perspective of Social Capital, Community Competence, Information and Communication and Economic Development – policy domains identified as essential for creating community disaster resilience (Kulig *et al.*, 2013; Norris *et al.*, 2008). A combination of literature study and empirical methods was used to examine if, and how, policy objectives linked to these domains underpin the implementation of disaster resilience activities at different levels of government and in the business and community sectors.

The results point to a general need to plan disaster resilience implementation more thoroughly, including ensuring it is better informed by evidence. In addition, consideration should be given to the opportunities and limitations on disaster resilience outcomes posed by the characteristics and policy mechanisms of Australia's federal system.

Furthermore, not only do relevant policy objectives for supporting disaster resilience need to be more carefully identified, selected and applied, but more attention needs to be given to the principle of subsidiarity¹ to ensure successful implementation within our federal system.

¹ An organising principle that says that matters ought to be handled by the smallest, lowest or least centralised competent authority (Marshall, 2008). "Powers and responsibilities should be left with the lowest level of government practicable. Such a devolved system means there is greater local input into decision-making and states/territories can customise policies and services to suit local preferences" (Council for the Australian Federation, 2017)



INTRODUCTION

The Commonwealth Government plays a national leadership and coordination role in the Australian disaster management system, including implementation of the National Strategy for Disaster Resilience (NSDR). At the highest level this process is managed by the Council of Australian Governments (COAG), a key instrument of modern Australian federalism. When the NSDR was adopted in February 2011, Australian governments committed to the implementation of a suite of key national disaster resilience initiatives (Council of Australian Governments, 2011; Standing Council on Police and Emergency Management, 2011). Some of these were already in progress and were regrouped and rebadged under the NSDR. There was no additional funding provided for the NSDR.

Six years on, the language of resilience has become more mainstream within the disaster management lexicon and the disaster resilience message has penetrated the disaster management system at all levels. For example, all the states and territories and many local governments articulate disaster resilience goals in their policy documents and several jurisdictions have adopted state wide approaches to disaster resilience. For example, Victoria has recently adopted a state wide disaster resilience strategy (Victorian State Emergency Service, 2016)

The evidence base on disaster resilience has also grown. This is helping to resolve earlier definitional issues and providing indicators and instruments that will allow resilience to be measured more effectively (Arbon, 2014; Cohen *et al.*, 2013; Cutter *et al.*, 2010; Kafle, 2012; Parsons, 2016).

Exhortations to become more disaster resilient have generally not been accompanied by detailed guidance on how to implement disaster resilience policy. This research addresses this by examining the extent that evidence on good practice is guiding disaster resilience policy implementation in Australia.

Achieving a disaster resilient nation is a long-term objective. The changing emphasis of national disaster resilience policy was also highlighted by this research. This raised questions about its strategic direction for ongoing policy implementation.



BACKGROUND

AUSTRALIAN DISASTER MANAGEMENT ARRANGEMENTS

Each level of government has its own arrangements to govern their responsibilities and actions during a natural disaster. While these vary across jurisdictions, the emergency service organisations all have state and regional disaster and emergency coordination functions and facilities. The emergency services are largely state-run entities with some functions devolved to local government. Their workforces consist of a mix largely made up of volunteers and a smaller number of professional employees such as firefighters, ambulance and police. They have historically focused on acute disaster response, and the more immediate relief and recovery activities. Their role has become more varied over time and now extends to hazard monitoring, predicting the impacts of extreme weather events, and communicating hazard information and warnings to the community. They also manage and participate in a range of hazard risk reduction activities.

Non-government organisations, such as the Australian Red Cross, work alongside governments and the emergency services to provide welfare services and support during and in the aftermath of a natural disaster. These organisations often provide medium to longer-term recovery assistance in the affected area, usually in partnership with state, local government and existing non-government welfare agencies and service providers. The Australian Red Cross is also involved extensively in disaster preparedness. Its RediPlan (Australian Red Cross, 2009), which adheres closely to disaster resilience principles, supports communities and households to develop personalised emergency preparedness plans.

Non-traditional or informal forms of volunteering are an emergent area of capability in the Australian disaster management system. A growing trend in recent years indicates that fewer people, especially in younger age-groups, want to commit to an established volunteer organisation (Australia, 2016; Barraket *et al.*, 2013; Whittaker *et al.*, 2015), and prefer to volunteer in specific circumstances or events. This came to the fore in the aftermath of the 2009 Victorian Bushfires and the 2010-11 Queensland Floods when Volunteering Queensland received around 100,000 offers of help from community members. Hundreds of citizens mobilised to perform community led activities such as BlazeAid² in Victoria and to join the "mud army" which formed to assist in the Queensland clean-up (George, 2013; Barraket *et al.*, 2013).

Although businesses regularly donate to disaster relief and recovery appeals and provide other forms of material assistance following a disaster, the role of business in natural disasters within Australia's disaster management system is relatively undefined. Two possible exceptions are the insurance industry and the

Trusted Information Sharing Network (TISN)³. However, commercial and security considerations may constrain the open exchange of information that is needed to

² BlazeAid occurred after the Black Saturday in Victoria and was a community volunteer response to calls for assistance from farmers to repair their fences (Whittaker *et al.*, 2015).

³ Australia has a long-standing partnership with business in the area of organisational resilience under the National Critical Infrastructure Resilience Strategy (NCIRS) (Commonwealth of Australia, 2015a; Commonwealth of Australia, 2015b). This includes the Trusted Information Sharing Network (TISN), supported by the Commonwealth Government. The TISN is a platform for government and



support disaster resilience from the highest level to the grass roots. For example, the insurance industry, in spite of pressure from government and other stakeholders remains unwilling to disclose insurance premium pricing methodology. Furthermore, the extent to which the role of the critical infrastructure groups is integrated with disaster preparedness and risk mitigation functions at different scales is not clear. There is potential for business to contribute to disaster resilience in a range of other ways, particularly through improved inclusion in state, regional and local disaster plans, through more Public Private Partnerships and investment in risk mitigation (Hunt and Eburn, 2016 unpublished).

Funding for disaster assistance is provided mainly under the jointly funded Natural Disaster Relief and Recovery Arrangements (NDRRA). Commonwealth NDRRA funding is provided (on a reimbursement basis) when state expenditure reaches an initial threshold. The percentage of Commonwealth funding as a proportion of the total increases as the cost of state losses climbs above further thresholds.

Payments to individuals and families are provided by the Commonwealth Government under the *Social Security Act 1996 (Comm)*. The Commonwealth Government also provides support for disaster management via a number of national high level committees within the COAG structure including the Law, Crime, and Community Safety Council (LCCSC) and the Australian and New Zealand Emergency Management (ANZEMC) Committee. The LCCSC's members are relevant commonwealth, state and territory and New Zealand government ministers and a representative of the Australian Local Government Association. The ANZEMC is the corresponding senior officials' group. These high level committees and a network of sub-committees provide the policy platform for national disaster policy development and coordination. If a disaster of any form is of significant severity or magnitude the National Crisis Coordination Arrangements can be activated.

Funding in addition to that available under the NDRRA is provided through an assortment of programs that provide education and skills development, research funding, funding for national demonstration-type projects under the National Emergency Management Program (Commonwealth Attorney-General's Department) and funding to state and territory governments to disburse for disaster risk mitigation activities and volunteer training (Commonwealth of Australia, 2016-17).

The level of funding provided for post disaster recovery has been estimated at \$560 million per year compared with an amount of \$50 million per year allocated to prevention and risk mitigation (Deloitte Access Economics, 2013). This is inconsistent with the principles of disaster resilience. In spite of cost benefit analyses overwhelmingly supporting investment in disaster mitigation and calls for change from influential stakeholders, including recommendations from the Productivity Commission (Australian Government Productivity Commission, 2014), government has not indicated that it intends to address this disparity.

A CHANGING DISASTER RESILIENCE SYSTEM

Disaster resilience policy in Australia is changing. This may be in keeping with the Commonwealth Government's position that the states have the major responsibility for

private owners and operators of critical infrastructure to share information to prevent, prepare and mitigate risks to the continued provision of essential services.



disaster management (Commonwealth of Australia, 2014). From a different angle, it can be viewed in terms of a change in its position on federalism.

The six Australian colonies were persuaded in 1901 to adopt the Australian Constitution, which was designed to retain the sovereignty of the states. Specific powers were ascribed to the Commonwealth (primarily under Section 51) that would enable it to efficiently manage issues of national importance such as national security and economic development and trade. Since Federation, the overwhelming trend has been, toward an expansive interpretation of the Australian Constitution that has led to increasing centralisation of powers to the Commonwealth Government. (Australian Government, 2005).

The COAG is a key instrument of modern Australian federalism and ostensibly provides a platform for whole-of-government. In practice, it has tended to be dominated by the Commonwealth Government and as such, reinforces centralisation (Brumby and Galligan, 2015; Committee for Economic Development of Australia, 2014; Fenna, 2012; Head, 2007; Carling, 2008). During 2011-2013 the Standing Council on Police and Emergency Management (SCPEM), (the COAG sub-committee and LCCSC's predecessor), released communiques that routinely reported on the progress of the NSDR (Standing Council on Police and Emergency Management, 2011-2013). Since the inauguration of the LCCSC in December 2014, mention of disaster resilience has dwindled until the latest communiques make no reference to disaster resilience whatsoever (Law Crime and Community Safety Council, July 2014 - May 2017). Given the Commonwealth influence at COAG, this change reflects a shift in how it sees its role in relation to national disaster resilience policy and its implementation.

In contrast to the diminished prominence of disaster resilience in high level Commonwealth and whole-of-government documents, *Strategic directions for fire and emergency services in Australia and New Zealand 2017-2021* (Australasian Fire and Emergency Services Authorities Council, 2016) has a strengthened focus on disaster resilience. This imbues the emergency services with a significant leadership role in disaster resilience policy implementation in state, regional and local areas. Similarly, responsibility for disaster resilience education and knowledge management now rests with the Australian Institute of Disaster Resilience, and a national strategic research agenda for disaster resilience is being managed by the Bushfire and Natural Hazards Co-operative Research Centre.

This represents a move away from direct implementation of disaster resilience policy by the Commonwealth. Meanwhile, it has turned its attention to the NDRRA and its plans to introduce an up-front assessment of estimated damages and costs to replace the current reimbursement model. It also remains directly involved in approaches for developing and sharing disaster risk information. For example, via the National Emergency Risk Assessment Guidelines (Commonwealth of Australia, 2015c). These policy priorities, particularly when aimed at reducing NDRRA costs, may signal a willingness to increase future investment in disaster prevention, preparedness and mitigation. Unfortunately, this is not a simple matter of opportunity cost due to the way NDRRA funding is appropriated through the Federal Parliament. Therefore, any such expectation should be held with caution.



METHODS

Qualitative methods are predominantly used in this research including literature review and thematic analysis of information obtained from documents and interviews. Quantitative data from secondary sources is referenced as required. In keeping with a public policy approach, it draws from a range of disciplines, including but not limited to economics, sociology, political science, and international relations.

The terms of analysis are set out in the framework at Table 1. They consist of four policy domains, Social Capital, Community Competence, Economic Development and Information and Communication. These were adapted from a model of community disaster resilience developed by Norris et al (2008) and later expanded upon by Kulig et al (2013). The Norris model was chosen because it has been widely cited and can be applied to both individuals and groups operating at different levels in a system, including when a sudden shock is experienced, like a natural disaster.

Each of the domains includes a set of variables adapted and labelled as policy objectives to better capture the idea of policy implementation through operational practice. During the process of developing the terms of analysis, unifying themes for each of the domains were identified. These are trust, self-efficacy, economic sustainability and behaviour change. With such a large number of variables, using these themes helped to simplify and focus the analysis and provided a check for internal consistency throughout the process. Mechanisms to achieve the policy objectives were identified as policies, (which includes laws and regulations), institutions/organisations (which includes governance), and programs. This framework (Table 1) was used to guide the selection of journal articles and other documents as part of the design of the project and the choice of literature that was reviewed. This was widely sourced from academic and grey literature and from official websites relevant to disaster resilience policy and the Australian disaster management system.



TABLE 14 - DISASTER RESILIENCE POLICY IMPLEMENTATION – DOMAINS & POLICY OBJECTIVES				
Domain	Social Capital	Community Competence	Economic Development	Information & communication
Theme	<i>Trust</i>	<i>Self-efficacy</i>	<i>Sustainable development</i>	<i>Behaviour change</i>
Policy Objective	1.Networks 2.Non-adverse geography/place-based attachment 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

The research involved two components: The first was broadly based and examined elements of the Australian disaster management system using document study. Complementing this was a primary research component. It consisted of interviews with experts in five organisations implementing disaster resilience measures. It also included the study of documents relating to these organisations and activities, some of which are internal and unpublished. A total of 15 face-to-face, semi-structured interviews were conducted using questions designed to elicit information about how, and whether, the policy domains inform their activities.

The five activities are:

- The National Flood Risk Information Project, a Commonwealth Government NSDR initiative agreed by COAG in 2012 and managed by Geoscience Australia (Commonwealth of Australia) – 1 interview,
- The Community Resilience Innovation Program, managed by the NSW Government under the Federal and State jointly funded National Partnership Agreement – Natural Disaster Resilience (NSW Government)- 2 interviews,

⁴ Table 1 was adapted from the following sources:

- Norris et al (2008), Brown (1996), and Kulig (2013) in relation to the four adaptive capacities for disaster resilience and sub-scales of community engagement, leadership and empowerment, and non-adverse geography;
- The Productivity Commission (2003) and Australian Bureau of Statistics (2004) on social capital ;
- Handmer and Dovers (2013), in relation to information and communication as a “universal” policy instrument and the role of community participation;
- Richardson (2014) in relation to security as a principle for economic development as an adaptive capacity for disaster resilience;
- Hussey et al (2013) regarding intra governmental and administrative policy mechanisms,
- The links between stakeholder engagement and leadership and empowerment (Porteous, 2013).
- Fenner and Hollander (2013), Jordan A (1999) and McAllister et al. (2003) on principles of co-operative federalism.



- The Lake Macquarie City Council Local Adaptation Plan for Flooding (Lake Macquarie City Council, 2015) – 3 interviews,
- The Rivers and Ranges Community Leadership Program, a Not-For-Profit organisation established following the 2009 Victorian fires and later affiliated with the Victorian Government Regional Community Leadership Program Network (Rivers and Ranges Community Leadership Program) – 8 interviews, and
- The Australian Business Roundtable for Disaster Resilience and Safer Communities, managed and established by the Insurance Australia Group and a partnership between the insurance, building and building financing sector and the Australian Red Cross (Insurance Australia Group) – 1 Interview.



RESULTS

Evidence of one or more of the policy domains and objectives was found in each of the five disaster resilience programs and activities. There were no examples found of all the policy domains within one discrete activity. Exceptions were found where numerous diverse activities are funded under one program. For example, the Community Resilience Innovation Program (CRIP) in NSW and the Commonwealth National Emergency Management Program (NEMP). These programs offer a strategic coordinated approach to implementing disaster resilience programs which can create synergies that help sustain outcomes.

There did not appear to be a correlation between particular levels of government or sectors and the predominance of one policy domain over another. For example, it was expected that local level disaster resilience activities would have a comparative advantage in terms of building Social Capital and Community Competence over Economic Development. While the Rivers and Ranges Community Leadership Program did display highly developed knowledge and skills in these areas, they were also able to apply these attributes to partner with business to expand into programs aimed at building Economic Development within their catchment areas. It was assumed that governments, having more economic policy mechanisms at their disposal, would focus on economic over social outcomes. This was generally found not to be the case.

The NSW CRIP program was seen to be innovative and highly literate in relation to community development. Some of the CRIP outcomes include the establishment of working partnerships between emergency service organisations and community service/welfare organisations based on shared disaster resilience narratives. This is significant in light of calls for cultural change within the emergency services to develop more community inclusive disaster resilience approaches.

Some issues around the application of disaster resilience principles to Commonwealth managed nation-wide disaster resilience activities were raised by the research. For example, the aims of the National Flood Risk Information Project (NFRIP) align with the domains of Information and Communication, Social Capital (the need to establish trust within the project's stakeholder networks), and Economic Development (support for equitable risk allocation). Unfortunately, COAG's agreement to share information did not translate into a willingness by data custodians to provide the information (Hazelwood, 2016a; Hazelwood, 2016b). This proved to be a major obstacle to the successful implementation of the National Flood Information Portal, an element of the NFRIP.

There were indications that many disaster resilience programs with Information and Communication goals were designed based on assumptions that the provision of information, particularly from an authoritative source, will result in the recipients of this information taking the desired action. However, there is a lack of evidence to support this assumption (Commonwealth of Australia, 2010; Paton, 2003). This is a concern given that a major goal of disaster resilience behaviour change is to enable all sections of the community to take responsibility for learning about, and taking action to reduce their disaster risks.

Other results included evidence of a high level of commitment to many of the policy objectives across several domains in the development of the Lake Macquarie City Council (LMCC) Local Adaptation Plan for Flooding (the Plan). In particular, LMCC's support for community engagement, its organisational resilience and determination to



develop and implement the Plan via a hard won participatory process. This achievement has recently been recognised at both state and national levels as one of the only plans of its type in Australia (Lake Macquarie City Council, 2016).



DISCUSSION

It is not intended that these results be used as a basis for judging the effectiveness of specific disaster resilience projects or the ability of a particular level of government or sector to implement disaster resilience policy. The purpose is primarily to raise awareness among disaster resilience stakeholders of the need to consider the determinants of successful disaster resilience programs and how these can be incorporated into the design of implementation approaches.

These approaches should also take into account the interdependencies and feedback loops that characterise a federal system. Furthermore, roles and responsibilities need to be defined and negotiated for implementation to occur at the appropriate level and so that capacity building can be targeted effectively.

In its present form the framework that was used to guide the analysis presented some limitations when applied to government policy development because of its greater relevance to acute disaster management rather than the whole disaster resilience spectrum. It was also difficult to conceptualise all of the domains within a multi-level system of governance such as the Australian federation. For example, Social Capital and Community Competence are more usually seen as goals of local levels of activity and not at higher levels of the system.

What the research does suggest, is that in the federal context, there is a fifth policy domain that cuts across the existing four and can explain the gaps. This is subsidiarity, which is often used synonymously with federalism. The policy objectives relating to subsidiarity are the division and sharing of powers, identification and negotiation of roles and responsibilities, co-ordination and cooperation, and devolution of activities with the authority that is needed to undertake these activities. Importantly, subsidiarity is also applicable to social organisation more broadly “Subsidiarity as a principle applies to the allocation of government functions but it also applies at a sociological level” (Grewal, 2014). As such, it is not confined to commonwealth versus states issues but is better conceptualised as a systems issue.

The argument for ensuring adherence to the principles of subsidiarity is strengthened by recent developments including the allocation of responsibility to the BNHCRC and the AIDR for the strategically important areas of research, and education and training. At the same time, the Commonwealth Government appears to be retaining core activities relating to mainstream disaster management including reform of the NDRRA as well as continuing direct involvement in supporting evidence based and uniform approaches to risk management communication.

While these developments may be a sound application of the principle of subsidiarity, this will depend on the details of the new arrangements. The changing configuration of roles and responsibilities may offer benefits, although it will be important to ensure that the feedback loop/s and capacity building that are necessary for healthy systems are not overlooked.

Open exchange of information, coordination and accountability must also be built in to the current approach to implementation to avoid weakening the disaster resilience message and fragmentation of disaster resilience effort.



CONCLUSION

Disaster resilience is a long-term objective. Accordingly, the changing emphasis of disaster resilience policy implementation raises questions about ongoing priorities and the roles and responsibilities of the various actors and vice versa.

This research highlighted aspects of disaster resilience good practice through the lens of Social Capital, Community Competence, Economic Development, Information and Communication and their related policy objectives. While information obtained from the five participating organisations demonstrated that there were instances where some of the good practice elements were not apparent, they each showed themselves to be exemplars in one or more of these four policy domains. Some gaps were also identified across the broader disaster management system. For example, information and Communication should not only address the provision of risk information but should also incorporate behaviour change strategies.

In terms of Social Capital, the need for better systemic and institutionalised connectivity and networking was identified, including in parts of the Federal system. Community Competence is synonymous with self-efficacy and it is only through authentic community and stakeholder engagement, combining top down and bottom up approaches, that this domain can be strengthened. In terms of Economic Development, the persistent imbalance between levels of funding for prevention, preparedness and risk mitigation compared with relief and recovery remains unresolved. Solutions to this persistent problem could include working with the private sector to encourage more opportunities for sustainable and innovative investment and funding models for disaster risk mitigation through public private partnerships, enhanced cooperation, information sharing, and more transparent insurance pricing.

Subsidiarity is at the nexus of disaster resilience policy and a compatible multi-level system of governance. Therefore, subsidiarity principles need to guide disaster resilience policy implementation to maximise its success in the Australian federal context.



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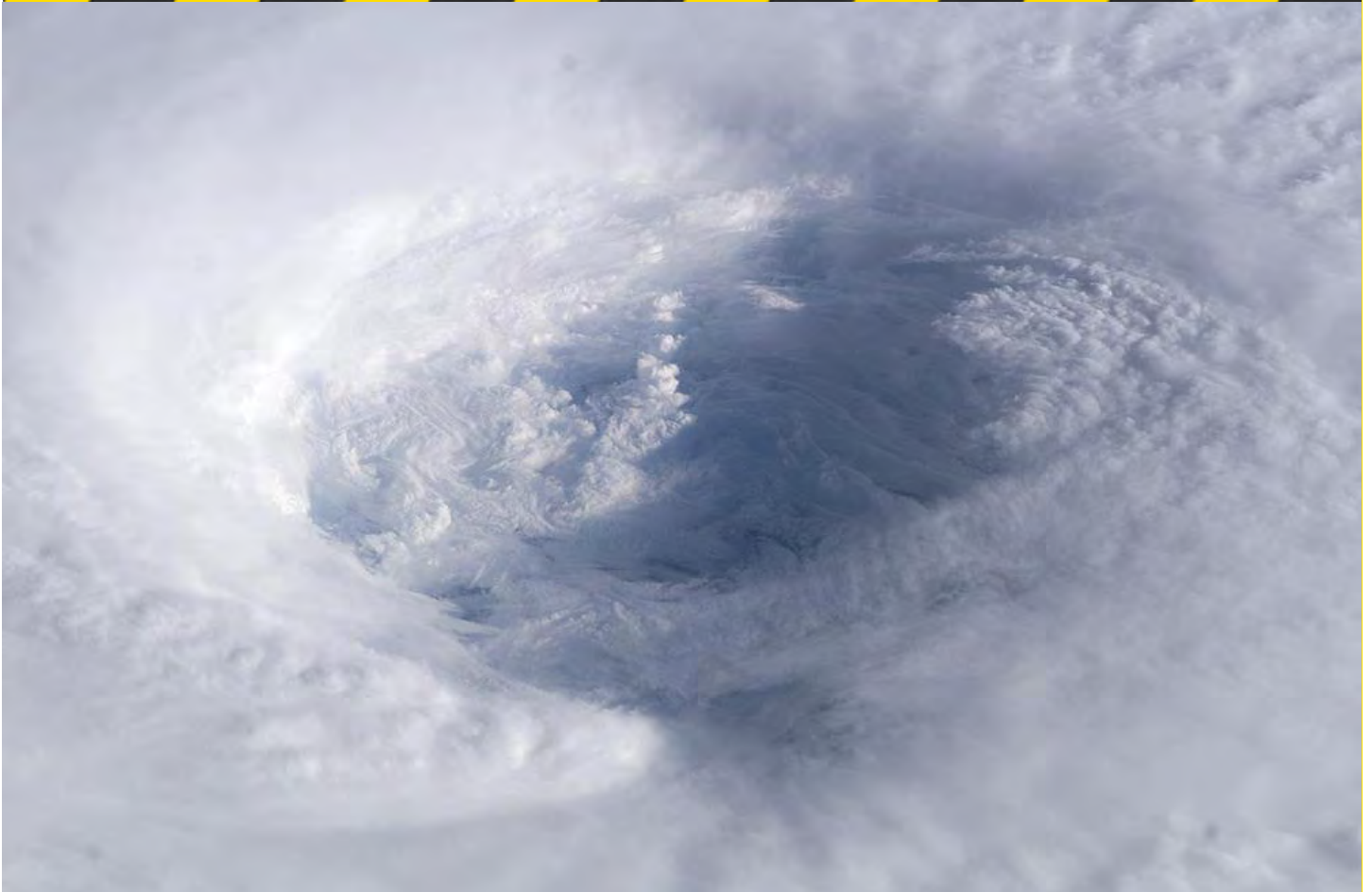


SECONDARY EYEWALL FORMATION IN TROPICAL CYCLONES

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ABSTRACT

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Roughly half of all intense tropical cyclones experience an eyewall replacement cycle. In these events, a new eyewall forms concentrically around the original one. This secondary eyewall develops its own wind maximum, and both the secondary eye and the wind maximum typically intensify and contract, whilst the original eyewall and wind maximum weaken and eventually dissipate. While the evolution of a storm with concentric eyewalls is reasonably well understood, the mechanism or mechanisms by which the outer eyewall forms remain elusive. Understanding secondary eyewall formation is an important problem, for the subsequent eyewall replacement cycle can significantly affect the intensity of the storm, and the formation process and replacement cycle are usually associated with a major expansion of the outer wind field. Both these factors significantly affect the cyclone's impact.

We investigate a high resolution simulation of an eyewall replacement cycle. Boundary layer convergence due to friction substantially influences the evolution of the convection, and we present evidence for a positive feedback involving convection, vorticity and frictional convergence that governs the subsequent evolution of the system. In this feedback, frictional convergence strengthens the convection, stretching of vortex tubes in the buoyant updrafts increases the vorticity, and the vorticity structure of the storm determines the strength and location of the frictional updraft.

Changes in the structure and intensity of tropical cyclones cause difficulties for their management, especially if these changes occur in the last day or two before landfall. Our improved knowledge of these processes will lead to better forecasts and mitigation.



INTRODUCTION

In literature, “the eye of the storm” is an apt description for a region of peace and calm, around which tumult and turmoil reign (White, 1973). The analogy is to a tropical cyclone, where the eye, characterised by light winds, little cloud and little or no precipitation, is surrounded by the towering clouds of the eyewall. These eyewall clouds slope outwards from the centre of the storm with height, giving the appearance of a giant amphitheatre. The strongest winds are close to the surface immediately below these clouds, and they generate substantial amounts of rain. Often, the formation of a symmetric eye signifies that the cyclone is entering an intense and destructive phase. Truly, the literary analogy is apt.

About half of all intense tropical cyclones experience an eyewall replacement cycle (ERC). In an ERC, a secondary eyewall forms, concentric about the existing eyewall. Over the next day or so, the new eyewall intensifies and contracts, while the initial eyewall weakens and eventually disappears. During eyewall replacement, the cyclone's intensity is steady or weakens, but intensification typically resumes once the replacement of the initial eyewall is complete. Notable examples of Australian tropical cyclones with an ERC include cyclones Vance (1999), Larry (2006) and Yasi (2011).

Figure 1 illustrates a typical sequence, using satellite images from a variety of passive microwave sensors in the 85 – 91 GHz band on polar-orbiting satellites. These frequencies can see through the dense cirrus overcast that normally obscures our view of the inner workings of tropical cyclones, and hence reveal the rainband and eyewall structure. At the start of the sequence, the primary eyewall is the red circle near the centre, surrounded by the deep convection of the spiral rainbands. Over the next 12 hours, the rainbands become more symmetric and organise into an outer eyewall by 22:43 on 22 August (panel d). The outer eyewall continues to become more symmetric, while the inner one weakens and decays, with the last vestige visible at 12:47 on 28 August (panel i).

The fundamental dynamics of the tropical cyclone eyewall replacement cycle (ERC), after the outer eyewall has formed, have been understood for over three decades (Shapiro and Willoughby 1982; Willoughby et al. 1982). In contrast, the cause of the initial formation of the outer eyewall has proved to be more elusive. Numerous theories have been proposed (see the reviews by Rozoff et al. 2012; Wu et al. 2012) but a consensus has not been achieved. More recently, attention has focussed on the possible role of the boundary layer in secondary eyewall formation (SEF) (Huang et al. 2012; Kepert 2013; Abarca and Montgomery 2013). Therefore, it is of interest to diagnose the boundary-layer processes occurring during SEF and the subsequent evolution of the eyewalls. This report describes our analysis of a SEF/ERC simulated by a high-resolution WRF simulation of a hurricane. An earlier report (Kepert and Nolan 2014) focussed on the boundary layer dynamics. Here we consider the effects of heating and the cloud processes also.

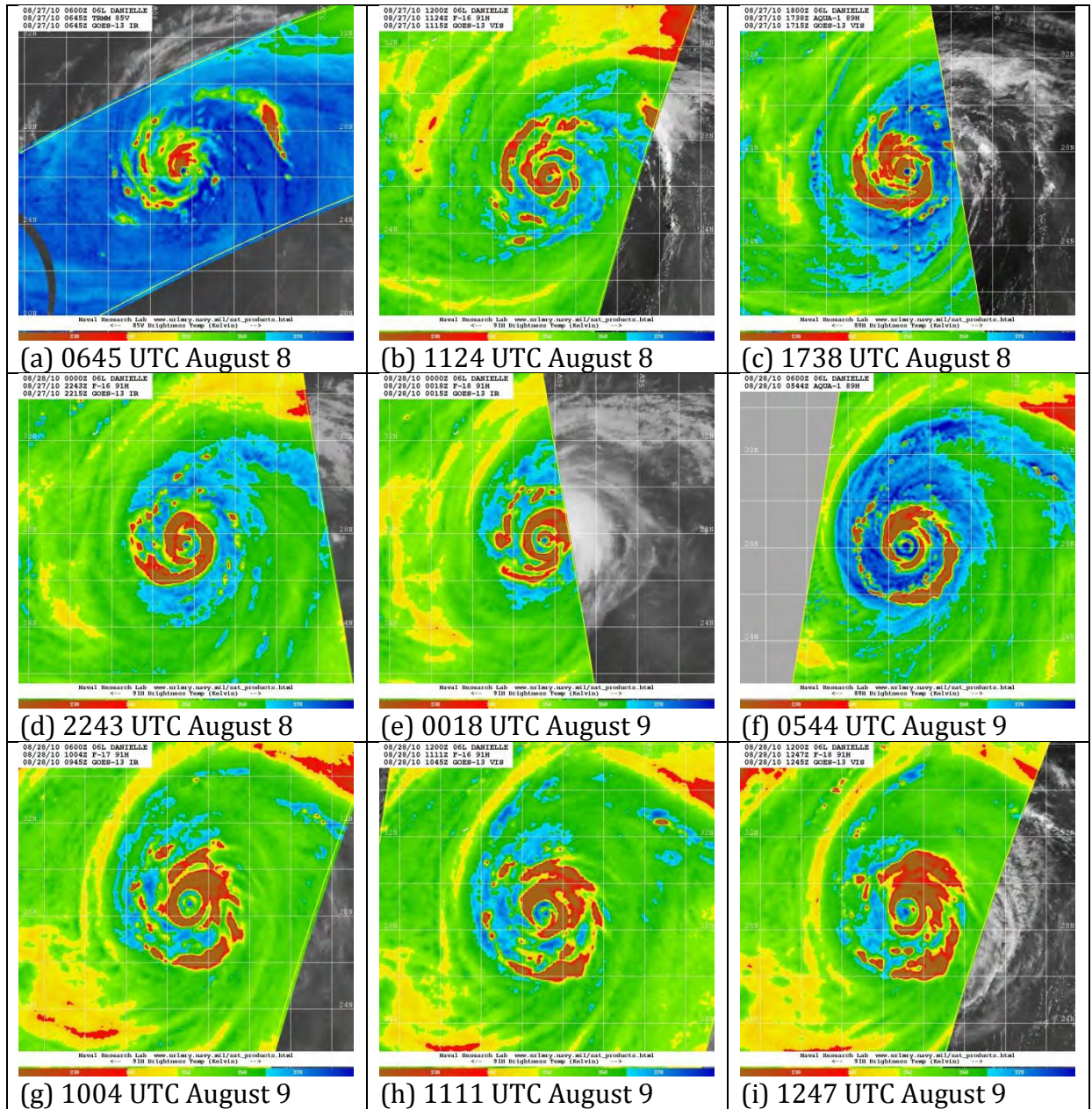


FIGURE 1: PASSIVE MICROWAVE IMAGERY IN THE 85 – 91 GHZ BAND FROM TRMM, DMSF AND AQUA SATELLITES, FOR HURRICANE DANIELLE OF 2010. RED AND BROWN SHADING INDICATE DEEP CONVECTION. TIMES AND DATES ARE INDICATED BENEATH EACH IMAGE. NOTE THAT THE TIME INTERVAL BETWEEN IMAGES VARIES. DATA COURTESY OF THE US NAVAL RESEARCH LABORATORIES.

THE SIMULATION

We use a WRF simulation of a TC that includes a SEF and ERC, prepared as a nature run for data assimilation experiments and described by Nolan et al. (2013). That simulation nested the WRF model (Skamarock et al 2008) from 27km down to 1 km and covered the full life of the hurricane, although we will focus attention on the 48-h period beginning at 0000 UTC 3 August. Details of the simulation, including the choice of the nesting and initial fields, and the model setup including the physical parameterizations, are given by Nolan et al. (2013).

Figure 2 shows the evolution of relevant fields, azimuthally averaged, from the simulation. Panel (a) shows the latent heat release, which is an indication of the occurrence of deep convection. The initial contraction and intensification of the primary eyewall is apparent, as is the formation and subsequent contraction and intensification of the secondary eyewall, indicated by the magenta curve. Panel (b) shows the similar evolution of the near-surface gradient wind, with the formation of the primary wind maximum and its replacement by the secondary one readily apparent. Note also the general outwards expansion of the wind field during the process. Panels (c) and (d) show the convective available potential energy (CAPE), a measure of the favourability of the atmosphere for convective cloud formation, and the vorticity¹ of the gradient wind, respectively, and will be discussed later, as will the green curve.

¹ In an axisymmetric vortex, the *vorticity* is defined as $\zeta = v/r + \partial v/\partial r$, where v is the azimuthal wind and r is radius. More generally, it is defined as the vector curl of the wind velocity. Given the crucial importance of vorticity to understanding these processes, it is appropriate to give a physical interpretation. Imagine a paddle wheel suspended in the air, with its axis vertical, moving with the wind. It may rotate, for instance if the flow is curved (curvature vorticity), or if the wind is stronger on one side of the paddle wheel than the other (shear vorticity). If observed from a fixed coordinate system, rather than the earth, it also rotates because the earth is rotating (planetary vorticity, accounted for by the Coriolis parameter f), and the *absolute vorticity* is the sum of the earth-relative and planetary vorticities. In tropical cyclones, the curvature and shear vorticity are of opposite sign outside of the eyewall, and these two terms cancel to some degree, but the net vorticity is mostly of the same sign as f ; that is, cyclonic.

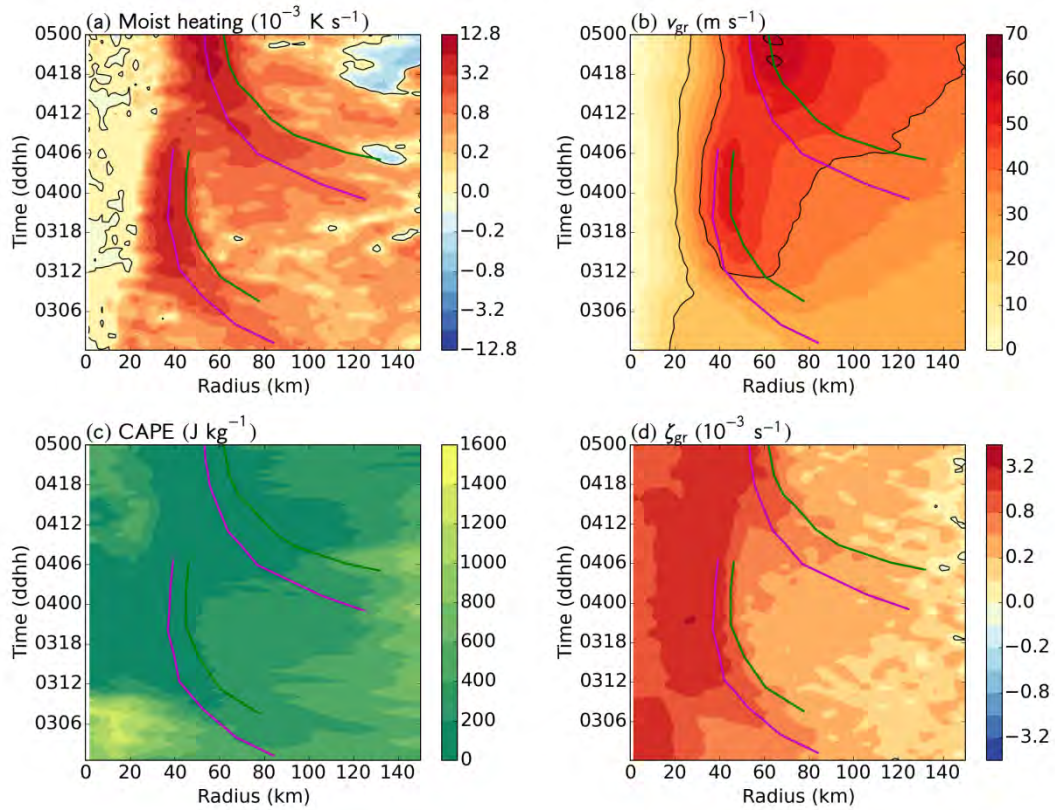


FIGURE 2: TIME-RADIUS DIAGRAMS OF (A) THE MOIST HEATING RATE, AVERAGED OVER 1-5 KM HEIGHT; (B) THE GRADIENT WIND SPEED AT 2-KM HEIGHT; (C) THE SURFACE-BASED CAPE; AND (D) THE VORTICITY OF THE GRADIENT WIND. ALL FIELDS ARE AZIMUTHALLY AVERAGED. THE MAGENTA CURVES INDICATES THE APPROXIMATE LOCATION OF THE TWO EYEWALLS, AS DETERMINED FROM THE MOIST HEATING. THE GREEN CURVES INDICATE THE APPROXIMATE LOCATION OF THE RADII OF MAXIMUM NEGATIVE RADIAL VORTICITY GRADIENT.

ANALYSIS TOOLS

The tropical cyclone flow can be divided into two components: the primary circulation, which is the rotational flow, and the secondary circulation, which consists of inflow mainly near the earth's surface, ascent mainly near the cyclone centre, and outflow mainly in the upper troposphere. The secondary circulation is often described as “in, up and out”. It is forced by two main mechanisms: surface friction causing the near-surface flow to spiral inwards rather than being purely circular, and latent heat release in the clouds, particularly in and around the eyewall, which causes buoyant ascent. Mathematically, we adopt the convention that a radial flow component directed towards the centre of the storm (i.e. inflow) has a negative sign, whereas outflow is positive.

The frictional component of the secondary circulation, to a first order approximation, does not intensify the cyclone or change its structure, because the inwards advection of absolute angular momentum² nearly balances its destruction by surface friction (Kepert 2013). The heating component, in contrast, can intensify the cyclone since its lower branch advects absolute angular momentum inwards, spinning up the storm by the “ice-skater effect”.

We assess the heating-induced component by the Sawyer-Eliassen equation, and the frictional component using a diagnostic boundary-layer model.

THE SAWYER-ELIASSEN EQUATION

The Sawyer-Eliassen equation (SEeq) diagnoses the secondary circulation due to latent heat release and other diabatic heating sources. It can also diagnose the effect of momentum sources and sinks, but may be less accurate for boundary layer friction due to the violation of a key assumption within the boundary layer.

We use the form of the SEeq given by Pendergrass and Willoughby (2009), discretised on a uniform grid with 75 grid points in radius, from 4 to 300 km, and 39 in height, from 0 to 19.5 km. The boundary conditions are that the flow perpendicular to the inner, upper and lower boundaries is zero, and that the flow is purely horizontal at $r = 300$ km. The discretised equation is solved directly using QR decomposition, which is feasible on modern computers with a problem of this size. Although not especially efficient, direct solution avoids the problem of potential nonconvergence of iterative methods should the SEeq be slightly non-elliptic, as sometimes happens in the upper-level outflow at large radius.

In this application, the inputs to the SE equation describing the structure of the storm and the heating are taken to be the azimuthal means, calculated

² Absolute angular momentum is similar to the familiar concept of angular momentum, but is calculated from a fixed frame of reference and therefore takes into account the earth's rotation. If r is the radius and v the azimuthal wind, then the absolute angular momentum is $Ma = rv + 0.5fr^2$, where the Coriolis parameter f is the local vertical component of the earth's rotation.



directly from the WRF simulation output. Heating is taken to be the sum of latent heat exchanges and radiation.

THE BOUNDARY-LAYER DIAGNOSTIC MODEL

The boundary-layer diagnostic model has been described by Kepert and Wang (2001), and Kepert (2012, 2017). It solves the equations of fluid motion, with high-quality parameterisations of friction and turbulence, for a prescribed fixed pressure field representative of a tropical cyclone. It is run forward in time to a steady state, and the resulting flow represents the equilibrium boundary-layer flow given that pressure forcing. One day of model time usually gives a sufficiently steady state. For convenience, the pressure field is specified in terms of the gradient wind,

$$\frac{v^2}{r} + fv = -\frac{1}{\rho} \frac{\partial p}{\partial r},$$

where v is the azimuthal wind, r is radius, f is the Coriolis parameter, ρ is density and p is pressure.

In contrast to the SEeq, where the domain includes the full depth of the troposphere, here the domain is only 2.25 km deep, sufficient to contain the boundary layer.

As with the SE equation, the necessary input to this model of the gradient wind is calculated from the azimuthal mean of the WRF simulation output, at hourly intervals. The boundary-layer models turbulence and friction parameterisations were configured to be reasonably consistent with those in WRF.

The boundary-layer model has been shown to be able to accurately reproduce the distribution of vertical motion in tropical cyclones when used in this way (Kepert and Nolan 2014, Zhang et al 2017).

DYNAMICS OF THE EYEWALL REPLACEMENT CYCLE

DOES FRICTIONAL CONVERGENCE INFLUENCE THE CONVECTION?

Figure 3a shows the azimuthal-mean vertical velocity at 1-km height from the WRF simulation. The evolution of the two eyewalls is clear, and closely follows that of the latent heat release in Figure 2a, as is usual in tropical cyclones. Figure 3b shows the diagnosed frictional updraft from the boundary-layer model, which clearly reflects a very similar pattern. There are two significant differences: the updraft in the boundary-layer model is consistently weaker, and located at slightly larger radius. We will show shortly that the difference in strength of the updraft is due to the absence of buoyant convection in the boundary-layer model.

To confirm that boundary-layer frictional convergence is the cause of the convection, we have to eliminate other possible causes, in particular thermodynamic factors. Convective available potential energy (CAPE), shown in Figure 2c, is a widely-used measure of the favourability of the atmosphere for convection, with higher numbers being more favourable. The values shown there are somewhat, but not strongly, favourable. There are no features in the CAPE field which would promote convection at the time and location of the secondary eyewall. Indeed, the CAPE at this time is amongst the lowest in the figure, and decreases as the eyewall strengthens. This decrease is due to two reasons (not shown): cold downdrafts from convection cooling and drying the lower troposphere, and the broadening of the upper warm core reducing the equilibrium level for deep convection.

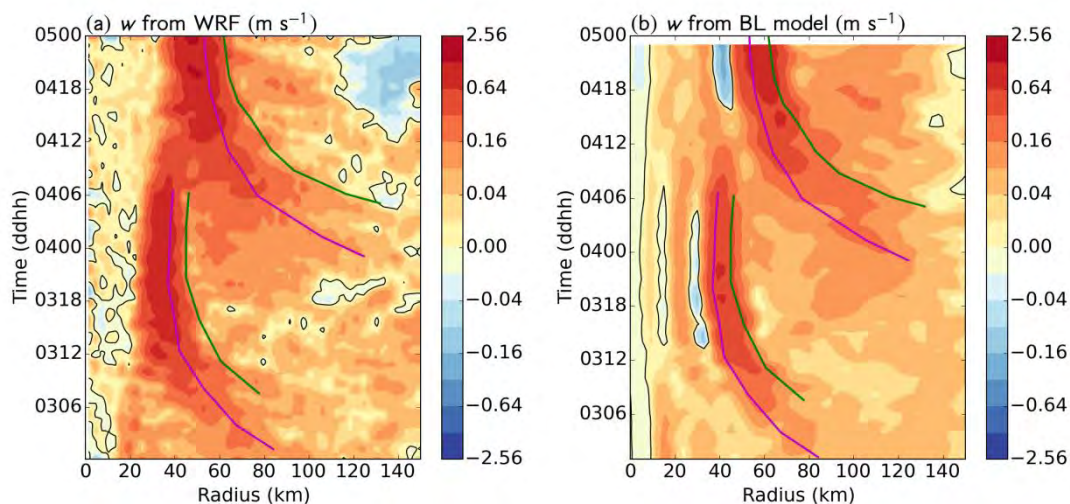


FIGURE 3: TIME-RADIUS PLOTS OF THE AZIMUTHAL-MEAN VERTICAL VELOCITY AT 1-KM HEIGHT, FROM (A) THE WRF SIMULATION AND (B) THE DIAGNOSTIC BOUNDARY-LAYER MODEL.



HOW DOES THE CONVECTION ALTER THE CYCLONE STRUCTURE AND INTENSITY?

The modelled secondary circulation at four key times before and during the ERC are shown in Figure 4, together with the corresponding diagnosed fields from a preliminary calculation with the SEeq. There is generally quite good agreement. One systematic differences is that the diagnosed main updrafts are often too weak in the lowest 2 km of the atmosphere, likely due to the absence of friction in this calculation. Indeed, the updraft in this region appears to be forced by both latent heat release and friction, since both diagnostic methods underestimate it. The diagnostic calculation also has inflow around 3 km height and 80 km radius, whereas WRF has outflow. Again, this may be due to the absence of friction. There are also a number of technical issues still to be resolved with the SEeq calculation, whose contribution is presently unknown – we note that this is a preliminary calculation.

Nevertheless, there is quite good agreement with the WRF simulation. We may therefore appeal to earlier studies with the SEeq (Shapiro and Willoughby 1982, Willoughby et al 1982) to note that the expected storm evolution from this pattern would be for the outer wind maximum to intensify and contract, qualitatively consistent with the evolution in Figure 2b. Future work will examine the extent to which quantitative agreement is obtained.

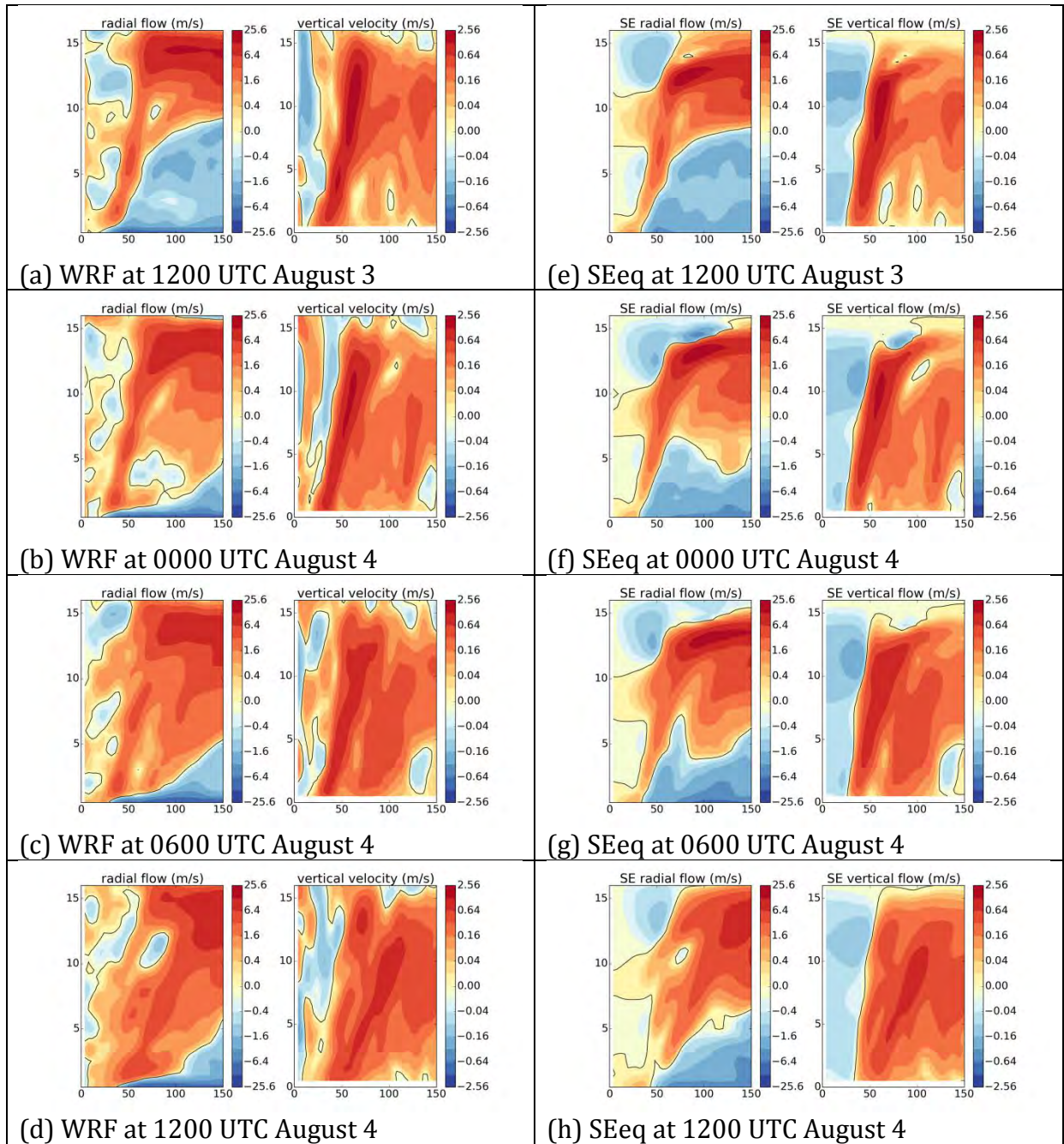


FIGURE 4: SECONDARY CIRCULATION DURING THE ERC AND SEF. PANELS (A – D) SHOW THE AZIMUTHAL-MEAN RADIAL WIND (LEFT, POSITIVE IS OUTWARDS) AND VERTICAL WIND (RIGHT, POSITIVE IS UPWARDS) FROM THE WRF SIMULATION AT TIMES AS INDICATED. PANELS (E – H) SHOW THE CORRESPONDING DIAGNOSED SECONDARY CIRCULATION USING THE SEEQ.



HOW DOES THE CYCLONE'S PRESSURE FIELD AFFECT THE FRICTIONAL CONVERGENCE?

We have seen above that the diagnosed frictional convergence determines the location and intensity of the convective heating. The only data passed from WRF to the diagnostic model in this calculation is the pressure field, in the form of the gradient wind. The question, then, is what characteristic of the pressure field leads to localised updrafts outside of the primary eyewall?

In Figure 3, we saw that the diagnostic BL model reproduces the location and relative strength of the two eyewall updrafts reasonably accurately, although underpredicts the strength because in the WRF simulation that is enhanced by the additional forcing from buoyant convection. It is also apparent in this figure that the changes in the gradient wind are spatially smoother than the vertical velocity response, and are relatively subtle. Pressure is the radial integral of gradient wind, so the changes in pressure must be even smoother than for gradient wind³. Nevertheless, these subtle changes must be responsible for the changes in the frictional forcing of the updraft, because they are the only information passed to the boundary-layer model. In other words, we know **that** the pressure field affects the frictional convergence, and we need to determine **how**.

Keper (2001) developed a simplified diagnostic tropical cyclone boundary layer model. Compared to the model used here, the simplifications included a linearization, and adoption of less realistic representations of turbulent diffusion and the air-sea momentum transfer. While calculations with this model are expected to be less accurate than from the full diagnostic model, they offer the great benefit that an analytic solution is available. That is, we can directly examine the equations to understand how the vertical velocity relates to the pressure (or gradient wind) structure.

Keper (2013) used that model to show that near the eyewall(s) of typical tropical cyclones, the updraft is approximately proportional to the radial gradient of the vorticity of the gradient wind, multiplied by the drag the wind exerts on the sea surface (approximately proportional to the square of the wind speed), divided by the square of the absolute vorticity. This equation suggests that we can expect to find enhanced updrafts where there is a locally strong negative radial vorticity gradient. Such gradients are especially effective if they occur where the vorticity is relatively low, because of the division by the square of the vorticity. The surface friction has a lesser effect on locating the updraft, because it varies relatively slowly with radius.

³ Differentiation acts as a high-pass filter, emphasising the small scales, as can be easily shown using the Fourier transform.



DISCUSSION AND CONCLUSIONS

Figure 2b,d and Figure 3a compare the joint evolution of the vorticity of the gradient wind, the frictional updraft, and the moist heating. These figures show the mutual contraction of the region of strong vorticity gradient and the region of strong convective latent heat release. Indeed, a similar relationship is also apparent earlier in the cyclone's life, during the initial contraction and intensification of the primary eyewall between 0000UTC and 1200UTC on August 3.

Clearly, these features are strongly correlated. However, correlation is not causation. The fact that A and B are correlated may occur for several reasons: A causes B, B causes A, or that both are caused by some third factor C.

In this paper, we have provided additional information that does allow us to attribute cause. In particular, using the diagnosed frictional convergence, which depends only on the cyclone's pressure field, we have shown that the distribution of vertical velocity at the top of the boundary layer is determined largely by frictional processes, although friction is insufficient to explain the full magnitude of the ascent. By comparing the evolution of the diagnosed frictional convergence to that of the convective latent heat release, together with the absence of any features sufficient to explain the localisation of the convection in the stability or moisture fields, we show that the frictional updraft is largely determining the location and strength of the convection. Calculating that part of the secondary circulation induced by heating, using the Sawyer-Eliassen equation largely accounts for that part of the low-level updraft missing from the frictional calculation. The evolution of the vortex structure explained by advection of absolute angular momentum by this secondary circulation is largely consistent with the evolution of the cyclone; that is, it leads to changes in the gradient wind that are similar to those in the WRF simulation. Most importantly, these include an inwards migration and strengthening of the vorticity features that we have theoretically linked to the evolving frictional updraft.

To summarise, we have confirmed that the positive feedback mechanism hypothesised by Kepert (2013) and further discussed by Kepert and Nolan (2014) and Kepert (2017) is indeed operating in this case. Here, vorticity-induced boundary-layer convergence acts to promote convection, provided that the stability and moisture are also favourable. Vortex-stretching in convective updrafts increases the local vorticity. We have analysed the combined, cyclone-scale, effect of many individual clouds by applying their combined heating to the Sawyer-Eliassen equation, but analyses at the cloud scale (not shown) similarly show that convective updrafts are acting to increase the vorticity beneath the developing secondary eyewall. These vorticity changes in turn further strengthen the frictional updraft. There is a further important subtlety in all of this, in that the relative location of the various processes is important for the precise details of the interaction, particularly the initial rapid contraction of the outer eyewall, followed later by slower contraction and intensification. These can be largely explained as a contribution of nonlinearity in the boundary layer, as detailed in Kepert (2017).



PRACTICAL IMPLICATIONS

Forecasting ERCs is challenging, because it is clear from the work described here that the changes in the early stages are quite subtle, and therefore difficult to detect. This is especially true in the harsh environment of tropical cyclones, where observations are difficult to take. Modelling ERCs is likewise challenging, for this work implies that the interaction between friction, clouds and pressure in the cyclone must be represented with sufficient fidelity. Nevertheless, the success of the simulation used here and others shows that that fidelity has been achieved in current NWP systems.

The initialisation of such simulations is challenging, especially since the early signs of an ERC are subtle. Small errors in the initial pressure field could completely remove local vorticity perturbation, and hence the frictional updraft, or add a spurious one. The necessary precision in the initialisation will be beyond the reach of our observing and data assimilation systems, at least in the absence of aircraft reconnaissance, for some time. Ensemble prediction methods provide the only presently viable means of dealing with this uncertainty.

In spite of these considerable difficulties, forecasting ERCs is important. They represent a substantial additional difficulty for intensity forecasting, because of their large impact on the intensity evolution of the storm. They also strongly affect the ocean response. A substantial import of vorticity to the storm in the region of the developing outer eyewall seems to be an inherent part of the ERC process, and this import of vorticity explains (through Stoke's theorem) the wind field expansion. The wind field expansion affects not just the width of the damage swath, but also the timing and duration of damaging winds. It also profoundly increases the ocean hazard, because applying strong winds to a larger area of the ocean's surface greatly increases the severity and extent of storm surge, damaging waves and coastal erosion. With the high concentration of vulnerable populations and infrastructure near the coast in Australia, improving our ability to predict ERC will clearly help mitigate tropical cyclone impacts.



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From research to red tape - the challenges in implementing fit for duty programs amongst emergency management agencies

Peer reviewed research proceedings from the Bushfire and Natural Hazards CRC & AFAC conference

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ABSTRACT

Fit for duty programs are becoming increasingly prominent within the Australian and international emergency management sector. The physical fitness of workers in physically demanding roles is an important element within the broader occupational health and safety strategy. A growing body of evidence continues to mount on best-practice fit for duty practice. It is becoming increasingly apparent the value of robust methodologies and validation techniques to produce fit for duty tests which are legally defensible and specific to each organisation. However, despite increases in the knowledge of evidence-based strategies for fit for duty design and implementation, there remains a reluctance for organisations to utilise such knowledge. Here, we explore the reasons why such a reluctance exists and the current barriers to scientifically-backed fit for duty programs. Specifically, we explore the complications with the knowledge repositories, the effects of organisational structure, and the communication processes which currently exist between emergency management agencies and research bodies. Finally, we discuss the role of perceived organisational barriers, including: time, resources, capital, and obligations to meet ambiguous health and safety targets. With these issues explored, we expand on the role that individuals, departments and organisations can play in improving the utilization of fit for duty research. Concurrently, we critique the current limitations of research institutions and the dissemination of fit for duty knowledge. When all parties in the research continuum are properly aligned, organisations can implement fit for duty programs that will improve the health and safety of their workforce, assist with compliance obligations and boost workplace productivity.



INTRODUCTION

In the Australian emergency management sector, access to the right knowledge is critical in preventing and controlling natural hazard incidents. Beyond the internal knowledge generated from training and peer to peer communication, there is no shortage of external information for emergency personnel to access. This includes a host of online repositories such as the Australian Disaster Resilience Knowledge Hub, the Australasian Fire Authorities & Emergency Council (AFAC), the Bushfire and Natural Hazards Cooperative Research Centre (BNHCRC), and the Australian Journal of Emergency Management and Emergency Management Victoria (EMV). The important question is not whether there exists sufficient knowledge to inform emergency management personnel, but whether this information is being effectively utilised. Knowledge utilisation is a growing field of research amongst academic institutions, government organisations, and industry end users. Increasingly, we are becoming aware of the gap that exists between research and practice. The Australian Government is currently investing considerable resources into knowledge utilisation through its flagship program, the National Innovation and Science Agenda (NISA, 2015). There are also many other governing bodies and research institutes that have addressed the issue of knowledge utilisation, providing an array of recommendations to bridge the research-practice divide. These include increased research-industry collaboration (Farand & Arocha, 2004), increased peer to peer interaction (Dawes & Sampson, 2003; Parboosing, 2002), greater investment into repositories (Nguyen & Pham, 2011), and developing appropriate 'knowledge adoption' frameworks (Ward et al., 2006).

The current paper discusses issues of knowledge utilisation in the context of fit for duty, an evolving field of research within the emergency management sector. We define fit for duty as the capacity of workers to meet the physical demands associated with occupational roles (Roberts et al., 2016). Fit for duty programs represent an occupational health & safety strategy, complimentary to other strategies such as workplace education, workplace design (ergonomics), manual handling training, drug and alcohol screening, health and wellness programs, rehabilitation, and return-to-work practices. Fit for duty presents an important and powerful resource for employers to make decisions regarding who to hire, discipline, or terminate; they are expressions of contractual freedom which influence workplace rules, policies, and working conditions (Adams, 2016). Subsequently, developing appropriate fit for duty tests is of great importance. The tests themselves are founded on a particular scientific process, owing to many of the physical sciences, including exercise physiology, ergonomics, functional anatomy, and biomechanics. Scientists have made considerable advancements in the methodologies relating to fit for duty procedures in the previous decade, where tests, and their associated standards, are now modelled on a number of frameworks developed by prominent researches in Australia and abroad (Jamnik et al., 2012; Payne and Harvey, 2010, Taylor & Groeller, 2003; Tipton et al., 2012).

There is no shortage of access to peer-reviewed information relating to fit for duty. There are several hundred journals, both open access and non-open access, which house research related to fit for duty. Prominent journals include the *European Journal of Applied Physiology*, *Applied Ergonomics*, *Ergonomics*, *Military Medicine*, *International Archives of Industrial Ergonomics*, *International Archives of Occupational and Environmental Health*, and *Applied Physiology, Nutrition and Metabolism*. Such is the scope of fit for duty research, there are often entire



journal issues dedicated to this field. Beyond peer reviewed journals, there are conference proceedings from a host of fit for duty specific international conferences which are held annually or biannually, including the *International Conference on Physical Employment Standards* and the *International Congress on Soldiers' Physical Performance*.

Despite the ease of access to evidence-based research, fit for duty testing amongst emergency management organisations often deviates from what is considered 'best practice'. A host of agencies still utilise inappropriate tests, which are not founded on evidence-based research. A salient example is the common use of the multistage run test, which assesses cardiorespiratory fitness (Ramsbottom et al., 1988). Research shows that the use of the multistage run test is inappropriate for many policing and firefighting organisations, since endurance tests performed in clean skin conditions are poor predictors of performance of tasks in which personnel wear external load (Bilzon et al., 2001). However, many Australian responder agencies continue to utilise the multistage run test for both recruitment and ongoing selection procedures (e.g., CFA, 2017; DFES, 2017; TFS, 2017). In this paper, we examine the research to practice nexus that exists for fit for duty, and why there is often a mismatch between evidence-based practices and real-world practices. We focus on the barriers presented by both research organisations and emergency management organisations, with special attention brought to responder agencies within Victoria, Australia. The barriers discussed are reflective of the experience of the authors, working in a host of industries which utilize fit for duty practices. We have contextualized these barriers with literature which supports cases where these barriers are prominent. In total, we have identified five key barriers, including: (1) information dissemination, (2) education (3) legislation complexities, (4) staff responsibilities, and (5) time and cost. A brief commentary is provided on each barrier.

BARRIER 1 - INFORMATION DISSEMINATION

In the context of applied research, information sharing is a complex and fluid process between researcher and end user. When simplified, this process of information sharing can be represented as push-pull dichotomy (Kerner et al., 2005) where each party has one primary responsibility. It is the responsibility of the researcher or practitioner to 'push' information to the end-user, and it is the responsibility of the end-user to 'pull' the information from the researcher or practitioner in return. One of the key features which inhibits information flow in the context of fit for duty is the prevailing medium in which researchers choose to 'push' their work: peer-reviewed journal articles. Owing to the 'publish or perish' culture within research institutes, research has shown that in many cases the main reason academics publish their work is to boost their research impact (Swan, 2006; Ware & Mabe, 2012). Researchers are motivated to produce peer-reviewed articles as a priority (when compared to other forms of publication), since funding and career progress are contingent upon it (Ware and Mabe, 2012). Although it is often anecdotally recognised that efforts need to be made to change the medium of communication (i.e. alternative formats to journal articles), academics are not incentivised to do so because this falls outside of the scope of their key performance indicators. Thus, researchers may not view knowledge sharing as part of their role, and may feel that they lack the skills to communicate their research to non-academics (Tsui et al., 2006).

Generally speaking, journal articles are a poor medium from which to communicate information to end users. It has been reported that half of academic papers are read only by their authors,



reviewers, and journal editors (Eveleth et al., 2014). In fact, the information contained in journal articles may actually deter many readers, as the articles impose large time periods to read, and often the reader doesn't have the necessary skills to appraise and understand the information (Grimshaw et al., 2012). Although efforts are being made in Australia to change career incentives pertaining to publication records (ARC, 2016; EIA, 2014), such changes are still a long way off becoming mainstream. Until a time where academics are rewarded for producing end-user-friendly mediums to communicate fit for duty research, the majority of communication will continue to reside within journal articles. In doing so, the divide between fit for duty knowledge and practice is likely to expand, unless intervening actions are taken to address the breakdown in communication via ineffective mediums.

BARRIER 2 - EDUCATION

Despite the developing body of knowledge relating to fit for duty, the issue itself is still poorly understood by many within the emergency management sector. Consequently, several misconceptions still exist, many of which relate to the breakdown in communication between researchers and end users previously noted. It is also true that poor education applies to the definition of fit for duty itself. In many professions, the term has much broader connotations than job-specific physical fitness, and for many employers and managers, their understanding of the term differs from the strict confines of what we refer to in the context of job fitness. From an agency perspective, it is important that staff become aware of the specific nature of fit for duty when discussed in the context of physical fitness. This aligns with the 'push' responsibility of researchers to ensure no ambiguity is inherent in the fit for duty terminology, and the need for ongoing communication between researcher and end user.

It is also the case that fit for duty has also been associated with more generic types of occupational screening. The most common example is the pre-employment medical test, in which medical staff assess employees on generic health measures such as blood pressure, blood sugar, cholesterol, body mass index, and lung function (Schaafsma et al., 2016). It should be understood by emergency management personnel that these measures differ from fit for duty tests, as they do not relate to the 'duty' itself. Instead, they provide holistic measures of employee health. While many organisations describe fit for duty in the context of pre-employment medical checks, such descriptions are inaccurate and should not be considered a true test of occupational fitness.

Perhaps the greatest misconception relating to fit for duty testing is the misnomer that tests discriminate against certain populations, such as women, older personnel, or smaller individuals. A common strategy amongst military and emergency service organisations is to scale the cut-scores on physical tests to accommodate sex, age, and sometimes rank (Kenny et al., 2016). A recent commentary by Petersen and colleagues (Petersen et al., 2016) utilised a series of empirical studies to reject the notion that agencies should scale fit for duty standards based on the age or sex of the person undertaking the test. Such procedures are considered inappropriate and would be contentious in many jurisdictions. As commented by the authors, "assuming that the force application and energy demands of a task are sex-neutral, the logic of lower physical fitness for work standards for females is untenable." (Petersen et al., 2015). The same principle applies to workers of different ages and ranks.



Another misconception with fit for duty testing is the notion that organisations with similar job roles can use the same tests. A common example amongst policing and firefighting agencies is the adoption of physical testing procedures from other agencies that have implemented a validated fit for duty test. The Physical Aptitude Test (PAT) developed by Fire and Rescue New South Wales, in conjunction with the University of Wollongong (Groeller et al., 2015), is a prominent example of test adoption in Australia. Since the PAT was endorsed as a valid fit for duty test in 2015, other firefighting agencies, both within New South Wales and other states / territories, have adopted the test (or components of the test) on the premise that the test is valid for their firefighting population (e.g., MFB, 2017; QFES, 2017). Such adoption is inappropriate, as tests need to be validated for each organisation individually, regardless of similarities between job roles (Petersen et al., 2016). Recycling of tests can only occur with the appropriate comparison of job tasks and the necessary analyses which liken the adopted tests to new job roles (Petersen et al., 2016). Even though job roles may share common traits, often there are individual tasks which are unique to each organisation. Such tasks need to be considered in relation to test development, which is why testing adoption does not always align with organisations' precise job roles. Misconceptions around the discriminatory nature and test adoption, in addition to many other misconceptions, may result from poor education relating to fit for duty programs. Improving the education of end users would eliminate some of the resistance which is often associated with such programs.

BARRIER 3 - LEGISLATION COMPLEXITIES

Fit for duty testing, when attentive to human rights and diversity, plays an important role in the creation of safe, just, and equitable workplaces (Adams, 2016). However, how these programs relate to human rights and diversity laws can be complicated. Within Australia, fit for duty testing is governed by several Commonwealth and state / territory legislations. The Commonwealth legislation includes the *Fair Work Act 2009* (Cth) (Fair Work Act) and any industrial agreements made pursuant to the Fair Work Act. The state / territory legislation includes a mix of general workplace legislations as well as local organisational Acts. In Victoria for example, the legislation includes the *Equal Opportunity Act 2010* (Equal Opportunity Act) and the *Occupational Health and Safety (OHS) Act 2004*, in addition to responder agency legislation (e.g. *Metropolitan Fire Brigade Act 1958*, *Victoria State Emergency Service Act 2005* and *Country Fire Authority Act 1958*). Further to each respective legislation, enterprise agreements govern the provisions around workplace health and safety initiatives such as fit for duty. The interplay between the relevant legislation makes for a complex and often confusing system. To use another Victorian example, The Fair Work Act does not prevail over the Victorian OHS Act or the Equal Opportunity Act; any enterprise agreement established under the Fair Work Act is subject to the OHS Act and Equal Opportunity Act. At the same time, when in conflict with a clause in an enterprise agreement, most Victorian responder agency and emergency management legislation will be subordinate to the enterprise agreement.

Without validated fit for duty tests, agencies are potentially liable under anti-discrimination and OHS legislation. If there is a demonstrated need to introduce fit for duty policies to mitigate significant OHS risks, a responder agency would be able to do so under the OHS Act. However, in Australia, fit for duty tests have not figured prominently in discrimination case law to date. This lack of legal challenge may add to the uncertainty surrounding fit for duty policy implementation. Differences in how legislation is interpreted, and opinions on strategies to



mitigate OHS risks, may lead to internal organisational disputes which could delay fit for duty policy implementation. Disputes may also escalate into legal challenges, which further impose time barriers to implementation. The precedent has, however, been set in other common law jurisdictions such as Canada (see for example, British Columbia [Meorin Greivance case], 1996), which demonstrate the largescale changes that have ensued from legal challenges to invalid fit for duty programs. In the recent commentary by Adams (2016), the author suggests that there is no reason to think that fit for duty testing will not be the subject of future legal challenge in Australia.

BARRIER 4 - STAFF RESPONSIBILITIES

Emergency management agencies are large, complex systems containing a diverse mix of staff roles, units, divisions, and working groups. Fit for duty programs can be the responsibility of various staff from health and safety divisions, human resources divisions, legal divisions, capability divisions, training and deployment divisions, and accounting / finance divisions. For staff tasked with implementing a fit for duty program, there is often limited full time employment (FTE) allocated to such projects. Consider, for example, staff involved in health and safety roles, who are often charged with the development and administration of fit for duty programs. To these staff, fit for duty only constitutes a small portion of their broader health and safety remit, which includes a host of programs related to workplace design, hazard identification, workplace injury analysis, return-to-work strategies, health check programs, exercise programs, and nutrition programs. Using the State Emergency Services (SES) as an example, the health and safety staff are responsible for: (i) workplace safety, (ii) risk and hazard assessment, (iii) building resilience, (iv) clinical support, early intervention, health checks, compliance and reporting, and health and wellbeing (SES 2015-2016 Annual Report). When fit for duty is then added to the workload, it is reasonable to assume that little time is left to ensure that appropriate resources are allocated to these programs.

The dilution of staff resources can compromise the quality of each project and inhibit communication between units / divisions within an organisation, as well as between the organisation and external providers (i.e. research partners). If only small portions of FTE are allocated to fit for duty projects, the projects are drawn out over a longer time period than necessary. As a result, projects such as fit for duty can lose their momentum, resulting in wasted time, money, and human capital. It is incumbent on employers to ensure that fit for duty programs are allocated the necessary staff, time, and resources to enable their effective delivery and implementation.

BARRIER 5 - TIME AND COST

To implement scientifically robust tests, practitioners and end users need to adhere to a strict research process, which can take months or years to complete. As demonstrated by the implementation of successful fit for duty programs within the Australian Army (Australian Army, 2015) and Fire and Rescue New South Wales in 2015 (Groeller et al., 2015), tests can take up to five years from inception to full implementation. Such a timescale is understandably unattractive to many employers. To ensure faster delivery of fit for duty programs, organisations may place unrealistic, arbitrary deadlines on projects (e.g. completion within 6 months, 12 months or by December 31st). When projects are performed under these confines



and not allowed to occur organically, the research process may be compromised and quality, evidence-based fit for duty tests may not eventuate.

Much like time, money is considered another barrier to the implementation of adequate fit for duty programs. Employers want to know that investment into these programs will yield financial returns. When considering the economic value of health programs, there is no shortage of research demonstrating the benefits on work performance, productivity, absenteeism, and employee health risk (Mills et al., 2007; Østerås & Hammer, 2006; Pronk et al., 2014; van Dongen et al., 2011). Previously, the return on investment from health programs has varied from \$1.40 to \$10.10 for every dollar invested (Aldana, 2001; Goetzel et al., 1999; van Dongen et al., 2011). The problem, however, is that these numbers result from more generic forms of health programs, such as pre-employment screening, health checks, and functional movement screening. When considering fit for duty specifically, there are far fewer cases reported on the economic returns. Longitudinal studies have yet to formally document the economic benefits within the Australian, or indeed the international, emergency management sectors. Although economic benefits have been reported amongst alternative industries (Harbin & Olsin, 2005; Kalkan and Bunch, 2006), there remains a void in the emergency management sector. Consequently, employers may be reluctant to invest in fit for duty programs as there remains uncertainty in the precise long term fiscal benefits.



CONCLUSIONS

Knowledge utilisation is an important tenet of effective emergency management operations. Efforts need to be made to ensure that personnel within the industry are utilising the most effective and up to date knowledge arising from research institutions. Fit for duty is a prime example of the mismatch between evidence-based practice and real-life practice. If developed properly, fit for duty tests can create a healthier and safer working population, whilst improving business compliance and safeguarding organisations against litigation. In Australia however, many responder agencies are utilising fit for duty programs, or components of programs, which do not reflect best practice. This review provides a brief commentary on some of the possible causes as to why this situation exists. The inherent barriers within the research-to-practice nexus have been explored, including information dissemination, education, legislation complexities, staff responsibilities, and time/cost. By understanding these barriers, researchers, practitioners, policy makers and end users can explore options in order to minimise the effect of each barrier, thus promoting a more evidence-based fit for duty culture within the emergency management sector.



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IDENTIFYING LESSONS FROM EXERCISING AND TRAINING FOR STRATEGIC EMERGENCY MANAGEMENT DECISION-MAKING

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ABSTRACT

Decision-making is a skill that permeates every emergency event and every level of emergency and disaster management. The decision environment is often complex and uncertain, with challenging physiological contexts such as fatigue, and major consequence for poor decisions. This makes for a fertile ground for decision scholars, and significant opportunities to support the continual improvement of the management system. Emergency management organisations maintain, assess, and improve the quality of decisions in a number of ways. These include exercising teams in simulated emergency events and training focused on improving skills and knowledge.

We report on a series of training and exercising related studies that specifically examined this area. Study One included observation and surveying participants following multiple exercises in a range of end-user organisations. Study Two included detailed analysis of the set of decisions made by a commander during a Search and Rescue deployment to evaluate the core skills utilised. Study Three involved a training intervention – a one day decision-making course where participants were provided with both knowledge and tools to assist them in their decision-making.

Our results identify several consistent themes in terms of where participants perceive their organisations to be performing well, and several lessons are identified that can lead to improvements in decision-making.

Finally, we describe how the BNHCRC Research project 'Practical Decision-Tools for Improved Decision-making in Complex Situations' is building and testing cognitive decision tools based on these results.

INTRODUCTION

Decision-making is a skill that permeates every emergency event and every level of emergency and disaster management. The decision environment is often complex and uncertain, with challenging physiological contexts such as fatigue, and major consequence for poor decisions. This makes for a fertile ground for decision scholars, and significant opportunities to support the continual improvement of the management system.

