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LESSONS AND INSIGHTS FROM SIGNIFICANT BUSHFIRES IN AUSTRALIA AND OVERSEAS

Informing the 2018 Queensland Bushfires Review

Commissioned by the Office of the Inspector-General Emergency Management, Queensland

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FireNinti Consulting- May 2019

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Cover: Waroona fire, Western Australia 5 January 2016 (photo courtesy DFES)

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1. EXECUTIVE SUMMARY

A future with an increased potential for catastrophic bushfires as a consequence of climate variability, increased fuel availability, population growth at the rural-urban interface and land use changes means communities need to be better educated, prepared and embrace the concept of 'shared responsibility'. Fire managers and emergency services will also need to be better prepared, trained and resourced to undertake activities such as risk assessment, hazard mitigation, fire prevention and suppression, community engagement, and disaster recovery. Urban development will need to include a more thorough appraisal of bushfire risk and building standards to account for the worsening projected bushfire potential. Emergency services and the broader community will need to adjust to the changing fire-proneness of regions and regional vegetation types that historically were not prone to fire.

In meeting these challenges, the Queensland Government recognises the importance of 'lessons management' as a component of continuous improvement. The purpose of this Work Package (2) is to review a number of documented Australian and overseas wildfire case studies to collect and analyse key lessons and insights that could be helpful in the 'lessons management' and continuous improvement framework of Queensland emergency services, and informing Queensland's Bushfire Review 2019 process. Lessons learned from the case studies will also provide assurance that Queensland's policies and procedures are world current best practice. Available documentation of thirteen relatively recent, significant bushfires from Australia (six) and overseas (seven) was reviewed, and many lessons and insights collected and analysed. Due to ongoing litigation proceedings, documentation for a number of significant fire events could not be sourced.

A high price has been paid for the lessons collected from the case study wildfires. This includes almost 500 lives, injury, trauma, community dislocation and environmental damage, and an estimated economic cost of almost $40 billion (based on data in the case study documents). Numerous lessons and insights have been collected from the case studies and are itemised in the body of this report. In this summary, I draw out re-occurring lessons and insights under six themes:

- <u>Prevention, planning and preparedness</u>: Most fires were human-caused, including from the electricity distribution network. Maintenance of the network and an on-going community education campaign, together with punitive measures, are important fire prevention measures. Climate and weather cannot be managed but to some extent can be forecast, enabling improved planning and preparedness. Climate variability is resulting in an increased frequency, duration and severity of drought and heat wave conditions, which will require greater investment in hazard mitigation, prevention, preparedness and response capability. What is considered to be 'out-of-scale' today will be within the range of normal variability of events going forward. The adequacy of current arrangements and capabilities to meet the challenges of a hotter, dryer future need to be continually assessed in a risk-based framework, and in consultation with stakeholders. Emergency services and fire managers will need to consider whether they prepare for 95th or 99th percentile fire weather conditions – a decision that will ultimately be based on acceptable risk and the extent to which government is able to commit funding in an environment of competing interests. The option of sharing resources with other jurisdictions to assist with suppression may need to extend to hazard mitigation (prescribed burning). However due to extended and overlapping fire seasons across Australia and overseas, the option of resource sharing may not always be available. Regular training and mock-exercises for L3 incidents will greatly improve the effectiveness of emergency services.

- Community preparedness: This means having defensible space, ensuring hazard mitigation around buildings and infrastructure, appropriate building standards for fire-prone environments, having a bushfire response plan, being educated, informed, alert and situation aware, having access to fire refuge areas, and authorities having an evacuation plan. With support from state government, local governments have a key role to play in community preparedness.

- Hazard mitigation: The fuel hazard in the landscape, at the rural-urban interface and in 'backyards' (around buildings and critical infrastructure), can and must be managed – bushfires draw their energy and 'killing power' from the fuel. Investment in adequate fuel hazard mitigation in the broader landscape and at the rural-urban interface is essential. It will greatly synergise and enhance suppression effectiveness and community preparedness measures. Prescribed burning at appropriate spatial and temporal scales is not a panacea, but it is the cornerstone to mitigating the wildfire threat. Prescribed burning is a complex, risky, costly business. Many of the challenges to prescribed burning can be overcome by having people with the skills, expertise and resources to plan and safely implement programs, together with ongoing focussed research and education programs to address impediments. In the absence of adequate landscape fuel hazard mitigation, a damaging and costly bushfire cycle will continue, regardless of suppression capability. Prescribed burning is also an opportunity for firefighters to gain valuable training and fire ground experience.

- Incident response: In all case studies, emergency services were initially overwhelmed and overpowered by the fires, especially in situations of synchronous multiple fire outbreaks under severe fire weather conditions. The fires were only controlled when they ran low on fuel, or the weather conditions abated. There needs to be a state-wide bushfire policy supported by regional risk mitigation and emergency response plans. There needs to be clarity of decision making authority, functions and responsibilities, and interoperability of agencies involved. To be effective, suppression operations require early detection, rapid and aggressive response by firefighters who are prepared, well trained in rural firefighting, well equipped and who are operating in effective incident management structures. Augmented intelligence systems can assist with the capture and management of a barrage of information generated in a very dynamic environment. For safety and efficiency, it is essential to have an incident resource management system that will enable better registration, tasking, tracking, management and coordination of personnel and appliances.

People with local knowledge, including local volunteers, should be meaningfully integrated into incident management structures.

- Recovery: There needs to be seamless overlap between response and recovery. Pre-incident 'transition from response to recovery' plans should be in place, identifying roles and functions of various agencies. Local government must play a key role in recovery, but to do so, it will need to be adequately resourced. Recovery needs to start as soon as possible, with rapid deployment of damage assessment teams, making the impact site(s) 'safe', providing immediate assistance and welfare support to displaced, homeless, traumatised citizens, and on restoring essential services and critical infrastructure.

- Research and development: Better understand of the effects of climate change on regional fire-proneness; improved fuel and fire behaviour models, especially understanding the development of PyroCb events; improved prediction of drought, heatwave and strong wind events; augmented intelligence systems to assist decision makers during complex and dynamic emergency incidents; evaluation of the effectiveness of community education programs; measures to raise public awareness of wildfire risk and mitigation measures; risk-based frameworks for identifying and prioritising mitigation measures.

2. BACKGROUND

The recent global trend of increasing wildfire activity and associated damage to human communities and the environment, and of escalating wildfire suppression costs, is well documented. The primary driver of this is global climate variability (climate change) attributed to increasing levels of atmospheric 'greenhouse gasses' resulting primarily from the burning of fossil fuels (Figure 1). In many bioregions of the world, this has resulted in a warmer, dryer climate conducive to the start and spread of bushfires. The specific effects of climate change on the bushfire environment are regionally variable. Broadly, the 'fire season', or the period when vegetation (fuels) are dry enough to burn, has been extended by about 19% globally (Jolly *et al.* 2015), there has been an increase in the frequency and duration of severe fire weather conditions, and in some regions of the world, an increase in dry lightning activity. There has been an increase in the frequency of long term fire weather across about 54% of the planet's vegetative surface (Jolly *et al*. 2015) and in Australia, weekly bushfire frequency increased by 40% over the period 2011-2016 (Dutta *et al*. 2016). Climate variability has also resulted in a doubling of the burnable area of the planet due to the drying and combustion of historically mesic, fire independent vegetation types, some of which have never been prone to fire, or which have historically experienced very long fire return intervals. In some regions of the world, such as the Australian interior deserts and some other semi-arid grasslands, the climate has tended to become warmer and wetter, increasing the rate of vegetation growth and fuel accumulation, resulting in an increase in the severity and frequency of bushfires.

The other important driver of the increase in global wildfire activity and increased frequency of catastrophic fires is accumulations of flammable vegetation (fuel). In most fire-prone regions of the world, fuel levels have increased as a consequence of anthropogenic behaviours including fire suppression policies, inadequate levels of prescribed burning, the cessation of traditional burning practices and changing land use such as the abandonment of marginal agricultural land, the cessation of grazing by domestic stock in natural vegetation systems, and public land purpose changes such as well resourced production forests becoming poorly resourced national parks. Fire severity, suppression difficulty and damage potential are primarily a function of the speed and intensity (kW/m) of a fire which, *ceteris paribus*, is a function of fuel load and structure. Another factor contributing to the global increase in wildfire disasters is population increase and expansion of settlements into the rural-urban interface. Too often urban development at the interface, and semi-rural subdivisions, are poorly planned and take insufficient account of the bushfire risk.

The increase in the incidences of disastrous wildfires globally has caused significant loss of life, destruction and damage to the built and natural environments, and has been very costly financially (UNFAO 2007; Climate Council 2016). For example, in the USA, annual suppression costs alone have trended up from about $300 million (16% of USDA Forest Service budget) in 1995 to about $1.5 billion (52% of budget) in 2015 (US Forest Service 2015). Accurate data on the full financial cost of global wildfires is unavailable, but estimates place it in the many billions of dollars per annum, and rising (UNFAO 2007; Jolly *et al*. 2015). Similarly, a full and accurate cost of bushfires in Australia is not available but estimates place the recent annual average cost at about $1.1 billion, with large year-to-year variability (Deloitte 2017). For example the total cost (response and damage) of bushfires in Australia in 2005 was estimated at $5.2 billion (Ashe and McAneney 2012). More importantly catastrophic bushfires are human tragedies, with loss of life and homes, physical and emotional trauma, and major disruption to regional economies and communities. Catastrophic fires also harm the environment, damage and destroy critical infrastructure and regional industries, and kill and injure livestock and wildlife. For example, the 2009 'Black Saturday' fires, Australia's worst 'natural disaster', burned 450,000 ha, killed 173 people, and more than 2,000 homes and 3,500 other buildings were destroyed; the RSPCA estimates up to 1 million domestic and wild animals were killed. The total economic cost has been conservatively estimated at $4.4 billion (VBRC 2010). Studies using general circulation models and making some assumptions about future greenhouse gas emissions, consistently show that the future wildfire potential will significantly increase in the USA, South America, central Asia, southern Europe, southern Africa and Australia as a result of a warming and drying climate throughout this century (e.g. Lui *et al.* 2009; Jolly *et al*. 2015). Importantly, the models also indicate that many regions and ecosystems that have historically not been prone to bushfires, will become so as the climate becomes hotter and dryer.

