



Government of **Western Australia**
State Emergency Management Committee

Western Australia's Natural Hazards Risk Profile 2017

Executive Summary

This document follows on from the initial assessment of Western Australia's seven sudden onset natural hazards in 2013. This iteration fulfils the State's obligations under the National Partnership Agreement (NPA) on Natural Disaster Resilience and presents the results of the updated state-level risk assessment of its natural hazards – bushfire, cyclone, earthquake, heatwave, flood, storm, and tsunami.

In 2013, the SEMC coordinated the first risk assessment workshop series to analyse the risks from these same hazards using the 2010 National Emergency Risk Assessment Guidelines (NERAG). While there are some similarities, the results of the two series vary. These variances are primarily due to the different criteria and methodology used, and notably, a greater maturity of our understanding of risk.

Among the high risks that have remained constant across the two assessments are the impact of heatwave to people's health and the effect of flooding on the state's economy. Widespread flooding is expected to result in longer-term disruption to transport networks and resource sector operations, potentially slowing the State's productive capacity.

Workshops with stakeholders were held in May and June 2017 to determine the risks posed to the state's economy, its people, public administration, environment and community. The approach used credible worst case scenarios and follows the ISO 31000:2009 standard and the methodology outlined in the NERAG 2015.

A total of 435 risks were assessed for the seven hazards. Of the risk statements assessed, there are no extreme risks, 4.6% are high, 18.9% are medium, 50.3% are low and 26.2% are very low. The bushfire, heatwave and storm scenarios are dominated by low risks and cyclone and tsunami by low and very low risks. While the majority (50.5%) of the risks have been assessed as low, each hazard does have some high risks, with earthquake and flood having the greatest number.

Of the 20 high risks identified, there are nine statements (2% of all statements) that have catastrophic consequences which relate to the earthquake, storm and tsunami scenarios. These are consequences that have the potential to strain or outstrip the State's resources. Table 1 lists these 20 statements, their consequence and the area that they impact. The hazard with the greatest number of high risks (6), all having catastrophic consequences, is earthquake.

The results have been analysed and themed across nine different facets: agency core service delivery; agriculture; built environment; business and industry; community wellbeing; environment; health; transport and utilities.

Agriculture, community wellbeing and environment risks were assessed as low and very low, with a few medium risks. In most cases, it was expected that the likely

impacts would be localised or that existing resources would be sufficient to return the community to normal.

The highest risks for transportation come from the damage to aviation infrastructure from the storm scenario and the disruption to transportation routes from the flood scenario. No hazard scenarios were assessed as posing an extreme or high risk to utilities. Power supply infrastructure and services are most at risk of all of the utilities.

The greatest risks to government services stem from the bushfire, earthquake and flood scenarios. The impact to Department of Fire and Emergency Services (DFES) and Parks and Wildlife (P&W) from the bushfire scenario could result in these agencies having to temporarily halt some core services, with the majority of their organisations focused on responding to the event. The volume of displacement anticipated in the earthquake scenario would result in the Department for Child Protection and Family Support (CPFS), who are responsible for welfare support, being unable to deliver their core services in the short to midterm when dealing with the anticipated volume of displacement expected. A critical issue would be the sourcing of appropriate evacuation centres. The impact on local governments from state wide flooding was assessed as a high risk as their ability to maintain core services would be severely reduced due to the focus on recovery.

The highest risks to the built environment are expected to come from the earthquake and tsunami scenarios. The earthquake is likely to cause catastrophic damage to private and commercial buildings. Modelling by Geoscience Australia indicates the potential for 30% of private buildings in the Perth area to sustain moderate to complete damage. Similarly, the tsunami scenario is anticipated to cause catastrophic impacts to commercial buildings, particularly those associated with marinas and ports. High risks to commercial buildings are also expected from the storm and flood scenarios from hail damage and inundation (\$1 - 10 billion losses).

The greatest risks to people's health are from the deaths, injuries and illnesses directly attributable to the hazard scenarios. All seven natural hazards have the potential to result in deaths, with earthquake, heatwave and tsunami anticipated to lead to the greatest number of deaths. The earthquake scenario could result in catastrophic consequences, estimated as having a 50% chance of at least 263 deaths. Heatwave and tsunami were expected to result in at least 27 deaths.

The greatest impacts to commercial activities stem from the earthquake, flood and tsunami scenarios. Earthquake and tsunami scenarios were assessed to have catastrophic economic consequences for the state of greater than \$9.5 billion in losses. As a result of the earthquake, damaged buildings that contained asbestos or buildings that could collapse, would likely have a cordon around them for health and safety reasons. These cordons could restrict access to nearby businesses impacting commercial activities. The tsunami scenario would result in a number of businesses along the whole WA coastline requiring remediation of building interiors, during which

they would likely need to close. Impacts to the mining industry from the cyclone scenario were assessed as a high risk, with losses stemming from the costs associated with ships remaining anchored offshore during the event and the need to evacuate approximately 1500 people from Barrow Island.