Emergency management organisations maintain, assess, and improve the quality of decisions in a number of ways. These include exercising teams in simulated emergency events and training focused on improving skills and knowledge. In a previous evaluation of decision-making structures and processes within end-users of the Bushfire and Natural Hazards CRC project, a number of aspects of good decision-making knowledge and skills were evaluated. The process of evaluation included the review of organisational processes and semi-structured interviews with senior staff. Our focus was around the response to so-called 'Level 3' incidents. Participant organisations include a range of emergency response organisations, however were mostly Fire Agencies (both rural and urban) and State Emergency Services. The results identified a range of possible opportunities for improvement, as demonstrated in Table One.

Decision Concept	Coverage in Surveyed Aust/NZ Organisations
Decision-Styles: Awareness of and an ability to work across the spectrum from intuitive to classically rational decision approaches as the context requires them to.	<15%
Monitoring themselves and their teams for evidence of bias or decision errors. (Linked with decision-styles)	<15%
Sense-making: Recognition of the dynamic nature of the process, and the need to not just decide, but to make sense.	50%
Record Keeping: Balancing the need to record decisions for future reference with the effect recording has in creating bias in decision-making	<15%
Creating psychologically safe decision environments that build and maintain trust between teams.	50%

Table One: Evidence of Implementation of Decision Concepts (Adapted from Brooks et al, 2016).

Several key concepts will re-appear throughout the paper in the different studies and are therefore discussed in the conclusion to the paper. These are briefly defined below:



- Sense-Making – is a collaborative process in which people identify meaning within their experiences. It is qualitatively different from decision-making in that it does not necessarily have a discrete start and end point. Further, sense-making identifies how a range of factors – both distant (e.g., our previous experiences) and close (the information at our disposal) combine to create our 'sense' of the current situation. It is often used to characterise the building of shared awareness in ambiguous or uncertain situations and therefore particularly appropriate for emergency management incidents.
- Decision Styles – different styles of decision-making include creative, procedural (following rules), heuristic (quick rules of thumb), the classical evaluation of a range of alternatives for their utility and intuition. These styles vary with the degree to which they require conscious evaluation, however all have value in certain decision contexts.
- Meta-cognition – can be described as our 'thinking about our thinking' or the awareness and understanding of our own thinking processes. In this scenario meta-cognition relates both the the decision styles and the other elements that influence the quality of the decision –such as bias.
- Cognitive Bias – is an artefact of human cognition that systematically leads to a particular way of deciding, which is quite often incorrect if viewed from a 'rational' decision-making perspective. For example, cognition is typically 'anchored' from early information or intelligence, even if the subsequent information changes.
- Psychological Safety – is a state of the environment of a team where everyone within the team is comfortable to speak-up about issues or information that could be considered discrepant or divergent from the dominant understanding. It therefore counters particular biases (such as 'group-think' or the tendency to side with the majority view), and creates an appropriate environment to explore and catch errors.

Following the evaluation identified in Table One, we triangulated these results with further research. This paper reports on the preliminary data associated with these efforts, and subsequent research utilisation products. Study One included observation and surveying participants following multiple exercises in a range of end-user organisations. These end users included a Fire Agency, a Critical Infrastructure organisation and a private oil and gas company. The exercises were complex enough to require the establishment of a team above what would typically be considered an Incident Management Team – and was therefore focused on strategic-level decision-making. Scenarios varied depending on the organisation and hazard type, but were all what would be considered a 'Level 3' incident. Study Two included detailed analysis of the set of decisions made by a commander during a Search and Rescue deployment to evaluate the core skills utilised. Study Three involved a training intervention – a one day decision-making course where participants were provided with both knowledge and tools to assist them in their decision-making.



BACKGROUND

STUDY ONE

A survey was developed to assess decision-making in a series of crisis management exercises. The statements in the survey were based on the decision-making indicator in the Australian Government's Organisational Resilience Good Business Guide. We used this model as its development was research-driven and identified all the significant components of resilience at a broad level. The various components of resilience are shown in Figure 1. The survey comprised of twenty-one decision-making statements grouped into seven themes. These statements significantly extended the initial decision-making elements identified in the Good Business Guide based on our review of the decision-making literature.



Figure 1: The Components of Resilience (Attorney Generals Department, 2016).

Decision-making Theme	Score*
Sense-making	83
Structural support for adaptive decision-making	80
Clarity in decision-making processes	75
Encouraging employees to engage in decision-making	71
Management of bias	81
Record keeping	69
Managing stakeholder expectations	79

*Preliminary data n=32; Score = combination of two scores – a 5 point likert scaled response and a measure of inter-rater reliability across the data, multiplied to create a score out of 100.

Table Two: Results of Decision-Making Survey following Crisis and Emergency Management Exercises



The preliminary results for two exercises are shown in Table Two. These results demonstrated that the participants considered their exercise teams (be they an IMT or Crisis Management Team) had built solid structures in order to be flexible and adaptive in their decision-making; were effective in making sense of the emerging situations and consistently managed bias in their decisions.

Opportunities for improvement included creating psychologically safe places for employees to speak up, and improved record-keeping of decisions. Participants also rated issues associated with the clarity of the decision processes – such as documenting alternative options and info/events that might change decisions; exploration of future scenarios as slightly lower. This suggests that Options Analysis remains an area of significant improvement in significant incidents.

STUDY TWO

Using the Critical Decision Method, a Search and Rescue (SAR) Commander was interviewed about the decisions made during an international SAR deployment. "A critical decision method is described for modelling (sic) tasks in naturalistic environments characterized by high time pressure, high information content, and changing conditions. The method is a variant of a J.C. Flanagan's (1954) critical incident technique extended to include probes that elicit aspects of expertise such as the basis for making perceptual discriminations, conceptual discriminations, typicality judgments, and critical cues" (Klein et al., 1989, p.462).

The purpose of this study was to deepen our understanding of the challenges associated with strategic decision making during emergencies. Following the commander's interview we identified a set of 10 decisions that were made. We then interviewed four of team members also on the deployment. Subsequent to this we re-interviewed the commander. An example of a decision and the deepening of the analysis can be found below.

This analysis created several insights. Good strategic emergency management decision-making addresses a range of issues previously identified in this research project (Brooks et al., 2016).

- It requires team leaders to build psychologically safe environments where team members can speak up.
- It requires decision-makers to be aware of their own thinking (meta-cognition), particularly when they are moving between different decision-styles (e.g., from intuitive to more rational analyses).
- It requires they evaluate important decisions for the influence of possible bias or error.

This study also identified broader questions that need to be examined in order to improve decision-making competence in emergency management. Does an Incident Controller or SAR commander require hazard specific expertise in order to make effective decisions? The analysis of this SAR deployment suggests that hazard specific knowledge was important. This has implications for cross-jurisdictional deployments, for how we train emergency management personnel and for their trajectory of professionalization through these organisations.



Also, if deployments such as the one identified above occur infrequently, how do you build capacity and provide experience of these sorts of incidents/deployments to a broader group of professionals? For the research team the response to this question involved the use of this sort of analysis to support training interventions, and this was the focus of the final study.

Decision context – first interview	Info from 2nd interview	Info from Team interview
<p>In establishing the base of operations the team leader had numerous complex decisions to make due to locally identified risks. The risk of subsequent earthquakes was high with the country still experiencing up to 20 aftershocks per day that could result in further tsunamis. However there were other risks to be considered – hypothermia from the extreme cold and the radiological hazard from the Fukushima nuclear reactor. The team leader also needed to balance risk against the ability to meet the task</p>	<p>The team leader was highly rational in his approach to determining the level of risk. In this situation the team leader identified 4 high level risks: (1) tsunami; (2) earthquake; (3) cold; and (4) radiation (the latter was actually manageable due to strict regulation surrounding radiation). He was constantly reassessing the risks and confirming on a regular basis that the team could pull out in 4 hours if required. If the severity is held constant in this situation (i.e. the worst case scenario involves multiple fatalities in the team), the team leader was making judgements about probability of that outcome and ranking them in order of likelihood and ability to reduce likelihood through the teams actions</p>	<p>Team-member – Initially thought baseball field where BOO (Base of Operations) was going to be grass but only when they arrived they realised it was dirt. Addressed risks in that were away from the coast on elevated ground and not in close proximity of any tall buildings. Knew prior to arriving that the baseball field was large enough to accommodate team and had not previously been impacted by the tsunami. ID site through google maps etc. but importantly trust the locals.</p>

Table Three: SAR Commander Decision Process

STUDY THREE

This study involved a training intervention – a decision-making course where participants were trained to provide them with both knowledge and support skills that assist them in their decision-making. Participants were represented from all Australian jurisdictions, and had previously experience at an Incident Management Team level.

Figure 2 identifies the different modules included in the course. The two lower modules we considered the foundations of good decision-making. Unless psychologically safe environments are built, maintained and retrieved (when they go wrong) it is difficult to make good decisions. Team members will not speak up about divergent intelligence and the decision-making becomes susceptible to a range of individual biases such as availability (relying on most recent experience even if it differs from the current situation). Teams become susceptible to group-think. Managing pressure is also foundational because the inability to manage pressure tends to create either fibrillation errors (doing many things but none effectively) or fixation errors (focusing on one issue to the exclusion of other important issues). Finally there are a range of individual



cognitive biases (beyond just anchoring or availability) that also support effective decision-making. The skills around scenario planning and anticipatory thinking tend to build on the foundational skills of managing bias, error and safe psychological environments. We note that this approach is open to argument and will continue to be tested through further assessment of the training modules in the second half of 2017.

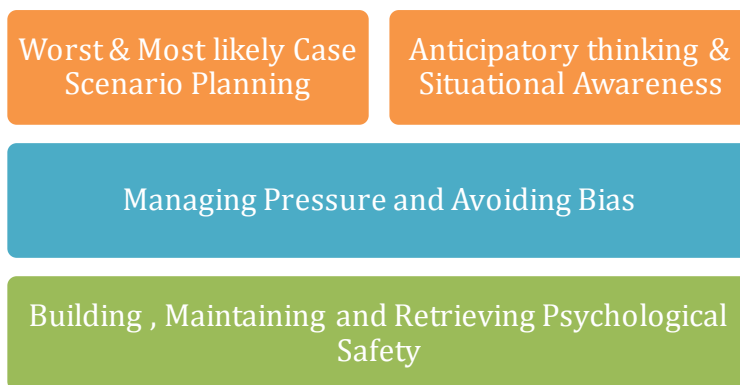


Figure 2: Modules of the Decision-Making Training Intervention

The training modules are described below – working from the bottom of Figure 2 upwards:

Managing Pressure - This module explores the various factors that create pressure on the decision-maker and identifies strategies that can be put in place to mitigate those pressures.

Managing Bias and Errors - This module starts with consideration of the key challenges to making decisions in EM environments such as uncertainty, time and resource constraints. The key sources of bias and error in decision-making are identified. The implication for how decisions are recorded is explored.

Psychological Safety - This module uses a simple 3-step strategy to improve the psychological safety of teams. The aim is to produce greater levels of engagement and allow team members to feel comfortable to speak up if they disagree or have divergent opinions, and underpins good decision-making.

Anticipatory Thinking, Situational Awareness, Worst and Most Likely Scenario Planning - This module examines concepts including situational awareness, mental models, sense-making and cognitive predictions (anticipatory thinking). It explores how these concepts are used to build and influence Common Operating Pictures, and to develop Options Analyses.

From the available literature a set of checklists (aides memoir) were developed that were linked to these concepts. The participants then engaged in an exercise that had been specifically designed with injects to test the concepts in the aide memoir, but embedded within a realistic emergency scenario. An example of an aide memoir is identified below:

AIDE MEMOIR: Situational Awareness:

PERCEPTION: Are you comfortable with the quality and quantity of intelligence you are receiving/producing? What are you missing?



COMPREHENSION: Are you transferring your analysis of the intelligence into SMEAC's or similar and contributing to building a Common Operating Picture?

PROJECTION: Are you planning for what is going to happen next shift, next 24 hours, next 48 hours or next 7 days?

Participants evaluated the usability of the checklist following an exercise. The exercise was a major oil spill event. To do this they used the Quality In Use Scoring Scale, or QIUSS. Quality in use is a usability measure of the degree to which a product enables specified users to accomplish specified goals with effectiveness, productivity, safety and satisfaction. The quality in use scoring scale used here is made by Brian Sherwood Jones, Process Contracting Limited, v1.0 17 March 2008. It is used under a creative commons licence. The full tool can be found in Appendix 1. The results of the assessment for the aide memoir for situational awareness are identified in Table Four below. The range for all criteria was between 2-4 on each scale (i.e. no participant ranked the aide memoir a '1' or a '5'). These results are both encouraging – given the median descriptor across the four criteria, but also indicate the possibility for improvement.

Criteria	Median Descriptor	Average and SD
Effective	Functional – You can get a good outcome. It enables you to perform your tasks. 75% chose this descriptor or better.	Ave = 2.80 SD = 0.5
Safe	Dependable – It provides good protection and you would feel safe if you used it again. 71% chose this descriptor or better.	Ave = 2.83 SD = 0.6
Efficient	Helpful – It is efficient and tuned to your needs. 71% chose this descriptor or better.	Ave = 2.83 SD = 0.6
Satisfying	User friendly – You are happy to use it and use it out of choice. 83% chose this descriptor or better.	Ave = 2.80 SD = 0.4

Average scores from 27 surveys, ratings between zero and 5 as per QIUSS, see Appendix 1 for details.

Table Four: Quality in Use Scoring Scale Results



CONCLUSION

This body of research has followed a process called 'User-Centred Design'. Typically this design process begins with establishing the context of use. This required the researchers to visit end-user agencies and collect documentary and interview data to understand the nature of strategic decision making at that point in time. This identified opportunities for improvement, but also built our awareness of the context of use for any tools we might develop. Following this we conducted three studies:

1. Surveys of participants in emergency management and crisis management exercises, asking them to evaluate their decision-making. This data demonstrated opportunities for improvement in the involvement of employees in decision-making, record keeping and the clarity of decision processes.
2. We assessed the decisions of a SAR commander for one international deployment using the Critical Decision Method – we then interviewed 4 of his team members, and re-interviewed the commander. Our aim was to provide a deep contextual understanding of the decision-making. This work identified to us the value of building psychologically safe environments, managing changes in decision styles and controlling for cognitive bias and error.
3. Finally we conducted a training intervention. We created training modules on key decision-making issues and paired them with an aide-memoir. We then exercised participants with injects that directly tested the particular decision concepts and asked them to identify the value of an aide memoir that supports that decision concept. Using an aide memoir from one part of the training intervention we identified that 75% of participants found it to be at least functional, dependable, helpful, and user friendly. This also indicates that 25% of participants did not ascribe the same level of usability to the aide memoir. This identifies an opportunity to continually improve the product.

The results of this series of studies identify a consistent set of decision themes that can change the quality of strategic emergency management decision-making. If managed appropriately, these themes can support effective, efficient, safe and satisfying decision-making. The research is still in progress – and while we can confidently identify the decision challenges facing strategic decision-makers in emergency management, there is still a significant way to go before the research utilisation products are completed and implemented. Data will continue to be collected from exercises throughout 2017 to verify the preliminary results of Study 1, and the training materials will also continue to be trialled and improved during the same period.

This points to a design process which is user-centred and research driven. This process is iterative, which means the research team will consistently revisit the conclusions as data-sets increase in size, and iterate on the design of the research utilisation products. Through the use of these products it should be possible to improve strategic decision-makers knowledge and skills in decision-making, and therefore improve decision processes during Level 3 type emergencies.



The research has also highlighted important questions currently beyond the scope of the research but worthy of further examination. In particular our Study 2 of the SAR deployment indicated to us the value of hazard-specific knowledge to the decision-making process. In a world of cross-jurisdictional and cross-service deployments, this particular issue warrants further examination. We also note that other aspects of decision-making remain to be investigated. We are yet to fully understand the challenges and opportunities associated with the use of creativity and divergent thinking during emergencies, or whether new research associated with brain plasticity can be used to support improvements in the fundamentals of cognition (e.g., memory, attention, perception). All of this points to the need for further research in this important area of human performance.



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APPENDIX 1

Quality in Use Scoring Scale (QIUSS)

Effective

0	Useless	No useful functionality at all. Might as well not have it.
1	Inadequate performance	It provides very little help with performing a task. Even if you use all the features, you still get a very poor result.
2	Does the job	You can achieve adequate performance but nothing more than that.
3	Functional	You can get a good outcome. It enables you to perform your tasks.
4	High performance	You can achieve your goals completely. You get very good outcomes under all circumstances.
5	Transforms the task	You get outstanding results and can achieve exceptional performance. Even a regular user will award this score very rarely.

Safe

0	Dangerous	It puts people in harm's way, or provides no protection whatsoever.
1	Risky	Using it puts you or someone else at risk, and it can only be used with considerable care.
2	Neutral	It has no impact on safety or security.
3	Dependable	It provides good protection and you would feel safe if you used it again.
4	Trusted	It provides very good protection against all threats.
5	A real protector	It provides completely assured protection. Even a regular user will award this score very rarely.

Efficient

0	Impossible	It takes so much time and effort that it prevents you from doing the task. Dysfunctional, and prevents you achieving any outcome.
1	Tedious	So long-winded that you can hardly get the task done. You waste a lot of time and effort with it.
2	Workmanlike	You can perform the tasks without hindrance but it does not provide any real assistance.
3	Helpful	It is efficient, and tuned to your needs.
4	Slick	It really helps you achieve your goal with no effort at all.
5	Almost psychic	Anticipates what you want to do next. Even a regular user will award this score very rarely.

Satisfying

0	Horrible	You refuse to use it unless it is absolutely necessary.
1	Unpleasant	Unpleasant to use, and is only used with considerable resentment. A pain in the neck.
2	Bland	Using it is just something you do when necessary.. You are not involved or interested.
3	User friendly	You are happy to use it and you use it out of choice.
4	Joy to use	You get a kick out of using it. Using it provides real enjoyment.
5	A miracle of rare delight	Possibly the most enjoyable system you are ever likely to find. Even a regular user will award this score very rarely.

Extreme weather: improved data products on bushfires, thunderstorms, tropical cyclones and east coast lows

Peer reviewed research proceedings from the Bushfire and Natural Hazards CRC & AFAC conference

Sydney, 4 – 6 September 2017

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ABSTRACT

Extreme weather events can cause a wide range of impacts on different regions throughout Australia, including costs associated with damage to natural and built environments. Effective disaster risk reduction, emergency response, infrastructure design/operation, planning and policy making all require data and information about how extreme events will change in the future.

New data products and information are currently being developed on bushfires, tropical cyclones, east coast lows and thunderstorms (including associated hazards such as extreme rainfall, winds, hail and lightning) by a project on extreme weather events in the National Environmental Science Programme (NESP: <http://nespclimate.com.au/extreme-weather-projections/>). This project addresses knowledge gaps on the past and future frequency and intensity of these phenomena, including the physical processes that influence the long-term variations in their characteristics, to produce practical tools and guidance products for use by planners and decision makers throughout Australia.

FIRE WEATHER

A number of fire weather products are being developed, based on new gridded datasets designed for use by end users, to provide improved capability to understand and prepare for the impacts of climate change on extreme fire weather conditions throughout Australia. In relation to the current climatology and the changes that have already occurred, a daily dataset of the Forest Fire Danger Index (FFDI: McArthur 1967) from 1950 to present has been produced. This dataset was produced based on a gridded analysis of temperature, rainfall and vapour pressure observations from the Australian Water Availability Project, AWAP (Jones et al. 2009), as well as NCEP/NCAR reanalysis (Kalnay et al. 1996) used for wind speed (with bias correction applied to provide a better match to the wind speeds used operationally by BoM for producing fire weather forecast products).

This FFDI dataset was recently provided to the Climate Information Services section within BoM for use with their existing analysis tools, allowing them to produce climatological guidance products such as shown in Figure 1a (highlighting how extreme the February conditions were during 2017 as compared to other years back to 1950). This AWAP-based dataset is also being used for assessing new climate model projections of extreme fire weather conditions, as well as for assessing the potential for long-range model predictions of FFDI (based on hindcasts from ACCESS-S, BoM's seasonal forecasting model: Figure 1b).

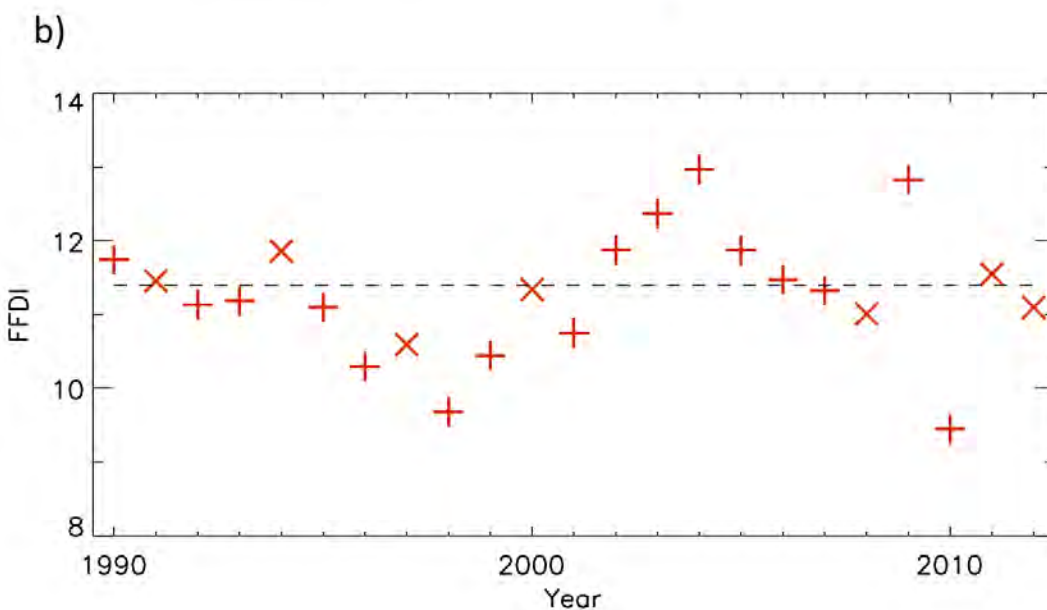
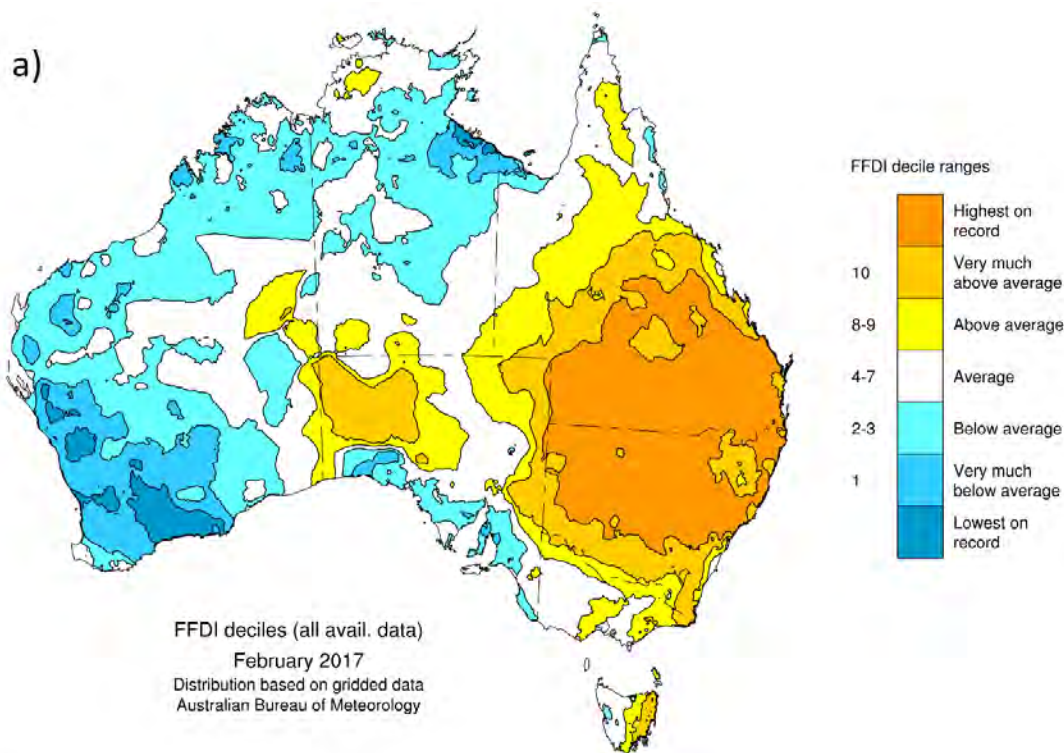


Figure 1: Climatological guidance and new capability development based on gridded fire weather data products. **a)** Mean FFDI values for February during 2017 as compared with other years from 1950-2017 based on AWAP data. **b)** Long-range prediction of FFDI values based on ACCESS-S model run from November 1st input conditions, with correct ('+') and incorrect ('x') predictions (assessed against the AWAP-based FFDI dataset) of mean FFDI in the southern half of Australia during summer (December-February).



TROPICAL CYCLONES

Tropical cyclone (TC) formation and intensity observations are being examined in detail and a subsequent extensive analysis of climate models and higher resolution downscaled simulations are being used to provide more detailed and regionally specific projections of TCs under future climate conditions. This will include projections of changes in TC maximum potential intensity.

Changes in TC activity are also being analysed in relation to tropical expansion. Possible implications of tropical expansion on TCs include TCs travelling further south of their typical current-climate range. A number of other knowledge gaps are being examined in relation to observed TC track directionality and intraseasonal variability, including in relation to the influence of the Madden-Julian oscillation (MJO), so as to provide improved intraseasonal guidance and enhanced preparedness to TC impacts on the Australian region (Lavender and Dowdy 2016).

EAST COAST LOWS

Although fewer east coast lows (ECLs) are expected in the future in general, particularly during the cooler months of the year, there are significant gaps in relation to projected changes in the intensity of extreme weather conditions associated with these storms. To help address these gaps, the role of model resolution in relation to representing extreme weather associated with ECLs is being investigated to help assess different methods of downscaling for producing projections of future ECL characteristics. Additionally, the energetics of ECLs and associated extreme weather conditions are being investigated, including the relative contributions of baroclinic and barotropic forcings for their development.

Improved understanding of the drivers of ECL development and associated extreme weather conditions, as well as of the ability of modelling methods to represent these conditions, will lead to increased understanding and greater confidence in projected changes in extreme weather associated with ECLs. This research will underpin a review and synthesis of the current understanding of the influence of climate change on ECLs and associated hazards, with the outputs of this review process designed to meet the needs of end users.

THUNDERSTORMS

The characteristics of thunderstorms and associated extremes (such as extreme rainfall, winds, hail and lightning) are expected to change in a warmer world. Modelling methods to examine the influence of climate change on thunderstorms and associated extremes are being developed as part of this research, with the goal of producing the first-ever projections of these extremes for different regions throughout Australia for direct use in informing planning and adaptation.

The projections will examine the variation between different models and methods in representing the range of different extreme weather conditions associated with thunderstorms, including based on global climate model output as well as finer-scale dynamical downscaling (with horizontal grid spacing of about 2 km in some locations and 50 km more broadly throughout Australia).



MULTI-HAZARD CONCURRENT EXTREMES

The impact of thunderstorms in combination with other phenomena such as cyclones and fronts is also being investigated. Although these phenomena have been examined in numerous studies, they have not all been systematically examined in combination with each other, including in relation to extreme precipitation and extreme winds. Consequently, the combined influence of these phenomena represents a substantial gap in the current understanding of the causes of extreme weather events.

The highest risk of extreme rain and wind events is found to be associated with a triple storm type characterized by concurrent thunderstorm, cyclone and front occurrences, with this type of storm being of particular importance in coastal regions for eastern Australia (Dowdy and Catto, 2017). The results provide new insight on the relationships between thunderstorms, cyclones and fronts and clearly demonstrate the importance of concurrent phenomena in causing extreme weather. Additionally, an improved ability to decompose different causes of extreme weather could also have benefits for climate modelling applications, such as for distinguishing different drivers of variability and constraining uncertainty estimates in projected changes to extreme events

SUMMARY

Understanding extreme events is an important research priority, particularly given that many of the early impacts of global warming are expected to be experienced through hazards associated with extreme events. It is intended that an improved understanding of extreme weather events, including based on observations for the current climate and model output for the projected future climate, will help lead to improved resilience to their impacts as well as inform the prioritisation of disaster risk reduction and adaptation efforts. This project intends to provide enhanced quality, utility, discoverability and accessibility of information, communication products and decision support tools to improve resilience to extreme weather events, covering bushfires, tropical cyclones, east coast lows as well as thunderstorms and associated impacts on regions throughout Australia. This paper represents an overview of the project including describing some initial results as well as intended outputs prior to the finalisation of the project in June 2019.



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YOUTH JUSTICE CONFERENCING FOR YOUTH MISUSE OF FIRE: A CASE STUDY OF COLLABORATION

Peer reviewed research proceedings from the Bushfire and Natural Hazards CRC & AFAC conference
Sydney, 4 – 6 September 2017

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ABSTRACT

Youth misuse of fire (YMF) refers to any illegitimate use of fire or incendiary materials by a person under the age of 18 years (Pooley & Ferguson, 2017). Existing literature exposes YMF as a multifaceted and complex behaviour (Martin, Bergen, Richardson, Roeger, & Allison, 2004) that presents a significant risk to life and property (Pooley, 2015). To address this concern, programs have been specifically designed to target and reduce misuse of fire by young people. One such program is Youth Justice Conferencing for YMF. This program involves firefighter participation in Youth Justice Conferencing convened for young people who commit fire-related offences. The role of firefighters is to provide education on the consequences of misusing fire and to suggest fire safety related tasks for a young person to complete as a means of making reparation for harm caused by their behaviour (NSW Government, 2016). These mechanisms aim to stimulate cognitive and behavioural change in young people, reducing the risk of recidivism.

Despite formally operating in New South Wales (NSW) since 2006, this program had not undergone independent empirical inquiry. To partially fill this void, a research-oriented evaluation was conducted. This evaluation revealed that the efficacy of the program relies heavily on successful collaboration between urban fire and juvenile justice services, government and non-government entities, and young people and adults. However, the evaluation also highlighted areas in need of improvement. For best practice to be attained, collaboration is also required with the rural fire service, between practitioners and researchers, and between proponents of restorative justice, fire prevention, and child-centred disaster risk reduction. Such findings have implications for enhancing the efficacy of the program, and reflect a useful case study of collaboration.



BACKGROUND

Youth Justice Conferencing for YMF is an extension of Youth Justice Conferencing; a juvenile justice mechanism that aims to divert young offenders away from intrusive state intervention and future criminal behaviour (Braithwaite, 1992; NSW Government, 2014). Youth Justice Conferencing is informed by restorative justice. **The most widely supported definition of restorative justice is “a process whereby all the parties with a stake in a particular offence come together to resolve collectively how to deal with the aftermath of the offence and its implications for the future”** (Marshall, 1996, p. 37). Youth Justice Conferencing brings together the young offender and their support group, the victim(s) or their representative(s) and their support group, a conference convenor, Youth Liaison Officer, and other members of the community who hold a stake in the offence (s47 *Young Offenders Act 1997* (NSW)). Conferencing provides an avenue through which these stakeholders collectively determine an outcome plan for the young person to complete (s34(2) *Young Offenders Act 1997* (NSW)). This outcome plan should hold the young person accountable and encourage the acceptance of responsibility, while empowering the victims and families, and making reparation for the offence (s34(3) *Young Offenders Act 1997* (NSW)).

Youth Justice Conferencing for YMF is differentiated from Youth Justice Conferencing generally by inclusions which tailor the intervention to fire-related offenders. When the offence involves fire, the conference should include a firefighter for the provision of fire safety education (NSW Government, 2016). Further, a young person's **outcome plan must provide for fire-specific components** such as: attendance at a program, or at the screening of a film or video, designed to provide education as to the harmful effects of fire; assistance in clean-up operations and in the treatment of injured animals; and payment of compensation (s8 *Young Offenders Regulation 2016* (NSW)). These mechanisms tailor Youth Justice Conferencing to YMF.

This program has formally been in operation in NSW since 2006, when Juvenile Justice NSW (JJNSW) and Fire and Rescue NSW (FRNSW) signed a Memorandum of Understanding to facilitate firefighter involvement in Youth Justice Conferencing convened for young people who commit fire-related offences. Despite being used for over a decade, this program had not undergone independent empirical investigation. This void is problematic for a number of reasons: an evidence base is required to ensure the highest quality, most reliable, and most effective services are available at any given time (Sexton, Gilman, & Johnson-Erickson, 2005); research should form the foundation upon which juvenile justice planning and policy is formulated (s30 Beijing Rules, United Nations, 1985); Youth Justice Conferencing should be carefully tested in particular contexts before being deemed effective or even appropriate (Sherman & Strang, 2007); and because there is an urgent need, in the context of climate change, for research into misuse of fire prevention (Stanley, March, Read, & Ogloff, 2016). The aim of this study was to contribute to the literature on these grounds.



METHOD

A research-oriented evaluation of Youth Justice Conferencing for YMF was conducted to provide an evidence base for program verification and modification. A theory approach logic model provided an empirically sound foundation for the evaluation (de Carvalho, 2013), which consisted of two parts. The retrospective research design involved quantitative (univariate, bivariate, covariate) analyses of ten years' (2006-2016) worth of Youth Justice Conferencing for YMF record and recidivism data to identify the factors, activities, outputs, and outcomes of the program. The prospective research design comprised qualitative (content) analysis of semi-structured telephone interviews conducted with program practitioners to explore the theory, factors, activities, outputs, outcomes, and impact of the program. The use of strategic (retrospective/prospective) and methodological (quantitative/qualitative) triangulation, coupled with intra-judge reliability (conducting all analyses on two separate occasions), triangulated empirically-derived findings to inform program verification and modification. The results highlighted the presence of three forms of collaboration, and the absence of three forms of collaboration, all of which have implications for enhancing the efficacy of Youth Justice Conferencing for YMF.



RESULTS AND DISCUSSION

WHAT WORKS?

Quantitative analyses of record and recidivism data, alongside qualitative analysis of interviews with program practitioners, revealed that the efficacy of Youth Justice Conferencing for YMF relies heavily on successful collaboration between urban fire and juvenile justice services, government and non-government entities, and young people and adults.

Collaboration between urban fire and juvenile justice services

Youth Justice Conferencing for YMF is governed by an interagency agreement between JJNSW and FRNSW. This memorandum of understanding (MoU) was first signed in 2006 to administer firefighter involvement, the provision of fire safety education, and the inclusion of fire safety related outcome plan tasks within conferencing convened for young people who have misused fire. The MoU provides a framework through which FRNSW engage with practitioners involved in an existing JJNSW mechanism to tailor this mechanism towards YMF.

Interviews conducted with program practitioners revealed that collaboration between JJNSW and FRNSW was one of the main strengths of the program. One interview participant stated that the MoU arose from the need for a whole-of-government approach to YMF prevention. This participant said that FRNSW had a lot of contact with JJNSW and that the idea for firefighter participation in conferencing emerged from collaboration between the agencies. When describing the MoU, another participant stated that,

...an understanding between the services is paramount... So, we've got an understanding from a framework which can be developed, which overarches all agencies in attendance...

Interagency collaboration is also important because both JJNSW and FRNSW have legislative obligations to prevent misuse of fire by young people. JJNSW, as the combat agency for youth delinquency and crime in NSW, aims to prevent and reduce crime and recidivism (NSW Government, 2015). FRNSW, as a combat agency for fire in NSW, must take all reasonable measures for the prevention and suppression of fire (s6 *Fire Brigades Act 1989* (NSW)). Both JJNSW and FRNSW are thus legislatively bound to prevent YMF.

Formal collaboration between JJNSW and FRNSW is pertinent to the efficacy of the program because it particularises Youth Justice Conferencing to YMF and, in doing so, furthers **each respective agency's mandate**.

Collaboration between government and non-government entities

One of the purposes of Youth Justice Conferencing is to bring stakeholders of an offence together. The stakeholders of YMF include government representatives from JJNSW and FRNSW, alongside members of the community such as the young offender, their support group, the victim(s) or their representative(s) and their support group, and any other party affected by the offence (s47 *Young Offenders Act 1997* (NSW)).

Interviews conducted with program practitioners highlighted the importance of this government-community collaboration. Participants stated that when firefighters attended conferencing they could provide fire safety education to at-risk groups within the community, namely young people who misused fire and the people around them. As one program practitioner explained,



It's an opportunity to engage with the young person and their family, who you normally wouldn't be engaging with. Thinking that, if they [a young person] are lighting fires, you could potentially lose that family in a fire. I think that is the focus. Some would argue, are we really making a difference? If that's the least we achieve out of it, we've got this captive audience we wouldn't normally engage with, that's fine by me.

Youth Justice Conferencing for YMF thus provides an avenue through which juvenile justice professionals and firefighters engage with members of the community to reduce the risks and consequences associated with a young person's misuse of fire.

Collaboration between young people and adults

Conferencing for YMF is initiated by an adult, such as a police officer or Magistrate, after a young person has committed a fire-related offence (s40 *Young Offenders Act 1997* (NSW)). The program is then led by an adult, a conference convenor, who organises the meeting and mediates discussion between all participants (s60 *Young Offenders Act 1997* (NSW)). Although conferencing for YMF is an adult-initiated and mediated program, decision-making is shared with young people. In fact, young people must consent to the holding of the conference (s36(c) *Young Offenders Act 1997* (NSW)). Further, young people make suggestions as to the type of tasks they can complete to make reparation for their behaviour (s52 *Young Offenders Act 1997* (NSW)). While other conference participants also engage in this process, the young person maintains the right to veto components or the entirety of the plan (s52(4) *Young Offenders Act 1997* (NSW)). If vetoed, the outcome plan may be re-negotiated until agreement is reached. This collaborative process empowers young people with the right to express their opinion, make decisions, and determine the outcomes of the conference, whilst being assisted and supported by adults (Pooley, 2017b).

WHAT IS MISSING?

While highlighting three forms of effective collaboration, this evaluation also revealed three areas where collaboration is currently missing yet is required to enhance the efficacy of the program. These areas include collaboration with the rural fire service, between practitioners and researchers, and between proponents of restorative justice, fire prevention, and child-centred disaster risk reduction.

Collaboration with the rural fire service

The MoU between FRNSW and JJNSW facilitates FRNSW firefighter involvement in Youth Justice Conferencing. However, as per the NSW State Emergency Management Plan (NSW Government, 2012), FRNSW only maintain jurisdiction for fire in NSW fire districts. Fire districts are local government areas or reserved areas (national parks, conservation areas) placed under the jurisdiction of FRNSW (*Fire Brigades Act 1989* (NSW); *Local Government Act 1993* (NSW)). When a fire occurs outside of a fire district, in a rural fire district, NSW Rural Fire Service (NSWRFS) maintain jurisdiction (NSW Government, 2012; *Rural Fires Act 1997* (NSW)). When YMF occurs outside of a fire district, in a rural fire district, and the young person responsible is referred to conferencing, either FRNSW firefighters participate in a conference convened for a fire they did not attend, NSWRFS firefighters participate without governance or guidance, or firefighters do not participate in the conference at all.



Quantitative analysis of ten years' worth of Youth Justice Conferencing records revealed that firefighters attended 61.7% of conferences convened for YMF in a major city, yet only 45.5% of conferences convened in an inner regional area, and 41.7% of conferences convened in an outer regional area.

Quantitative analysis also indicated that firefighter involvement in conferencing significantly increased the time between referral of a young person to a conference and the facilitation of that conference. Interviews conducted with program practitioners revealed that this may have occurred because the administration of firefighter involvement prolonged the planning and preparation stages of conferencing. As one participant explained,

We had to wait for this particular person [firefighter]. So, in terms of resourcing, I think that's a problem. Because we wanted to look at other dates and all that, but we were quite limited because of the personnel involved. I asked, 'Is there any other personnel than yourself?', and he said 'No'. I thought, 'Wow. That's a big job'.

According to these findings, firefighter involvement occurred disproportionately more often in metropolitan, or fire district, areas, in which limited firefighter availability prolonged the administration phase of conferencing.

A MoU between FRNSW and NSWRFSS adopted in 2005 recognised the operational jurisdiction and responsibilities of each service, stating that the two agencies complemented each other in meeting community needs (Fire Services Joint Standing Committee, 2005). This interagency collaboration should be extended to include NSWRFSS within the JJNSW/FRNSW MoU, and thus Youth Justice Conferencing for YMF. The inclusion of NSWRFSS will provide:

- All young people who are referred to conferencing for YMF the opportunity to participate with a firefighter, regardless of the geographical area in which the conference is held,
- All firefighters the opportunity to participate in conferencing as a stakeholder of a fire-related offence, regardless of the agency for which they work, and
- All conference convenors with a larger pool of firefighters from which to draw.

Collaboration between practitioners and researchers

There is a large body of literature pertaining to what works best for reducing recidivism in young offenders (Murphy, McGinness, Balmaks, McDermott, & Corriea, 2010). Within this body of evidence, there is growing consensus that restorative alternatives to state intervention, such as Youth Justice Conferencing, have the potential to instigate an ongoing process of cognitive and behavioural change in young people (Braithwaite, 1992). What makes Youth Justice Conferencing so effective is its commitment to restorative standards, such as non-domination, empowerment, respectful listening, equal concern for all stakeholders, accountability and appealability, honouring legally specific upper limits on sanctions, and respect for international conventions and human rights (Braithwaite, 2002). As Richards and Lee (2013) highlighted, restorative justice is more about how the criminal justice system responds to a young person than the expected outcomes.

When a firefighter participates in conferencing, it is therefore vitally important that they are aware of the principles and purposes of conferencing to ensure they contribute to, rather than impede, restorativeness. However, interviews conducted with program practitioners revealed cultural resistance to the progressive concepts which inform Youth Justice Conferencing. As one participant explained,



It's [FRNSW] been a very blokey organisation for so long and, sort of cultural issues associated with all that. So, I was trying to bring some fires [firefighters] into the modern times, which was a little bit of a challenge.

Cultural resistance to an understanding of restorativeness was compounded by a lack of adequate training prior to participation in conferencing. As one practitioner stated,

There was a tendency for them [firefighters] to revert back to the big stick, punish someone, scare them. Scare them about the consequences of fire and that sort of thing.

According to these findings, firefighter participation in conferencing had the potential to impede program efficacy.

Collaboration between practitioners and researchers, specifically firefighters and Youth Justice Conferencing experts, is therefore required to ensure firefighters have access to training and resources that enhance their understanding of the principles and purposes of conferencing. In addition, better collaboration between practitioners and researchers will provide researchers with the opportunity to gather practice-based evidence to ensure the program is continually monitored and evaluated to attain best practice.

Collaboration between proponents of restorative justice, fire prevention, and child-centred disaster risk reduction

Youth Justice Conferencing has traditionally been defined as a restorative justice mechanism. Existing literature focusses primarily on the program's capacity to attain restorative processes and outcomes. Although Youth Justice Conferencing for YMF piggybacks an existing restorative justice mechanism, and thus falls along the continuum of restorativeness, the program intends a broader scope.

From a fire prevention perspective, conferencing for YMF is a specific endeavor, a unique mechanism that facilitates the prevention of YMF by educating young people, and the people around them, on the consequences of misusing fire (Pooley, 2017a). Further, conferencing for YMF exists as a child-centred disaster risk reduction mechanism that improves young people's understanding of the risks posed by fire and the impact fire can have on their communities (Pooley, 2017b).

This unique program logic justifies an evaluation of Youth Justice Conferencing for YMF which accounts for its distinctiveness. Program evaluation and modification thus requires collaboration between the proponents of restorative justice, fire prevention, and child-centred disaster risk reduction.



CONCLUSION

Taken together, the findings derived from this study indicate that effective collaboration, and the lack thereof, have implications for the efficacy of Youth Justice Conferencing for YMF. The findings suggest that effective collaboration between JJNSW and FRNSW, government and community entities, and young people and adults, successfully enhances program efficacy. Allocation of resources to ensure the continuation of these forms of collaboration is recommended. However, this effectiveness is reduced by an absence of collaboration with the rural fire service, between practitioners and researchers, and between the proponents of restorative justice, fire prevention, and child-centred disaster risk reduction. Resource allocation to these areas is recommended to enhance the capacity of Youth Justice Conferencing for YMF to target and reduce misuse of fire by young people. In addition to these main findings and their implications, some important supplementary findings include that, in addition to seeking formal mechanisms of collaboration (between urban fire, rural fire, and juvenile justice agencies), there is a need to investigate, develop, implement, and evaluate informal collaborative approaches (between researchers and practitioners, and diverse proponents) to deliver effective services to the community. Resources should thus be allocated to strengthening these informal forms of collaboration.

Overall, the findings derived from this research have implications for enhancing the efficacy of Youth Justice Conferencing for YMF, and reflect a useful case study of collaboration. However, this study was limited to an evaluation of the program based on Youth Justice Conferencing record and recidivism data, and interviews conducted with program practitioners. Future research would benefit from conducting interviews with young people and other conference participants, such as victims, to gain deeper insight into the perspectives and experiences of the end users of the program.



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MODELLING FEEDBACK BETWEEN FUEL-REDUCTION BURNING AND FOREST CARBON AND WATER BALANCE IN EUCALYPT FORESTS

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ABSTRACT

Empirical evidence from Australia shows that fuel-reduction burning significantly reduces the incidence and extent of unplanned fires. However, the integration of environmental values into fire management operations is not yet well-defined and requires further research and development.

While in reality carbon and water processes in forested ecosystems are coupled, effects of fire on these processes are often studied in isolation. Models that simulate the dynamic interaction and feedbacks between these processes are essential for investigations of the effects of fuel management in an environmental setting.

WAVES, a soil-vegetation-atmosphere transfer (SVAT) model, was used to simulate the hydrological and ecological effects of four fuel management scenarios on a forest ecosystem. WAVES was applied using inputs from a set of forest plots across south-east Australia for a period of 1 year after four potential scenarios: (1) no fuel-reduction treatment (unburnt), (2) all litter removed, (3) all litter and 50% of the understorey vegetation removed, 4) all litter and all of understorey vegetation removed.

The impacts of fuel-reduction burning on water processes were mainly due to changes in vegetation interception capacity and soil evaporation. The effect of fuel-reduction burning on evapotranspiration is discussed considering the balance of vegetation biomass in the overstorey and the understorey. Recovery of aboveground carbon as plant biomass was strongly linked to variability in available light and soil moisture. We describe how these modelling efforts can be used for impact assessment in terms of water, vegetation and carbon outcomes for planning of fuel reduction burning.



INTRODUCTION

Eucalypt forests play a significant role in balances of carbon, water and energy in Australia. These forests are also heavily managed with low-intensity fuel reduction burning (FRB) to reduce the risk of fire spread (Boer et al. 2009; McCaw 2013). Fires contribute significant amounts of carbon to the atmosphere each year as carbon dioxide and other greenhouse gases (van der Werf 2006; Haverd et al. 2013). Accounting for carbon emissions requires a reasonably comprehensive knowledge of the amount of all fuel types that are consumed in a FRB (Strand et al. 2016) and of the carbon stored in the soil (Santín et al. 2015; Jenkins et al. 2016).

In addition to altering carbon balances, forest fires have potential consequences for water availability. Fire can affect the water balance of an ecosystem primarily by changing rates of evapotranspiration – the major component of the water balance (Mitchell et al. 2009; Nolan et al. 2015). Fuel reduction burning on land within water supply catchments is considered to be an effective means of reducing the likelihood and magnitude of large bushfires for protection of water supplies (Ellis et al. 2004). While the effect of bushfires on water yield may be substantial and can potentially last for several decades, the effect of FRB appears to have different characteristics that are not clearly tested yet (William and Jerry 1992; Flerchinger et al. 2016).

In Australia, environmental effects of FRB in forested ecosystems have been investigated regularly for the past few decades using field data, often derived from inventories (e.g. Possell et al. 2015; Volkova and Weston 2015; Jenkins et al. 2016) but also coming from a small number of long-term experimental studies in Victoria (Department of Sustainability and Environment, 2003) and New South Wales (e.g. Harris et al. 2003; Penman et al. 2009). Even so, detailed processes of vegetation growth and water balance, and the feedback between overstorey and understorey vegetation have been difficult to measure in an experimental setting. For example, it is challenging to isolate the effect of FRB on soil evaporation from interception evaporation as part of the combined changes in total evapotranspiration due to fire.

Soil-Vegetation-Atmosphere (SVAT) models have the capacity to quantify each of these feedbacks and identify any offsetting effects in detail. In addition, SVAT models can simulate long term effects from the more immediate effects due to FRB. With recent advances in availability of digital data and remote sensing, the impact of FRB on carbon and water balances in forests can be studied over large areas with significantly lower costs.

In this study we used WAVES, a well-regarded soil-vegetation-atmosphere transfer model, to test four different FRB scenarios and simulate the impact on carbon and water one year after fire. The situations tested include: (1) unburnt (Unburnt), (2) all litter removed (Scenario 1), (3) all litter and 50% of the understorey removed (Scenario 2), and (4) all litter and 100% understorey removed (Scenario 3). We aim to address the following questions for each scenario: What is the impact of FRB on individual plant growth (carbon gain)? What is the impact on hydrological processes? What is the combined effect? How long does it take for processes of carbon and water to return to the pre-burning condition?



DATA AND METHODS

EXPERIMENTAL SITE

Our three research sites – Helicopter Spur, Haycock Trig and Spring Gully – are all located within mixed-species forests in NSW, south-eastern Australia. Each site corresponded to one FRB (Table 1).

WAVES MODEL

There are three main data sets related to the climate, vegetation and soil that are required for simulating the carbon and water balance using WAVES. A detailed description of WAVES is provided by Zhang et al. (1996) and Zhang and Dawes (1998).

Climate data required for WAVES include rainfall, rainfall duration, solar radiation, vapor pressure deficit, and maximum and minimum air temperature. We extracted daily climate data from 0.05° resolution gridded weather data provided by the Australian Bureau of Meteorology (Jones et al. 2009).

Vegetation type-specific parameters for the overstorey and the understorey were taken from the literature or from the model manual (Zhang et al. 1996; Zhang and Dawes 1998).

Measurements of litter and vegetation biomass, and total carbon content in the litter was collected following the methodology described in Gharun et al. (2017) (Table 1).

TABLE 1 MEASUREMENTS OF ABOVEGROUND BIOMASS COLLECTED AS DESCRIBED IN GHARUN ET AL. (2017). TOTAL CARBON CONTENT WAS USED TO CONVERT BIOMASS TO KILOGRAMS OF CARBON PER DAY PER SQUARE METER OF GROUND. FRB: FUEL REDUCTION BURN; HT1: HAYCOCK TRIG; SG1: SPRING GULLY; HES1: HELICOPTER SPUR.

FRB name	FRB size (ha)	Latitude	Slope (°)	Aspect	Overstorey biomass (t ha ⁻¹)	Understorey biomass (t ha ⁻¹)	Litter biomass (t ha ⁻¹)
HES1	634	-33.8	5	NE	255.5	34.8	10.7
HT1	612	-33.0	4	NE	137.8	28.8	4.8
SG1	166	-34.1	5	NE	170.9	40.9	17.3

For soil texture, samples were taken from the top 0–10 cm and characterized using the particle size analysis method (PSA). The analytical soil model of Broadbridge and White (1988) (BW soil model) was used to describe the relationships among water potential, volumetric water content and hydraulic conductivity.

VALIDATION WITH SATELLITE DATA

Timeseries of MODIS LAI were downloaded and LAI values were extracted for each site. MODIS product MOD15A2H which is an 8-day composite dataset with 500 m pixel size were retrieved from the online Data Pool courtesy of NASA Land Processes Distributed Active Archive Centre (LP DAAC). A local polynomial regression (span = 0.3) was used to interpolate 8-day MODIS LAI to daily values.



RESULTS

After 1 year in unburnt forests carbon stored in the litter layer was predicted to decrease from 0.502 to 0.360 kg C m⁻² in HES1, from 0.225 to 0.191 kg C m⁻² in HT1 and from 0.811 to 0.338 kg C m⁻² in SG1. Removing the understorey reduced the addition of carbon to the litter layer and, after a year, the amount returned to the soil was estimated to be only 0.1 kg C m⁻² (\pm 0.03 standard error of the mean) (Figure 1).

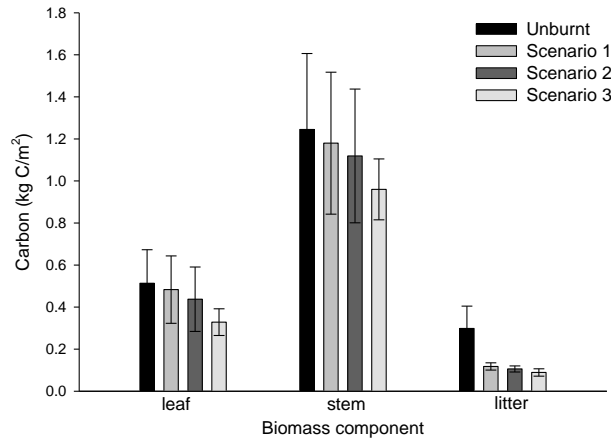


FIGURE 1 PREDICTED ABOVEGROUND CARBON POOLS 1 YEAR AFTER FUEL REDUCTION BURNING. BARS REPRESENT AN AVERAGE VALUE FOR EACH SCENARIO FOR THE THREE SITES (I.E. HAYCOCK TRIG, SPRING GULLY AND HELICOPTER SPUR). ERROR BARS ARE 95% CONFIDENCE INTERVAL.

The highest incremental change in LAI occurred in the absence of the understorey (i.e. all litter and 100% understorey removed). Removing the understorey increased LAI for the overstorey in the site with the most initial understorey biomass (Figure 3, Table 1).

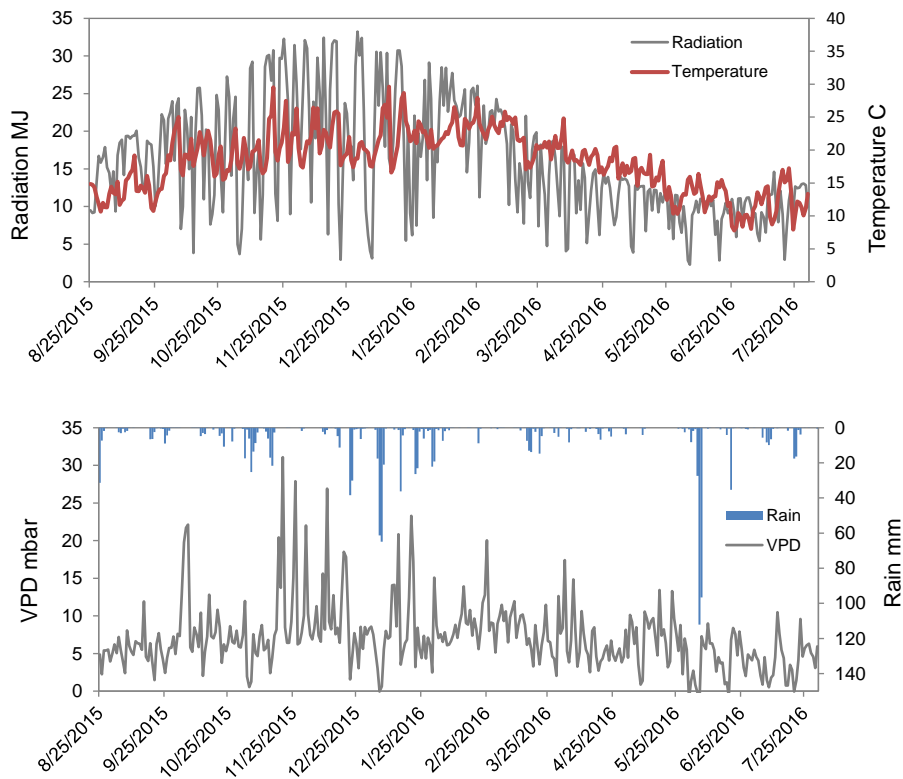


FIGURE 2 AVERAGE CLIMATE CONDITIONS (UPPER GRAPH) RADIATION AND TEMPERATURE; (LOWER GRAPH) VAPOUR PRESSURE DEFICIT (VPD) AND RAINFALL) FOR THE THREE SITES (I.E. HAYCOCK TRIG, HELICOPTER SPUR AND SPRING GULLY). DATA WAS EXTRACTED FROM DAILY GRIDDED WEATHER



MAPS AVAILABLE FROM THE BUREAU OF METEOROLOGY, AUSTRALIA.

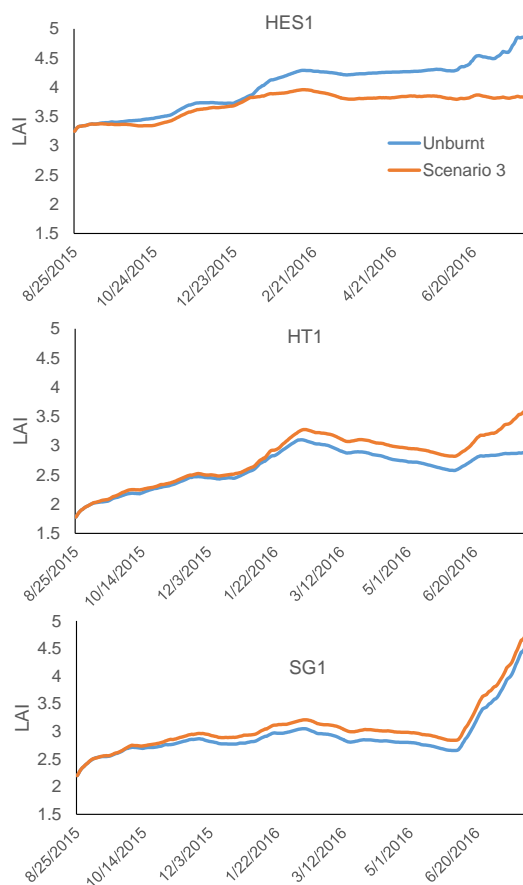


FIGURE 3 OVERSTOREY LEAF AREA INDEX (LAI) RESPONSE TO REMOVING ALL OF THE LITTER AND ALL OF THE UNDERSTOREY (SCENARIO 3) AFTER ONE YEAR FOR SITES (UPPER PANEL) HES1, (MIDDLE PANEL) HT1, AND (LOWER PANEL) SG1.

HYDROLOGICAL FLUXES

In general, with removal of the understorey, net rainfall (the amount of rainfall reaching the soil) will increase and understorey transpiration will decrease (data not shown). Changes in total ET due to FRB consisted of changes in the amount of understorey ET, an increase in soil evaporation and a decrease in interception and interception evaporation. The combined effect was that average annual evapotranspiration increased with the removal of vegetation by not more than 17% of that in unburnt forest sites (from 859 to 1009 mm yr⁻¹ in HES1, from 1032 to 1082 mm yr⁻¹ in HT1 and from 1117 to 1234 mm yr⁻¹ in SG1). For unburnt forest sites, the average soil evaporation was 53 ± 10 mm yr⁻¹, understorey ET was 306 ± 60 mm yr⁻¹ and overstorey ET was 623 ± 14 mm yr⁻¹. After removal of the litter layer with FRB, soil evaporation increases to 134 ± 9 mm yr⁻¹, understorey ET to 308 ± 60 mm yr⁻¹ and overstorey ET to 623 ± 13 mm yr⁻¹. After removal of the litter layer and 50% of the understorey, soil evaporation increased to 147 ± 10 mm yr⁻¹, understorey ET to 245 ± 41 mm yr⁻¹ and overstorey to 691 ± 22 mm yr⁻¹. After completely removing the understorey, soil ET increased to 166 ± 14 mm yr⁻¹, understorey ET to 7 ± 2 mm yr⁻¹ and overstorey ET to 935 ± 55 mm yr⁻¹.



TABLE 2 TEST OF SIGNIFICANT DIFFERENCE IN PRODUCTIVITY AND WATER FLUX BETWEEN UNBURNT FORESTS AND DIFFERENT BURNING SCENARIOS FOR THE HELICOPTER SPUR (HES1), HAYCOCK TRIG (HT) AND SPRING GULLY (SG1) SITES USING A MANN-WHITNEY-WILCOXON TEST. NS: NOT SIGNIFICANT AT ALPHA = 0.05. ET: EVAPOTRANSPIRATION, E: EVAPORATION

Site	HES1			HT1			SG1		
	S1	S2	S3	S1	S2	S3	S1	S2	S3
ET _{total}	ns	ns	ns	ns	ns	ns	ns	ns	ns
ET _{canopy}	ns	ns	ns	ns	ns	$p < 0.05$	ns	ns	$p < 0.001$
ET _{understorey}	ns	ns	$p < 0.001$	ns	ns	$p < 0.001$	ns	ns	$p < 0.001$
E _{soil}	$p < 0.001$	$p < 0.001$	$p < 0.001$	ns	ns	ns	ns	ns	ns
LAI _{canopy}	$p < 0.001$	$p < 0.001$	$p < 0.001$	ns	$p < 0.05$	$p < 0.001$	$p < 0.001$	$p < 0.001$	$p < 0.001$
LAI _{understorey}	$p < 0.001$	$p < 0.001$	$p < 0.001$	ns	$p < 0.001$	$p < 0.001$	$p < 0.001$	$p < 0.001$	$p < 0.001$
Litter	$p < 0.001$	$p < 0.001$	$p < 0.001$	$p < 0.001$	$p < 0.001$	$p < 0.001$	$p < 0.001$	$p < 0.001$	$p < 0.001$
Soil storage	$p < 0.001$	$p < 0.001$	$p < 0.001$	ns	ns	ns	ns	ns	ns

VALIDATION WITH REMOTELY-SENSED LAI

The result of a Pearson's correlation test showed a reasonable agreement between MODIS LAI and modelled total LAI (overstorey plus understorey). Outputs of the statistical test (df = 340 and $p < 0.05$) for HES1 was $r = 0.69$ and $r = 0.66$ for HT1, but for SG1 this correlation was not significant ($p > 0.05$).



DISCUSSION

Fuel loads are highly sensitive to climatic conditions, forest productivity and species composition (Gould et al. 2007; de Mar and Adshead 2011). Variation in litter production between sites can be attributed to differences in initial standing biomass of the forest along with differences in local and seasonal climatic conditions that control canopy growth rate (Capellesso et al. 2016). Litter is decomposed over time as a function of temperature and moisture availability at the soil surface and it provides surface resistance to evaporation. It is for this reason that soil evaporation might or might not increase significantly after burning depending on the unburnt litter biomass (Table 2).

Biomass production varies with local site characteristics, including topography (Nippert et al. 2011). In this study, litter production correlated with changes in LAI, particularly during periods of decreasing LAI (when no leaf growth occurred) and less during periods of increasing LAI (data not shown). Removal of the litter layer can sometimes enhance productivity in the understorey layer (Table 2). The impact of burning on site productivity (i.e. canopy and understorey leaf area) however is not always significant (Table 2). Fuel reduction burning affected productivity more (compared to the water balance) in sites with lower initial understorey biomass (see site HT1 in this study).

The mismatch between modelled productivity and satellite data in SG1 could be related to the underlying assumption made about the soil profile (Jackson et al. 2000). Information about the soil beyond the surface was not available and assumptions had to be made about the nature of soil and the arrangement of root biomass in each soil layer. A reverse modelling approach in which soil profile is calibrated against satellite data and then validated with field observations could improve our knowledge of forest productivity and moisture balance at the local scale considerably.

In forests, evapotranspiration continuously provides a feedback to the microclimate below the canopy of each vegetation layer. For example, available radiation is reduced by the amount of energy that is required to evaporate the water intercepted by each vegetation layer (Zhang et al. 1999). In addition, atmospheric VPD, the main driver of transpiration in eucalypt forests (Gharun et al. 2013) is affected by transpiration below each vegetation layer in the previous time step. In some sites, overstorey ET increased significantly after total removal of the understorey (Scenario 3) because there was more soil water available for transpiration. Since ET is directly controlled by the amount of water stored in the soil (Wetzel and Chang 1987; Verstraeten et al. 2008), reduced interception of rainfall by the understorey and lower or limited understorey ET resulted in greater availability of soil moisture for the overstorey trees. The enhanced productivity in the canopy layer is also related to resource partitioning (water availability) after the understorey was removed by burning.

Investigating the impact of fire (planned or unplanned) on the water balance of a forest requires that different components of evapotranspiration (transpiration, soil evaporation, interception evaporation) are investigated separately and interpreted in combination with one another (Sutanto et al. 2012). Removal of the understorey and the litter layer can result in changes in the amount of energy available at the forest floor and underlying soil which affects the sensible and latent heat fluxes that determine ET (Hutley et al. 2000). While FRB might increase transpiration, an increase



in soil evaporation following the removal of this layer can counter the overall effect on evapotranspiration depending on the local partitioning of ET before the fire.



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APPENDIX

Table A1 Vegetation parameters used in the WAVES model. Calibrated parameters are based on parameterization with sap flow data, MODIS evapotranspiration, and soil moisture measurements from Vervoort et al. (2016). LWP: leaf water potential; IRM: integrated rate methodology.

Vegetation parameter	Overstorey	Understorey	Source
1 minus albedo of canopy	0.8	0.8	(Lee 1980)
1 minus albedo of soil	0.85	0.85	(Dawes et al. 2004)
Rainfall interception ($\text{m d}^{-1} \text{LAI}^{-1}$)	0.0003	0.0003	(Vertessy et al. 1996; Dunin and O'Loughlin 1988; Hatton et al. 1992)
Light extinction coefficient	-0.42	-0.6	(Pook 1985) for overstorey, measured by authors for understorey
Max assimilation rate ($\text{kg C}^{-2} \text{d}^{-1}$)	0.1	0.1	Calibrated
Slope of Ball and Berry	0.9	0.9	(Dawes et al. 2004)
Max LWP (m)	-200	-200	(Cheng et al. 2014; Dawes et al. 2004)
IRM water	3.4	3.4	Calibrated
IRM nutrients	0.3	0.3	(Hatton et al. 1992; Dawes et al. 2004)
Ratio of stomatal to mesophyll conductance	0.2	0.2	(Dawes et al. 2004)
Temperature when growth $\frac{1}{2}$ of optimum ($^{\circ}\text{C}$)	15	15	(Dawes et al. 2004)
Temperature when growth is optimum ($^{\circ}\text{C}$)	20	20	(Küppers et al. 1987; Hatton et al. 1992)
Year day of germination (d)	-1	-1	(Dawes et al. 2004)
Degree-daylight hours for growth ($^{\circ}\text{C hr}$)	-1	-1	(Dawes et al. 2004)
Saturation light intensity ($\mu\text{moles m}^{-2} \text{d}^{-1}$)	1000	800	(Küppers et al. 1987)
Maximum rooting depth (m)	10	5	(Canadell et al. 1996)
Specific leaf area (LAI kg C^{-1})	12.6	12.6	Calibrated
Leaf respiration coefficient (kg C kg C^{-1})	0.00065	0.0008	(Cheng et al. 2014; Vertessy et al. 1996)
Stem respiration coefficient (kg C kg C^{-1})	0.00014	0.0012	(Cheng et al. 2014; Vertessy et al. 1996)
Root respiration coefficient (kg C kg C^{-1})	0.0023	0.001	(Cheng et al. 2014; Vertessy et al. 1996)
Leaf mortality rate (fraction of C d^{-1})	0.0015	0.0015	Calibrated
Aboveground partitioning factor	0.24	0.24	Calibrated
Salt sensitivity factor	1	1	(Dawes et al. 2004)
Aerodynamic resistance (s d^{-1})	15	30	(van de Griend and van Boxel 1989; Leuning et al. 1991; Vertessy et al. 1996)



Figure A1 Cumulative effect of fuel reduction burning on (a, c, e) total evapotranspiration (ET) and (b, d, f) soil evaporation one year after fire in forest sites at (a, b) Helicopter Spur (HES1), (c, d) Haycock Trig (HT1) and (e, f) Spring Gully (SG1).

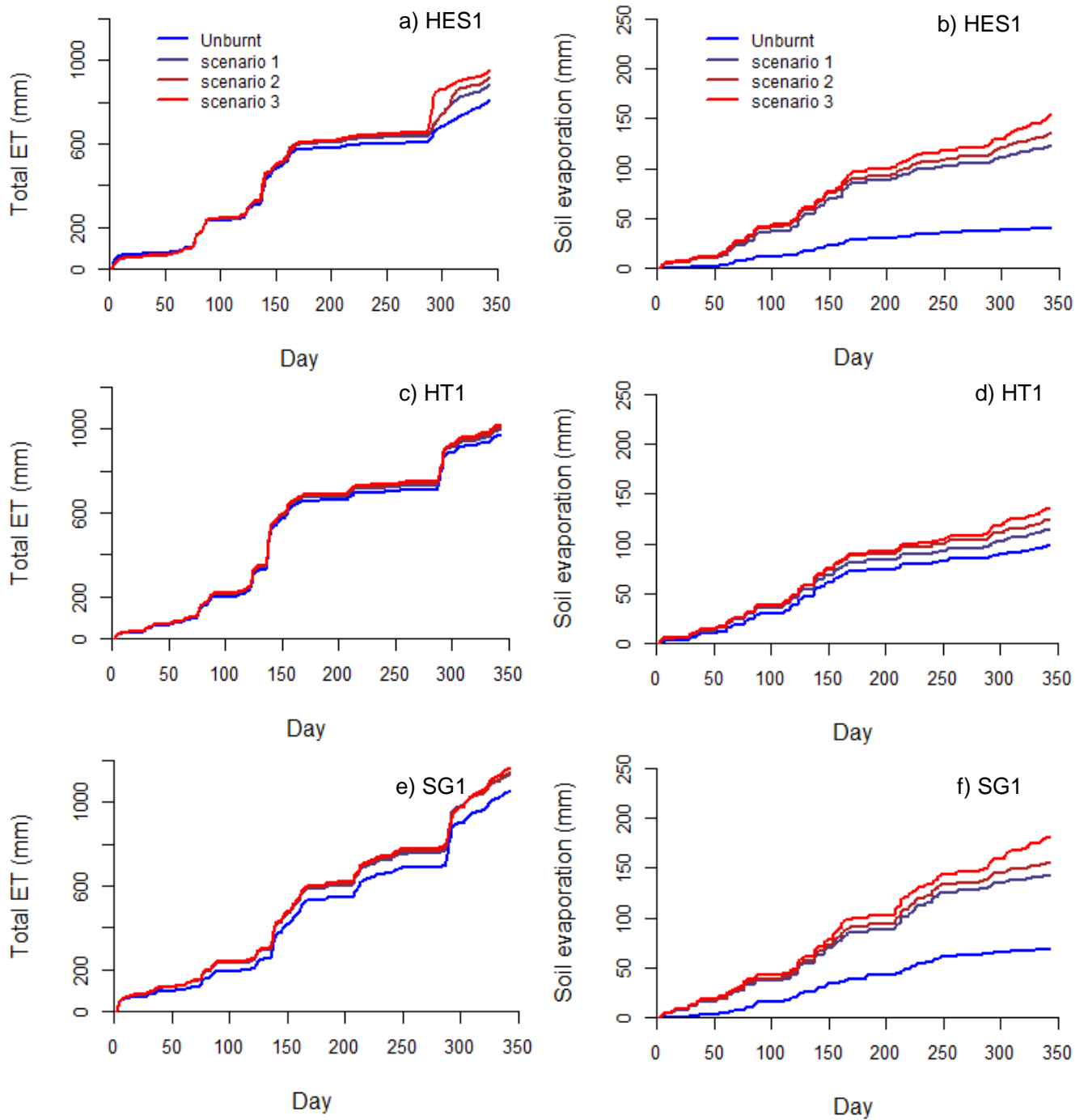
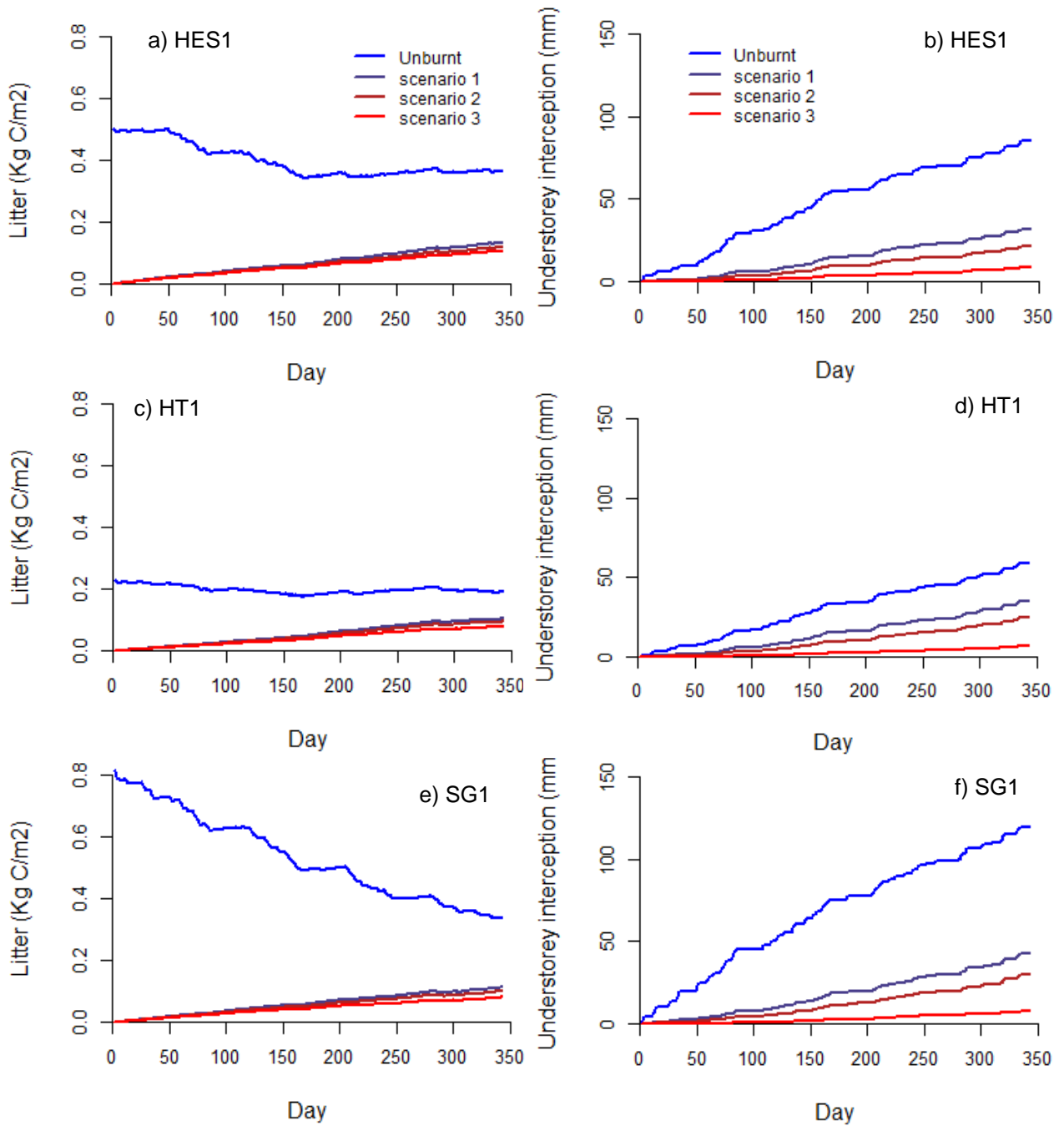




Figure A2 Cumulative effect of fuel reduction burning on (a, c, e) litter production and (b, d, f) understorey interception for one year after fire in forest sites at (a, b) Helicopter Spur (HES1), (c, d) Haycock Trig (HT1) and (e, f) Spring Gully (SG1).