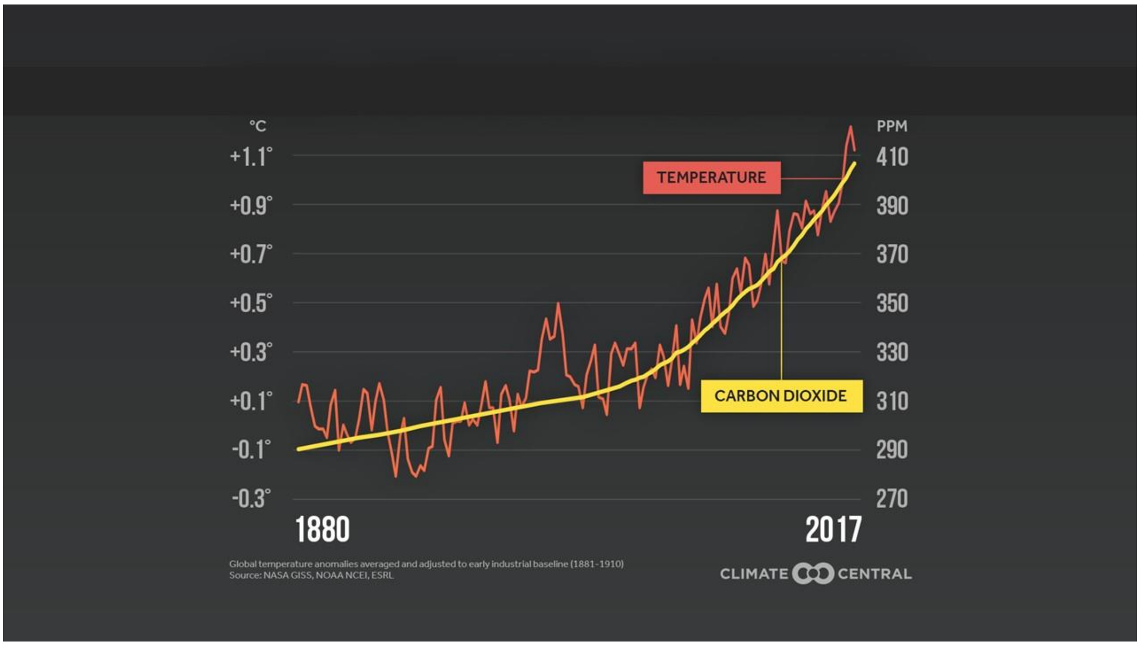

Figure 1: Trends in mean global temperature and carbon dioxide, driving climate variability.

That climate change is affecting Queensland is well documented, with seven of the state's hottest years on record occurring since 1998 (BoM 2018). With hotter, dryer weather comes a temporal and spatial increase in bushfire potential, which has been increasing significantly in recent decades. More than 50% of Queensland's extreme fire days over the period 1945 to 2007 have occurred since 1990, with extreme fire days most prevalent in the southeast of the state (Climate Council 2016). Fire threats to tropical and subtropical Queensland have increased. Weekly bushfire frequencies in Australia have increased by 40% between 2008 and 2013, with tropical and subtropical Queensland the most severely affected (Dutta *et al*. 2016). As with other parts of the world, ecosystems and bioregions that have been historically non-flammable because they are wet for most of the year, are drying and burning. For example, Queensland's rainforests, which historically have not burnt or have experienced very long fire intervals, are drying more frequently so are now more vulnerable to bushfires. El Niño conditions are likely to become more frequent, increasing the potential for rainforests to dry and burn. While many rainforest plants are capable of resprouting and regenerating after fire (Marrinan *et al*. 2005), many are not, so frequent fires may exceed their evolutionary capacity to persist, with potentially adverse impacts on biodiversity.

A future with a significantly increased potential for catastrophic bushfires means communities need to be better educated, better prepared and embrace the notion of 'shared responsibility'. Fire and emergency services and land managers will also need to be better prepared and better resourced to undertake activities such as proactive hazard mitigation and fire prevention, suppression, and disaster recovery. Urban development will need to include a thorough appraisal of bushfire risk and building standards to account for the worsening projected bushfire potential. Importantly, emergency services, land managers and the broader community will need to adjust to the changing fire-proneness of regions and vegetation types that were historically not prone to fire, but are now fire-prone.

To meet these challenges, the Queensland Government recognises the importance of 'lessons management' as a key to continuous improvement. As defined by the AIDR (2013), lessons management has four steps; collection (of lessons), analysis (of lessons), implementing changes based on analysis of lessons, and monitoring and reviewing performance. Lessons can come from both success and failure, from agency experiences or from the experiences of other agencies.

To this end, the primary purpose of this Work Package (2) is to review a number of documented major wildfire events (case studies) in Australia and overseas to identify (collect) and analyse to some extent, lessons and insights from these events that could be helpful in a) the 'lessons management' and continuous improvement framework of Queensland fire and emergency services and b) informing IGEM's 2019 Bushfire Review process. Being time-limited, the analysis of the case studies focusses on key lessons and insights. It is beyond the scope of this project to consider or make specific recommendations about if and how these lessons should be 'learned' or implemented.

3. METHODOLOGY

In searching for lessons and insights with respect to the management of significant wildfire events, I examined documentation (primarily formal reviews and inquiries) of thirteen major wildfire case studies, including seven from overseas (Table 1 and Figure 2). The quality, comprehensiveness, content and usefulness of the documentation was variable, ranging from comprehensive, detailed and rigorously analysed resulting from processes such as a Royal Commission and Special Inquiries, to comparatively brief descriptions of events and impacts with superficial analysis of the causal factors and effectiveness of response by emergency services. I limited my case study selection to those fires that were characterised as 'significant' events or 'disasters' – usually fires that resulted in loss of life and/or caused significant structural damage, and met the criteria for Level 3 (L3) events. I also restricted my study to fires that occurred in the last 12 years or so to ensure a degree of relevance to the present with regard to climate variability, socio-economic, legal and cultural factors, and the current level of sophistication and capacity of emergency services and fire and land managers.

In terms of potential lessons from these case studies, I have focused on the 'findings', 'recommendations', or 'lessons learned', specified in the review or inquiry documents. Where these are not explicit, I have attempted to draw my own conclusions about lessons and insights based on what I could glean from the documentation, and drawing on my experience as a fire scientist, fire investigator and member of a preformed Incident Management Team (IMT).

As part of this analysis, I was interested to discover any common lessons and insights to emerge from the diverse set of case studies drawn from six countries spanning four continents. In doing so, I summarised the often voluminous documents to a concise list of lessons and insights under the headings and themes used in the original documentation, omitting minutiae that was case-study specific and probably irrelevant to other contexts. Not having an in-depth knowledge of Queensland Fire and Emergency Services (QFES) and the Office of the Inspector-General Emergency Management (IGEM) beyond reading readily available literature, I am not best placed to determine the extent to which the lessons and insights collected here are new, or are well known and embedded into the policies, procedures and plans of QFES and IGEM. Therefore, there is likely to be some new lessons and insights that can be considered for adoption and implementation, as well as lessons that are well known, which will serve to reaffirm existing knowledge and confirm world current best practice.

There is currently little or no available official documentation of a number of significant, highly publicised wildfires that I had intended including in the Work Package. These are the 2017 Bega Valley fires in NSW (sub judice – litigation proceedings), the 2018 Canada fires, and the 2018 California fires (sub judice – litigation proceedings). The 2014 Cascade fire (WA) during which four people lost their lives is currently the subject of a Coronial Inquiry. There is some documentation of the 2015 Sampson Flat (South Australia), the California 2017 and the Chile 2017 fires, so I have included these in this WP (see Table 1).

Case study	Information source
Australia	
1. 'Black Saturday' fires, Vic. 2009	Well documented: VBRC Final Report; BoM 2009; McCaw *et al*. 2009
2. Wambelong fire, NSW 2013	Well documented: Parliamentary Inquiry (Anon. 2015); Coronial Inquiry (Dillon 2015)
3. Dunalley fire, Tas. 2013	Well documented: 2013 Tasmanian Bushfire Inquiry (Anon. 2013); Marsden-Smedley 2013
4. Sampson Flat fire, SA 2015	Limited documentation: AFAC *sensu* Neotic solutions 2016
5. Pinery fire, SA 2015	Well documented: Neotic Solutions 2016; Zimmerman 2015
6. Waroona fire, WA 2016	Well documented: Ferguson 2016; McCaw *et al*. 2016
Overseas	
7. Canada fires 2011	Well documented: Wildfire Science Documentation Group 2012; Flat Top Complex Wildfire Review (Anon. 2012)
8. Canada fires 2016	Well documented: KPMG 2017; MNP 2017
9. California fires 2017	Limited documentation: Allianz California Wildfire Review 2018; Nauslar *et al*. 2018
10. Chile fires 2017	Limited documentation: UN 2017; International Federation of Red Cross 2018; Dunstall *et al*. 2017; McWethy *et al*. 2018
11. Greece fires 2007	Well documented: Chalaris *et al*. 2007; Xanthopoulos 2009
12. Greece fires 2018	Well documented: Lekkas 2018; GFMC 2019
13. Portugal fires 2017	Well documented. Viegas 2017; Comissao Tecnica Independente 2018; Castellnou *et al*. 2018; Molina-Terren *et al*. 2019

Table 1: Summary of case studies and associated documentation (references) used in this Work Package.

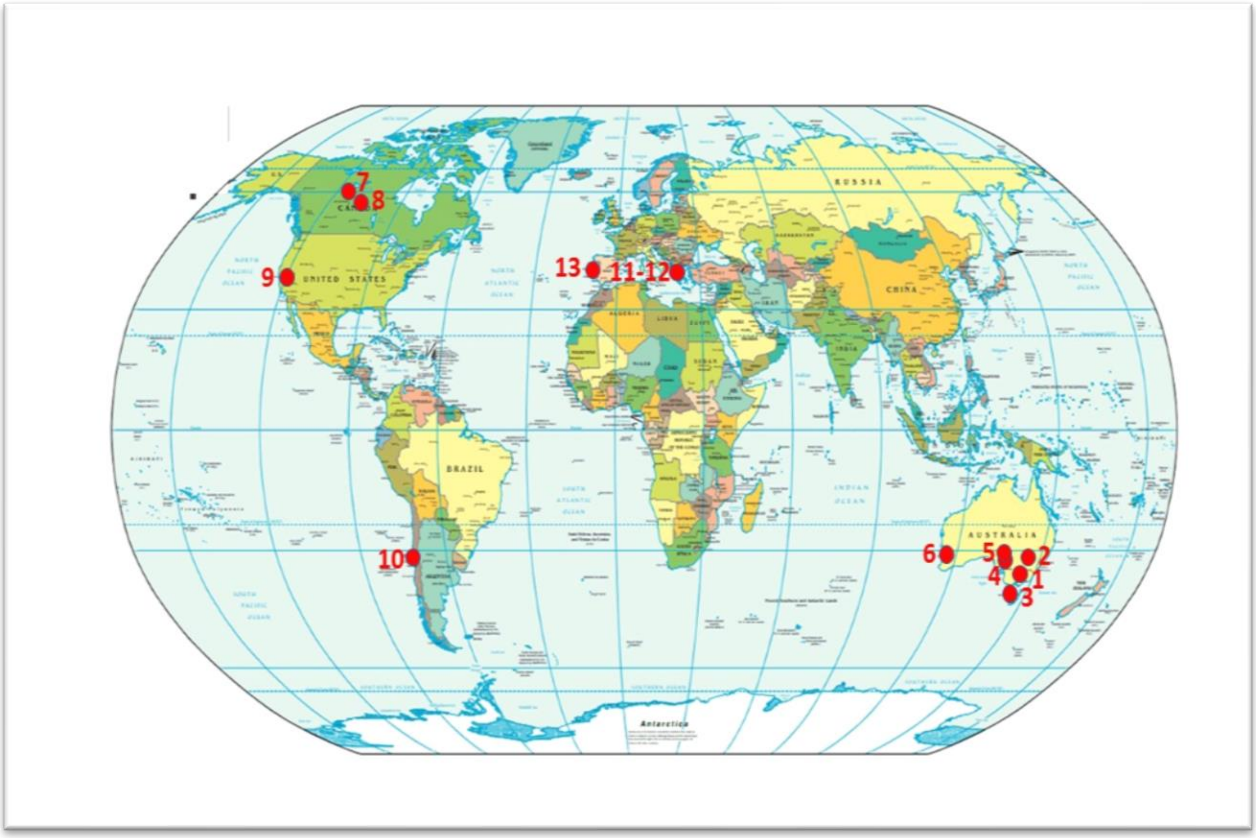

Figure 2: Location of thirteen case study wildfires. Numbers refer to case studies as shown in Table 1.