As our collective understanding of risk has improved over the last four years, the 2017 assessments provide a substantially more robust and advanced picture of the State's risk profile than the 2013 assessment. Changes in the workshop format and methodology have provided a balanced view of risk. Combined with a greater appreciation of the scale of the assessment, this has changed is how the impacts are perceived. An additional factor may be that there have been a few relatively large emergency events in WA in the last four years, which have shown that the credible worst-case scenarios are, in fact, credible.

Hazard	Risk Statement*	Impact Area	Consequence	Risk Level	Confidence Level	Priority
Earthquake	will impact the health of people and cause death(s).	People	Catastrophic	High	Low	2
Earthquake	will impact the health of people and cause injury and/or serious illness.	People	Catastrophic	High	High	3
Earthquake	will impact commercial buildings and contents, resulting in financial losses.	Economy	Catastrophic	High	Moderate	2
Earthquake	will disrupt business activities, resulting in financial losses.	Economy	Catastrophic	High	Low	2
Earthquake	will impact private buildings and contents, resulting in financial losses.	Economy	Catastrophic	High	High	3
Earthquake	will impact CPFS, impacting their ability to maintain core services.	Public Administration	Catastrophic	High	High	3
Tsunami	will impact commercial buildings and contents, resulting in financial losses.	Economy	Catastrophic	High	Low	2
Tsunami	will disrupt business activities, resulting in financial losses.	Economy	Catastrophic	High	Lowest	2
Storm	will impact the aviation sector (e.g. damage to infrastructure, disruption to services), resulting in recovery costs and/or financial losses.	Economy	Catastrophic	High	Moderate	2
Storm	will impact commercial buildings and contents, resulting in financial losses.	Economy	Major	High	Low	2
Cyclone	will impact natural resource industries (mining, oil, gas) infrastructure and/or operations, resulting in a lack of production, recovery costs and/or financial losses.	Economy	Major	High	Low	2
Bushfire	will impact DFES services, impacting their ability to maintain core services.	Public Administration	Major	High	High	2
Bushfire	will impact on Parks & Wildlife services, impacting their ability to maintain core services.	Public Administration	Major	High	High	2
Flood	will impact commercial buildings, contents and services, resulting in financial losses.	Economy	Major	High	Low	2
Flood	will disrupt business activities, resulting in financial losses.	Economy	Major	High	Low	2
Flood	will disrupt major freight routes, resulting in financial losses.	Economy	Major	High	High	3
Flood	will impact DFES services, impacting their ability to maintain core services.	Public Administration	Major	High	Moderate	2
Flood	will require recovery works to be undertaken by Local Governments, impacting their ability to deliver core services.	Public Administration	Major	High	Moderate	2
Heatwave	will impact the health of people and cause injury and/or serious illness.	People	Major	High	Moderate	2
Heatwave	will impact the health of people and cause death(s).	People	Major	High	High	3

*As the workshops took place before 1 July 2017 when some WA government departments were amalgamated, the agencies are referred to by their name prior to this date.

1 Introduction

This report presents Western Australia's (WA) second iteration of a state-level risk assessment of its seven sudden onset natural hazards – storm, earthquake, bushfire, tsunami, heatwave, cyclone and flood.

The risks from these seven hazards have been analysed by their impacts to the state's economy, its people, public administration, the environment and the social setting. The approach used follows the ISO 31000:2009 standard and the methodology outlined in the National Emergency Risk Assessment Guidelines (NERAG) 2015.

All hazards were assessed within a workshop setting in Perth (see Table 1 for schedule) and used a credible worst-case hazard scenario developed by relevant hazard experts. Credible worst-case scenarios are chosen with the rationale that planning and risk reduction activities for the largest event will address impacts of smaller events, even if the smaller events are more frequent.

During each workshop relevant experts presented the hazard context, the anticipated vulnerabilities and impacts, and described the scenario. Following this, as a group, the participants worked through a series of risk statements to estimate the potential consequences of the scenario event. Each risk statement describes an impact that is likely to eventuate given the scenario and is collectively assigned a likelihood, consequence and confidence level using the *NERAG 2015* criteria. Discussion was encouraged among participants to explore different aspects of the hazards and impacts. Decisions were based on group consensus. Risk statements are grouped into five impact areas: economy; people; public administration; social setting; and environment with approximately 60 risk statements assessed per hazard. Data were captured and analysed following the workshop. The results are presented in this report.

A range of agencies attended the workshops and contributed to the assessment. A list of agencies involved can be found in Appendix A. As the workshops took place before 1 July 2017 when some WA government departments were amalgamated, the agencies are referred to by their name prior to this date.

Table 1: Dates of risk assessment workshops.