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THERMODYNAMIC CONSIDERATIONS OF PYROCUMULUS FORMATION

Peer reviewed research proceedings from the Bushfire and Natural Hazards CRC & AFAC conference
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ABSTRACT

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

Here, a conceptual study of the thermodynamics of fire plumes is presented to better understand the influence of a range of factors on plume condensation. Recognising that plume gases are undilute at the fire source and approach 100% dilution at the plume top (neutral buoyancy), we consider how the plume condensation height changes for this full range of dilution and for a given set of factors that include: environmental temperature and humidity, fire temperature, and fire moisture to heat ratios. The condensation heights are calculated and plotted as saturation point (SP) curves on thermodynamic diagrams for a broad range of each factor. The distribution of SP curves on thermodynamic diagrams provides useful insight into pyroCb behaviour. Adding plume temperature traces from Large-Eddy Model simulations to the thermodynamic diagrams provides additional insight into plume buoyancy, how it varies with height, and the potential for dangerous pyroCb development.



INTRODUCTION

Pyrocumulus (pyroCu) clouds are produced by heating of air from fire or volcanic activity that leads to ascent and subsequent condensation when the rising air becomes saturated due to cooling from adiabatic expansion. The process is similar to conventional convective cloud formation, when a lifting mechanism (e.g., orographic lifting, intersection of two air masses) raises air above the level at which cloud forms (the lifting condensation level). Additional lifting and condensational heating may raise the air to the level of free convection, above which it is positively buoyant. Turbulent entrainment of cooler and drier air from outside the rising air mass dilutes the cloud buoyancy, which can limit the size and growth of the cloud (e.g., fair weather cumulus). Larger and more intense lifted regions can accelerate to the tropopause (e.g., cumulonimbus thunderstorms). The main difference between conventional cumulus and cumulonimbus and fire-sourced pyroCu and pyroCb (hereafter referred collectively as pyroCu/Cb) clouds is that the initial lifting in the latter cloud types is provided by the buoyancy from the heat and perhaps moisture released by the fire. In large fires with an intense convection column the cloud may resemble towering cumulonimbus with updrafts that penetrate into the stratosphere (e.g., Fromm et al. 2010). We refer to these plumes as pyroCb. (See Tory et al 2015, 2016 for a review of pyroCu/Cb literature and forecast techniques respectively).

There is abundant evidence to suggest that the presence of pyroCb activity can have a significant impact on fire behaviour, including: (i) the amplification of burn- and spread-rates (Fromm et al. 2006, Trentmann et al. 2006, Rosenfeld et al. 2007, Fromm et al. 2012), (ii) enhanced spotting due to larger, taller and more intense plumes (e.g., Koo et al. 2010), and (iii) ignition of new fires by pyroCb lightning strikes due to pyroCb conditions favouring hotter and longer-lived lightning strikes (e.g., Rudlosky and Fuelberg 2011, Peace et al. 2017).

Given the potential threat posed by pyroCb there is great interest in being able to predict its development. Unfortunately, pyroCb are very difficult to forecast. Current forecast techniques draw on similarities between pyroCb and conventional thunderstorms, and the recognition that conditions that favour thunderstorm development will also favour pyroCb development (e.g., Peterson et al. 2015, Lareau and Clements 2016, Peterson et al. 2017). Ideal pyroCb conditions are thus similar to ideal thunderstorm conditions but with a dry rather than moist boundary layer. These conditions appear on a thermodynamic diagram as the classic inverted-V profile (e.g., Fig. 1), in which a dry adiabatic temperature profile of constant potential temperature (θ_{env}) forms the right side of the inverted-V, while the constant specific humidity (q_{env}) moisture profile makes up the left side.

In this paper we construct an idealized theoretical plume model in an inverted-V environment to aid our understanding of how the environment and fire properties influence plume condensation levels, which is important for understanding pyroCu/Cb formation.

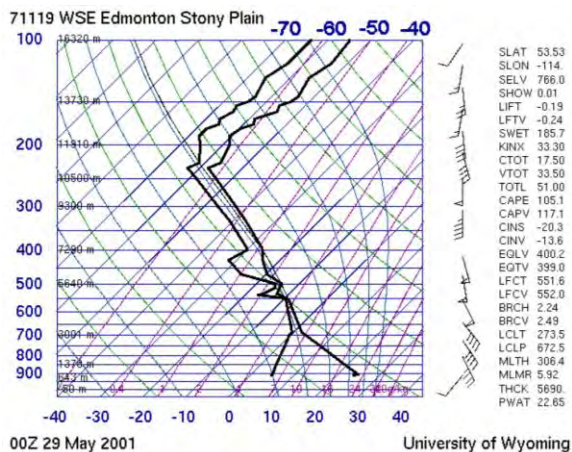


Figure 1: A classic inverted-V thermodynamic sounding associated with pyroCb formation (Edmonton, Alberta 0000 UTC, 29 May 2001, 150 km south of the Chisolm fire). The right-most black line shows air temperature as a function of height above the surface. The left-most black line shows the corresponding dew-point temperature. Reproduced from Fig. 4 of Rosenfeld et al. (2007).

METHODS: PLUME MODEL

Table 1: Plume model variables and constants

θ	Potential temperature (units K)
θ_{env}	Constant environment potential temperature (up to the condensation level)
θ_{fire}	Potential temperature of the fire/flames ($\theta_{fire} = \Delta\theta_f + \theta_{env}$)
θ_{pl}	Plume potential temperature
$\Delta\theta_f$	Fire potential temperature increment, per unit mass of combustion gas released
q	Specific humidity (units $kg\ kg^{-1}$, mass of water vapour to total mass of air)
q_{env}	Constant environment specific humidity (up to the condensation level)
q_{fire}	Fire specific humidity (includes moisture from the air consumed in combustion)
q_{pl}	Plume specific humidity
Δq_f	Fire moisture increment per unit mass of combustion gas released (includes evaporation of fuel moisture and moisture produced from the chemistry of combustion)
α	Plume dilution factor. Ranges from 1 (100% dilute = environment value) to 0 (pure combustion gas)
β	Plume buoyancy factor. Ranges from 0 (plume 100% dilute) to $\gamma - 1$. (Useful range $0 \rightarrow \sim 10^{-1}$.)
γ	Fire temperature multiplication factor to express θ_{fire} as a multiple of θ_{env} .
φ	Ratio of fire moisture to potential temperature increments (units $kg\ kg^{-1}\ K^{-1}$).

The fire plume is a mixture of hot combustion gases and entrained air from the immediate environment. This mixture could vary considerably throughout the plume and with time. The plume model focuses on hypothetical plume parcels (termed "plume elements") that begin as pure combustion gas and become increasingly diluted with time due to entrainment of environment air. The spatial and temporal plume mixture variability is represented in the model by an ensemble of plume elements. The plumes develop in a well-mixed (homogeneous) atmospheric boundary layer of constant potential temperature (θ_{env}) and constant specific humidity (q_{env}). The condensation level (CL, which is the saturation point on a thermodynamic diagram) for each plume element occurs within this well-mixed layer. While this latter condition is necessary to maintain model simplicity, the condition is unrealistic for CLs that are more elevated than the environment lifting condensation level (ELCL), because by definition the homogeneous boundary layer must be super-saturated in the cooler air above the ELCL. We demonstrate below that realistic CLs occur close to the ELCL, and that this unrealistic condition has no impact on the conclusions. For simplicity the thermodynamics of plume condensation, which begins at the CL, is not considered (i.e., the plume model begins at the fire and ends where condensation is about to occur). However, useful information on plume behaviour can be determined from the plume element thermodynamic quantities (θ_{pl} and q_{pl}) at the CL, and diagnostic quantities derived from these variables.

θ_{pl} and q_{pl} for each homogeneous plume element are expressed as functions of θ_{env} and q_{env} , the fire thermodynamic quantities (θ_{fire} and q_{fire}), and the plume dilution fraction α ,



$$\theta_{pl} = \alpha\theta_{env} + (1 - \alpha)\theta_{fire} \quad 1.$$

$$q_{pl} = \alpha q_{env} + (1 - \alpha)q_{fire}. \quad 2.$$

θ_{env} and q_{env} are specified for each scenario, and α is varied to represent a range of plume dilution amounts from pure combustion gases at $\alpha = 0$ to pure environmental air at $\alpha = 1$ (i.e., infinitesimal quantities of combustion gases). These parameters and other variables introduced below are listed and described in Table 1.

The potential temperature of combustion gas, θ_{fire} , can be expressed as a multiplier (γ) of the environment potential temperature, $\theta_{fire} = \gamma\theta_{env}$. Assuming $\theta_{env} \sim 300 \text{ K}$, γ ranges from $2 \rightarrow 5$ representing flame temperature estimates from forest fires (e.g., Wotton et al. 2012) of 600 K (flame tips) to 1500 K (flame base)¹. The fire produces increments of θ and q per unit mass of combustion gas (Luderer et al. 2009, hereafter LTA09), which we express respectively as, $\Delta\theta_f = (\gamma - 1)\theta_{env}$ and $\Delta q_f = \varphi\Delta\theta_f$. Here, φ , the ratio of the two increments, is a specified quantity. Δq_f incorporates the moisture of combustion and the evaporation of fuel moisture. Moisture from the air consumed in combustion is considered separately, such that $q_{fire} = \Delta q_f + 0.86q_{env}$, with the latter term taking into account the 6 to 1 air to fuel mass ratio of combustion (e.g., Ward 2001).

An iterative process is used to calculate the CL based on estimates of the CL pressure (P_{CL}). The CL temperature is calculated from θ_{pl} and P_{CL} , which is used to calculate the saturation vapour pressure at P_{CL} . If this saturation vapour pressure is less than (greater than) the actual vapour pressure the plume must be saturated (unsaturated) at P_{CL} and the process is repeated at a lower (higher) level until the plume CL is approached to the nearest 1 hPa.

A number of diagnostic equations have been developed to illustrate plume characteristics. Each can be expressed as a function of a buoyancy-like parameter (e.g., Smith et al. 2005, Eq. 3),

$$\beta = (\theta_{pl} - \theta_{env})/\theta_{env} = (1 - \alpha)(\gamma - 1), \quad 3.$$

which reduces the experimental parameter space by replacing α and γ with β .

¹ Wotton et al. (2012) observed flame temperature ranges from about 600 to 1400 K in experimental forest fires. We chose an upper temperature of 1500 K to extend the parameter space to include potentially higher temperatures that might occur in very large and intense wild fires. This value matches observed temperatures for methane fires (Smith et al. 1992).

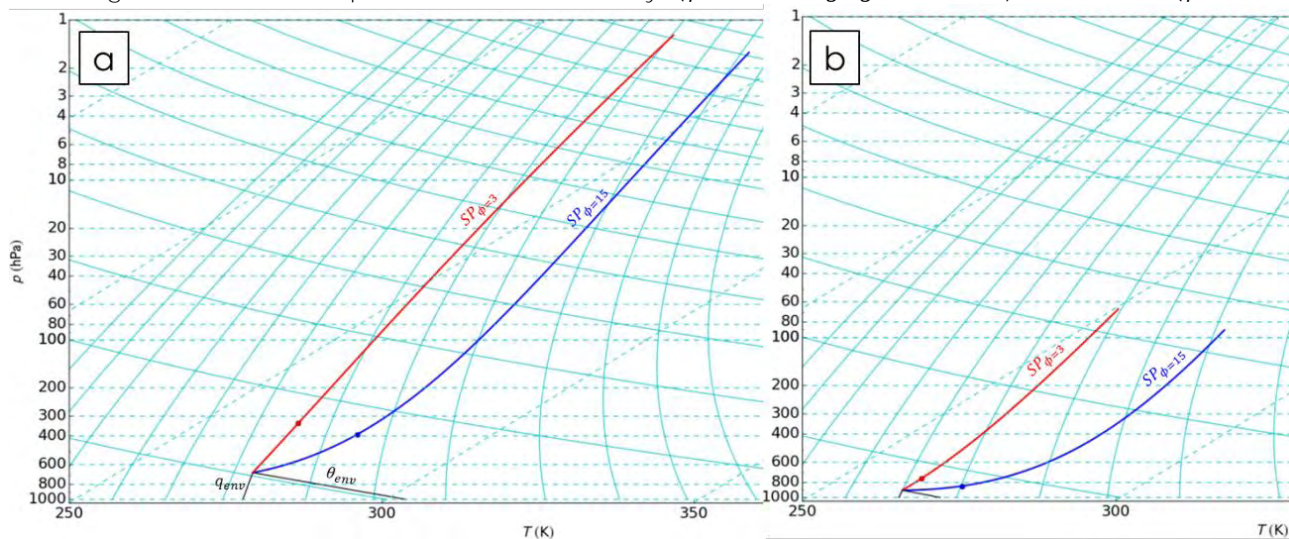
RESULTS

Two well-mixed boundary layer profiles are considered, one warm (Fig. 2a) and the other cold (Fig. 2b). The first has $\theta_{env} = 303\text{ K}$, $q_{env} = 5 \times 10^{-3}\text{ kg kg}^{-1}$, 19% relative humidity, and an elevated ELCL about 3 km above the surface. The second has $\theta_{env} = 271\text{ K}$, $q_{env} = 2 \times 10^{-3}\text{ kg kg}^{-1}$, 61% relative humidity, and a relatively low ELCL height (representing the Flatanger fire in Norway, January 2014, which destroyed 140 houses). The LCL is located at the apex of the θ_{env} and q_{env} curves.

SATURATION POINT CURVES

Fig. 2 includes SP curves for the hottest fire ($\gamma = 5$) in the warm environment (Fig. 2a) and the coolest fire ($\gamma = 2$) in the cold environment (Fig. 2b), and each with the two values of fire moisture to potential temperature increment ratios that represent LTA09's driest ($\varphi = 3 \times 10^{-5}\text{ kg kg}^{-1}\text{ K}^{-1}$, red) and wettest ($\varphi = 15 \times 10^{-5}\text{ kg kg}^{-1}\text{ K}^{-1}$, blue) realistic fires. Each SP curve represents the position of the plume element condensation level corresponding to α varying from 1 (100% dilution, lower left) to 0 (pure combustion gas, upper right) for the specified environment conditions, and the fire parameters, φ and γ . For example, the dots on the SP curves represent the apex of plume temperature and moisture traces for a plume element consisting of 95% environment air and 5% combustion gas.

Figure 2: Saturation point curves for the dry ($\varphi = 3 \times 10^{-5}\text{ kg kg}^{-1}\text{ K}^{-1}$, red) and moist ($\varphi =$



$15 \times 10^{-5}\text{ kg kg}^{-1}\text{ K}^{-1}$, blue) fires, for the two cases (a) hot fire ($\gamma = 5$) in a warm environment ($\theta_{env} = 303\text{ K}$), and (b) cool fire ($\gamma = 2$) in a cold environment ($\theta_{env} = 271\text{ K}$), on a skewT-logp diagram. The 95% dilution points are indicated by dots. The environment LCL is located at the apex of the grey lines of constant θ_{env} and q_{env} . The pale blue lines are lines of constant pressure (dashed, horizontal), temperature (dashed, diagonal), potential temperature (solid, shallow gradient) and specific humidity (solid, steep gradient).

Of the parameter space investigated, the two most extreme cases are included in Fig. 2: hottest and driest fire in the warm environment (red curve in Fig. 2a), and coolest and moistest fire in the cold environment (blue curve in Fig. 2b). 100% dilution coincides with the ELCL, and zero dilution (at the upper right end of the coloured curves) shows exceptionally high CLs. These are $\sim 1.5\text{ hPa}$ ($> 40\text{ km}$, Fig. 2a) and $\sim 90\text{ hPa}$ ($> 20\text{ km}$, Fig. 2b).



Fig. 2a shows that for pyroCu/Cb to form in the lower troposphere (e.g., below 500 hPa) in the warm environment, significant dilution is necessary (e.g., > 95 %). The actual dilution amounts corresponding to the four SP curves (from left to right in Fig. 2) at 500 hPa, exceed, 99, 97, 85 and 75 % respectively (not shown). Furthermore, Large-Eddy Model simulations (LEM, Thurston et al. 2016) suggest typical dilution amounts in condensing plume elements are likely to be 99% or greater. It follows that substantial amounts of dilution must occur in typical pyroCu/Cb plumes (that form in warm/hot environments).

This result appears to be at odds with statements that suggest pyroCb formation requires plume cores that have experienced minimal (Taylor et al. 1973), or zero dilution/entrainment (e.g., “significant core of air unaltered by entrainment”, Potter 2015; “a lack of entrainment to the convection column”, Finney and McAllister 2011). The inconsistency arises from the fact that most plumes do not condense because they lose buoyancy after becoming too diluted. It follows that a somewhat less diluted plume or plume core is required for pyroCu/Cb formation (e.g., McRae et al. 2015). The plume model provides some quantification on how much less diluted condensing plumes need to be, and suggests that the amount is at the opposite end of the spectrum (large dilution) than that speculated in the aforementioned studies (small or zero dilution).

From Eq. 3 it can be seen that a plume element from a hot fire (γ) with moderate dilution (α) could have the same buoyancy (β) as a plume element from cooler fire with less dilution. This overlapping parameter space produces overlapping SP curves (i.e., varying γ only changes the length of the SP curve). Thus, all conclusions based on the position of the SP curve on thermodynamic diagrams are insensitive to the fire temperature. Hereafter, we discuss plume element buoyancy represented by the parameter β instead of fire temperature and plume element dilution. We conclude from Fig. 2 that for pyroCu/Cb to form in the lower troposphere, $\beta \leq 0(10^{-1})$. Typical condensation level values of β in the LEM simulations are one to two orders of magnitude smaller than this (not shown).

Because β at condensation (β_{SP}) is small, the origin and gradient of the SP curves provide useful information about the height at which a plume element will condense, and thus the potential for pyroCu/Cb formation. The origin ($\beta_{SP} = 0$) coincides with the ELCL, which provides a first order estimate of the plume element condensation level. The difference between the actual plume element condensation height and the ELCL is of second-order importance (for small β_{SP}) which can be estimated from the product of β_{SP} and the SP curve gradient. Thus for a given β_{SP} , steep SP curves (e.g., dry fires) correspond to greater condensation heights than flatter SP curves (e.g., moister fires).

Fortunately, the most important factor for estimating plume condensation heights (the ELCL) does not require any information about the fire. The secondary factor is dependent on φ and β_{SP} . To determine β_{SP} , we expect detailed knowledge would be required of how plume buoyancy is affected by fire size, distribution and intensity, and how the atmosphere (e.g., wind and thermodynamic stability) affect the entrainment rate (plume dilution), and thus the distribution of β with height. One might also expect detailed knowledge of the fire and fuels would be required to determine φ . However, within the assumptions of the simple theoretical plume model (i.e., plume moisture and potential temperature are diluted at the same rate), φ remains constant



throughout the plume element (and is independent of β), which means it can be estimated from a single plume element measurement,

$$\varphi \cong \frac{q_{pl} - q_{env}}{\theta_{pl} - \theta_{env}} \tag{4}$$

In reality φ is likely to vary with time (and perhaps spatially), as the fire burns through a variety of fuels, but as long as the measurement is taken above the flaming zone (where additional radiative heat losses are relatively small) the measured plume element should maintain a constant φ throughout its ascent through a well-mixed boundary layer (constant θ_{env} and q_{env}). Multiple observations would produce a range of φ values, with a corresponding cluster of SP curves that represent the SP curve variability for the overall plume. Thus, in practice it should be possible to produce thermodynamic diagrams with the ELCL and a cluster of SP curves plotted, similar to Fig. 2, from observations at the fire ground, provided a representative sample of q_{pl} and θ_{pl} measurements can be made.

PLUME TEMPERATURE TRACES

The SP curves provide insight into the height at which a plume element might condense for a given environment (θ_{env} , q_{env}), fire properties (φ) and plume buoyancy (β), but they do not tell us anything about specific plumes. In Fig. 3 temperature and moisture traces from two LEM plume simulations (reported in Thurston et al. 2016) are plotted on thermodynamic diagrams with SP curves included. An extra SP curve has been added representing φ from one of Potter's (2005) fireCAPE thought experiments (green curve), which LTA09 argued was unrealistically moist.

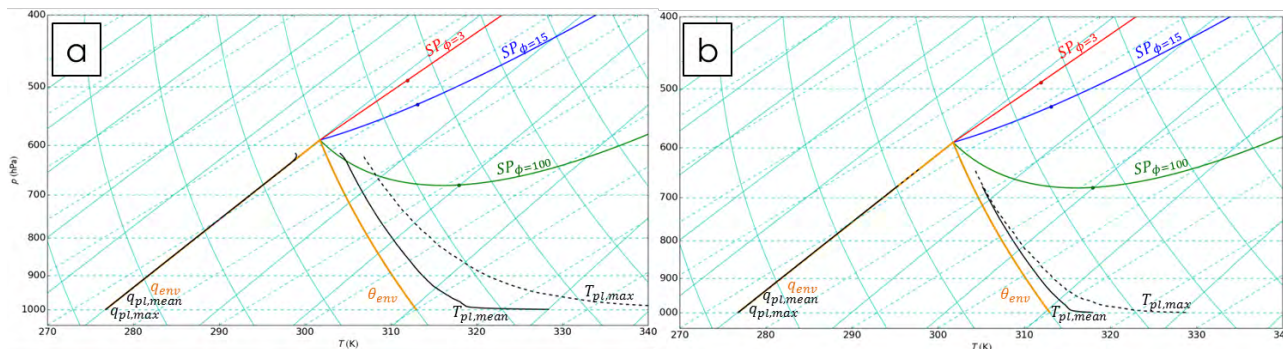


Figure 3: As in Fig. 2 but with mean (solid) and maximum (dashed) plume temperature and moisture traces in a hot and dry ($\theta_{env} = 310$ K and $q_{env} = 4 \times 10^{-3} \text{ kg kg}^{-1}$), zero wind environment from LEM simulations with a constant circular surface heat flux (Q) of 250 m radius. Saturation point curves for the dry (red, $\varphi = 3 \times 10^{-5} \text{ kg kg}^{-1} \text{ K}^{-1}$) moist (blue, $\varphi = 15 \times 10^{-5} \text{ kg kg}^{-1} \text{ K}^{-1}$) fires and an extremely moist fire (green, $\varphi = 100 \times 10^{-5} \text{ kg kg}^{-1} \text{ K}^{-1}$) are included. (a) hot fire ($Q = 30 \text{ kW m}^{-2}$) (b) cool fire ($Q = 5 \text{ kW m}^{-2}$).

As the LEM plume air ascends and approaches the ELCL it begins to entrain warm and dry environment air from above the boundary layer, which is a process that cannot be incorporated in our theoretical model. Thus, we discount the plume traces higher than about 620 hPa, and instead extrapolate them to the SP curves. Additionally, in order to make a clear distinction between plume and environment air, only plume elements that are at least 1 K warmer than the environment were included in the plume-average temperature trace. In reality



the plumes are expected to contain a mix of air parcels of temperature varying from the environment temperature (recently entrained parcels) up to the maximum temperature indicated by the dotted lines (least diluted plume elements).

For the hot fire (Fig. 3a) the mix of plume element temperatures would be expected to have a range of condensation heights extending from the ELCL to where the extrapolated dashed line meets the SP curve corresponding to the fire's φ value. The corresponding buoyancies range from $\beta_{SP} = 0 \rightarrow \beta_{SP,max}$ ($\beta_{SP,max} = 0.14$), with the plume element mean, $\beta_{SP,mean} = 0.04$. This simulation produced deep pyroCb with rain and evaporatively cooled downdrafts. Whereas the plume dilution was generally too great for condensation to occur in the cool fire simulation (Fig. 3b) as it mostly lost buoyancy near 650 hPa before intersecting any of the SP curves. A few parcels of buoyant air did occasionally reach the condensation level, producing short-lived puffs of shallow cloud.

WHAT CAN WE LEARN FROM THESE DIAGRAMS?

There is a surprising amount of information about conditions that support pyroCu/Cb development and plume behavior that can be gleaned from Figs 2 and 3.

- The positive gradients of the SP curves corresponding to the realistic range of fire moisture to potential temperature increment ratios (red and blue) demonstrate that buoyant plume elements condense at levels higher than the ELCL (consistent with LTA09 and Lareau and Clements 2016).
- An exception is for very moist fires (e.g., green SP curves in Fig. 3) and/or very dry environments (e.g., Fig. 2b) where the SP curve may have a negative gradient, in which case some buoyant elements might condense at levels lower than the ELCL (e.g., the Potter 2005 fireCAPE thought experiment). This is more likely to occur in cold and dry (small q) environments.
- Buoyant elements from moister fires will condense at lower levels than for drier fires.
- There is a broad range of temperatures and hence buoyancy within plumes, that decrease with height (due to dilution from entrainment, Fig. 3).
- Plumes with non-trivial buoyancy near their condensation level (e.g., Fig. 3a), contain plume elements with a range of buoyancy from zero to a maximum value corresponding to the least dilute plume element, with a corresponding range of condensation heights. These condensation heights are determined by the intersection of the plume element temperature trace and the relevant SP curve.



- Plumes that produce pyroCb (e.g., Fig. 3a) have non-trivial buoyancy near the condensation level, suggesting the fireCAPE² concept may be useful for pyroCb forecasting.
- The same LEM heat sources in environments with lower ELCLs (e.g., that might occur with the passage of a cold front or sea breeze) might produce very much more energetic pyroCb. At 900 hPa the hot fire β_{mean} and β_{max} are about three times greater than at 600 hPa, and the cool fire β_{mean} and β_{max} values at 900 hPa are very similar to the hot fire values at 600 hPa.

More insight will be described in a journal article (in preparation), based on a mathematical exploration of the model parameters. This journal article describes, among other things, how the environment affects the SP curves, what values of plume buoyancy are important for pyroCu/Cb activity, and the sensitivity of fireCAPE to plume buoyancy.

² FireCAPE is essentially a measure of the energy available for plume convection that takes into account the heat released from plume moisture condensation. It is analogous to the Convective Available Potential Energy (CAPE) used for predicting atmospheric moist convection.



SUMMARY

PyroCb can produce dangerous fire behaviour, through changes in fire rate of spread and direction, increased spotting, and additional ignitions from lightning strikes. Unfortunately, pyroCb is difficult to predict and not well understood.

In this paper we have introduced a simple theoretical model that provides useful insight into the conditions that influence plume condensation heights, the thermodynamic composition of fire plumes, and the relative sensitivity of environmental conditions to fire properties that have an influence on pyroCu/Cb formation and behaviour. Some of the more general results are summarized here:

- Substantial dilution (> 95%) is required for pyroCu/Cb cloud elements to condense in the lower troposphere for typical forest fire conditions. However, too much dilution and the plume may lose buoyancy before ascending high enough for condensation to occur.
- The environment lifting condensation level (ELCL) provides a good first order estimate of the plume condensation height.
- Typical forest fires that produce pyroCu/Cb will have buoyant plume elements that condense at elevations higher than the ELCL, because the additional heat provided by the fire contributes to raising the condensation level more than the additional moisture contributes to lowering the condensation level.
- PyroCu/Cb formation and behaviour is relatively insensitive to the amount of heat and moisture produced by the fire, but could be very sensitive to environment changes, such as might be experienced with the arrival of a cold front or sea-breeze that lowers substantially the ELCL due to the arrival of cooler and moister air.



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LARGE-EDDY SIMULATION OF NEUTRAL ATMOSPHERIC SURFACE LAYER FLOW OVER HETEROGENEOUS TREE CANOPIES

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ABSTRACT

Large-eddy simulation of a neutral atmospheric surface layer (ASL) flow is performed over a modelled tree canopy with heterogeneous leaf-area density. The canopy is arranged as a series of equally-sized stripes of different leaf-area density, emulating the study of Bou-Zeid et al. (E. Bou-Zeid, C. Meneveau, and M.B. Parlange. Large-eddy simulation of neutral atmospheric boundary layer flow over heterogeneous surfaces: Blending height and effective surface roughness. *Water Resources Research*, 40(2), 2004.) over heterogeneous rough surfaces. The simulation results are analysed to understand the qualitative similarities and differences between ASL flows over heterogeneous canopies and heterogeneous roughnesses. This will allow, in the future, the identification of the equivalent roughness length, displacement length, and blending height which parameterises the flow above the heterogeneous canopy. In the present work we restrict attention to the characterisation of the four canopy case and the blending height and β parameter, the ratio of shear stress to velocity at the canopy top. The general characteristics of the four-canopy case are representative of the other cases. Strong vertical velocities (ie up- and down-drafts) exist at the interface between the heterogeneous roughness stripes. However, for a canopy, vertical velocity couplets exist on the vertical interface between two canopies. This implies the presence of sub-canopy recirculation zones at canopy interfaces, which can be confirmed by visualisation of the fluid streamlines. Above the canopy internal boundary layers form over each canopy stripe and exhibit similar features to the characteristic upstream plumes of flow over a rough surface. The shear stress immediately above the canopy varies over the stripes but it varies more smoothly over a canopy than over a heterogeneous roughness. These simulations will allow the development of parameterisations for the near-surface layer and the sub-canopy winds. A better understanding of the effect of heterogeneous canopies on the sub-canopy winds will improve predictions of the wind reduction factor, and in turn, improve operational fire spread predictions.



INTRODUCTION

Knowledge of sub-canopy winds is important for characterising wildfire spread using operational models such as the McArthur [McArthur, 1967] model. The McArthur Mk V forest model takes wind speed at **10** m from the ground in the open (ie. outside of the forest) as an input and returns the forward-rate-of-spread of a fire within a forest. The McArthur model therefore implicitly accounts for the reduction in wind speed due to the tree canopy. McArthur [1967] includes a figure showing the a correlation between the open wind speed at **33** feet (approximately **10** m) from the ground and the wind speed at **5** feet (approximately **2** m) from the ground within the forest. Three eucalyptus forests each with different stocking density and height were considered. These wind speed measurements are valid only for the conditions under which they were made, and are not valid for any given forest.

In order to compensate for different forest types, densities, heights, and so on, a wind reduction factor (WRF) is typically used when applying the McArthur model to a real-world fire in forest types different to what McArthur [1967] considered. It is unclear how to best predict the WRF a priori from the data available to fire behaviour analysts such as forest type, prevailing wind speed, and canopy height [Heemstra, 2015]. Operational forecasting tools such as Phoenix RapidFire [Tolhurst et al. 2008] also use wind reduction factors to account for the drag of different forest types. Field studies have been conducted to measure wind reduction factors for various Australian forest types [Moon et al. 2016]. Moon et al. define wind reduction factor as the ratio of open wind speed at **10** m to the sub-canopy wind speed at a range of heights. Moon et al. present numerous measurements showing the variation in WRF with sub-canopy wind measurement height and forest type, height, and age. The purpose of their study was to provide a sound scientific basis for choosing the values of WRF used in operational models.

Another approach, present in the meteorological literature for some time, is to develop reduced analytical models for wind speed profiles within an idealized canopy. For large and spatially uniform forests it appears that an analytical model, originally due to Inoue [1963], and later modified and verified by Harman and Finnigan [2007] is sufficient to predict the sub-canopy wind speed. Although, to the best of our knowledge, this model has not been trialled by fire practitioners.

Most forests are not spatially uniform and contain many inhomogeneities (or heterogeneities) in all spatial directions. The leaf area density (**LAD**), the amount of volume occupied by all plant matter, is often used to characterise a canopy. In realistic canopies, the leaf area density has strong vertical variation essentially because the leaves tend to be concentrated at the top of a tree canopy. Often, forest canopies will end abruptly at a man-made break in the forest or will become sparse due to some change in forest type. Additionally there are small, effectively random, variations in **LAD** over all directions in tree canopies due to natural variation in the vegetation. The aerial photograph (figure 1a) taken near Ararat in Victoria, Australia, shows a canopy region with some heterogeneity in between forest type 1 and forest type 2.

In reality these changes are not abrupt, regular, in one particular direction, nor always aligned with the wind. However, as a first step to characterising the wind



flow over such canopies we will idealise the canopy to alternating stripes of high and low leaf area density. The flow over this heterogeneous, striped canopy will be simulated using the large eddy methodology.

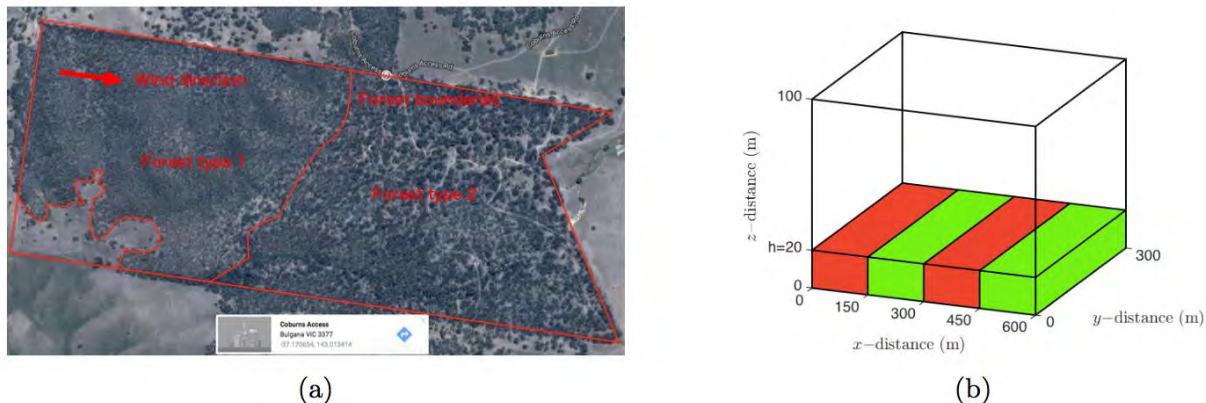


Figure 1: (a) Aerial photograph taken near Ararat in Victoria showing a forest canopy with step-like variation in leaf area density between forest type 1 and forest type 2. The wind direction aligned with this step change in forest type is shown by the arrow. (b) Simulation domain for the four-canopy case. Red: $LAD = 0.2$, green: $LAD = 3$. The x - and y -boundary conditions are periodic.

Grant et al. [2015] suggest using a canopy model has numerous advantages over simple roughness parameterisations particularly when flow separation occurs over complicated terrain. Harman and Finnigan [2007] have demonstrated that analytic canopy models and a canopy parameterisation, which in turn provide a roughness length, displacement length, and stability parameterisation can be used successfully for homogeneous forests. The aim of this work is to use Large Eddy Simulation (LES) to study the flow over heterogeneous canopies with an eye towards developing a canopy model and, subsequently, a parameterisation of the whole flow.

The code used to perform the simulations is Fire Dynamics Simulator (FDS) [McGrattan et al., 2013]. FDS has previously been benchmarked against experimental and other simulation results by Mueller et al. [2014] for flows over homogeneous canopies and canopies with finite edge boundaries. LES of flows over canopies with edge heterogeneities, where the canopy abruptly stops, have been conducted by Cassiani et al. [2008], who identified the presence of recirculation regions downstream of the canopy, and Kanani-Suhring and Raasch [2017] who studied scalar (eg. temperature, humidity, CO₂) transport near the edges of the canopy. Schlegel et al. [2015] conducted simulations with heterogeneous canopies where the leaf area index profile was obtained using LiDAR of a real world forest. Comparisons to field measurements revealed that small-scale plant inhomogeneities considerably influenced the observed flow statistics. In the present work we conduct idealised numerical experiments to identify how the effective roughness length, displacement length, and blending height vary above the heterogeneous canopy.



Similarly we aim to examine the features of the sub-canopy flow. A greater understanding of the effect of heterogeneous canopies will improve fire spread prediction, extend previous wind reduction factor studies [Moon et al., 2016], and improve the understanding of the transport of firebrands, smoke, and combustion products such as carbon dioxide [see for example Kanani-Suhring and Raasch, 2017].

NUMERICAL METHODS

In LES the equations describing conservation of mass and momentum in a fluid (the continuity and Navier-Stokes equations respectively) are spatially filtered retaining the dynamically important large-scale structures of the flow. The assumption is that the largest eddies contain the most energy and therefore make the largest contribution to momentum transport. The diffusive effect of the smaller scales on the resolved large scales is non negligible and is then accounted for by using a sub-grid-scale stress model. In FDS, the filtering operation is implicit at the grid scale. That is, the numerical grid acts as a high-pass filter on the velocity. Features which have a length scale smaller than the grid size simply cannot be resolved and therefore are implicitly filtered. The use of an implicit filter can cause problems with grid independence [Sarwar et al., 2017] and overestimation of mean domain stresses [Bou-Zeid et al., 2009]. However due to the validation work previously conducted for FDS simulations of canopy flows these effects are considered negligible for these flows and the implicit filtering method is employed.

The LES equations are

$$\frac{\partial u_i}{\partial t} + u_j \left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i} \right) = \frac{1}{\rho} \frac{\partial p}{\partial x_j} + \frac{\partial \tau_{i,j}}{\partial x_j} + F_{D,i},$$

$$\frac{\partial u_i}{\partial x_j} = 0,$$

where u_i is the resolved part of the velocities, $i, j = x, y, z$ are the coordinates, ρ is the fluid density, p is (the modified) pressure, and τ_{ij} is defined as:

$$\tau_{i,j} = -2(\nu + \nu_t)S_{i,j} + 3 \frac{\partial u_i}{\partial x_i} \delta_{i,j},$$

where $S_{i,j}$ is the rate of strain tensor, $\delta_{i,j}$ is one if i and j are equal, and zero otherwise. The subgrid-scale stresses appear as the eddy viscosity ν_t . Here the turbulence is modelled using the constant Smagorinsky model (see, for example, Pope, 2001):

$$\nu_t = -2(C\Delta)^2 |S| S_{i,j},$$

$$S_{i,j} = \frac{1}{2} \left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i} \right),$$

where $\Delta = (\delta x \delta y \delta z)^{1/3}$ is a measure of grid spacing. Here we assume the constant in the Smagorinsky model is $C = 0.1$ [Lesieur et al., 2005].

A simulation domain with four canopy stripes is shown in figure 1(b). Following previous canopy simulations (eg Dupont et al. [2011], Mueller et al. [2014]) the canopy of height h is modelled as an aerodynamic drag term of the form

$$F_{D,i,k}(x, z) = \rho c_D \chi_k(x, z, h) (u_j u_j)^{1/2} u_i^2.$$

We fix the value to be $c_D = 0.25$ roughly consistent with the measurements of Amiro [1990] and the study of Cassiani et al. [2008]. The function $\chi_k(x, z, h)$, defines the spatial location of the k th stripe canopy and h is constant across the stripes.

This is a simplified representation of the forest profile. In reality, there are often strong variations in LAD with height within the canopy. However, for the purposes



of our idealised study we neglect that variation to isolate features caused by only the streamwise variation in LAD . For the same reasons, we choose extreme values of the LAD . A value of $LAD = 3$ is found by Amiro [1990] for a dense spruce forest, while $LAD = 0.2$ is reasonable for a eucalyptus regrowth forest [Moon et al., 2016]. In figure 1(b) green represents the uniform $LAD = 3$ canopies, and red represents the uniform $LAD = 0.2$ canopies. Four cases with these extreme differences in LAD have so far been simulated. The length scale of the stripes is then $L_c = L_x/n$ where n is the number of canopies. There are also two, four, eight, and sixteen canopy cases. The height of the canopy is taken as $h = 20$ m and h is the natural length scale of the flow.

The size of the exterior domain is chosen so that the largest relevant structures are captured. The channel sizes are chosen to follow the proportions set out by Moser et al. [1999]. The channel height is dictated by the canopy height. Bou-Zeid et al. [2009] recommends the channel height be at least four times larger than the canopy height to avoid any artificial interaction between the top boundary and the canopy. The overall domain size is $600 \times 300 \times 100$ m ($30h \times 15h \times 5h$). The boundary conditions employed follow [Bou-Zeid et al., 2004] and are standard among most similar canopy flow simulations conducted in the literature. The streamwise and spanwise boundary conditions are periodic. The bottom (ground) boundary condition is enforced using the log-law of the wall. At the bottom of the canopy, u is small, hence canopy drag (proportional to u^2) is negligible and the log-law is appropriate here [Belcher et al., 2003]. In FDS, the log-law of the wall is enforced using a Werner-Wenkle approximation [McGrattan et al., 2013]. The top (sky) boundary condition is a free-slip condition, that is, the normal velocity vanishes at the top of the domain.

The resolution of the simulation 5 m in the horizontal directions and 0.5 stretched to 4 m at the top of the domain is chosen to be approximately three times finer than the resolution used by Bou-Zeid et al. [2009]. The flow is maintained by a constant pressure gradient of 0.005 Pa/m over the length of the channel. This gives a wind speed at the top of the domain (100 m) approximately equal to 72 km/h. This channel configuration and use of a pressure gradient driven flow to model an atmospheric surface layer is fairly standard [Bou-Zeid et al. 2004] and at the length scales considered here, the effect of the Coriolis force is negligible. The flow is initialised from a uniform velocity with a random perturbation to ensure tripping to a turbulent flow. The flow is allowed to develop to a statistically stationary state over approximately 3600 s and statistics are sampled every 2 s for 7200 s. The steady state is judged by negligible differences between instantaneous spatial mean velocities and time-averaged spatial mean velocities. The sampling time corresponds to approximately a large-eddy turnover time $t_L = h/u_h$ based on the canopy height and velocity at the canopy top. The total simulation time was selected to ensure relatively smooth derivatives of the mean velocity profiles.

RESULTS AND DISCUSSION

CHARACTERISTICS OF THE FOUR-CANOPY CASE

In this section the four-canopy case will be examined to give a representative characterisation of the flow above and within a heterogeneous tree canopy. The features of the four-canopy case are representative of all canopy cases. For all canopy cases the interesting features such as the up- and down-drafts, recirculation regions, plume structures, and variation in shear stress are periodic with a length-scale equal to two canopy lengths. For a qualitative discussion it is therefore sufficient to examine only the four-canopy case.

The results are nondimensionalised using the averaged canopy top friction velocity

$$u_* = \left\langle \frac{\tau}{\rho} \right\rangle_{t,x} = \left\langle v \frac{\partial u_{t,y}}{\partial z} - \langle u'w' \rangle_{t,y} \right\rangle_x,$$

where τ is the total shear stress at the top of the canopy. Typically, in a boundary layer calculation over an unobstructed or smooth surface, the friction velocity is taken at the surface $z = 0$. In these cases the sub- and above-canopy flow are coupled and velocity scale is at the canopy top. Angled brackets denoted quantities averaged with respect to the subscripts. For example $\langle u \rangle_t$ is the time average of the u –velocity. Vertical profiles of averaged streamwise velocity are

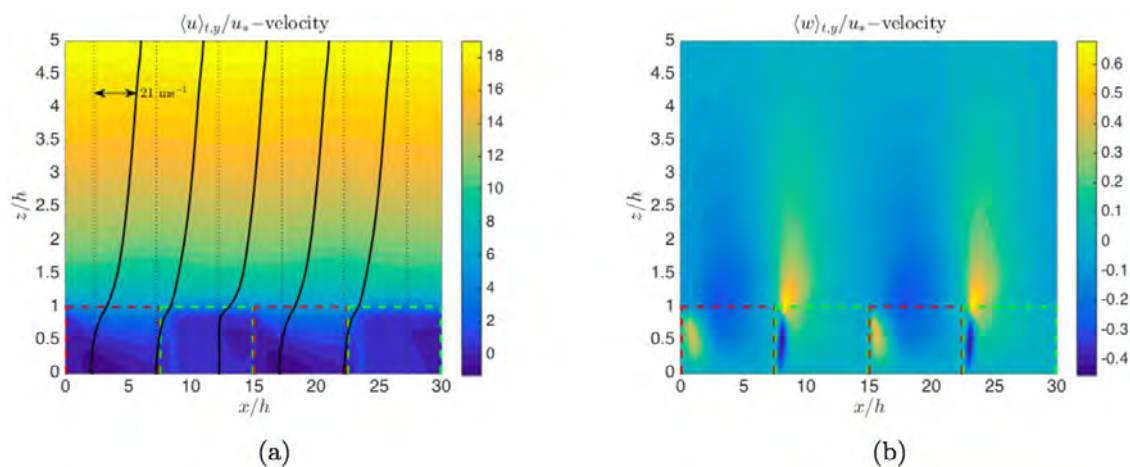


Figure 2 Contours of nondimensional average u -velocity with superimposed profiles of average u -velocity at a range of locations along the canopy. Note the contours (colours) are nondimensional but the profiles have an approximate dimensional scale as indicated. (b) Vertical velocity in the whole domain showing the strong up- (yellow) and down-drafts (blue) above and within the canopies. The canopy stripes are shown as dotted outlines.

shown at a range of locations along the four-canopy case in figure 2(a).

When the flow moves from a sparse canopy to a dense canopy the flow slows in the streamwise direction causing regions of strong upward vertical velocity above the dense canopies (figure 2(b)). Correspondingly there is a strong downward vertical velocity above the sparse canopies. The time and (xy)–mean sub-canopy flow for the homogeneous canopy cases exhibits the expected exponential decay profile predicted by Inoue [1963] and simulated by Mueller



et al. [2014] and others. Within the heterogeneous canopies the sub-canopy flow exhibits a qualitatively similar decay, however, several new features exist. In particular, due to the alternating streamwise accelerations and decelerations and the consequent updrafts and down-drafts, recirculation regions are present in the sparse canopies. These recirculation regions have been previously observed at the downstream edge of a finite canopy and deep within extremely dense canopies [Cassiani et al., 2008]. The recirculation regions are visualised by plotting the streamlines of the mean flow in figure 3(a).

Similar to the flow over heterogeneous rough surfaces an internal boundary layer develops above the canopy. Immediately above the canopy 'plumes' form over each individual stripe of canopy which affects the downstream flow. The plumes are characterised by large deviations in streamwise velocity gradient from the velocity gradient averaged over all patches, that is

$$\Delta u_z = \frac{h}{u_*} \left(\frac{\partial \langle u \rangle_{t,y}}{\partial z} - \frac{\partial \langle u \rangle_{t,x,y}}{\partial z} \right).$$

Above the plume structures the overall atmospheric boundary layer flow is well mixed and the flow is homogeneous in the streamwise and spanwise directions. The critical height where this well-mixed layer commences is called the blending height. In a blended layer there will be no localised deviations from the mean flow throughout the domain. The plumes, mixed layer, and blending height above the canopy can then be visualised as shown in figure 3(b).

The contours of τ and a plot of τ in the plane above the canopy is plotted in figure 4 (a and b). The stress immediately above the canopy varies periodically over the stripes as is expected. However, in contrast to the discontinuous jumps observed over heterogeneous roughness [Bou-Zeid et al., 2004], the variation over a canopy appears to be somewhat smooth. Over the sparse canopies τ appears to approach a constant value, but over the dense canopies, τ exhibits an inflectional variation.

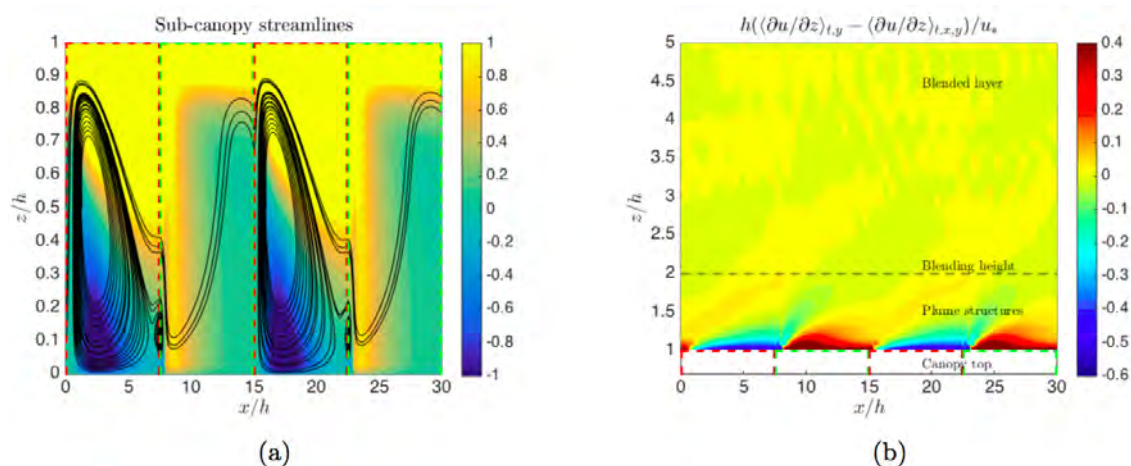


Figure 3 (a) Streamlines highlighting two recirculation vortices within the canopy. Superimposed on the nondimensional average u -velocity. (b) Contours of averaged velocity gradient difference above the canopy, clearly showing the plume structure immediately above the canopy. Above the blending height is a well-mixed boundary layer characterised by negligible fluctuations in the velocity gradients. Sub-canopy flow is omitted from this figure. The canopy stripes are shown as dotted outlines.

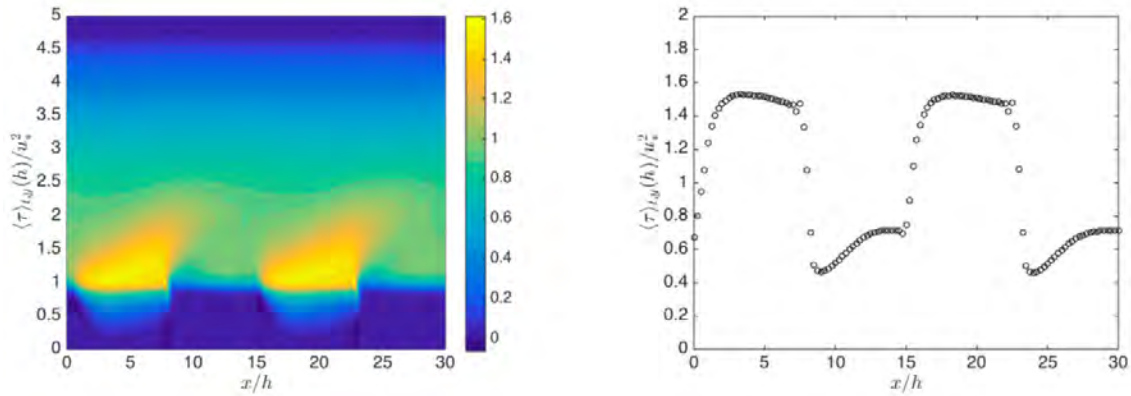


Figure 4 (a) contours of stress over the domain, (b) stress at the canopy top

BLENDING HEIGHT AND β FOR CANOPY LENGTH SCALES

The blending height is identified following Bou-Zeid et al. [2004]. In a blended layer, the difference between the domain averaged (in x, y , and t) velocity profile and the profiles of velocity averaged in y and t only is small. Plotting these profiles can then be used to identify the blending height. The upper and lower quartiles of $\langle u \rangle_{t,y} - \langle u \rangle_{t,x,y}$ are plotted, in figure 5, for each canopy case and the local minimum critical points, for $z/h > 1$, of these profiles are used to identify the blending height unambiguously. These minima points form the ‘neck’ of the velocity difference profile.

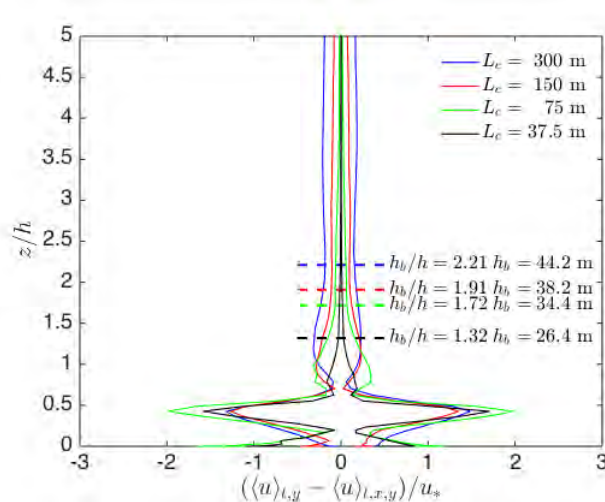


Figure 5 Upper and lower quartiles of the difference profiles. The ‘neck’ gives an unambiguous measurement of blending height

As the streamwise length scale of the canopies decreases (in this case, as the number of stripes increases) the blending height decreases. That is, the homogeneous boundary layer becomes closer to the canopy top. This is consistent with the idea that as the stripes become narrower, the heterogeneous canopy behaves like a uniform canopy with an average LAD value. In the case of a uniform canopy, there are no strong streamwise variations in the vertical

motions above the canopy. Therefore, there is no blending height above the canopy and the flow above the canopy is homogeneous in the x- and y-directions.

A homogeneous sub-canopy flow is parameterised by $\beta = u_*/u_h$, the ratio of canopy top friction velocity to canopy top velocity [Harman and Finnigan, 2007]. In that study β was found to be approximately constant with LAD in neutral atmospheric stability conditions; the value proposed for the neutral conditions $\beta = 0.3$. In figure, 6 β as a function of x/h is plotted for all canopy cases. We also find that the mean value of β is approximately constant across the heterogeneous canopies with a value of $\beta \approx 0.2$. In the simulations of Mueller et al. [2014] $\beta \approx 0.3$ was observed for some homogeneous canopy cases. However, decreases in the measured value of β were observed for LAD profiles with extreme vertical variation (unlike the cases here where there is no vertical variation) and cases with canopy edges. Further work is required to investigate

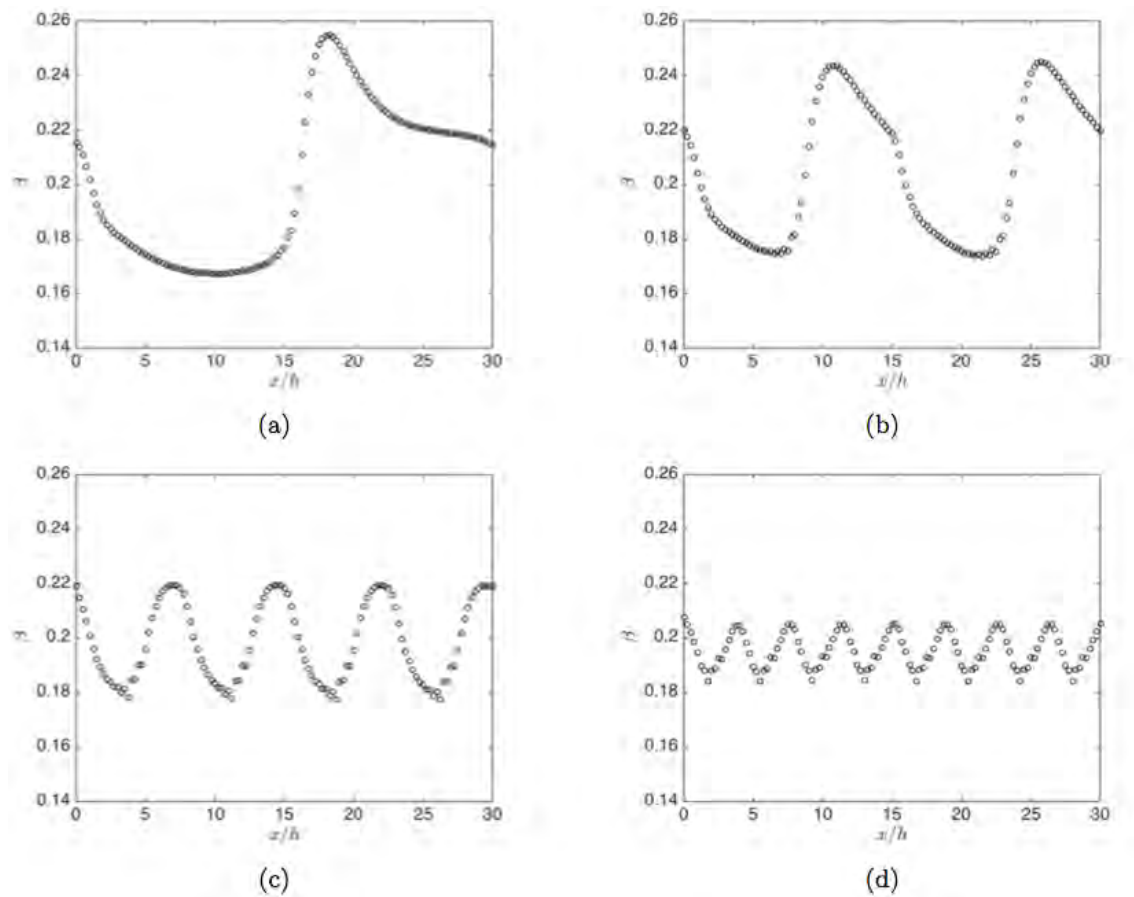


Figure 6 Variation of the β parameter for (a) two, (b) four, (c) eight, and (d) sixteen canopy cases. The mean value is approximately $\beta = 0.2$ in all cases.

the dependence of β on the canopy LAD . It is not possible to immediately extend the sub-canopy flow model of [Harman and Finnigan, 2007] because the recirculation regions which exist at the canopy interfaces will not be captured.



POTENTIAL IMPLICATIONS FOR FIRE SPREAD

Several of the features identified here may have significant effect on fire spread dynamics. Intuitively, the forward-rate-of-spread of a fire will be affected by the periodic decreases and increases of the mean sub-canopy wind speed. That is, within the sparse canopies, the McArthur model would predict a higher rate-of-spread (RoS) than in the dense canopies. However, this implies that the fire will accelerate between the alternating canopy stripes. The McArthur model, like almost all empirical fire models, assumes that the fire is spreading at a quasi-steady rate. How the accelerating fire is driven by the spatially varying sub-canopy wind speed is unclear. As the canopies become narrower, the fire has less distance over which to accelerate or slow down. The RoS may in fact remain roughly constant even though the sub-canopy wind speed is varying considerably over a short distance.

We also expect that smoke, firebrand transport, and spotfire ignition to be influenced by the strong updrafts and recirculation regions which occur at canopy boundaries. Previous work by Kanani-Suhring and Raasch, [2017] showed canopy boundaries lead to enhanced concentrations (of for example CO₂) in the lee side of a canopy. Analogously, boundaries between dense and sparse forests may also lead to enhanced concentrations of smoke and combustion products in these regions. Furthermore, the strong updrafts on the leading dense canopy edges and the large downdrafts over sparse canopies are likely to enhance firebrand lofting, at dense canopy leading edges, and falling firebrand distribution over sparse canopies. Therefore, spotfire ignition may occur more frequently in the sparse canopy regions, near an inhomogeneity in the canopy, because a greater number of firebrands land there relative to the rest of the canopy.

Small spot fire ignitions may be significantly influenced by recirculation regions. Simpson et al. [2013] found that recirculation in the lee side of hills can lead to lateral spread of large fires spreading over the hill. The magnitude of velocities in lee vortices is larger than observed in canopy recirculation regions, and therefore we expect that only small fires may be influenced by the canopy recirculation vortices. Therefore this effect may be significant in spotfire ignition and growth. It is unlikely that the recirculation regions will persist in the presence of a large buoyant fire plume which will disturb the background wind flow in the vicinity of the fire.

All of these effects must be rigorously studied in further simulation work before any useful conclusions may be drawn.



CONCLUSIONS

Large eddy simulations of flow over heterogeneous canopies have been conducted. The streamwise velocity profiles follow the inflectional profile typical of flows over canopies [Harman and Finnigan, 2007]. However, at the canopy interfaces prominent recirculation regions are observed, similar to the recirculation region which exists downstream of a finite canopy [Cassiani et al., 2008]. The vertical velocity exhibits up- and down-drafts corresponding to the dense and sparse canopies respectively.

For heterogeneous canopies the mean β appears to be slightly lower than measured experimentally for homogeneous canopies, and does not appear to vary significantly with the number of canopies. For the heterogeneous cases the time and domain mean flow exhibits a flow reversal, or a recirculation close to the ground. At the boundary at the dense-to-sparse canopy interfaces, a velocity couplet and a corresponding recirculating structure are formed inside the sparse canopy.

The data set presented here will be used to develop a parameterisation of the boundary layer above a heterogeneous tree canopy and it will also be used to model the sub-canopy flow. The determination of an equivalent blending height, displacement length, and surface roughness length in terms of the canopy parameters can be used in surface schemes of numerical weather prediction models which will improve the overall wind forecast accuracy. The development of a reduced model of sub-canopy winds in heterogeneous forests will be useful to wildfire management agencies that require estimates of sub-canopy wind speeds for operational fire models such as the McArthur model or the Rothermel [Rothermel, 1972] model. A particular question that arises from this study is the effect of recirculation regions on fire spread. Recirculation regions may not persist in the presence of a fire plume. It is possible to simulate the effects of the canopy on a fire spreading under a canopy using FDS and this is the subject of a forthcoming study. Simulations will be conducted to understand the effect the canopy has on the forward-rate-of-spread of a fire and examine if the recirculation regions influence the fire spread. Extending this work will contribute to understanding the effect of forest heterogeneities on firebrand and smoke transport.



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NON-PEER REVIEWED EXTENDED ABSTRACTS



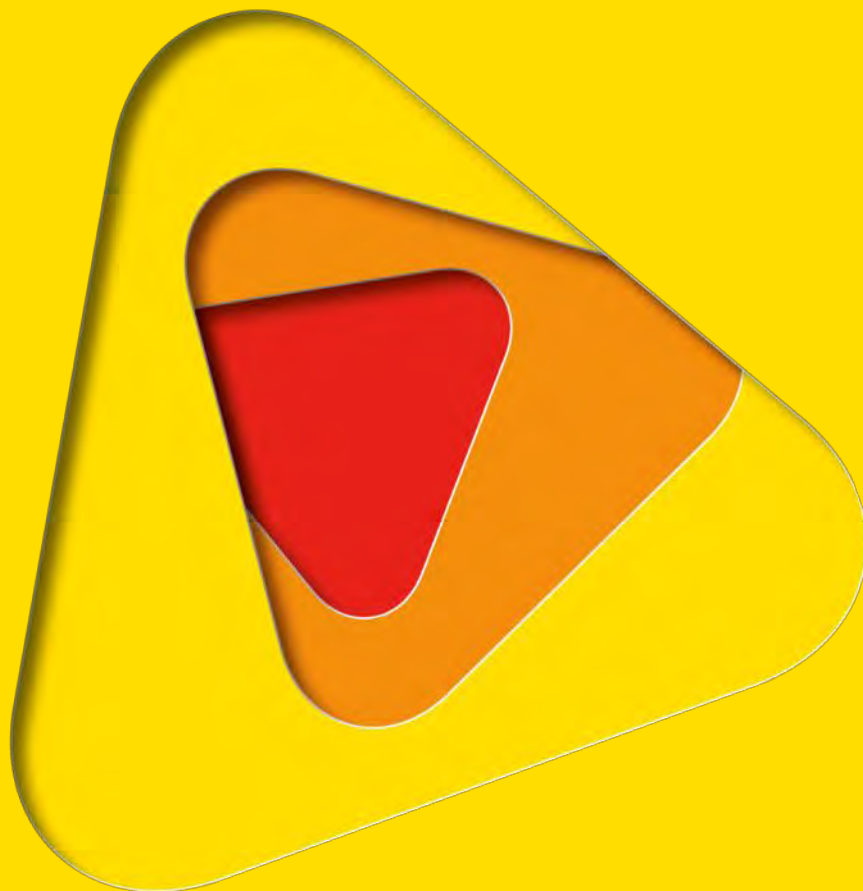


A UNIFIED APPROACH TO FIRE SPREAD MODELLING

Non-peer reviewed research proceedings from the Bushfire and Natural
Hazards CRC & AFAC conference
Sydney, 4 – 6 September 2017

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EXTENDED ABSTRACT

A UNIFIED APPROACH TO FIRE SPREAD MODELLING

One of the main goals of bushfire research is to provide a relatively simple and timely answer to the question “What is the fires’ forward rate of spread?” Indeed, pursuit of such an answer has engaged some of the brightest minds in wildland fire science, and has produced a variety of fire spread models that apply across a number of common vegetation or fuel types. In Australia, these models date back to the 1950s-60s, with the work of Alan McArthur, and extend through to the current day with the most recent developments in shrubland fire spread models and refinements to the curing function in the CSIRO grassland fire spread model. In the present work we consider the way that meteorological factors are incorporated into the suite of existing fire spread models, which encompass a variety of different fuel types, and discuss an approach that unifies their inclusion. The utility of this unified modelling approach is demonstrated via model comparison using real meteorological data over a range of vegetation types. In particular, we demonstrate that the meteorological (i.e. non-fuel) sub-models of the current suite of operational models, which are of many and varied functional form, can be replaced by a single, unified, two-parameter model, with no appreciable loss in model performance. The unified model has the distinct advantage of being conceptually straightforward and extremely parsimonious compared to current operational approaches. The existence of a simple, yet effective, unified approach to fire spread modelling has implications for initiatives such as the National Fire Danger Rating project, as it establishes a common modelling basis that can be applied to the many different fuel types that are encountered across the nation.

FIRE SPREAD MODELS

We consider current operational models for the following fuel types: grasslands; buttongrass moorland; temperate shrubland; South Australian mallee-heath; and dry eucalypt forest. The rate of spread models for each of these fuel types are described in detail by Cruz et al. (2015).

In this study we specifically focus on how the rates of spread derived from the models mentioned above depend on the fire weather variables: temperature, relative humidity and wind speed. Fuel-related factors such as availability and structural descriptors (e.g. fuel height) are assumed constant for each fuel type.

It is of interest to note the number of model parameters that are associated with each of the rate of spread models for the different fuel types considered. These parameters represent degrees of freedom in the model, and have to be determined through regression-type analyses of empirical data relating to the rate of spread and environmental predictor variables. Ignoring their fuel dependent components, the grassland model has 10 parameters (Cheney et al., 1998), the buttongrass moorland model has 6 parameters (Marsden-Smedley and Catchpole, 1995), the temperate shrubland model has 9 parameters (Anderson et al., 2015), the S.A. mallee-heath model has 7 parameters (Cruz et al., 2010), and the dry eucalypt forest model has 13 parameters (Cheney et al., 2012).



A UNIVERSAL FIRE SPREAD INDEX

Previous work (Sharples et al., 2009a; Sharples and Matthews, 2011; Sharples and McRae, 2012) has considered the utility of the following simple dimensionless index in describing fuel moisture content. The *fuel moisture index* is defined as:

$$FMI = 10 - 0.25(T - RH),$$

where T is air temperature ($^{\circ}\text{C}$) and RH is relative humidity (%).

The FMI has been combined with wind speed in simple functional forms, which have been shown to provide estimates of fire danger and rates of spread that are comparable to those derived from accepted models (Sharples et al., 2009b; Sharples and McRae, 2013). In this work, we extend this idea, and examine how predictions from a simple, two-parameter model for fire spread, based on wind speed U and FMI , compares to those from the various models for different fuel types. The particular model, which we refer to as the *spread index*, is:

$$S(\mu, p) = \left(\frac{\max(1, U)}{FMI + \mu} \right)^p,$$

where μ and p are the two parameters defining the model.

To facilitate the comparison between the current operational models and the spread index, we use half-hourly fire weather data recorded at Canberra Airport between November 2006 – March 2007; that is, approximately a fire season's worth of numbers.

RESULTS

In this preliminary work the spread index parameters μ and p were varied by hand until a good fit was obtained between predictions of the spread index and those arising from each of the rate of spread models for grassland, buttongrass, temperate shrubland, S.A. mallee-heath and dry eucalypt forest. An example of a comparison of the predictions of the spread index compared to the predictions of the temperate shrubland model (Anderson et al., 2015) and the dry eucalypt model (Cheney et al., 2012) can be seen in Figure 1. The parameter values used to calculate the spread index in each case are listed in Table 1. Note that in each case the spread index values have been scaled so that their mean equals the mean of the predictions from the fuel-specific model.

Table 1 summarizes the results across all the different rate of spread models. In the worst case the spread index accounts for around 94% of the variability in the dry eucalypt forest rate of spread model, while in the best case it accounts for over 99% of the variability in buttongrass moorland model. The table also indicates root mean square differences between the fuel-specific models and the spread index of 5-15%, with the exception of the dry eucalypt forest model, which has a root mean square difference of 33%. Root mean square differences have been expressed as a percentage of the mean value of the fuel-specific model predictions in this comparison.

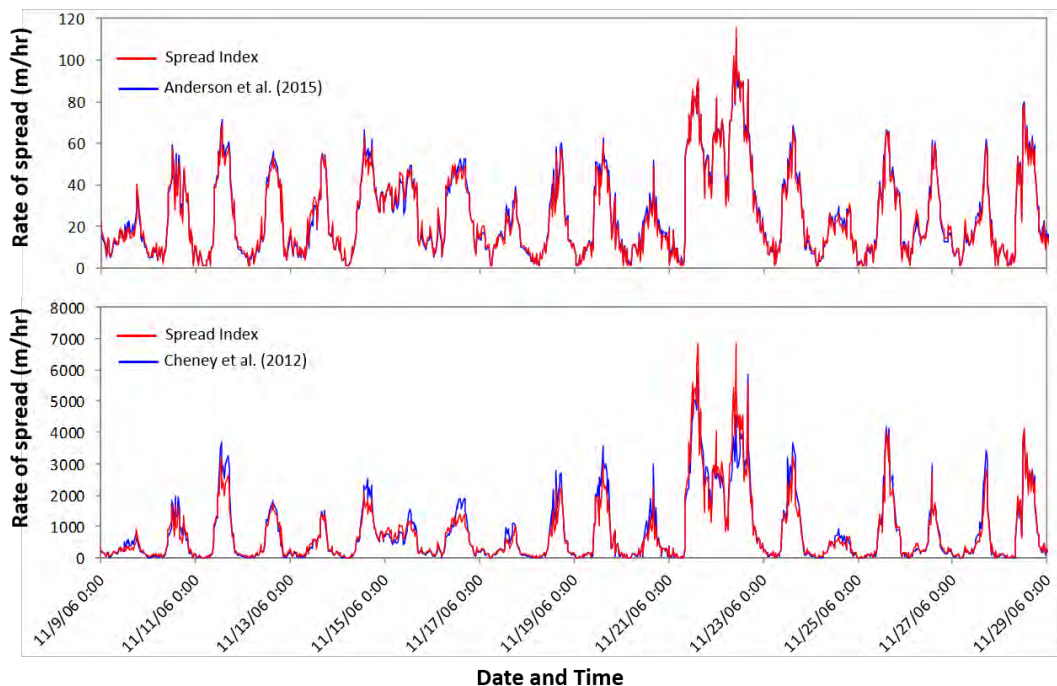


Figure 1. Rate of spread predictions from the temperate shrubland model of anderson et al. (2015) and the dry eucalypt forest model of Cheney et al. (2012) compared to those from the spread index. The spread index values have been scaled in each case so that their mean value matches the mean value of the fuel-specific model predictions.

Fuel type	No. model parameters	μ	p	Correlation with spread index (R^2)	Root mean square difference
Grassland	10	5	1.00	0.9880	15%
Buttongrass moorland	6	80	1.34	0.9968	5%
Temperate shrubland	9	10	1.00	0.9893	8%
S.A. mallee-heath	7	9	1.28	0.9896	13%
Dry eucalypt forest	13	3	1.40	0.9412	33%

Table 1. Results of comparison of the spread index with the various rate of spread models. The optimal spread index parameters are listed along with the inter-model correlations and root mean square errors.

CONCLUSIONS

Predictions from the meteorological sub-models of five state-of-the-art fire spread models were compared with predictions derived from a single two-parameter fire spread index. The results indicated that the simple spread index was able to reproduce the predictions of the more complicated models to a remarkable degree of accuracy ($R^2 = 0.94-0.99$). The results further suggest that the state-of-the-art models are considerably over-complicated: the predictions from models with 6-13 parameters can all be accurately emulated by a model with only two parameters (or three parameters, if a scaling/calibration factor is included). This indicates that the current suite of operational models have about 2-6 times more degrees of freedom than necessary. Indeed, the spread index offers a far more parsimonious approach to modelling rate of spread, is far more conceptually simple, and provides a unified way of assessing rate of spread across a variety of fuel types.



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HEATWAVES IN NEW SOUTH WALES: HOW ARE RESIDENTS AND BUSINESSES COPING?

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Natural Hazards CRC & AFAC conference
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ABSTRACT

Heatwaves are recognized as Australia's most deadly natural peril. During the summer 2016/2017, extreme heatwave conditions were experienced across New South Wales (NSW). Forecasts for heatwave conditions are provided by the BoM, and disseminated through traditional and online media, and by other agencies to communities. However, the full impacts of heatwave conditions and the ways in which these warnings are used by the public are not well understood. In this study, phone surveys of residents and business owners/operators were conducted following heatwaves in January and February 2017. These surveys explored how residents and businesses receive and monitor heatwave warnings, preparedness and protective measures taken, risk perceptions, and the impacts of the heatwave on the health and wellbeing of residents and staff, and on business activity. Initial findings show that communities recognise that temperatures are much hotter than previous years. Households are mainly coping with extreme heat by rescheduling outdoor activities, staying at home and running air conditioners and fans. In the main household members have experienced personal discomfort and poor sleep, however, a number of people have reported feeling unwell. Energy use and costs associated with preparedness and protective measures are key areas of concern to communities.



INTRODUCTION

Heatwaves are increasingly recognised as a critical public health issue, particularly after major events in the US and across Europe [1-3]. Within Australia, more fatalities have been attributed to heatwaves than to all other natural hazards combined [4, 5]. Vulnerability to heatwaves can be understood as medical vulnerability whereby some people experience greater physiological strain to maintain the body's thermal balance in extreme heat conditions [6, 7], energy or water-related vulnerability where people have limited access to cooling strategies [7], and building-related vulnerability where the housing available restricts the ability to adapt or remain cool during extreme heat events [8]. Each of these kinds of vulnerability need to be considered, alongside the extent to which they influence communities' experiences and coping strategies during extreme heat events. Efforts to understand the impacts of heatwaves typically focus on extreme impacts, such as excess morbidity rates or heat-related fatalities, or such quantifiable aspects as energy and water consumption or power cuts [5, 9]. Whilst these impacts are significant, it is also important to understand the broader health, social, and economic impacts of heatwaves.

Warnings and public messaging about heatwaves are an important means of reducing the likelihood and severity of impacts, especially as heatwaves are not a well-known or visible hazard. Studies have highlighted the effectiveness of these messages, with improved public awareness and reduced morbidity during heatwave events [2, 10]. The Bureau of Meteorology (BoM) has developed a methodology to define heatwaves in the Australian context [11, 12], and has introduced a heatwave service that provides regular updates and forecasts [13]. There is much interest in developing and evaluating warning systems and classifications of heatwaves [3, 14, 15], and in understanding how affected communities use warnings and perceive the risks of extreme heat [16, 17].

Here, we report the findings of rapid response projects conducted by Risk Frontiers and the BoM with the support of the Bushfire and Natural Hazards Co-operative Research Centre (BNHCRC). This research considers the experiences of residents and business owners in Western Sydney, and residents in the Northern Rivers region of NSW during heatwave events in early 2017. It focuses on 1) the impacts of heatwaves experienced by residents and businesses; 2) how warnings are received and understood; and 3) preparedness and protective actions taken to reduce the impacts of the heatwave. The BoM aims to use the findings of this study and future surveys to inform the development of its heatwave service, warnings, and updates. The study delivers valuable knowledge on key issues of risk perception and how residents and businesses respond to heatwave warnings and cope with extreme heat.



BACKGROUND

There were three main heat events in early 2017. The first was from 10-14 January and affected northern NSW and southern Queensland, the second was from 17-21 January and was experienced mostly in Queensland, and the final and most severe heatwave was from 31 January till 12 February [18]. During this summer, northern NSW experienced more than 55 days where the temperature was over 35°C, while Sydney experienced 35 days with heatwave conditions [18]. In January, peak temperatures in the Northern Rivers region were reached on 18 January, with Casino and Grafton recording 41.3°C. In February, daily maximum temperatures in Penrith (Western Sydney) during the heatwave were between 36.4°C and 46.9°C, while Parramatta North daily maximum temperatures were between 35°C and 44.5°C (BoM, n.d.-a). Through each of these events, the BoM's Heatwave Service provided forecasts.