4. LESSONSAND INSIGHTS: AUSTRALIAN CASE STUDIES

4.1 Case study 1: 'Black Saturday' fires, Victoria, 7 February 2009

Background
The 'Black Saturday' bushfires remain one of Australia's worst natural disasters, with multiple fires burning about 450,000 ha of forest and farmland, killing 173 people (7 others died later from injuries) and destroying over 2000 homes and 3500 other buildings. In addition to the economic cost (estimated $4.4 billion), the fires caused significant trauma, dislocation and disruption to affected communities. The incident was the subject of a Royal Commission (VBRC 2010), which focused on fifteen of the most damaging fires. There have been numerous detailed investigations, analyses and scientific reports, so the incident is well documented and is briefly summarised here. The VBRC recommendations formed the basis for the Fire Management Reform Program initiated by the Victorian Government.

Weather, fuel and fire behaviour
Black Saturday was preceded by drought conditions, with successive years of well below average rainfall. Coming out of winter and leading into the summer bushfire season, soils and live and dead forest fuels were relatively dry. On 9 February 2009, the KBDI, a measure of drought, was in excess of 150 throughout much of Victoria, and about 50 points above the long term average for that time of year. With the onset of summer and heatwave conditions, forest and grassland fuels were very dry. In the two weeks leading up to Black Saturday, Victoria experienced a heatwave; Melbourne experienced temperatures in excess of 43°C for three consecutive days, reaching 46°C on 7 February, the day on which most damage was done. Relative humidity (RH) dropped to 8-10%, creating very dry fine fuels (3-4% mc). Wind speeds consistently averaged 35-60 km/h with gusts up to 115k km/h.

These conditions resulted in an Extreme (now Catastrophic) forest fire danger rating (FFDR) throughout much of Victoria, with the Forest Fire Danger Index (FFDI) peaking at 135. Most of the forest fuels involved were long unburnt (1939 fires) with fine fuel loads ranging from 10-25 t/ha, and a Vesta fuel hazard rating of High to Very High. Grasslands were near 100% cured. While there had been some limited fuel reduction burning done, it had little effect on the outcome of the fires. This combination of fuel and weather, together with the hilly terrain, produced severe, uncontrollable fire behaviour with average head fire rates of spread ranging from 3.2-10.5 km/h, crowning fires, very dynamic convection columns, long and short range spotting and ember storms. Fire behaviour significantly exceeded predictions when fires transitioned from surface/wind driven fires, to 'plume driven' fires. A wind change from NW to SW occurred in the late afternoon - early evening, turning long flank fires into wide, intense head fires.

4.1.1 Lessons and insights

Lessons and insights from this event are best summarised by the sixty three VBRC recommendations made under eight themes. As these are detailed in the VBRC report, I will summarise what I consider to be the most important learnings and insights that are likely to be of most benefit to Queensland.

Bushfire safety policy

- o Need to revise the nationally adopted 'Prepare, Act, Survive', policy to ensure it provides timely and more informative advice to communities about how to respond.
- o 'Stay or go' policy assumed people had a plan and knew what to do when warned, but this was not always the case – many waited 'to see what would happen'. Leaving early is seen as the safest option.
- o Provide or identify community refuges.
- o Provide better community bushfire safety education programs.
- o With state government assistance, local councils to undertake better bushfire risk planning.
- o State to develop a comprehensive approach to bushfire shelter options.
- o State to develop a clear, comprehensive approach to evacuations.
- o The education curriculum to include fire history and the role of bushfires in Australian landscapes.

Emergency and incident management

- o State level emergency management faltered because of confusion about roles, responsibilities and accountabilities, and deficient leadership.
- o Better preparedness arrangements on FDR days of Severe or worse including the need to have in place by 1000h variously resourced Incident Management Teams (IMTs) under a Level 3 (L3) Incident Controller (IC).
- o L3 ICs, regardless of agency, need to be trained to the same standards.
- o Need for a uniform, transparent accredited training and performance review program for L3 ICs, and a traineeship program to ensure an adequate number of qualified L3 ICs.
- o A suitably qualified, experienced, competent person be appointed IC regardless of the control agency for the fire.
- o Clarify the function and powers of the Chief Commissioner of Police and of the Minister.
- o Amendments to the AIIMS framework to improve information dissemination and to ensure someone with local knowledge is part of the IMT.
- o Consider a graded scale of emergency declarations. (Note: some countries grade the scale of an individual fire severity similar to the way in which tropical cyclones are categorised).
- o IMTs that were well prepared and staffed by well trained people with experience, performed well.
- o Incident Action Plans (IAPs) are to developed within the first four hours of an incident and be made available to State and Regional operations centres.
- o Improved mapping support and delivery systems.
- o CFA volunteers to be issued with i.d. cards to facilitate passage through road blocks.
- o Review roadblock and traffic management practices.

Fireground response

- Rapid and aggressive initial attack using ground crews and air attack can be effective.
- Aircraft effectiveness was limited by weather and smoke.
- A number of recommendations to improve the effectiveness and efficiency of aerial operations including making standby arrangements when fire danger rating exceeds certain thresholds, and improving dispatch protocols.
- Better interoperability between agencies at all levels.
- Need to improve information for dispatching and tracking firefighters and equipment.
- Need to improve radio comms plans and radio spatial coverage.
- Need to improve training and protocols for back-burning.
- Inadequate briefings, communications and communications equipment, maps and weather information can jeopardise firefighter safety.
- Safety advisers to be appointed to IMTs.
- All safety incidents, including 'near hits', to be investigated.

Community warnings

- Warnings were not timely, did not reach all those at risk and were too narrow in terms of options - they did not provide information about specific actions to take.
- Better information about the fire behaviour and home defendability, and the risks of staying.

Electricity-caused fires

- Bushfires caused by the electricity distribution network are not uncommon, especially on hot, windy days, so there are a number of technical recommendations in the VBRC report to reduce the risk of this ignition source.

Deliberately lit fires

- Victoria Police continue to pursue and review a coordinated state-wide approach to arson prevention, and ensure it is given a high priority within the agency.

Planning and building

- Recommendations dealing with need for centralised responsibility and expertise in mapping bushfire risk and bushfire-prone areas, especially at the rural-urban interface.
- Improved processes for addressing bushfire risk at the planning stage for new urban developments and small undeveloped rural lots including restricting developments in high bushfire-risk areas.
- Amend the performance requirements in the Building Code of Australia to ensure they incorporate reducing the risk of ignition from ember attack.
- Remove deemed-to-satisfy provisions for buildings in the BAL-FZ.
- Apply a minimum construction level of BAL-12.5 to all new buildings and extensions in bushfire-prone areas.
- Provide advice on how to improve bushfire safety of existing buildings and provide education and training to improve bushfire risk management in the building and planning sectors.
- Local councils to adopt a bushfire policy in their local planning policy framework.

Land and fuel management

- o A most important and challenging recommendation deals with the need to implement a rolling fuel hazard reduction burning program of 5% of public bushlands per annum, as well as recommendations addressing fuel build-up in road verges and the need to assess bushfire risk on public roads.

Author's note:

- In the years leading up to Black Saturday, authorities averaged <2% of public lands burnt per annum, which was inadequate. Victoria has since moved away from the 5% target to a complex 'risk-based' approach, which conceptually appears logical. However, the government has accepted a theoretical 'residual risk' of 60-70%, meaning it will take measures to reduce risk (from a theoretical 100% worst case scenario) by 30-40%. This translates to less prescribed burning but a higher level of bushfire risk acceptance. Science and experience in other jurisdictions suggests the level of landscape burning needs to be 8-10% per annum if any significant risk reduction benefits are to be realised (e.g., see Boer *et al.* 2009; Burrows and McCaw 2013; Burrows 2018).
- Recently published computer simulations suggest landscape prescribed burning is of little benefit unless at last 25% is burnt per annum, and that only fuels within 100 m or so of settlements (the interface) need to be managed. The simulations are flawed, lack an understanding of severe fire behaviour, of prescribed burning and of fire suppression, and overlook vulnerable assets beyond the interface (see Burrows 2018 and case studies below). Although challenging, it is crucial to manage the fuel hazard a) in the landscape b) at the rural-urban interface and c) in 'backyards' at appropriate levels and to appropriate standards.

Organisational structure

- o Recommendations to appoint a Fire Commissioner as an independent statutory officer responsible to the Minister for Police and Emergency Services and as the senior operational firefighter in Victoria with the task of increasing inter-agency operability and building a fire management capability prepared for high risk days.

Research and evaluation

- o Recommendation to establishment a permanent national centre for bushfire research to investigate a number of issues (detailed by the VBRC).
- o Appoint an independent monitor to track the implementation of the VBRC recommendations.

4.2 Case study 2: The Wambelong fire, NSW, 12 January 2013

Background

Over 41 days this fire burned 56,000 ha of bushland (Warrumbungle National Park and other crown land) and agricultural/grazing land. No lives were lost but 56 homes, 131 other structures, ~1200 livestock, thousands of native animals, 700 km of fencing and the $200,000 fence around a town water supply dam were destroyed. The total cost is unknown but is in the vicinity of $50 million. The fire was the subject of a Parliamentary Inquiry (Anon. 2015), and a Coronial Inquiry (Dillon 2015), processes from which the current summary is mostly drawn.

Weather, fuels and fire behaviour

The region received above average rainfall during 2010 through to mid-2012, promoting the growth of vegetation (fuel), followed by below average rainfall leading up to the time of the fire. In the weeks preceding the fire the region experienced hot, dry (heatwave) conditions with maximum temperatures in the high 30s to mid-40s, and very low RHs. On the day of ignition and the following day, temperatures reached the low 40s with RH falling below 10% (Fawcett *et al*. 2013). These conditions resulted in very dry forest and grassland fuels, with fine fuel moisture content estimated to be 3-4%. Wind speed was generally moderate (20-35 km/h); atmospheric conditions were unstable with a high c-Haines Index (Mills and McCaw 2010) conducive to dynamic convection development. These conditions created a Grassland Fire Danger Rating (GFDR) of Severe. With the exception of a few small fires since 2000, most of the Warrumbungle National Park was long unburnt with heavy forest and woodland fuel loads of 10-18 t/ha. Fuels in much of the agricultural grasslands were characterised as 'high'. At its peak, the fire in the National Park displayed extreme behaviour –very large flames, crown fire, high rates of spread, a very dynamic convection column and associated long and short range spotting. The heavy, dry forest fuels and the unstable atmospheric conditions enabled the fire to transition to a 'plume driven' fire with PyroCb cloud formation, an indication of high energy release at the surface.

4.2.1 Lessons and insights

From the Parliamentary Inquiry:

Fuel hazard reduction

- o The need to commit more resources to fuel hazard reduction burning such that at least 5% per annum of public lands are burnt each year; greater priority to be given to fuel hazard reduction generally; reduce regulatory impediments to prescribed burning.
- o Initiate a community education program about prescribed burning.

Author's notes:

- Data from elsewhere (see above) show that 5% per annum is inadequate – 8-10% per annum is the point at which mitigation benefits become apparent.
- Current fire behaviour models are for surface or wind driven fires – there are no models to predict when fires will transition, and the fire behaviour thereafter. However, we do know that transition commonly occurs when fires are burning in heavy, dry forest fuels and the atmosphere is unstable (high c-Haines Index).