Hazard	Date of workshop
Bushfire	31 May 2017
Cyclone	25 May 2017
Earthquake	7 June 2017
Flood	9 May 2017
Heatwave	23 May 2017
Storm	25 May 2017
Tsunami	7 June 2017

2 Hazard scenarios

The seven credible worst case hazard scenarios (detailed below) used in the assessments were developed with the assistance of:

- Bureau of Meteorology (BOM)
- Department of Fire and Emergency Services (DFES)
- Department of Health (DOH)
- Department of Parks and Wildlife (P&W)
- Department of Water
- Geoscience Australia (GA)
- Office of Bushfire Risk Management (OBRM)
- Office of Emergency Management (OEM)
- Water Corporation
- Western Power

Bushfire

The bushfire scenario was developed by DFES, P&W and OBRM and has approximately a 3.9% chance of occurrence in any given year.

In February, a number of dry lightning strikes in the south west on a line from Jurien Bay to Bremer Bay result in 80-90 fires across the state. Trough movement causes changes in the wind direction from north-east to north-west to south-west. On the first day winds and thunderstorms are too strong for aviation services to continue for an extended period of time. Simultaneous to this event, the Midwest-Gascoyne is experiencing significant flooding.

Of the multiple ignitions, four fires become significant:

1. The Hovea fire was ignited by lightning in the John Forrest/Park Road/Hovea area (Figure 1). The fire forms a large front across John Forrest National Park towards the Great Eastern Highway which is crossed at approximately 8pm on the first day. There is a threat to residents in Hovea and National Park users due to the proximity of the fires and the single entry/exit roads in the area. The approximate duration of the fire is 9-10 days before it is passed back to local government.
2. The Harvey fire was ignited by lightning north east of the Harris River in the Harris River State Forest (Figure 2). The fire moves south and then later east threatening Worsley Alumina, Allanson and Collie (including the Muja Power Station). The approximate duration of the fire is one week before it is passed back to local government.
3. The Yellowdine Nature Reserve fire north of the Great Eastern Highway near the Yellowdine Roadhouse was thought to be ignited by human causes (Figure 3). The spread of the fire is slow due to the sparse vegetation; however after 36 hours the fire spreads and crosses the Great Eastern Highway and threatens the roadhouse. The approximate duration of the fire is up to four weeks before it is handed back to local government.
4. The Leeuwin Ridge fire was ignited by lightning along the coast approximately 10 km north of Yallingup (Figure 4). The fire spreads east and south towards Eagle Bay and

Dunsborough threatening and then impacting these town sites. The approximate duration of the fire is 2-4 days before it is passed back to local government.

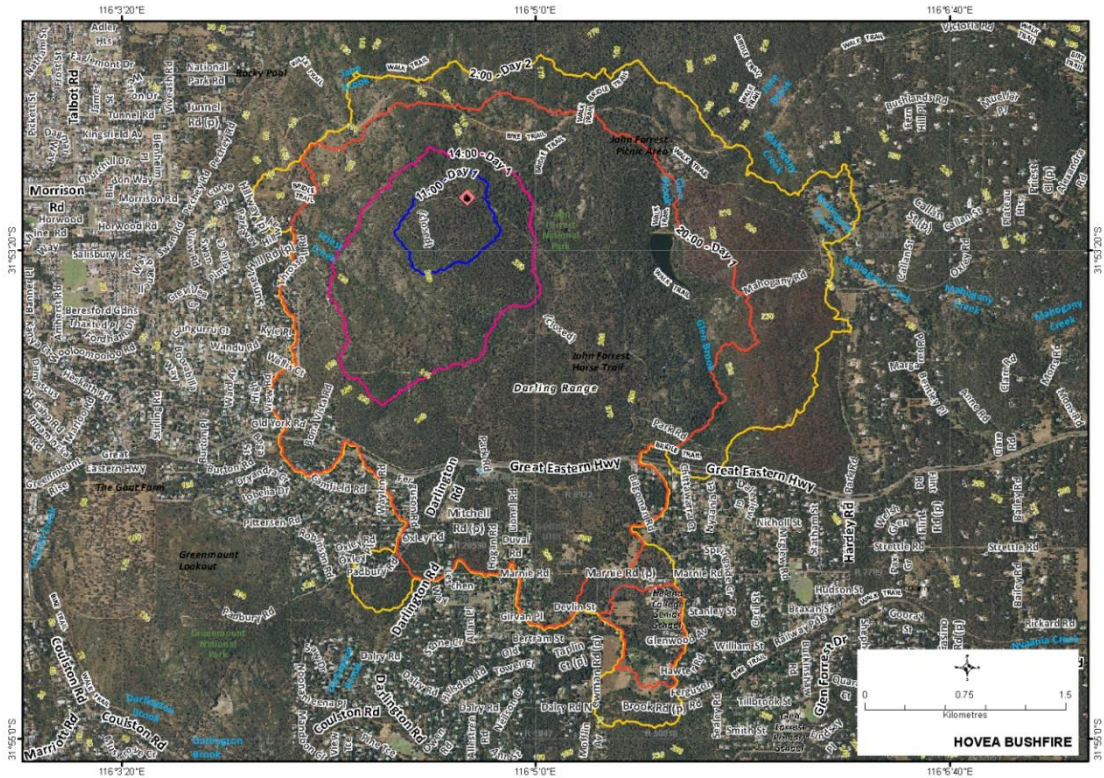


Figure 1: Hovea bushfire fire shape after 24 hours.