RESEARCH APPROACH

Here we report on the findings of three telephone surveys conducted as rapid response projects following heatwaves in NSW. First, a telephone survey of 150 residents affected by the heatwaves in the North Rivers Region of New South Wales (NSW) on 10-14 and 17-21 January 2017 was conducted in February. This region was chosen as it experienced severe and extreme heatwave conditions during these heat events. Second, a telephone survey of 101 residents affected by the heatwave in Western Sydney was conducted in February and March. Suburbs in two regions were targeted (see Error! Reference source not found.); suburbs in The Hills region had a Socio-Economic Indexes for area (SEIFA) score above 1000, and while those in the Western suburbs had an SEIFA score below 1000. Lastly, a telephone survey of businesses in Western Sydney was conducted. This survey targeted a range of business types located in The Hills and Western suburbs. Western Sydney was chosen as it experienced severe and extreme heatwave conditions during February, and regularly experiences higher temperatures than other parts of Sydney. It, therefore, is an apposite site at which to consider the impacts of heatwaves in urban area.

Surveying was carried out by two research assistants; residential surveys were administered between 11am and 7pm on weekdays and the business survey was administered between 9am and 5pm on weekdays. Survey questions were developed in consultation with the BoM.



FINDINGS

PERCEPTIONS AND CONCERNS ABOUT HEATWAVES

Heatwaves were perceived as a more severe risk to personal health and safety than severe storms, bushfires and floods, with 56% of residents and 60% of businesses in Western Sydney, and 51% of residents in the Northern Rivers region describing heatwaves as either a high or extreme risk. With regard to the heat in summer 2017, most residents in both locations considered this summer hotter than previous years, and many reported being concerned about the heatwaves. The main concerns residents identified were the potential impacts on physical health and personal discomfort, followed by impacts on vulnerable people. Business owners in Western Sydney were also concerned about the heatwave; the potential impact on employee health and safety was the most frequently mentioned concern, followed by potential impacts on productivity.

HEATWAVE IMPACTS AND COPING STRATEGIES

The everyday impacts of heatwaves on the health and wellbeing of residents in urban areas is a current research concern [7]. In Western Sydney, almost 60% of residents stated that they felt hot or uncomfortable during the heatwave, and 32% reported having difficulty sleeping. In the Northern Rivers region, the main impact reported was feeling hot and uncomfortable (60.5%), followed by being unable to sleep (21.7%), and feeling unwell (15%). The severity of this heatwave is indicated in such comments as:

One of the biggest impacts was having everyone at home. No one could go outside, kids just got burnt going out into the yard for a few minutes. The heat here is so insufferable that we are now thinking of relocating back to Western Australia (resident, Northern Rivers region).

The main actions taken by residents in both sites to reduce the Impacts of extreme heat were using air-conditioning, fans, and staying in a cool part of the house. Notably, few people reported checking in on neighbours, relatives, or friends during the heatwaves.

To better understand the impacts experienced by businesses, absenteeism, productivity, turnover, and disruptions to business during the heatwave are considered. These results provide an indication of the impacts as perceived by business owners. While most businesses (58%) described absenteeism as 'about normal' during the heatwave, and 30% described it as higher than normal. Around half of the businesses described their productivity as 'about normal,' but 41% reported that they had lower than normal productivity during the heatwave. This suggests the potentially significant economic Impacts of heatwaves. Interestingly, for some businesses turnover increased during the heatwave. Like residents, using air-conditioning and fans were the most common measures taken to reduce the impacts of heat, followed by taking more breaks and adjusting work practices. Both residents and businesses reported being concerned about electricity use during the heatwaves.



WARNINGS AND PREPAREDNESS

In both sites, around 70% of residents reported being warned about the heatwave, and the television was by far the most frequently identified source of information about the heat. Similarly, 78% of business owners in Western Sydney reported being advised about the heatwave, primarily through the television. The main messages recalled by all survey respondents were that 'It is going to be hot' and to 'stay hydrated.' Many residents and businesses took steps to prepare for the heatwave; for example, rescheduling activities and developing a plan for the hot days. Most were satisfied with the warnings and information that they received; however, some expressed interest in more locally-specific and accurate heat predictions, and more advice on how to cope with the heat.

When asked to consider how they could be better prepared for extreme heat events, many residents and business owners responded that no further preparations were needed, or that they were unsure. Several of the suggested ways to better prepare for heatwaves focused on building quality and features, for instance, installing air-conditioning or solar panels, or insulation.

Suggestions for ways that government agencies could better assist communities during heatwaves focused on reducing vulnerability from the built environment and reducing vulnerability due to social and economic factors. Subsidies for electricity was the most common suggestion, followed by subsidies and regulations to encourage installation of solar panels and other improvements to buildings. In addition, many people noted a concern for those without affordable access to air-conditioning and fans. Several people also linked heatwaves to climate change, and suggested that the government should 'take action' to address climate change.



CONCLUSION

These surveys provide an insight to the impacts experienced by residents and businesses in Western Sydney and residents in the Northern Rivers region during the heatwaves in January and February 2017, and the ways in which warnings were used. The findings highlight the important role traditional media (especially television) plays in informing residents and business owners about heatwaves. The survey of businesses reveals that the perceived impacts on absenteeism, productivity, and turnover were significant for many. The findings also reveal that many residents and business owners rely on air-conditioning to cope with heatwaves, and perceive that little more can be done to prepare. Reducing vulnerability to heat through improved building design (e.g., insulation, air-conditioning, shade), and reducing vulnerability to electricity pricing and outages through solar panels, were the main suggestions to improve preparedness.



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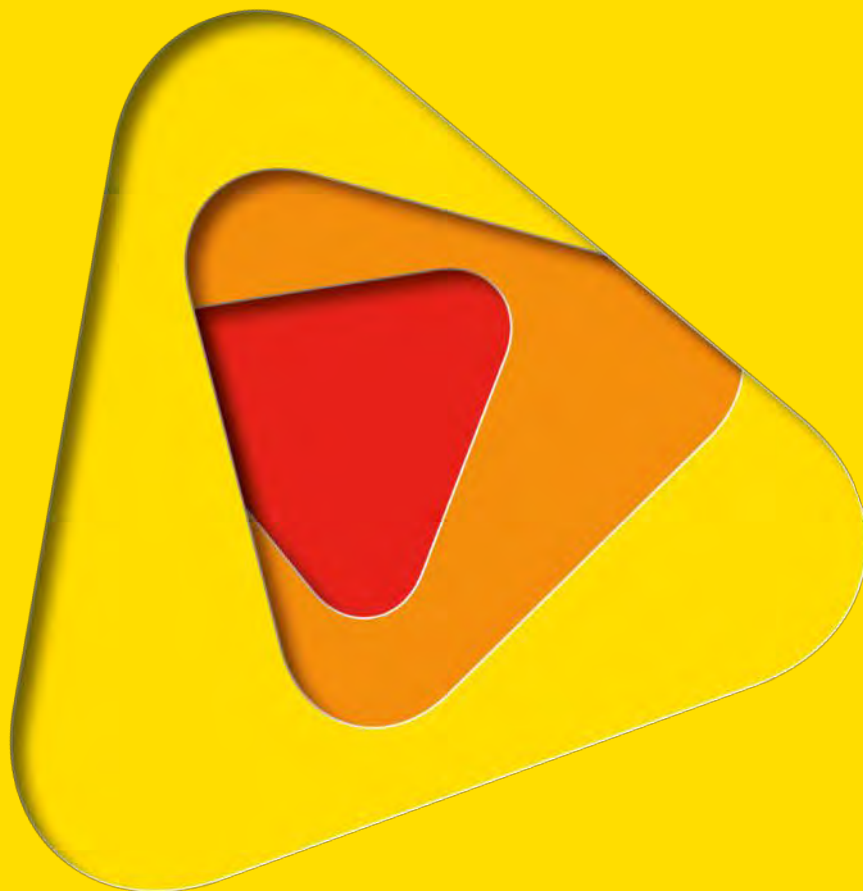


WHERE DO WE PUT OUR DOLLARS? ECONOMIC ANALYSIS OF DIFFERENT BUSHFIRE MANAGEMENT OPTIONS IN WESTERN AUSTRALIA

Non-peer reviewed research proceedings from the Bushfire and Natural Hazards CRC & AFAC conference
Sydney, 4 – 6 September 2017

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ABSTRACT

Funds for bushfire-risk management are limited but the bushfire threat to society continues to increase. Fire managers face a challenging resource allocation problem and they would greatly benefit from knowing which strategies generate the highest benefit per dollar invested. There are many options available for bushfire-risk management, but it is hard to know what benefits they generate and if those benefits exceed the costs of implementation. The aim of this project is to evaluate different bushfire-risk management strategies in contrasting environments to explore which option(s) provide(s) the best value for money and highlight the trade-offs between the different options. This information can be used by fire managers and policy makers to optimise the allocation of the available resources for bushfire management in Western Australia and other States.

Specifically, the analysis evaluates a set of management options that were selected by experts in the field and compares them with the status quo in order to determine which pathways are more likely to generate additional benefits to society. We quantify the costs and benefits of applying the selected management options in two different case study locations in WA and discuss the implications for other localities in the State. We found that in areas with a very large number of high value human assets (i.e. Perth Hills), strategies that remove the assets at risk from the areas concerned have a potential to generate significant benefits, while fuel reduction treatments are most beneficial when large areas are treated in a coordinated manner. Priority strategies for fire management vary by region and it is therefore important not to apply fire management strategies uniformly across the State.



INTRODUCTION

Funds for bushfire-risk management are limited but the bushfire threat to society continuous to increase (1-3), particularly with predictions for climate change (4, 5) and the increasing population living in fire prone areas (6-8). As a consequence, fire managers face a challenging resource allocation problem and they would greatly benefit from knowing which strategies generate the most significant net benefits. However, economic analyses of bushfire management options that illustrate the implications of different uses of the resources available are rare. Despite the significant amounts of money invested in bushfire risk mitigation activities every year, there is little information on the value for money that each option provides and the trade-offs between them to assist fire managers in their decision making. This study aims to provide insights into these issues in the south-west of Western Australia (WA) and infer state-wide implications from these insights.

The south-west of WA presents an interesting case of study because of the complexity of management in the area. In this part of the State, there are numerous areas where highly flammable vegetation and human assets are intermingled, which makes the protection of those assets more difficult because of the spatial interactions between housing and fuels (9). These urban-rural interface areas have become a real challenge for fire managers and policy makers (10). In addition, the south-west is located within an internationally recognised biodiversity hotspot and the environmental significance of the area needs to be taken into account in land management (11, 12). This produces a complex fire management environment, where there are multiple objectives that compete against each other for the use of resources, and knowing which investments provide the highest returns becomes all the more important.

The main purpose of this economic assessment is to determine which fire management option or which combination of options provide the best value for money. We evaluated a set of management options selected with experts in the field and compared them with the *status quo* in order to determine which pathways are more likely to generate additional benefits to society. However, the bushfire management context changes from one location to another, and what could generate large benefits in one location, may only generate little benefits in another. Therefore, it is important to evaluate the same strategies in different settings and understand how a change in settings affects the economic appeal of a management option.

For this purpose, we quantified the costs and benefits of applying the selected management options in two different case study locations in WA that represent contrasting examples of land use combinations: one location has a mix of predominantly urban and peri-urban areas, intermingled with and surrounded by natural areas; the other has a mix of predominantly rural, agricultural and natural areas, with a few interspersed urban areas.



METHODS

The approach taken in this study was inspired by INFFER (the Investment Framework for Environmental Resources) (13), a framework designed to develop, assess and prioritise environmental and natural resource projects. From its application to the Gippsland Lakes (14), INFFER was modified to evaluate fire management options in South Australia and in New Zealand (15). The model used for the application of INFFER to fire management in South Australia and New Zealand was adapted in this study to the Western Australian context. The model performs a quantitative analysis that integrates information about bushfire risk, bushfire spread, the damage caused by fires of different severities, asset values, fire suppression costs, environmental damage caused by the fires, weather conditions, the impacts of applying the management options evaluated, and the costs of those management options. Using this information, it calculates benefit-cost ratios for each of the management options evaluated.

To obtain two contrasting examples of land use combinations, the following locations were selected with a panel of experts: (1) case study area 1 is a combination of two Shires: the Shire of Mundaring and the City of Swan, located East of Perth, at the border of the metropolitan area, in an area known as the Perth Hills. This area has a mix of urban, peri-urban and natural areas. From this point forward, this case study area is referred to as the Perth Hills. (2) Case study area 2 corresponds to the Shire of Bridgetown-Greenbushes, located about 250 km south of Perth. This area represents the mix of rural, agricultural and natural areas with a few urban areas. This case study area is hereafter referred to as the Bridgetown area.

Of the management options discussed with the panel of experts, three were selected for this study:

- 1) Increased fuel reduction through the application of prescribed burning and/or mechanical works (either carried out by the Department of Parks and Wildlife or by the Shires).
- 2) Land-use planning to restrict future developments in high-risk areas.
- 3) Provide land owners with an increased capacity to manage fuels in their own land.

The model evaluates a hypothetical increase in investment in each these options separately and compares it with the *status quo* (i.e. business continues as usual) to estimate the benefits (i.e. asset losses avoided and suppression costs savings).



RESULTS

In the Perth Hills case study area, nearly all strategies generate positive net benefits (Table 1). Only the strategy that increases the capacity of land owners to manage fuels in their land generates benefits that are slightly smaller than the costs, mainly because the total area treated is relatively small and has little impact on fire behaviour, but the costs of implementation are relatively high. The strategy that generates the highest expected benefits per dollar invested per year is the land-use planning strategy, which restricts where people can build new houses in the Perth Hills. Overall, reductions in asset losses for all strategies are much greater than reductions in suppression costs (savings in asset losses are 8 to 11 times larger than savings in suppression costs).

TABLE 1. IMPACT IN THE PERTH HILLS FROM THE IMPLEMENTATION OF EACH STRATEGY

Result	Strategy				
	Increased fuel reduction (DPaW only)	Land-use planning	Fuel management (private landowners)	Increased fuel reduction (Shire only)	Increased fuel reduction (DPaW and Shire)
Proportion of area treated (fuel reduction)	2.97%	2.17%	2.42%	2.24%	3.04%
Cost of strategy	\$672,000	\$600,000	\$468,000	\$197,000	\$869,000
Savings in asset losses	\$2,793,000	\$9,154,000	\$396,000	\$320,000	\$3,689,000
Savings in suppression costs	\$325,000	\$0	\$35,000	\$30,000	\$377,000
Total expected benefit of strategy	\$3,118,000	\$9,154,000	\$431,000	\$351,000	\$4,066,000
Benefit : Cost ratio	4.64	15.26	0.92	1.78	4.68

These results are to be interpreted within the current fire context in the case study area; that is, the current bushfire risk management program is assumed to continue as it is implemented now, and the strategies presented here are implemented as an addition to the current program. Furthermore, current fire risk and suppression effort are assumed to remain constant over time for business as usual. The implementation of a strategy may have an effect on the probability of occurrence for certain types of fires, but the initial probability obtained from historical data for the *status quo* is assumed to remain constant. Similarly, suppression effort (i.e. the number of fire-fighters, fire trucks, and other resources deployed for each fire) is assumed to remain constant over time if the current scheme continues to be implemented.

In the South-West case study area, only two strategies generate positive net benefits: increased fuel reduction in DPaW managed land and increased fuel reduction in DPaW and Shire managed land simultaneously. For other strategies (i.e. land use planning, fuel management in private land and increased fuel reduction in Shire managed land only) the benefits generated are smaller than the costs (i.e. BCR < 1, see Table 2).

It is important to note that the benefits generated by the different strategies in the Bridgetown case study area are of a different order of magnitude compared to the benefits obtained in the Perth Hills area. In the Bridgetown area the benefits are of the order of AU\$20,000 to AU\$570,000 (Table 2); whereas in the Perth Hills they are of the order of AU\$350,000 to AU\$9.1 million (Table 1). The main reason for this is the



difference in the number of high value assets. In the Perth Hills area, which has a total area of approximately 169,000 hectares, there are more than 106,000 residential buildings and 5,300 industrial/commercial buildings. In contrast, in the Bridgetown area, for a similar size area (134,000 hectares), there are about 4,500 residential buildings and 300 industrial/commercial buildings (16).

TABLE 2. IMPACT IN THE BRIDGETOWN AREA FROM THE IMPLEMENTATION OF EACH STRATEGY

Result	Strategy				
	Increased fuel reduction (DPaW only)	Land-use planning	Fuel management (private landowners)	Increased fuel reduction (Shire only)	Increased fuel reduction (DPaW and Shire)
Proportion of area treated (fuel reduction)	5.15%	3.18%	3.38%	3.21%	5.18%
Cost of strategy	\$243,000	\$150,000	\$54,000	\$46,000	\$288,000
Savings in asset losses	\$380,000	\$20,000	\$18,000	\$20,000	\$427,000
Savings in suppression costs	\$129,000	\$0	\$4,000	\$6,000	\$144,000
Total expected benefit of strategy	\$509,000	\$320,000	\$22,000	\$27,000	\$571,000
Benefit : Cost ratio	2.09	0.13	0.41	0.59	1.98



CONCLUSION

The analysis shows that the strategies evaluated have different impacts in each case study area and the strategy that generates the highest benefit per dollar invested is different for each location. In the Perth Hills area, the strategy that generates the highest benefits per dollar invested is the land use policy, whereas in the Bridgetown area it is additional fuel reductions in DPaW managed land. In the Perth Hills, because of the large number of high value assets at risk in the area and the large number of fire incidents per year, the strategy that reduces the number of asset at risk generates the greatest benefits. In contrast, the Bridgetown area has a much lower number of high value assets, lower numbers of fire incidents per year, and a large proportion of natural and conservation areas; thus the strategy that reduces the chances of large, intense and costly bushfires occurring generates the greatest benefits.

The results from this study seem to indicate a tendency: in areas where there are high numbers of people, dwellings, commercial buildings and infrastructure (i.e. high value human assets), the highest value for money for additional investments in fire management is obtained from land use planning; while in areas where there is an abundance of natural areas, high values for biodiversity and a smaller concentration of high value human assets, the highest value for money for additional investments is obtained from fuel management. However, this observation is to be appreciated with caution. Each area is unique in its context and the results cannot be generalised to the whole State, even for similar areas. When the bushfire management context changes, the source of the costs and benefits also changes and the results between two seemingly similar areas can differ.



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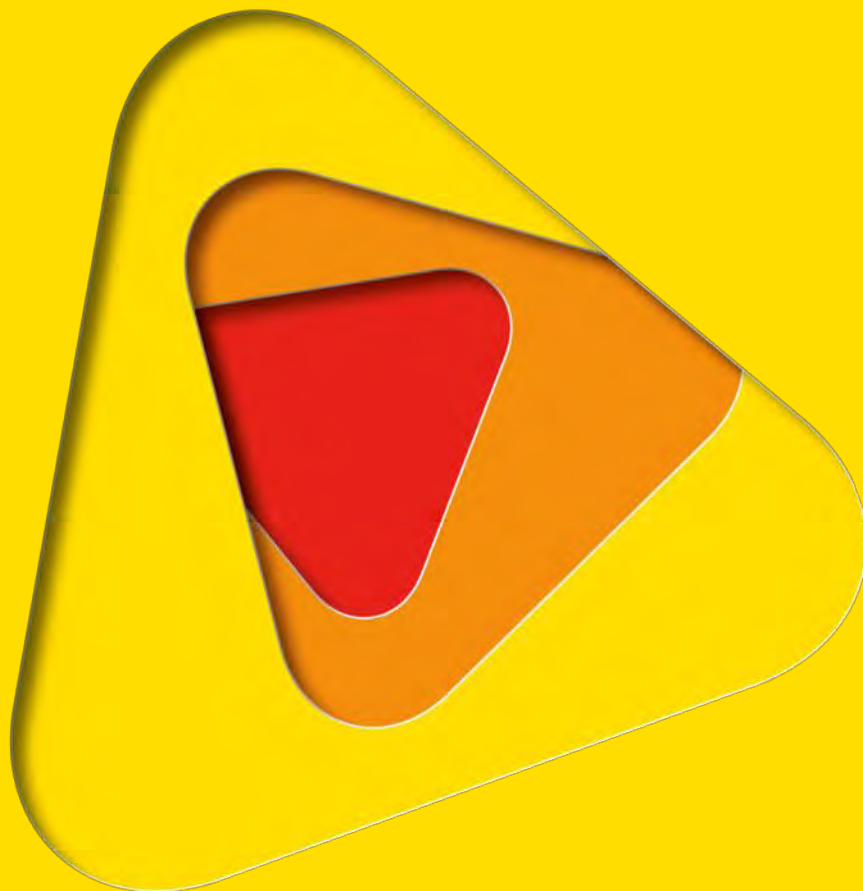
NATIONAL MENTAL HEALTH AND WELLBEING STUDY OF POLICE AND EMERGENCY SERVICES

Non-peer reviewed research proceedings from the Bushfire and Natural
Hazards CRC & AFAC conference
Sydney, 4 – 6 September 2017

Jennifer Bartlett

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Presenter: Nick Arvanitis, beyondblue





ABSTRACT

People who work or volunteer for ambulance, fire and rescue, police and state emergency services provide vital care and protection to the Australian community. The nature of emergency services work means police and emergency services personnel routinely face life and death challenges and can witness very distressing situations. Like other workers, they can experience common workplace risks to mental health, such as heavy workloads, high demands, and bullying. Stigma regarding mental health conditions is still prevalent in many traditionally male-dominated occupations, such as emergency services. There is also anecdotal evidence to suggest that police and emergency service personnel who retire or leave the job may have high rates of depression, anxiety and suicide.

beyondblue, with support from the Bushfire and Natural Hazards Cooperative Research Centre, is currently undertaking a national research study to build a comprehensive picture of the mental health and wellbeing of police and emergency services personnel in Australia. This study is using qualitative and quantitative methods in combination with a strong focus on knowledge translation to develop ways to improve mental health in the workplace. As part of this study, we are conducting the first national survey of mental health and wellbeing of current and former employees and volunteers across the sector.

This presentation will describe the development and design of the study. It is planned to survey over 20,000 employees and volunteers nationwide using an online survey vehicle. The survey will collect information about wellbeing and common mental health conditions such as anxiety, depression and Post Traumatic Stress Disorder, suicide risk, stigma, help-seeking behaviour and factors that support or jeopardise the mental health of police and emergency services personnel. A key aspect of the project will be the knowledge translation phase which will draw from the survey findings to identify and develop feasible, acceptable and practical interventions and strategies to improve the mental health and wellbeing of police and emergency services personnel around Australia.

A new quantitative smoke forecasting system for Victoria

Non-peer reviewed research proceedings from the Bushfire and Natural Hazards
CRC & AFAC conference

Sydney, 4 – 6 September 2017

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ABSTRACT

Smoke dispersion is a key concern for Government agencies. Government has a responsibility to protect community health in response to smoke events and to minimise the impact of smoke from planned burning. To inform community warnings and planned burn management, quality information is needed to support evidence-based decision making.

The Bureau of Meteorology has operated the HYSPLIT smoke dispersion system for use by fire and land management agencies for around 15 years. Recently DELWP funded research to improve smoke emission and transport modelling in Victoria. This project developed a new multi-tiered quantitative smoke prediction system which is a significant step forward compared with the old system. It applies recent observations of Victorian smoke emissions and atmospheric chemistry (as embodied in CSIRO's Chemical Transport Model) with the increased numerical capability in ensemble and high resolution weather modelling of the Bureau's ACCESS Numerical Weather Prediction suite.

The new smoke forecasting system has 3 tiers; Tier 1: 10-day ensemble forecasts of fire weather and fire danger indices to assist decisions on burn scheduling, Tier 2: 3-day forecasts of ambient air quality and smoke concentration from existing fires to provide background conditions for burns, and Tier 3: 1-day high resolution forecasts of smoke for planned prescribed burns to support go/no-go decisions.

In this presentation we will demonstrate the improved user interface for the smoke dispersion system and provide examples of output for each of the 3 forecast tiers. We will also describe the methodology for verifying the system output, including initial verification results. Finally areas of potential future work will be discussed, including how other jurisdictions can be involved so that this can become a national smoke dispersion system.



INTRODUCTION AND BACKGROUND

Government has a responsibility to protect community health in response to smoke events and to minimise the impact of smoke from planned burning. This involves monitoring smoke in the environment, particularly during fire events, and making evidence-based decisions about the effects of additional smoke from planned burning.

Smoke from vegetation fires is a mixture of different-sized particles, water vapour and gases. Microscopic particles such as PM_{2.5} and PM₁₀ (defined as particles with diameters of less than 2.5 or 10 micrometres, respectively) and gases are small enough to be breathed deep into the lungs and can cause harmful health effects.

A new smoke forecasting system has been developed as a collaborative effort between the Bureau of Meteorology, CSIRO and DELWP to provide quantitative forecasts of the concentration of particles and other pollutants at ground level, along with other supporting information, to enable better decision making by planned burn managers. The system builds upon recent scientific research involving Melbourne, Monash, Wollongong and Macquarie Universities which addressed many of the knowledge gaps related to smoke emissions from burning fuels typically found in southeastern Australia. The results were incorporated into an integrated smoke forecasting system that explicitly models the temporal evolution of smoke emissions from fires during different stages of the burn cycle.

SYSTEM OVERVIEW

The smoke forecasting system was designed to support risk mitigation and resource allocation planning at different time scales as shown in Figure 1. Agency personnel can access the forecasts on their desktop computer or mobile device by logging into a registered user website hosted by the Bureau.



FIGURE 1. 3-TIERED SMOKE FORECASTING SYSTEM

TIER ONE: COMING WEEK

To indicate whether conditions are likely to be favourable for planned burning in the coming week, medium range forecast products are generated from ensemble numerical weather prediction (NWP), where multiple runs of the weather model simulate the range of possible conditions. Probability charts for Forest Fire Danger Index (FFDI), as shown in Figure 2, are generated from the relevant weather variables (temperature, relative humidity, wind speed) in each ensemble member and drought factor forecasts from the Australian Digital Forecast Database are used to compute the forecast FFDI. At each grid point the probability of FFDI exceeding a certain threshold (for example, 25, or "very high") is estimated as the fraction of individual ensemble members forecasts with a FFDI value greater than or equal to the threshold.

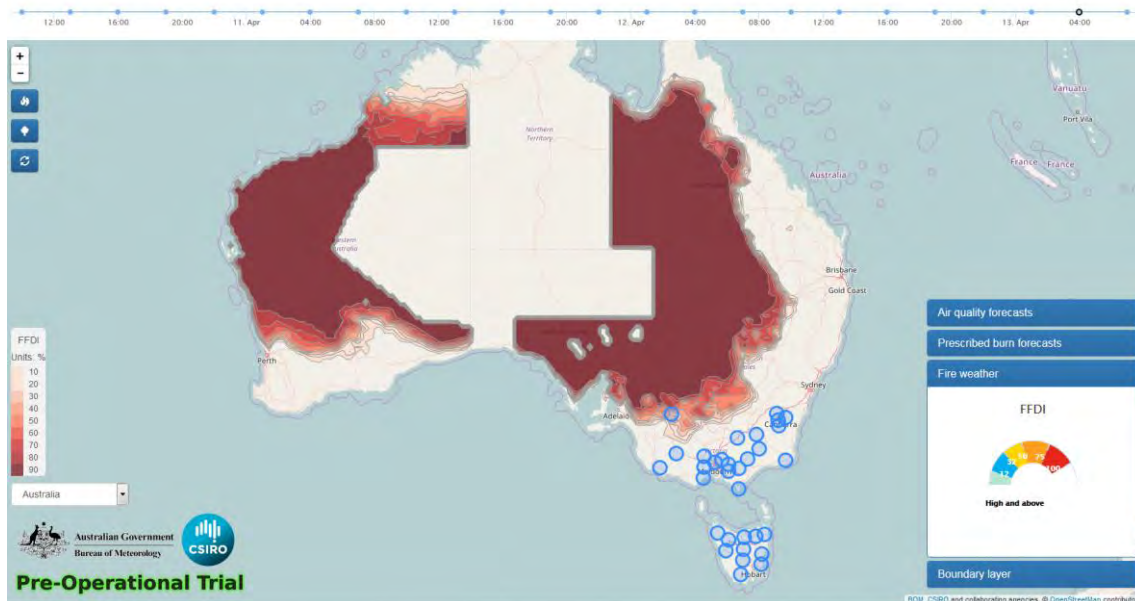


FIGURE 2. PROBABILITY CHART FOR FFDI > 12, VALID 4 AM LOCAL TIME 13 APRIL 2017. BLANK AREAS IN CENTRAL AUSTRALIA ARE DUE TO SOIL MOISURE DATA BEING UNAVAILABLE.

Ensemble meteograms are available for specific locations shown by blue circles on the map. These show the time evolution of wind speed, temperature, relative humidity, FFDI and GFDI. The median forecast is shown by the red line, while the box-whiskers show the distribution of possible values at each time. This is very useful for showing more extreme (but less likely) values that might be cause for concern.

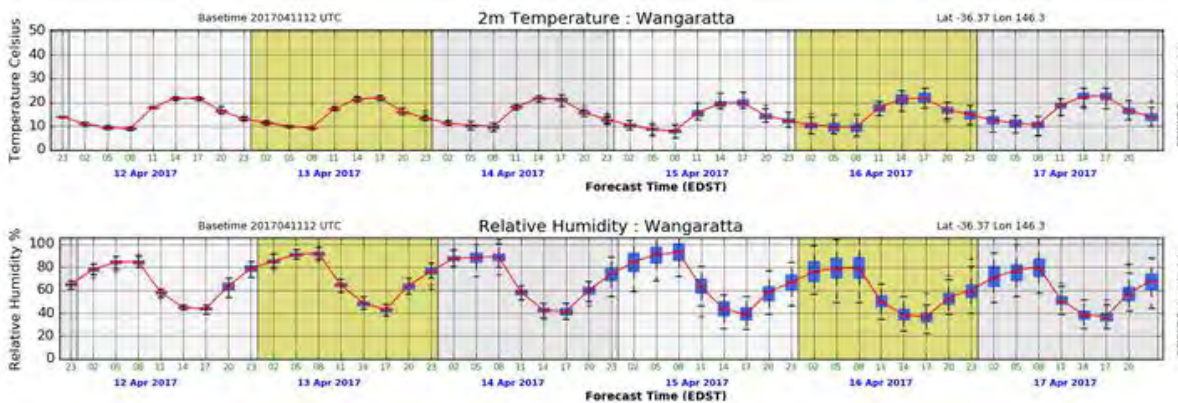


FIGURE 3. METEOGRAM SHOWING ECMWF ENSEMBLE INFORMATION OUT TO 6 DAYS (NOT ALL ELEMENTS DISPLAYED).

TIER TWO: NEXT FEW DAYS

To estimate the background air quality to which smoke from prescribed burning may be added, the regional air quality prediction system generates 3-day forecasts of fine particles and fine particle precursors for the Australian region. Meteorological forecasts from the ACCESS-R NWP model are used to drive CSIRO's Chemical Transport Model (C-CTM) in which aerosol and gaseous emissions are transported and can evolve, react with other compounds, and settle out. Sources of anthropogenic and natural emissions include

State EPA air emissions inventories, sea salt, dust and the biogenic emissions of volatile gases for the subsequent generation of secondary organic aerosol. In the case of fires, smoke emissions for the greater Australian region are generated from Sentinel hotspots. For Victoria, emissions are generated from DELWP active fire data with fire spread and intensity estimated using the Phoenix FireFlux modelling system (Walsh et al 2016).

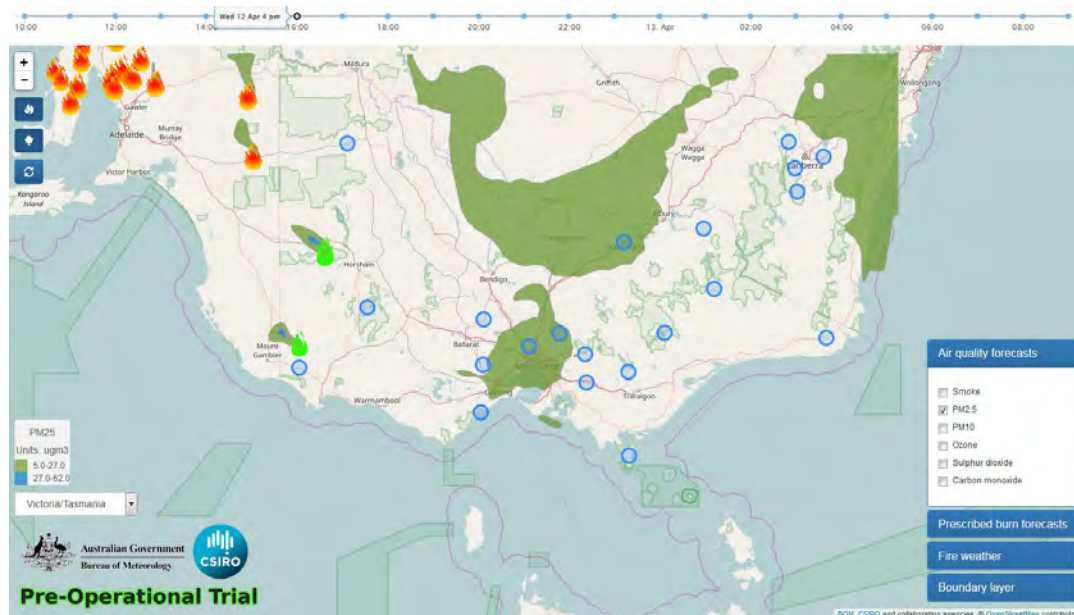


FIGURE 4. PM2.5 FORECAST VALID 4 PM LOCAL TIME 12 APRIL 2017, SHOWING INCREASED CONCENTRATIONS DUE TO GOING FIRES AND PRESCRIBED BURNS.

Additional meteorological forecast information to support prescribed burn planning includes spatial maps of ventilation index, atmospheric boundary layer height and transport wind and aerological (Skew T – log P) diagrams for specific locations.

TIER 3: TOMORROW

The prescribed burn forecast (see Figure 5) uses planned burn data from DELWP to create scenarios of the potential smoke effects from planned burns. Phoenix FireFlux is run based on burn information and weather data to generate a grid of cells burnt every 15 minutes. These grids are passed to an emissions module to estimate the emissions of PM2.5 and the plume rise of the smoke column. The emitted smoke is then dispersed by the coupled ACCESS-C weather model and C-CTM at 1km grid resolution. The ground-level footprint of each individual prescribed burn is then plotted in spatial maps at hourly time steps for use by DELWP. The model is run each afternoon so a final decision can be made on whether or not to go ahead on the following day, based on predicted PM2.5 concentrations. Smoke dispersion from up to 64 individual fires is tracked separately in the system, allowing them to be virtually “turned on” and “turned off” to assess their contributions to the overall particulate load and possible exceedances of the PM2.5 24-h average air quality standard ($25 \mu\text{g m}^{-3}$). Tier 3 prescribed burn forecasts utilise a simplified atmospheric chemistry.

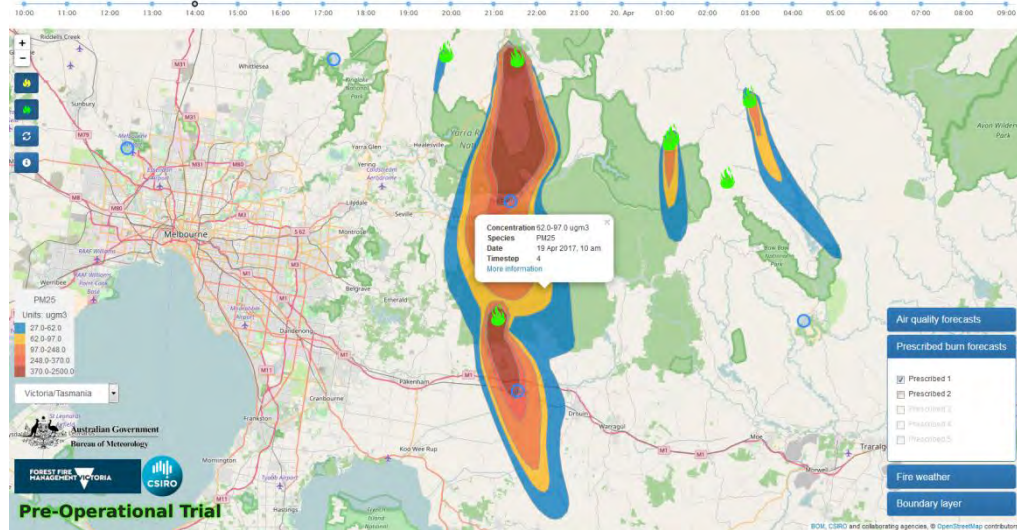


FIGURE 5. PRESCRIBED BURN FORECAST VALID 2 PM LOCAL TIME 19 APRIL 2017, SHOWING THE PM2.5 OUTPUT FROM 5 SEPARATE PLANNED BURNS

SYSTEM VERIFICATION

Environment Protection Authority Victoria (EPA) monitors levels of PM_{2.5}, PM₁₀, ozone, sulphur dioxide and carbon monoxide at 17 sites across the state.

Verification software has been developed which allows the EPA data to be easily compared with the model values.

Some initial verification results are shown in Figure 6. This validation is guiding improvements in the modelling.

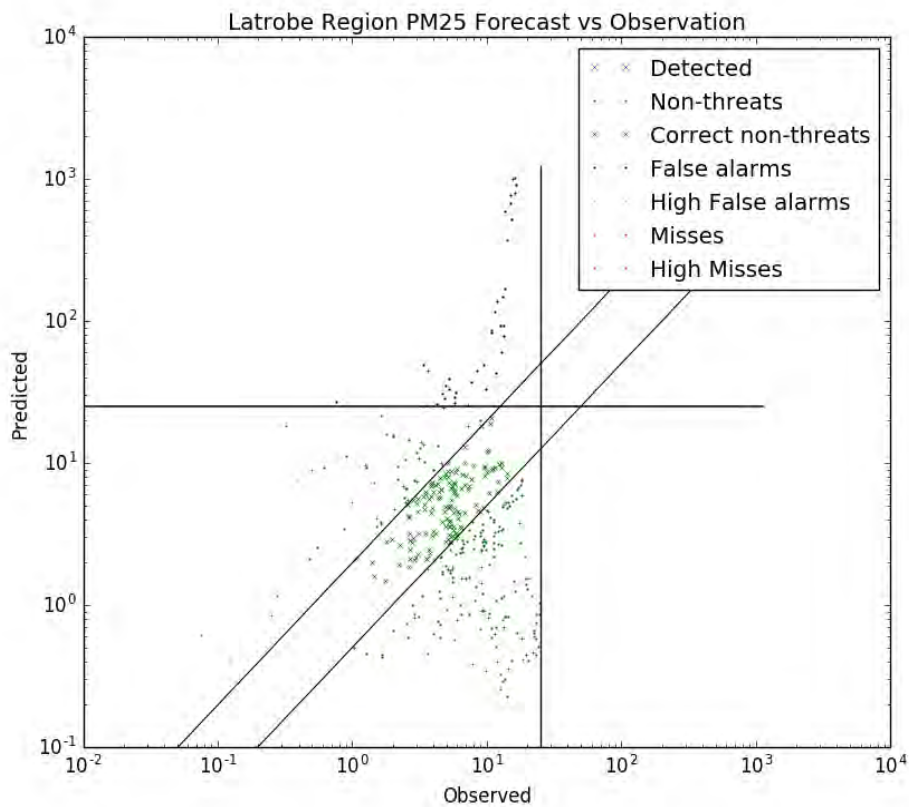


FIGURE 6. PREDICTED VERSUS OBSERVED PM_{2.5} FOR LATROBE VALLEY REGION, APRIL – MAY 2017. DIAGONAL LINES INDICATE WHERE THE FORECAST IS ACCURATE WITHIN A FACTOR OF TWO.



FUTURE WORK

Once the quantitative smoke forecasting system is operational, the Bureau will continue to provide an ongoing smoke forecasting service for fire agencies on a cost-recovery basis. The initial system is optimised for Victoria. With appropriate investment, the system could be expanded to provide all three tiers across the country. CSIRO are undertaking a new project to display real time smoke intelligence from satellite and radar remote sensing and social media reports of smoke. This will provide "ground truthing" for forecasts in real time, helping agencies to make better use of the products.



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EVIDENCE-BASED RISK COMMUNICATION: AN INDUSTRY- ACADEMY RESEARCH COLLABORATION THAT ENHANCED DAM RELEASE MESSAGE EFFECTIVENESS

Non-peer reviewed research proceedings from the Bushfire and Natural Hazards CRC & AFAC conference
Sydney, 4 – 6 September 2017

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INTRODUCTION

In the past, intuition, experience, and anecdotal information have shaped the design of public risk communication and education campaigns, potentially limiting their effectiveness (Wood et al., 2012). However, collaborations between industry and academia better use and combine theory with practice and can generate evidence to support or counter intuitive thinking. This extended abstract outlines the research collaboration between Seqwater and QUT, which supported Seqwater's response to the Inspector-General for Emergency Management's (IGEM) review of dam release messaging.

In their 2015 Review of Seqwater and SunWater Warnings Communications, the Office of the Inspector General for Emergency Management (IGEM) identified the need for more effective communication from Seqwater and SunWater during natural hazards. Specifically, under Recommendation one – Messaging, IGEM recommended that Seqwater and SunWater focus immediate attention and action on issues of collaboration with local disaster management groups, addressing information sharing, messaging responsibilities, terminology and timing (IGEM, 2015).



RISK COMMUNICATION

The research collaboration was informed by QUT researchers' synthesis of risk communication models collated for the Bushfire and Natural Hazards CRC and Seqwater's knowledge of dam operations and the capabilities of their communication system. Risk communication is an important tool for encouraging risk mitigation and response. Covello, von Winterfeldt and Slovic (1986) define risk communication as any purposeful exchange of information about risk between interested parties. How well people prepare for a natural disaster is influenced by effective communication (or the absence of it) (Basic, 2009). Failure to implement effective communication strategies can increase the risks faced by individuals and organisations during risk events (Sellnow, Ulmer, Seeger, & Littlefield, 2009).

To communicate risk effectively, emergency management organisations need to consider how warning messages are presented and whether such messages interact with individual information processing to inform protective behaviour in response to hazards (Griffin, Dunwoody, & Neuwirth, 1999). Previous research identifies eight message characteristics that may influence how community members process information to make decisions during natural hazards and ultimately contribute to protective behaviour. These characteristics are: accuracy, certainty, consistency, clarity, sufficiency, specificity, guidance, and relevance (Tippett et al., 2015). These characteristics have been central to the research and message design.



RESEARCH DESIGN

The research program adopted a multi-method, multi-phase approach. Prior to conducting empirical research, Seqwater's existing dam release messages were reviewed against the eight characteristics of effective messages (Tippett et al., 2015) and modified to add or enhance specificity, clarity, clear guidance, relevancy and consistency.

PHASE ONE. FOCUS GROUPS

In March 2016, six focus groups were conducted with participants who lived or operated businesses in areas downstream of North Pine, Wivenhoe and Hinze dams. In total 33 participants provided views on:

- flooding risk perceptions
- knowledge and expectations of dam operations
- communication expectations for Seqwater
- the efficacy of existing and modified dam release messages.

Focus groups were transcribed and thematically coded using NVivo to identify and examine the meanings and experiences of participants. In particular, participant sentiments around existing and modified messages were analysed against the eight characteristics of effective message design (Tippett et al., 2015). Collectively, these findings were used to further refine the messages for phase two testing.

PHASE TWO. COMMUNITY SURVEY

In June and July 2016, online surveys were developed and distributed to 1,334 respondents. Initially, residents within at-risk downstream suburbs and early warning notification subscribers were targeted. When this participant pool was exhausted, the approach was widened to residents of South East Queensland. Respondents were asked to report on:

- informational channels and platforms they use
- perceived trust in different information sources
- efficacy of existing or refined messages for message comprehension, risk perceptions, and information processing.

Data were analysed using descriptive statistics, paired sample t-tests, analysis of variance (ANOVA), and analysis of covariance.



FINDINGS

Key findings from the research are presented below.

INITIAL MESSAGE REVIEW

The initial review of Seqwater's existing messages against the eight characteristics of effective messages (Tippett et al., 2015) indicate that messages are accurate, certain and sufficient. However, message specificity, guidance, relevance, consistency and clarity could be improved. Modifications to the existing messages were made and tested during focus groups.

PHASE ONE: FOCUS GROUPS

Focus group findings are presented across four themes: 1) risk perceptions, 2) knowledge and expectations of dam operations, 3) expectations for Seqwater, and 4) message design. During the focus groups, participants noted that their perception of risk was influenced by past experiences, which may inadvertently increase their sensitivity to technical terms contained within messages. Participants demonstrated general understanding of dam operations and functions though were less familiar with the operational limitations of gated versus ungated dams. However, participants lacked geographical awareness about their position in relation to the dam or catchment areas despite having a strong understanding of how their local area would flood. During heavy rainfall events, participants expected to hear from Seqwater in relation to a dam release or spill but also from government and emergency management organisations, suggesting value in an integrated or collaborative response. Participants made a number of observations relating to the message design. In particular, participants expected messages to include specific information about spill timing and volume, contain clear and directive instructions, use clear and jargon-free language, and be consistent with warnings from other organisations.

PHASE TWO: COMMUNITY SURVEY

Based on focus group findings, Seqwater messages were modified in two ways. First, to assure community-centred communication, the 18 existing messages were reduced to a targeted suite of 12 messages. Second, within each message, content was modified to enhance clarity, specificity, relevance and guidance. Existing and modified messages were tested within the community survey.

Community survey findings are presented across three areas: 1) informational channels and platforms used, 2) perceived trust in information sources, and 3) effectiveness of existing or refined messages for comprehension, effectiveness, risk perception and information processing. First, respondents use a range of information platforms when seeking information about dams spilling or releasing water or the flooding of creeks and waterways. The most prevalent platforms included television, online news, radio, Google searches, and Facebook. Respondents' preferred information sources included Seqwater, local councils, media, and government agencies including the Bureau of Meteorology and Queensland Fire and Emergency Services. For both dams spilling or releasing water and flooding of creeks and waterways, the preferred overall source was local council but Seqwater was



considered to be a more preferred source of information for dams spilling or releasing water as opposed to the flooding of creeks and waterways.

Second, respondents' perceptions of trust in Seqwater's information was significantly positively correlated with the trust in information for each of the response agencies investigated (e.g. local council, Bureau of Meteorology, media, emergency management organisations). For some messages, trust increased following message exposure.

Third, the modified messages were often deemed to be more effective than existing messages. The modified messages generated greater perceived intentions to engage in mitigative action than existing messages. At the same time, results also highlighted the important role of systematic information processing and its relationship to message design.



CONCLUSION

The research yielded application-ready messages with evidence-based recommendations to improve the effectiveness of Seqwater's notification messages. The messages are based on the principles of risk communication theory and use plain language. In summary, the modified messages:

- use headings that clearly summarise the situation and add geographical markers by naming the affected dam (existing messages name the gated dam once releases commence)
- provide critical information in an uncluttered structure, removing unnecessary and potentially distracting headings (this is particularly the case for the modified message for Hinze Dam)
- phrase guidance or 'call to action' in direct and active language
- provide links to further information, categorised by type (e.g. weather) and supported by links to related organisations (e.g. Bureau of Meteorology)
- set expectations for timing of next message or notification once a flood event is declared for one or more gated dams
- perform well when compared to existing messages and can be easily integrated into appropriate manuals, procedures, and message templates.

The findings of this research program support Seqwater's response to the framework for action set by IGEM. Further, this research has the potential to inform policies and practices of other dam operators and be of interest and value to emergency management organisations. This collaboration also had mutual benefits: Industry partners strengthened skills in the theoretical basis of risk communication design and QUT researchers built understanding of the policies and practices that can enable and/or constrain applied communication research.



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First responder mental health: Fire and Rescue New South Wales experience

Non-peer reviewed research proceedings from the Bushfire and Natural Hazards
CRC & AFAC conference

Sydney, 4 – 6 September 2017

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ABSTRACT

Over the past decade, along with research into military populations, there has been strong interest in the mental health of first responders such as police, firefighters and paramedics, who are at risk of exposure to potentially traumatic events. For example, Harvey et al (2016) studied current and retired firefighters in NSW and found higher rates of Post-Traumatic Stress Disorder, depression, and alcohol misuse compared with the Australian adult population. Results also revealed that organisational strategies for support, treatment, and injury prevention could be enhanced. This research informed the development of FRNSW's strategic mental health framework including principles, policy and interventions. Furthermore, this framework reflects recommendations included in recent audits of emergency services' mental health programs, for example Metropolitan Fire Brigade (Cotton, 2016), Victoria Police Service (Cotton, 2016), and the 'Good practice framework for mental health' developed by Beyond Blue in their study of first responder agencies in several Australian states and territories (Beyond Blue, 2016).

This paper reports on FRNSW's 'lifecycle' approach to mental health care, which covers a firefighter and their family from recruit to post-retirement. This program builds on the existing and long-standing peer support program (in place since 1994), mental health literacy training, leader training, and initiatives to address stigma and barriers to care. Also covered will be an outline of programs developed with our partners at the Black Dog Institute, UNSW, and University of Sydney including a resilience program for recruits and incumbent firefighters.



INTRODUCTION

Research over the past few decades has revealed that firefighters are at an increased risk of mental health issues (McFarlane and Bryant, 2006; McFarlane 1989).

The operational nature of their duties poses a significant risk to a firefighters' mental health. Research with NSW firefighters by Harvey et al (2016) revealed elevated rates of psychiatric morbidity including depression, substance misuse, sleep disturbance, anxiety and post-traumatic stress symptoms. Despite being considered a generally healthy population (cf 'healthy worker effect'), rates of mental illness amongst this population exceed those found in the general adult population. This is not surprising given the nature of exposure and organisational demands of the role.

Across some agencies, including FRNSW, the traditional firefighting role has expanded beyond those of fire prevention and suppression to now include providing 'ambulance assist', rescue services (including motor vehicle accidents), 'concern for welfare', suicide, and bystander engagement such as dealing with families/others on-scene.

Additionally, firefighters may be, at times, exposed to a range of physical risks such as toxins, chemicals, and psychological risks such as high and sustained work tempo, lack of support, geographical isolation, communication difficulties, and interpersonal concerns. Unlike other workers, firefighters spend extended periods, such as 24 hour shifts with the same crew. Some crews also work together for some years within the same station or work area.

Finally, the human and economic costs to FRNSW of injuries and health concerns can be substantial. The results of an internal audit of worker's compensation claims for mental illness in 2010 found that the cost to the organisation was \$3.9M. It is therefore incumbent upon the organisation to ensure where possible that firefighters are provided with the appropriate supports and strategies to manage the stressors of their role through well researched and developed programs designed to enhance a firefighters' mental health.



BACKGROUND

This paper will address the history of mental health policy and program development at FRNSW. Our organisation is over a century old and currently employs 6,867 uniformed firefighters, of whom 3,530 are permanents, and 3,327 are retained, 446 non-uniformed, and 6,000 Community First Responders (600 units). Our people are spread across 339 locations across NSW. It is seventh largest urban fire service in the world.

The development of the mental health initiatives and their implementation will be discussed, with emphasis on the evidence base, collaboration with stakeholders (including research organisations), and incremental implementation, (including reviews), and current state. The paper will conclude with a summary of current initiatives and some discussion of points of departure for future activities in this critical area.

DEVELOPMENT OF THE MENTAL HEALTH INITIATIVES AND THEIR IMPLEMENTATION

In 2009, in collaboration with the Uni of Sydney and UNSW, FRNSW conducted a survey of permanent (Paterson al, 2012) and retired firefighters (Paterson al, 2010). The research aimed to examine interventions to enhance the coping skills and psychological wellbeing of firefighters. The findings informed and assisted FRNSW in developing practical and effective policies and initiatives to support firefighters' psychological wellbeing.

Taken together, the reports provided FRNSW with the baseline as to the nature and prevalence of mental illness within the organisation. They also provided an overview of individual coping strategies firefighters employ and suggestions as to what the organisation can do to assist them in building resilience and how better to manage the stressors inherent in their role.

On this basis, FRNSW sought to expand on the programs which existed at the time. These included a Peer Support Program, a Critical Incident Support Program (CISP), an Employee Assistance Program (EAP) and Chaplaincy support (full and part time). Moreover, FRNSW sought to develop innovative programs to address the findings of the reports. The key considerations specified that any program needed to be evidence-based or at the very least, evidence-informed, be accessible to all personnel (permanent, retained and volunteer), easy to understand, easily assimilated within a diverse workforce, and cost-effective.

There is emerging evidence supporting e-Mental Health in the treatment of depression, anxiety and post-traumatic stress disorder (Simblett et al. 2017; Rosso et al. 2016) and both supported and unsupported e-Mental Health sites in Australia such as e-couch and mindspot have proven efficacy in web-based therapy. Additionally, mobile health (mHealth) is an emerging field that uses wireless technologies such as mobile phones and other devices in health practice. The advent of apps has created new opportunities, and smartphones can keep the user connected to the Internet at all times. Furthermore, an implication of this wide acceptance of e-technologies is that they may offer a medium to improve the well-being of young people by supporting the development of mental health

initiatives such as cognitive behavioural therapy, mindfulness and health monitoring (Rosso et al. 2016).

In addition to the traditional methods of communication, FRNSW has adopted this evolving technology to ensure reach and access to all employees in metropolitan and regional areas for their mental health programs.

The innovative programs, which have been rolled out since 2012 include the following:

- Resilience At Work (RAW) is an interactive online mental health program based on 'Mindfulness'. It is aimed at developing resilience in firefighters, teaching them strategies to better deal with the challenges of life at work, and also day to day living. It is a self-paced mobile Smartphone 'app' (tailored platform) covering six 20-minute modules. Mindfulness is a skill that can be developed through practice and has been found to have beneficial psychological, somatic, behavioural and interpersonal effects (Rosso et al. 2016)). Mindfulness has been found to reduce psychological distress and optimize psychological functioning in young people, and there is growing evidence for the efficacy of mindfulness-based programs in promoting well-being, reducing depression and preventing relapse in depression (Rosso et al. 2016).
- FIT MIND is a training program to mentally and emotionally prepare recruits for their roles as firefighters. It is comprised of three fifteen-minute multi-media sessions which use the lived experiences of current and retired firefighters. It includes statements such as 'check yourself', 'check your mates', 'be responsible', 'be accountable', and 'ask for help if you don't bounce back as quickly as you once did'.
- RESPECT is an awareness program for FRNSW managers and involves a half-day face to face education session addressing mental health literacy and provides guidance on how to communicate with employees suffering a mental illness. At present, an online version of this program called HEADCOACH is being trialled by Ambulance NSW.

The newer programs are being evaluated in an ongoing fashion to determine their utility and effectiveness. In addition to these programs, FRNSW is also considering HEADGEAR, which is self-assessment Smartphone app. Trials are likely to commence in the latter half of 2017.

The suite of offerings has expanded in recent years and also includes some newer initiatives which are also in place across a number of emergency services and related organisations. These include Mental Health First Aid Training (www.mhfa.com.au/), Well-checks for Peer Support Officers and soon-to-be retired firefighters, family induction, and bystander engagement for rescue stations. The evaluation of each initiative and their compliance with our key considerations is ongoing.



SUMMARY OF CURRENT INITIATIVES AND SOME DISCUSSION OF POINTS OF DEPARTURE FOR FUTURE ACTIVITIES

In broad terms, the evaluation of the range of services and programs available within FRNSW has been limited to RESPECT. This evaluation was conducted in collaboration with the UNSW and the Blackdog Institute, and the published results will be available in the coming months. Early indications are that the program may have increased managers' confidence and likelihood in communicating with an employee suffering from a mental illness, and a reduction in sickness absence. Additionally, there was a likely cost benefit to the organisation when managers reached out to an absent firefighter.

The results for FITMIND and RAW will be forthcoming in 2017/2018. In the meantime, FRNSW is committed to continuing the programs, evaluating, and considering further approaches to build the resilience of firefighters and maintain their mental health and wellbeing.



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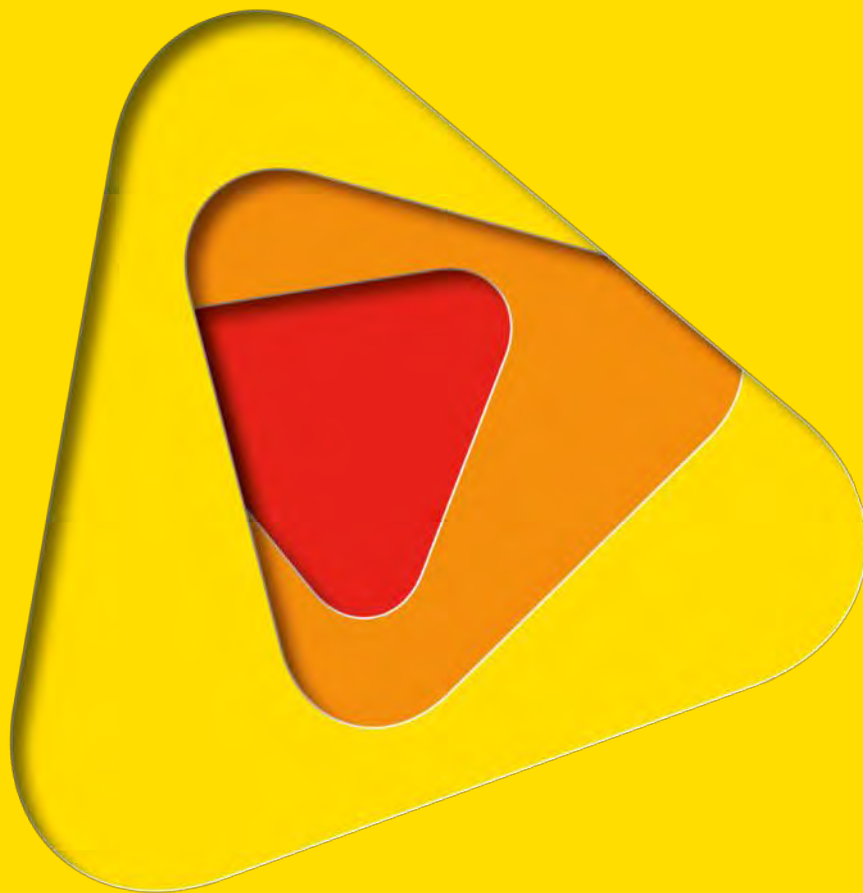


UNPACKING THE SECTORAL INCOME EFFECTS OF NATURAL DISASTERS: EVIDENCE FROM THE 2010-11 QUEENSLAND FLOODS

Non-peer reviewed research proceedings from the Bushfire and
Natural Hazards CRC & AFAC conference
Sydney, 4 – 6 September 2017

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ABSTRACT

The past few decades witnessed a rapid increase of researches that rigorously investigated the nexus between economic performances and natural disasters. However, the rise of the interest in studying this nexus is not surprising provided that natural disasters trigger severe destruction in capital stocks and incur disruption in income flows. As such, the focus of many the studies is on demonstrating disaster shock impacts on outcomes such as agricultural output, industrial output, labor productivity, energy demand, health, conflict, and economic growth, among others (Dell M. et al, 2014). This paper estimates the impact of the 2010-11 Queensland Floods on sectoral income level using the Australian Census Longitudinal Dataset (ACL), which brings together a nationally representative 5% sample from the 2006 Census with records from the 2011 Census of Australia. In our empirical setting, we treat the 2010-11 Queensland floods as a natural experiment by treating the flood-affected group of individuals as the treatment group, while treating the rest of the Queenslanders remains as the control group. This approach enables us to compare the economic differences in before (2006 Census) and after (2011 Census) the event between the group of flood-affected individuals and their counterfactuals. Our estimates indicate that the 2010-11 Queensland floods incident has no bearing on overall gross state product (GSP), but it adversely affects individuals working in construction, and accommodation and food services. However, Queenslanders working in retail trade, transport, postal and warehousing, and rental, hiring and real estate services cashed in opportunities brought by this catastrophic event. In addition, we find that the 2010-11 Queensland floods hit the lower income-group the hardest in terms of their loss in annual income. Our findings have several policy implications in that government's budgetary allocations related to disaster risk reduction programs should vary across sectors and group of individuals in accordance with their potential disaster effects.



INTRODUCTION

Natural disasters are natural in terms of their origination in physical environment, but their consequences on economic sphere are often obscure. According to the standard neoclassical growth theory, natural disasters destroy capital that leads to lower output. That is, natural disasters may cause a decline in gross domestic product (GDP) of a country. On the contrary, capital destruction may also allow the economy to replace the out-dated equipment and structures, which can shift the PPF outward boosting economic performance (Caballero and Hammour, 1994).

Empirical findings echo such double-edged theoretical arguments. For example, Cavallo et al. (2010), Cuaresma et al. (2008), Leiter, Oberhofer and Raschky (2009), Noy (2009), and Strobl (2012) indicated that natural disasters mark a downturn in the economy, while several scholars (e.g., Skidmore and Toya, 2002; Leiter, Oberhofer and Raschky, 2009; Loayza et al., 2012; and Fomby et al., 2013) document an upturn income effect of natural disasters. A few studies (e.g., Caselli and Malhotra, 2004; Albala-Bertrand, 1993; Cavallo et al., 2014) bring more ambiguities in this vein **indicating that natural disasters have negligible or even no impact on countries' development trajectories.**

One of the primary reasons of observing such contradictory findings is the application of different empirical strategies under different country settings for different time periods. Many studies take cross-country approaches using panel datasets, while several studies carry out country-specific analyses either using time series or survey datasets (see Felbermayr and Gröschl, 2014; Masters and Mcmillan, 2001; Loayza et al., 2012; Keefer, Neumayer and Barthel, 2011; Roger, 2007; Cuñado and Ferreira, 2011). In addition, some studies (see Kousky C., 2014) investigate all types of natural disasters in a single platform as if they are identical what they actually are not in term of their bearings on economic indicators. There are a few studies that investigated a single disaster type but allow multiple events over a given period (see Loayza et al., 2012). One caveat with this approach is that even a same set of disasters may vary in terms of their magnitude or intensity that tends to affect economic performance differentially (see Loayza N. V., et al., 2012). Above all, most of the extant studies suffer from having no counterfactuals, that is, what could happen with economic performance in the absence of such natural disasters.

The core objective of this paper is to extend this line of research by systematically investigating the impact of 2010-11 Queensland floods incident on sector-disaggregated economic outcomes using a Difference-in Differences (DID) technique at the individual level.



METHODOLOGY

We use the Australian Census Longitudinal Dataset (ACLD), 2006 and 2011, which brings together a nationally representative 5% sample from the 2006 Census with records from the 2011 Census administered by the Australian Bureau of Statistics. This is a unique and extensive dataset to facilitate the sectoral impact of a devastating natural disaster in Australia. The availability of such rare data lays the ground of conducting a natural experiment to explore how Australian citizens are truly affected due to the 2010-11 Queensland floods.

In our DID setting, we treat the 2010-11 Queensland floods as a natural experiment by treating the flood-affected group of individuals as the treatment group, while treating the rest of the Queenslanders remains as the control group. This approach enables us to compare the economic differences in before (2006 Census) and after (2011 Census) the event between the group of flood-affected individuals and their counterfactuals (i.e., group of Queenslanders residing in flood un-affected areas). We ensure comparability conditions between our treatment and control groups by matching individuals in terms of their level of incomes, employment status in the same economic sector, while also controlling for their ages and education attainment levels. This strategy is novel in that it pins down the causal income effects of the QLD floods 2010-11 at individual level (see Figure 1 that depicts the estimation method).

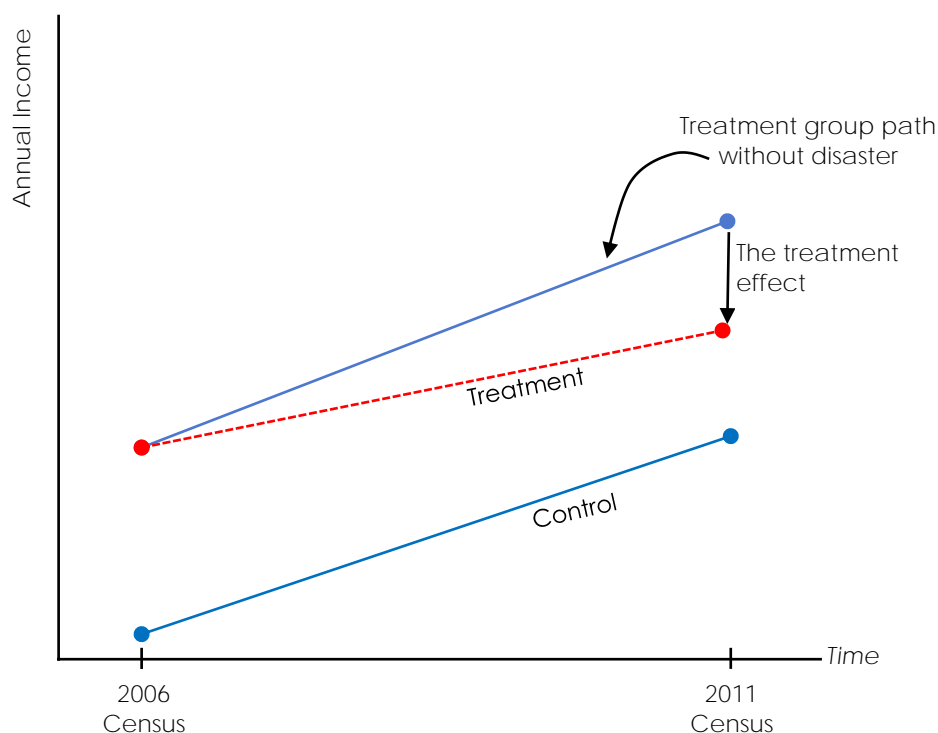


FIGURE 1 - DISASTER IMPACT ASSESSMENT METHOD

Besides our novel approach in estimating the causal impact of the 2010-11 Queensland floods, this paper extensively analyses several factors that might cause bias the findings. For example, floods may force some individuals to migrate from flood-ravaged areas to unaffected suburbs; This may contaminate our post-disaster control cohorts. To clear out such doubts, we empirically check whether individuals'



migration decision is a function of flood severity, and find no evidence for such hypothesis.

In this strand of research, no paper—to our knowledge—has hitherto estimated the spillover effects of natural disasters. To shed some lights on this, we split our control areas into two groups: the adjacent control areas that might have experienced some effects of the Queensland floods, and the distant control areas that are unlikely to expose any flood spillovers. We compare our treated cohorts first with the adjacent control cohorts and then with the distant control group. The difference is likely to uncover the spillover effect of such peril (if any).



KEY RESULTS

Our findings indicate that the 2010-11 Queensland floods incident has no bearing on overall gross state product (GSP), which is consistent with the extant literature. When we disaggregate our sample by economic sector, we find that individuals working in construction, and accommodation and food services lost their annual income by around AUD 779 and AUD 1198 on average, respectively. However, Queenslanders working in retail trade, transport, postal and warehousing, and rental, hiring and real estate services cashed in opportunities brought by this catastrophic event. In particular, workers in the rental, hiring and real estate services became the most beneficiary group; they earned approximately AUD 2617 more than what they could have earned in the state of no disaster. Finally, we find that the 2010-11 Queensland floods hit the lower income-group the hardest in terms of their loss in annual income.



CONCLUDING REMARKS

The findings of this paper have several policy implications. The policies that matter the most are those that bear directly on resource allocation—by both federal and state governments—across sectors and different individual groups. That is, policies related to sectoral development should not be generic in terms of addressing disaster risks. Disasters affect several economic sectors as well as different cohorts of population differentially; some experiences negative gains while a few even find positive gains. Hence, budgetary allocations related to disaster risk reduction programs should vary across sectors and group of individuals in accordance with their potential disaster impact.



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SHELTERING IN PLACE DURING FLOODING: A CASE STUDY OF EX CYCLONE *DEBBIE*

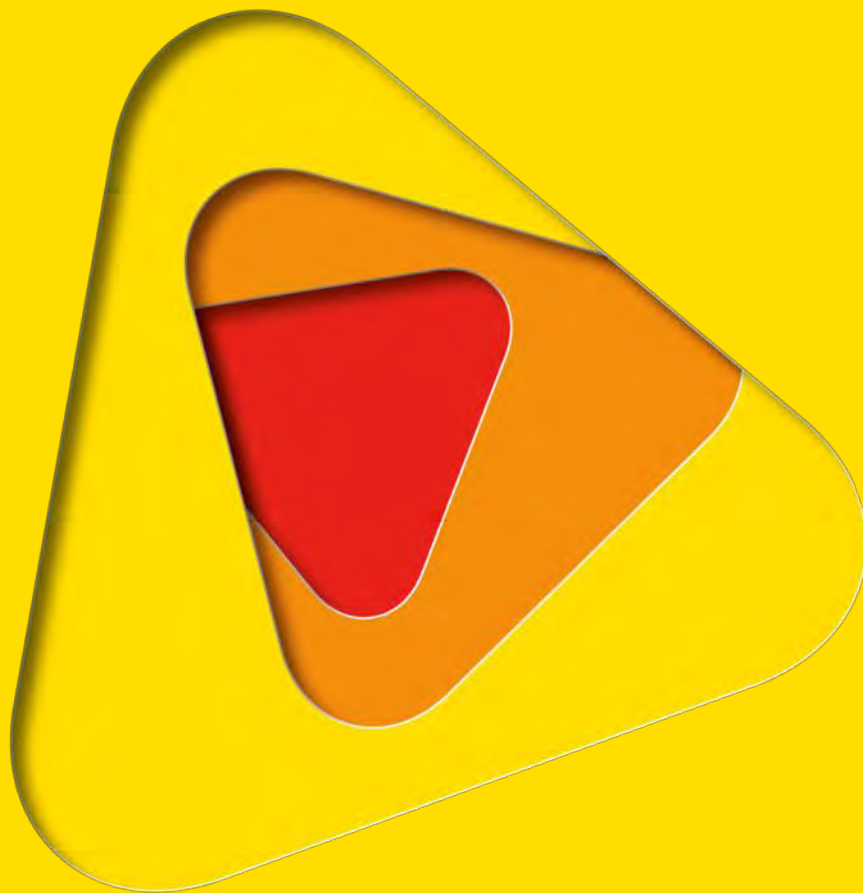
Non-peer reviewed research proceedings from the Bushfire and Natural Hazards CRC & AFAC conference
Sydney, 4 – 6 September 2017

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ABSTRACT

Some anecdotal evidence of the dangers and challenges that residents face when sheltering in place during flooding exists; however, little detailed research has been conducted documenting peoples' actual experiences. The March / April 2017 flooding in Northern NSW presented an opportunity to investigate the experiences of those who had sheltered in a home or business. The research methods included in-depth interviews and a questionnaire conducted online, over the phone and in-person with residents and business owners in the Richmond, Brunswick and Tweed river catchments. The research was conducted between April and July 2017. This paper will present findings about preparation and intentions, responses to warnings, factors influencing sheltering or evacuation behavior and the risks and challenges faced. Although early evacuation will remain the safest option in many flood situations, the research has identified that a culture of sheltering exists in the Northern Rivers area. This research provides insights into the challenges and risks of sheltering, but also to the diverse motivations and reasoning that influence how people respond to floods. This work will begin to inform how emergency services can better prepare communities, where sheltering is commonplace, for the physical and emotional realities they may face.



IMPROVING FLOOD FORECAST SKILL USING REMOTE SENSING DATA

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ABSTRACT

Floods are among the most important natural disasters in Australia. The average annual cost of floods in the last 40 years has been estimated to amount to \$377 million, with the 2010-2011 Brisbane and South-East Queensland floods alone leading to \$2.38 billion in economic damage, and 35 confirmed deaths. Flood forecasting systems are the most important tools to limit this damage, but are prone to a considerable degree of uncertainty.

During the last decades, significant research focusing on the monitoring of the global water cycle through satellite remote sensing has been performed. The strength of remote sensing is the opportunity to provide information at large spatial scales, including areas that are difficult or impossible to monitor using on-ground techniques. For these reasons it is believed that the use of remote sensing data can improve the quality of operational flood forecasts.

Operational flood forecasting systems typically consist of a hydrologic model, which estimates the amount of water entering a river system, and a hydraulic model, which models the flow of water inside the river system. However, hydrological and hydraulic models are prone to a significant degree of uncertainty and error, caused by errors and uncertainties in the initial conditions, meteorological forcing data, topographic data, and model errors and/or oversimplification (Li *et al.*, 2016; Grimaldi *et al.*, 2016). In order to reduce this predictive uncertainty, we propose to constrain the models using remote sensing data. In particular, remotely sensed soil moisture data are being used to improve the hydrologic model results, while remotely sensed water levels and/or flood extent data can be used to support the hydraulic model implementation, calibration and real time constraint.

The project focusses on two test sites, the Clarence River in New South Wales and the Condamine-Balonne River in Queensland. Figure 1 shows an overview of these test sites.

Initial catchment soil moisture plays an important role in controlling runoff generation and infiltration processes, which consequently impact streamflow forecasting. Recent development in remote sensing techniques provide a new potential to monitor spatially distributed surface soil moisture. As a result, soil moisture assimilation for flood forecasting has been a hot research topic in the recent years. The ensemble Kalman filter (EnKF) has been widely used for soil moisture assimilation by the scientific and operational communities, due to its relatively satisfactory efficacy and efficiency. However, one of the challenge is that streamflow forecasts are calculated not only from current states, but also from antecedent states in many hydrologic models, while the EnKF updates the current states only, and so may not achieve an optimal performance. As an alternative, assimilation of surface soil moisture by the ensemble Kalman smoother (EnKS) has been demonstrated to give better soil moisture reanalysis (Dunne *et al.*, 2006). Nevertheless, the impact of the EnKS-based soil moisture assimilation on flood forecasting remains a research question.

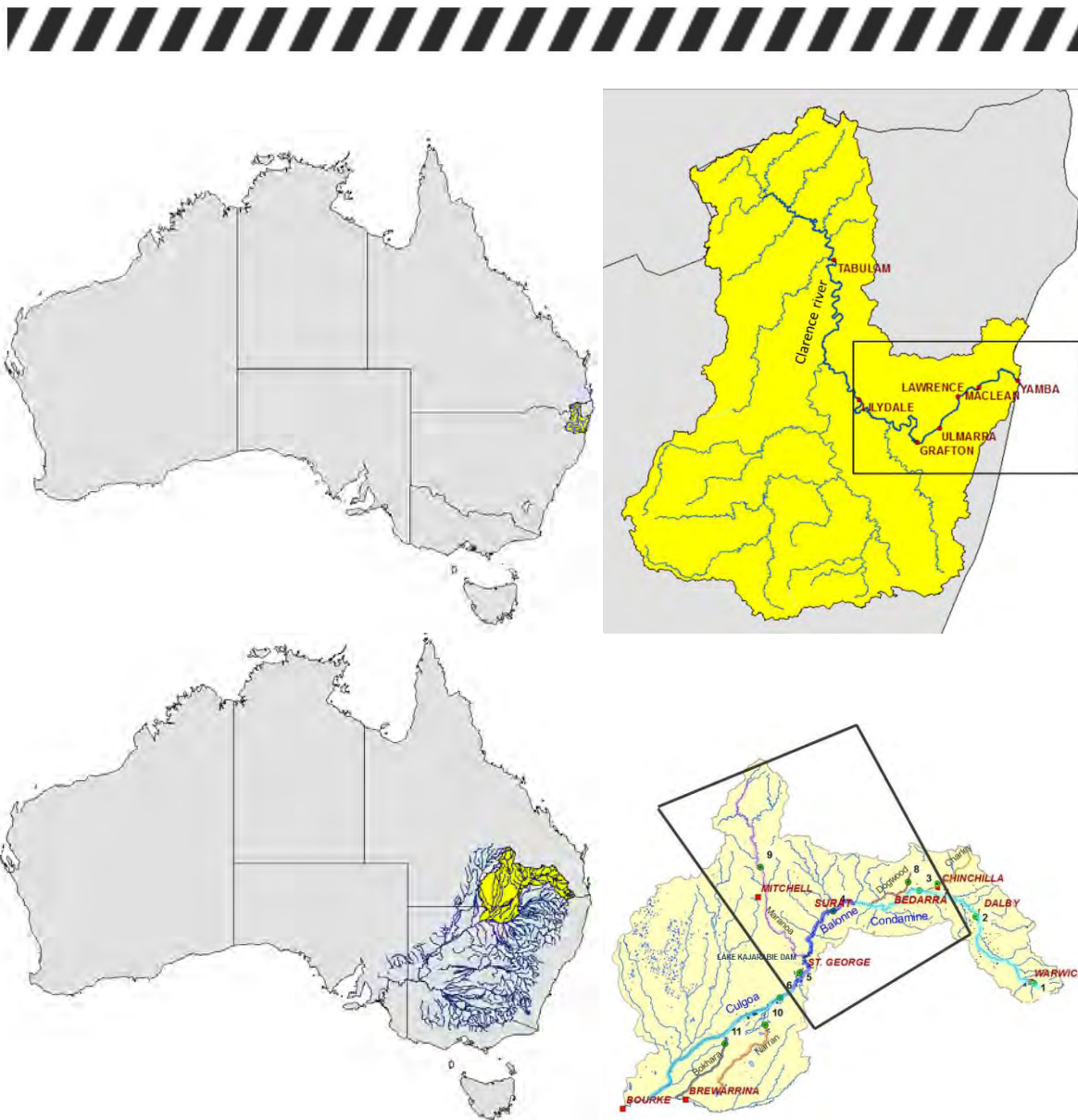


FIGURE 1. OVERVIEW OF THE TEST SITES. TOP LEFT HAND SIDE: LOCATION OF THE CLARENCE RIVER BASIN. TOP RIGHT HAND SIDE: DETAILED OVERVIEW OF THE CLARENCE RIVER BASIN. BOTTOM LEFT HAND SIDE: LOCATION OF THE CONDAMINE-BALONNE RIVER BASIN. BOTTOM RIGHT HAND SIDE: DETAILED OVERVIEW OF THE CONDAMINE-BALONNE RIVER BASIN.