Other preparedness and mitigation measures

- o Research into predicting mega-fires / plume driven fires.
- o Implement / enhance the network of fire access trails in national parks.
- o Improve protection through hazard / fuel mitigation including natural and anthropogenic fuels around towns and critical infrastructure.
- o Ensure adequate numbers of trained staff are on stand-by during periods of Extreme and Catastrophic FDR.

Suppression response

- o Enable Remote Aerial Response Teams to operate at night.

- Improve procedures for communicating with volunteer brigades; utilise and respect capabilities and local knowledge of volunteer brigades.
- Review procedures for notifying and providing information to communities.
- Give a priority to the protection of pastoral infrastructure, not just homesteads.
- Review the communications technologies used by various emergency services to ensure standardisation and interoperability.

The Inquiry also made recommendations about boundary fencing and monetary compensation given the fire started in a national park.

From the Coroner's Report:

Weather and fire prediction

- BoM launch weather balloons to assess atmospheric stability in areas experiencing Severe and Catastrophic fire danger days.
- Ensure clarity around limitations and reliability of fire behaviour predictions and that assumptions made in the absence of data are transparent.
- Include a fire behaviour analyst (Fban) in the IMT for Class 3 fires.

Preparedness and response

- Regular meetings between Rural Fire Service (RFS) and landholders / stakeholders during and outside the fire season to share information.
- Better training of Fbans to understand the effects of atmospheric instability on fire behaviour, and in recognising conditions when fires are likely to transition from wind driven, to 'plume driven' (and PyroCb formation).
- Public land managers to engage with neighbouring landholders to jointly deal with fuel hazards and asset protection before the bushfire season commences.
- Consider 'worst case' scenarios in firefighter training and exercises.
- National Parks and Wildlife Service (NPWS) to review its policies and strategies on prescribed burning in light of the potential fire behaviour in long unburnt vegetation.
- Consider greater use of aerial surveillance of Class 1 fires for intelligence gathering.
- NPWS to review its fire weather training.
- NPWS to ensure a plan exists for hazard mitigation and protection of assets within parks.
- Streamline approval process for prescribed burning.
- Better network of fire trails within parks.
- Initial fire response should be for the potential fire conditions, not the currently observed conditions (deploy for worst case scenario based on predictions).
- Review procedures for requesting aerial support for FDR conditions of Severe or worse, to facilitate rapid deployment.

4.3 Case study 3: Dunalley fire, Tasmania, 3 January 2013

Background

Multiple fires started by various causes occurred over the period 3-5 January 2013, burning a total of ~100,000 ha of forest and other bushland, and agricultural land. Losses included 431 buildings (203 dwellings), infrastructure, 662 km of fencing and 10,000 stock. The financial cost, which does not include suppression and recovery costs, was estimated at $100 million. The most damaging of the fires was the ~24,000 ha Forcett-Dunalley fire (the Dunalley fire), so is the focus of the current study.

Weather, fuel, fire behaviour (Forcett-Dunalley fire)
Rainfall in 2012 was average or slightly below average across Tasmania, although for the last three months of 2012 and into January 2013, it was below average. The Soil Dryness Index (SDI) was 143, which was above average for that time of year, indicating dryer than normal fuels (Marsden-Smedley 2014) and the likelihood of 100% of fine surface fuels being available. However, the fires were not preceded by 'drought' conditions *per se* and while there were warm to hot periods during the course of the fire, conditions were not considered 'heat-wave'. Ambient temperature during the peak fire period reached 38.5^{o}C, RH fell to 13% and mean wind speeds reached 35-45 km/h, generating FFDRs of Very High and Extreme. The fire mostly burnt long unburnt forest, although there were some recently burnt patches. Fine fuel loads were mostly 14-15 t/ha, with a minimum diurnal moisture content of 4-6%. These peak surface conditions generated periods of severe fire behaviour, with the development of fast spreading crown fires (rates of spread up to 3.5 km/h), long and short range spotting and severe ember storms. Most dwellings were lost as a result of ember attack. Marsden-Smedley (2014) notes that fire behaviour abated significantly when the fire burnt into patches of recently burnt forest.

4.3.1 Lessons and insights

The 2013 Tasmanian Bushfires Inquiry made 103 recommendations, which, for brevity, I summarise here under the thematic headings used in the report.

Cause and circumstances of the fires
- A recommendation to continue supporting efforts to develop better methods for forecasting and simulating fire risk.
- Measures to reduce the risk of fire starts from the electricity distribution network.

Response
- Need for better records management and information sharing during incidents.
- Need for clarity around roles and responsibilities of the State Controller, and in multi-agency events, of the various agencies –clarifying who is in charge.
- Amendments to the legislation regarding state of emergency declarations.
- Activate the Emergency Management Plan at lower thresholds to practice arrangements.
- Need for integrated communications technology and interoperability in radio comms.
- More timely development and issuing of Incident Action Plans (AIPs), inclusion of people with local knowledge in the IMTs and better integration of local knowledge and volunteer brigades.
- Adopt a proactive approach and an aggressive first attack on fires commensurate with forecast potential fire behaviour rather than current observed behaviour.
- Review approach/standards to mop-up and blackening out.

- Develop better operating procedures for night time operations.
- Review procedures and evaluate the use of fixed wing water bombers including trigger points for activation on high risk days.
- Review emergency traffic management policy.
- Develop a state-level policy on evacuations; decisions on opening refuge centres are to be coordinated with Police.
- Emergency management plans to include means of effectively engaging with local communities and services.
- Discuss with Government, the adequacy of resources to deal with fire emergencies including future needs in a changing world.

Transition to recovery

- Recommendations pertaining to a review of the State Special Emergency Plan – Recovery, and details about what should be considered in the review including rapid damage assessment, rapid repair and functioning of essential services and critical infrastructure.

Community alerts, warnings and information

- The state Emergency Management Plan should include a comprehensive communication policy and plans.
- Predictive modelling of fire spread to identify communities at risk and to develop emergency communications for those communities.
- Warnings are not only issued when fires are 'out of control' but also on initiation.
- Appropriate use of social media as an emergency management communication tool.
- Review approaches to communicating with communities threatened by bushfire to ensure information is timely, accurate and helpful – individuals need to know what action to take.
- Better mobile phone coverage.

Preparation and planning

- Recommendations pertaining to implementation of approved recommendations and lessons from the VBRC.
- Mock exercises, training and development to improve state of readiness of emergency services.
- An accountability process for managing continuous improvement in emergency services.

Managing fire risk

- Recommendations pertaining to accounting for demographic (population) change in assessment of the consequences of climate change on emergency events.
- State Emergency Management Committee (SEMC) to consider structuring the Tasmania Emergency Management Plan so it provides more specific guidance, commitment to and accountability for action to be taken.
- SEMC to determine suitable risk management tools, such as the Bushfire Risk Assessment Model, and encourage their use in assessing bushfire risk in a consistent manner.
- A specific risk prevention and mitigation advisory body be established for the SEMC.

- SEMC consider developing a bushfire hazard reduction program with municipal councils and Tasmania Fire Service.
- Review resources available to Tasmania Parks and Wildlife Service to manage bushfire risk.
- Revise the fire permit system.
- Government should continue to support the Strategic Fuel Management Plan, which must have measurable targets that are monitored and reported.
- Government makes land use planning and building construction to prevent and mitigate bushfire risk, a high priority.
- Develop a bushfire community education and information strategy.
- SEMC to develop a whole-of-government community resilience strategy for emergencies.

Improving emergency management arrangements

- A number of recommendations pertaining to Tasmania Police (TASPOL) – to ensure that emergency management is a priority and a section responsible for developing expertise in emergency management is established.
- The Dept. of Justice to conduct a review to develop a model for integrated and interoperable emergency management.

4.4 Case study 4: Sampson Flat fire, South Australia, 2 January 2015

Background

This fire became the most destructive fire in the Adelaide Hills in 30 years, burning 12,600 hectares of forest/woodlands and agricultural land with losses including 24 homes, 146 other structures, five businesses, livestock and fencing. The damage bill alone was estimated at $13 million. To my knowledge, there was no formal, publicly available review of or inquiry into this fire, so documentation is scarce. However, certain aspects of the fire were investigated by the then Bushfires CRC focusing on community response (Every *et al.* 2016) and by the Australasian Fire Authorities Council (AFAC), which conducted an operational audit of the response of both the Sampson's Flat and Tantoola fires in South Australia (*sensu* Neotics 2016).

Weather, fuels and fire behaviour

Rainfall leading up to the Sampson Flat fire was well below average. Reflecting this, the regional SDI was ~160, which is well above average for that time of year, and approaching peak dryness. This indicates that surface soil, heavy forest fuels including logs and deeper forest/woodland surface fuel profiles were very dry, as was the forest/woodland understorey and bark on standing trees. Grass in paddocks was 100% cured and the McArthur drought index was 10. On 2 January the fire ground was under the influence of a hot, dry airflow from the interior with maximum temperatures ranging from 39° – 43°C and minimum RH from 6-10%, resulting in very dry dead fine fuels. Average wind speeds were in the range 25-35 km/h, peak GFDR was 40-50 (Very High) and peak FFDR (FFDR) was 60-70 (Extreme). The fire mostly burnt in heavy, long unburnt low forest/woodland fuels on hilly terrain, and in cured pasture. At its peak, the fire displayed severe behaviour in the long unburnt bushland and woodlands, with crowning fire and flames up to 30 m, high rates of spread, medium range spotting and at times, heavy ember storms.

4.4.1 Lessons and insights

As mentioned, I was unable to source a comprehensive review or inquiry into this fire, so the following is a paraphrased summary of the recommendations made in the AFAC response audit (*sensu* Neotics 2016).

- Powers for the State Controller to determine operational levels of readiness in some circumstances.
- Triggers in the Chief Officer's standing orders to escalate the State Controller role to rank of Asst. Chief Officer.
- Review how regional resources are managed and tracked and incorporated into the Chief Officer's standing orders.
- Emergency Management Australia's, "Arrangements for interstate assistance" be applied for all future requests for assistance by SA authorities.
- Review nomenclature of personnel and centres consistent with the recommendations of the VBRC.
- Ensure that areas affected by a 'declaration' are clear.
- Increase the number of IMTs to align with the number of regions.
- Plan for one multi-agency Coordination Centre with capacity to deal with all incidents.
- Review Country Fire Service (CFS) operational facilities to provide more effective communications, connectivity and resource management.
- Review procedures to ensure effective communications between IMTs, Regional and State operational centres.
- Regional Controller to be appointed as IC on L3 incidents in the region.
- Review practices of issuing 'emergency alert/warning/watch and act' telephone messages to ensure it is consistent, relevant, and necessary.
- Review current weather, fuel loads and curing to ensure the most appropriate and accurate forecast is prepared, validated and issued.
- Consider the 'Traffic Management' guidelines developed in Tasmania as a model.
- Consider adopting common terminology and capability requirements for strike teams consistent with other jurisdictions.
- Develop an effective inter-agency messaging system and resource management and tracking system.
- Review legislation and regulations to ensure a consistent approach to emergency management to minimise risk of duplication and inconsistencies.