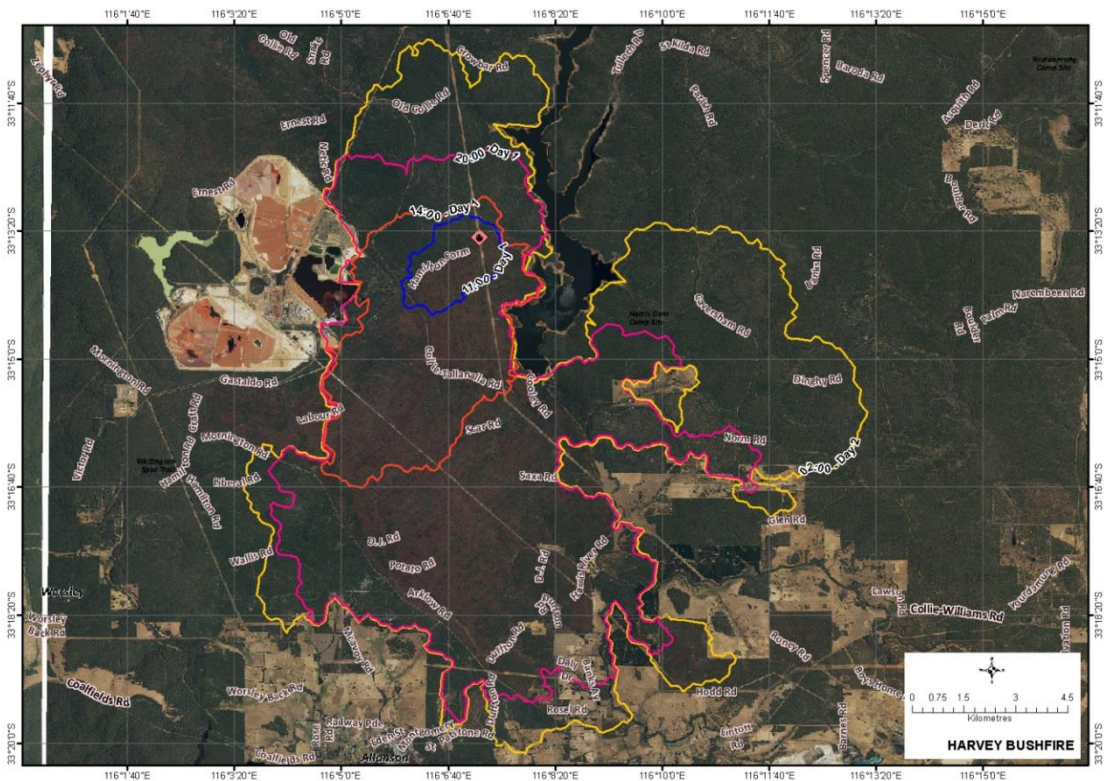


Figure 2: Harvey bushfire fire shape after 30 hours.