In this study, the EnKF and EnKS were compared through a synthetic soil moisture assimilation experiment in the Warwick catchment, an upstream catchment in the Condamine-Balonne River Basin. A two-soil-layer conceptual hydrologic model, GRKAL, was adopted in this study. The model parameters were estimated through a joint calibration approach using gauged discharge and remotely sensed soil moisture, prior to the data assimilation experiment. The joint calibration was demonstrated to lead to a better match between observed and simulated surface soil moisture without degrading the predictability of streamflow, compared to the traditional streamflow calibration approach.

The synthetic true soil moisture and streamflow were generated by running the model with errors imposed to the input rainfall and the two simulated soil moisture states. The rainfall error was assumed to follow a lag-one autoregressive multiplicative lognormal distribution. The soil moisture errors were assumed to follow Gaussian distributions truncated by the boundaries of the two soil moisture states. The synthetic remotely sensed soil moisture was generated at 6 AM everyday (i.e., under the assumption that



only one image per day is available) by adding an observational Gaussian error to the synthetic true surface soil moisture. The synthetic true surface soil moisture was assimilated into the open loop model and the results were evaluated by the synthetic truth.

The data assimilation experiment was conducted from Jan 2012 – June 2014. Figure 1 shows a flood event in 2013. It can be seen that both the EnKF and EnKS reduce the ensemble spread compared to the open loop. The flood peak is overestimated by the open loop model according to the ensemble mean, and this overprediction is reduced by the EnKF and EnKS. Comparing the EnKF and EnKS, it can be seen that the EnKS provides more accurate streamflow predictions immediately after data assimilation, compared to the EnKF. This is because the smoothing method can address errors in antecedent state variables more thoroughly and the improvement in antecedent state variable analysis can be further propagated to the streamflow forecasts through the routing process. Nevertheless, the difference between the EnKF and EnKS becomes less significant with the increase of the forecast lead time. This can be explained by the fact that the benefit of updating antecedent states has a decreased impact with the increase of the lead time. When the forecast lead time is longer than the catchment concentration time, the EnKF and EnKS should theoretically give equivalent forecasts as the antecedent states will not be used in streamflow calculation.

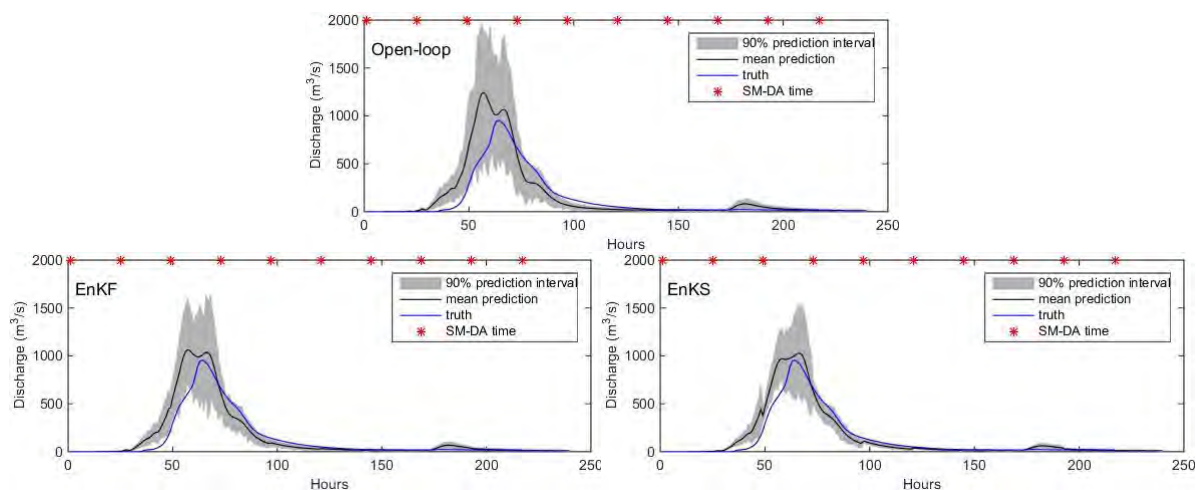


FIGURE 2. MODEL PREDICTIONS BEFORE AND AFTER DATA ASSIMILATION. THIS IS AN EXAMPLE FLOOD EVENT IN 2013.

The hydraulic model is based on LISFLOOD-FP (Bates *et al.*, 2010) and it uses the finite difference method to solve the inertial approximation of the shallow water equations.

Accurate modelling of river flow dynamics is essential to simulate floodplain inundation. Bathymetric data are thus critical to the application of hydraulic models. However, it is impossible to measure river bathymetry along the total river length, especially in large basins. While river width can generally be retrieved from space, river depth and channel shape cannot be systematically observed remotely. Where channel geometry is unknown, channel shape, depth, and friction can be estimated through calibration, but different parameter sets can often map model predictions to the observed data generating an equifinality problem. Conversely, even an approximated knowledge of river bathymetry can provide a more robust model setup.



Bathymetric data were available for ~80% of the total modelled length of the Clarence River. This peculiarly data rich case study provided the opportunity to investigate (1) the level of geometrical complexity required for the representation of river bathymetry in hydraulic flood forecasting models; (2) the definition of a data parsimonious methodology for the representation of river bathymetry in many data scarce catchments in Australia and worldwide.

A number of simplified geometrical models of river bathymetry were derived from cross sections sampled along the Clarence River. These simplified geometrical models had to be data-parsimonious. That is, each geometrical model was built from the combination of a limited number of measured cross sections selected from the complete field database, a global database and remote sensing data of river width.

The effectiveness of the proposed simplified geometrical models for flood prediction was tested using a numerical experiment. A high resolution model realization based on all available bathymetric field data was considered as truth. Subsequently, each simplified geometrical model of river shape was embedded into LISFLOOD-FP and the results compared against "true" water level hydrographs and maps of flood extent and levels. Based on this analysis, a data-parsimonious methodology for the definition of an effective river bathymetry representation in medium to high resolution raster-based flood forecasting hydraulic models was derived. A rectangular, width-varying shape was identified as the most effective simplified geometrical model, with width values derived from remote-sensing data; depth values assessed using a combination of global database and limited field data. Alternatively, an exponential cross section shape could be used; shape, depth and width were estimated using a combination of a global database and limited field data.

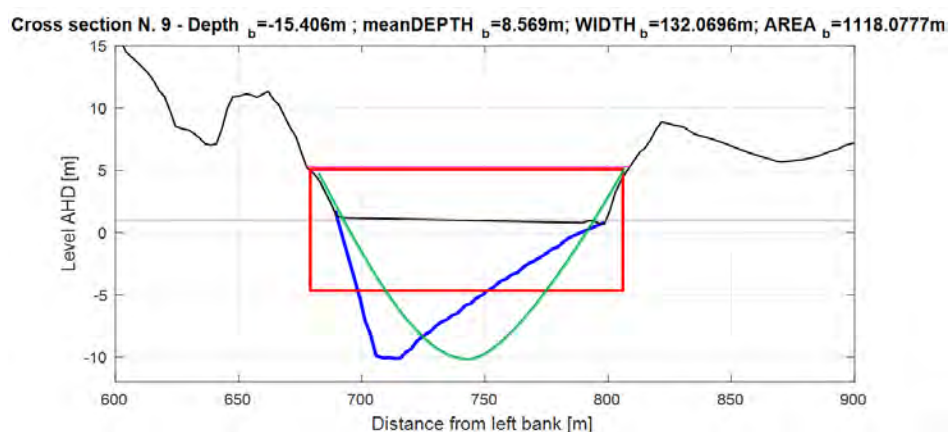


FIGURE 3. CLARENCE RIVER, EXAMPLE OF CROSS SECTION. BLUE: FIELD DATA; MAGENTA: BANKFULL LEVEL; RED: RECTANGULAR SIMPLIFIED GEOMETRY; GREEN: EXPONENTIAL SIMPLIFIED GEOMETRY.



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A COMMUNITY'S EXPERIENCE OF BUSHFIRE RESPONSE AND RECOVERY

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ABSTRACT

Introduction: This paper documents the research of a community's experience of the 2013 Forcett Tasmania bushfire disaster.

Background: Friday 4 January 2013 was one of the most significant fire days in Tasmania since 1967. It was the Forcett bushfire that caused the most damage. During and immediately after the bushfire event some of the small communities were inaccessible due to the hazard and road closures. Many local people isolated in these small communities impacted by the bushfire fulfilled various roles and acted in response to the evolving individual and community needs. It appeared over time that much of this energy and focus shifted to accommodating the external response, i.e. donations, help and goodwill.

Literature: There are numerous studies and articles that draw attention to the concept of resilience in disasters. The disaster management sector recognises the critical role that community members play in the disaster management process, nevertheless in practice it has been problematic.

Research inquiry: This study aims to understand a community's experience of the 2013 Forcett bushfire disaster in southeast Tasmania. Constructivist grounded theory offered a practical method to gain insight into understanding the local processes. The research investigated: what happened; how community members approached the event and what they thought was important; and what supported or hindered their involvement. The study aims to communicate rich insights into the community's experience of a bushfire disaster to assist in refining ways of working with people, groups and communities impacted by these types of hazard events.

Bushfire and Natural Hazards CRC project: This study is linked to the 'Out of Uniform building community resilience through non-traditional emergency volunteering' project.



INTRODUCTION

Irrespective of the best intentions in a disaster the need or problem will be greater than, or will exceed, the ability of the community to respond and resource the impact of the event. Wisner et al. (2004) claim it would be naïve to think that local coping will suffice in hazards and disaster, that there is no need for external support and assistance, or that it is the single best response. However, quite often, many people experiencing hazards and disaster events will self-organise and draw on their individual capabilities, capacity and available resources to approach the circumstances to the best of their ability.

This paper introduces a study seeking to understand a **community's experience of** the 2013 Forcett Tasmania bushfire disaster. The background describes the bushfire disaster and **the author's** experiential knowledge. The brief literature review emphasises the significance of this research, followed by the research purpose and the merit of a constructivist grounded theory methodology that suited this type of inquiry. Finally, a brief account of the findings to date is provided and a conclusion. Maintaining the parameters and keeping in line with the ethos of constructive grounded theory, writing in first person acknowledges my presence in the research process and the co-construction of knowledge.



BACKGROUND

Friday 4 January 2013 was one of the most significant fire days in Tasmania since 1967 with numerous fires burning. Among these were fires in the Forcett, Lake Repulse and Bicheno areas. The Forcett fire caused the greatest damage, burning 20,165 hectares and destroying 193 dwellings. 186 other buildings were also destroyed or damaged (Boylan et al., 2013). Fortunately, there were no deaths attributed to the fire. However, the catastrophic fire conditions impacted **significantly on people's lives**. Although many people had survived a life-threatening experience, they endured varying degrees of injury, trauma, and loss. The Tasmanian Ambulance Service recorded one of its busiest days on record (Department of Premier & Cabinet, 2013).

During and immediately after the bushfire event many of the small communities were inaccessible due to the hazard and road closures. Many of those residents who remained in the fire impact zone fulfilled various roles and undertook a range of activities. There were stories of amazing feats, acts of courage and demonstrated resilience. It became evident that people who lived in these communities, had a diverse range of skills, extensive knowledge and a broad base of experience that they were able to pull together and direct to the common benefit. For example, isolated with the fire still burning, local people located a barbeque and then fed over one hundred people. Over the next five days, the hotel kitchen provided three meals daily to local people and visitors stranded in the area, mainly driven by local people women with experience in hospitality. Residents who still had dwellings accommodated neighbours, friends and relatives who had lost their homes.

The fire threatened life and left a trail of destruction, however in spite of this a level of social structure and processes were evident. Over time, much of this energy and focus shifted to accommodating the influx of external donations, help and offers of goodwill. The external response also brought structures, systems, and activities that **often conflicted with the community's experience** and some residents felt undervalued and excluded from decision making.



LITERATURE

There have been numerous studies and articles that draw attention to the efforts of local people who demonstrate the ability to draw upon local resources, norms and values, roles and relationships and organise themselves during the different phases of disaster management (Camilleri et al., 2007, Cox and Elah Perry, 2011, Lindell, 2013, Marsh et al., 2004, Orange County Fire Authority, 2007, Proudley, 2013, Pupavac, 2012, Webber and Jones, 2012, Wisner et al., 2004).

People impacted by disaster can experience an overwhelming sense of powerlessness which can often result in trauma. It is therefore important that people living and coping in an emergency and/or disaster are recognised and where possible interventions should emphasise empowerment (Harvey 1996, cited in Norris et al., 2008, p.143 in Australian Emergency Institute, 2011, p.26).

In Australia, people living in communities impacted by a disaster have in the aftermath claimed that the pre-existing formal and informal local processes were often not acknowledged (Taylor and Goodman, 2014) or the reservoir “of skills, expertise and energy were not sufficiently tapped into by some institutions” (Camilleri et al., 2007, p.169).



RESEARCH INQUIRY

The aim of the study is to understand a community's experience of a bushfire disaster. To develop an understanding of local processes, what happened, how community members approached the event, and why, the importance and/or meaning and what supported or hindered their involvement. This understanding aims to assist in refining ways of working with people, groups and communities impacted by these types of hazard events.

Grounded theory offered a practical method that shifted away from testing theory. It creates an opportunity to generate theory and gain fresh insights into how people (social actors) interpret their reality (Suddaby, 2006). Grounded theory has the potential to illuminate common issues by providing opportunities that allow people to associate with the knowledge or theory around those issues and then apply it to daily life (Mills et al., 2006). A constructivist grounded theory method is a systematic approach to inquiry. It is achieved through data generation and analysis that is both inductive and abductive qualitative research. A feature of grounded theory is that it studies process, the 'what' and 'how' questions that often give reason or answer to the 'why' questions. Participants' views and voices are a fundamental and represented throughout the analysis. It assumes that there are multiple realities, these are an interpretive understanding with subjectivities acknowledged throughout the analysis. A reflexive stance recognises my influence as a researcher, it requires me to turn the lens back on myself to examine and account for decision making and actions that influenced this enquiry (Charmaz, 2014).

The study is situated in southeast Tasmania. The 40 people participating in this study were residents of the small communities impacted by the bushfire disaster, external support volunteers, representatives of local and state government and non-government services. In August and October 2015, I carried out two field trips to Tasmania, and conducted 27 interviews.

The sensitising concept of community-led recovery was considered a tentative tool to assist with data generation and the initial analysis, a starting point. The 27 audio interviews were transcribed, followed by line by line coding 6 transcripts. The initial coding interrogated the data looking for new ideas using gerunds, nouns 'ing' words that foster theoretical sensitivity. For example, *comprehending* the severity, *remaining* blasé, *locating* family and *stepping* up. A valuable tool that nudged my attention away from the participant's, topics, themes and structures to focus on actions and processes, and assist in developing an analytical sense of what was happening. The 6 transcripts produced approximately 4,000 initial codes. The second major phase involved focused coding where the most significant, frequent and analytical codes were elevated, tested and scrutinized, resulting in 784 focused codes. I worked with these codes constantly comparing, making links, looking for patterns, gaps and constructing tentative categories. The focused codes in the tentative categories were then used to comb through the remainder of the transcripts, looking for properties that illustrated analytical points, gaps and to saturate subcategories. Memo writing stimulated the theoretical sampling, and was essential in analyzing ideas and data, constructing categories and identifying relationships between categories (Charmaz, 2014).

The developing theory suggests a core category that encompasses three subcategories representing phases in a community's experience of a bushfire



disaster. The community's experience was the journey, and individual values and actions influenced, motivated or directed people on that journey.

The three sub-categories that represent these phases are LOSING THE FAMILIAR, RESTORING THE FAMILIAR and LIVING WITH CHANGE. The sub-category LOSING THE FAMILIAR contains four properties that help define it. KNOWING ABOUT THE FIRE marked the beginning of this phase and involved the following actions and processes: acting blasé or thinking the fire was not a threat, knowing about the fire and paying attention, predicting a bad fire or having a sense of intuition, monitoring the fire, planning, preparing, and making the decision to stay or go.

For example, as the intensity and threat increased, subsequently so did the level of monitoring, including listening to the radio and tapping into customary networks. People were considering the warning signs and information, analyzing this information, consulting with others, planning actions and responding. KNOWING ABOUT THE FIRE and COMPREHENDING THE GRAVITY of what was happening influenced varying decision making and actions in SAFEGUARDING RESPONSIBILITY'S largely concentrated toward the safeguarding of people, animals and place. The fourth property in this category is LOCATING FAMILY AND OTHERS. This subcategory helps understand what was happening and the differing decision making, actions, relationships, capabilities and capacity that participants relied on during this phase.

These phases are an interpretive view of the participant's reality gained through a method of interacting with people, learning about their experiences and perspectives, combined with a research practice where data is scrutinized in a manner that preserved the evidence of the analytical ideas and identified actions (Charmaz, 2014).



CONCLUSION

Living in Australia people are often faced with the prospect of being exposed to a range of natural hazards, like bushfire, flood, cyclones and severe weather events. Hazards have the potential to cause loss of life or injury, destroy and significantly damage property, infrastructure and the environment. This study suggests that some people experiencing these types of events will self organise, work with others to problem-solve with greater commitment, along with a convincing sense of self-sacrifice and values concentrated toward the good of the community. Although it is important to have a clear definition of resilience in the context of disaster policy, it is far more valuable to focus on some of its common characteristics, like functioning well under stress, self-reliance, social capacity, and successful adaption (National Emergency Management Committee, 2011:5 in Reid & Botterill, 2013). This research concludes that it is necessary to consider the possibilities of people functioning under stress in hazards and disaster, and develop approaches that value and support their participation in a way that is meaningful and respectful of their experience.



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THE UNCOMFORTABLE CONVERSATION: UNDERSTANDING VALUE THROUGH RISK OWNERSHIP

Non-peer reviewed research proceedings from the Bushfire and Natural Hazards CRC & AFAC Conference

Sydney, 4–6 September 2017

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ABSTRACT

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Being able to effectively determine risk ownership is critical for effectively managing natural hazards. This, however, is not a simple task: the risks are systemic, the impacts can resonate across multiple time lines and geographical scales and, in many cases, ownership is shared. As risk ownership is frequently not formally allocated to particular activities, allocation is often a negotiated process. This requires being able to combine expert and local knowledge with economic understandings to support decision making in this area. This type of planning extends beyond surviving an event and rebuilding, to focusing on sustaining the values we treasure most, by planning for the future we want, in the face of changes that go beyond our previous experience. This presentation will explore these different aspects and show how they have been brought together in a risk ownership framework. This framework has been co-designed with end users and provides a companion process that integrates strategic risk into current risk assessment and planning processes. This process uses the identification of values (what is most important), and who owns these, as a premise for assessing risk. Risk ownership provides not only a focus for specific activities, but also acts as a connecting thread that runs through the strategic risk assessment process – binding ownership of values and ownership of assets in a way that supports actions rather than disabling them. Our presentation will explore how the different phases of this process can be used to help communities identify what is most important and to explore risk reduction strategies to protect these. It will also show how valuation methods can provide a pathway for building a more comprehensive understanding of how to make long-term investments aiming to avoid damage and loss. It will show how drawing together the threads of this difficult



conversation to a point of consensus, actively supports resilience activities and strategic thinking.



INTRODUCTION

Natural hazards are dynamic events that damage assets and values that are key to our existence. They have no boundaries and can cross property and state lines, with reverberations that often transmit all the way to governments and into board rooms. These reverberations can echo through communities for years, creating new risks and compounding pre-existing vulnerabilities. They are often unpredictable and can happen concurrently. As a result, people and places may be recovering from one event only to experience another.

Natural hazards and vulnerabilities are also changing in response to factors such as climate change, new technologies and changing demographics. Longer term management and flexible approaches are needed to effectively manage this changing risk profile of natural hazards. As a result, these events require strategic planning across the areas of prevention, preparedness, resilience and recovery. One of the objectives of the BNHCRC project *Mapping and Understanding Bushfire and Natural Hazard Vulnerability and Risks at the Institutional Scale* was to develop a framework for understanding the ownership of risks from bushfires and natural hazards, in order to improve risk governance and support strategic decision making.



BACKGROUND

This presentation introduces the *Risk Ownership Framework for Emergency Management Policy and Practice* which was developed in collaboration with Emergency Service agencies and risk practitioners. The project was undertaken through a combination of scenario-based workshops, which explored decision making preferences across multiple hazards with end users, a desktop study of publicly available policy and plans across the government sector, and the development of economic theory linking individuals, communities and groups, and institutions to support risk ownership decisions.

This framework is intended for use by government, community and business agencies who are part of, or work with the Emergency Management Sector. It has three components:

- Key concepts and knowledge areas needed to support risk ownership and strategic decision making.
- A values-based companion process that links ownership of values to ownership of risk (Figure 1) which can be integrated into current assessment processes.
- Tools that can be used to support the process.

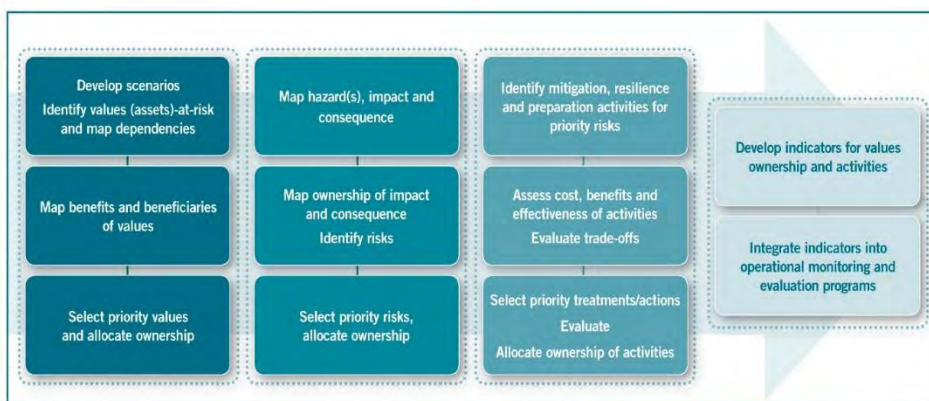


FIGURE 1: VALUES-BASED DECISION-MAKING PROCESS. (YOUNG, ET AL., 2017)



Objectives of this framework are to:

- Support more effective strategic planning and management of natural hazard risk through better identification and uptake of risk ownership.
- Identify key risk owners at the beginning of the risk process and include them as an active part of decision making.
- Provide a companion process (Figure 1) that use values as a starting point for risk assessments, providing a pathway for better management and the implementation of systemic risk.
- Assist the development of arrangements that support longer term activities, such as the building of resilience, and the shorter term activities that support this.
- Support development of new knowledge and the collation of new types of data to support strategic decision making.

As social contracts and shared arrangements are key aspects of risk ownership, the framework was developed with a focus on consensus building as part of the process.



WHAT IS RISK OWNERSHIP?

Risk ownership is a term used to define who owns a risk and how they own it. If a risk is not owned, or its ownership is not acknowledged or is unclear, it is highly likely that risk is not being managed. Making this concept workable required combining the two traditions of risk ownership from economics and risk management.

In its assessment of natural disaster funding arrangements, the Productivity Commission aligned risk ownership with assets stating "... asset owners are generally best placed to manage risks to their property" (Productivity Commission, 2014, p 314). This is a standard economic interpretation but provides substantial challenges when governments are asset owners on behalf of the community, or those assets provide a wide range of benefits for both public and private parties. In contrast, the international risk standard, ISO 31000, defines a risk owner as "... a person or entity that has been given authority to manage a particular risk and is accountable for doing so" (ISO, 2009).

By combining both the ISO definition with the expanded definition of an asset owner to include those who receive the benefits from that asset, risk ownership can be expanded to a broad range of end users who have a stake in the effective management of strategic natural hazard risk.

The RAP criteria – who is responsible, who is accountable, who pays – was developed to provide a simple mechanism that would help define levels of ownership related to key activities.



Owners can be categorised as institutions, groups and individuals. Each category helps classify the different actors who make up the ownership system and can be used to define how they exercise ownership (Table 1).

LEVEL	DEFINITION	EMERGENCY MANAGEMENT CONTEXT
Institutional	Formal or informal structures and arrangements that provide 'the rules of the game' (North, 1990) that govern and shape behaviour of a common set of groups and individuals.	Community, state, local and federal government, boundary organisations, business and industry.
Group	Groups of individuals who share a common interest or purpose.	A particular community, organisation, agency or network (this can also be a virtual community).
Individual	Individual person or legal entity.	Risk manager, house owner, property manager.

TABLE 1: LEVELS OF RISK OWNERSHIP (YOUNG, ET AL., 2017)

These levels can be assessed across three decision-making areas:

- Ownership of the assets at risk from natural hazards.
- Ownership of the risks associated with short to long-term impacts and consequences of natural hazard events (both direct and indirect effects).
- Ownership of actions in relation to those assets (values) at risk to either mitigate, build resilience to, or recover from natural hazard events.

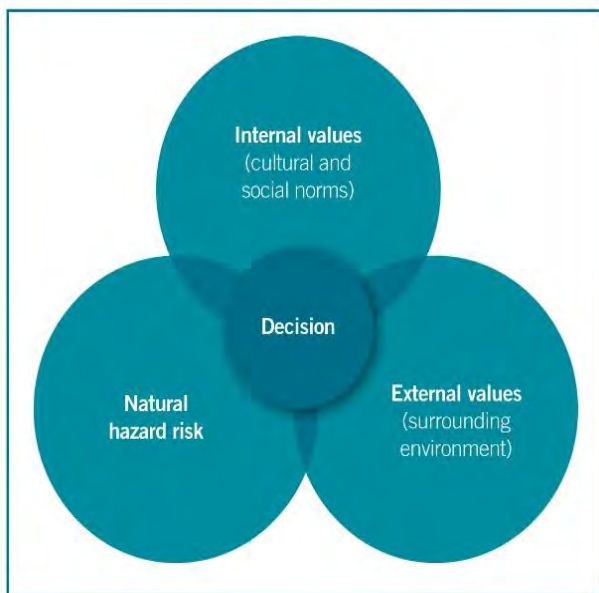
Ownership of values and the associated natural hazard risks are often shared. This can lead to a lack of clarity as to how a risk is owned or what aspects may be unowned. This is particularly the case with over-arching, intangible values that depend upon multiple stakeholders, such as resilience and community wellbeing.

Risk ownership can also be unacknowledged until an event occurs – unprepared owners may not be able to fulfill their ownership obligations as a result. In other cases, the size of the event can exceed the capacity of owners to effectively prepare for or recover from such an event. In both cases, the risk may be transferred to another owner. For example, the cost of recovery from the 2011 floods in Queensland resulted in all Australians paying a flood levy. Damage and loss that is not compensated or transferred by a risk owner may be accommodated, but can result in increased vulnerability to future events.

The impacts of events can also result in the loss of important values that sustain communities. For example, damage to key environmental assets that sustain tourism or agriculture can lead to a loss of income and employment in small communities.



VALUES AND DECISION MAKING



Types of values associated with decision making in relation to natural hazards fall into three key areas (Figure 2):

Internal values – Values internal to an individual, a group (e.g., community or organisation) or institution. These determine what the priority is.

External values – Social, environmental and economic values (assets) that surround an individual community or institution.

Value attributed to risk by individuals, groups or institutions.

FIGURE 2: DIFFERENT VALUE COMPONENTS RELATED TO DECISION MAKING (YOUNG, ET AL., 2016)

Values can be highly subjective and often depend upon who is doing the valuing as to what is given priority. As a result, it is important to understand how the interaction between these different components determines what is valued and why.

Decisions that are aligned with values are more likely to support motivation for action which will be sustained. This is because these decisions are supported by the beliefs that determine what is most important, (Schwartz, 2012, p 4). This is important because risk ownership actions need to be maintained across strategic planning horizons, where activities are longer term and the benefit from this may be seen as remote. Values can also provide a way of prioritising areas of risk and are a powerful tool for bringing together "multiple perspectives" in a way that supports decision making (Hall & Davis, 2007).

Values-based approaches define important values through meaningful deliberation and rely on a level of consensus between stakeholders as part of their process. This can provide a pathway for negotiating trade-offs and obtaining shared understandings across different groups and agendas that support action. An example of this type of process is Appreciative Inquiry, a form of transformation management, which identifies values through the collection of individual "stories" and creates a collaborative vision that contains these values (Nauheimer, 1997).

The use of values as the basis of the risk ownership process framework places the focus on what is most important as a starting point for assessing risk and is a key part of being able to scope and focus activities.



TRADE-OFFS

By locating and utilizing the skills and interests of risk owners at the individual, community and institutional levels, delegations of ownership for different actions can be assessed and trade-offs made between different owners. For example, benefits of an action may be partly public and partly private, opening up the potential for co-funding arrangements between different institutional partners. Locating aspects of the circular economy where the returns will flow into the local community and potentially be re-invested within a region, can also help make the case for investment. It also broadens the scope of investment from “Who pays?” to incorporate time, material resources and skills. Non-monetary investment is also more likely to be allocated to high priority non-market tangible and intangible values, whereas monetary investment is spent on rebuilding damaged assets.

Starting simply and bringing in more complex assessments when needed is the best strategy. Ideally, the criteria for assessment are determined before the assessment begins. This is where stakeholders set up their rules of engagement for agreeing as to what they value the most. Criteria can be based on factors such as cost effectiveness, return on investment, maintenance of specific values, ability to represent policy, ease of implementation, degree of ownership and ease of financing. Qualitative and robust measures that use simple criteria to sort options can be used as a starting point. Straightforward questions such as “how well owned are our key values?” and “what level of resourcing is required to develop ownership?” provide the basis for this sort of assessment.

Methods for evaluation can range from informal voting, ranking methods, multi-criteria analysis, return on investment and/or cost effectiveness (Young et al., 2017; Jones, et al., 2017). Options such as new infrastructure, buy-back and retrofit schemes, and public and private insurance strategies will require comprehensive cost-benefit analysis.

Trade-offs between a broad variety of actions across the different phases of strategic risk management (e.g., preparedness, prevention, resilience and recovery) cannot always be assessed through the standard economic methodology of calculating return on investment via cost-benefit analysis. Many of the values that communities deem important such as community health and welfare, connectedness and resilience cannot be easily costed. Often assessments of these types of values require damage-cost curves across a range of hazards such as storm, fire, flood and heat wave and can be beyond the capability of less well-resourced organisations.



CONCLUSION

“We can’t do this without our communities and know we can’t just keep telling them what to do because that just doesn’t work.....We have to think about this in the longer term otherwise we are just setting ourselves up to fail.”

Tasmanian workshop participant
(Young, et al., 2016)

Resilience is fundamentally changing how we need to think about natural hazard risk and who owns it, as everyone is now a potential risk owner. For risk ownership to be fully realised, people need to understand the risks they are faced with, be willing to accept them and have the capability to undertake the actions associated with that ownership. This requires collaboration and well-structured processes and facilitation, and is a long-term proposition. Maintaining trust during this process is pivotal and requires the creation of spaces where diverse people with different agendas can reflect, discuss and achieve a consensus beyond the pervading ‘just in time’ decision-making context. Discomfort is part of the process, particularly at a community level where emotions and passion need to be acknowledged and managed carefully.

“People don’t value what they don’t understand, and I think some values and risks get dismissed because they are seen as too much hard work.”

(Victorian Workshop Participant, Young et al., 2016)

If we are to achieve broader and more effective risk ownership within and beyond the Emergency Services sector, we need to start embracing these “difficult conversations” about what values are at risk and how we need to respond to this. Natural hazard risks are also becoming increasingly complex as the social, environmental and economic systems that shape them change. Negotiation through this complexity to a point of consensus, where risk ownership is accepted and acted upon, is a crucial aspect of effectively managing these risks. To achieve this community, governments and organisations need take the time to make conscious and well-informed decisions. The risk ownership framework can be used to support this process in a way that will help ensure that our decisions today enable rather than disable, our future sustainability.





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IMPROVING RESILIENCE TO STORM SURGE HAZARDS

Non-peer reviewed research proceedings from the Bushfire and Natural Hazards CRC & AFAC conference
Sydney, 4 – 6 September 2017

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ABSTRACT

IMPROVING RESILIENCE TO STORM SURGE HAZARDS: ASSESSING RISK THROUGH WAVE SIMULATIONS, SHORELINE MODELLING AND FIELD OBSERVATIONS

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Winds, waves and tides associated with storms are capable of causing severe damage to coastal property and infrastructure. Locations that are prone to erosion and inundation first require an accurate assessment of risk before deciding the most cost effective mitigation option. This research aims to produce probabilistic assessments of the coastal erosion and inundation risks associated with storms, particularly for coincident or clustered events, thereby helping to strengthen the resilience of coastal communities.

Coastal erosion and inundation hazard is modelled in this study by simulations of realistic storm condition forcing (waves and tides) through a morphodynamic model to calculate return periods for maximum extent of shoreline retreat. This approach of estimating erosion return periods is superior to the assumption that the most energetic storm causes maximum erosion. The methodology is demonstrated at Old Bar, NSW, which is currently an erosion hotspot. The model will also be applied for the metropolitan Adelaide beaches. These sites were selected to test the methodology for a span of geographic conditions in terms of storm climate and deep-water wave exposure, working towards developing this method into a transportable framework applicable to other coastal areas.

Desktop and field assessments of each site were conducted to document geomorphic and sediment characteristics to inform shoreline modelling. Having established the historical framework at each location, multivariate statistical analysis of wave (buoy or hindcast models) and tides for peak storm events has allowed for the synthesis of realistic future conditions. This complex sequencing of cycling between accretion and erosion incorporating cross-shore and alongshore sediment transport has been estimated using a probabilistic shoreline translation model. Here, model outputs for Old Bar are illustrated, which indicate a complex response over decadal time frames. Further work will then assess risk to infrastructure based on the most probable envelope of shoreline position. This information can then be used to inform coastal management strategies.



INTRODUCTION

Relied upon heavily by coastal management agencies, beach morphodynamic models are a valuable tool for understanding the past, present and future evolution of sedimentary shorelines. Accuracy in these beach morphodynamic models is constrained by the proper characterization of the corresponding hydrodynamic processes that are directly responsible for mobilizing sediment and changing the configuration of the shoreline. Further, decadal shifts in wave climate may lead to complex sequences of erosion and accretion at a given site.

Detailed description of the nearshore mean water levels, waves and the associated littoral currents is required as forcing conditions used within the morphodynamic models. Two common techniques for this purpose are fully coupled hydrodynamic and morphodynamic models, (e.g. Delft3D), or pre-calculated wave lookup tables built from stationary wave model simulations, (e.g. SWAN), which are then used to force morphodynamic models based on the CERC longshore sediment transport equation. The lookup table approach is attractive owing to its ability to be adapted in a probabilistic framework, often desired by coastal managers. The coupled models are too slow to run the multiple realisations of the wave climate required to generate robust statistical measures of the beach response to changes in wave climate.

This study presents a framework based on modelling nearshore wave transformation with the SWAN model and creation of wave lookup tables for beach morphodynamic modelling at two study sites, Old Bar, NSW, an erosion hotspot at present (figure 1), and the Adelaide metropolitan beaches. The results for Old Bar are the focus here. A shoreline evolution model is developed using the EVO model (Teakle, 2013), which combines both cross-shore (Miller, 2004) and longshore sediment transport processes. The former process is commonly associated with episodic erosion due to storm events; the latter is associated with longer term erosion or accretion at a given location. We document the sensitivity of the models to different realisations of statistically similar wave climates, using the same initial conditions.

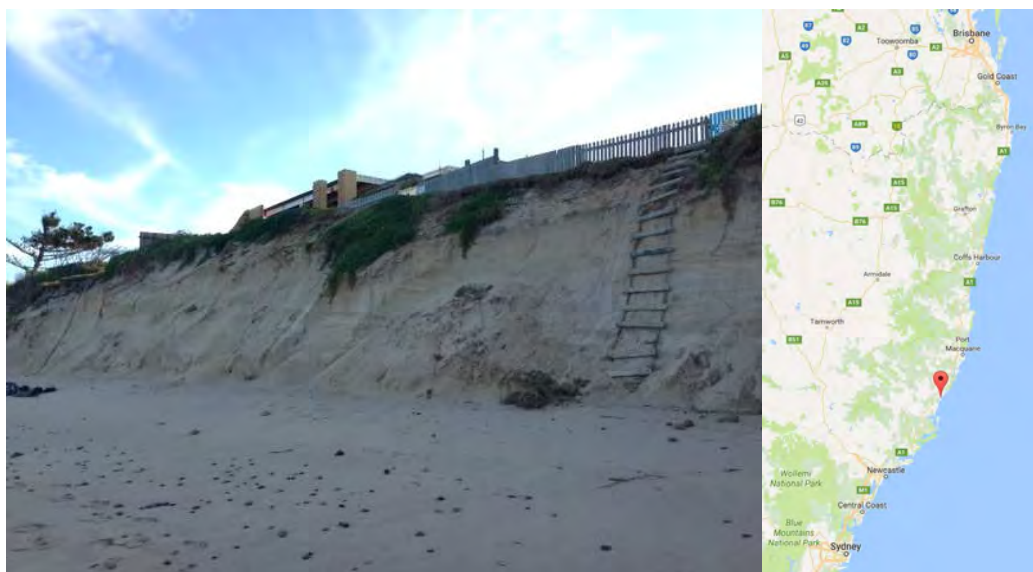


Figure 1. Beach erosion at Old Bar, NSW, June 2015.

METHODS

WAVE MODELLING

Wave data and beach profile data were combined to build a SWAN model for nearshore waves (figure 2 & 3), based on a statistical representation of the offshore wave climate. This model provides wave height, period and direction at 137 transects along the selected model domain, at a spacing of approximately 200 m. These wave conditions are then used to drive the sediment transport model. One of the particular features of the Old Bar site is the nearshore reef and Dennis shoal (figure 2), which is immediately to the north of the main erosion hotspot.

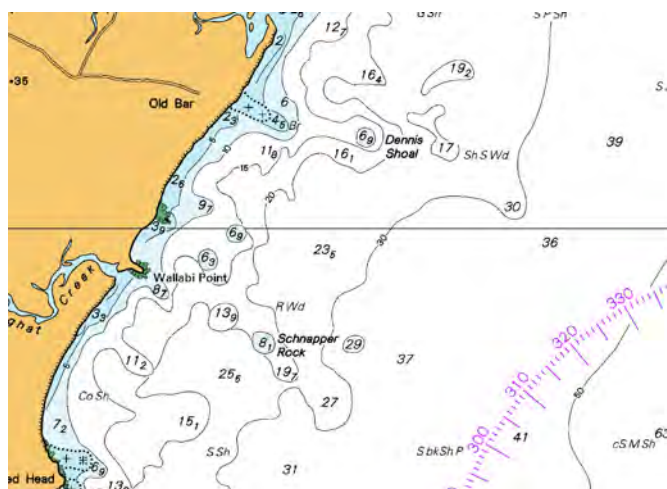


Figure 2. Bathymetry at Old Bar, NSW, showing the reef and Dennis shoal directly offshore. **NOT TO BE USED FOR NAVIGATION.** Source: Australian Hydrographic Service (see acknowledgements for copyright statement).

The offshore wave climate is determined from historical records from tide gauges, offshore wave buoys (see acknowledgements), and wave model hindcasts, which were gathered and analysed for the case study sites. Through statistical approaches (Davies et al., 2017), these historical records were recreated as synthetic time-series preserving the original hydrodynamic properties, yet allowing for storms to occur within a wide range of alternate yet realistic sequencing scenarios. Due to only short historical record being available at Old Bar, wave data from Sydney was transformed to the Old Bar site. The final synthetic offshore wave climate comprises of one thousand, 1000 year records of waves at hourly intervals, from which an expected wave climate and multiple 50 year long realisations of the same statistical wave climate can be generated.



The incident offshore waves have complex interactions with the continental shelf and nearshore bathymetry. The transformation of the offshore wave height, period and direction is unique for each nearshore transect (figure 4) along the case study beaches. The transformation is performed using a nearshore hydrodynamic wave model, SWAN (Booij, 1999), initiated at the offshore boundary of the model. For this purpose, wave lookup tables were generated through a series of stationary SWAN wave model simulations covering the full range of potential offshore wave conditions. The results from this work compared favourably with the NSW wave transformation toolbox (Taylor, 2015).

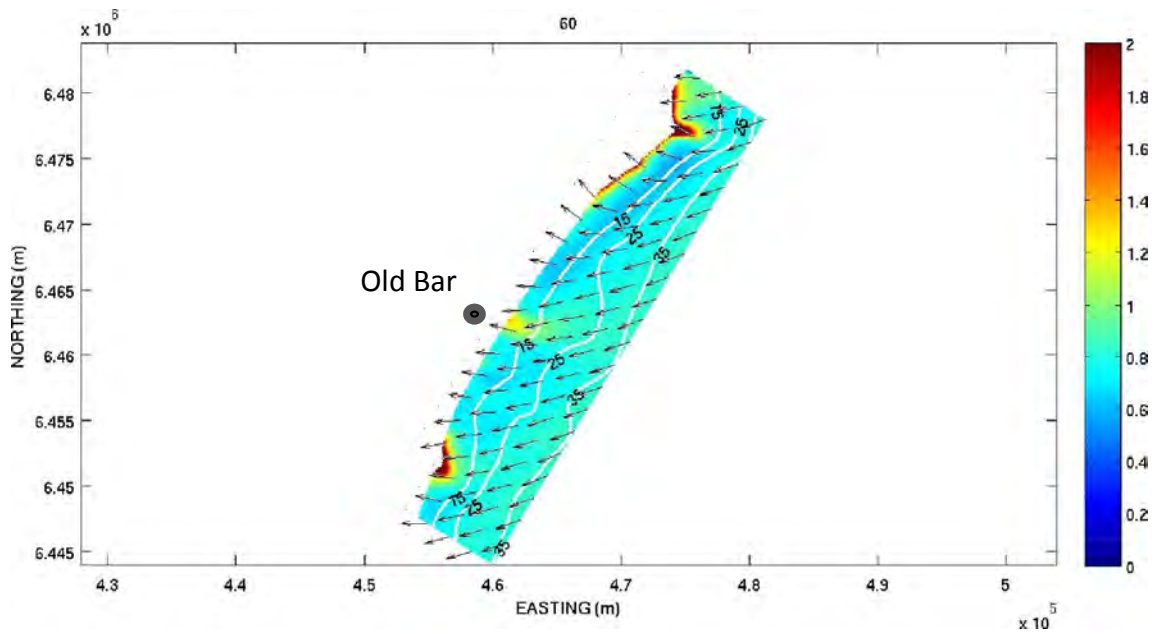


Figure 3. Example of wave transformation from offshore to nearshore for a wave with period 11s and offshore direction from 60deg N. Colours show wave height amplification.

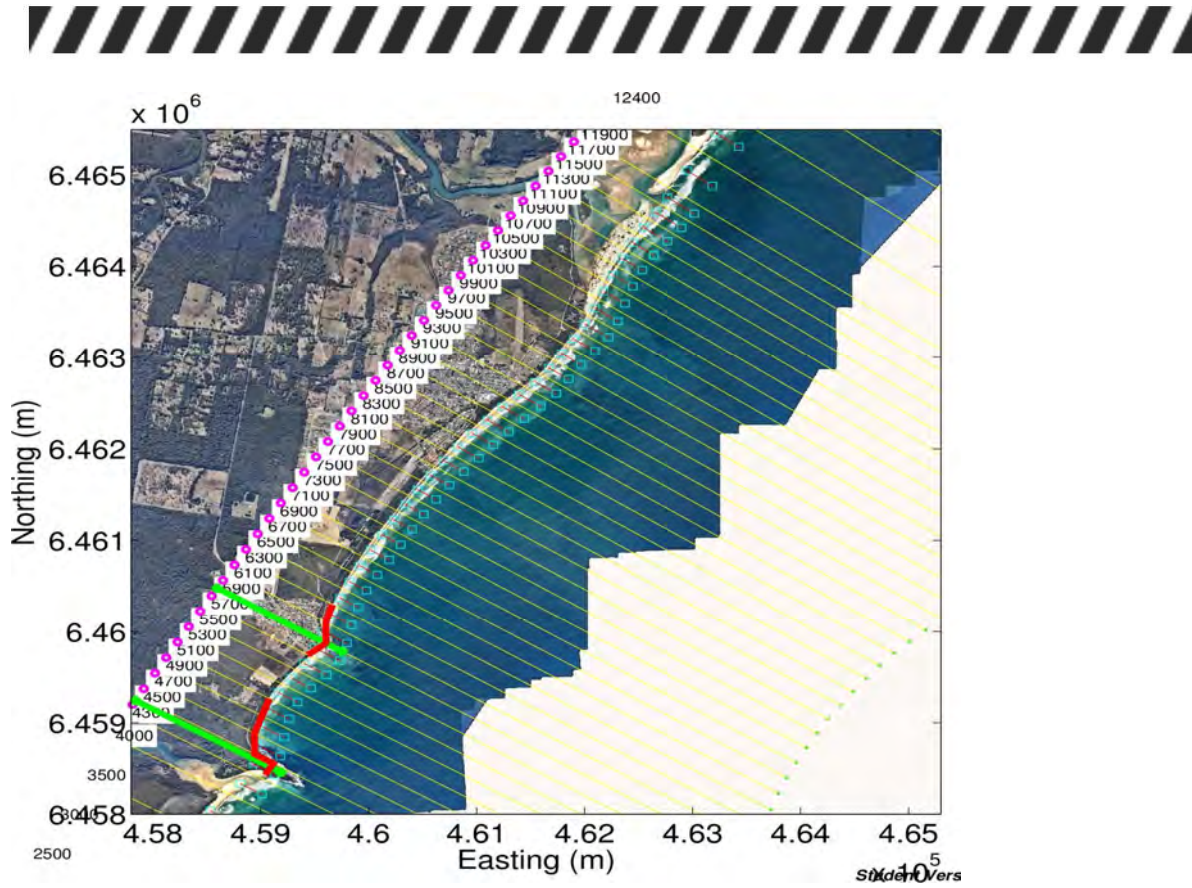


Figure 4. Model transects used for shoreline modelling at Old Bar, with sections of rocky shoreline ((red) and headlands (green) indicated. Headlands are incorporated into the modelling as barriers to longshore transport.



SHORELINE MODEL

The shoreline model is a hybrid model, based on the classical one-line model approach for longshore transport, combined with a beach profile evolution model for cross-shore transport. The project determined that the EVO model developed by BMT (Teakle, 2013) was the most appropriate (Gravois, 2016) and with the potential to be made available for future research as an open source model. A typical cross-shore profile (figure 5) responds to storm wave conditions by erosion of the upper beach and subsequent accretion under non-storm conditions. This process is manifest along the beach and is represented in the modelling by longshore sediment transport. Here, longshore transport is determined by the classical CERC formulation (*Shore Protection Manual*, 1984), which uses the breaking wave height, period and direction at each transect determined by the wave model (figure 4). The gradient in the longshore transport provides the imbalance in sediment transport that drives shoreline accretion and/or erosion. The longshore transport gradients are in turn influenced by supply of sediment at model boundaries (i.e. headlands), sediment sinks at estuary mouths, and also by small headlands and reefs that can temporarily trap sediment moving along shore. The model requires calibration to observed transport rates, which over the last 50 years at Old Bar show a general pattern of erosion (figure 6), possibly influenced by sand extraction in Harrington inlet. However, the longer term sediment balance is unknown.

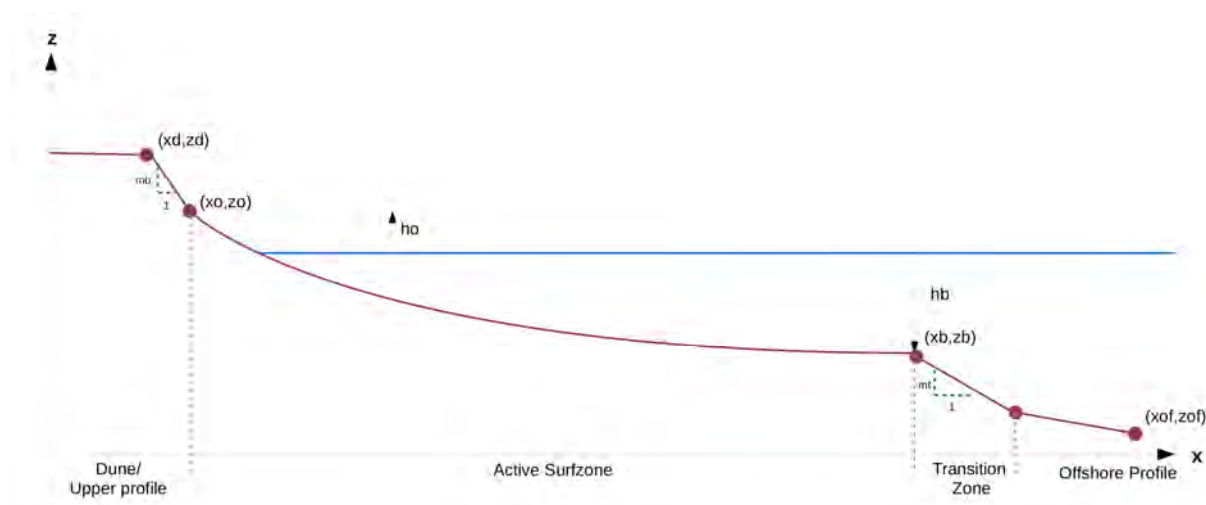


Figure 5. Beach profile for the EVO model, showing coordinate points that adjust for different wave conditions.

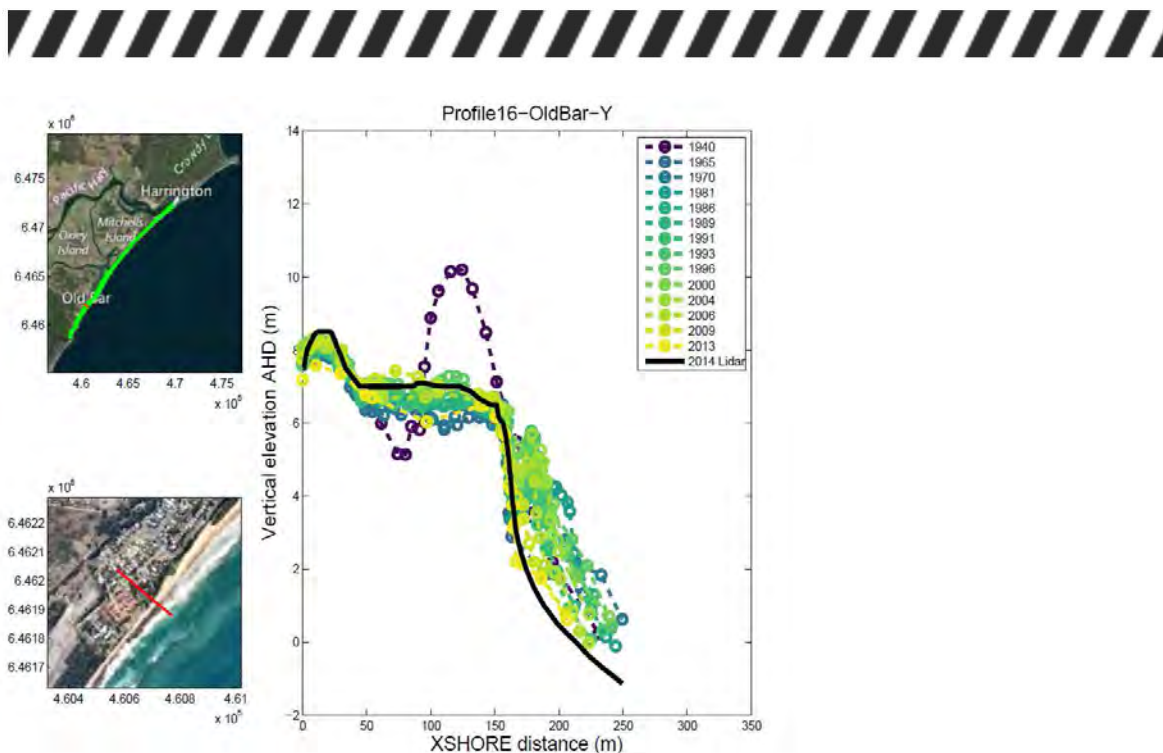


Figure 6. Dune erosion and shoreline recession at Old Bar, NSW, since 1965.

RESULTS & PRELIMINARY INTERPRETATION

An example of the shoreline movement over 50 years for one realisation of the modelled waves at Old Bar is shown in figure 7. The shoreline position oscillates over a range of 40m, with a net recession of about 20m in this case. Annual and decadal oscillations are apparent. Running many simulations with different realisations of the same statistical wave climate provides multiple predictions of the shoreline position, from which a statistical distribution can be derived. For Old Bar, this distribution indicates a wide variability in the shoreline recession or accretion and a strong sensitivity to wave climate (figure 7). This variability is interpreted to be due to Old Bar being situated at a pivot point on the longshore transport pathway, with the net sediment transport oscillating between northward and southward over decadal time frames. Hence, annual and decadal oscillations in shoreline position are predicted by the model. The results indicate that the current erosion trend may lie within an envelope of evolutionary behaviour that includes stable or accretionary phases with durations of several decades. Combining the results from thousands of model runs will provide an expected position and the most likely maximum erosion for different return periods.

CONCLUSIONS

Coastal erosion and inundation risks associated with storms, particularly for coincident or clustered events, are stochastic, requiring a probabilistic approach to assess the resilience of coastal communities in a changing climate. The dynamic nature of the shoreline, with strong feedback between response and forcing, requires simulating many realisations of statistically similar forcing conditions to calculate return periods for the maximum extent of shoreline retreat. This project is representing these processes by linking a new analysis of the wave climate with a morphodynamic model to assess the combined effects of longshore and cross-shore



sediment transport on shoreline oscillations at an erosion hotspot on the NSW coast. The results suggest the current erosion trend at Old Bar may lie within an envelope of behaviour that also encompasses stable or accretionary phases of beach evolution. Having this understanding of the range of shoreline responses to storms will allow coastal managers to implement more targeted management strategies, such as establishing hazard zones that accommodate for the envelope of change. The methodology is being developed to be transferable to other locations and will be further tested at the Adelaide Metropolitan beaches.

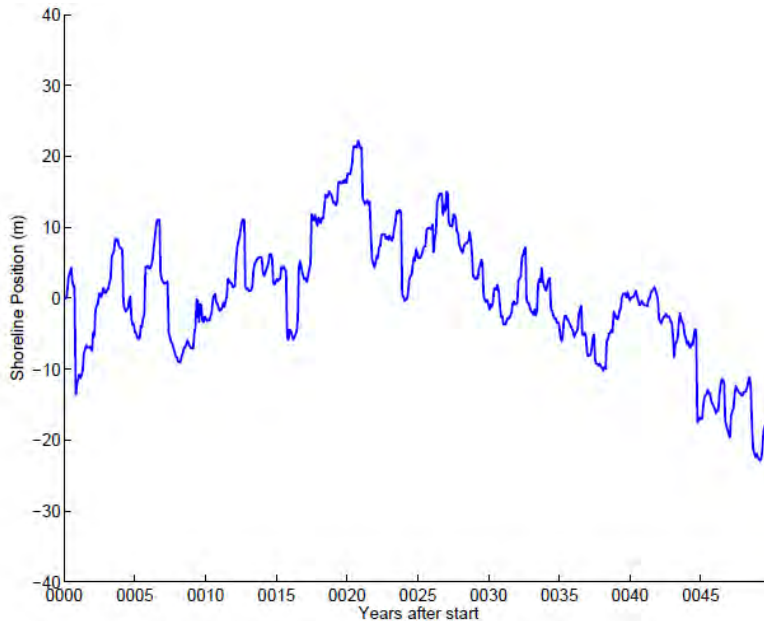


Figure 7. Example of shoreline movement over 50 years for one realisation of the modelled waves at Old Bar, NSW corresponding to location depicted in figures 1 and 6. Negative values correspond to erosion (landward motion of the shoreline).

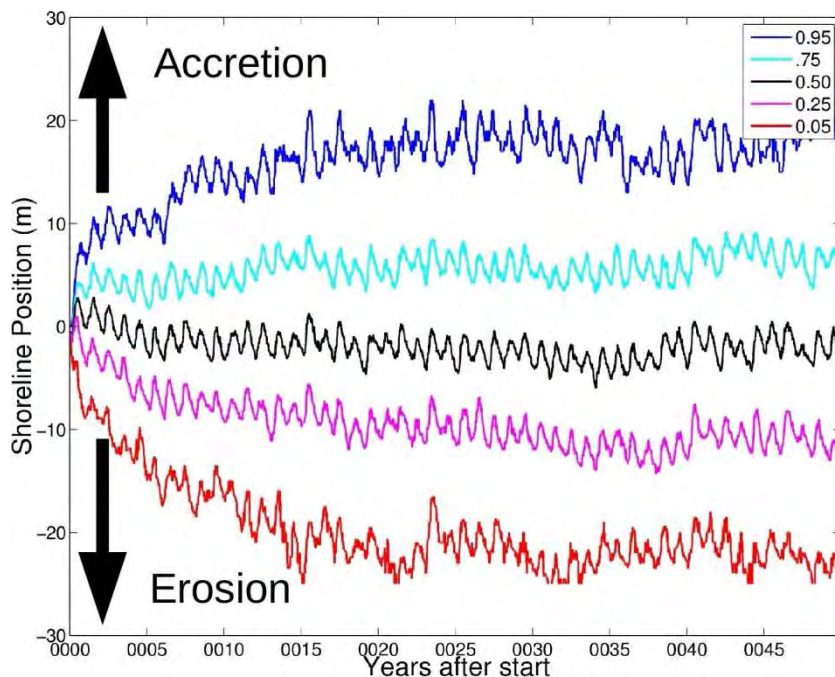




Figure 8. Results from EVO model calibration at Old Bar, NSW corresponding to location depicted in figures 1 and 6. Shown are 5%, 25%, 50%, 75% and 95% of the cumulative distribution of modelled shoreline position from 200 different synthetic forcing scenarios. For example, at a given time 10 of the 200 modelled shoreline positions were seaward (more erosive) than the red line. Negative values correspond to erosion (landward motion of the shoreline).

Acknowledgements

1) In reference to figure 2:

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MAPPING THE EFFICACY OF AN AUSTRALIAN FUEL REDUCTION BURN USING FUELS3D POINT CLOUDS

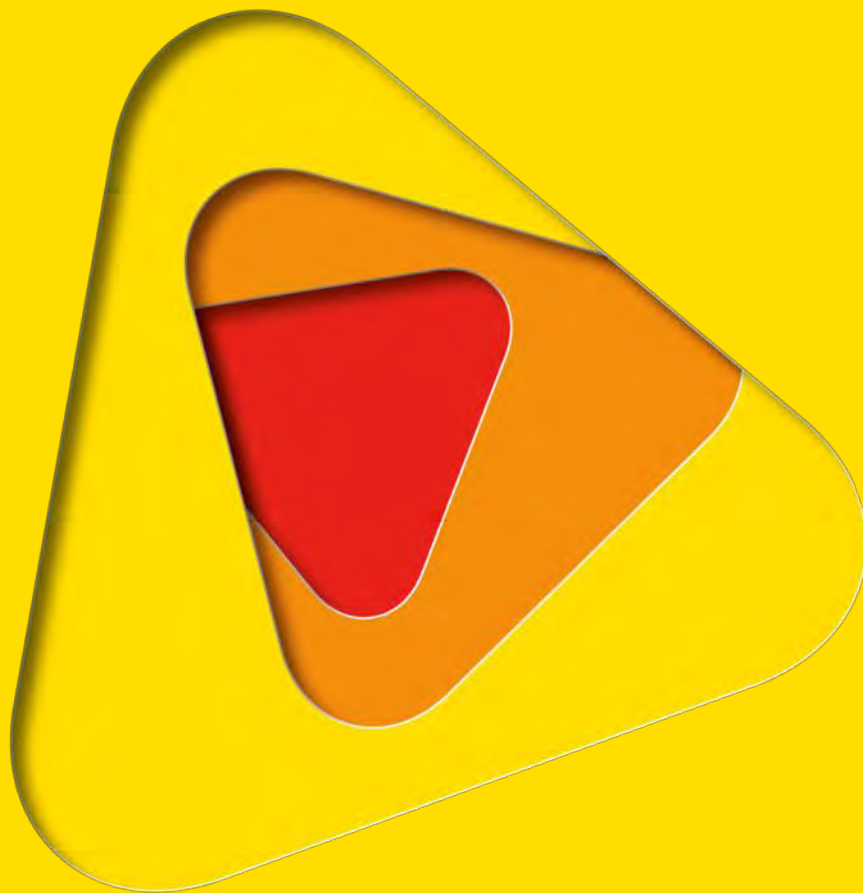
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1. INTRODUCTION

Fuel reduction burns are commonly used in fire-prone forests to reduce the risk of wildfire and increase ecosystem resilience. As such producing quantified assessments of fire-induced change is important to understanding the success of the intervention. Remote sensing has also been employed for assessing fuel hazard and fire severity. Satellite, airborne and UAV remote sensing, for example, have shown potential for assessing the effects of large wildfires and fuel hazard in areas of open canopy. Fuel reduction burns, however, often take place under dense canopy and result in little or no change to the canopy cover. As such terrestrial techniques are needed to quantify the efficacy of these burns.

This study presents a case study on the use of image based point clouds, captured terrestrially following the fuels3D methodology outlined in Wallace et al. (2016), for describing the change in fuel structure induced by a low intensity fuel reduction burn. The specific objectives of this study were to evaluate whether fuel structure maps produced from fuels3D point clouds are sensitive to the changes that occur during a low intensity fuel reduction burn, and how these changes may be quantified.



2. METHODS

2.1 STUDY AREA

The study was conducted in a lowland forest within Cardinia Reservoir, Emerald, Victoria (Figure 1). The overstorey consisted of stringy and rough-barked eucalypts including Messmate stringybark *Eucalyptus obliqua*, Red stringybark *E. macroyhyncha*, and Narrow-leaf peppermint *E. radiata*. The understorey was dominated by Prickly tea-tree (*Leptospermum continentale*), graminoid species (Thatch saw-sedge *Gahnia radula*, Spiny-headed mat-rush *Lomandra longifolia*) and Austral bracken (*Pteridium esculentum*).

An autumn prescribed burn was conducted by Melbourne Water on the 28 April 2016. Pre-burn field data and imagery was collected on the 11 March 2016 and post-burn data on the 5 May 2016. Three 10 m radius plots were subjectively located within the burn area. The plots were selected based on having varying levels of fuel hazard structure and to be close to known ignition points to increase the likelihood of the vegetation undergoing fire induced change.

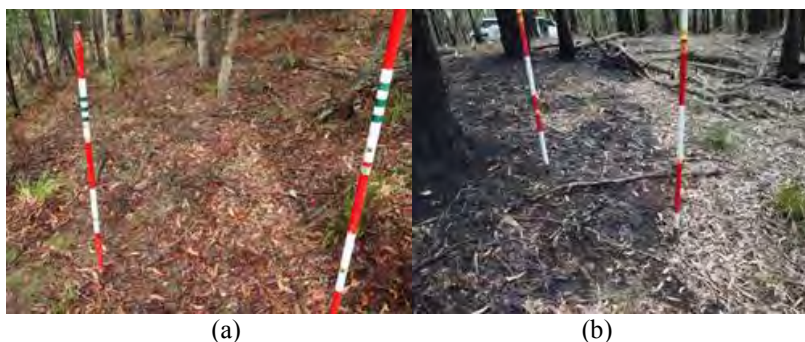


Figure 1 – Images of the fuel state a) pre and b) post burn

2.2 POINT CLOUD GENERATION AND PROCESSING

Ten sets of approximately 38 images around subplots were collected with an Olympus OM-D EM-10 camera with a 14 mm lens within each plot. Each subplot was located pre and post burn based on distance and angle from the plot center to four control marks using a total station. Point clouds were generated from this imagery using Agisoft Photoscan Professional software version 1.2.3 (Agisoft LLC, Moscow, Russia). The high quality matching setting was used to generate a sparse point cloud. Following this, high quality and mild filtering settings were used to generate a dense point cloud. Scale and coordination of the samples was achieved by manually digitizing the location of the four control targets within 6 to 10 images per sample.

Metrics were then extracted from each point cloud to describing surface fuel height and cover, near surface fuel height and cover based on the three dimensional geometry of the point clouds. Near surface fuel fate was also calculated based on the spectral properties of the points.



2.3 FUEL LOAD AND FIRE SEVERITY ANALYSIS

Fuel load was estimated through a linear model which was created based on 10 post-fire samples for which dry weights measurements were made and aggregate vegetation volume (surface height*cover area + near surface volume*cover area) within the dry weight sample area. Four change metrics including; (1) total burnt area, (2) reduction in fuel load, (3) reduction in surface and (4) near-surface height and cover, were used to map and quantify the severity of the burn. The results were assessed against similar metrics collected following the Victorian Overall Fuel Hazard Assessment Guide (Hines et al. 2010) and Cawson and Muir (2008).



3. RESULTS

3.1 POINT CLOUD PROPERTIES

An example of a point cloud collected pre and post burn is shown in figure 2. Visually the point clouds appear to provide accurate representation of the fuel structure. The point clouds contain 67 points/cm² pre-fire and 110 points/cm². The collocated area captured between point clouds totalled 116 m² (or 37% of the measured area).

3.2 FUEL CONDITIONS

Visual assessment of the surface fuel layer indicated a “high” surface fuel hazard pre-fire, with an estimated litter depth of 35 mm and estimated fuel coverage at 80%. In comparison, the surface fuel height was estimated from the image based point cloud to be 14 +/- 2 mm (Figure 4), while fuel coverage was estimated at 83%. Post-fire visual assessment undertaken by the same observers also indicated high surface fuel hazard, with estimates of cover (80 – 85%) and litter depth (37 mm) slightly increasing. In contrast, the surface fuel height was estimated from the image based point cloud at 12 +/- 2 mm, while fuel coverage also decreased to 76%. Following Hines et al. (2010) this suggests that the surface fuel represents a “moderate” to “high” fire risk as assessed by the point cloud method.



Figure 2 - Example of a pre and post fire point clouds captured following the Fuels3D approach.

3.3 NEAR SURFACE FUEL CONDITIONS

Visual assessment of the near surface fuel layer indicated a high hazard both pre and post fire. Pre fire cover was estimated at 20% with an average height of 500 mm. 25% of this cover was estimated to be dead. In comparison, the near surface fuel height was estimated from the image based point cloud to be 40 +/- 10 mm (Figure 5). Cover was estimated at 41% with 33% of the near surface fuel indicated as being dead. Post fire cover was visually estimated at 25% with an average height of 500 mm, with 25 – 30% of the near surface cover estimated to be dead. In comparison, the near surface fuel height was estimated from the image based point cloud to be 24 +/- 7 mm (Figure 5). Cover was estimated at 35 % with 65% of the near surface fuel layer indicated as being dead.



3.4 FIRE SEVERITY AND CHANGE IN FUEL LOAD

The visual assessment of burnt area indicated 25 % of the area measured had been burnt. A slightly higher estimate of burnt area (37%) was derived from the image based point clouds (Figure 3). Utilising the model developed based on destructive samples the fuel load was estimated to have reduced by 12% between pre (7.87 t/ha) and post (6.91 t/ha) fire data capture.



4. DISCUSSION AND CONCLUSION

The fuels3D approach to quantify the efficacy of the prescribed burn suggests similar changes to fuel as those estimated through visual assessment. The new approach presented in this work, however, has several advantages over visual assessments. The approach allows data collectors to follow a simple method to quantify fuel hazard and severity metrics. In contrast to visual assessment, this removes subjectivity from the assessment process. Furthermore, the approach produces a quantified digital record of the landscape allows for decision rules to be revisited and the spatial products to be examined beyond those collecting the data in the field.

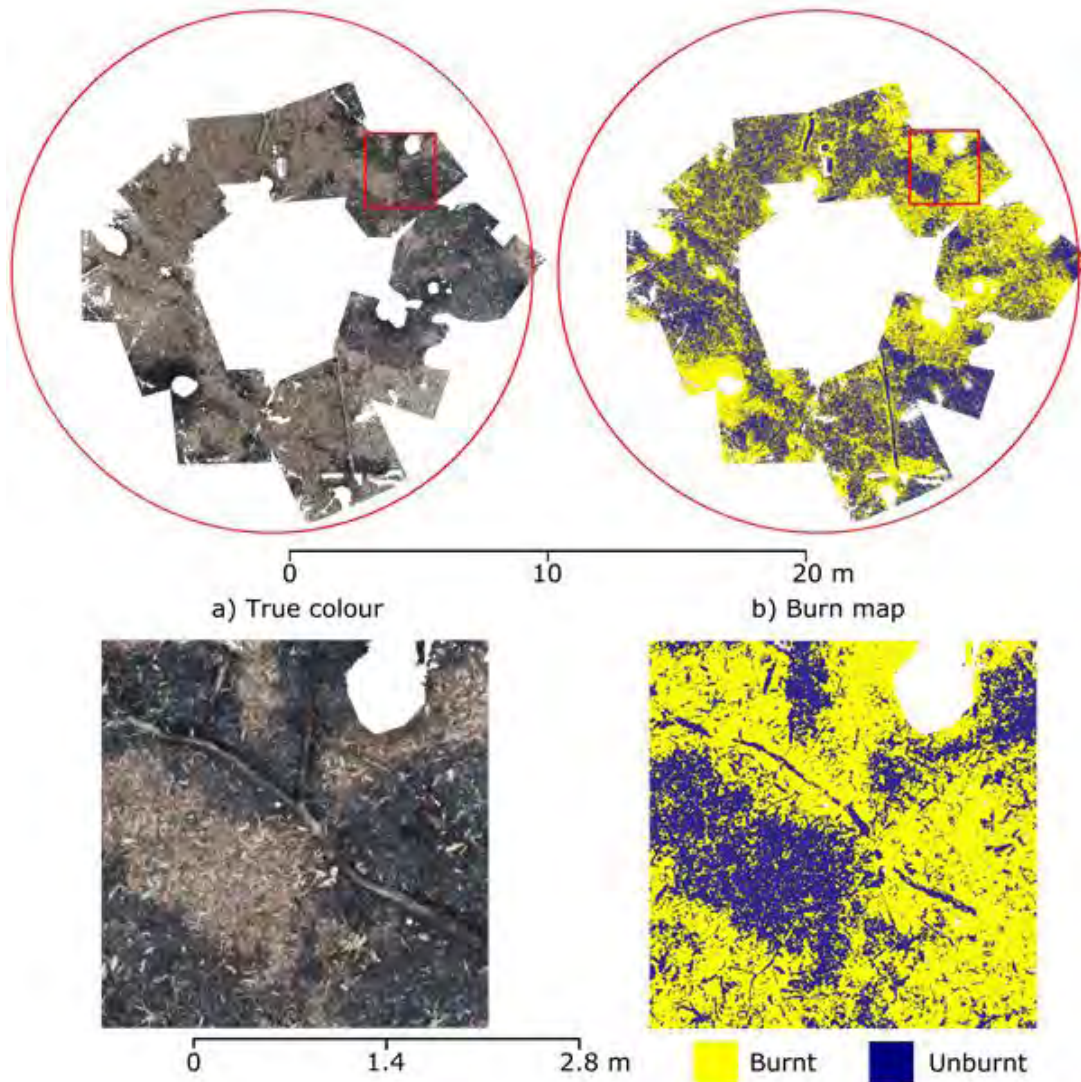


Figure 3 - a) true colour orthophoto and b) map of burnt area derived from the post fire point clouds in plot 1. The upper images are of the entire plot while the lower images are taken from the red inset box.



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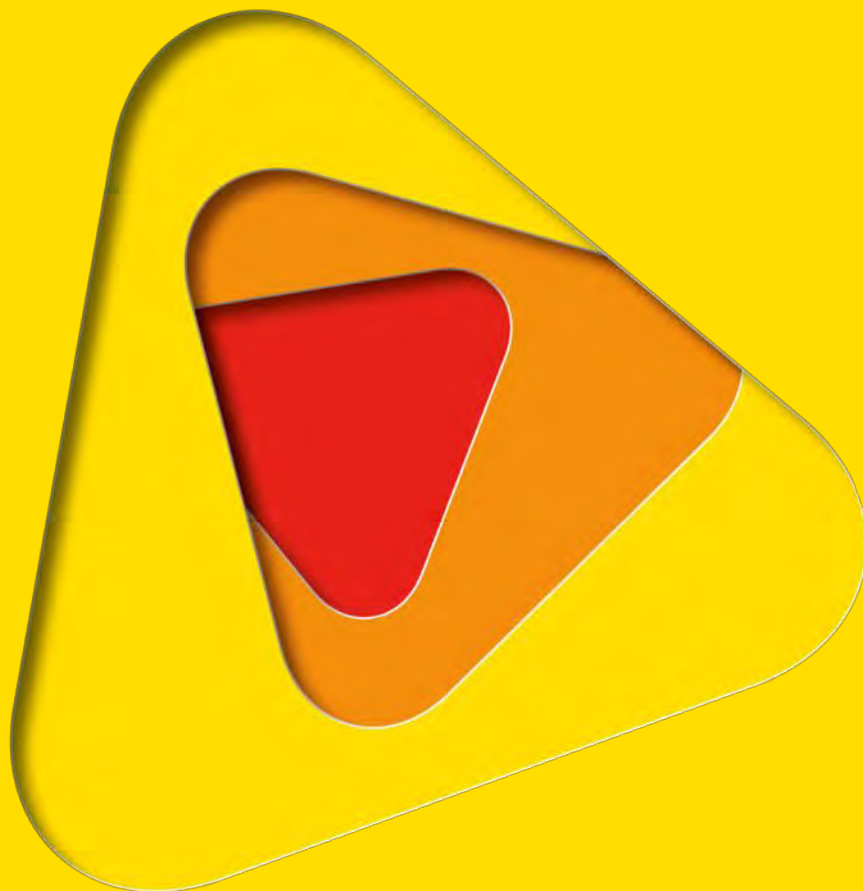


CULTURAL WORLDVIEWS AND NATURAL HAZARD RISK PERCEPTION: A PILOT STUDY OF AUSTRALIAN ADULTS

Non-peer reviewed research proceedings from the Bushfire and Natural Hazards CRC & AFAC conference
Sydney, 4 – 6 September 2017

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ABSTRACT

Perception of the risks of natural hazards is considered to be one of the precursors of desirable behaviors of mitigation, preparation, and resilience. However, the processes of risk perception are complex and are likely related to underlying cognitive factors associated with information processing. Cultural worldview theory suggests that people actively choose what to fear (and how much to fear it) in order to support their ways of life (Kahan, 2012). Aspects of these choices may include prioritizing public vs. private interests, choice vs. control, and differing levels of belief and/or adherence to egalitarianism, hierarchy, individualism, and communitarianism. To assess whether and how cultural worldviews relate to perceptions of risk to natural hazards we recruited 503 residents of New South Wales (stratified between urban and regional areas) who completed a cultural worldview questionnaire and a new questionnaire developed by the researchers to assess four aspects of natural hazards: 1) perceptions of the risk of natural hazards; 2) perceptions of control over natural hazards; 3) perceptions of responsibility for natural hazard preparation and outcome; and 4) trust in different sources of information about natural hazards. Results indicated significant but varying relationships among cultural cognition types (i.e., egalitarianism, hierarchy, individualism, communitarianism) and the four aspects of natural hazard risk perception. Some consistency was found regarding how cultural cognition types predicted risk perception across four different types of natural hazards (bushfire, flood, severe thunderstorm, earthquake) but this also varied by geographical location. Understanding the influence of cultural worldviews on attitudes toward natural hazards might lead to community engagement messages orientated to the views of egalitarianism, hierarchy, individualism, and communitarianism.