4.5 Case study 5: Pinery fire, South Australia, 25 November 2015

<u>Background</u>
The Pinery fire, which is believed to have been caused by a faulty electric fence, burnt more than 82,500 hectares of mostly cleared/cropped farmland with patches of forest reserves in South Australia's mid-north. Losses amounted to 97 homes, 546 sheds and other structures, 413 vehicles and pieces of farm machinery, 18,600 livestock, 54,000 poultry, $30 million in crops, and thousands of livestock. Insurance claims were ~$172 million (Zimmerman 2017), on top of suppression and other costs. During the fire, two people lost their lives. The SA Country Fire Service (CFS) engaged Noetic Solutions (2016) to prepare a 'lessons learnt' review of the bushfire. The 'Lessons learnt' section of the Pinery

fire recovery final report (Zimmerman 2017) lists 41, detailed recommendations, which are summarised here.

Weather, fuels and fire behaviour

The region experienced record breaking rainfall in the first week of November, resulting in increased grass growth and increased fuel loads. However this was followed by a spell of hot, dry weather with maximum temperatures well above average for this time of year, drying the fuels. Weather conditions on 25 November were extreme with maximum temperatures of 38-41°C, low RHs (~11%) and sustained strong NW winds at 50-60 km/h gusting to 90 km/h. The GFDI peaked in excess of 200 (Catastrophic). These conditions generated extreme fire behaviour in predominantly agricultural grasslands with the fire front reportedly travelling 50 km in 4 hours (mean ROS =12.5 km/h), with up to 10 m flames. With a SE wind change later in the day, the long flank fire became a fast spreading, intense head fire.

4.5.1 Lessons and insights

Incident Management

- Better preparation and training for 'out-of-scale' incidents.
- Predefined clarity of roles and decision-making responsibilities throughout the various structures and agencies involved in incident management.
- Early establishment and 'bedding down' of the incident management structure, including IMTs and higher level structures.
- Early development and sharing of incident action plans enhances effective management of an incident.
- Need to improve the Situation Analysis function as the collection of information, its analysis and dissemination is critical for decision making.
- Incident management facilities and work areas need to be adequate to enable incident managers to operate effectively over a long time.
- Vehicle tracking systems improve personnel safety and incident management.
- The priorities and action plans of the control agency need to be clearly understood by all agencies with a direct or indirect role in emergency management.
- Better firefighter fatigue management.

Public information and warnings

- Timely dissemination of necessary information, and issuing of warnings and actions to be taken, is critical for enabling appropriate community responses. To this end, best use should be made of current understanding of the situation, of fire behaviour and weather predictions, and of various communications media including the mobile phone network and the internet, including social media.

4.6 Case study 6: Waroona fire, Western Australia, 5 January 2016

Figure 3: Two lives and 166 homes lost in the town of Yarloop

Background
Started by lightning, this fire burnt 70,000 ha of forest and farmland. There were two fatalities and 181 buildings destroyed including 166 homes in the township of Yarloop, virtually destroying the town. There was significant damage to public and private infrastructure, rural industries, water catchments and forest and environmental values. The estimated economic cost of the fire was $155 million.

Weather, fuel and fire behaviour
Antecedent conditions were dry, with 2015 rainfall in the region being well below average; BoM records show that rainfall totals were in the lowest 10% on record, consistent with a trend of declining rainfall in the region since the 1970s. While the fire did not occur during a heat wave, 2015 was overall a very warm year with the region experiencing its warmest year on record. The Soil Dryness Index (SDI) was 175, about 30 points above average for that time of year. Maximum temperatures reached 37°C and minimum RH reached 14%. Average wind speeds were 20-30 km/h, gusting to 50 km/h. Peak FFDRs were mostly High or Very High, reaching Severe for a brief period. Dry, heavy, long unburnt forest fuels caused bursts of severe fire behaviour, including sustained crowning fire with rates of spread up to 3.5 km/h, long and short range spotting, PyroCb events and associated lightning. For a brief period in the early evening of 7 January the fire front was turbo-charged by a fast moving parcel of hot, dry air from the interior, which caused the FFDR and fire behaviour to rapidly escalate to Severe for a brief period.

4.6.1 Lessons and insights

Fuel management and fire prevention

- The State to readjust expenditure away from fire response and recovery and towards prevention and hazard (fuel) mitigation.
- Contiguous tracts of heavy, dry forest fuel resulted in severe fire behaviour, preventing the early suppression of this fire and before it reached settlements. This emphasises the importance of adequate levels of landscape fuel hazard reduction as well as the need to manage fuels around settlements and critical infrastructure.
- Need to regularly quantify extent of risk of fuel build-up around communities in order to develop risk-based mitigation programs.
- Need to target hazard reduction on public and private land at the urban-rural interface. The Department of Fire and Emergency Services (DFES) to develop a fast-track hazard reduction burn planning and approvals process to ensure the timely conduct of township and asset protection burns.
- Heavy fuels in road reserves (verges), along irrigation drains, tree lines and other linear features act as 'fuses' or 'fire wicks' frustrating suppression operations and taking fire into communities.
- A massive ember storm originating from patches of long-unburnt forest near the town of Yarloop ignited natural and anthropogenic fuels within the town. Many houses ignited simultaneously from ember attack and many were lost from house-to-house ignitions.
- Fuel hazard mitigation in and around settlements, in road reserves and at the rural-urban interface is complex, risky and costly. Expand the 'Bushfire Mitigation Grant Scheme' using state and federal funds to implement hazard reduction works on these lands. Every community is unique and local government, supported by the state government, is best placed to coordinate these activities.
- Develop guidelines with respect to clearing of vegetation / fuels by landholders from dwellings and other assets.

Incident management

- The State Emergency Management Committee (SEMC) to adopt across all hazards, the doctrine of a) the primacy of life, b) the 'Strategic Control Priorities', and c) community warnings that are timely, tailored and relevant.
- Develop a 'network' of agency personnel who can be called upon for bushfire and emergency incident management capability within Western Australia. The arrangement will be led by the SEMC and modelled on systems used by the Department of Parks and Wildlife (DPAW).
- All L3 multi-agency IMTs will be integrated and pre-formed before the start of the bushfire season.
- In conjunction with AFAC, explore the development of a standardised initial (4 hr) Incident Action Plan (AIP).
- Extending fire behaviour predictions out from time of detection to longer periods will enable better appreciation of fire potential and earlier call on declaring the scale of the incident.
- Better training of ICs on the capabilities and limitations of large air tankers (LATs) and very large air tankers (VLATs).
- Having updated information (maps) on the position of the fire(s) is essential for developing reliable predictions of its spread. This is critical for community warnings and for planning suppression strategies. Need to investigate aerial and satellite intelligence gathering capacity.

- Review procedures to ensure that only vehicles 'fit-for-purpose' are dispatched to fire incidents.
- Incident management structures should include people with local knowledge. This will necessitate providing training for local volunteers to participate in IMTs.

Resource Efficiency

- The SEMC, in consultation with other key stakeholders, establish a system for the voluntary registration of firefighting units, contractor and forestry industry firefighting resources. The purpose is to facilitate the safe, efficient and effective recognition, organisation, deployment, management and coordination of these resources. The systems would include a process for enabling access through traffic management points during bushfires.
- DFES and DPAW to investigate and adopt an emergency services resource management system that will enable better registration, tasking, tracking, management and coordination of personnel and resources.

Information, Alerts and Warnings

- DFES to investigate and adopt a system that will allow the public to opt in, monitor and receive, through a 'push mechanism', bushfire and other emergency warnings, maps and information using a wide variety of devices including personal hand held smart devices.
- SEMC (State Emergency Management Committee) to discuss with local governments the installation of bushfire emergency 'sirens' in fire-prone communities.

Evacuation and Shelter Issues

- Residents advised to evacuate but didn't know where to evacuate to! Need for early and clear instructions re evacuations.
- DFES to work with the Department of Planning and Local Governments to adopt a policy that enables local governments to identify, register and communicate, 'Places of Bushfire Last Resort' in settlements and town sites where the life risk from bushfire is very high.
- DFES develop a policy and guidance on a range of suitable bushfire shelter options.

Traffic Management

- DFES to issue a photo identification card to all *bona fide* personnel involved in firefighting and consider temporary windscreen signage to identify vehicles carrying personnel.
- SEMC to review the policy for traffic management at emergency incidents to reflect national 'best practice'.

Transition to recovery

- Need for rapid damage assessment teams.
- Recovery needs to start early - SEMC to develop an aide-memoire for ICs to guide the initial recovery considerations during an incident.

Rural Fire Capability

- The State Government to create a Rural Fire Service (RFS) to enhance the capability for rural fire management and bushfire risk management.

- SEMC to establish a State Bushfire Coordinating Committee (SBCC) as a sub-committee of SEMC - the SBCC will have the primary responsibility to develop a State Bushfire Management Policy and long term bushfire risk management objectives and advise the SEMC on matters pertaining to bushfire.
- The Department of the Premier and Cabinet to conduct an independent review of the current arrangement for the management and distribution of the Emergency Services Levy.

Under this heading there were also recommendations pertaining to volunteerism (in particular the better integration of local knowledge and volunteers into the incident management structure), occupational health and safety issues, and managing workload and firefighter fatigue. There was also a suggestion to establish a WA Centre for Excellence in rural and forest fire management.

<u>Research issues</u>

- Investigate the causes of, and effects of, PyroCb formation in bushfires.

<u>Other insights</u>

- There are cultural and structural deficiencies in learning lessons from previous incidents.
- "If there was nothing else done but to manage fuels properly in areas vulnerable to bushfire then much of the work of this 'Special Inquiry' would be done". (Ferguson 2016).
- Automatic vehicle location (AVL) capability – "…a very, very good tool".
- Relevant DFES staff need enhanced training in hazard reduction burning, forest and rural fire behaviour, and rural firefighting techniques.
- DFES to implement a volunteer emergency services worker consultation framework.

5. LESSONSAND INSIGHTS: OVERSEAS CASE STUDIES

5.1 Case studies 7 & 8: Canada (Alberta) fires May 2011 and the Wood Buffalo (Horse River) fire May 2016

2011 Alberta fires

Background
Numerous wildfires in British Columbia in 2017 and 2018 burnt an unprecedented (for Canada) ~2.5 million ha of predominantly forest land. There are few available statistics on losses, but the cost is estimated at ~$1 billion. While large areas were burnt, these fires were not considered 'disasters', so to the best of my knowledge, were not the subject of formal reviews or enquiries. However, multiple wildfires in Alberta in 2011 (the Flat Top complex) were considered a 'disaster', and at the time, were the most destructive fires in Canada's history so were the subject of review and inquiry. The Flat Top complex burnt 2.5 million ha, destroyed 510 structures including 491 homes and caused major disruption to oil and gas pipe lines. The insurance losses alone exceeded $700 million (Wildlife Science Document Report 2012) with total costs estimated to be in excess of $1 billion.

Weather, fuels and fire behaviour
Multiple fire outbreaks were preceded by normal to above normal seasonal precipitation. When fires started in spring, the minimum RH reached 15% with maximum temperatures reaching 20°C. Dead fine fuels were dry and grass was 90% cured. Sustained strong winds at 58 km/h gusting to 84 km/h and steep terrain elevated the fire danger, which, in coniferous forests with heavy fuels, resulted in severe fire behaviour, crown fires with rates of spread of 2-6 km/h, extreme ember storms and short and long range spotting.

2016 Wood Buffalo (Horse River) fire

Background
The 2016 Wood Buffalo fire burnt 240,000 ha of mostly forest land, destroyed about 2000 structures and caused the evacuation of 88,000 people. Estimated insurance losses were $3.7 billion and the total economic impact was estimated at $8.9 billion. It was the subject of a number of post-incident reports including by KPMG (2017) and MNP (2017).