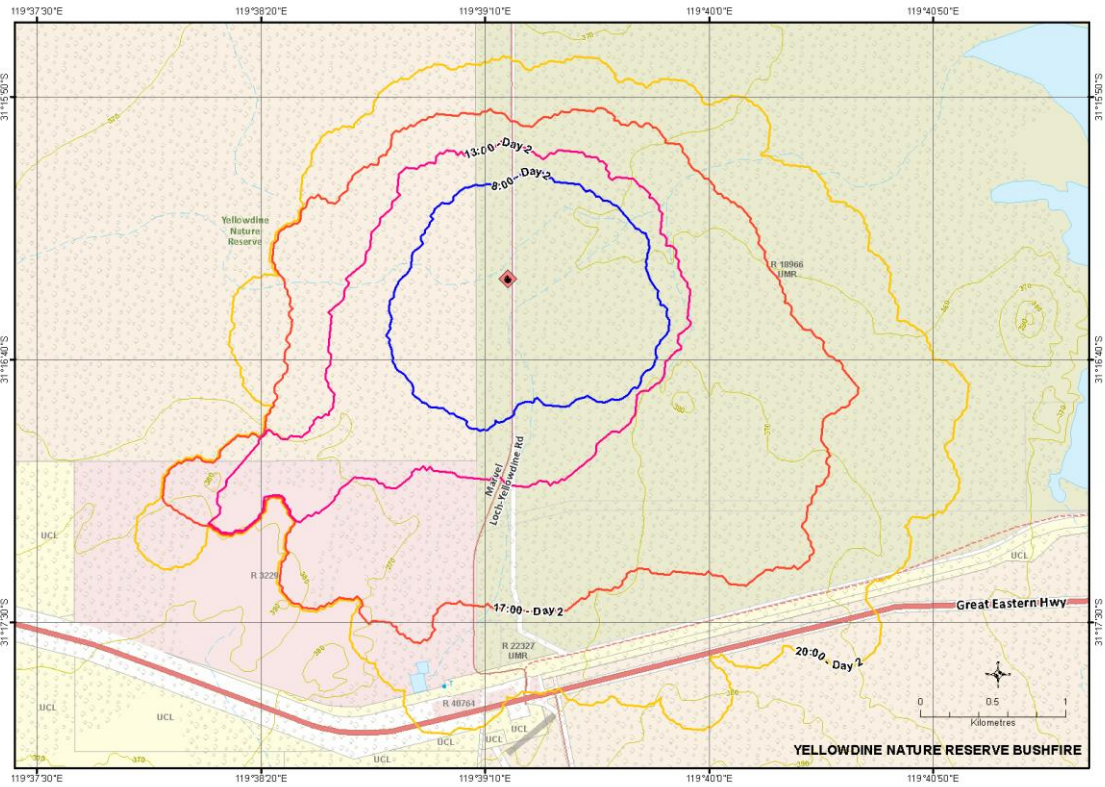


Figure 3: Yellowdine Nature Reserve bushfire fire shape after 36 hours.

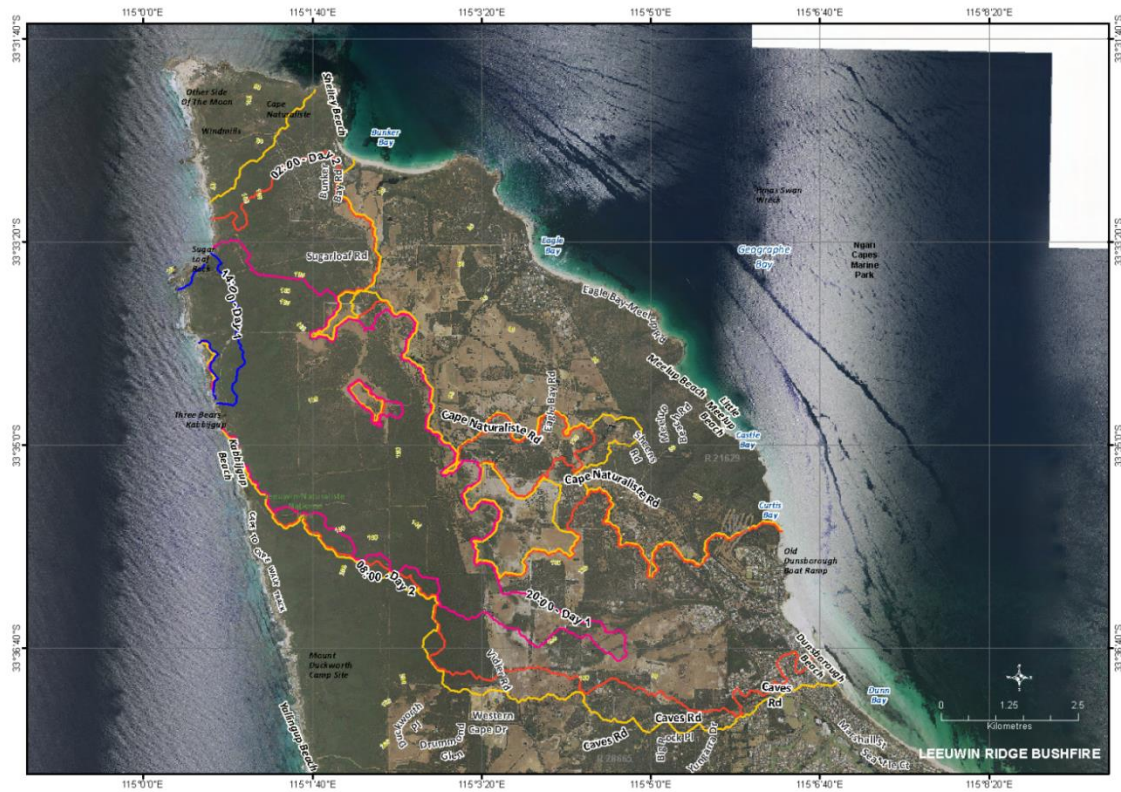


Figure 4: Leeuwin Ridge bushfire fire shape after 24 hours.

Cyclone

The cyclone scenario was developed by BOM and DFES and has approximately a 0.5% chance of occurrence in any given year.

The week before Christmas a tropical low forms off the coast of the Northern Territory and increases to cyclone intensity as it tracks down the coast (Figure 5). The system makes landfall as a Category 3 cyclone east of Derby, before heading back out to sea.