INTRODUCTION

“Why do people do that?” is a common refrain from agencies involved in assisting communities during natural hazard events. The answers to this question are likely to be complex. However, it is possible that contextual psycho-social factors such as personality, affect (emotion), cognition, and worldviews will strongly influence the actions that people take to prepare for and respond to natural hazard events (Paton and McClure 2013). Sophisticated studies are beginning to unravel the mechanisms behind, for example, bushfire preparation (e.g. McNeill et al. 2016). It is within this setting that we examine the relationships between cultural worldviews of risk and the perceptions that people hold about natural hazards in Australia.

BACKGROUND

Cultural theory proposes that there are two dimensions of sociality – grid and group (Thompson et al. 1990). The grid dimension is the extent of regulation within or without the group, or how one interacts with others (Figure 1). The group dimension is the strength of allegiance to a group, or who one interacts with (Figure 1). These dimensions reflect how people with a common outlook are disposed to impose order on reality in particular ways (Tansey and O’Riordan 1999). The grid-group axes can be labelled as four possible forms of social environment, which inclines people towards four different ways of life (Figure 1). The two dimensions should be seen as polythetic scales – they include a series of aspects but those are not necessarily present in each case observed. (Mamadouh 1999). In terms of risk, cultural theory suggests that people choose what to fear (and how much to fear it) in order to support their way of life (Wildavsky & Dake, 1990). This is known as the cultural theory of risk.

Cultural worldviews are important determinants of environmental risk perceptions (Xue et al. 2014) although studies tend to examine the perceived risks of technological, social and natural hazards together. In this study we focus on different aspects of natural hazards – risk, responsibility, control and trust in information – and examine the associations between these aspects and cultural worldviews.

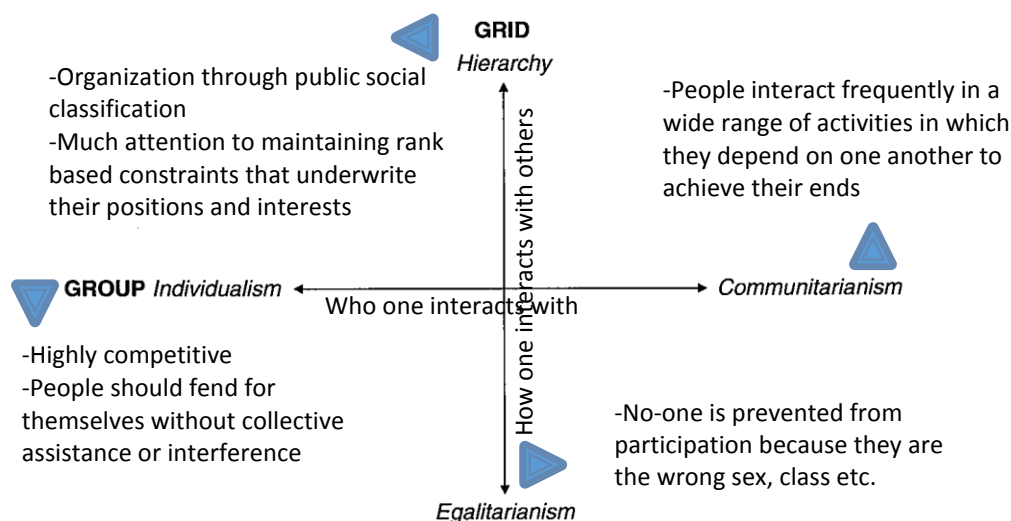


Figure 1. Cultural worldviews or 'ways of life'. Modified from Kahan (2012).



METHODS

To assess whether and how cultural worldviews relate to perceptions of risk to natural hazards we recruited 503 residents of New South Wales (stratified between urban and regional areas) who completed a cultural worldview questionnaire (Kahan 2012) and a new questionnaire developed by the researchers to assess four aspects of natural hazards: 1) perceptions of the risk of natural hazards (Chronbach's Alpha = 0.796); 2) perceptions of responsibility for natural hazard preparation (Chronbach's Alpha = 0.782); 3) perceptions of control over natural hazards (Chronbach's Alpha = 0.670); and 4) trust in different sources of information about natural hazards (Chronbach's Alpha = 0.906). The same questions were repeated for four natural hazards: bushfire, flood, storm and earthquake. Survey participants were recruited using a panel of the Online Research Unit, Sydney. Participants received a reward for completing the survey. The study was conducted under UNE Human Research Ethics Committee approval HE15-332.

Of the 503 survey participants, 60% were female and 40% male. Mirroring the distribution of the NSW population, 64% of participants were from city postcodes and 36% from regional postcodes. Ages of participants varied, with 12% aged 18-30, 59% aged 31-65 and 28% aged 66 or over.



RESULTS

CULTURAL WORLDVIEWS

The survey participants were distributed across the four cultural worldviews (Figure 2). More participants fell into the hierarchical individualism and egalitarian communitarianism worldviews than into the hierarchical communitarianism and egalitarian individualism worldviews (Figure 2). Many of the participants clustered around the midpoints of the axes, indicating that their worldview is not strongly held.

Relatively even numbers of male and female participants fell into the hierarchical individualism (M = 51%, F = 49%) and hierarchical communitarianism (M = 45%, F = 55%) worldviews. However, females dominated the egalitarian individualism (M = 28%, F = 72%) and egalitarian communitarianism (M = 31%, F = 69%) worldviews.

Participants aged 31-65 tended to be distributed relatively evenly across the four worldviews. Participants aged 18-30 were most likely (44%) to fall into the egalitarian communitarianism worldview whereas participants aged 66 and over were most likely (50%) to fall into the hierarchical individualism worldview.

Participants from city and regional areas were distributed relatively evenly across the hierarchical individualism, hierarchical communitarianism and egalitarian individualism worldviews. However, more participants from the city (76%) fell into the egalitarian communitarianism worldview than from regional areas (24%).

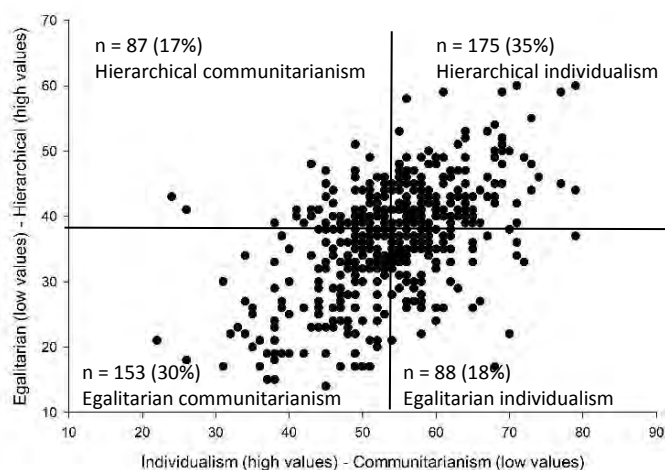


Figure 2. Distribution of participants among cultural worldview dimensions. The boundaries of each cultural worldview are set at the median scores of the egalitarian-hierarchical axis and the individualism-communitarianism axis (n = 503).



RELATIONSHIPS BETWEEN CULTURAL WORLDVIEWS AND NATURAL HAZARD RISK PERCEPTION

There was a significant difference in risk perception among people with different cultural worldviews (Table 1). This was consistent for most natural hazards, although there were no differences among people with different cultural worldviews in the perception of risk or the perception of responsibility for bushfire and flood (Table 1).

Table 1. Differences in risk perception among the four cultural worldviews for bushfire, flood, storm and earthquake. The table shows the significance values from a non-parametric Kruskal Wallis test. NS = not significant.

Risk perception item	Natural hazard type			
	Bushfire	Flood	Storm	Earthquake
Perceived risk	NS	NS	0.031	0.009
Perceived responsibility	0.000	0.000	0.000	0.000
Perceived control	0.001	0.020	0.012	0.041
Perceived trust – personal	0.022	0.041	0.044	0.039
Perceived trust – impersonal	0.000	0.000	0.000	0.000

While we only have space to show the results for bushfires here, risk is perceived differently by people with different cultural worldviews (Figure 3). People with the egalitarian individualism worldview perceive higher risks associated with bushfires than those with the other worldviews (Figure 3a). People with the hierarchical individualism or hierarchical communitarianism worldviews perceive greater self-responsibility for bushfires than the other worldviews (Figure 3b). People with the egalitarian communitarianism worldview perceive less control about bushfires than the other worldviews (Figure 3c). People with the egalitarianism individualism or egalitarian communitarianism worldview have greater trust in both personal and impersonal sources of bushfire information (Figure 3d and 3e).

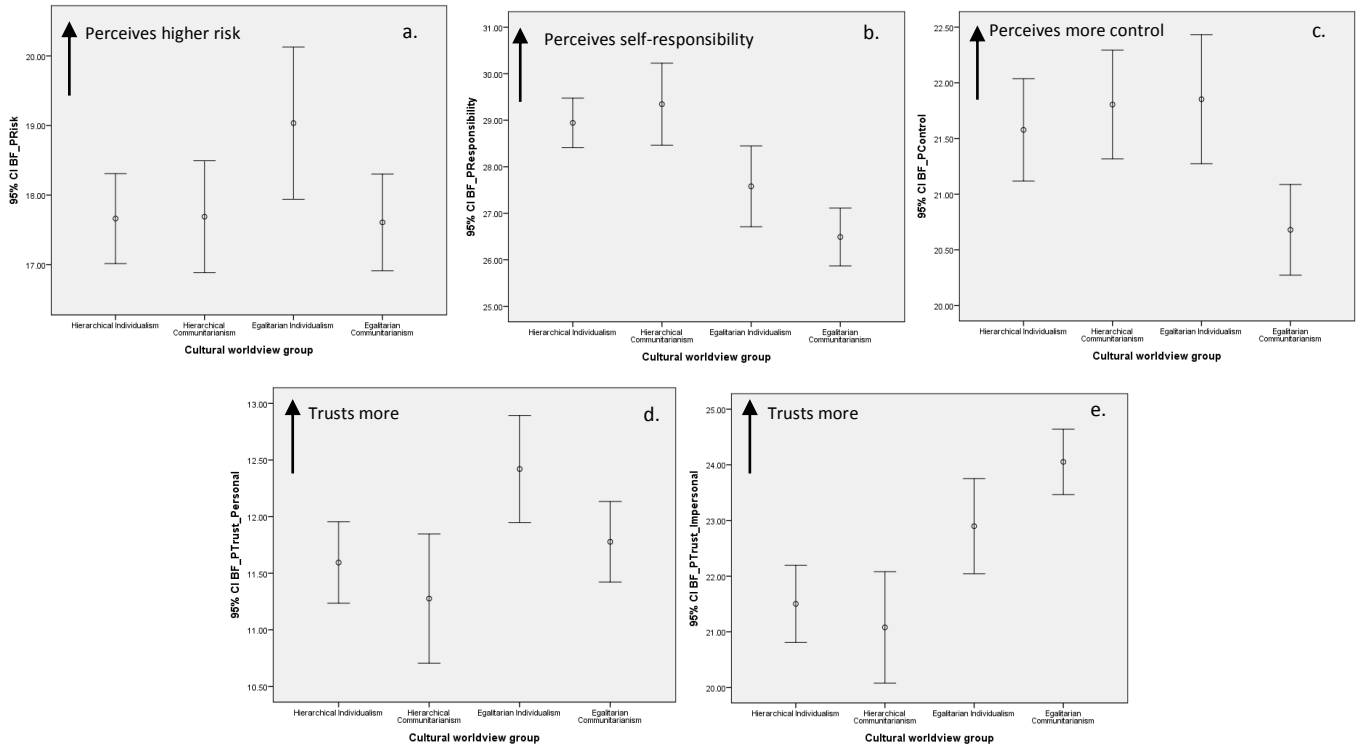


Figure 3. Bushfire risk perception among four cultural worldviews. a) perception of risk, b) perception of responsibility, c) perception of control, d) perception of trust (personal sources) and e) perception of trust (impersonal sources). Arrows on the graphs show the direction of risk perception. In each graph groups from L to R are hierarchical individualism, hierarchical communitarianism, egalitarian individualism and egalitarian communitarianism.



DISCUSSION

The grid-group typology has been used to explain risk perception in different contexts (e.g. Kahan 2012, Xue et al. 2014). The results of this study show that the hypothesis that a person's cultural worldview influences their perception of natural hazards. However, as with other studies (e.g. Brenot et al. 1998, Bouyer et al. 2001) these relationships are variable in strength. Nonetheless, there was a significant difference in the four aspects of risk perception among the cultural worldviews, which was largely consistent for bushfire, flood, storm and earthquake.

People with hierarchical grid orientation may see assertions of danger as implicit indictments of the competence and authority of societal elites (Kahan 2012). In our study we found that people with hierarchical worldviews perceived more self-responsibility for bushfire hazards, and had lower levels of trust in personal and impersonal sources of bushfire information. People with an egalitarian grid orientation may adhere to principles of social justice and cooperation. In our study, we found that people with egalitarian worldviews had more trust in both personal and impersonal sources of information about bushfires, and perceived the responsibility for bushfires to be a collective action. People with the egalitarian communitarianism world view also perceived less control over losses from bushfires.

Future work will analyse the moderating effects of sex, rural or regional location and education on the perception of natural hazard risks.



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THE AUSTRALIAN FLAMMABILITY MONITORING SYSTEM

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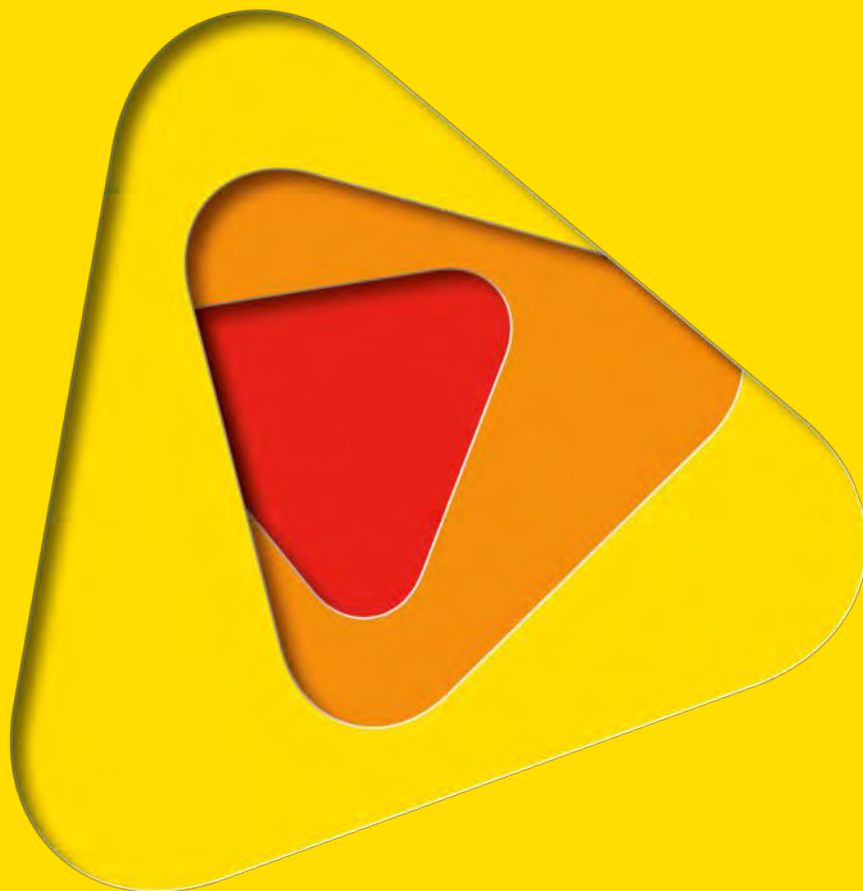
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ABSTRACT

The Australian Flammability Monitoring System (AFMS) is the first, continental-scale prototype web explorer providing spatial information on current Live Fuel Moisture Content (FMC) and landscape-scale fuel flammability derived from satellite observations. The satellite observations are converted into FMC using a radiative transfer modelling inversion approach. Evaluation of the FMC estimates using 408 observations at 35 locations around Australia shows similar accuracies ($r^2=0.60$, RMSE=39%) across the vegetation classes studied (grassland, shrubland and forest) to those derived elsewhere globally. Flammability estimates are calculated using logistic regression models relating fire occurrence to FMC. Separate prediction models were developed for grassland, shrubland and forest, obtaining performance metrics (Area Under the Curve) of 0.70, 0.78 and 0.71, respectively (where skillful predictions range between 0.5 and 1). A web-based data explorer will be available to fire and land management agencies and any other interested parties in all states and territories. The AFMS can support a range of fire management activities such as prescribed burning and pre-positioning of firefighting resources and can inform the future National Fire Danger Rating System.



INTRODUCTION

The Fuel Moisture Content (FMC) of live bushfire fuel affects fire danger and fire behaviour, as it strongly influences the key components of flammability including ignitability, fire sustainability and combustibility (Anderson 1970). Spatially comprehensive and temporally frequent estimates of FMC should be a fundamental component of fire danger rating systems in support of a wide range of fire risk management and response activities, such as prescribed burning and pre-positioning firefighting resources. In recent years, there has been considerable development in the estimation of FMC from satellite imagery. These developments have mainly been in Mediterranean and temperate ecosystems in Europe (Al-Moustafa et al. 2012; Garcia et al. 2008; Jurdao et al. 2013a; Yebra and Chuvieco 2009b), Western North (Casas et al. 2014; Hao and Qu 2007; Peterson et al. 2008) and south-eastern Australia (Caccamo et al. 2012; Nolan et al. 2016). Further research is needed to assess the full utility of FMC estimation across other fire-prone ecosystems (Yebra et al. 2013).

The conversion of FMC values into a Flammability Index (FI) can be an important additional step that facilitates the inclusion of FMC estimates into an integrated fire risk assessment system (Chuvieco et al. 2004). Research has produced several methods for this conversion based on (i) the concept of moisture of extinction, defined as the moisture threshold above which fire cannot be sustained (Chuvieco et al. 2004); (ii) critical FMC thresholds derived from empirical statistical relations between FMC and fire occurrence (Dennison and Moritz 2009; Nolan et al. 2016); and (iii) fitting a continuous logistic probability model between fire occurrence and FMC (Chuvieco et al. 2009; Jurdao et al. 2012). However, so far none of these methods has been evaluated across a region as climatologically and ecologically diverse as Australia.

Through the use of remotely sensed data, this paper aims to present the first national-scale, pre-operational, near-real time FMC and flammability monitoring system for Australia. The overarching objective is to contribute to the development of operational tools that can assist in better resources allocation in fire protection and response and improved awareness of fire hazards to people and property.



METHODS

The methodology used to map FMC in Australia is based on previous experience in retrieving FMC in Europe using MODIS reflectance data, ancillary information on vegetation type and Radiative Transfer Model (RTM) Look up Table (LUT) inversion techniques (Jurdao et al. 2013b; Yebra and Chuvieco 2009a, b; Yebra et al. 2008). Three different LUTs that contain spectra simulated for different moisture contents and fuel types (LUTgrassland, LUTshrubland and LUTwoodland) are used as reference tables. These tables were generated using three different RTM. The leaf-level PROSPECT (Feret et al. 2008) and the canopy-level SAILH (Verhoef 1984) were coupled to simulate the spectra of grasslands and shrublands whereas PROSPECT was coupled to the canopy-level GeoSail (Huemmrich 2001) to simulate the spectra of woodlands/forest. For each MODIS reflectance pixel and date, the MODIS land cover map was used to select the reference LUT corresponding to the specific land cover class covering that pixel. All the simulated spectra from the selected LUT were compared to the spectrum of every MODIS pixel that passes the quality control test.

Existing field FMC data collected in grassland (Newnham et al. 2015), shrubland (Caccamo et al. 2012) and forest (Nolan et al. 2016) between 2004 to 2014 were used to validate the algorithm retrievals.

The FMC retrievals were used to map a dimensionless Flammability Index (FI) based on logistic regression models between fire occurrence derived from the MODIS burned area product (the binary dependent variable) and predictor variables derived from the satellite FMC estimates described above. Following Jurdao et al. (2012) we use a cumulative logistic distribution function (Eq. 1-2):

$$FI = \frac{1}{1+e^{-z}} \quad (1); \quad z = a + \beta_1 x_1 + \beta_2 x_2 + \dots + \beta_n x_n \quad (2)$$

where FI is the Flammability Index (equaling the probability of fire occurrence in the training sample), a is the model intercept, β_1, \dots, β_n are the equation coefficients, x_1, x_2, \dots, x_n are the independent variables.

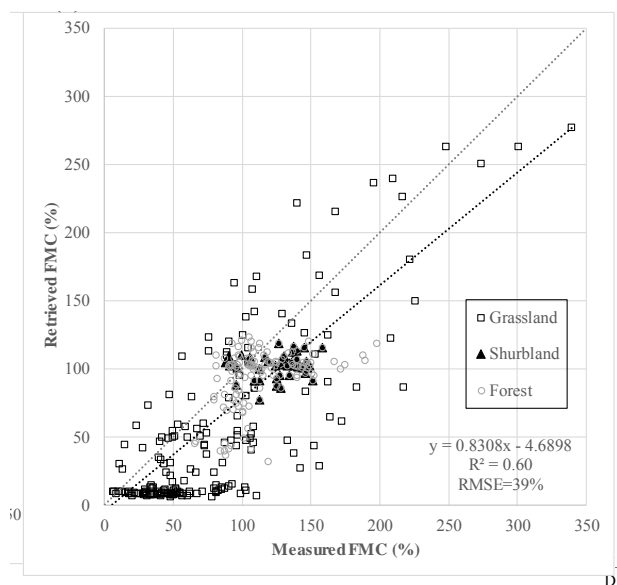
The training sample was constructed as a series of data pairs, in which each data pair includes (i) FMC of a pixel before burning, and (ii) the mean FMC of a representative sample of unburned pixels that is sufficiently close to represent a similar land cover class, but did not burn. Areas not affected by fires were selected from cells surrounding the burned pixels using the semi-variogram geostatistical technique (Jurdao et al., 2012).



RESULTS

A result of this study is a multitemporal FMC and flammability dataset at an 8-day resolution for the period 2001 to 2016 over Australia. The dataset is accessible at, <http://dapds00.nci.org.au/thredds/catalog/ub8/au/catalog.html>.

Overall, the FMC algorithm explained 60% of the measured FMC across all sites and vegetation types with an RMSE of 39% (n=374). The slope (0.83) and offset (-4.68) of the linear regression between measured and retrieved FMC (Fig. 1) suggest no significant bias in the estimates.



Three separate logistic regression models (Eq. 3-5) were fitted for grassland, shrubland and forest obtaining an area under the curve from the receiving operating characteristics curves of 0.70, 0.78 and 0.71, respectively.

$$FI_{\text{grassland}} = 0.18 - 0.01 * FMC_{t-1} + 0.02 * FMC_D - 0.02 * FMC_A \quad (3)$$

$$FI_{\text{shrubland}} = 5.66 - 0.09 * FMC_{t-1} + 0.005 * FMC_D - 0.28 * FMC_A \quad (4)$$

$$FI_{\text{forest}} = 1.51 - 0.03 * FMC_{t-1} + 0.02 * FMC_D - 0.02 * FMC_A \quad (5)$$

where FMC_{t-1} is the FMC corresponding to the 8-day period prior to the 8-day period including the fire date; FMC_D is the FMC difference between the two consecutive 8-day periods prior to the 8-day period including the fire date ($FMC_{t-2} - FMC_{t-1}$), representing a rate of change, and FMC_A the departure of FMC_{t-1} from the average FMC value for that period for the time series (2001-2016)

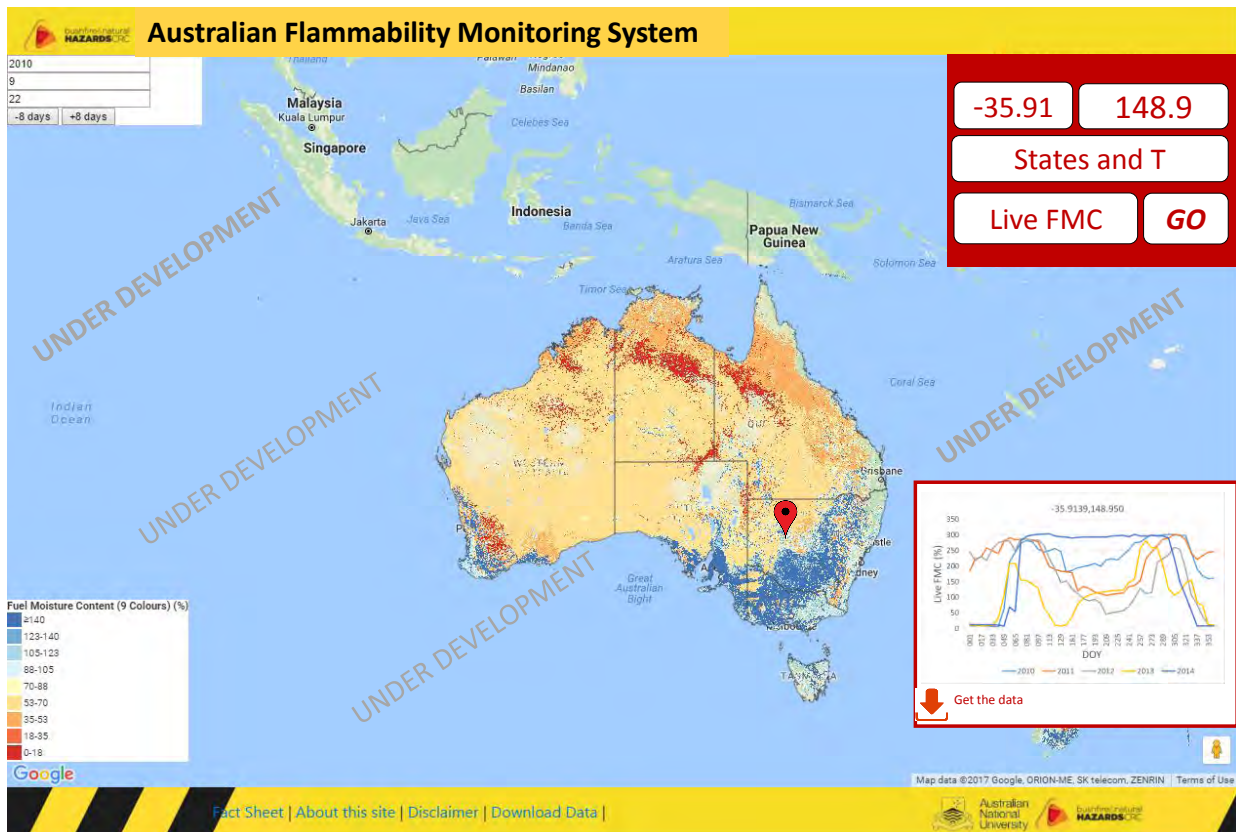


FIG. 2. A SCREEN CAPTURE OF THE AFMS WEB EXPLORER SHOWING THE CHANGE IN FMC FOR A SPECIFIC LOCATION

A prototype web explorer was built in consultation with end-users to make spatial information on FMC and FI easier and faster to access for interested users (Fig. 2). The AFMS offers advanced functions for professional users to interrogate the data and download options. It also offers the flexibility to incorporate other relevant information that might be currently available (e.g. fire weather, intensity and occurrence, soil moisture).



DISCUSSION AND CONCLUSIONS

We presented the first Australia-wide product of FMC and associate flammability based on MODIS imagery and radiative transfer model inversion. The overall accuracy of the FMC algorithm was reasonable, although a reduction of estimation error is desirable to further improve fire risk estimation and use by practitioners. FMC was converted into a flammability index using logistic regression models. The advantage of these models is that they offer the possibility of predicting fires one week before the beginning of the event. The long-term objective is to integrate FMC with other key fuel structural properties and fire weather into fire propagation models, to derive more reliable estimates of flammability and rate of spread for local conditions.



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THE AUSTRALIAN NATURAL DISASTER RESILIENCE INDEX: ASSESSING AUSTRALIA'S DISASTER RESILIENCE AT A NATIONAL SCALE

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ABSTRACT

The Australian Natural Disaster Resilience Index (ANDRI) is Australia's first national-scale standardised snapshot of disaster resilience. Because of its national extent, the ANDRI takes a top-down approach using indicators derived from secondary data. The ANDRI has a hierarchical design based on coping and adaptive capacities representing the potential for disaster resilience in Australian communities. Coping capacity is the means by which people or organizations use available resources, skills and opportunities to face adverse consequences that could lead to a disaster. Adaptive capacity is the arrangements and processes that enable adjustment through learning, adaptation and transformation. Coping capacity is divided into themes of social character, economic capital, infrastructure and planning, emergency services, community capital and information and engagement. Adaptive capacity is divided into themes of governance, policy and leadership and social and community engagement. Indicators are collected to determine the status of each theme. This paper will present a preliminary assessment of the state of disaster resilience in Australia, and the spatial distribution of disaster resilience across Australia. We then outline the framing of the assessment outcomes as areas of strength and opportunities for enhancing the capacities for disaster resilience in Australian communities. The utilisation of the ANDRI into emergency management agency programs and tools will also be discussed.



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INTRODUCTION

The focus in managing natural disasters in Australia and internationally has, in recent years, moved from risk and vulnerability towards resilience, which includes an emphasis on shared responsibility. This shift towards disaster resilience recognises the uncertainties inherent in natural hazards. These uncertainties range from the unpredictability of natural hazard location and impact, to the changing patterns of hazards resulting from climate change, to the demographic, economic and institutional patterns in society. Understanding how to improve disaster resilience will help communities, governments and organisations to develop the capacities needed for living with natural hazards.

There are many ways to operationalise resilience into policy and programs. Part of operationalising disaster resilience in Australia involves assessing the current state of disaster resilience. Researchers from the Bushfire and Natural Hazards CRC have teamed with emergency service agencies around Australia to develop an index of disaster resilience that is designed to help meet the challenges of Australia's increasingly uncertain hazard future. For the first time, this index will assess and report the state of disaster resilience on a large scale – Australia-wide. The index will use a nationally standardised measure that will make it easy for end-users to identify areas of strength and areas needing improvement, to plan future actions, policies and programs and provide a baseline from which to measure progress in disaster resilience. The index of disaster resilience has potential inputs into macro-level policy, strategic planning, community planning and community engagement at national, state and local levels.

This paper outlines the structure of the Australian Natural Disaster Resilience Index.



BACKGROUND

Academic research on disaster resilience is diverse and active, and resilience is increasingly the foundation of public policies and programs in natural hazard and disaster management (Parsons et al., 2016). There are many definitions of disaster resilience but they are consistent in three aspects. These are the capacities to:

- absorb or accommodate the effects of an external disturbance or stressor event
- recover and return to a functioning state or to persist following an event
- learn, adapt or transform.

For the Australian Natural Disaster Resilience Index, disaster resilience is defined as the capacities of communities to prepare for, absorb and recover from natural hazard events; and to learn, adapt and transform towards resilience (Parsons et al., 2016). Importantly, this definition does not highlight the actual realisation of resilience but the capacities for resilience.

DESIGN OF THE INDEX

Coping and adaptive capacities

The Australian Natural Disaster Resilience Index assesses resilience based on two sets of capacities – coping capacity and adaptive capacity (Figure 1).

Coping capacity enables people or organizations to use available resources and abilities to face adverse consequences that could lead to a disaster (sensu UNISDR, 2009). In a practical sense, coping capacity relates to the factors influencing the ability of a community to prepare for, absorb and recover from a natural hazard event.

Adaptive capacity is the ability of a system to modify or change its characteristics or behaviour to cope with actual or anticipated stresses (Folke et al., 2002). Adaptive capacity entails the existence of institutions and networks that learn and store knowledge and experience, create flexibility in problem solving and balance power among interest groups (Folke et al., 2002). In a practical sense, adaptive capacity relates to the factors that enable adjustment of responses and behaviours through learning, adaptation and transformation.

Together, these coping and adaptive capacities form the core of our assessment of resilience to natural hazards. Coping capacity and adaptive capacity help to answer the question 'How able is a community to prepare for, respond to and recover from a natural hazard event and return to a satisfactorily functioning state in a timely manner, and to strategically learn and adapt to improve its resilience to future natural hazard events?'

Indicator themes

Themes divide coping capacity and adaptive capacity into its sub-components (Figure 1). Themes are the factors – related to coping capacity or adaptive capacity – that contribute to community resilience to natural hazards (Table 1). Themes have a basis in the literature: some with empirical evidence of the relationship between the theme and resilience, and others that conceptualize this relationship but with little empirical testing (Parsons et al., 2016).

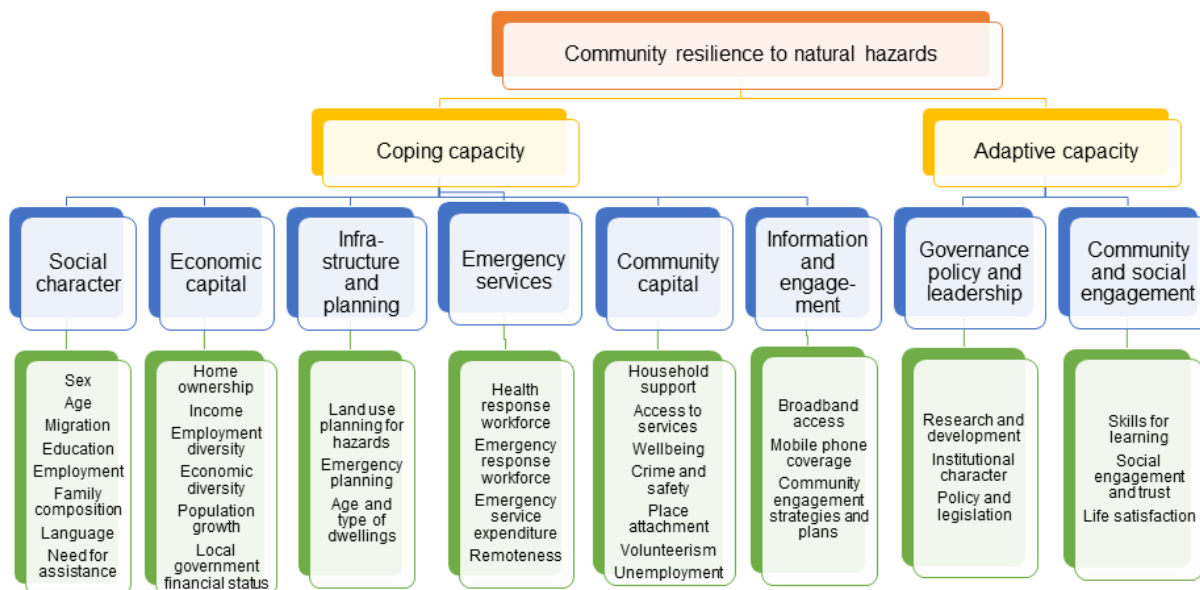


Figure 1. Hierarchical structure of the Australian Natural Disaster Resilience Index.

Indicators

Indicators provide the data for a theme – together the indicators measure the status of the theme. Selecting indicators is both an art and a science. Many indicators have a basis in the literature and have demonstrated relationships with aspects of natural hazards or disasters. For example, there is a documented relationship between income, housing type and gender and the ability to prepare for and respond to natural hazard events (Morrow, 1999). The indicators used to measure the status of the theme can be selected using a set of criteria that increase confidence in the associations between an indicator and disaster resilience (Winderl, 2014).

We have collected 89 indicators across the eight themes. Each indicator has data available in each State and Territory and represents the relationships to disaster resilience outlined in Table 1. For brevity in Figure 1, indicators have been grouped into dimensions. However, there may be several indicators associated with one dimension. For example, employment is comprised of three indicators: % of the labour force unemployed; % not in the labour force; and % managers and professionals.



Table 1. Explanation of themes within the Australian Natural Disaster Resilience Index. The right hand column overviews the relationship between the theme and natural hazard resilience, although a review process will further explore these relationships as part of the project

Theme	Description	Influence on natural hazard resilience
Social character	<ul style="list-style-type: none"> The social characteristics of the community. Represents the social and demographic factors that influence the ability to prepare for and recover from a natural hazard event. 	<ul style="list-style-type: none"> Gender, age, disability, health, household size and structure, language, literacy, education and employment influence abilities to build disaster resilience (Morrow, 1999; Thomas et al., 2013).
Economic capital	<ul style="list-style-type: none"> The economic characteristics of the community. Represents the economic factors that influence the ability to prepare for and recover from a natural hazard event. 	<ul style="list-style-type: none"> Access to economic capital may be a barrier to resilience building activities (Bird et al., 2013). Losses from natural hazards may increase with greater wealth, but increased potential for loss can also be a motivation for mitigation. Economic capital often supports healthy social capital (Thomas et al., 2013).
Infrastructure and planning	<ul style="list-style-type: none"> The presence of legislation, plans, structures or codes to protect infrastructure. Represents preparation for natural hazard events using strategies of mitigation or planning or risk management. 	<ul style="list-style-type: none"> Considered siting and planning of infrastructure is an important element of hazard mitigation. Multiple levels of government are involved in the planning process (King, 2008; Crompton et al., 2010). Planners can be agents of change in building disaster resilience (Smith, 2009).
Emergency services	<ul style="list-style-type: none"> The presence, capability and resourcing of emergency services, warning systems and disaster response plans. Represents the potential to respond to a natural hazard event. 	<ul style="list-style-type: none"> Emergency response capabilities and systems support resilience through the entire PPRR cycle.
Community capital	<ul style="list-style-type: none"> The cohesion and connectedness of the community. Represents the features of a community that facilitate coordination and cooperation for mutual benefit. 	<ul style="list-style-type: none"> Social networks assist community recovery following disaster (Akama et al., 2014). High levels of social capital can enhance solutions to collective action problems that arise following natural disasters (Aldrich, 2012).
Information and engagement	<ul style="list-style-type: none"> Availability and accessibility of natural hazard information, engagement of the community with natural hazards and public-private or other partnerships to encourage risk awareness. Represents the relationship between communities and information and the uptake of information about risks and the knowledge required for preparation and self-reliance. 	<ul style="list-style-type: none"> Emergency management community engagement is made up of different approaches including information, participation, consultation, collaboration and empowerment (EMA, 2013). Community engagement is a vehicle of public participation in decision making about natural hazards (Handmer and Dovers, 2013).



Table 1. (cont.)

Theme	Description	Influence on natural hazard resilience
Governance, policy and leadership	<ul style="list-style-type: none"> The capacity within government agencies to adaptively learn, review and adjust policies and procedures, or to transform organizational practices. Represents the flexibility within organizations to learn from experience and adjust accordingly. 	<ul style="list-style-type: none"> Effective response to natural hazard events can be facilitated by long term design efforts in public leadership (Boin, 2010). Transformative adaptation requires altering fundamental value systems, regulatory or bureaucratic regimes associated with natural hazard management (O'Neill and Handmer, 2012). Collaborative learning facilitates innovation and opportunity for feedback and iterative management (Berkes, 2007; Goldstein, 2012).
Community capital and social character	<ul style="list-style-type: none"> The cohesion and connectedness of the community and the social and demographic character of a community. Represents the resources and support available within communities for engagement, learning and adaptation and the factors influencing the uptake of adaptation information and strategies. 	<ul style="list-style-type: none"> High levels of social capital can enhance solutions to collective action problems that arise following natural disasters (Aldrich, 2012). Cooperation and trust are essential to building disaster resilience and arise partly through social mechanisms including social capital (Folke et al., 2002; Kaufman, 2012).

INDEX COMPUTATION AND ANALYSIS

Index calculation is the process of bringing together the indicators to form an index. Methodological issues in the construction of composite indices have been extensively discussed and/or analysed in a number of different disciplines, including sustainability, environmental condition, climate change and international development. The history of composite index development shows that the representation of a complex system with a single number has an irresistible allure. The addition or averaging of rescaled indicators has had an intuitive appeal that has made it the most widespread of aggregation methods. However, as composite index construction has received increasing scrutiny, and an increasing number of fields have found applications for composite indices, their shortcomings are becoming better understood. Chief among these are the issues of indicator rescaling and compensability. These problems have driven the search for non- or partially compensatory aggregation methodologies where weights can validly be interpreted as measures of importance.

The Australian Natural Disaster Resilience Index will consider and apply best practice composite index methods in the component areas of computation: functional form, construct validity and content validity; populations, samples and outliers; transformations of indicators; indicator reversals; correlation between indicators; and, weighting and aggregation. The computation of the index is presently underway.



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HOW RISK INFORMS NATURAL HAZARD MANAGEMENT: A STUDY OF THE INTERFACE BETWEEN RISK MODELLING AND LOCAL GOVERNMENT POLICIES AND PROCEDURES

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EXTENDED ABSTRACT

This extended abstract explores the use of risk modelling as a tool to support local government in New Zealand to better develop policy and procedure for natural hazard management.

New Zealand is an island nation in which events such as earthquake, volcanic activity, tsunami, flooding, storm, and landslide occur with sufficient intensity that substantial damage and loss of life results (King & Bell, 2006). Given the severity of natural hazard risks, it is an increasingly important focus for national and local governance to ensure natural hazards are understood and managed effectively. However, local government understanding and management of natural hazard risk is fraught with challenges, including uncertainty over how they should be managed (LGNZ, 2014; Saunders et al., 2015), scarce data on natural hazards (Tonkin & Taylor, 2016; MWH, 2016), and limited appreciation of natural hazard risks (LGNZ, 2014; Tonkin & Taylor, 2016).

Underlying these challenges is the disconnect of 'science to policy', and the subjective nature of risk perception. While scientists, policy writers and practitioners agree on the importance and value of science informed policy and practice, bridging the science to practice gap is not a simple task. It depends on a mutual spirit of partnership and interest between the scientific and practice communities (Vogel, 2007). Kilvington & Saunders (2016) reflect on this in their recent review of how natural hazards science is incorporated in local government decision making in New Zealand, recognising that "despite genuine and ongoing efforts to improve the relationships between science information users and producers, research agencies still struggle in many ways to fully transition their communication practice towards new ideals" (Kilvington & Saunders, 2016. p4.). Secondly, risk is a social construction. It is an intangible concept that only exists through being individually qualified within a social context (Dake, 1992; Renn, et al., 1992; Van Nuffelen, 2004). As such, risk perception is subjective, involving a person's feelings, beliefs, attitudes and judgements about the harm and loss associated with the consequences of an event. Risk perception is framed by culture, society, experience, and feelings (Doyle et al., 2014), is built on local values and norms, and is depend on disciplinary frameworks (WSS Fellows on RIA, 2014). Therefore, the way one person perceives a risk can be significantly different to the way another person perceives that same risk, which then influences their motivation to engage in natural hazard risk management actions (Donahue, et al., 2014; McIvor, et al., 2009; Paton, et al., 2013).

Given this background, the need for improved risk communication between science, policy and practice has been increasingly recognised (WSS Fellows on RIA, 2014; Kuhlicke & Demeritt, 2014). However, much of the research has focussed on the tenets and mental models of risk communication (Bostrom, et al., 2008; Fischhoff, et al., 1993; Khan and Kelman, 2012; Lindenfeld, et al., 2014), and while there has been a call for the use of tangible heuristics and models to support decisions for effective risk management (The World Bank, 2014; WSS Fellows on RIA 2014), little is known about how effective risk models are for the communication of natural hazard risk from science to policy and vice versa (Komendantova et al., 2014).

Given the time restraints for practitioners, an engagement method was adopted that rapidly provided an inclusive space for discussion, avoided engagement fatigue and remained focussed. In light of this, the research team used focus group discussions. A focus group is a qualitative research method enabling a group of



people to discuss their perceptions, opinions, beliefs, and attitudes towards something in an interactive group setting where participants are free to talk with other group members. This method was used because it enables open and creative discussion and produces data and insights that would be less accessible without the interaction found in the group (Flick, 2006).

Five regional councils were engaged, using focus group methods, to explore the use of risk modelling as a tool to support local government natural hazard risk management. Each council approached has varied attributes relating to the size of the region for which it has responsibility, management structure, and the regional hazard landscapes. Focus group sessions were held with:

- Wellington
- Hawke's Bay
- Canterbury
- Nelson/ Tasman
- Bay of Plenty

Focus group sessions had six to fifteen participants attending from natural hazard risk management roles across the council. Data was captured through notes taken during the focus group sessions and through dictaphone recordings. The data were then analysed using thematic analysis, a common form of analysis in qualitative research. Themes were identified using an inductive, 'bottom up' approach, where the themes identified emerge from the data itself (Patton, 2015). Resultant themes were coded according to themes inspired by the objectives of the research in addition to unexpected themes that were identified during the analysis. Two qualitative analysis software packages were used for this - NVivo and QDA Miner 4 Lite.

Following the thematic analysis, the individually identified codes were reviewed and regrouped into mutually agreed themes. This approach is based on content analysis, a process of organising information into categories related to the central questions of the research (Bowen, 2009). The goal of content analysis is to reduce the material; for this research it meant that less relevant themes were skipped, and then the remaining similar themes were bundled and summarised.

The results identify three themes: 1) 'the role of natural hazards management within and across councils'; 2) 'risk data drivers and needs for natural hazard management'; 3) 'risk data pathways'. These themes interact and influence each other, and are examined in turn.

1) Some councils recognised the confusion of different roles being 'responsible' for natural hazard risk management, i.e. emergency management, land-use planning, engineering, or building control, yet it being a shared function across most departments and groups across council. There was disagreement between raising the profile of these roles within council decisions that require a risk informed approach, versus labelling natural hazard risk management as a certain roles responsibility alone. Entry points for natural hazard management to engage across council were a common point of discussion. There were a spread of approaches ranging from complete integration of the natural hazard function across council, which naturally provided easy access to important discussions and decisions, through to issues where the natural hazard risk management function remained isolated and had to 'push' its way into discussions that they were able to find out about. The ease of integration across council appeared to stem from the influence of key individuals within the



group, either explicitly in terms of specially designed 'knowledge broker' roles (Meyer, 2010), where the role bridges across the range of natural hazard roles within the council, or specific staff with a strong drive and influence to integrate across council, or the ability of groups to draw in staff from across council.

2) The two most frequently discussed needs for natural hazard risk management data focussed on risk communication and real-time event response. However, cutting across these activities were influential threads relating to uncertainty, external influencers and experience. Communicating natural hazard risks was recognised not just for increasing hazard awareness, but also as key for gaining input and agreement for council policies designed to reduce community exposure and vulnerability. Natural hazards practitioners discussed the importance of communicating risk information for influencing decision making on future development, specifically the communication of economic loss information to justify actions for reducing risk. Speed of data access, analysis and interpretation was a critical discussion point, with most participants agreeing that the ability to gather or produce real-time information during a crisis would be beneficial.

3) Essential to discussions was **each natural hazard management function's** ability to access risk data and the relevance of information available. This was most prevalent with the emergency management function, which described themselves as '**gatherers**' rather than **generators** of risk information and therefore reliant on a range of external information sources from other parts of the council as well as from outside agencies. Participants also reported a lack of knowledge of what data their council held, adding that even if they knew of its existence it was often in a format that **couldn't be used outside of its original context**. Another challenge lay in the cost of data collection or management, where the cost of collecting data for cross-council use did not meet the benefits and was abandoned.

In summary, the results depict a challenging environment for the natural hazard management function to better develop policy and procedure in New Zealand local government. This is not only because of confusion over the different roles for natural hazard risk management and limited influence for decision making, but also because of lack of data availability and suitability. As such, results show that there appears to be no standard approach to generating or sourcing risk data and there is no simple pathway for its communication.

While it is a challenging environment, there is definite engagement from natural hazard management practitioners on the use of risk modelling to better develop policy and procedure. In general, practitioners have a good understanding of what the risks are, and how risk modelling can aid in natural hazard risk management. However, the focus group sessions show that there is a continued disconnect across science – policy interface and resulting practice. Even though the risks are known by the scientists and practitioners, there is a disconnect between them and the development of better policy and practice.

The disconnect between science, policy and practice is well covered, identifying challenges such as the different knowledge discourses between scientific knowledge and local knowledge (Nurse-Bray et al., 2014); lack of integrative processes linking bottom-up and top-down actions (Gaillard & Mercer, 2012); and the need for more inter-connectedness across contributing programmes (Glasgow & Emmons, 2007). Saunders and Kilvington (2016) refer to a mix factors disconnecting science from practice, including: differing planning time frames, lack of skills and resources, unavailability of consultants or knowledge brokers, and social and political pressures.



Nevertheless, practitioners agree that the use of natural hazard risk modelling can be useful as a communication pathway, specifically with its ability to spatially communicate risk on a map, being a very engaging way to influence decision maker perceptions to develop better policy (Bostrom, 2008; McInerney et al., 2014; Thompson et al., 2015). However at its current state of development, natural hazard risk modelling has a long way to go, with simple risk models, 'klunky' usability, and lack of supporting data. Even though the only way that natural hazard risk modelling can develop is through being used, practitioners are reluctant to use it because of the pre-existence of alternative tools, the considerable resource pressures (time, capability and money) needed to invest in its development, and the lack of assurance that an improved perception of natural hazard risk would actually change decision maker actions, considering their wider social and political environments.

Given these challenges, what options are there to enable risk modelling as a tool to support local government in New Zealand to better develop policy and procedure for natural hazard management?

- Legislate greater mandate for how natural hazard risk management is achieved in New Zealand local government
- Support and enable knowledge brokerage for natural hazard risk management
- Employ participatory, democratic approaches between 'science', 'practice and 'policy' for developing natural hazard risk management policy
- Enable greater capacity and capability for collecting natural hazard risk data



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ENHANCING TEAM PERFORMANCE

Non-peer reviewed research proceedings from the Bushfire and Natural Hazards CRC & AFAC conference
Sydney, 4 – 6 September 2017

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ABSTRACT

Effective teamwork is vital when managing emergencies. Emergencies can exert extreme pressures on emergency teams, their leaders and co-responders. These pressures sometimes cause breakdowns in teamwork that can lead to impaired operational response. This project helps to improve teamwork through better real-time identification and resolution of teamwork issues. To do this the project has developed two tools: the Emergency Management Breakdown Aide Memoire (EMBAM) and the Team Process Checklist (TPC). The tools' flexibility and ease of use helps emergency managers to strengthen teamwork before, during and after emergencies. The tools can be used during training, in actual emergencies, and in after-action reviews. End-users have so far found the tools to be highly valuable.

CONTEXT

The highly demanding nature of managing emergencies can disrupt effective team performance. These disruptions can lead to an impaired operational response, creating risks to public safety, property and other assets. This project is helping to foster cohesive teamwork when it is most needed – when teams are responding under pressure to emergency events.

BACKGROUND

Teamwork is an essential part of emergency management. To a large extent, emergency management can be characterised as teams of people interacting within the hierarchical structure of an agency (Bearman et al., in press). Within this structure, information flows within a specific team (for example, a strike team), between that specific team and a broader team (that includes radio operators or brigade officers), other teams (for example, other strike teams) and teams at more senior levels (such as group officers or regional-level personnel).

During emergencies, individuals and teams often work under considerable pressure that can disrupt effective team performance. The implications of these disruptions can be serious. An analysis of three large-scale bushfires in Australia, (Bearman et al., 2015a) showed examples where team breakdowns led to confusion, miscommunication and inconsistent fire-management plans.

It is important, however, to acknowledge that people managing emergencies will sometimes make errors and that disruptions to teamwork will occur. Many organisations now recognise that error is a normal part of human performance and emphasise both error recovery and minimisation (Reason, 1990). This moves the focus away from blaming people to designing mechanisms and systems that can identify and resolve disruptions as quickly as possible (Bearman et al., 2017, Grunwald and Bearman, 2017, Reason, 1990).



BUSHFIRE AND NATURAL HAZARDS CRC RESEARCH

Since 2015 the project team has been developing two tools that help to identify and resolve breakdowns in teamwork. These tools are known as the Emergency Management Breakdown Aide Memoire (or EMBAM) (Grunwald and Bearman, 2017) and the Team Process Checklist (TPC). The TPC is based on research into teamwork breakdowns by Wilson et al. (2007) and Bearman et al. (2015b). These tools are checklists that help people to think about teams and team processes and are designed to be used in real time during an incident or training session.

The two tools take slightly different approaches to monitoring teams. EMBAM is designed to be integrated into the activities of a senior officer and focuses on the outputs of teams and organisational networks. This checklist is reasonably quick and easy to apply and identifies problems at a general level. EMBAM also includes different strategies that can resolve issues in teams (see the box – About EMBAM)

About EMBAM

EMBAM is a checklist that helps people to recognise teamwork breakdowns through team outputs (for example, incident action plans) and formal/informal organisational networks. It also provides some practical resolution strategies shown below.

How you might resolve breakdowns.

1. Delegate: Find someone who is close to the breakdown or has the most appropriate skills and have them resolve the issue.
2. Resource: Breakdowns can be caused by missing resources. Find out what is missing, or what will assist the other teams, and get it to them.
3. Mentor: A subtle form of resolution, mentoring allows you to tactfully suggest alternatives, opinions and strategies.
4. Assert: **If you've tried more subtle strategies without success, you can use your authority to resolve the problem.**
5. Replace: If breakdowns are caused by disruptive personalities in the management team, or even factors like fatigue, you can stand the disruptive person down or give them other duties.

If EMBAM identifies a problem, or if a more detailed health check of the team is needed, then the TPC is used. The TPC contains questions about the coordination, cooperation and communication processes that should occur in effective teams. **The team's performance is considered in relation to each of these questions. Any issues that the tools identify should be discussed with the team (see the box – About TPC)**



About TPC

The TPC checklist is designed to provide a health check for teams and, if there is a problem, to help determine what that problem is. This tool is designed to assist people to think through three aspects of teamwork: communication, coordination and cooperation. Examples of the communication items are below.

- Are team members passing on information in a timely manner?
- Are team members passing on information accurately?
- Is communication between team members clear?
- Are team members providing appropriate feedback?
- Are team members providing updates on the situation?
- Are appropriate communication procedures being used?

RESEARCH FINDINGS

The researchers developed the tools together with end-users through an iterative cycle of testing and redevelopment (see Bearman et al. (2017)). The initial version of the tools was based on an extensive literature review of methods that could be used by an observer to monitor teams (which was the original intention of the tools). For more details see Bearman et al. (in press). A preliminary evaluation study of the tools suggested that they both showed promise and should be developed further (Bearman et al., 2017).

The tools were then developed and evaluated by a team consisting of four state-level end-users during five regional exercises. These exercises required a fully staffed regional coordination centre to manage one or more significant large-scale fires. During the exercise, actors simulated radio traffic on the fire-ground and adopted the roles of key stakeholders (such as police). Observers used the TPC to help assess the team and to inform the debrief at the end of the exercise. After each exercise, the team met to provide feedback on the checklist, evaluating whether each question needed to be removed or amended. Any changes were made before the next exercise, where the process was repeated.

The tools were also evaluated by six regional and state coordinators during two large-scale storm and flood events. During the events, the research team did a telephone interview with each of the coordinators participating in the study. In these interviews, the coordinators considered the performance of teams against each item on the TPC. This allowed the coordinator to identify issues in those teams that needed to be considered in the next hour, the next shift, the next day and the next week. As part of the discussion, the participant evaluated whether each item on the checklist provided useful information.

Finally, two senior officers (a state controller and state information officer) used both tools throughout a fire season. This fire season contained many significant bushfires which the agency needed to manage. At the end of the fire season the researchers interviewed the two senior officers about how they used the tools and whether the tools were effective. The participants found the tools to be valuable, and had used them as memory aids to ensure nothing had been overlooked, to do team health checks and to resolve team problems before they escalated.



HOW COULD THE RESEARCH BE USED?

The tools are a very flexible way to examine teamwork from many perspectives.

They can be used as a health check to ensure the team is functioning effectively, to identify suspected problems, as a debrief tool and to foster better teamwork. They can be used in real time during an incident, as a way to reflect on teamwork during periods of relative calm, and as an assessment and/or debrief tool during training. They can be used by team members, team leaders, external people who have operational oversight (for example, regional coordinators) and by independent observers.

FUTURE DIRECTIONS

The tools have been developed together with end-users and used in a number of different settings. In each setting, the tools have provided useful information to the user and all of the agencies involved in developing the tools have either adopted them or are considering adoption. More testing to validate the use of the tools in different settings will be done over the next year (2017-2018). However, both EMBAM and TPC have shown considerable promise as a viable way of identifying and managing issues in teams.



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An organisational response to Stage 3 Geography and the study of a contemporary bushfire event

Non-peer reviewed research proceedings from the Bushfire and Natural Hazards
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Sydney, 4 – 6 September 2017

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ABSTRACT

The NSW Geography Syllabus now requires that Stage 3 students (Years 5 and 6) study a contemporary bush fire event using an Inquiry Learning approach. The NSW Rural Fire Service (NSW RFS) estimates that in 2017 2,500 schools, 4,000 classroom teachers and 100,000 students will be undertaking this Unit.

The NSW RFS has supported the development of An evidence-based practice framework for children's disaster education. The Framework is a primary guidance to the Stage 3 Geography work now being undertaken by the NSW RFS, addressing the majority of elements identified under the Framework's 6 areas (Curriculum, Pedagogy, Assessment, Professional Development, Scaled Implementation, Monitoring and Evaluation).

This is an opportunity for inter-generational change. Stage 3 students will experience disaster resilience education framed around a contemporary bush fire event.

NSW RFS volunteers and staff already undertake numerous activities with schools and students, most commonly with the delivery of key fire and bush fire safety messages with younger children.

The Geography Syllabus change has required the NSW RFS to reflect on how to support explicit educational outcomes. The NSW RFS response to the change has four key elements:

- collaborations with NSW education sector, professional associations, schools and interested teachers to develop approaches and tools that can contribute to educational values and outcomes.
- Capability development for teachers through participation in professional learning events and communications as well as supporting resources.
- a revised NSW RFS Schools webpage that has a focus on Stage 3 Geography, reflects inquiry-based learning principles, and has information pathways for teacher, students and NSW RFS Members
- skills development for NSW RFS Members to support Stage 3 students and teachers, including an RFS Members pathway on the Schools Education landing page;

This work also complements key elements of the research utilization roadmap 2016-21 for the BNHCRC Building Best Practice in Child Centred Disaster Risk Reduction (CC-DRR) project. This work will help to create effective CC-DRR programs that can be sustainably implemented at scale, and that increase resilience and reduce current and future disaster risk.



SUMMARY OF THE NSW RURAL FIRE SERVICE RESPONSE

The body of evidence around disaster resilience education highlights the capacity of children and young people to be active participants in responding to disaster events can be built. No longer do they have to be passive bystanders needing adult direction and support. Further, children are also able to positively influence the actions of adults in disasters and emergencies.

The NSW Rural Fire Service (NSW RFS) has responded to the introduction of the NSW Geography Syllabusⁱ changes by collaborating with the NSW education sector, revising the NSW RFS website, capability development for teachers and support to NSW RFS volunteer and staff Members.

This Stage 3 Geography approach reflects most elements of the evidence-based practice frameworkⁱⁱ for children's disaster education developed under the Bushfire and Natural Hazards Cooperative Research Centre's *Child Centred Disaster Risk Reduction*ⁱⁱⁱ (CC-DRR) project - Curriculum, Pedagogy, Assessment, Professional Development, Scaled Implementation, Monitoring and Evaluation.

This work will help to create effective CC-DRR programs that can be sustainably implemented at scale, and that increase resilience and reduce current and future disaster risk, particularly around bush fire.

NSW GEOGRAPHY SYLLABUS STAGE 3

In 2017 alone, it is expected that 2,500 schools, 4,000 classroom teachers and 98,000 students will be delivering or undertaking this Unit about the impact of one contemporary bush fire hazard in Australia. The key learning outcomes are that students can describe places and environments, explain interactions and connections, and compare and contrast influences.

Students will achieve these learning outcomes by a number of means including exploring the impact bush fires have on people, places and environments and propose ways people can reduce the impacts of bush fires; describing the impact of the disaster on natural vegetation and the damage caused to communities.

Inquiry learning is expected to be used, with students researching and investigating problems, and devising solutions and mitigation actions.

COLLABORATIONS

Delivery of Curriculum and Syllabus outcomes are not the province of the NSW RFS. The NSW RFS is seeking to position itself as a valid, valuable and authentic support organisation to the education sector.

The NSW RFS is collaborating with the three education providers in NSW (Department of Education, Catholic Education Commission, Association of Independent Schools) as well as with professional associations such as the Geography Teachers Association, schools and interested teachers to develop approaches and tools that can contribute to educational outcomes.



APPLICATION OF THE PRACTICE FRAMEWORK

The development of resources and materials by the NSW RFS for the Stage 3 Geography bush fire unit reflects key elements of *An evidence-based practice framework for children's disaster education* across the Framework's 6 areas (Curriculum, Pedagogy, Assessment, Professional Development, Scaled Implementation, Monitoring and Evaluation). That work is summarized in Table 1.

Area of the Framework: Curriculum

The Stage 3 bush fire Unit is within the NSW Geography Syllabus, aligned to the Australian Curriculum^{iv}; Vertical integration occurs across STEM Science Technology Engineering and Mathematics^v;
Reflects current scientific knowledge of hazards and disasters.
Reflects relevant policy and practice of bush fire agencies.
Incorporates local and indigenous knowledge though cultural burning and Firesticks.

Area of the framework: Pedagogy

Clearly articulated learning objectives and outcomes from the Syllabus
Learning outcomes are achieved through child-centred Inquiry Learning^{vi} approaches
Student participation in their schools and households

Area of the framework: Assessment

Assessment elements remain the province of schools and teachers. Generally assessment is both formative and summative, is directly aligned with stated learning objectives and outcomes, uses a range of assessment methods.

Area of the framework: Professional Development

Resources and materials to support teacher delivery of the Unit are collaboratively formed to meet the needs of teachers.
Educators are being provided with professional training via existing Sector channels, such as webinars

Area of the framework: Scaled Implementation

The approach is guided by the context of scale by explosion.
Enabling factors such as existing Curriculum support for teachers are being utilised.

Area of the framework: Monitoring and Evaluation

Monitoring and evaluation of student learning outcomes is generally being undertaken by teachers and schools
Unit resources and information is modified and updated to reflect M&E outcomes.

TABLE 1 - NSW RFS ACTION DIRECTED BY AN EVIDENCE-BASED PRACTICE FRAMEWORK FOR CHILDREN'S DISASTER EDUCATION

TEACHER CAPABILITY DEVELOPMENT

Teachers have clearly stated that they are seeking general knowledge about bush fire and confidence in delivering this Unit most effectively. Guidance and support is framed by what teachers actually need and want, rather than what the NSW RFS thinks teachers might want or like.

NSW Department of Education Curriculum Advisors created an initial Bushfire Mitigation Teaching and Learning Framework^{vii} to support teachers with this Unit in its first year of implementation. The NSW RFS has worked with those Curriculum Advisors to enhance that Framework to include specific advice, direction and resources to support students' inquiry learning on bush fire.

The NSW RFS continues to engage with teachers in professional learning events, conferences and workshops, as well as through webinars and other online forums conducted through education providers.

CASE STUDY: ST IVES NORTH PRIMARY SCHOOL 'FIRESTORM' STEM PROJECT^{viii}



In late 2016, St Ives North Primary School connected STEM (Science, Technology, Engineering and Mathematics) to link with the Stage 3 Geography bush fire unit through the Firestorm^{ix} project. The success of Firestorm is a consequence of:

- Being real-life and authentic
- application of the Stanford University model of design thinking^x
- A clear and open-ended driving question: how can the community of St Ives prepare for, survive and recover from a catastrophic bush fire?
- Knowledge integration of science - fire behaviour, material fire resistance
- Knowledge integration of mathematics - rates of spread, effect of wind and slope
- Technology - data logging, coding, and web design

NSW RURAL FIRE SERVICE SCHOOL WEBPAGES

The NSW RFS Schools website^{xi} is designed the support Teachers and Students in the delivery of the Stage 3 Geography bush fire Unit. The pathway is Teachers, Stage 3 Geography, October 2013 fires. Content reflects Inquiry Learning principles. Information and resources represent key Geographical Tools identified in the Syllabus documents, including:

- Maps - bush fire prone land, fire impact areas,
- Graphs and statistics - Tables, graphs, statistics and indexes
- Visual representations - videos, images, aerial photos, webtools, apps, timelines
- Spatial technologies - fire related maps, satellite imagery, weather and climate, GIS layers, line scans



MEMBER CAPABILITY DEVELOPMENT

The NSW RFS respects that schools and teachers will determine how the Stage 3 Geography learning outcomes are met in the classroom. The Schools website goes a long way to provide authentic information that can be freely accessed in exploring problems and identifying solutions.

NSW RFS Members are actively engaged with Teachers and Students, from providing general advice and direction, to conducting bush fire expert visits to classrooms. In the first year of this Syllabus implementation, skills development workshops have been conducted with small groups of Members. Guidance and advice is regularly communicated through existing Member social media channels.

CONCLUSION

Internationally the UN Sendai Framework for Disaster Risk Reduction 2015 – 2030^{xii} sets out deliver substantial reduction of disaster risk and losses in lives, livelihoods and health and in the economic, physical, social, cultural and environmental assets of persons, businesses, communities and countries. This study of a contemporary bush fire event will contribute to broader resilience to disasters and emergencies.

Through the Bushfire and Natural Hazards Cooperative Research Centre, the Child Centred Disaster Risk Reduction (CC-DRR) project has developed an evidence-based practice Framework. The NSW RFS embraces the application of evidence based practice to producing disaster resilience education programs that reduce risk, increase resilience, and can be implemented at scale.

This Framework and the Stage 3 Geography Unit align very well through clearly articulated learning objectives and outcomes, adoption of child-centred learning approaches, promotion of student participation in the school, household and communities, providing professional development and support for teachers.

Together, teachers, students and the NSW Rural Fire Service together can build the capability of children and young people to be active participants in responding to disaster events, and not be passive bystanders needing adult direction and support.



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ENHANCED ESTIMATION OF BACKGROUND TEMPERATURE FOR FIRE DETECTION USING NEW GEOSTATIONARY SENSORS

Non-peer reviewed research proceedings from the Bushfire and Natural Hazards CRC & AFAC conference
Sydney, 4 – 6 September 2017

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ABSTRACT

ENHANCED ESTIMATION OF BACKGROUND TEMPERATURE FOR FIRE DETECTION USING NEW GEOSTATIONARY SENSORS

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Recent increases in the frequency and intensity of active fire has heightened the importance of remote sensing as a source of early warning information for fire incidents. The launches of new geostationary sensors, such as Himawari-8 over the Asia-Pacific, have vastly increased the information available with which to detect and attribute these incidents, with observations every 10 minutes possible over key parts of the electromagnetic spectrum (3.8 -- 4 μ m). Remotely sensed fire products such as Sentinel Hotspots and the MODIS active fire product have focussed upon use of contextually derived background temperatures for isolating hotspots, dictated by the low temporal frequency of available images. This research proposes a new paradigm in fire detection, which utilises the increased temporal resolutions of geostationary sensor imagery to provide a baseline dataset for land surface temperature estimation based upon location and time of day. To achieve this, a multi-temporal diurnal characterisation of temperature is calculated for each pixel based upon a large area latitudinal transect. Hot spot anomalies are then identified based upon the deviation of the location's temperature from the expected diurnal cycle. Validation of the fire detection algorithm has focussed upon case study fires from the 2016/17 fire season, by way of inter-comparison with commonly used MODIS and VIIRS active fire products, and a burned area product. Results show increased capability for early fire detection using the new algorithm in comparison to traditional single image contextual algorithms employed for polar orbiting systems. Other advantages include notable resilience to sources of occlusion such as cloud and smoke. Further research will focus on the wider application of this method across the Australian continent and methods for countering more challenging detection conditions.



1. INTRODUCTION

The use of remote sensing for fire detection is an increasingly important tool for emergency services and land management agencies, to ensure adequate warning is given to the public, and to plan fire mitigation and asset protection strategies. The introduction of new geostationary satellites such as the Advanced Himawari Imager (AHI) onboard Himawari-8 provides a dramatic improvement of fire detection capability over previous geostationary sensors, with increases in temporal resolution and reductions in the spatial footprint over previous geostationary sensors (Xu 2017 and Hally 2016). This increased capability, along with a far larger pool of information about the characteristics of the land surface during the diurnal cycle, allows us to attempt innovative methods for early fire detection.

This paper presents a case study of fire detection over a portion of northern Western Australia during August 2016. The study uses the method outlined in Hally et al. (2017) to provide a fitting of the background land surface temperature of an individual pixel using training information gathered from areas of similar latitude. This fitting then has a simple threshold placed over it to determine pixels affected by positive thermal anomalies, which may be indicative of fire. This study compares fire detection results back to a commonly used burned area product developed for the study area (Maier, 2010), and describes some of the issues involved with fire detection using temporal-based techniques.



2. METHOD

2.1 STUDY AREA

The study area is situated in north-western Australia, bounded by latitude 15°S and 20°S and longitude 125°E and 130°E, as shown in Figure 1. This area, straddling the NT-WA border, comprises of open savannah woodlands in the north, with dry and arid areas further south. The study period was during the northern dry season, from 1st to 28th August 2016, when a significant portion of yearly fire activity occurs and cloud cover in the area is limited in comparison to other times of the year. This minimises the effects of cloud activity on diurnal model fitting, and provides an indication of the method's utility in optimal conditions.

2.2 DATA AND INTERCOMPARISON

The study utilises medium wave infrared imagery (Band 7, 3.8 - 4 μ m, 2km x 2km pixels) from the AHI for the period of August 2016. Pixels were randomly selected for location and time, and a cloud mask based upon CLAVR-x (Heidinger, 2004) was applied to eliminate cloud affected pixels. Once a pixel is identified as non-cloud affected, a 24-hour period of brightness temperature from each pixel was fitted using the Broad Area Training method described in Hally et al. (2017). Anomalies were identified as brightness temperatures that exceeded the fitted background temperature by more than 4 Kelvin. This threshold was selected based upon initial analysis of differences between background temperatures and fire detections in the study area.

To obtain information about the commission and omission rates of the method, the recorded potential fire detections were compared to a burned area product sourced from the TERN AusCover project, as outlined in Maier (2010). This burned area product uses MODIS imagery to determine locations and times of fire-induced change. The times and locations of AHI detections were related to this burned area product, with emphasis placed upon examination of burned area detections that occurred in the 48 hours after the AHI fitting commences. To minimise the effects of co-registration issues causing burned areas to be missed, a buffer of one pixel was used around each AHI detection.

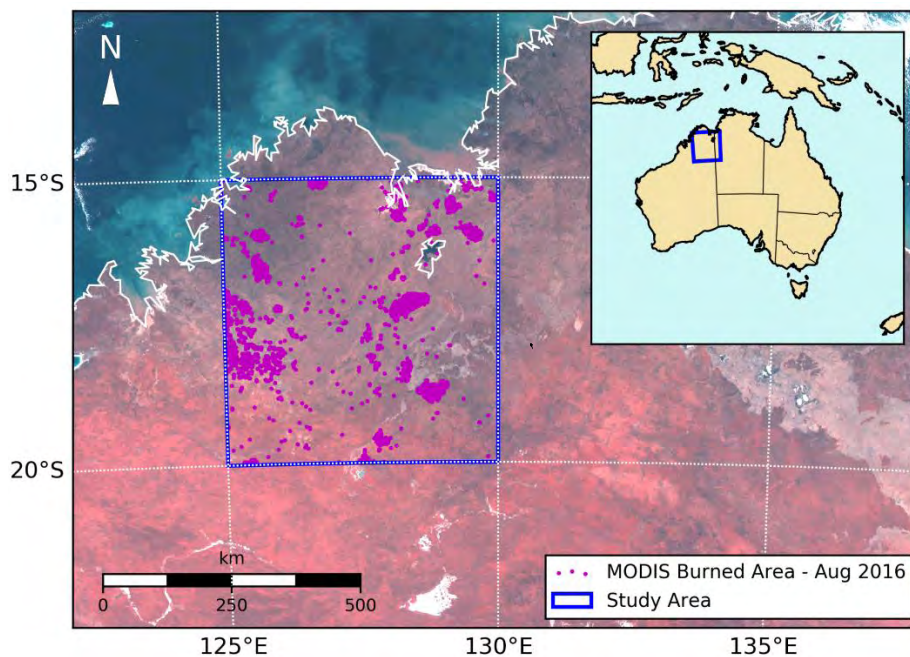


Figure 1 - Map showing the location of the study area and the location of burned area detections taken from the TERN AusCover MODIS Burned Area product for August 2016.

2.3 EXAMINATION OF DETECTION CAUSES

A consistent issue with the use of this method for fire detection is the correct attribution of perturbing influences. To examine these influences, a visual assessment was conducted on AHI pixel fittings that were determined as detections. Anomalies were classified by the apparent cause of the anomaly: (1) clouds not detected by the cloud product used, causing poor fittings; (2) fires, which appear as sudden increases in temperature in the diurnal observation set; and (3) anomalies which have no obvious explanation, which could be considered the actual commission rate. Examples of fittings displaying these behaviours can be found in Figure 2. These classification sets were split by the existence of a burned area product detection within the study period after the start of each temperature fitting.