Weather, fuels and fire behaviour
The fire was preceded by extremely dry conditions. When the fire started, minimum RH was 20% and maximum temperature was 25°C. Wind speeds were ~20 km/h gusting to 35 km/h. Forest fuels were dry and plentiful.

5.1.1 Lessons and insights – both Canadian case studies

Prevention and preparedness

- The legislative framework for emergency management needs review.
- Develop a disaster resilience strategy.

- Need to enhance wildfire prevention measures including introduction of fire bans, forest area closures, a burn permit system, and aggressively addressing the issue of rising incidence of human-caused fires.
- Empower and support local authorities to take measures to reduce risk at the rural-urban interface and in and around buildings.
- Emergency services to work with local government to develop a structure protection program, including building codes, sprinklers, etc., at the interface.
- Revise the delivery model of the FireSmart program (community awareness and education) to ensure it reaches all those in need and it changes behaviours.
- More needs to be done to reduce fuel loadings in forests, with the priority being near communities.
- Enhance the Community Emergency Management Program, a web-based emergency management planning support platform and application.
- Enhance fire management support for indigenous communities and lands.
- Increase inter-agency training effort, including exercises and training in mock-events.
- Review skill, capability and resource gaps within emergency services in the light of increasing fire potential.
- Bring forward the (seasonal) 'start times' and state of readiness of firefighting resources including crews, equipment and aircraft contracts.
- Develop in-house expanded attack firefighting crews (hot shots) to provide sustained action capability, and which can also be available for prescribed burning.
- Ensure there are sufficient, trained fire behaviour specialists (Fbans)on hand as part of the IMT during and outside events.
- Initiate resource requests in advance of potential demand based on potential fire behaviour, especially in anticipation of extreme fire weather.
- Have in place emergency response plans, mutual assistance agreements, resources and equipment inventories, and training and exercise programs.

Communications

- Emergency services must respond quickly and seamlessly into an emergency response structure.
- Need for regular inter-agency emergency response training and mock exercises to ensure responders have built a relationship, understanding and a communications protocol that will withstand the challenges during an emergency.
- Better training for personnel involved with wildfire community liaison and information communication.
- Issue community fire weather advisories that include information about fire behaviour, and better interpretation, including defining what the warning means and what actions need to be taken.
- Improve dispatch, personnel and resources management and tracking systems.
- Expand communications by fully utilising alternative technologies such as texting and social media.

Incident management

- Clarify and document processes for legislative delegation of authority in the Alberta Emergency Plan.

- Realign wildfire operations to a direct line reporting system to provide clearer responsibilities and authorities (clear chain of command). Eliminate redundant levels of command authority. Chain of command to be composed of trained wildland wildfire professionals.
- Need a common, predefined but flexible incident management structure that enables commanders to delegate responsibilities and manage workloads.
- Establish a standard operating procedure that requires the immediate assignment of a senior, experienced Incident Commander to undertake responsibility for tactical planning for wildfire containment.
- Develop improved procedures for airspace management.
- Have a preformed risk-based framework for setting suppression priorities, resource allocation and other priorities in scenarios of multiple fire outbreaks.
- When there are multiple agencies involved in suppression at the wildland-urban interface, need to establish clear standard operating procedures for the implementation of an Incident Command System and process.
- Need predefined and agreed methods to integrate interagency requirements into the incident management structure.
- Regularly review and benchmark wildfire management strategies, tactics and firefighting priorities.
- Work with Emergency Management to align implementation of the Incident Command System and use IMTs in a consistent model, including training and emergency simulation exercises.
- Incident Command teams must be supported at the local level – having local knowledge and relationships with community and local government is critical in times of emergency.
- Predefine incident interagency resource sharing and mutual assistance agreements.
- Resources should only respond to an incident when requested or when dispatched by an appropriate authority.
- Management by objectives – incident action plans (AIPs) must be developed early and shared in a timely manner. The articulation of a Common Operating Picture (COP) will improve coordination and procedures. Implementation of incident management software can support the development of a COP and enable situational awareness information and other intelligence to be readily shared.
- Formalised (pre-formed) IMTs will improve response effectiveness.

Recovery
- Revise the provincial emergency recovery plan.
- Rapid return of functioning critical infrastructure, utilities and services is critical.
- Provide necessary financial and welfare support to impacted communities.
- Better coordination of government departments.
- Plan for environmental rehabilitation.
- Expand the use of rapid damage assessment technology and processes.

Research and development
- Factors contributing to wildfire threat and structure losses.
- Community urban planning and development including building codes.
- Effectiveness of community education / information programs.
- Public awareness regarding wildfire risk and risk mitigation measures.

- Improved fuel and fire behaviour models and improved prediction of strong wind events.

Other insights

- Expansion of residential and industrial development at the rural-urban interface, together with increasing frequency of severe fire weather, requires an increased focus on risk assessment and the need to make adjustments to preparation, mitigation and response to wildfires.
- An increasing firefighting load caused by climate variability, population growth and land use change requires emergency managers to continually assess their capacity for adequate hazard mitigation and incident response going forward.
- Establish a joint provincial Wildfire Planning Task team comprised of senior personnel from relevant agencies.
- Develop a provincial emergency evacuation plan.
- Enhance communications coverage and interoperability.
- During an incident, operational priorities and wildfire management objectives need to be clear and communicated.
- There must be good coordination between ground and aerial firefighting resources.
- Strong wind, rugged terrain and thick low-level smoke severely restricted the use of aircraft for suppression and made monitoring fires difficult.
- Smoke is a public health concern, so smoke warnings should be issued based on best available modelling.
- Long and short range spotting and ember attack caused rapid expansion of the fire perimeter, and breached community protection barriers, igniting fuels and structures in settlements.
- Fires were also carried into communities by a variety of 'fuel wicks' such as rows of trees, grass along fence lines and fuels along unmaintained driveways.
- Multiple fire outbreaks placed a heavy load on firefighting resources.
- High volume of radio traffic overloaded the comms. system, frustrating suppression operations.
- Reliable fire spread predictions and simulations depend on accurate weather forecasts and fuels data. Upper level winds, which could mix to the surface, need to be included in the forecast.
- More detailed five-day weather forecasts are needed to support 3-5 day fire behaviour projections.
- There is a need to improve connections between weather forecasting and fire behaviour analysts (meteorologist embedded in the incident management structure and in communication with the IMT).
- Expand the Planning Section in the Alberta Wildfire Coordination Centre to provide daily fire behaviour predictions at the commencement of the 'fire season', not just during an incident. This role should also provide briefings on current and forecast weather and fire behaviour conditions with respect to potential wildfire workload, difficulty of control, and resource needs.
- Establish an electronic file sharing system for the distribution of fire behaviour, weather and situation and planning information.
- Need to formalise criteria and operational procedures for de-escalating an incident command structure.

5.2 Case study 9: California fires, October and December 2017

Background

A complex of fires in northern and southern California in October (northern) and December (southern) 2017 burnt more than 500,000 ha, killed 47 people and destroyed some 10,000 structures. Suppression costs were estimated at US$1.8 billion and there were US$12.5 billion of insurance claims. The total economic cost to California including suppression, insurance claims, recovery and aftermath costs such as mudslides and floods, has been estimated at US$18 billion (Allianz California Wildfire Review 2018). I have been unable to source any substantial published formal inquiries or reviews, but Cal Fire's investigation found many fires were caused by the electricity distribution network, prompting a wave of lawsuits.

Weather, fuels and fire behaviour

The fires were preceded by a four year drought (2012-16), followed by well above average rainfall in the 2016/17 winter, which promoted significant vegetation (fuel) growth. The wet winter was followed by an unprecedented long spell of exceptionally warm, dry weather through spring, summer and autumn, with the region recording its second longest dry spell on record (Nauslar *et al.* 2017). Leading up to and during the fires, weather was warm (maximum temperatures in the low 30s) and dry (minimum RH <15%), resulting in very dry fuels. However, it was the persistent, strong foehn winds that created the extreme fire weather with consistent wind speeds of 30-40 km/h gusting to 90 km/h. The fire weather conditions at the time the fires started were forecast several days before. A variety of vegetation/fuel types were involved including forests (north), grasslands and shrublands (chaparral). No detailed fire history or fuel load data are readily available, but much of the vegetation involved was long unburnt on account of suppression policies (Nauslar *et al.* 2017). The wind-driven fires displayed extreme behaviour with crowning fire, high rates of spread, with long range spotting and ember storms being responsible for most of the home loss at the wildland-urban interface.

5.2.1 Lessons and insights

- The fire suppression policy allowed fuel load and fuel hazard in forests to increase, creating the opportunity for fast moving, high intensity fires that were destructive and unstoppable at their peak.
- The effects of fire exclusion in shrublands (chaparral) are mixed and generally weaker, with fire behaviour dominated by fire weather conditions, especially wind speed.
- The increased extent of fire in mesic (wet, flammability-limited) forests is due in part to changed climatic conditions, which are causing these forests to become dryer and flammable more frequently.
- The unexpected severe fire weather conditions occurring near populated regions, poor wildfire preparedness by the communities, and poor evacuation protocols contributed to the impacts.
- The cost and damage of wildfires is increasing due to an expanding wildland-urban interface, a legacy of suppression and fire exclusion and subsequent fuel build-up, and climate variability, increasing the frequency and severity of weather conditions favourable for severe fires.

- Emergency management and city planners must consider planning for extreme fire events beyond those observed or modelled using 90th or 99th percentile observed meteorological conditions.

5.3 Case study 10: Chile fires, February 2017

Background

Multiple fire outbreaks resulted in an unprecedented ~600,000 ha being burnt most of which was native forests and plantations, but also included prairie (grasslands) and agricultural land. Eleven people died, more than 1500 homes destroyed, more than 7000 people were dislocated, and critical infrastructure such as water and sanitation services were damaged. Costs have been conservatively estimated at more than US$330 million.

Weather, fuels, fire behaviour

Fires were preceded by drought. Fire weather conditions were characterised as 'exceptional' (Dunstall *et al*. 2017). Record high temperatures (maximum temperatures 40°C - heat wave conditions), low humidity, dry fuel and strong winds resulted in extreme fire behaviour. Fuels were mostly abundant flammable forests and plantations, many of which were established on abandoned agricultural land with little regard for fire protection measures including fuel hazard mitigation, firebreaks, water points and fire lookouts. There are no documented quantitative measures of fire behaviour but it has been described as extreme, crown fires, long and short range spotting and heavy ember storms, the latter being largely responsible for house loss.

5.3.1 Lessons and insights

- After climate (and weather), landscape composition of the vegetation / fuels was the most important driver of large fires.
- Fuels in forests / plantations need to be proactively managed.
- Plantations were too close to settlements, which were destroyed by ember storms.
- Fire services were poorly prepared at many levels for such an event and were overpowered and overwhelmed.
- VLAT (US Boeing 747 supertanker) was ineffective in mountainous terrain, strong winds, low thick smoke and at night.
- Modelling suggest that if a fixed wing and a helicopter, accompanied by ground crews, can aggressively attack a fire within 20 minutes of ignition, there is a high probability the fire will be contained (Dunstall *et al.* 2017).
- Modelling suggests that a fleet of 13 fixed wing and 13 helicopters, with ground support, should enable the suppression of multiple fire outbreaks under most conditions (Dunstall *et al*. 2017).
- Chilean Government has launched an investigation into the cause of the fires and whether the response was adequate. (Author's note: Should also review community preparedness, forest fuel management, and recovery plans).