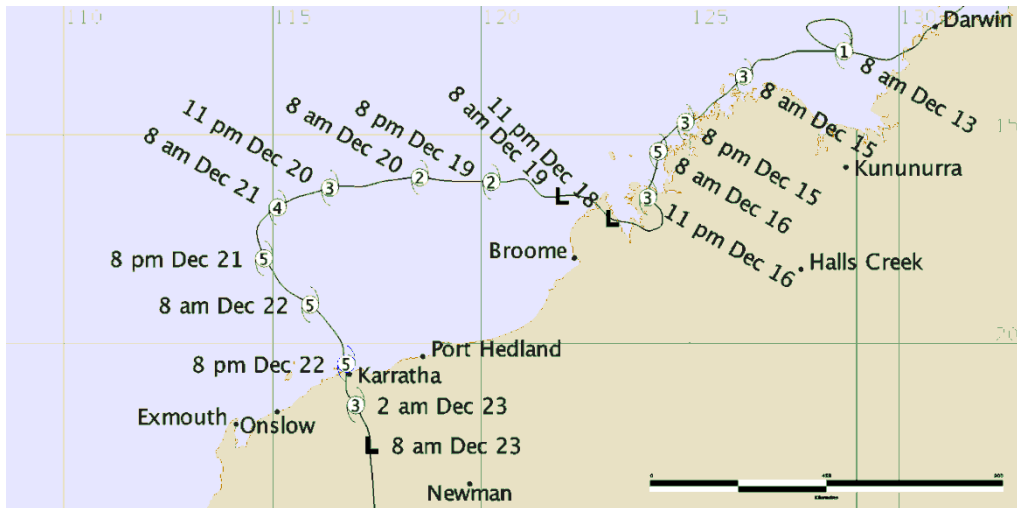


Figure 5: Track of Severe Tropical Cyclone Emily.

The system re-energises and reaches Category 5 intensity to the north west of Karratha before moving south east to make landfall just west of Karratha on 22 December (Figure 6). At Karratha a storm tide of 8.7 m above highest astronomical tide (HAT) is expected. The system continues inland weakening to a Category 2 as it passes over Tom Price early on 23 December.

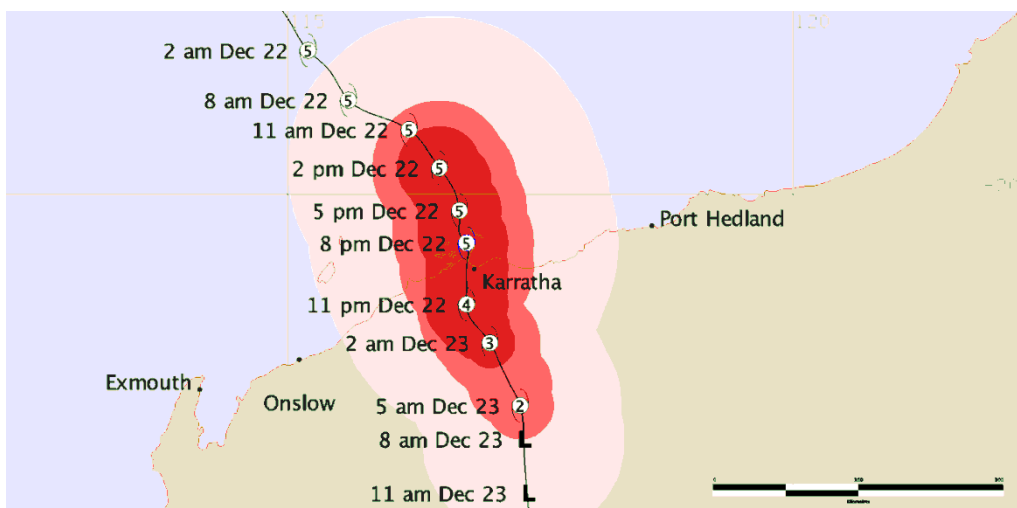


Figure 6: Severe Tropical Cyclone Emily's Track between 22nd and 23rd of December.

Earthquake

The earthquake scenario was developed by Geoscience Australia and has approximately a 0.04% chance of occurrence in any given year.

A magnitude 6.4 earthquake occurs at 5pm on a Tuesday in June. The Perth greater metropolitan area experiences shaking of 7-7.5 on the Modified Mercalli Intensity scale (Figure 7). Shaking lasts approximately 30 seconds. The epicentre is located 25 km west of Perth in the Badaminna Fault System at a depth of 10 km. Building losses (Table 2, Figure 8) and human casualties (Table 3) are anticipated.