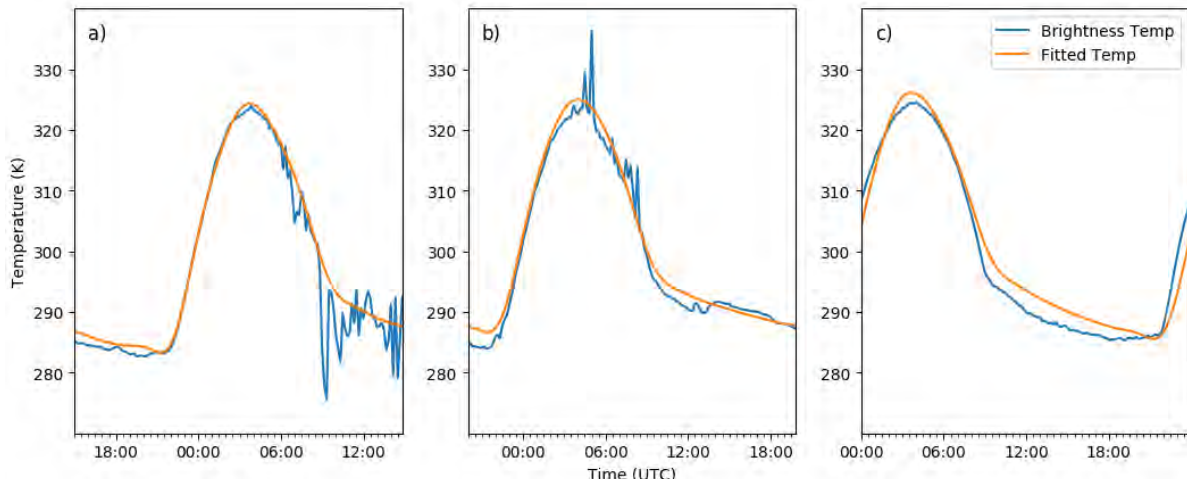


Figure 2 - Examples of the classifications used to determine the cause of detection – a) shows a fitting affected by cloud, which lowers the mean brightness temperature of the diurnal cycle and causes false attribution when temperature returns to normal; b) shows a temperature profile typical to fire, with a sharp initial spike in temperature; and c) is an example of a detection with neither cloud nor fire as an obvious cause.



3. RESULTS

Initial analysis of detections found a raw detection rate using this method on AHI imagery of around 0.6% of all fitted pixels over the study period. For the same period, the burned area product recorded approximately 4% of the study area as being fire affected. The rate of AHI fire detection correlates well with the burned area figures, as fire activity may continue in a pixel over many days. Table 1 depicts the breakdown of possible causes of detections from the 602 pixels that have detections. From the pixel fittings that recorded a detection, around 63% of those had an associated detection in the burned area product at the same location or immediately adjacent to it. In cases where a burned area detection is present or adjacent, obvious fire activity accounts for 79% of AHI detections. The cloud mask used in this study misattributes almost 15% of detections in this case. Where a burned area detection does not exist, fires account for approximately 7% of AHI detections, with two thirds of AHI detections in this case due to poor model fitting caused by cloud.

TABLE 1 - CAUSES OF ANOMALIES IN THE 4K DETECTION DATASET DETERMINED BY VISUAL ASSESSMENT. A FITTING APPEARS IN THE BURNED AREA COLUMN IF EITHER THE PIXEL IN QUESTION OR AN ADJOINING ONE HAVE A CORRESPONDING BURNED AREA DETECTION DURING THE STUDY PERIOD

Anomaly Type	Burned Area Detection	No Burned Area Detection
Fire	79.2%	7.2%
Cloud	14.5%	66.8%
Other	6.3%	26.0%
Total	379	223

Separating out AHI detections that occur within the 48 hours prior to a burned area detection shows that 96% of all AHI detections determined to be caused by active fire. Based upon the visual assessment of detections the commission rate (the percentage of detections not explained by fire or cloud) of this method for fire detection is 26%.



4. DISCUSSION AND CONCLUSION

This study assesses the ability of the AHI geostationary sensor to detect fire, with verification against a commonly used burned area product. The method used here does demonstrate a relatively high commission rate, but this is less of a concern in an early detection system, where ensuring complete capture of potential hotspots remains the primary concern. Whilst this demonstration is meant to be assessing the algorithm's effectiveness on clear sky days, deficiencies in the cloud mask used, both in commission and omission, mean that the set of results given here may not be wholly reflective of results under ideal weather conditions. A review of effective cloud masking for the AHI sensor is required to improve the accurate flagging of cloud-affected model fittings.

This cloud masking issue is also apparent when breaking down the time of day of AHI detections which have no apparent cause. Of the 602 total detections in the 4K threshold set, 82 of these had no obvious explanation – detections were caused by an inability of the diurnal fitting model to adapt to changing conditions in a pixel, especially in the case of anomalous physical phenomena. Out of the 82 anomalous fittings, 59 of the detections occurred immediately after sunrise, when the brightness temperature of a pixel changes most dramatically. The propensity of the fitting model to produce false detections during the morning was noted in a similar study by Roberts & Wooster (2014), who attributed the anomalous detections to increased solar reflection off low cloud. If a significant portion of the false detections in mornings are related to this phenomenon, the true commission rate of the method would reduce even further.

The visual assessment of the 4K dataset seems to confirm the effectiveness of the MODIS burned area product in this area. Most of the AHI detections associated with a burned area detection have active fire in them, and those without a burned area detection have active fire in only 7% of cases. These figures are encouraging given the spatial disparity between the two products – the burned area product works with low earth orbit data, which is of a much higher spatial resolution. The results seem to suggest that the advantages of the increased temporal resolution available from the AHI sensor outweigh the coarser spatial resolution of the available imagery.

Further expansion of this work will look to address the effectiveness of this fire detection method versus commonly used low earth orbit active fire products, such as those from MODIS and VIIRS, to ascertain the ability of the method to provide synchronous fire detection. This work will also look to extend the evaluation of the method to other areas of Australia, with a focus on the heavily populated coastal areas of south-eastern Australia.



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ORGANISATIONAL SOCIALISATION OF VOLUNTEERS IN AN AUSTRALIAN EMERGENCY SERVICES AGENCY

Non-peer reviewed research proceedings from the Bushfire and
Natural Hazards CRC & AFAC conference
Sydney, 4 – 6 September 2017

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EXTENDED ABSTRACT

In many OECD countries, emergency response to accidents and natural disasters is heavily reliant on volunteers trained in areas of fire, rescue, medical care, and relief. Australia is no exception. Australian communities, the government, and businesses rely on the hard work and dedication of tens of thousands of volunteers to keep Australians and their property safe from the impact of fire and natural disaster. However, while incidents of natural disaster are on the incline, volunteers, those who are capable of and willing to serve their communities in times of crisis, are on the decline.

A wealth of literature has examined retention of volunteers and how to address it. However, while it is acknowledged that volunteer turnover occurs at various stages of the volunteering life cycle (recruitment, training, socialisation, performance, and retirement (Alfes, Shantz, & Saksida, 2015; Cuskelly & Boag, 2001)), little attention has been paid to turnover during the critical socialisation stage, when turnover presents the greatest cost to the organisation: after resources have been devoted to training the volunteer, and before they have returned on the investment by performing.

This article presents a predictive model of volunteer retention, which maps socialisation, expulsion, and self-exclusion based on social fit. The model is derived from an inductive examination of the processes of volunteer turnover during the socialisation of emergency service volunteers in Australia. Using a grounded theory approach, through 17 focus groups and 63 interviews with 137 volunteers across seven locations, the study identified the processes of volunteer turnover during the socialisation stage. The model predicts that during this stage, volunteers either stay or leave their respective units based on the level of their social fit with existing peers. This model contributes to theory by categorizing volunteer turnover according to the stages of the volunteering life cycle, and to practice by drawing attention to the need to consider social fit prior to investing in new volunteer training.

Irrespective of being a volunteer or paid staff member, the process of joining an organisation, followed by participating in it and eventually leaving it, is known as organisational socialisation (Figure 1). This model is discussed below.

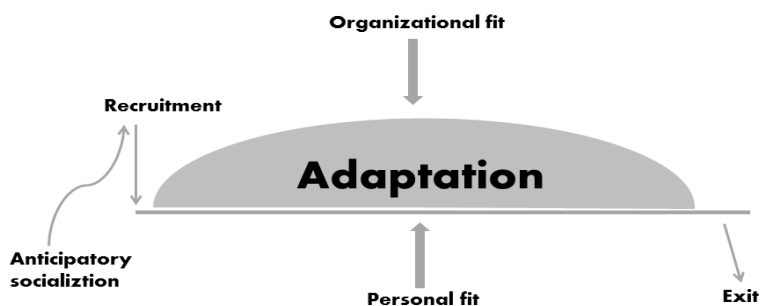


FIGURE 1 - GENERAL MODEL OF THE SOCIALISATION PROCESS FOR AESA VOLUNTEERS

ANTICIPATORY SOCIALISATION

Anticipatory socialisation describes the period prior to joining the organisation, from expectations starting in early childhood until that moment of entry (Kramer, 2010). Research shows that a large percentage of volunteers join their chosen volunteer organisation through the influence of family and friends.



RECRUITMENT

The volunteer-based AESAs consist of local units or brigades that are largely autonomous and are run by the volunteers themselves. Career staff are in charge of the administrative and managerial structure of the organisation (Headquarters and regional centers).

The local units manage their own recruitment predominantly through media campaigns and personal contacts (Baxter-Tomkins & Wallace, 2009; Esmond, 2009). Most hold an information night for prospective volunteers to explain the work of the organisation (Hatcher, 2015). The recruitment procedure is in stark contrast to corporate organisations that seek career staff for specific roles that have detailed selection criteria. Some of the larger regional units however can be more selective in their recruiting.

THE OPERATIONAL UNIT

The period following recruitment, when the volunteer enters the operational unit, is termed adaptation (Figure 1 and in more detail Figure 2). The volunteer makes sense of the volunteer interactions in the unit, learns about what is expected and what the organisation's rules and values are (organisational fit). It is at this point where the volunteer's needs are negotiated and evaluated by the organisation, for example in terms of specific roles that the volunteer would like to fulfill (personal fit) (Kramer, 2010).

New recruits arrive mostly for the same values and reasons – e.g. to help their community through a current emergency or the one they have just experienced. Upon joining, they are usually grouped together and inducted into the organisation through shared training experiences and social events. The initial training period may take up to 12 months and occurs in virtual isolation to the larger population (not in all units) of the main body of volunteers who are of relatively longer standing. Members cannot go to emergency incidents before the induction is complete and some members in larger units have never been called up.

Facing the longer-term volunteers, recruits are hit with a 'trial by personality' where they measure themselves against the character of the unit based on its amalgam of individual traits and characteristics and the unit culture (Figure 2).

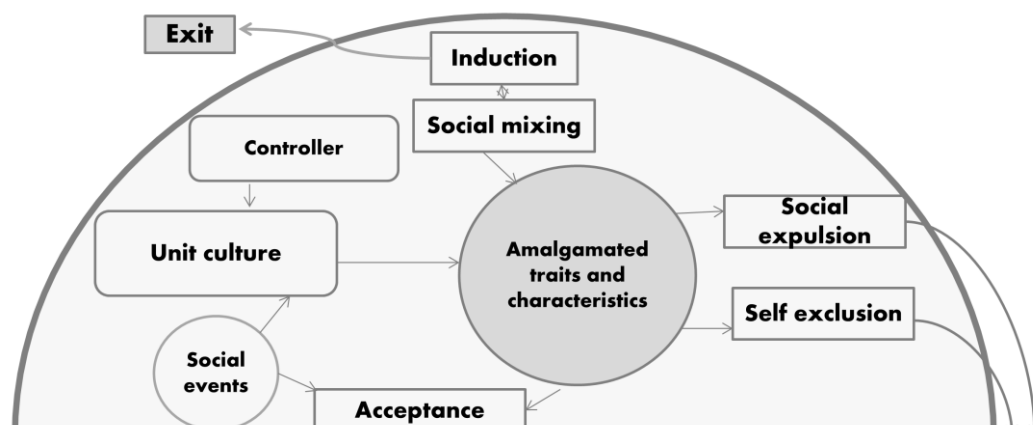


FIGURE 2 - MODEL OF THE ADAPTATION PROCESS FOR VOLUNTEERS IN AN ES AGENCY. IT REFERS TO THE ADAPTATION CURVE (SHADED AREA) IN FIGURE 2.



SOCIAL MIXING

Recruits and longstanding unit members are introduced to people in different walks of life and age and the shared experiences of weekly training nights, call-outs to road crashes, floods and storms often under wet and cold conditions for long hours and the occasional social event may lead to social cohesion within the unit.

In Figure 3, we propose a model of a unit's social cohesion (mixing) that, when nurtured well, leads to long term commitment to the organisation.

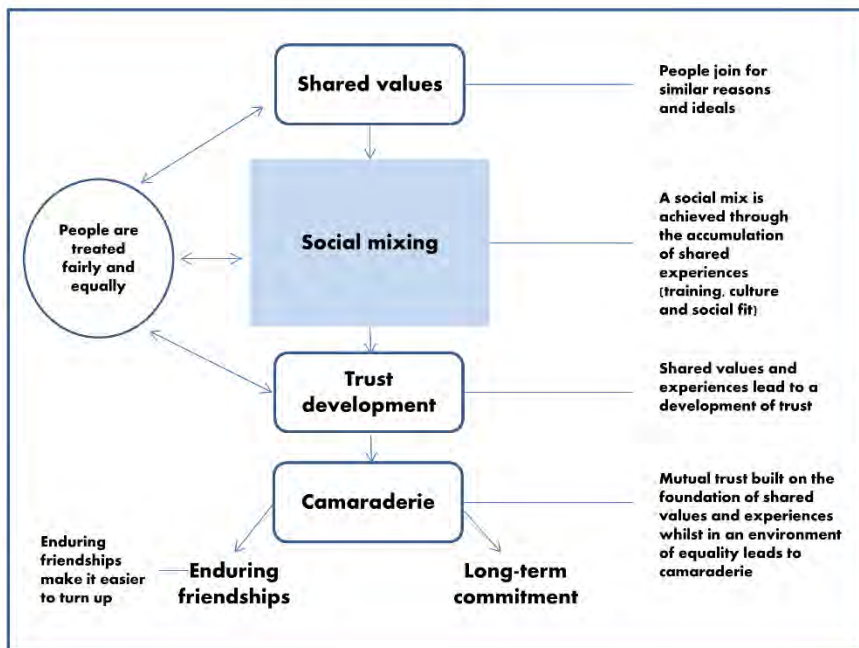


FIGURE 3 - MODEL OF THE SOCIAL COHESION OF A AESA UNIT

With time the volunteers take on a psychological ownership of the unit which leads to loyalty and long term commitment to the organisation (Pierce, Kostova, & Dirks, 2001). However, breaches of trust or inequality can often make the difference between staying and leaving the unit.



ACKNOWLEDGEMENTS

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The interaction between firefighting boot design and lower body injury risk at work

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Sydney, 4 – 6 September 2017

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INTRODUCTION

When responding to emergency operations, firefighters must wear a range of personal protective clothing (PPC) and equipment (PPE) to maintain their safety. Indeed, in some environments, such as those where high heat and smoke exist self-contained breathing apparatus' (SCBA) and structural clothing ensembles are vital to a firefighters' ability to undertake work. When PPC and PPE are combined, the weight added to the ambulating individual can exceed 23kg in addition to tools or equipment required to complete any given work task. When at work, firefighters are tasked with occupation specific, repetitive movement patterns that can include climbing stairs, alighting from fire appliances and negotiating obstacles. It is therefore likely that, when combined with the requirement to carry significant loads, the repetitive nature may be predisposing firefighters to significant repeated loading, which may lead to increased risk of developing chronic injuries.

For firefighters to work safely in hot and unstable terrain, in addition to firefighting PPE, they wear structural firefighting boots (referred to as Type 2). Boots in this category are required to have protection against penetration and heat, along with toe protection in the form of hard toe caps. These design requirements, while providing necessary thermal and impact protection, add weight while concurrently reducing the flexibility of the boot. Another significant design requirement is that a boot-shaft that terminates above the line of the ankle joint, to increase stability and reduce the incidence of ankle injuries and provide firefighting specific protection. Specifically, boot design standards (ISO) require boots to have a minimum shaft height. For example, for size 45 boots and above, a shaft no shorter than 192mm is needed.

During landing movements, such as alighting from a fire appliance, ground reaction forces (GRFs) are transferred from the distal to the proximal extremities. Specifically during landing, forces are absorbed and dissipated through the ankle, knee and then hip-joint in sequence. This is generally referred to as the kinetic chain and alterations to this will change the body's natural ability to attenuate forces. When landing without restriction to the ankle joint, such as when barefoot, the foot is generally in plantar flexion (toe down). When the ankle is restricted, thus not allowing for plantar flexion on landing, a heel-toe landing (HTL) technique occurs. A HTL landing pattern has been associated with greater vertical GRFs. This then results in increased compressive forces in the soft tissue and joints surrounding the hip and knee joints. It is widely believed that chronic exposure to such forces may lead to lumbar instabilities resulting in lower lumbar and lower body injuries.

Soft tissue injuries, both acute and chronic, in the lower body and lower lumbar region of the spine are reported as being the leading cause of disability and early retirement in firefighters. Thus, it is intuitive to expect that, in addition to work specific movement patterns, an interaction between boot design and injury may be occurring. In research undertaken into non-firefighting boots, such as ski-boots and ice-skates, which share common design features at the ankle joint, reduced range of motion has been observed at both the ankle and the knee joint. As such, we hypothesised that firefighting boots with designs that restrict the ankle joints may elicit similar reductions in range of motion in firefighters when they complete landing tasks. Furthermore, as a consequence, boots may increase the risk of suffering an injury to the lower body or lumbar region as a result of alterations to the kinetic chain.

METHODS

Twenty professional male urban firefighters and officers from ACT Fire & Rescue (Mean \pm SD; weight 84.4 kg \pm 11.6, height 1.81 \pm 0.06 m and age 41.3 \pm 8.8 years) were recruited to participate in this study. All participants were fully operational at the time of testing and had 13.5 \pm 10.9 years of operational service. Participants were excluded if they were injured or currently undertaking any form of lower limb or back rehabilitation. Ethics approval was granted and written informed consent was obtained for each participant before the commencement of the study in accordance with the requirements of the Human Research Ethics Committee at the University of Canberra.

Data collection was conducted in a purpose-built Biomechanics laboratory located at the University of Canberra. Three-dimensional marker trajectories were captured using a 12-camera Vicon motion capture system sampling at 250Hz (Oxford Metrics Ltd., Oxford, UK). GRF data were collected at 1000 Hz using two 400 x 600 mm AMTI Force plates (Advanced Mechanical Technologies, MA, USA). Prior to testing, participants had 37 retro-reflective markers placed on their lumbar and lower body (Figure 1).



Participants were instructed to perform four drop jump landings from a contextually specific height under four randomly assigned conditions (firefighting boots unloaded, firefighting boots loaded, control unloaded and control loaded). Participants used their own athletic footwear for the control condition with a caveat being that they were purchased within the past six months. Brand new Type 2 structural Haix Fire Flash Xtreme (Lexington, Kentucky, USA) boots were used for the boot condition. Loaded conditions composed of participants wearing a firefighting helmet and a 9.5kg backpack to replicate the SCBA. The backpack was located at the thoracic level of the spine to prevent coverage of the lumbar spine markers. A 42cm platform, which replicated the bottom step of an Australian urban fire truck, was placed 10 cm from the edge of two force plates (Figure



2). Participants were instructed to step off the platform by shifting their weight forward onto their right leg then drop down as vertically as possible to eliminate additional upward motions and reduce horizontal motion from the step off. Participants then simultaneously landed two-footed with one foot on each force plate.



RESULTS

Wearing firefighting boots resulted in significantly increased vGRFs when landing when compared landing in control shoes ($p < 0.05$). The additional load of the stimulated SCBA in loaded conditions (control loaded 2.31 ± 0.65 body weight (BW), boot loaded 2.55 ± 0.53 BW) also showed significant increases ($p < 0.05$) in vGRF, independent of firefighting boots (control unloaded 2.14 ± 0.65 body weight (BW), boot unloaded 2.40 ± 0.58 BW).

A significant loading and footwear effect was found in peak ankle displacement between all conditions during landings ($p < 0.01$). Peak ankle plantar flexion angle for the control loaded conditions were greater in comparison to the control unloaded and boot loaded conditions ($-42.05 \pm 11.55^\circ$, $-32.49 \pm 9.95^\circ$, $-28.83 \pm 13.12^\circ$, $p < 0.01$ respectively).

At initial contact, increased plantar flexion was observed in the control shoe for both the unloaded and loaded conditions compared with the boot (control $-36.41 \pm 10.43^\circ$, boot $-25.59 \pm 9.17^\circ$, $p < 0.01$ and control $-40.73 \pm 11.55^\circ$, boot $-28.31 \pm 13.51^\circ$, $p < 0.01$).

Landing in firefighting boots under unloaded (222.89 ± 18.47 deg·s⁻¹) and loaded (240.91 ± 24.37 deg·s⁻¹) conditions showed greater peak lumbo pelvic (LP) flexion angular velocity ($p < 0.05$) when compared to the control unloaded condition (187.56 ± 60.96 deg·s⁻¹). Peak LP flexion force was also observed when wearing firefighting boots (unloaded 13.40 ± 1.48 N·kg⁻¹, loaded 14.46 ± 1.46 N·kg⁻¹) in comparison to the control shoe (unloaded 12.32 ± 5.44 N·kg⁻¹, loaded 14.37 ± 6.94 N·kg⁻¹). Greater peak lumbar internal rotation angular velocities and moments were also observed when wearing firefighting boots unloaded (111.06 ± 13.07 deg·s⁻¹, $p < 0.05$; 3.26 ± 0.34 Nm·kg⁻¹, $p < 0.05$ respectively) and loaded (114.49 ± 16.30 deg·s⁻¹, $p < 0.05$; 3.81 ± 0.42 Nm·kg⁻¹, $p < 0.01$ respectively) in comparison to the unloaded control shoe (80.51 ± 47.23 deg·s⁻¹, $p < 0.05$; 2.60 ± 0.78 Nm·kg⁻¹, $p < 0.05$ respectively).

Landing in firefighting boots resulted in greater peak LP adduction force when compared to the unloaded control condition (control 19.84 ± 11.44 N·kg⁻¹, boot 30.54 ± 19.76 N·kg⁻¹, $p < 0.01$). These findings were also observed in the peak LP adduction moments (control 2.21 ± 1.01 Nm·kg⁻¹, boots 3.15 ± 0.50 Nm·kg⁻¹, $p < 0.01$).



DISCUSSION

This study aimed to establish a relationship between ankle restricting boot designs and changes to GRFs, and ankle and lumbar biomechanics during a simulated landing task. Our data indicate that the design of a structural firefighting boot increases vGRFs, decreases ankle displacement and increases load to the lumbar region, compared with a control shoe. This study provides novel findings by exploring the influence of ankle restrictive firefighting boots on the kinetics and kinematics of the LP segment during landing.

On landing, we observed reduced ankle plantar flexion in firefighters when they were wearing the firefighting boots. It is likely that these findings resulted from the rigid shaft design, resulting in restricted range of motion (ROM) of the ankle joint. Previous research into landings in military settings, along with sports such as figure skating, basketball and skiing showed similar increases in vGRFs as we observed in this study. By limiting the ROM of the ankle during landing, firefighters adopted a HTL technique, previously observed to lead to reductions in knee flexion and increased hip flexors. Thus, it is likely that the changes to the biomechanics of firefighters during landing tasks observed in this study, has the potential to expose soft tissue and joints in the lumbar region and the lower body to greater compressive forces and other kinematic changes. It must be noted that it is further likely that the reduced range of motion observed may not be solely attributed to shaft inflexibility. Rather, other components such as the rigid sole or the protective steel toe cap may also have played a part due to restrictions to the range of motion in the toes and should be examined in further research.

As demonstrated in this study, the ability of the ankle joint to dissipate forces through the kinetic chain may be being negatively impacted by the current design standards of structural firefighting boots. Thus, based on our findings, it is likely that the design standards required for firefighting boots may be contributing to an increased risk of lower back injuries in firefighters. However, to date there remains limited understanding of the effects of load and lower body biomechanics during landing and walking tasks. As such, we recommend further investigation of the links between boot design and injury rates in firefighters and possibly re-examining the design standards required. At the minimum, consideration for maximising the natural movement of the ankle should occur when designing future firefighting boots.



WHEN POLICY, POLITICS AND EMERGENCY RESPONSES COLLIDE: MANAGING COORDINATION IN CRISES

Non-peer reviewed research proceedings from the Bushfire and Natural Hazards CRC & AFAC conference
Sydney, 4 – 6 September 2017

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ABSTRACT

Crises place a clear focus on how governments at different levels respond and highlight the important intersection between policy, politics and emergency responses in highly charged circumstances. Large scale natural disasters represent a significant test of the public sector's ability to respond in an efficient and coordinated way in the face of uncertainty and adversity. The intersection between policy, politics and operational response can be seen as a perfect storm where competing priorities and objectives may arise and require resolution. The pressures of managing crisis situations come against a backdrop in Australia where trust in government and public services from its citizens continues to decline. The public retain high expectations of government's ability to plan, prepare and respond to disasters in a timely manner. The level of scrutiny and accountability to which politicians, bureaucrats and responders are held to means that collective and collaborative action is a necessity. Crises are also occurring not in a vacuum but where changes in the public sector mean that whole of government, or connected forms of working are a highly pervasive mantra. It is within this context that political, bureaucratic and operational agencies work in the response to crises.

This presentation provides the finalised outcomes from a doctoral project which examined the abovementioned issues within the framework of Australia's two most significant events of the past decade: the 2009 Victorian bushfires and the 2011 Queensland floods (this work is currently being published as: *Disaster Management in Australia: Government Coordination in a Time of Crisis*. Routledge).

The research was premised on understanding how the states confronted each disaster and how they can be seen to epitomise the challenges of crisis management in Australia. The research was underpinned through a model which examined: whole of government arrangements, the nature of crisis management, executive leadership, inter-organisational coordination, organisational culture, social capital and institutions of state. It examined these thematic areas from the: policy, politics and emergency response perspectives. In doing so, it has established that these three streams of activity and the actors who work in each domain represent a symbiotic network. Within this network, the interfaces between these streams represents a critical part of preparation, response and recovery from major crisis events, as important as any of the individual components.

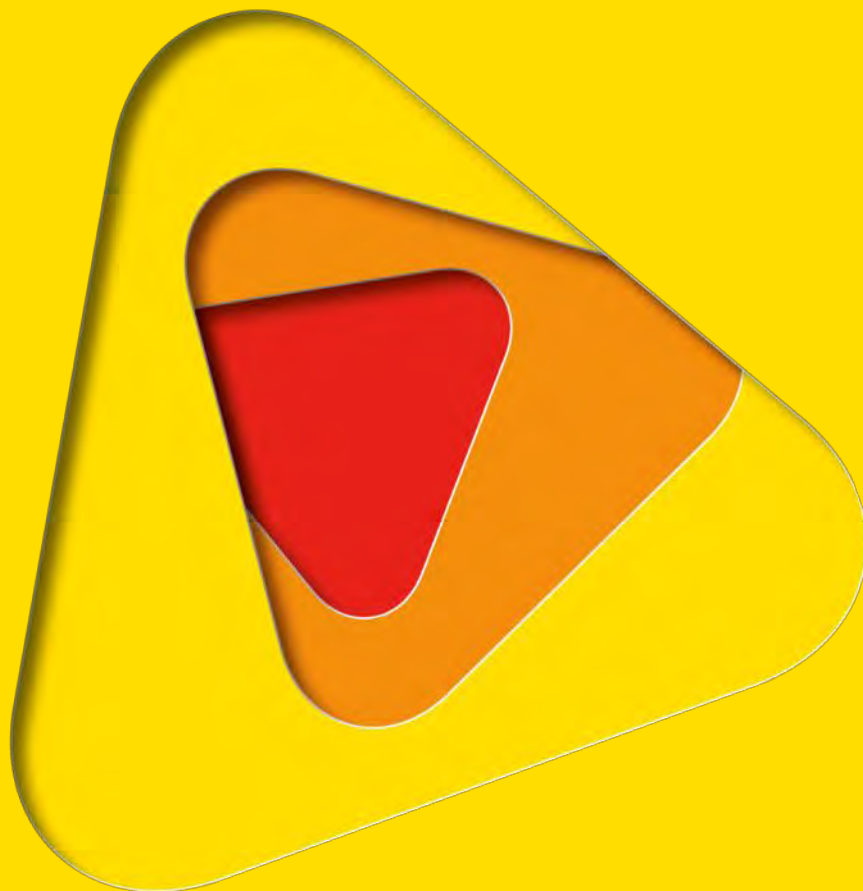


EMERGENCY MANAGEMENT AND POLICY: RESEARCH IMPACT AND UTILISATION

Non-peer reviewed research proceedings from the Bushfire and Natural Hazards CRC & AFAC conference
Sydney, 4 – 6 September 2017

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ABSTRACT

Emergency management is an important and curious sector. Important because of urgency, high stakes and public and political interest; curious because it deals with complex and difficult problems, and it constantly seeks and appreciates improved knowledge. Much discussed over the years has been the need for research to inform policy change (beyond management change), and how such research can be measured in terms of changing the policy settings that define and constrain emergency management. This is a complex matter, and difficult to answer simply.

This paper extends commentary by the author in a keynote address to the CRC/AFAC Research Forum 2012 on the interface of research, policy and politics. Can “policy research” actually change policy and if so how? The paper does not seek to (and nor should it try) answer the question prescriptively, but explores the interface between research, policy, management and politics in four parts:

1. Clarifying the relationships between management, policy and politics, and the institutional systems that define these, so that the targets of policy change are better understood.
2. How different disciplines relate to policy: some with competence, directly and thus controversially; others less directly, with no inbuilt understanding of public policy and at a safe distance.
3. Different forms of utilisation of information in policy in the context of emergency management (direct, conceptual, political, etc), which are different and need to be understood as such.
4. Policy hooks and windows – the coincidence of knowledge and events (ie. great ideas wither in calm times; bad ideas take hold in a panic).

A summary checklist is presented, to guide research design and communication and to manage expectations. Clarity in this space is important for research design, and for increasing relevance to policy and management.



INTRODUCTION

Over the course of the Bushfire and now Bushfire and Natural Hazards CRC, there has been an increase in support for research that speaks directly to public policy. How is such research utilized, and how can we measure its impact? This paper does not provide a clear answer, but seeks clarity over the expectations of policy-oriented research, what policies and policy actors might be the targets of such research, and what different kinds of uptake might be expected. The paper draws ideas from the discipline of public policy to: (i) clarify what 'policy' and related terms mean and the implications of that; (ii) map out different research disciplines, their comprehension of policy, and the role of other information providers; (iii) consider different forms of information utilization and the notion of 'evidence-based policy'; and (iv) consider 'hooks' and 'windows', or times and contexts of possible policy change. The paper concludes with a check list to clarify the policy relevance of research and thus of pathways for utilization.



BACKGROUND

Some research produces a useable 'thing', such as a mapping technique, signaling device, or code of practice for working in heat. Assessing the impact or uptake of such research outcomes is reasonably straightforward: it works or doesn't; it gets used or it doesn't.

Other research produces less tangible results. For example, Eburn and Dovers (2012) and Eburn (2017) make recommendations regarding better ways to run post-disaster inquiries, informed by examination of recent quasi-judicial inquiries, the experiences of those involved, and the efficacy for learning. Many emergency managers agree with our suggestions, but researchers and emergency managers cannot implement this knowledge – the form of post-disaster inquiries is a decision for first ministers, Cabinet, a minister, or an appointed commissioner. They may or may not agree, or even listen.

Consider this continuum:

Practice – Management – Policy – Statute Law – Institutional Settings and Governance.

In terms of research utilization, the further to the left the easier to implement research and measure impact, because practice and management are within the purview of emergency service organisations. The further to the right, the less influence ESOs have, the more within central agencies the power lies, and the more minor an input research is. The further to the right, the more political it gets:

Politics is the essential ingredient for producing workable policies, which are more publicly accountable and politically justifiable ... While some are uncomfortable with the notion that politics can enhance rational decision-making, preferring to see politics as expediency, it is integral to the process of securing defensible outcomes. We are unable to combine values, interests and resources in ways which are not political. (Davis et al. 1993: p257, emphasis in original)

Policy is political, about 'values, interests and resources', about deciding who gets what and who doesn't, whether that be funding, legal rights or access to information, decision processes or places. The policy settings that enable or constrain emergency management are not only or even mostly about EM, and are mostly made in other portfolios, such as land use planning, building standards, infrastructure, communications technology provision – the list is long. Relevant policies also affect other things: public access, conservation, building costs, workplace practices, and public funds not available for other purposes. Policies are trade-offs and compromises. Thus, research findings that have a bearing on policy may be listened to by those who formulate policy (more on that below), but will rarely be the only or dominant consideration. Much else matters, like cost, practicality, public opinion, legal issues, or impacts on other goals like housing affordability. EM research that makes policy recommendations is one voice in the cacophony of noise and information that influences policy in areas like land development, transport, housing and infrastructure.

The next four sections distil key considerations that allow more clarity about the potential of policy research, leading to the subsequent checklist that can be used to appraise the design and outcomes of research. The perspective is drawn



from Handmer and Dovers (2013) and Dovers and Hussey (2013), which in turn summarise and apply public policy theory and practice to the contexts of emergency and environmental management. The word limit here precludes fuller coverage of the literature and associated referencing: those so inclined can delve into the voluminous and sometimes turgid public policy literature.

(I) POLICY, OR SOMETHING ELSE?

Is the issue at hand a policy problem? There are some ways of exploring this. First, fascinating research questions are rarely the same as the policy problem faced by an agency or society, and negotiation is required to align the two, or at least frame the research to relate usefully to a policy matter in its findings. Second, 'policy' is a vague term. Simplifying much terminology and theory, the fictitious but believable case of over-achievement below in its emphasised terms indicates the complexity beneath the simple term 'policy':

In line with relevant regulations (subsidiary to statute law) enabling the Emergency Management Procedures (a policy), the Emergency Services Bureau and Forestry Dept (state organisations), ordered controlled burning (management action under a regulatory policy instrument) in the Great Big State Forest. The burn escaped and damaged assets belonging to adjacent landholders, who took legal action arguing negligence (legal doctrine within the institution of the common law) in the District Court (an organisation manifesting that institution). Damages were awarded against the two agencies (responsible authorities). On advice from the Bureau, a commissioned research report, independent inquiry, submissions from the community and legal advice (parts and players in the policy process), a new policy of negotiated, regional fuel reduction plans (new policy instrument) was announced, reflecting a shift from a top-down, regulatory to an inclusive, cooperative policy style.

If research is to focus on or be relevant to policy, then clarity over the difference between say, management, policy, law and institutions is important. By so doing we can define who is responsible for or relevant to the issue/s being investigated, in what ways and with what powers, and how they might be involved in or at least made aware of the research.

(II) DISCIPLINING PUBLIC POLICY

If research is to speak to policy, then the research design and process, and those involved, must reflect a coherent understanding of the public policy process. Some disciplines do, some have partial understandings, and some do not: and that is not a criticism. Policy is a social phenomenon and thus the domain of the social rather than natural sciences (social scientists are awful at fire modelling, by the way). This is important and should be interrogated by research funders and end users. The author's own discipline, public policy, is also a profession and an arena of practice, and that most directly aligned. Related disciplines such as public administration, political science and institutional theory are similarly policy-focused and any practitioner have a clear and communicable conception of the policy process, and stated research methods. Other disciplines are policy-oriented, but with a narrower view of policy: eg. law, economics and program



evaluation. Other social sciences are policy-relevant, at least to some aspects of policy problems, but lack an overall conception of the policy process (eg. sociology, psychology and demography). Some disciplines in the humanities are policy relevant too, such as history in constructing records of human experience. Policy-relevant in a different way are the natural sciences, having needed perspectives but no explicit grasp of policy, human behavior or institutions.

Appreciating the differences between policy-focused, -oriented and -relevant disciplines is a starting point for engagement. But within each discipline, different schools of theory and thought exist and will shape research fundamentally in terms of assumptions regarding human motivations, the role of particular policy actors and validity of different policy instruments. A neo-classical economist is very different to an ecological or institutional economist, as are a social versus a cognitive psychologist, or a black-letter lawyer versus a law-in-society researcher. Those differences will shape research design, methods, data sought and the findings. This can be challenging, as finding a social scientist who can assist agencies or research funders navigate this may be hard.

Often, a particular disciplinary or professional input to a research project may be brief or minor to ensure relevance to policy, but crucial. If statute law or regulatory implementation is involved, an early discussion with a lawyer can ensure that later findings target the correct statute. Similarly, input to a scientific project from a public administration perspective (whether researcher or agency official) might correct any lack of clarity over policy responsibilities within a federal system and multiple, partly-responsible agencies.

(III) INFORMATION UTILISATION IN POLICY, AND 'EVIDENCE-BASED POLICY'

In a perfect world (which some vainly hope could exist), clear policy problems (they are rarely simple and clear) would be considered rationally by empowered governments (which have many parts and often limited power), acting on solid evidence from experts (consensus on facts may not exist), and robust decisions would be made. In messy reality, three perspectives expose the complicated nature of how information is used in policy: sources of information, forms of information utilization, and the notion of 'evidence-based' policy.

- a) Research and other forms of methodologically clear investigation is one source of information, whether from independent researchers, in-agency work, or (increasingly) consultants. While these may be important, decision makers also use opinion polls, focus groups, lobbyist submissions, parliamentary and other inquiries, media opinion and their own knowledge and judgement (non-research sources of information and argument may or may not be based on robust research).
- b) Information (facts, propositions, opinions) is used variably in policy debates and processes. Quality research or analysis can be used directly or rationally as a prime source of intelligence, in a positive manner: this is termed instrumental use. Information is also utilized in a conceptual manner, not changing decisions directly or soon, but reframing problems, starting new debates, and asking new questions: less direct, but still positive. Less positively, information and even accepted facts can be



used: tactically, to delay or deflect making decisions; strategically, to gain power in a debate through suppression; or politically, using whatever facts suit a pre-determined argument with no consideration of the rigour of those facts. Think climate change.

- c) The principle of 'evidence-based policy' is popular and, reverse jokes about 'policy-based evidence' aside (see political use in (b) above), is hard to disagree with. Head (2008) recognizes three 'lenses' of evidence that are used: (i) systematic ('scientific') research; (ii) program management experience; and (iii) political judgement. All three are inevitable and valid. Even where the slightly tighter prescription of 'best available science' (if that indeed can be agreed), there is more besides.

With policy-focused or -oriented research, it is not just 'the science' across (a-c) above, as information from more than one social science will likely be present, and possibly in disagreement, and policy ideas may come from multiple, intersecting sources (eg. research synthesized by consultants or by agencies, different research picked up by lobbyists in their submissions, other sources (mis)quoted in the media, etc.).

(IV) ON HOOKS AND WINDOWS

Policy change is uneven: the oft-drawn 'policy cycle' spins unevenly, stalls, goes into reverse and jumps gears. However useful a research finding, if the five-year management plan has just been released the research may be easily and justifiably ignored. Ditto if the budget for a program is irrevocably set and committed. Policy research and advocacy need to be aware of policy 'hooks' and 'windows', times where change is more possible, enhancing the uptake of research findings, or at least the chance of being considered. Consider two broad categories:

- a) Predictable or regular, for example the lead up to an election or budget, the later stages of an existing program or a scheduled policy review (directly in EM, or in an adjacent and relevant sector). Ears, and perhaps budget purse strings, are more open at these times.
- b) Unpredictable or irregular: changes of government or Minister, a crisis event, unexpected developments in a related sector, technological shifts, or a sudden change in an international situation or policy.

In our field, the 'crisis' moment and opportunity after a major disaster (and the inevitable inquiry) is not unpredictable: we know it will happen, just not where or when. To have well-researched policy ideas ready is unlikely to be a waste of time – such ideas can have a fair shelf-life – and is certainly preferable to belatedly entering the contest unprepared against the predictable avalanche of bad ideas that proliferate at such times.

IN CONCLUSION: A CHECKLIST FOR POLICY RELEVANCE

The foregoing is a truncated treatment of relevant areas of public policy. Box 1 distils this into a framework to be used to negotiate connections between research and public policy, usable by research funders, researchers and end-users – preferably all three together – to reach common understanding of the potentials and limitations of research. It can also make clear where research may have little bearing on policy (that is not a negative).

Box 1: A checklist for linking research and policy in emergency management

Guiding questions:	Considerations:
1. Is it really 'policy'?	Is the issue under investigation a <u>public policy</u> matter, or does it relate to more operational management, or to larger considerations of social values, institutional settings or governance styles?
2. What's the policy problem?	Ensuring that the <u>research questions</u> and hypotheses, and thus the subsequent data gathering and analysis, match sufficiently with a defined <u>policy problem</u> so that findings are relevant to the policy community.
3. Who might listen, and why? And, should and if so how can they be connected to the research design and process?	<p>(i) Defining the portfolios of government, and specific agency sections, relevant to addressing the policy problem. These may be within EM or in other portfolios; alone or in combination.</p> <p>(ii) What kinds of information and learning do these actors seek: instrumental, conceptual, strategic, tactical?</p> <p>(iii) What other information inputs are relevant to the policy problem (media, interest groups, public opinion, other research). Can these inputs be accounted for in the research?</p> <p>(iv) How can research findings be best presented to the relevant audience?</p>
4. What policy tools are likely to be considered?	Usually, a limited range of policy instrument options (from the very many available: eg. regulation, standards, price mechanisms, education, training) will be realistically on the table: do these suggest particular research skills or strategies to be needed?



5. What disciplines are needed?	Given (1-4) above, what research disciplines and sub-disciplines are required, to provide suitable theoretical propositions, methods, data capture, communication of results, etc. What mix of the policy-focused, -oriented and -relevant should be assembled, for what parts of the research process?
6. Any policy hooks or windows?	In the area of investigation, are there policy 'hooks' or 'windows' such as strategic reviews, parliamentary inquiries and budget or program cycles that present opportunities for communicating the research and policy implications?

A final observation. Subject to funding contracts and clearances by a funding agency, academic researchers can make policy-oriented material and even policy critiques and recommendations public through open, peer-reviewed literature and other means. Mostly, those in ESOs cannot do so publicly or loudly, nor can consultants. While it is rare that criticism or questioning of sensitive policy matters are singular research 'discoveries' or findings, but more often are being discussed around the sector, it is a benefit of researcher engagement that they can speak and write openly, bolstered by transparent methods and peer review quality control. Is that half the value of supporting policy-oriented research?

This article has not simplified the research-policy interface but hopefully has clarified it. The checklist above may be valuable at minimum for the management of expectations, but perhaps also in more specific design of a research project and of the policy targets it is or is not relevant to.



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MULTI-HAZARD MITIGATION PLANNING, COMBINING MODELLING, SCENARIOS AND OPTIMISATION: RESULTS FROM SOUTH AUSTRALIA

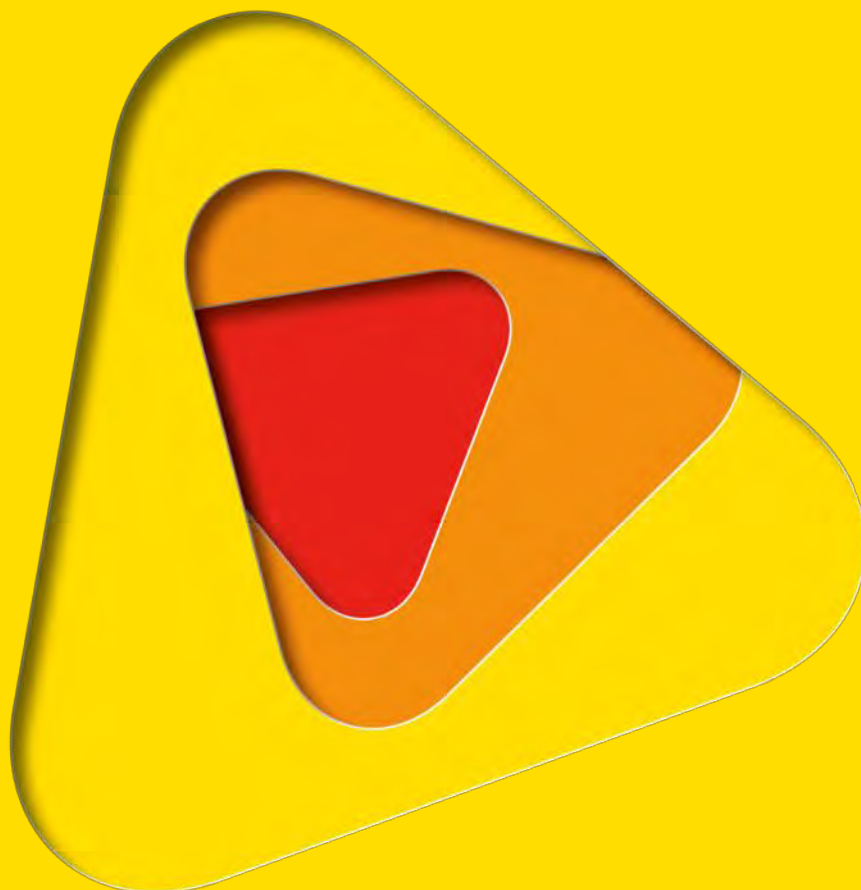
Non-peer reviewed research proceedings from the Bushfire and Natural Hazards CRC & AFAC conference
Sydney, 4 – 6 September 2017

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EXTENDED ABSTRACT

Natural hazards are an unavoidable component of life in Australia, but with effective planning and mitigation spending, their impacts can be minimised significantly. Analysis shows an average cost of natural hazards in Australia for 2015 totalled \$9.6 billion, and this figure is projected to increase to \$33 billion by 2050 (Deloitte Access Economics, 2016). These figures correspond to a substantial impact and coupled with the social and environmental impacts of disasters, paint a bleak picture. However, tomorrow's risk is a function of decisions made today, including the developments permitted and laws passed, and as such there is significant scope to minimise tomorrow's impacts.

To assist in the understanding of tomorrow's risk, driven by changing hazards, exposure and vulnerability, a decision support system (DSS) and integrated use process have been developed. This DSS models risk into the future and how it is driven by climatic, economic and demographic factors. Figure 1 shows the integration of risk across exposure, vulnerability and hazard along with some of the factors that are encompassed, as well as the drivers and uncertainties surrounding these factors that make the future so hard to predict.

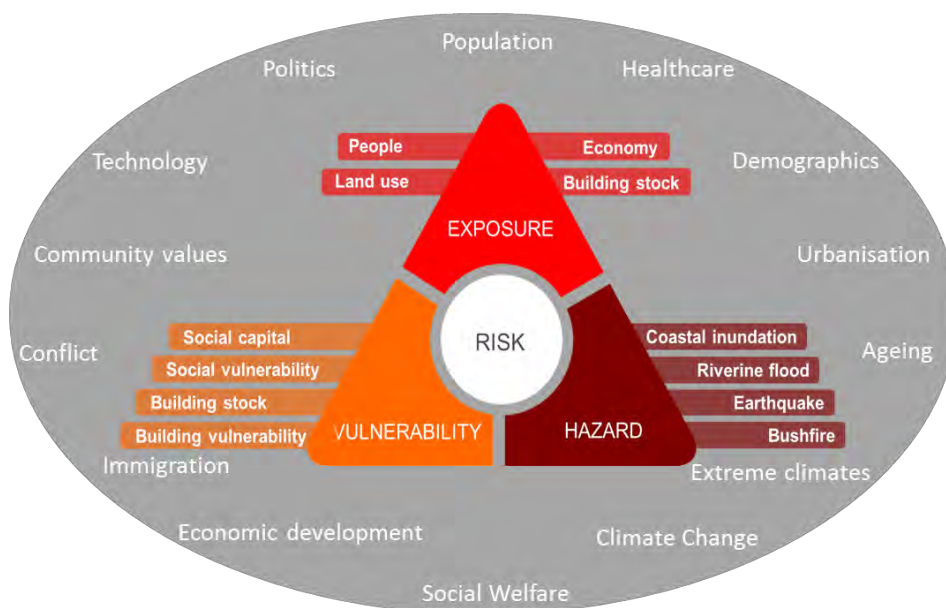


FIGURE 1 - FACTORS, DRIVERS AND UNCERTAINTIES OF RISK

The DSS was developed for Greater Adelaide, South Australia (SA), through an iterative, stakeholder-focused process to ensure the system was capable of providing the analysis required by policy and planning professionals in the emergency management field. The process involved a series of interviews and workshops with members of the South Australian Government, aligning risk reductions to be included, policy relevant indicators and future uncertainties, such that the system can sit within existing policy processes. The overarching system diagram of the DSS is shown in Figure 2, and consists of drivers, modelled processes, risk reduction options and indicators (currently only risk metrics, but this is to be modified to consider broader socio-economic-environmental factors).

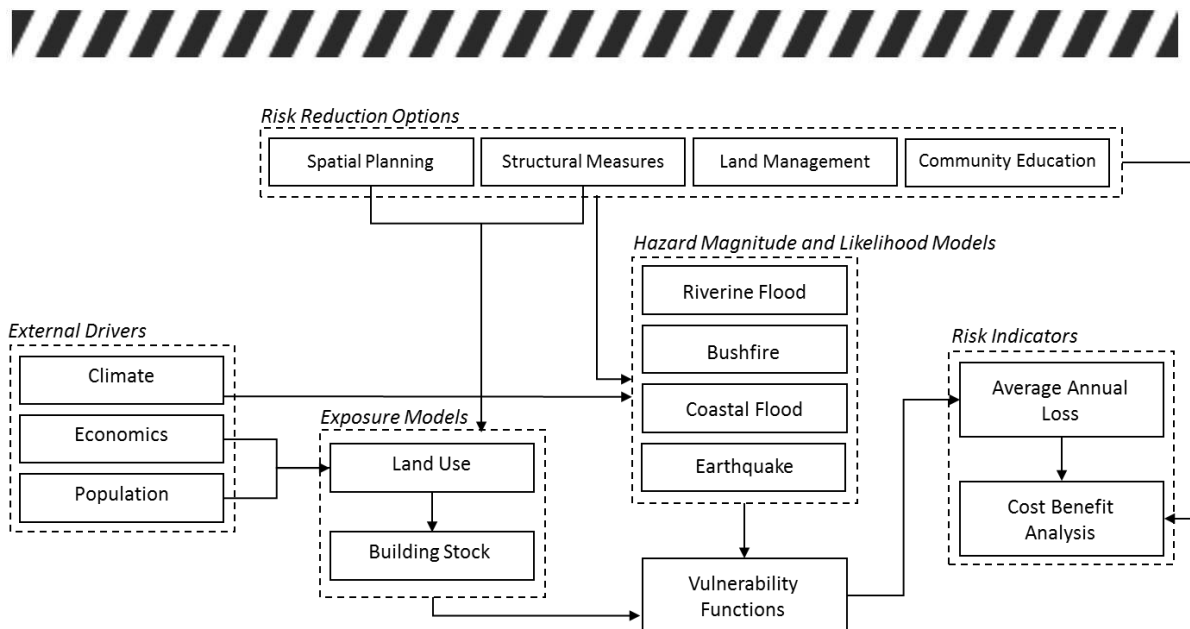


FIGURE 2 - SYSTEM DIAGRAM FOR DSS FOR GREATER ADELAIDE, SA

Within the DSS, exposure is considered dynamically with the inclusion of a land use allocation model (RIKS, 2015) and building stock information retrieved from the NEXIS database (Dunford et al., 2015). The land use allocation model operates on a square grid of 100m cells. The model is the cellular automaton (CA) based Metronamica model which calculates the state of each cell within the overall growth of the region of interest (Greater Adelaide for this study), driven by population and economic demands (White and Engelen, 1993; RIKS, 2015).

A suite of hazard models is also included, as shown in Figure 2. For bushfire, coastal inundation, riverine flood and earthquake, average annual direct loss is calculated using appropriate processes and input data to capture the nature of the hazard. For example, bushfire hazard likelihood and intensity is considered using three factors; ignition potential (a function of land use, road proximity and vegetation), suppression capability (the probability of first wave attack success), and fire behaviour (a function of climate, slope and fuel load). Hydro-meteorological hazards are considered using a digital elevation model and inundation depths for various return periods and future climate scenarios. Earthquake hazard is calculated by using a probabilistic set of 100 events calibrated on historical earthquake events in the region. For each of these hazards, direct losses are considered by taking the magnitude outputted from the hazard models and converted using vulnerability curves for the building stock dependent on its construction type. By using these curves, for specific hazards and construction types, relative damage indices can be multiplied by the building stock's value, providing an output of direct monetary loss.

Risk reduction options are considered across hazard, exposure and vulnerability. For hydro-meteorological hazards, structural measures such as levies and sea walls can be implemented to alter flow and inundation paths, whereas vegetation management (planned burns) can be used to influence fuel loads in the calculation of bushfire intensity. Spatial planning measures can also be implemented, reducing exposure to all hazards. In addition, changes to building codes and retrofitting can be considered by altering the vulnerability curves that relate hazard magnitude to damage. The impact of these risk reduction options is shown through the calculation of average annual loss for baseline conditions with no risk reduction versus the average annual loss after an option has been implemented. The



difference between these two scenarios is used in the cost benefit analysis of various risk reduction options.

Within the integrated participatory use process for the DSS, scenarios for Greater Adelaide's development were also developed. The purpose of these scenarios was to begin to handle the complexities and uncertainties that impact on natural hazard risk reduction planning by capturing them within internally consistent, plausible explanations of how events unfold with time (Raskin et al., 2002). Five scenarios were developed considering how the Greater Adelaide region progresses to be either more or less socially resilient, or more or less open to government implementation of mitigation options. The qualitative aspects of the scenarios are summarised in Table 1 via their motivating factors. The scenarios were also translated to quantitative model parameters and modelled to provide five different perspectives on the region's development, future land use and associated risk profiles across each of the four hazards included within the DSS.

TABLE 1- SCENARIOS FOR GREATER ADELAIDE, MOTIVATING FACTORS

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

The scenarios propose various futures for Greater Adelaide that are all considered relevant and plausible by stakeholders involved in the development and use process of system. The scenarios, once modelled using the spatially-explicit simulation model, can be applied to assess mitigation options and portfolios. Options and portfolios can be tested across them to consider which options are most effective under different conditions or robust for a variety of future conditions (Maier et al., 2016).

The development of portfolios for each scenario is performed by multi-objective evolutionary algorithm optimisation. This optimisation searches the solution space, different mitigation options implemented at different times and locations, to assess which are the most effective in terms of risk reduction (reducing average annual loss) and cost (cost of designing, implementing and maintaining any option). The mitigation portfolios, and visualisations of how they perform with regard to the indicators, is then fed back to the stakeholder group to allow improvement of the exploratory storylines. There is the allowance for fine-tuning of scenario drivers,



mitigation options and indicators. This process should be iterative, and stakeholders should be involved throughout the process, as this is critical in achieving effective scenarios.

The combination of developing the DSS with stakeholder perspectives throughout, coupled with scenarios and the optimisation of mitigation options, presents a novel way for considering the challenges, and complexity of long term risk reduction planning. A participatory approach is critical in considering the vast degree of ambiguity and uncertainty around long term planning. This, coupled with quantitative assessment via simulation modelling and optimisation, offers a method for transparent and robust decision making. The process also enables the development of strategic capacity in understanding and subsequently managing the drivers of risk into the future. Further work will look to improve the modelling processes along with the implementation of the system within existing policy processes.



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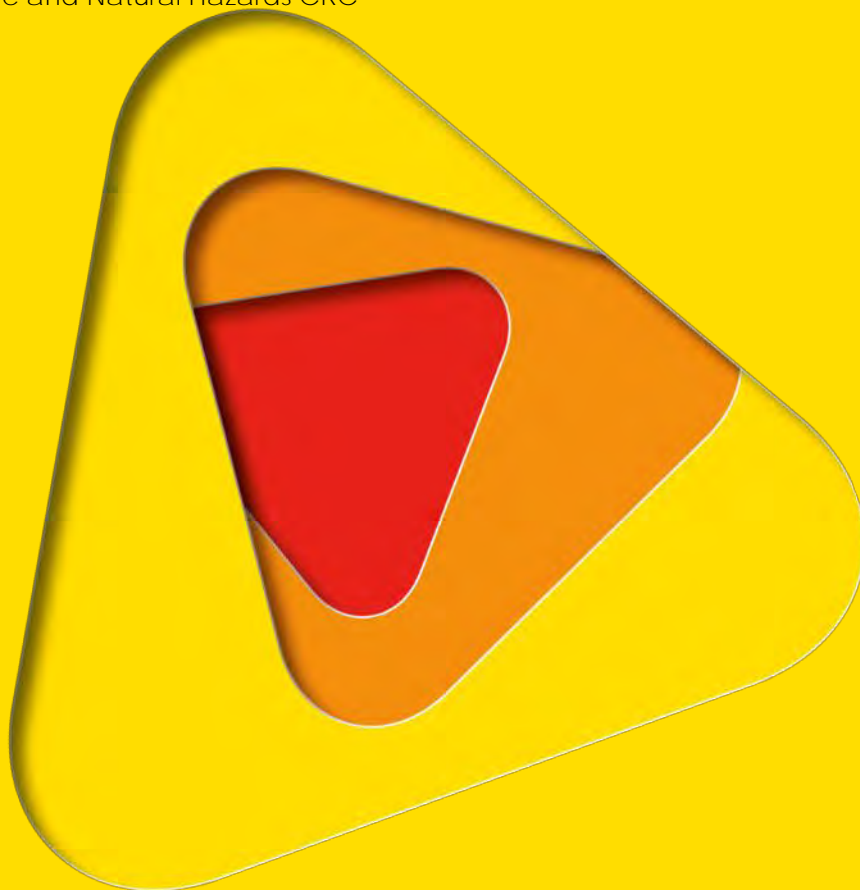
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TOO GOOD TO BE TRUE? HOW A REMOTE ISLAND COMMUNITY DEVELOPED A 100% EFFECTIVE RISK COMMUNICATION STRATEGY AND WHAT AUSTRALIA CAN LEARN FROM IT

Non-peer reviewed research proceedings from the Bushfire and Natural Hazards CRC & AFAC conference Sydney, 4 – 6 September 2017

Steve Sutton
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INTRODUCTION

On 13 October 2005 the leaders of the island of Simeulue were presented with a prestigious award by the United Nations. The Sasakawa Award for Disaster Reduction was given in recognition of the island community losing a remarkably low number of people during the 26 December 2004 Indian Ocean tsunami. The award paid tribute to the fact that Simeulue accomplished a “unique achievement in the midst of all the death in Aceh due to the tsunami” and acknowledged that an oral story saved the community. In fact, of a population of 80,000, only 7 people died during the incident – and locals insist that 6 of those died during the earthquake and only one – a man named Laksahmin – died from the tsunami.

Research published soon after the tsunami indicated that the essence of this unique achievement was a traditional story which included information on the signs of an impending tsunami and the action to be taken to minimise loss of life.

In the indigenous story tsunami is called “smong” and the knowledge of smong is based on the community's experience of a previous smong event. This earlier tsunami occurred on 4 January 1907 and affected 950 km of the Sumatran coast.

The core of the old story (from both the literature and from the interviews that comprise this research) is that the big tsunami struck Simeulue in 1907 killing a great proportion of the population. The survivors were those who ran to the nearby hills. Ever since then the story has been repeated in many private and public social contexts. Old people and grandmothers in particular reiterate the story. The principal story elements are:

- | | |
|---------------------------------|------------------------------------|
| 1) Jika gempa kuat | 1) If there is a strong earthquake |
| 2) Jika laut surut | 2) If the sea recedes |
| 3) Lari ke gunung | 3) Run to the mountains |
| 3b) Ngakk menunggu - lari saja! | 3b) Don't wait - just RUN! |

This paper sets out the preliminary results of a PhD research project which is exploring the Simeulue DRR phenomenon. This project aims to generate an understanding of how the simple narrative described above came about and in particular, why it was so effective in minimising loss of life in 2004. It is hoped that these findings can be adapted to improve risk communication and DRR in other locations in Indonesia and indeed the rest of the world.

PULAU SIMEULUE

Simeulue lies at the end of the string of islands off the coast of Sumatra that parallel the Sunda megathrust and that mark the edge of the Sunda tectonic plate.

Simeulue itself is located about 80km from the subduction zone. Following the 9.2 Mw earthquake on the morning of 26 December 2004, Simeulue was the first place to be struck by the subsequent tsunami.

Pulau Simeulue is the largest of a group of 62 islands that constitute Simeulue Regency in the province of Aceh, Indonesia (see Figure 1). In total, the Regency covers an area of about 205,000 ha, lying about 155km off the Sumatran coast. Until 1999, Simeulue was part of Aceh Barat but seems to have maintained its own distinct sense of identity and, apart from travel restrictions, seems to have been relatively untroubled by the long-running conflict between Acehese separatists (GAM) and the Indonesian government.

Most of the 93,499 people on Simeulue live in 138 villages spread along the coast, with a sparsely occupied and steep rainforest hinterland. The population has been growing at approximately 2.5 percent. The economy is dominated by agriculture and fishing with a relatively small influx of surf-based tourists.

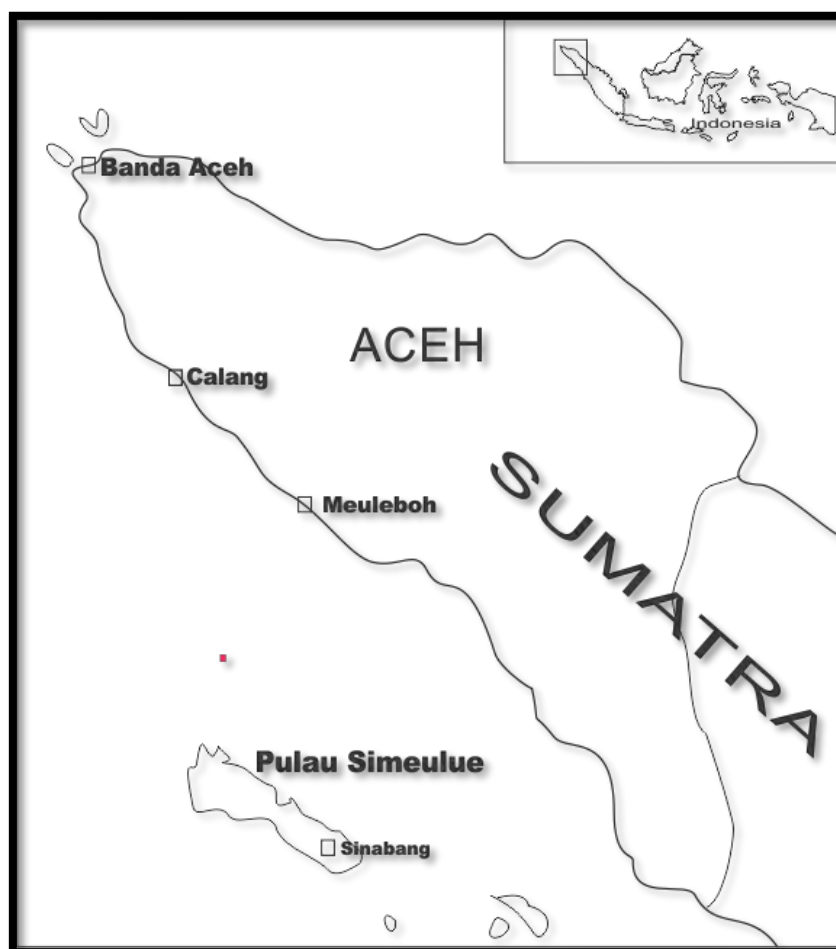


FIGURE 1 - LOCATION OF PULAU SIMEULUE



While few people died in the 2004, the earthquake and tsunami had a devastating effect on Simeulue's infrastructure. Of the 171 schools on the island, 169 were completely destroyed. Sixty bridges collapsed and 210 km of roads were damaged, as were three fishing ports, 40 medical clinics and the general hospital in Sinabang, the island's capital. More than 85 per cent of Simeulue's people saw their homes or livelihoods destroyed.



PRELIMINARY FINDINGS

Narrative interviews were conducted in Simeulue in 2016 and 2017. Most interviewees volunteered that they felt a duty to contribute to the research.

Ahmadi: “We hope that many researchers come to Simeulue to do research and I wish you all the best with your research because I want the story to become popular so that more people can be saved from the disaster.”

They expressed a sense that the local tsunami story in Simeulue was a 'gift' that they wished to provide to their countrymen. They felt that they were given so much by others after the tsunami demolished towns and communities that they should give something back.



KEEPING THE DRR NARRATIVE ALIVE

ISOLATION AND POVERTY

With respect to the issue of maintenance of a story over 100 years and its salience, several threads of evidence seem important. First the island was isolated and poor. Infrastructure inhibited mass transit and people were responsible for their own affairs.

Denny said: Prior to the tsunami "things were not good. There were only 6 cars on the island. There was no petrol station. The roads were gravel and in poor condition. There was only a clinic, no hospital."

As Rampengan et al. (2014) point out, while poverty and isolation are not desirable, island communities can develop considerable degrees of resilience through a self-reliance born of necessity. On Simeulue isolation may have contributed to a relatively reduced immersion in national or international news and information and a self-reliant program of entertainment and information sharing. Much of this devolved to typical cultural pursuits such as music "ngangdong" and story-telling "inafi-inafi".

PEACE

For most of the 20th Century Simeulue was relatively peaceful century. In this situation, personal and family security was not threatened by warfare. While occupied by the Japanese during WWII, participants tacitly indicate that this period was relatively benign. Further, the long-running civil conflict between the GAM separatists in Aceh (of which Simeulue is a part) and the Indonesian government (Gaillard et al., 2008; Sukma, 2006) seems not to have touched Simeulue. A number of participants seemed proud to mention that 'GAM was not here'.

CULTURAL 'FOUNDER EFFECT'

Another factor that may be contributing to the strength of the tsunami narrative in Simeulue might be called 'cultural founder effect'. Founder effect is a phenomenon well described in biology. Schwaegerle et al (1979:1210) note that "[d]uring the course of migration and dispersal, new populations of a species may be founded by a small number of initial colonists. The genetic material of such a population will be limited to those alleles introduced by these few founders and may not be representative of the species as a whole."

On Simeulue, the small number of survivors of the 1907 tsunami founded a cultural tradition of 'smong'. Survivors repeated the story regularly and put great emphasis on its key messages.

A SIMPLE FORMULA WITHIN A MORE TEXTURED NARRATIVE

The key messages grandma reiterated comprise the 'essential knowledge' required to take appropriate action when a tsunami threatens are incorporated in the four-point list in the introduction. While the actual story may be transmitted differently by individuals, local colour added, references made to specific family members etc., research participants consistently reported the four elements of the story that really mattered.



This very simple construction provides critical information about the signs that indicate a high likelihood of an impending tsunami. There are other natural signs and these may be reported as embellishments to the main story.

The key elements also gives a clear direction about what action to take if the tsunami signs are present. And the instruction is readily achievable in Simeulue, with no inhabited land being more than a few kilometres from a suitable elevation. This means that the story recommends action which is readily achievable. This realistic action contributes to self-efficacy on Simeulue in a way that may not be as effective in other geographic settings.

Finally, element 3b provides a mental prod to action. Once you have identified that a tsunami is likely, do not think about it, do not wait to see what happens, just act.

'HERD IMMUNITY'

Interviews indicate that not everyone on Simeulue knew the story of smong in 2004. One woman interviewed had moved to live in Sinabang from the mainland only months before the tsunami.

In the midst of the shock and confusion of the massive earthquake which destroyed her home, she was aware of people, all of them, all around her yelling "smong" and "lari". In a sense the 'peer group pressure' was immense and she ran to the nearby hill with the rest of the village.

So in another analogy, this time to vaccinations, not everyone knows the smong DRR story. But the percentage of people who do is so high that the few outliers are protected and almost literally swept up in the spontaneous evacuation that occurred following the earthquake.



TAKING ACTION

INFORMATION FROM A TRUSTED SOURCE

There is one observation arising from the testimony of participants in the project so far that may go some way to explaining why people did not just repeat the tsunami story, but took direct action when the signs materialised. This is the fact that grandmothers are central to the transmission of the story. All but one participant related the importance of the telling and re-telling of the tsunami story by their grandmother. The story was told in many family contexts and many participants told how grandma told them the story at bedtime. In Simeulue as much as anywhere, grandmothers are held in very high esteem and many participants described their 'special' relationship with their grandma as a child.

Abdi: "My grandmother told me about smong. The role [of nenek] in my period is like - she always spoil her grandchildren - so we are closer to our nenek than our parents. She send us to bed, she gives us money. So we are closer to her than to our parents. So before she sends us to bed, or while sitting and relaxing she tells us that if some day the big earthquake happens usually a big wave will come. In Simuelue grandma used to be someone I report about everything to. So for example if my dad or my mum were angry at me, or people disturb me I report it to my grandma because nenek plays dominant role, and it's very common that people are really close with their grandmother."

Andre's grandma told the story every Thursday night after the family read the Koran:

"The earthquake happened my grandma said. Her skin was wrinkled but her hair was still black and her teeth were good. She said "If earthquake happens - run, don't bring anything. After the earthquake take the rice, the water, clothes, trousers and check the sea, if the water recedes RUN FAR."

She said shaking her finger. She was still young in 1907, she knew many people died. In her version only her tribe survived. After one month when the water had retreated my family went down from the mountain and they found that other tribes had survived. After that they had **two children**."

The inculcation of the simple tsunami DRR story by highly esteemed and much loved grandmas may be an important aspect of the Simeulue DRR phenomenon. Trust has been identified as one fundamental component of effective risk.

There is possibly no more trusted information source than grandma.



CONCLUSION

The tsunami DRR model on Simeulue invokes a simple program of observation and action that is phrased in highly local terms. The smong story is autochthonous and repeated so frequently that it may not be thought of as a DRR message. Smong is simply part of the culture of Simeulue - part of the island's particular character. Three (older male) participants described how they had not passed the story on when living in cities on the mainland. They gave a sense that the story was attached to Simeulue, it was parochial and they did not think it was relevant to life in the big city – at the time.

The story is in a real sense public information. While the periodicity of tsunami is long and the likelihood of a tsunami event in any given year is low, the story has become widely accessible. It is 'open-access'.

On Simeulue then, the responsibility for taking action in the event of tsunami is placed upon each individual via the recurrent telling of the story. Some participants described their own actions in rousing their neighbours or village to action, but it is clear from the pervasive testimony that these actions, while not redundant, merely make a timely reinforcement of a course that everyone already knows. Following the massive earthquake many people in a community are yelling "smong, smong". This spurred on Simeulue locals, but was not understood or acted upon in Meulaboh or Banda Aceh.

The widespread and regular repetition of the simple core message of the Simeulue tsunami story means that there is little risk of the narrative changing or losing its veracity as in the game "Chinese Whispers". Everyone knows the terms and repeats them accurately. This public re-verification of a simple wisdom enlists everyone in the DRR program. It may be that by combining this with the delivery of that information by grandmothers (as opposed to teachers or agency officers) the people of Simeulue have created the ultimate risk communication program. Rather than being 'Too good to be true' the granting of the Sasakawa Award for Disaster Reduction to the people of Simeulue seems entirely appropriate.



ACKNOWLEDGEMENTS

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Implementing CRC research: development of a tool for assessing post-fire hydrologic risk

Non-peer reviewed research proceedings from the Bushfire and Natural Hazards
CRC & AFAC conference

Sydney, 4 – 6 September 2017

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ABSTRACT

An output of the Bushfire CRC was the development of methods for assessing post-fire hydrologic risks to human life, infrastructure, and water quality. The work was delivered as part of the Fire in the Landscape research theme and built on many years of research conducted by the Forest Hydrology research group at the University of Melbourne in collaboration with the Bushfire CRC, Melbourne Water and DELWP.

The Bushfire CRC project was identified for research utilisation by CRC end-users and a face-to-face meeting between end-users, researchers and AFAC research utilisation staff was arranged. The meeting resulted in the development of a three phase research utilisation plan. The first phase was a nationwide assessment of hydrologic risk related to wildfire and the development of a set of national guidelines based on general principles. This work was resourced by AFAC and delivered in 2014. Phase two was managed by ACT Parks and Conservation Service and aimed at advancing the generalised risk guidelines developed for AFAC and applying them to ACT catchments. This was completed in 2016 with the delivery of a suite of GIS tools that built on the algorithms that were developed for the Bushfire Rapid Risk Assessment Teams in Victoria. Additional research - phase three - could parameterise models for specific catchments, with the aim of delivering quantitative information on the probability and magnitude of post-fire erosion.

The project has generated some lessons about the research utilisation process:

1. End-users must be clear about what they need and have a sound technical understanding of the research.
2. All parties need to have a common picture of what is to be developed and how it is to be used.
3. Researchers should be prepared to synthesise their work such that the complexity of processes does not impede the development of practical tools.

INTRODUCTION

Heavy rain in areas burnt by bushfire can mobilise enormous volumes of sediments and nutrients into rivers and water reservoirs, threatening the quality and supply of water to Australia's capital and regional cities and damaging freshwater ecosystems (Sheridan et al. 2009; Nyman et al. 2011). This is because burned headwater catchments contain large amounts of ash sediment and debris that is readily flushed into rivers and water supply reservoirs by surface runoff. High sediment loads from debris flows cause high turbidity and water contamination due to increased nutrient and metals from pollutants in the runoff (Nyman et al. 2015; Langhans et al. 2017).

This type of contamination occurred from post-fire debris flows after the Canberra fires in 2003, resulting in water restrictions in the ACT (White et al. 2006) until a new water treatment plant was constructed. Similar contamination occurred in the Ovens River after the Eastern Victorian alpine bushfires in 2003 and in Lake Glenmaggie after the 2007 bushfires in Victoria. Serious post-fire water quality issues have also been documented in the Nattai Catchments near Sydney and the Lofty Ranges near Adelaide. These scenarios from various landscapes across south eastern Australia highlight the importance of considering water quality issues when managing fire in high value water-supply catchments (Nyman and Sheridan, 2014).



FIGURE 1 - RASIED TURBIDITY IN A MOUNTAIN CREEK IN THE ACT FOLLOWING HIGH INTENSITY FIRE



RESEARCH

The problem that fires pose to water quality was recognised by fire and land management agencies represented on the former Bushfire CRC. In response, the CRC commissioned the Forest Hydrology research group of the University of Melbourne to investigate the effects of forest fire on catchment processes. The project was part of the Fire in the Environment theme which ran from 2010-2014. Research investigated how fire severity and rainfall intensity in steep hilly landscapes contributes to sedimentation and pollution in forested water supply catchments in south eastern Australia (Bell et al. 2014; Jones et al. 2014). The aim was to deliver findings that could help inform and guide development of tools and resources for land and fire managers to assess and address risks to critical water assets in forested catchments. The work built on many years of research conducted by the Forest Hydrology research group in collaboration with Melbourne Water and Victorian Department of Environment, Land, Water and Planning (DELWP; e.g. Sheridan et al. 2009; 2011).

RESEARCH METHODS

The research addressed two key questions. 1) What are the real risks to uninterrupted water supply if catchments are burnt by bushfires. 2) Can the risk be reduced with prescribed fire? The scientific methods included reviews of the international research literature, surveys of extreme erosion events and field experiments to quantify the relationships between fire severity, aridity and post-fire erosion (Nyman et al. 2011). The field studies encompassed a wide range of forest environments in Victoria burned during the 2009 Black Saturday bushfires.

RESEARCH OUTPUTS

The research showed that at the study site water quality risk was primarily associated with slope, fire severity and aridity. Risk increased on steeper slopes, at higher fire severities and in drier landscapes. The relationships between the factors were characterised in a series of models and published in international journals (Nyman et al. 2013a; 2013b; 2013c; 2015; Noske et al. 2016; Sheridan et al. 2016; Langhans et al. 2017).

Another key outcome from the research was that the results showed the risks to water quality are largely associated with large-magnitude events that are threshold driven. So during most erosion events the risks to water quality are relatively small. But in a few cases the combination of rainfall intensity, fire severity and slope result in extreme events such as debris flows and these are the ones most likely to have consequences for water supply and infrastructure. The focus of model development is therefore to represent the conditions when thresholds of extreme events are exceeded.



SCIENCE TO ACTION

Utilisation of the research commenced with a meeting between the lead end users, researchers and AFAC. A key issue going into the meeting was: to what extent can novel research outputs from a Victorian catchment be applied to the landscapes of AFAC members which span Australia and New Zealand? The challenge was to make practical sense of the science and translate it so that the value was maximised for all AFAC members (AFAC, 2017).