5.4 Case studies 11 & 12: Greece fires, August 2017 and July 2018

2007 Greece fires

Background
Multiple fires burnt ~270,000 ha of forest, agricultural land and settlements. Seventy eight people lost their lives, 3144 structures including more than 1000 homes were destroyed, as was considerable critical infrastructure. Industries such as agriculture were severely impacted with 1.5 million olive trees and 60,000 head of stock destroyed. Total cost is estimated at $4.8 billion.

Weather, fuels, fire behaviour
Drought and heatwave conditions were experienced leading up to and during the fires, with maximum temperatures to 40°C, minimum RH <20% and wind speed averaging 20-30 km/h, gusting to 50 km/h. The Fire Danger Rating was High to Very High (Canadian Fire Weather Index system) and multiple fire outbreaks (June, July, August), overwhelmed suppression forces – there was a heavy reliance on suppression, including water bombers, rather than hazard mitigation. Fire behaviour was extreme, and, as with all case studies, fires were only brought under control when they ran out of fuel or the weather improved.

2018 Greece Fires

Background
Burnt ~1300 ha of forest, shrublands and agricultural land, 100 deaths, hundreds injured 1220 buildings and 305 vehicles destroyed, damage to critical infrastructure – transport corridors, power grid, telecommunications, water supply, substantial damage to industries such as agriculture and forestry, community and economic disruption, loss of ecosystem services. Total cost is estimated at $200 million, which is likely significantly underestimated.

Weather, fuels, fire behaviour
The fire was preceded by below average winter rainfall and heat wave conditions. On the day of the fire, winds were 60 km/h gusting 100 km/h, maximum temperature was 37°C, low RH, dry fuels and an FDI of Severe (Canadian FWI system). The fire burnt in forests, woodlands and grasslands, and shrublands intermixed with settlements. Fire behaviour was most severe in long unburnt forests and noticeably less severe in patches of forest and other vegetation that had been burnt by previous smaller wildfires. The fire followed vegetation corridors through settlements. Fire behaviour was severe, with the fire crowning through forests, average rates of spread of 3-4 km/h, with long and short range spotting and ember storms.

5.4.1 Lessons and insights – both Greece case studies

Fuel management and hazard mitigation

- Primary causal factors were drought, heatwave and flammable vegetation / fuels as a result of abandonment of rural areas, reduced grazing in forests, decline in active forest and fuel management, weakening of the forest service, reduced capability of citizens to manage fuel on their land, lack of regulations requiring fuel hazard management at all scales - severe, crown fire, long range spotting and ember storms caused destruction in settled areas by igniting natural and anthropogenic fuels, and dwellings.

Preparedness

- Emergency services and the community were poorly prepared, including:

- Lack of appreciation of the wildfire threat / risk at the rural-urban interface;
- Forest fire management was transferred from the Forest Service to the Fire Service, who lack landscape fire management expertise.
- Lack of a coordinated, cooperative approach to landscape fire management planning among the agencies involved.
- Lack of coordination and operational readiness.
- Lack of coordination in prevention measures.
- Lack of a unified, coherent national landscape fire protection plan.
- Absence of approved, documented regional fire management plans.
- Lack of an integrated approach to landscape fuel management including prescribed burning.
- Political 'interference' that is not evidenced-based.
- Lack of professional and appropriately trained staff to undertake landscape fire management and firefighting roles.
- Poorly regulated and poorly planned settlement at the urban-wildland interface.
- Low level of information sharing and cooperation between agencies.
- Poor data management systems, including spatial data.
- Inadequate, outdated equipment.
- Poor fire history / fuels data that could guide actions such as risk assessment and hazard mitigation.
- Poor uptake of modern technology and science to support planning and operations.
- Limited public information and fire awareness.
- Inadequate public warning system.
- No evacuation plans, escape routes or fire refuges.
- Loss of rural fire knowledge and rural fire fighting techniques.
- Inadequate knowledge and lack of appreciation of the emerging hazardous condition of forest fuels.
- Increased and unplanned settlement / population growth at the rural-urban fringe.
- Poor building construction.
- Lack of fuel hazard mitigation regulation near structures at the interface.

<u>Response</u>

- o Poor coordination during suppression operations.
- o Lack of interoperability between agencies.
- o Too greater reliance on suppression and inadequate level of funds and effort allocated to hazard mitigation and fire prevention. Increased funding allocated to suppression over the last 20 years has not resulted in a proportionate increase in effectiveness of suppression operations.
- o Reliance on costly aerial suppression without recognising a) limitations and b) how to integrate it with ground suppression strategies.
- o Inappropriate application of urban firefighting tactics in rural landscapes, e.g., lack of use of indirect attack tactics such as back burning, commencing operations at the back of the fire and progressing forward, and machines to track fires.
- o Under estimated the potential fire behaviour so not aggressive enough on initial attack.
- o Ineffective organisation of volunteers.

5.5 Case study 13: Portugal fires, October 2017

Background
Multiple fires burnt 240,000 ha of mostly forest. The fires killed 67 people, destroyed 1712 homes, impacted on the infrastructure of 768 businesses including public utilities and essential services, 4500 jobs were affected and it cost an estimated $412 million (conservative). The fires were controlled when weather conditions abated.

Weather, fuels, fire behaviour
The fires occurred during a period of severe drought accompanied by strong winds, high temperatures and low RHs, resulting in a FDR of Extreme. Fine fuel moisture contents were very low (3-6%) and the fires mostly burnt in forests with very high fuel loads. Together with unstable atmospheric conditions (high c-Haines), the fires displayed extreme fire behaviour including sustained crown fires, maximum rates of spread of 3-6 km/h, long and short range spotting and heavy ember storms. At times, and deriving energy from the heavy forest fuels, fires transitioned from wind-driven to plume-driven with associated PyroCb events. This generated severe fire behaviour as a result of downdrafts, even though ambient wind speeds had abated. Some fires were 'greatly constrained' by a previously burnt area, but such areas were rare and spatially inadequate to have any effect on the unfolding disaster.

5.5.1 Lessons and insights

Risk assessment and fire danger ratings
- Assessment of rural fire risk should be based on routine assessment of fuels in relation to assets and communities.
- Fire danger ratings (FDR) to be based on fire weather criteria and be developed at appropriate spatial scales.
- As well as a basis for issuing public warnings, including clear advice on what the public needs to do, fire danger ratings should guide levels of fire surveillance (detection) and suppression readiness, and the imposition of total fire bans.
- FDR system also needs to be linked to expected fire behaviour, especially potential fire severity based on fire intensity (kW/m).
- Consider using six fire severity categories based on predicted fire intensity to characterise a fire's damage / house loss potential and suppression difficulty.
- The fire danger rating system to be expanded to include a category 'Catastrophic' (as per Australian FDR).
- Weather forecasts need to include the possibility of fires transitioning to 'plume driven' and formation of PyroCb (based on expected fire behaviour and atmospheric stability – c-Haines Index).
- Fire danger forecasting to include some weighting, or interpretation of the civil risk or danger based on factors characterising levels of community preparedness and resilience.

Fuel hazard management
- Heavy forest fuels were a significant factor contributing to the severity of the fires, their damage extent and suppression difficulty.

- Need to re-build expertise and capacity in forest fire and fuel management to mitigate the potential of megafires and of plume driven (PyroCb events) fires.
- Landscape-scale fuel management is essential to limit the development of megafires that breach community barriers - fire suppression alone is not the answer.
- The cause of ignition of structures was mostly spotting and ember attack so creating narrow buffers around settlements had limited benefit – more effort should be directed towards the mitigation of fire behaviour in the landscape.
- Lowering the intensity of landscape fires by reducing fuel loads or altering fuel structures will improve the effectiveness of buffers and other preparedness measures.
- Expand forest landscape fuel reduction programs to at least 5% of the area burnt per annum. (Author's note: I suspect the 5% figure was adopted from the VBRC recommendation. It's too low – in forested landscapes, need to strategically burn at least 8% per annum to be effective – see case study 1).
- Low fuel condition 'buys' time (fires burn slower, lower intensity, less spotting and ember attack), increasing the likelihood of early suppression success.
- Heavy roadside fuels entrapped people – almost all deaths were people trying to escape the fires by car.
- Better urban planning rules to minimise mixing communities with flammable vegetation ("resilient villages").
- Increasing the resistance of structures to the impact of embers, and removing fuel in the immediate vicinity of the structures.

Incident management and community warnings

- Need for restructuring of government departments and re-allocation of budgets including re-structuring of the Fire Department and re-defining its mission, including building a professional organisation with better training and career opportunities.
- Rebuild the capacity of the Forest Service to manage forest fuels and fire.
- Need for a centralised agency responsible for, and adept at, integrated forest and rural fire management.
- Current forest and municipal fire protection plans and planning process were absent or totally inadequate or inoperable.
- Need to pay greater attention to the most vulnerable areas, being the rural and rural-urban interface areas.
- Build the capacity (training, equipment, funding) of local municipalities to better respond to fire emergencies including the recovery phase.
- Better preparedness procedures of emergency services on Severe or worse fire danger rating days.
- Under Severe or worse FDR, early detection and rapid response at a level appropriate to the potential fire behaviour, not current fire behaviour, is essential. In heavy fuels, if fires are not suppressed within the first 20 minutes, then they are unlikely to be suppressed for days.
- Better location and resourcing of 'Command Posts' to enable more effective suppression management.
- Better communication systems and comms plan – comms systems lacked interoperability and collapsed under load.
- With different organizational cultures involved in the emergency, it is necessary to have a clear, disciplined and recognized leadership

framework with clear definitions of the responsibilities and functions of the various agencies.
- Use decision support technologies for assimilating large amounts of complex information in a dynamic environment.
- Better support, training and integration of volunteers.
- Multiple fire outbreaks overwhelmed the capacity of emergency services – need a system for rapidly prioritising which fires are to be attacked.
- Timely, accurate information and communication around alerts and warnings, including clear messaging about how the community should respond.
- Revise the policy of compulsory evacuations – some citizens were capable of defending their homes, but lost their homes because they were evacuated.

Other
- Medical systems were unable to cope with the large number of burns victims.
- Better trained and equipped search and rescue teams.
- Invest in upgrading the economic base and infrastructure in rural areas to increase their resilience to fire and other natural disasters.
- Expansion of fire research and generation and dissemination of science-based knowledge to;
    - better understand changing climate,
    - investigate ways of combating forest fires under adverse weather conditions,
    - improve fuel management including in forests and at the urban interface,
    - improve post-fire damage assessment and restoration of environmental values and services,
    - to create landscapes that are more fire resilient and less flammable,
    - develop risk management and real time decision support systems.

6. CONCLUDING DISCUSSION

Since European settlement, Australia has a history of bushfire disasters, many of which have been the subject of formal inquiries, including Royal Commissions. While we have learnt from these disasters, and our equipment, training, preparedness and response to bushfires has improved over time, many recommendations made in early enquiries such as Royal Commissions into the 1939 Victorian Bushfires and the 1961 Western Australian bushfires, reappear, variously worded, in recent inquires suggesting some lessons have not been learnt. Continuous improvement in an adaptive management framework comes in large part from learning by doing, and by learning from the experiences of others, but it also requires foresight – imagining what the future fire and emergency management landscape looks like. The fire disaster case studies reviewed and summarised here provide a rich opportunity to gain valuable insights and lessons from the experiences of others. If we are unable or unwilling to learn, that is, to adjust policies and procedures in response to these lessons, then the devastation wrought by these historical fires will have been in vain, and the bushfire cycle will continue. In some cases this will require increased investment, but in other cases it will require doing things differently with existing resources.