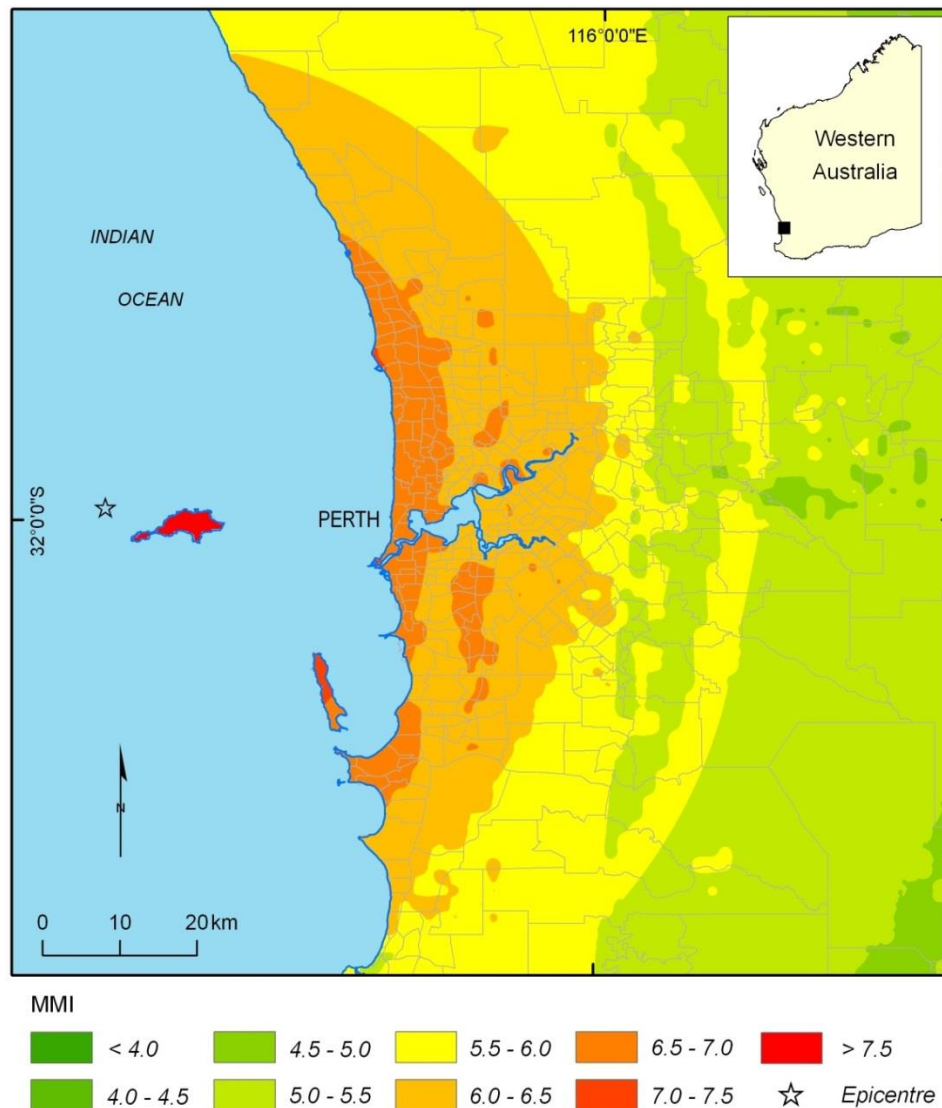


Figure 7: Ground shaking (MMI) from a M6.4 earthquake off the coast of Perth. Image supplied by Geoscience Australia¹.

¹ Wehner M., Ryu H., Corby N., Robinson D. and Edwards M. 2013. Earthquake Impacts Scenarios for Western Australia. Professional Opinion 2013. Geoscience Australia: Canberra.

Table 2: Modified Mercalli Index, examples and expected impacts².

MMI	Example event	Expected impact
V	Kalgoorlie, CBD 20 April 2010	Cracking of vulnerable masonry (e.g. parapets & chimneys) with minor falls. Minor cracking to masonry houses.
VI	Boulder CBD 20 April 2010	Collapse of vulnerable masonry and severe cracking to other masonry structures.
VII	Newcastle 27 December 1989	Severe damage to URM buildings, some damage to housing, damage to low ductility framed buildings, particularly irregular buildings with some collapses.
VIII	Christchurch 22 February 2011	Severe to complete damage to URM buildings, severe damage to low ductility buildings.
IX	Meckering 14 October 1968	Destruction of URM and low ductility framed buildings, damage to all other types.

Table 3: Anticipated human casualties for the earthquake scenario based on ATC-13 methodology².

Minor injuries	Major Injuries	Fatalities
3793	508	127

Table 4: Estimated residential building loss ratio and number of buildings in each damage state for the earthquake scenario².

Mean loss ratio	Number of buildings			
	Slight damage	Moderate damage	Extensive damage	Complete damage
6.3%	119 444 (22.3%)	82 270 (15.4%)	59 635 (11.2%)	39 077 (7.3%)

² Wehner M., Ryu H., Corby N., Robinson D. and Edwards M. 2013. Earthquake Impacts Scenarios for Western Australia. Professional Opinion 2013. Geoscience Australia: Canberra.