The solution was found in recognising that the validity of the detailed knowledge obtained from the study site decreased as the domain over which it was applied increased. This was represented in a matrix that aligned management objectives against the state of knowledge and data availability (Figure 2). Quantitative predictions about the amount of sediment that was likely to be produced following fire were valid for the study site. Qualitative predictions about hydrologic risk were valid for similar landforms with the same hydro-geomorphic properties. In light of this matrix it was also established that the broad assessment of risk associated with bushfire could be carried out at a landscape scale across Australia and New Zealand using existing data and models. The resulting research utilization plan had three phases reflecting the stages identified in the matrix.

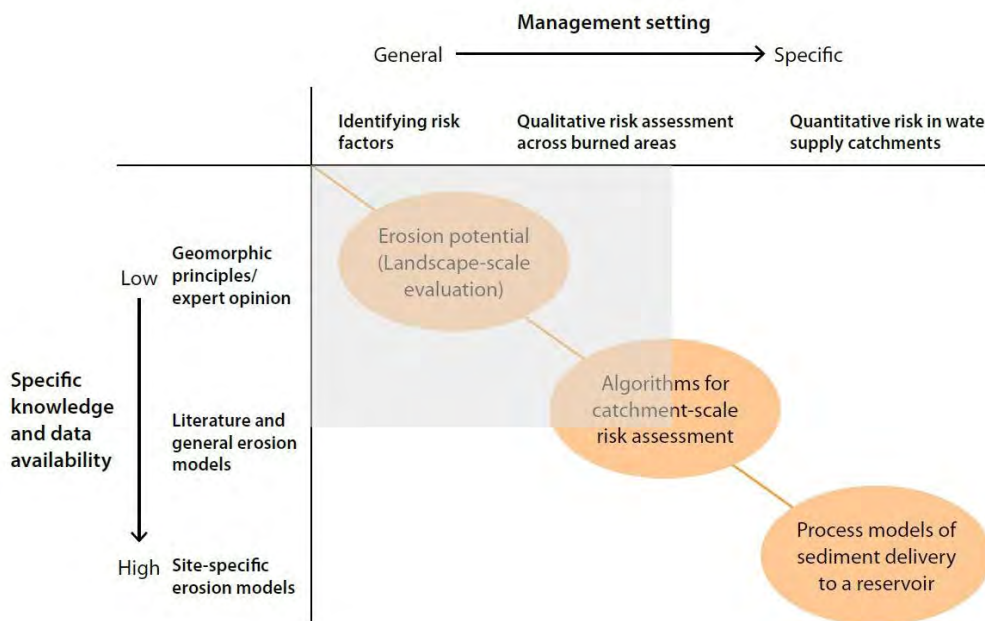


FIGURE 2 - THE TYPES OF MODELS FOR RISK ASSESSMENTS VARY DEPENDING ON THE MANAGEMENT SETTING (TOP AXIS) AND THE SCIENTIFIC KNOWLEDGE (LEFT AXIS) OF THE UNDERLYING HYDRO- GEOLOGICAL PROCESSES. THIS DIAGRAM ILLUSTRATES HOW SCIENCE GAINED FROM ONE SPECIFIC SITE COULD BE TRANSLATED GENERALLY FOR APPLICATION IN DIFFERENT CONTEXTS. THE SHADED AREA REPRESENTS THE REGION OF THE SCIENCE-MANAGEMENT SPACE THAT WAS TARGETED IN THE FIRST PHASE OF UTILISATION.

PHASE ONE: NATIONAL GUIDELINES

The first utilisation product, funded by AFAC, was an Australia and New Zealand wide assessment of erosion risk associated with wildfire (Nyman and Sheridan, 2014). The work assessed the post-fire erosion potential in water catchments in every Australian

State and Territory and New Zealand and was accompanied by generic guidelines for evaluating risk to water quality. Spatial data generated during the project were distributed to each jurisdiction and the report was made available to AFAC members from the AFAC website.

PHASE TWO: RISK ASSESSMENT TOOLS FOR THE ACT

The second utilisation product, funded by ACT Parks and Conservation Service, was a suite of GIS tools that generate post-fire risk assessments of erosion, flooding and water quality for the ACT. The tools were developed by combining the results of the CRC research with other work funded by the Victorian Department of Environment, Land, Water and Planning for use by the Bushfire RRATS in Victoria. The tools were trialled successfully during the 2015-2016 bushfire season and are in use in the ACT.

PHASE THREE: QUANTITATIVE PREDICTIONS

Implementation of the third phase of utilisation in the ACT requires the calibration of models to deliver quantitative predictions. Data for this purpose are being collected in conjunction with the burning program. Rainfall gauges, turbidity monitors, streamflow monitors and sediment traps (Figure 3) are being installed in suitable locations as soon as possible after burns to gather these data.



FIGURE 3 - A SEDIMENT TRAP AND A V-NOTCH WEIR INSTALLED IN A BURNED GULLY

OPERATIONS

ACT Parks and Conservation Service uses the post-fire hydrologic risk tools for two purposes: 1) to plan prescribed burning operations; and 2) to target drainage and infrastructure works in identified risk-prone areas with significant water assets and important ecosystems.

CONDUCTING A FUEL REDUCTION BURN

The work flow for incorporating water quality risk into a prescribed burn has four stages illustrated using the Wombat Creek fuel reduction burn conducted by ACT Parks and Conservation Service in April 2017:

1. assessment of the proposed burn for erosion sources (Figure 4);
2. completion of the burn plan taking account of water quality risk (Figure 5);
3. assessment of fire severity (Key and Benson, 2006; Leavesley et al. 2015; Figure 6); and
4. assessment of the post-fire hydrologic risk using the tools (Figure 7).



FIGURE 4 - POTENTIAL SOURCES OF DEBRIS FLOW WITHIN THE WOMBAT CREEK BURN; EROSION SOURCE AREAS ARE INDICATED BY BROWN SHADING

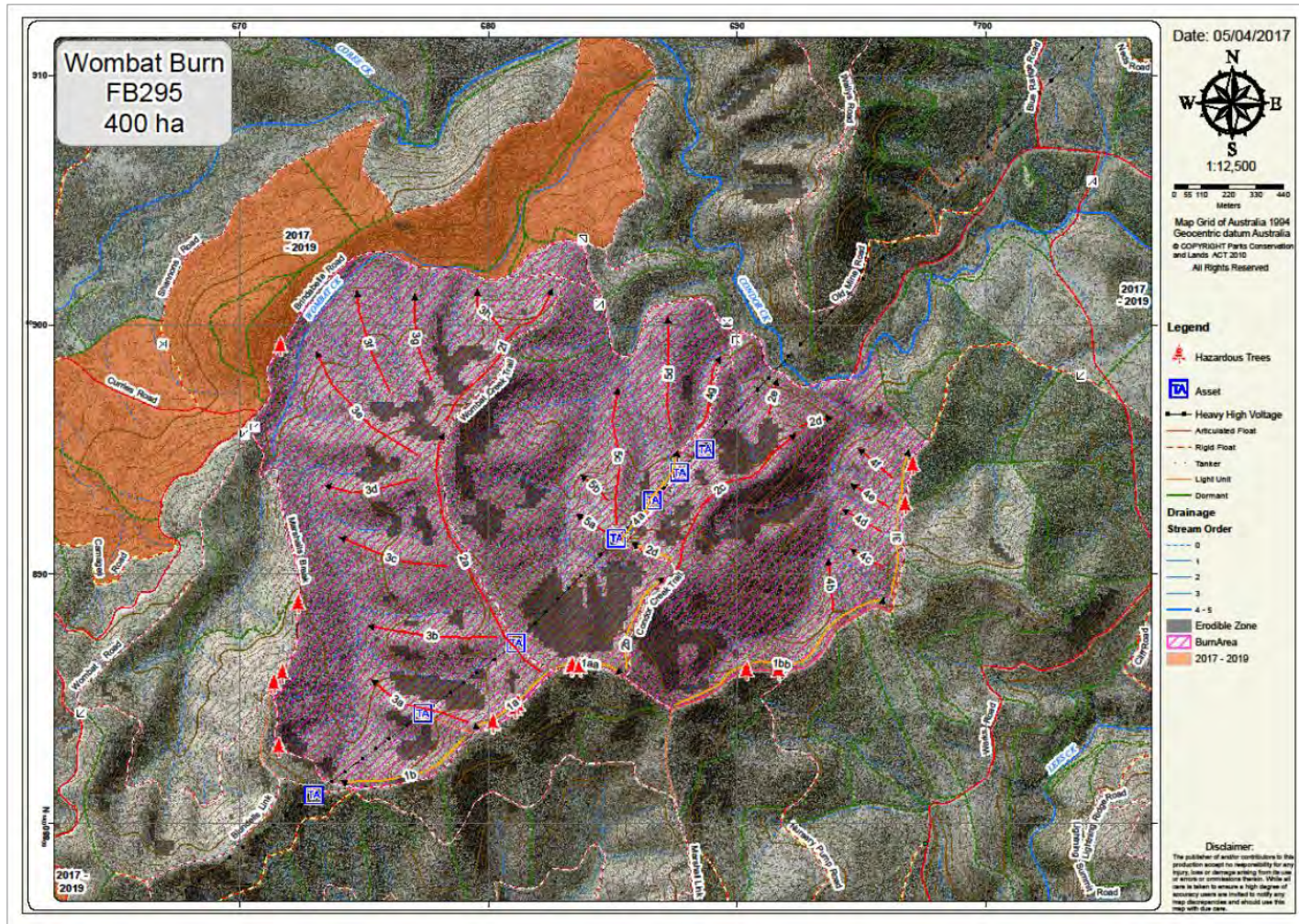


FIGURE 5 - BURN MAP FOR THE WOMBAT CREEK BURN. PINK CROSS-HATCHING INDICATES THE FIRSGROUND; BROWN SHADING INDICATES POTENTIAL SOURCES OF EROSION; RED ARROWS INDICATE THE IGNITION PLAN. THE IGNITION PATTERN WAS DESIGNED TO MINIMISE BURNING OVER THE POTENTIAL EROSION SOURCE AREAS ON SOUTH-EASTERN ASPECTS OF THE BURN

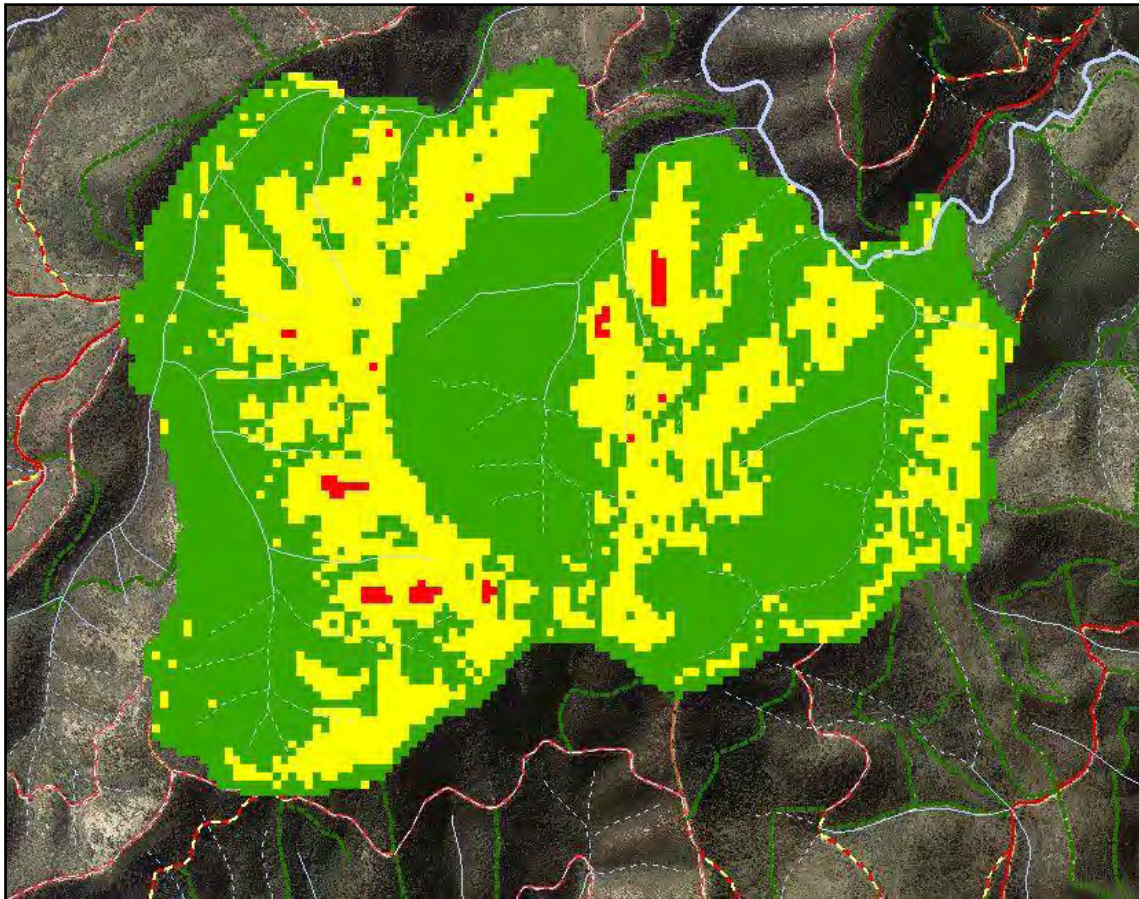


FIGURE 6 - FIRE SEVERITY ASSESSMENT OF THE WOMBAT CREEK BURN USING THE FIREMON METHOD DEVELOPED BY THE UNITED STATES FOREST SERVICE AND ADAPTED FOR THE ACT. GREEN INDICATES UNBURNT; YELLOW INDICATES MINIMAL BURN AFFECTS TO THE CANOPY; AND RED INDICATES CANOPY SCORCH OR CONSUMPTION. THE OBJECTIVE OF MINIMISING BURNING WITHIN POTENTIAL EROSION SOURCE AREAS WAS ACHIEVED.

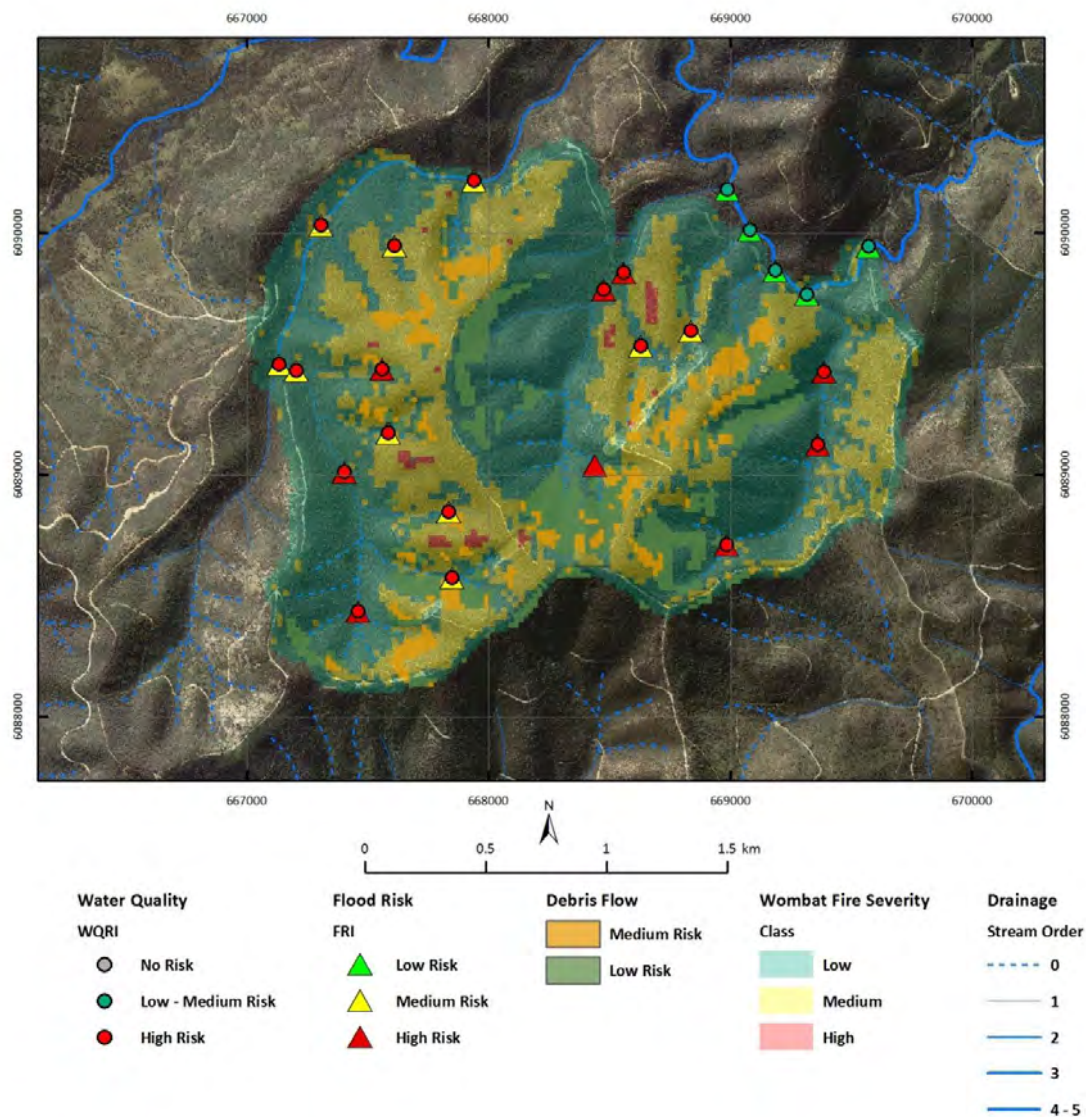


FIGURE 7 - POST-FIRE HYDROLOGIC ASSESSMENT OF THE WOMBAT CREEK BURN. THE BURN WAS CONDUCTED IN STEEP TERRAIN WITH RELATIVELY HIGH RISK OF POST-BURN HYDROLOGIC AFFECTS. THE BURN INCREASED THE RISKS BUT THE AFFECTS WERE LOCALISED TO THE BURN AREA SO THE AFFECT AT THE NEARES MAIN STREAM, CONDOR CREEK, WAS LOW.

IDENTIFYING RISK PRONE AREAS AFTER A WILDFIRE

The identification of hydrologic risk prone areas following a fire is a two stage process requiring an assessment of fire severity (Figure 8, 9) and an assessment of the post-fire hydrologic risk (Figure 10, 11, 12).



FIGURE 8 - THE BRANDY FLAT BURN ESCAPED CONTAINMENT ACROSS A CREEK AND BURNED AT HIGH INTENSITY CAUSING FULL CANOPY CONSUMPTION OR SCORCH OVER A WIDE AREA.

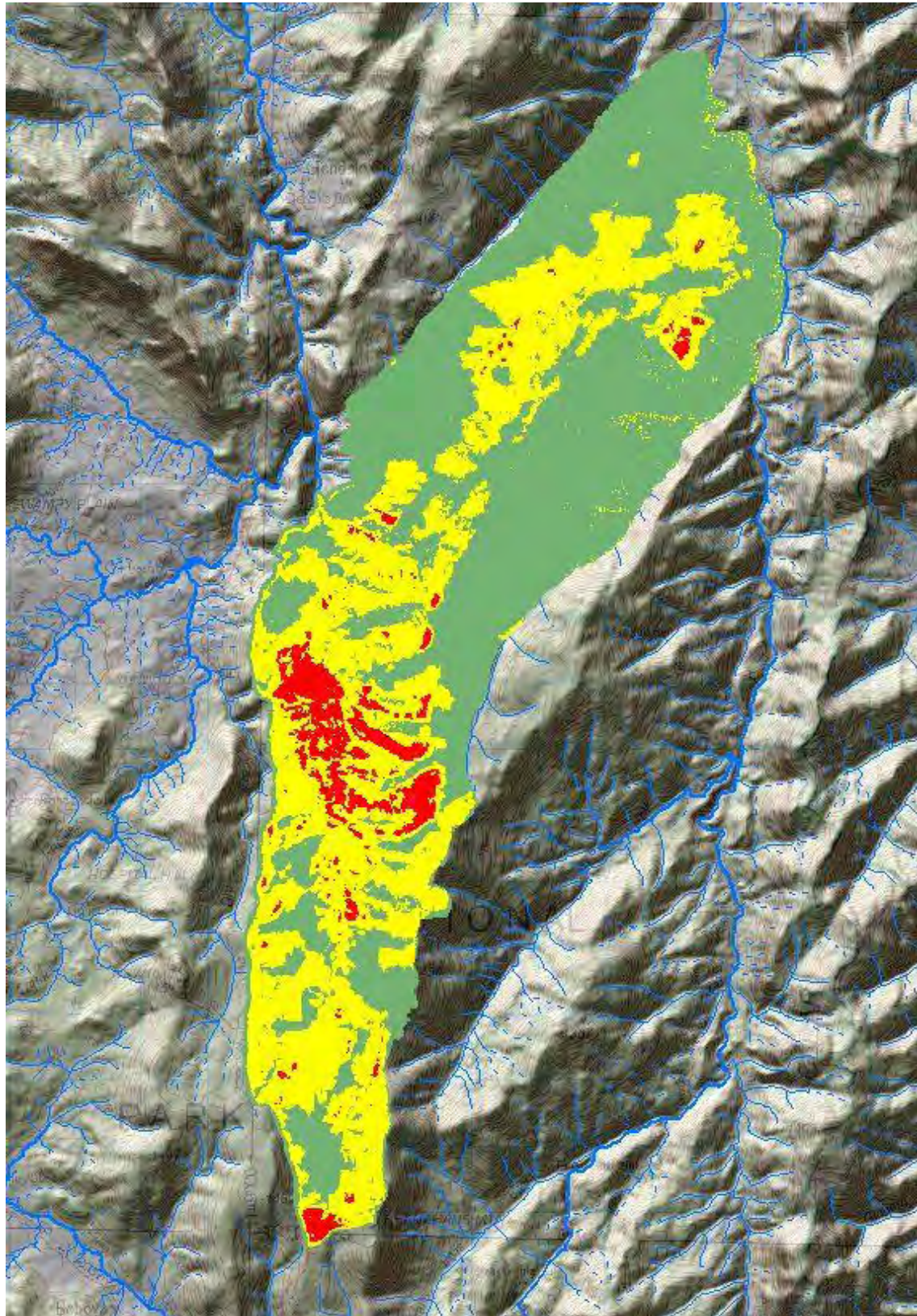


FIGURE 9 -FIRE SEVERITY ASSESSMENT OF THE BRANDY FLAT BURN USING THE FIREMON METHOD ADAPTED FOR THE ACT. THE BURN WAS CONDUCTED IN APRIL 2016 AND ESCAPED CONTAINMENT ACROSS A CREEK. THE FIRE THEN BURNED AT HIGH INTENSITY CAUSING FULL CANOPY CONSUMPTION OR SCORCH OVER A WIDE AREA. GREEN INDICATES UNBURNT; YELLOW INDICATES MINIMAL BURN AFFECTS TO THE CANOPY; AND RED INDICATES SUBSTANTIAL CANOPY SCORCH OR CONSUMPTION.

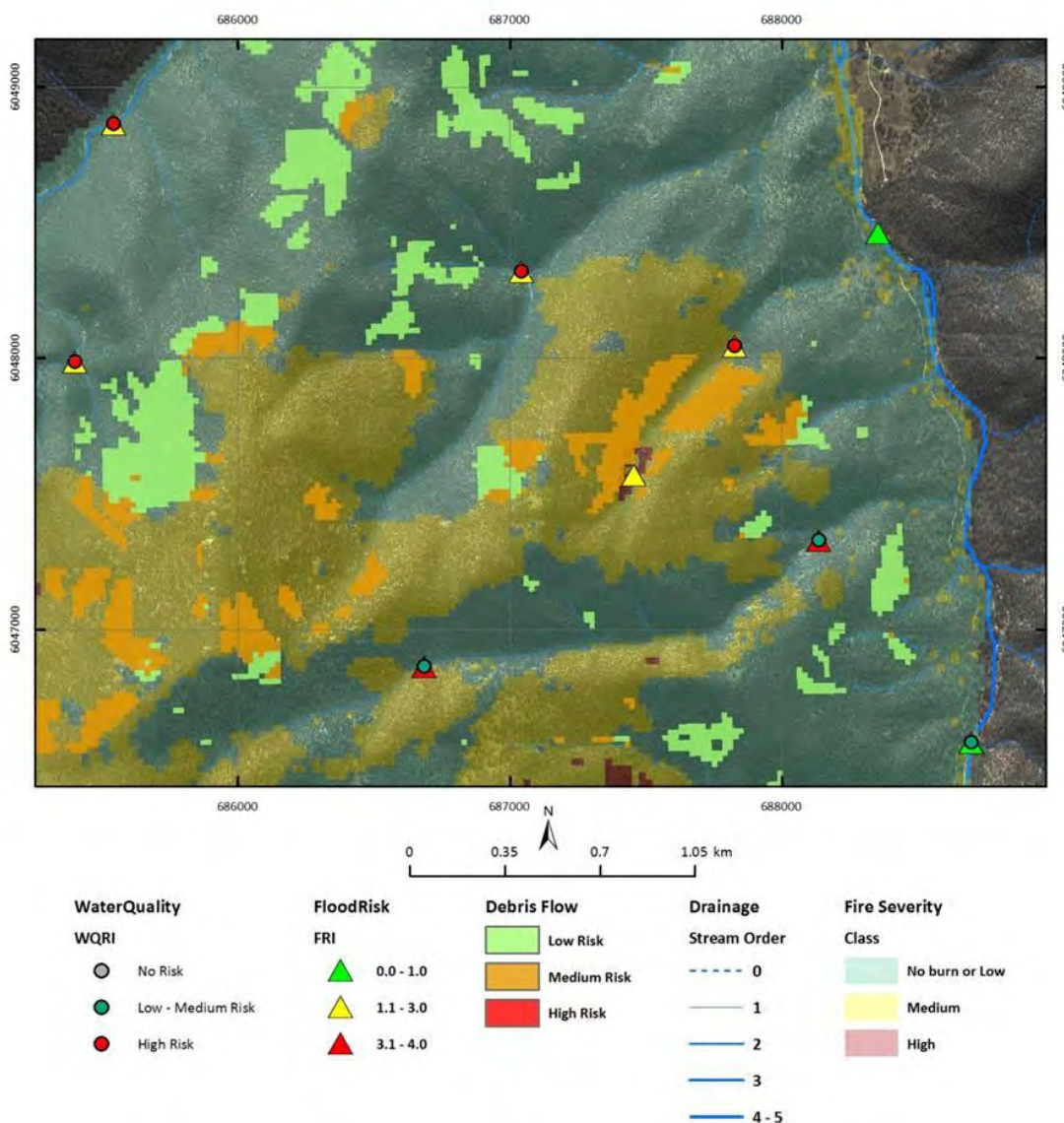


FIGURE 10 - POST-FIRE HYDROLOGIC ASSESSMENT OF THE NORTHERN END OF THE BRANDY FLAT BURN. THE BURNED GULLY IN THE CENTRE OF THE PICTURE WAS SUBJECT TO EROSION DURING AN INTENSE STORM EVENT TWO WEEKS AFTER THE BURN. THE ASSESSMENT SHOWS INCREASED HYDROLOGIC RISK IN THE GULLY BUT ONLY LOW RISK IN THE NAAS RIVER WHICH IT FLOWS INTO.



FIGURE 11 - A BURNT HILLSIDE THAT WAS THE SOURCE OF EROSION FOLLOWING THE BRANDY FLATE BURN IN THE ACT 2016



Eroded material from

FIGURE 12 – SEDIMENTATION IN THE NAAS RIVER ACT 2016 AFTER THE BRANDY FLAT BURN. THE BOULDERS IN THE BACKGROUND ARE FROM A PREVIOUS AND MUCH LARGER EVENT POSSIBLY ASSOCIATED WITH BUSHFIRES IN 2003. ERODED MATERIAL CONSISTS OF ASH, ORGANICS (RIGHT TOP) AND MINERAL SOIL (RIGHT BOTTOM).



CRITICAL SUCCESS FACTORS

The critical factors in improving the management of post-fire hydrologic risk were the creation of a strong researcher-end user partnership, appreciation of the science and research methods and a shared commitment to collaborative discovery in the utilisation phase (AFAC, 2017).

There are three key lessons from this research utilisation process.

1. ACT Parks and Conservation Service staff undertook the lead end-user role during the BCRC research phase of the project and were motivated to do this because a high proportion of the ACT is water catchment. This meant there was end user involvement early in the project ensuring that researchers were aware at the outset of the context in which the bushfire sector would need to use the information.
2. Continuous engagement in the partnership made end users comfortable supporting the project as it travelled the path of investigative discovery. This was important because the results of research are by definition uncertain, so it is not usually clear where a project will lead or what might be delivered at the end.
3. The shared commitment to collaborative discovery in the utilisation phase allowed the complexity of the research models to be simplified for operational use in a way that maintained the quality of the information. This type of work can be particularly challenging for researchers whose research work typically involves a focus on details and a concomitant expansion of complexity.



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A SEDIMENT DEPOSIT ADJACENT TO A MOUNTAIN CREEK FOLLOWING A BURN IN THE ACT



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BUILDING AN ARC IN THE MOUNTAINS: A COMMUNITY-LED INITIATIVE TO BUILD AN ANIMAL-READY COMMUNITY (ARC) IN THE NSW BLUE MOUNTAINS TO PROVIDE A TEMPLATE FOR SIMILAR INITIATIVES

Non-peer reviewed research proceedings from the Bushfire and Natural Hazards CRC & AFAC conference
Sydney, 4 – 6 September 2017

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ABSTRACT

Responsibility for animals in emergencies lies with the owner. However, owners are often underprepared and have not planned for their animals, or themselves. This can lead to late evacuation, failure to evacuate, or risky acts trying to rescue, return to, or save animals. These situations can jeopardise public and responder safety and, as seen in several recent natural disaster events, loss of both human and animal lives. The loss of animals in disasters, often in extremely traumatic circumstances, can severely impede owner recovery, through loss of livelihoods, reductions in social capital, and enduring (disenfranchised) grief. Research in the United States has found that grief responses to loss of a pet can be equivalent to the loss of a sibling or family member (for example, Archer, 1997). Despite this evidence-base, there is still a tendency in emergency management to ignore or underestimate the significance of animal emergency management (AEM) as a legitimate area for mainstream consideration.

The *Managing Animals in Disasters (MAiD)* project is part of the BNHCRC's research program and sought to identify best practice approaches to AEM. As part of this research the MAiD project has teamed up with a new community-led group called Blue ARC: Animal Ready Community. The aim of Blue ARC is to support community resilience in emergency events through better awareness, preparedness, planning and response for companion animals, livestock, and native wildlife. MAiD sought to work alongside, and support, Blue ARC to become established. The goal of this activity is to generate a community guide to establishing an ARC; a resource that could be used by other communities to promote emergency preparedness through a focus on animals. This paper provides an overview of some of the activities of Blue ARC and the plans for the community guide and supporting resources.



BACKGROUND

THE VALUE OF COMMUNITY

In Australia, since the 2009 Black Saturday bushfires there has been a move towards empowering communities to share responsibility for bushfire preparation and planning (McLennan and Handmer, 2012). Beyond building capacity to anticipate and respond to bushfire risk, the advantages of community participation in mitigation programs include the generation and distribution of information, fostering a sense of community, developing ideas, empowering residents by strengthening capacity, and enhancing relationships between residents and government agencies (McGee, 2011; Mileti, 1999; Allen, 2006). A study by McGee (2011 p. 2531) examining three neighbourhood level bushfire mitigation programs in Australia, the United States, and Canada found that they all appeared to “contribute to community resilience by building social networks and generating knowledge”. The way disaster is experienced is context specific, relating to the hazard itself, social structure, vulnerability, and agency. Empowering people at the local level, through community development and participation, enhances individual agency and resilience (Bohle et al, 2009; Paton and Johnston, 2001). Therefore, through community-led initiatives individuals can become more informed about their risk, prepared for, and able to cope with bushfire threat.

Animals provide an avenue to connect communities; enabling community members to work together in disaster preparedness and planning. In Australia, 62% of households own pets and the majority consider them to be family members (Animal Medicines Australia, 2016). In addition, many households also have other (non-‘pet’) animals, with which they have special bonds and will be motivated to protect and save in an emergency, such as horses, pet livestock, and chickens. The *Managing Animals in Disasters (MAiD)* project is part of the BNHCRC’s research program and sought to identify best practice approaches to AEM with the goal of increasing public and responder safety, and improving animal welfare. Activities outlined in this paper are part of one sub-project of MAiD. More information can be found on the project page of the BNHCRC website (<https://www.bnhcrc.com.au/research/hazard-resilience/237>).

THE OCTOBER 2013 BLUE MOUNTAINS BUSHFIRE AND PETS

The Blue Mountains area in NSW is regarded as the most bushfire prone area in the State. In October 2013, the area experienced its worst bushfires in over 30 years. Three fires burnt for four weeks, burning over 118,000 hectares of land, and destroying 203 homes. Research following these bushfires identified the impact pets and other animals had on owner behaviour (Wilkinson et al, 2016). Many pets and other animals died in these fires, and although no official record of pet deaths was compiled, the longer term impact has been recognised by groups and community members assisting with recovery including the Salvation Army, Red Cross, school teachers and counsellors.





THE FORMATION OF BLUE ARC

Shortly after the October 2013 bushfire, a group of community members came together to produce a book about recovery after the fires. This book 'As the Smoke Clears' largely contained photographs of recovery of fauna and flora, and was sold to raise money for the Blue Mountains Mayoral Bushfire Relief Fund. Many of these group members went on to form the Blue ARC group. This group received funding back from the Mayoral Bushfire Relief Fund, and is auspiced by Springwood Neighbourhood Centre Co-operative Ltd. The group was formed in September 2015.

BLUE ARC ACTIVITIES AND OUTPUTS

BLUE ARC RATIONALE AND APPROACH

One of the first activities of the group was to establish what its main goals were, and what it would or would not do. Accordingly, the stated aims of Blue ARC are to support community resilience in emergency events through better awareness, preparedness, planning and response for companion animals, livestock, and native wildlife. To achieve these aims, the main activities of Blue ARC to date have been to identify and pursue ways to increase community awareness of the need to consider animals in emergency planning, to start a dialogue with emergency services and supporting agencies to address local barriers to preparedness and planning for animals, and to identify ways to support formal response and recovery organisations in responding better to the needs of animal owners and animals.

Importantly, the Blue ARC group aims to work with formal response agencies, supporting their general messages and promoting their materials, as well as networking widely with local animal groups (e.g. societies, associations) to produce locally-relevant outputs. Thereby strengthening and reinforcing official advice whilst assisting the community with more tailored and locally-relevant support.

CURRENT ACTIVITIES TO IDENTIFY NEEDS AND POTENTIAL SOLUTIONS

Before developing materials, it was important to establish the needs of the community and of responders; their barriers and challenges, and the information/resources needed. Four activities have been undertaken, and are at varying stages of completion.

1. *Community Survey* – more than 300 residents have completed an online survey about their preparedness and planning for their animals, their needs, their expectations, and their interests in training and education in this area. This information is being analysed, and is being used to prioritise activities and materials development, and to present to and ask questions of various response and recovery agencies and local groups.
2. *Audit of local veterinary services* – one of the early findings from the survey was the importance placed on local veterinarians, and emergency services, as sources of information and assistance with animals in an emergency event. Given the special role of veterinarians we have surveyed local practices to identify their services, including specialist services, their perceptions of their

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ANIMAL READY COMMUNITY

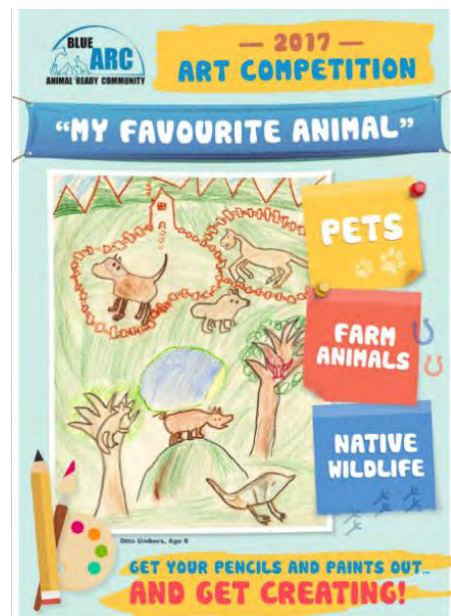
role in emergencies, their needs (training, resources), and the support given to the community in the 2013 fire.

3. *Interviews with key stakeholders* – to understand what has been done in past events for animals and their owners, and for wildlife, and to start to address the various needs of community, identified from the survey, interviews are being undertaken with key agencies, local groups, and organisations. This work is ongoing and will inform outputs.
4. *Developing low-cost community training* – based on community needs and interest in training from the survey, and basic relevant information and skills, we are working with a local veterinarian to develop short community workshops and YouTube video resources. This activity is in its early stages, but will include pet first aid training, basic animal/wildlife handling skills, and emergency preparedness for animals.

CURRENT ACTIVITIES TO RAISE AWARENESS AND ENGAGE WITH THE LOCAL COMMUNITY

To support awareness raising, the Blue ARC group is involved in four activities:

1. *School Art Competition* – as a pilot for a more widespread activity, we are running a competition (see right), asking children at Winmalee Public School to draw or paint their 'Favourite Animal' and say why that animal is important to them. Although this activity is not bushfire-specific it is focussed on why animals matter to children - and (indirectly) why they need to be considered in emergencies. Entries will be judged, winners identified, and all entries will be compiled into a book, available in November 2017 for sale at the school's 'Grandparents' Day' – raising a small amount of money for Blue ARC and for the school. Due to local interest, in 2018 we plan to expand this project to other schools in the region, with an emergency preparedness theme.
2. *Animal preparedness factsheets (Chickens)* – A set of species-specific factsheets are being developed to support animal owners to prepare and plan for their animals. These will include generic animal preparedness information and locally-specific information, e.g. local association contacts, specialist veterinary care. As chicken ownership is prevalent in the Blue Mountains and survey results suggest that chickens are poorly prepared for in emergencies, the first factsheet is being developed for chicken and poultry owners. This is being developed with the assistance of NSW Hen Rescue and a local vet.
3. *Emergency preparedness poster for local community members*– the community survey identified vulnerable populations, including multiple animal households and elderly residents who were ill-prepared, or had potentially unrealistic expectations for themselves and their ability to evacuate their pets





in an emergency. To highlight the need for individuals to prepare and plan for themselves and their pets, Blue ARC is teaming up with the Blue Mountains Resilience and Preparedness Group to produce an emergency preparedness poster showing a (positive) image of a well-prepared older person ready to evacuate with her dog & chicken. This poster will be displayed around the mountains at council facilities, vet clinics, Neighbourhood Centres and other community locations, and an accompanying flyer is also being prepared with a list of links to resources produced by NSW RFS, NSW SES, NSW DPI and others, to assist with preparing for animals in emergencies.

4. **'Get Ready Weekend' Activities** - Blue ARC will be involved in local NSW RFS bushfire preparedness activities in September 2017 sourcing and distributing emergency preparedness brochures, identifying potential animal carrier options and suppliers, producing brochures with links to online resources produced by RFS, DPI and other official sources, and our locally-prepared database for local vet clinics and boarding options.



ROLE OF THE BUSHFIRE AND NATURAL HAZARDS CRC MAiD PROJECT

Observing and supporting the Blue ARC group provides an opportunity to learn from the group start-up process, be part of the development of various community-focused initiatives, and to provide a degree of evaluation of these outputs. The strategic purpose of this partnership, beyond supporting the Blue Mountains community in AEM, is to distil and translate these learnings into a generic guide for communities wanting to develop a similar community-led group. This resource will be freely available for other communities, and it is expected that it will comprise a brief *'How to' Guide* and an accompanying *Resource Pack*.

The Guide can be used to promote emergency preparedness and planning through a focus on animals. It will include advice on group formation, agreement on group aims and objectives, identify challenges and potential opportunities, and identify a range of activities that could be customised for different communities – with many tried and tested by the Blue ARC group.

The Resource Pack will include materials developed as part of the current work with Blue ARC, including a question bank for surveys, templates for posters and fact sheets and plans for low-cost community training.

Content for the Guide and Resource Pack is evolving as the MAiD team and Blue ARC group roll-out the activities outlined previously. It is anticipated that the first draft of these resources will be available in 2018, once the current set of activities have been completed and evaluated. The Guide and Resource pack is likely to evolve and expand as the activities of Blue ARC increase and evaluation outcomes are known. Further information about the MAiD/Blue ARC work can be found online in *Hazard Note 35* (Bushfire and Natural Hazards CRC, 2017).



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LESSONS LEARNED FROM A MULTIDISCIPLINARY INVESTIGATION INTO THE WAROONA FIRE

Non-peer reviewed research proceedings from the Bushfire and Natural Hazards CRC & AFAC conference
Sydney, 4 – 6 September 2017

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ABSTRACT

THE WAROONA FIRE

The Waroona fire burnt over 68,000 ha and destroyed more than 160 homes in southwest Western Australia in January 2016. This conference paper is an abbreviated and less technical version of a longer case study that has been submitted to the Journal of Southern Hemisphere Earth Systems Science (Peace et al., 2017). More detail and supporting analysis is contained in the JSHESS version and interested readers are directed there.

Our investigation revealed processes that contributed to four episodes of extreme fire behaviour and the findings are highly relevant to other fires where extreme fire behaviour may develop. This study draws on two reports that highlight the difference between observed FDI's and fire activity at Waroona (Bureau of Meteorology, 2016 and McCaw et al., 2016).

There were two pyroCb events; both were associated with anomalously fast fire spread in the prevailing winds; one ignited new fires downwind and the other was against normal diurnal timing. Two evening ember storms occurred; the first impacted the town of Waroona and on the second evening, there were two fatalities when the fire made an unexpected run and produced a destructive ember storm over the town of Yarloop.

EXTENDED ABSTRACT

THE WAROONA FIRE

The Waroona fire burnt over 68,000 ha south of Perth on 6 and 7 January 2016, with devastating consequences for the towns of Waroona and Yarloop and the broader community of Western Australia. Figure 1 shows the fire perimeter and nearby localities. The meteorology and fire behaviour have been closely examined in a multidisciplinary case study and processes have been identified that are likely to have contributed to the extreme fire behaviour that was observed (Peace et al., 2017). This paper is an abbreviated and less technical version of the longer case study.

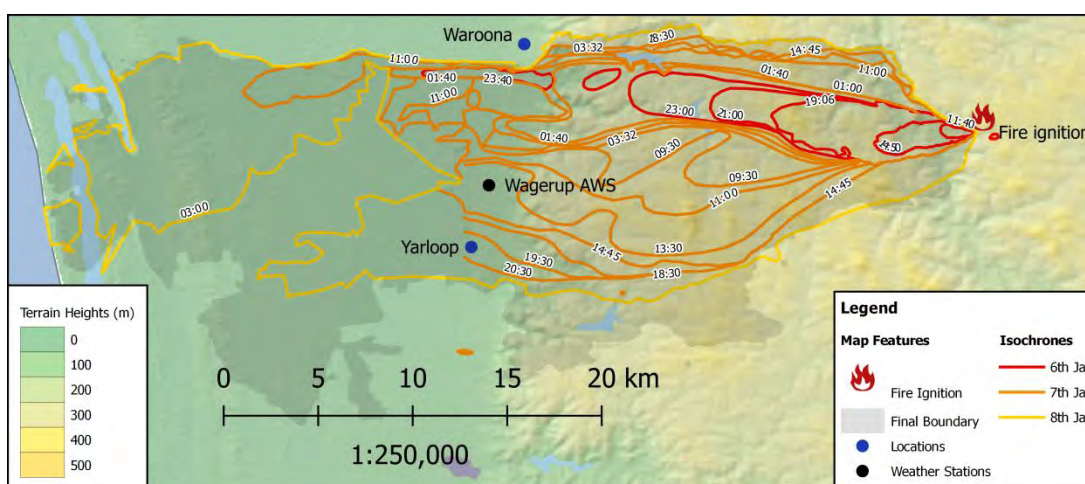


Figure 1: Reconstruction of the spread of the Waroona fire, modified from McCaw et al. (2016). This case study focusses on the first two days of the fire (red and orange isochrones show 6 and 7 January respectively).

FOUR EPISODES OF EXTREME FIRE BEHAVIOUR

During the first two days of the fire there were four separate periods of extreme fire activity. PyroCb developed over the fire on two separate occasions; the first was late afternoon on 6 January and the second at around midday on 7 January. Two destructive evening ember showers occurred; the first over the town of Waroona on 6 January and the second, on 7 January, destroyed the town of Yarloop. None of the four episodes of extreme fire behaviour occurred when fire danger indices (FDI's) were at their daily peak. Times in this paper are quoted as Local Time (LT) in order to easily reconcile events with diurnal trends.

PYROCB ON 6 JANUARY

Figure 2 shows a satellite image of the pyroCb on 6 January. The pyroCb development was triggered by local convergence on the leading edge of a sea breeze front (for more detail see Peace et al., 2017). The pyroCb plume extended to above 14 km and it produced an extensive cirrus anvil, a feature consistent with stratospheric intrusion. Observers saw lighting from the pyroCb ignite a new



fire downwind of the main fire front, closer to the town of Waroona, although no time or location is recorded.

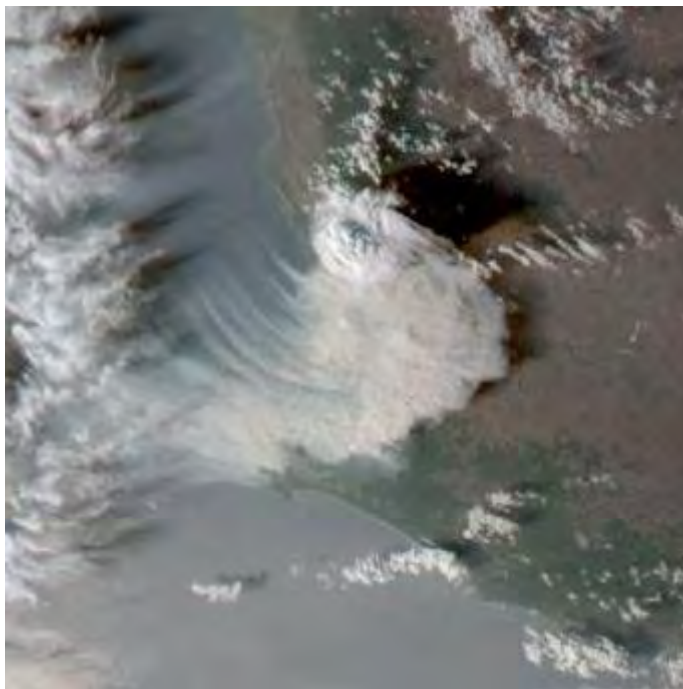


Figure 2: High resolution visible image from Himawari satellite at 1810 LT 6 January 2016.

The downdraft outflow from the storm hit passed across the nearby Automatic Weather Station (AWS) at Wagerup refinery, where a peak in wind speed and wind gust and a marked drop in temperature was recorded just before 1900LT (see Figure 3). The gust outflow recorded at Wagerup AWS illustrates the danger of pyroCb (or dry convective microbursts) produced in a fire environment as the outflow boundary produces increased wind speed and enhanced turbulence. Consequently, the gust front provides a local environment which is favourable for anomalously fast and erratic fire spread as well as transport of large quantities of embers. Pyroconvective dry microbursts have been associated with fatalities at other fires (including the Dude Fire (Goens and Andrews, 1998), the Yarnell Fire (Yarnell Serious Accident Investigation Team, 2013) and the Waldo Canyon Fire (Johnson et al., 2014).)

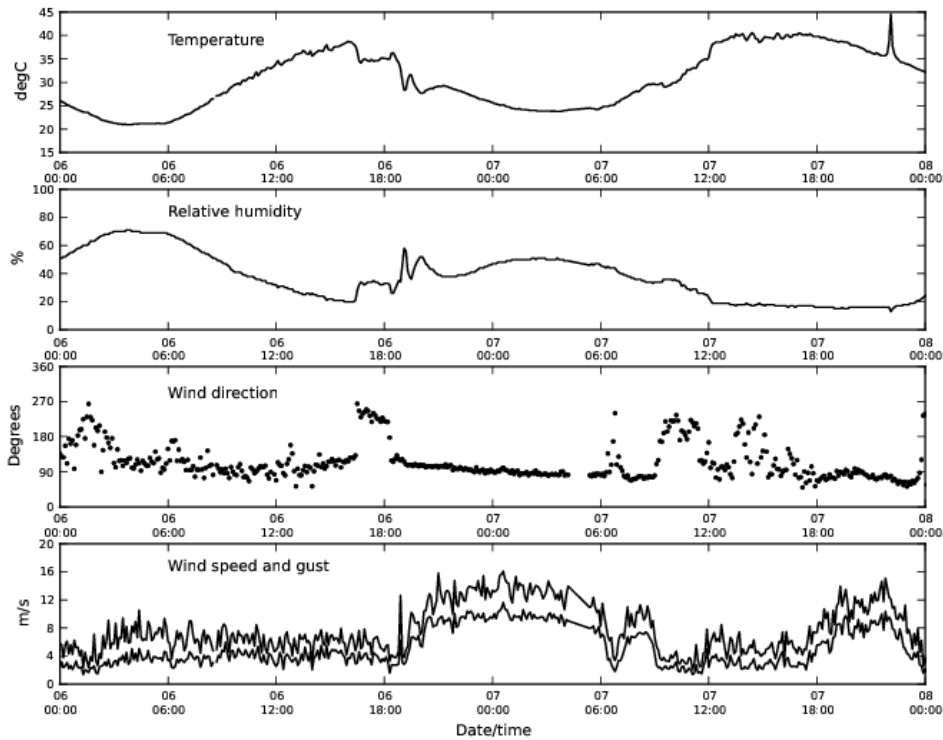


Figure 3: Observations from Wagerup Automatic Weather Station from midnight 6 January to midnight 8 January 2016.

The environmental near surface winds were relatively light during the pyroCb event and the rate of spread of the head fire does not reconcile with the observations at nearby AWS (see McCaw et al., 2016 for further detail).

PYROCB ON 7 JANUARY

On 7 January, a pyroCb developed over the fire during the late morning, against normal diurnal trends (e.g. Peterson et al., 2016). Features of the storm that can be seen in Figure 4 include a low level smoke layer, a deeply turbulent vertical plume and a cirrus outflow layer near the top of the atmosphere.



Figure 4. Pyrocumulonimbus over the Waroona fire on 7 January 2016 (Photo provided by Tracey Vo, Channel 9 Perth).

The late morning development of pyroCb on 7 January is unusual. We attribute it to two factors; firstly, high energy output resulting from the long fire front, which was nearly 20 km long and spreading in heavy, 20 year old fuels and secondly, rapid forward spread and resulting high energy release driven by momentum entrainment of the morning low level wind jet (the wind maximum was located around 1-1.5km above the surface).

The late morning convection featured two transient pulses that overcame a weak elevated temperature inversion, and strong updrafts produced a pileus cloud cap above the pyroCb. Strong, fire-induced low-level wind convergence along the fire-line can be seen in the wind velocity fields on Doppler radar. It is likely that heavy fuel loads and the low-level convergence were key factors in meeting the threshold for deep convection to occur.

THE EMBER STORMS AT WAROONA AND YARLOOP

At around 2100LT on the evening of 6 January, the Incident Management Team received reports that the town of Waroona was under sustained ember attack. The source of the embers is likely to have been a new spot fire that was started by a lightning strike closer to the town than the main fire front. The analysis described in Peace et al., (2017) indicates that the new fire was probably driven towards Waroona by a density current outflow produced by the thunderstorm downdraft, assisted by channeling along a local gully.

On the evening of 7 January, the town of Yarloop was destroyed by an ember storm. The ember storm was described as "*...the whole thing exploded in a massive downdraft*" (in Ferguson, 2016). Heavy, long unburnt fuels to the east of



the town were a significant contributing factor to the intensity of the fire, as well as being a source of fire brands. However, the change in fuels does not fully explain the exponential increase in fire activity.

Close examination of velocity scans from the Doppler radar show the smoke plume doubled in vertical extent from below 4 km to nearly 8 km in around 20 minutes. In addition, localised convergence can be seen on radar at the time Yarloop was destroyed by the ember storm.

THE DYNAMICS OF DOWNSLOPE WINDS AND EMBER STORMS

Analysis of the observations and Numerical Weather Prediction output (see Peace et al., 2017) suggests that the evening ember storms over Waroona and Yarloop were caused by the fire interacting with downslope winds.

Downslope winds occur along lee slopes during the evening and overnight period under favourable conditions. A temperature inversion above the mountain top acts as a stable lid, effectively squeezing the airstream as it moves up the windward slope, into a narrow channel above the topography. On the downward slope, the squeeze is released and the airstream accelerates and develops into highly turbulent flow. Under certain circumstances a hydraulic jump can develop, which takes a wave form located above the base of the slope, with rapid up and down motion in the jump region.

The slopes of the Darling Scarp are known to experience downslope winds, (locally known as 'scarp winds') and on both evenings, Wagerup AWS shows an increase in wind speed consistent with downslope wind development (see Figure 3). An important aspect of the dynamics of downslope winds in driving ember showers is that downslope winds are extremely gusty, so that, when co-located with a fire, the environment is highly turbulent and conducive to ember transport, particularly if local fuels are favourable for firebrand production.

Two conceptual models (with and without a hydraulic jump) are presented in the schematics in Figures 3 and 4. The schematics are not intended to be to scale and have been produced to provide a visual representation, rather than an accurate scientific depiction of the physical processes. Figure 5 depicts a downslope wind environment without a hydraulic jump; the gusty and turbulent downslope winds enable transport of firebrands to adjacent properties. Figure 6 shows a downslope wind environment with a hydraulic jump present; the firebrands are lofted and rapidly accelerated upwards a distance of several hundred metres, then deposited rapidly downwards onto properties.

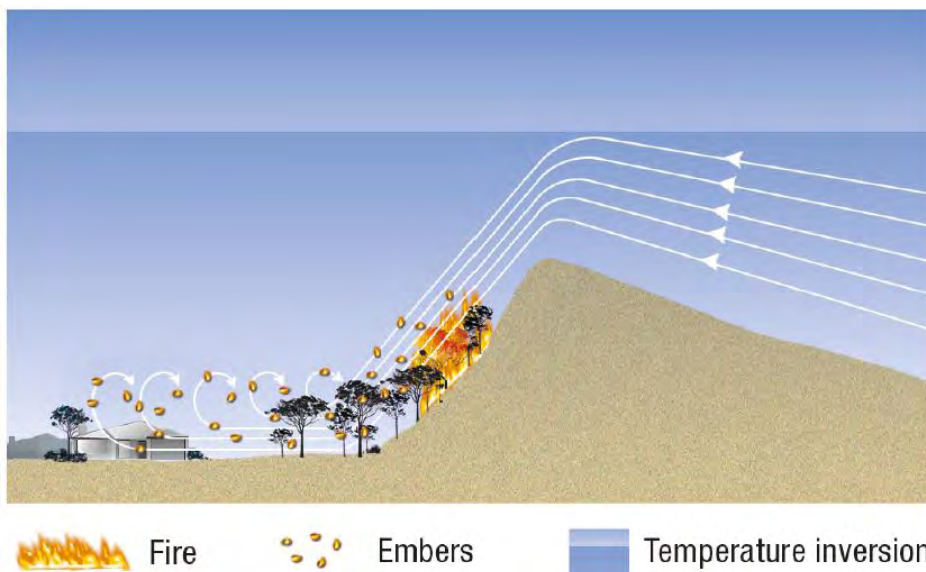


Figure 5. Schematic showing how downslope winds can transport embers from a fire burning near the base of the hill (without the presence of a hydraulic jump).

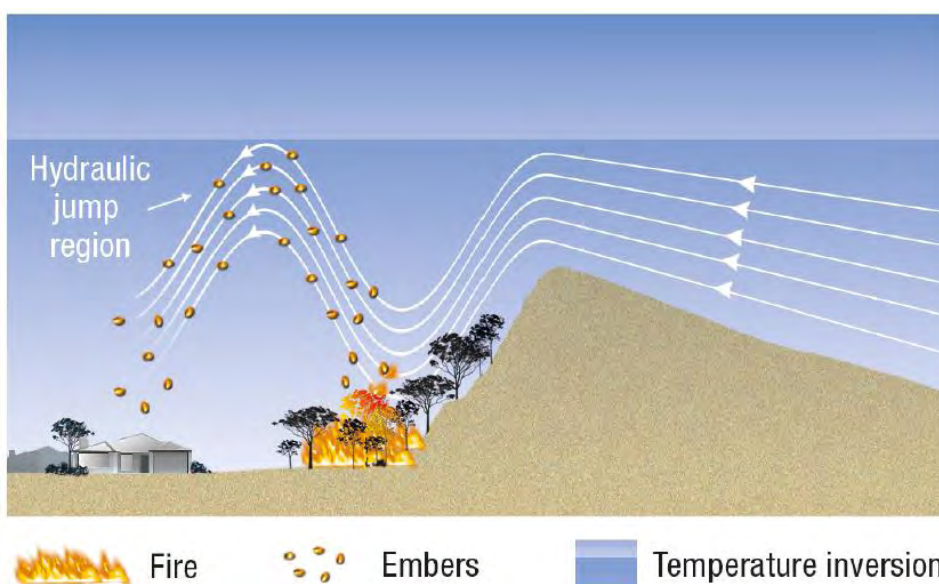


Figure 6. Schematic depicting transport of embers by downslope winds where the embers are lofted by the hydraulic jump then deposited on properties.

The presence of a hydraulic jump provides an enhanced mechanism for lofting and deposition of large numbers of firebrands over a local area. A feature of both models of downslope wind transport is that the transport of embers occurs quickly over a short distance in the vertical plane, and this permits large numbers of fire brands with burnout times of a only a few minutes to travel distances of hundreds of metres to a few kilometres (Ellis (2013) reports burnout times up to seven minutes). In comparison, embers lofted vertically in a traditional fire plume are likely to have a longer transport time and therefore more likely to extinguish before deposition.



A simple 'back of envelope' calculation, using wind speeds of 50-80km/h (typical for a downslope wind regime) and a firebrand burnout time of 2-3 minutes, suggests embers may travel up to 2-4 km before extinguishing. Importantly, the embers in downslope winds can be produced and transported in large numbers when fuel types are favourable and this is consistent with the description of the ember attack on Waroona and Yarloop.



LESSONS LEARNED FROM THE WAROONA FIRE

There are several findings from the Waroona fire that may be applied to future events to help identify situations where an escalation to extreme fire behaviour is possible. Advance warning of such circumstances may enable mitigation efforts that allow lives and properties to be saved. This section is intended to be of use for fire weather forecasters and for fire managers in the context of operational decisions and planning at fire grounds.

FDI PEAK

The timing of the extreme fire behaviour at Waroona was against normal diurnal trends in the fire danger index (FDI). The normal peak in FDI occurs mid-afternoon, whereas the four episodes of extreme fire behaviour at the Waroona fire were in the late afternoon, early evening, mid evening and late morning. This timing discrepancy has been seen at other fires, but there are limited operational tools for identifying such situations correctly in advance and the knowledge gap presents opportunity for development of robust predictive aids.

Both of the pyroCb episodes produced extensive crown fires and defoliation. A correlation between the development of a significant plume or smoke column over a fire and transition to crown fires has not been established in the scientific literature. However, anecdotal evidence suggests links between likelihood of defoliation or crown scorch and an unstable atmosphere, even in benign wind and temperature conditions.

A contributing factor to the extreme fire behaviour is likely to have been limited overnight fuel moisture recovery in the hot, dry conditions.

Fire managers periodically describe prescribed fires that are much more active than expected in the prevailing meteorological surface conditions. Atmospheric stability is a contributing factor in some cases, but including this information into operational risk assessments is difficult. However, there is a need for more information on how the vertical structure of the atmosphere may affect fire behaviour. This may include greater use of available tools such as C-Haines (Mills and McCaw 2010), FireCape (following Potter, 2005) and Mixing Height. However, these are subjective and it would be of benefit to have improved approaches on how to interpret the information and relate it to likely fire activity, especially in a quantitative way.

ENTRAINMENT

Entrainment in this context describes the process by which a fire plume brings down elevated higher momentum air to the back of the head-fire, which consequently increases the rate of spread above that expected given the prevailing surface winds. At the Waroona fire, there are two occasions when this seems to have occurred; during the morning pyroCb event and during both evening ember storms.

The effects of dry air from above the surface impacting a fire have previously been described, for example at the Wangary fire (Mills, 2008). A region of dry air was identified over the Waroona fire ground on the evening of 7 January at



around the same time the fire activity escalated. However, increase in fire activity cannot be directly attributed to the dry air, as there will be a time lag due to the delayed response of fine fuels to changes in atmospheric humidity. In contrast, the response of a fire to entrainment of momentum will be almost instantaneous. At going fires, data describing the airmass above a fire should be examined and the potential for entrainment should be assessed, recognising that the impacts of momentum entrainment on fire behaviour will be dominant over moisture.

DOWNSLOPE WINDS

A key finding from the examination of the Waroona fire (Peace et al., 2017) is that turbulence associated with downslope winds produced the transport mechanism for the ember storm over Yarloop that resulted in two fatalities. Any fire burning in a downslope wind regime has the potential to develop very rapidly and produce ember showers and highly anomalous fire spread. This is highly relevant for Australian fires as there are many locations where downslope winds occur, including the Mount Lofty Ranges in South Australia and the Darling escarpment in Western Australia. The environments that are favourable for downslope winds are also often favourable for enhanced rainfall and therefore heavy loads of flammable vegetation, thus exacerbating the risk to life and properties.

Predicting the potential for development of downslope winds can be assessed through the strength of the pressure gradient across a region in combination with the structure of the temperature and moisture profiles above topography. In addition, Numerical Weather Prediction (NWP) forecast models are run at sufficiently high resolution over Australia to coarsely resolve the downslope wind mechanism. In forecasting operations, examining NWP cross sections of wind vectors and potential temperature can identify the presence of stronger, elevated winds.

Forecasting techniques should be complemented by local knowledge of downslope wind regimes. 'Hot spots' in downslope winds typically form near gullies, and knowing the locations where winds are strongest may be critical information at fire grounds. Downslope winds develop near the lee slopes of ranges. Therefore, the risk of escalation for fires may not be identified, as a conventional risk assessment may identify the windward slope as more exposed to stronger winds and consequently having higher fire risk.

Fires burning in elevated terrain are affected by topographic processes due to the fire behaviour being impacted by unstable atmospheric environments and by fire modified winds (e.g. Sharples, 2009). The effect of topographic wind modification and fire interaction is typically assessed over high terrain, specifically over steep mountain ranges. However there are cases of extreme fire behaviour triggered by wind flow over terrain with elevation of just a few hundred metres (e.g. Kepert et al. 2016).

PYROCUMULONIMBUS

Two separate pyroCb events developed over the Waroona fire. While in both cases the fire was burning through heavy fuels beneath a conditionally



unstable atmosphere, the trigger and the mechanism driving each event were slightly different. In both cases, the energy released by the fire triggered PyroCb development in an environment that was marginally unfavourable for non-fire thunderstorms. On the 6 January, the trigger for thunderstorm development was the passage of a sea breeze front, This demonstrates that wind change boundaries near fires should be closely monitored to assess their potential for triggering an increase in fire activity. The radar data showed the pyroCb updrafts and downdrafts separated by a considerable distance (Peace et al. 2017). The evidence that has been examined suggests that the downdraft produced anomalous fire spread speed and direction and drove a spot fire that was ahead of the main fire front closer to the town of Waroona.

On 7 January pyroCb developed late morning, against normal diurnal trends. The pyroCb development has been linked to the long fire line of 10-20 km, which combined with a deep flaming zone in heavy fuels to produce a high instantaneous energy release over a large area. Long fire lines should be a watch-out for deep pyrocumulus or pyroCb. Doppler radar data showed strong convergence in the fire modified winds and it is likely the convergence played a role in triggering the two pyroCb pulses that occurred. Radars are not always in fortuitous proximity to large fires, but any fires near radar should be closely monitored on both reflectivity and velocity scans, and skilled interpretation may assist in critical decisions (e.g. McCarthy et al. 2016).

The timing of the extreme fire behaviour and the ferocity with which it burnt took experienced fire managers by surprise. The fire reconstruction (McCaw et al., 2016) describes discrepancies between the observed and predicted spread rate at several stages of the fire. These discrepancies were found by examining field observations such as leaf freeze and comparing calculated spread rates. Fire prediction tools currently used operationally in Australia are focused on near-surface conditions. Therefore, they have no capacity to capture the potential for pyroCb development, or fire plume interaction with downslope winds; which are the processes that led extreme fire behaviour at the Waroona fire.



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OUT OF UNIFORM (BUILDING COMMUNITY RESILIENCE THROUGH NON-TRADITIONAL EMERGENCY VOLUNTEERING): WHAT HAVE WE LEARNT?

Non-peer reviewed research proceedings from the Bushfire and Natural Hazards CRC & AFAC conference
Sydney, 4 – 6 September 2017

Blythe McLennan, Joshua Whittaker, Tarnya Kruger and John Handmer
RMIT University
Bushfire and Natural Hazards CRC





ABSTRACT

How can the emergency management sector build capability and enable community resilience by supporting forms of volunteering that fall outside the scope of their current volunteer and community engagement models? That – in a nutshell – is the question that the *Out of Uniform (building community resilience through non-traditional emergency volunteering)* research project was set up to answer. The project concluded in June this year, and this presentation reports on key themes that emerged across four cases studies of 'out-of-scope' volunteering in action, all of which reinforce in various ways the role and importance of coproduction.

The cases studied were diverse in context and characteristics. Despite their wide variation, however, quite a number of shared themes were found across them that included: the value of coproduction, the impact of job mobility amongst public officials, the shapes and styles of volunteer leadership, the rising importance of brokering actors, groups, networks and platforms; and the challenge of sustainability.

Taken together, these findings reveal some surprising areas where emergency management organisations can make changes to the way they engage with communities and volunteers (both affiliated and not) that can reap potentially significant capacity-building and community resilience benefits. Many of the changes are likely to concern changes to internal organisational processes, structures, and training to build capacity for establishing, maintaining and resourcing co-productive relationships with actors, groups and organisations that have not been traditionally involved in emergency management in the past.

Context
The highly demanding nature of managing emergencies can disrupt effective team performance. These disruptions can lead to an impaired operational response, creating risks to public safety, property and other assets. This project is helping to foster cohesive teamwork when it is most needed – when teams are responding under pressure to emergency events.



INTRODUCTION

How can the emergency management sector build capability and enable community resilience by supporting forms of volunteering that fall outside the scope of their current volunteer and community engagement models? That – in a nutshell – is the question that the *Out of Uniform (building community resilience through non-traditional emergency volunteering)* research project was set up to answer. The project concluded in June this year, and this presentation reports on key themes that emerged across four cases studies of ‘out-of-scope’ or ‘non-traditional’ emergency volunteering in action, all of which reinforce in various ways the role and importance of coproduction as a model of public service delivery in this sector.



BACKGROUND

A key rationale for the *Out of uniform* project is the changing landscape of volunteering, in Australia and internationally. Large-scale socioeconomic changes have recast the conditions in which people volunteer in the 21st Century [1]. As a result, emergency managers can expect to engage with a much wider and more diverse range of volunteers than in the past. At the same time, there is also growing recognition of the valuable resources and capacities within local communities and the broader public that can contribute to overall disaster prevention, preparation, response and recovery [2, 3]. With disaster risk increasing worldwide due to population growth, urban development and climate change it is likely that non-traditional volunteers will provide much of the additional surge capacity required to respond to more frequent emergencies and disasters in the future.

This changing landscape challenges existing volunteer models. It also presents new opportunities to strengthen emergency management capability and capacity, and build community resilience. However, it requires more flexible volunteering models and community engagement strategies that incorporate and respond to newer styles and contexts of emergency volunteering.



FOUR CASE STUDIES

The four case studies included here were diverse in context and characteristics. They spanned preparedness, response and recovery; fire and flood; three jurisdictions; four very different social and hazard environments; and numerous, divergent forms of volunteering in varied organisational contexts.

CASE STUDY 1, COMMUNITY-LED PREPAREDNESS

Be Ready Warrandyte (Be Ready) was an award-winning, community-led bushfire preparedness project coordinated by the Warrandyte Community Association between May 2012 and June 2015 [4]. Its goal was to have more households in Greater Warrandyte with effective bushfire plans. Be Ready undertook a diverse range of locally-targeted activities and involved a high degree of collaboration between local community volunteers, local governments and the Country Fire Authority (CFA).

CASE STUDY 2, COMMUNITY-LED RECOVERY

Community-On-Ground Assistance (COGA) was a citizen-initiated project that provided assistance to people who experienced property damage as a result of the 2009 'Black Saturday' bushfires in Victoria, Australia [5]. The project was funded by the Victorian Bushfire Appeal Fund (VBAF) and utilized a workforce of qualified, paid employees and corporate volunteers. COGA assisted eligible individuals, couples and families to undertake a range of activities such as property clean-up to enable rebuilding to start, carpentry and building related tasks, and rebuilding and recovery planning and advice.

CASE STUDY 3, NGO-COORDINATED SPONTANEOUS VOLUNTEERING

Emergency Volunteering – Community Response to Extreme Weather (EV CREW) is a model for registering offers of help from the public when a disaster strikes and live-matching these people to specific requests for volunteers from organisations that are helping communities [6]. It was developed by Volunteering Queensland and is now also being used in adapted forms by the volunteering peak bodies in the ACT, Tasmania and Victoria. During its major activation for the 2010/11 Brisbane floods, the EV CREW system managed approximately 120,000 registrations and referred more than 23,000 volunteers to helping organisations, predominantly the Brisbane City Council, to assist with post-flood clean up.

CASE STUDY 4, RECOVERY VOLUNTEERING WITH NGOS, PINERY FIRE

The final case study examined the breadth of disaster recovery volunteering following the Pinery Fire in South Australia in 2015, with a particular focus on faith-based groups [7]. There is a move toward engaging volunteers and NGOs that are not traditionally involved in disaster recovery alongside those with more established roles. NGOs that coordinated volunteers to assist with the recovery effort following the Pinery fire comprised both traditional and non-traditional recovery organisations and groups, and included both faith based and non-faith based organisations.



KEY THEMES

Despite the wide variation in the four cases studied, there was a surprising number of themes and issues shared across them. Five of the most influential, and in some cases surprising, themes were the:

1. Value of coproduction,
2. Impact of job mobility amongst public officials,
3. Shapes and styles of volunteer leadership,
4. Rising importance of brokering actors, groups, networks and platforms; and
5. The challenge of sustainability.

VALUE OF COPRODUCTION

Co-production here refers to the direct and active involvement of citizens in the production or execution phase of public policy through the design and delivery of public services at the level of specific programs [8]. Co-production draws attention to the relationships between volunteers and public officials through which “synergy between what a government does and what citizens do can occur” [9, p.1079]. It aligns closely with ideas underpinning community-based disaster risk reduction [10].

All four cases studied involved coproduction of various depths and degrees. Also in all cases, the involvement of, and relationships between, volunteers and public officials was held by participants to be vital for the outcomes of the various groups and initiatives. This was particularly evident for Be Ready, for example, with participants stressing that the group’s achievements would not have been possible without the active support of public officials. However, they also agreed that it was the combination of being *community-led* and *government-supported* enabled it to achieve things that would not be possible as either a solely community or government undertaking.

IMPACT OF JOB MOBILITY AMONGST PUBLIC OFFICIALS

The narrative around the change in volunteering in modern times has tended to stress the management and coordination problems associated with increasingly shorter-term and more episodic styles of volunteering. However, the other, largely overlooked side to this narrative is that paid work is also changing in a similar way [1]. In all the cases examined, job mobility amongst public officials made it difficult for volunteers and NGOs to establish and maintain good relationships with public officials, and thus garner the consistent support required from emergency management organisations for coproduction to be effective. Thus, it is not only voluntary work that is becoming increasingly shorter-term and episodic in nature, but also paid work. In both cases, this presents challenges for undertaking effective coproduction that need to be tackled.

SHAPES AND STYLES OF VOLUNTEER LEADERSHIP

The shape and function of volunteer leadership is an incredibly important but little-recognised factor that both enables and challenges community- and volunteer-led coproduction. People with the vision, drive and tenacity to start up community- and volunteer-led initiatives tend not to be the kinds of leaders that are easy or comfortable for public officials to work closely with. They are likely to be critical of



the status quo and advocate for change that may challenge or disregard government policies and activities to greater or lesser extents. This more activist, driven and entrepreneurial form of volunteer leadership is often necessary to get innovative and impactful voluntary initiatives off the ground, however. Notably some of the initiatives started in this way go on to garner considerable government praise once established.

Consequently, these types of leaders should not necessarily be seen to be a problem, but also an asset. For longer-standing co-production to be successful, however, developing good working relationships between volunteers and public officials is needed. In some cases, more entrepreneurial and disruptive volunteer leaders may adapt their leadership style to help facilitate this. In other cases, leadership may change in time, with new people stepping into the role as initiatives evolve into more established activities and services.

A second noteworthy observation concerning volunteer leadership is the important leadership role of older volunteers. Often, it is older volunteers that have the professional and leadership skills, available time and good standing within their local community to lead impactful voluntary activities. This finding contrasts to some degree with the predominant narrative in emergency management that an ageing population is a problem, even a threat, for the future of emergency volunteering [see also 11].

RIISING IMPORTANCE OF BROKERING ACTORS, GROUPS, NETWORKS AND PLATFORMS

Almost all examples of non-traditional emergency volunteering encountered throughout this project, inclusive of these four case studies, have involved non-governmental organisations, civil society groups or private entities acting as brokers of relationships and interactions between volunteers and emergency management organisations. The case of EV-CREW is particularly illustrative, with Volunteering Queensland fulfilling a vital role as catalyst and enabler of coordinated spontaneous volunteering that was integrated with the formal emergency management system. Meanwhile, the important recovery work of faith-based organisations and groups following the Pinery fire highlights a lack of recognition of the role and potential of faith-based groups as brokers of voluntary activity in disaster recovery, and also risk reduction [see also 12].

In some cases, including that of EV-CREW, this brokering role is enabled via online platforms that help link players and functions together. The findings of these case studies as well as other research on non-traditional emergency volunteering strongly indicates that partnerships with NGOs, established community groups and private entities *that have not traditionally been involved with emergency management, and mobilised increasingly through online platforms*, are likely to be ever more important as brokers of co-production in the future.

CHALLENGE OF SUSTAINABILITY

The fifth and final theme concerns recognising and tackling the financial and administrative barriers for sustaining volunteer participation in coproduction, as well as the work of brokers of co-production. Government-centric views of community resilience tend assume that community-led and voluntary initiatives ought to be self-sustaining over time, and government funding opportunities are commonly



restricted to the start-up phase only. However, seeing these initiatives through the lens of coproduction highlights how they may involve ongoing or repeated public service delivery that does not fit well with short-term project funding models and which are arguably justified recipients of public spending. Additionally, all the cases studied either struggled under the weight of administrative and reporting burdens, or alternatively flourished with administrative support, as was the case for Be Ready which benefited from government funding that it used to contract local project managers.



CONCLUSION

Taken together, these findings reveal some surprising areas where emergency management organisations can make changes to the way they engage with communities and volunteers (both affiliated and not) that can reap potentially significant capacity-building and community resilience benefits. Many of the changes are likely to concern changes to internal organisational processes, structures, and training to build capacity for establishing, maintaining and resourcing co-productive relationships with actors, groups and organisations that have not been traditionally involved in emergency management in the past. Another implication of this research is to suggest a partial convergence of volunteer management and community engagement functions within emergency management organisations in the future. As emergency volunteering is increasingly mobilised through co-productive relationships with 'non-traditional' volunteers, and through partnerships with new brokers of co-production, the spheres of volunteer management and community engagement are increasingly likely to overlap and coalesce within these organisations.



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