In terms of their value and importance to QFES and IGEM, the numerous experiences, insights and lessons gleaned from the case studies reported here fall into several categories. Firstly, because of biophysical, socio-economic and cultural differences, not all will be relevant to Queensland. Secondly, many will be redundant in that they are well known by Queensland authorities (e.g. QFES 2019), however, they serve to reaffirm policies and procedures. The third category will be insights and lessons that are of relevance and of interest to Queensland authorities and could be incorporated into their doctrine. Not being sufficiently familiar with the policies and procedures of Queensland emergency services, it is not for me to so categorise the numerous lessons from these case studies.

While there are numerous learnings and insights detailed above, some of the key broad lessons and common themes are summarized in Table 2.

Phase of wildfire management	Key lessons and insights
Prevention and mitigation	➢ Adequate fuel hazard reduction at all scales ➢ Maintenance of the electricity distribution network ➢ Community education and information ➢ Up-to-date bushfire law and enforcement capability
Preparedness	➢ Maintaining an adequate fire response capability in response to climate change, population growth and land use change ➢ Setting levels of preparedness based on indicators of drought and forecast fire danger ➢ A state-wide bushfire policy that, in a risk-based framework, addresses regional hazard mitigation strategies ➢ Appropriate urban development planning and building codes in fire prone environments ➢ Educated, informed and aware communities
Response	➢ A state-wide bushfire policy that, in a risk-based framework, addresses regional emergency response arrangements ➢ A capacity for rapid detection and resource deployment based on potential fire behaviour ➢ Rapid set-up of functioning, clearly tasked, capably led incident management structures ➢ A resource management system to register, task, track, coordinate and manage resources ➢ Augmented intelligence systems to rapidly gather and process information to assist decision-making in an information-rich, dynamic environment
Recovery	➢ State and regional recovery plans in place ➢ Seamless transition from response to recovery ➢ Rapid damage assessment teams ➢ Involvement of local government is critical ➢ Timey restoration of critical infrastructure and essential services

Table 2: A summary of some key lessons and common themes to emerge from the case studies

At a greater level of detail than presented in Table 2, common emergent lessons and insights include:

<u>*Climate variability hazard*</u>
In almost all case studies, the fire disasters were preceded by drought and heat wave – in some cases, of unprecedented severity. As discussed in the

introduction to this Work Package, global climate change is now well accepted by fire and land management agencies. Having adequate early warning systems (EWS) in place is the key to implementing adequate mitigation and preparedness measures (UNISDR 2006). Other than offering general climate outlooks based on the El Nino-Southern Oscillation (ENSO) and Indian Ocean Dipole (which are very useful), it is not yet possible to reliably and accurately predict the timing, spatial dimension and severity of drought.

Science-based systems for monitoring regional build-up and trends in seasonal dryness of fuels, such as the Keetch-Byram Drought Index (KBDI) (sub-tropical climates) and the Soil Dryness Index (SDI) (temperate climates) are effective ways of estimating seasonal moisture deficiency and 'drought' in bushland fuel complexes. More recently, remote sensing (satellite) is being used to map virtual real-time grassland curing, and sophisticated models, such as the BoMs Australian Water Resources Assessment Landscape model (AWRA) (Frost *et al*. 2018) provide daily, fine-scale (0.05° grid) estimates of soil moisture balance. In addition to effective drought monitoring systems that generate index values or maps, it is essential that this information is turned into useful intelligence. This includes calibrating drought monitoring systems to convey information about the moisture deficit or status of broad vegetation / fuel complexes at regional and local scales. With climate variability, historical patterns of seasonal drying and wetting cannot be relied upon. Drought indices can alert agencies and the broader community to temporal and spatial anomalies, which can be useful for planning hazard mitigation measures such as prescribed burning, and setting levels of preparedness for the impending fire season. As well as temporal anomalies, calibrated drought indices can provide early warning of the moisture status of historically mesic vegetation types such as rainforests, which, as a consequence of climate variability, are now periodically drying and burning. It is important that drought build-up information is disseminated and communicated in a timely manner to inform decisions about the regional and local levels of preparedness of fire and emergency services and communities.

Fuel hazard reduction
It is neither feasible nor desirable to eliminate fuels (live and dead vegetation), but it is critical that fuels in landscapes, at the urban fringe, and in 'backyards' (adjacent to structures), are reduced on all land tenures. In all case studies, continuous and heavy fuel loads, especially in forests / bushland, was a significant factor in suppression difficulty and extent of fire damage. Established fires burning in heavy fuels under fire danger ratings of Very High or worse, were unstoppable and destructive because of their speed, intensity, spotting potential and density of ember storm. Many high energy fires transitioned from surface, wind driven fires to very dangerous 'plume driven' fires generating PyroCb (thunderstorm) cloud formations. The spatial and temporal extent of fuel reduction in the three spatial units referred to will depend on many factors including the structure of the vegetation and the rate at which it re-accumulates after fire. Fuel hazard mitigation programs must be guided by a risk-based approach, be strategic and be done to a high standard.

Landscape prescribed burning is not a 'panacea', but it is the cornerstone to managing the bushfire threat. I reject the dangerous conclusions of recently published computer simulations that to be effective, at least 25% of the region must be prescribed burnt each year. These theoretical studies have many shortcomings, including flawed, unvalidated assumptions and a lack of appreciation of the complexities and nuances of operational prescribed burning and fire suppression (Burrows 2018). It is beyond the scope of this Work Package to discuss the features and benefits of a properly implemented landscape prescribed burning program, but there is ample scientific and experiential evidence from Australia and overseas that, done to a standard and at the appropriate spatial and temporal scales, it is cost-effective, greatly assists suppression operations and greatly synergises other threat mitigation and community preparedness measures, most of which collapse beyond relatively low fire intensity thresholds.

The case studies have demonstrated that in dry, heavy forest / bushland fuels and under severe fire weather conditions, fires will become very large if they are not suppressed within a very short time after ignition. The case studies also demonstrate that suppression, community protection barriers and other measures of preparedness fail when challenged by large, fast spreading, high intensity landscape fires. A reliance on suppression alone, including the deployment of aircraft, will likely fail under severe weather and heavy fuel conditions, especially when there are multiple synchronous outbreaks. Therefore, it is critical to get the right balance between expenditure on hazard mitigation and suppression capability. There are a number of risk-based frameworks available to assist with this decision making process (e.g., DELWP 2015; Daniels *et al*. in press).

Community risk assessment

It is essential to understand the geo-spatial bushfire risk to communities and other critical assets to inform communities, to inform planning and prioritising risk mitigation measures, and to up-date incident response plans. This requires a centralised responsibility to generate up-to-date maps of the juxta-position of the fuel hazard and assets at risk, especially at the convoluted, often complex, rural-urban interface. Linked to this is the need for better processes for addressing bushfire risk at the planning stage for new urban developments and small undeveloped rural lots including restricting developments in high bushfire-risk areas. All new buildings in bushfire-prone areas should comply with modern building codes to ensure they incorporate reducing the risk of ignition from ember attack. Advice should be provided on how to 'harden' existing buildings, and training and education provided to improve bushfire risk management in the building and planning sectors.

Issuing of warnings

Timely (early) assessment, dissemination and communication of public warnings is critical for informing and preparing communities. Using a variety of media including social media, warnings must reach all those at risk, and should be issued in such a way that they are clearly understood and the community knows what to do. Warnings will usually be based on fire spread predictions and weather forecasts, so having reliable models to do this in a timely manner is clearly important. Linked with this is the need to provide, or identify community refuges, have in place sound and well communicated evacuation plans, and the need for better community bushfire safety education programs.

Incident response

From the case studies, there are numerous insights and lessons for fire and emergency services and the broader community on preparedness and incident response. Some re-occurring themes include;

- the need for a pre-incident emergency response plan(s), on-going training of personnel, and regular multi-agency training and mock exercises for L3 incidents;
- clarity of authority, roles and functions within and between emergency services agencies, state-level emergency structures, local government and relevant Ministers;
- clarity around the roles of state and regional operations centres and how they interact with each other, with IMTs and with local government;
- developing and training multi-agency pre-formed IMTs;
- ensuring that a 'common operating picture' (COP) is defined and communicated;
- the need to improve the flow of information within IMTs, and between IMTs and the various state and regional operations centres;
- better integration of local rural knowledge and of volunteer brigades;
- Incident Action Plans (IAPs) should be developed within the first few hours of an incident and be made available to state and regional operations centres;
- training, accreditation and performance reviews of L3 ICs; a succession plan for L3 ICs;
- better preparedness / readiness arrangements on FDR days of Severe or worse;
- integrated communications technology and interoperability;
- a coordinated, aggressive initial attack using aerial and ground resources based on forecast rather than current fire weather conditions;
- better augmented intelligence systems to assist decision makers manage the barrage of data associated with major fire incidents;
- emergency services can be quickly overwhelmed by multiple fire outbreaks under severe weather conditions, so need a rapid risk-based system for prioritising which fires will be attacked and which assets will be defended if early suppression of all fires is not feasible;
- urban firefighting techniques in rural landscapes will fail on severe fires;
- review procedures and evaluate the use of water bombers including trigger points for activation on high risk days; water bombers without ground crew support will likely be ineffective on all except small developing fires or low intensity fires;
- review emergency traffic management policy;
- develop a state-level policy on evacuations.

Recovery

Few case studies dealt with the recovery phase to any detail but those that did emphasised having policies, plans and structures in place that mostly focusses on restoring essential services and critical infrastructure as quickly possible and rapid deployment of damage assessment teams. Local government, supported by state and federal governments, has a key role in recovery.

Research and development

There is a universal need to better understand the effects of climate change on regional fire-proneness. Linked with this is the need for an expansion of, and improvement in, fuel and fire behaviour models. There is a need to better understand the mechanisms of the transition from surface or wind driven fire to 'plume driven' fire, and the development of PyroCb events. An improved drought prediction capability would provide earlier warning of the impending fire season, and an ability to predict strong wind events would enhance preparedness. Augmented intelligence systems to assist decision makers during complex and dynamic emergency incidents would be of great benefit. Considerable resources are expended on community education and awareness programs so an evaluation of the effectiveness of these programs would be instructive. Evidence-based risk frameworks would be of great benefit for identifying and prioritising fuel hazard mitigation measures.

To conclude, the following insight from Ferguson (2016):

"There is little value in organising for the last 'war'. How do we create an organisation that will maximise our readiness for the next extreme event? How do we prepare for something that might be beyond our imagination? The focus must be on using foresight and imagination to anticipate what the future risks might be, and what organisational structure might best fit that future. Labelling the fire as an 'out of scale' event should not be an excuse or an explanation for any shortcomings that occurred. Is it not part of the role of fire and emergency managers to plan for and be ready for extreme and 'out of scale' events? When plans have a reliance on what happened in the past, the risk is one misses the potential for a future that is different, unseen and unimaginable.

Hindsight, learning the lessons from the past, is necessary but planning should also be driven by imagination and foresight. We all need to be driven by a future that is volatile, complex, uncertain and ambiguous. If everyone feels uncomfortable, then there is less chance of complacency. Organisational characteristics that are more likely to be effective on 'out of scale' events include:

- *Distributed leadership*
- *Connected and empowered communities*
- *A culture of inquiry and imagination*
- *Flexibility, agility and adaptiveness*
- *Thinking and acting with humility.*

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