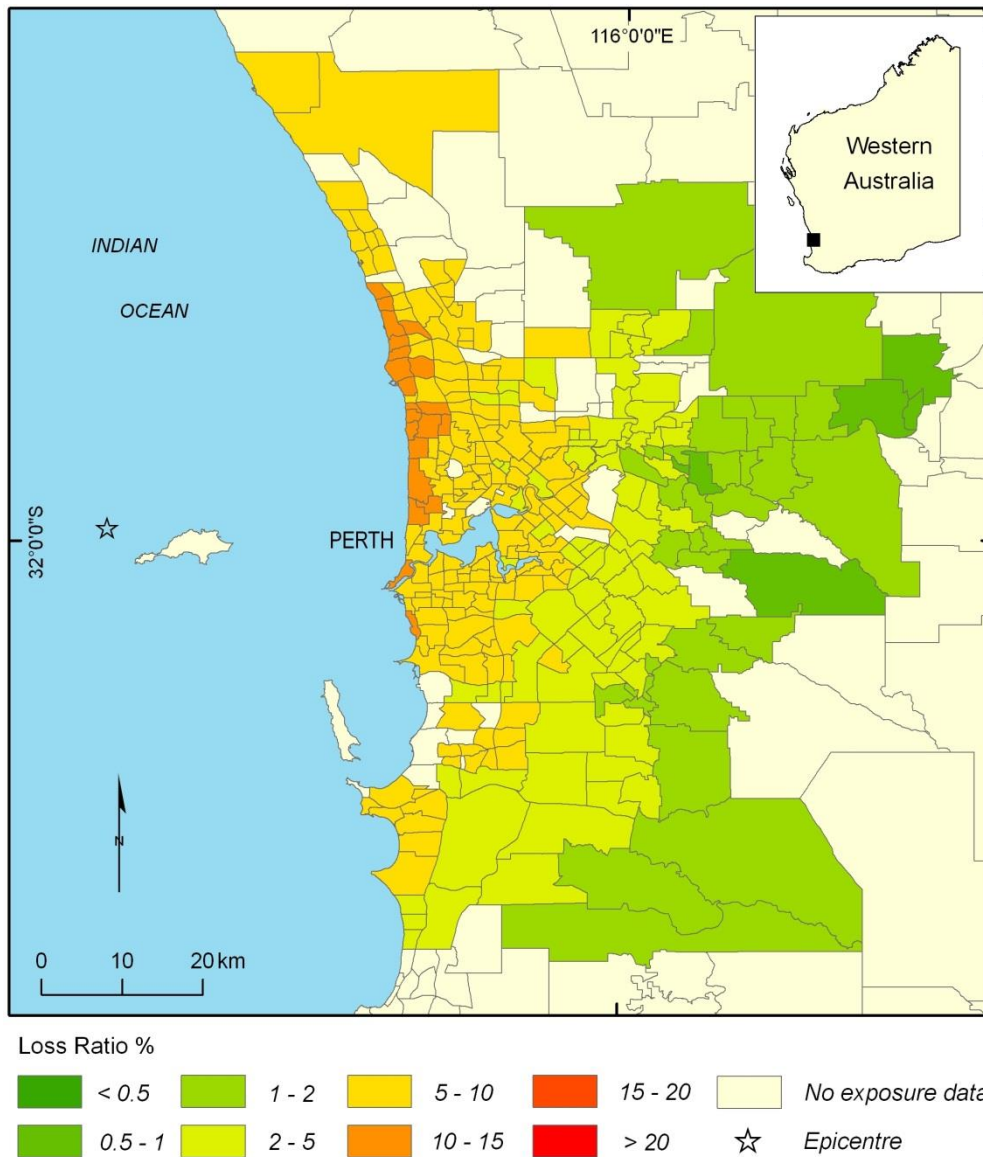


Figure 8: Average building loss ratio across all building types by suburb for the earthquake scenario. Image supplied by Geoscience Australia³.

Flood

The flood scenario was developed by BOM and has approximately a 0.5% chance of occurrence in any given year.

The flood scenario occurs during late March. In the previous winter (April-November) the South West Land Division had an above average rainfall. Catchments recorded 400-600 mm of rainfall over this period, filling farm dams and causing minor to moderate flooding throughout the winter. Similarly, during the previous summer (December-March) the coastal areas of the Pilbara and Gascoyne regions had above average rainfall. Rainfall of

³ Wehner M., Ryu H., Corby N., Robinson D. and Edwards M. 2013. Earthquake Impacts Scenarios for Western Australia. Professional Opinion 2013. Geoscience Australia: Canberra.

200-400 mm fell over these districts saturating the soil and causing minor flooding in some catchments.

The flooding scenario resulted from two consecutive tropical cyclones – TC “Alpha” and TC “Beta” – crossing the coast two days apart. Both cyclones travel down the coast bringing flooding rain to coastal areas of the Gascoyne and Central-West catchments. TC “Alpha” makes landfall at Geraldton (Figure 9) and TC “Beta” crosses at Exmouth (Figure 10) before tracking inland through the Midwest-Gascoyne, Wheatbelt and into the Southern Goldfield districts, bringing heavy rain.

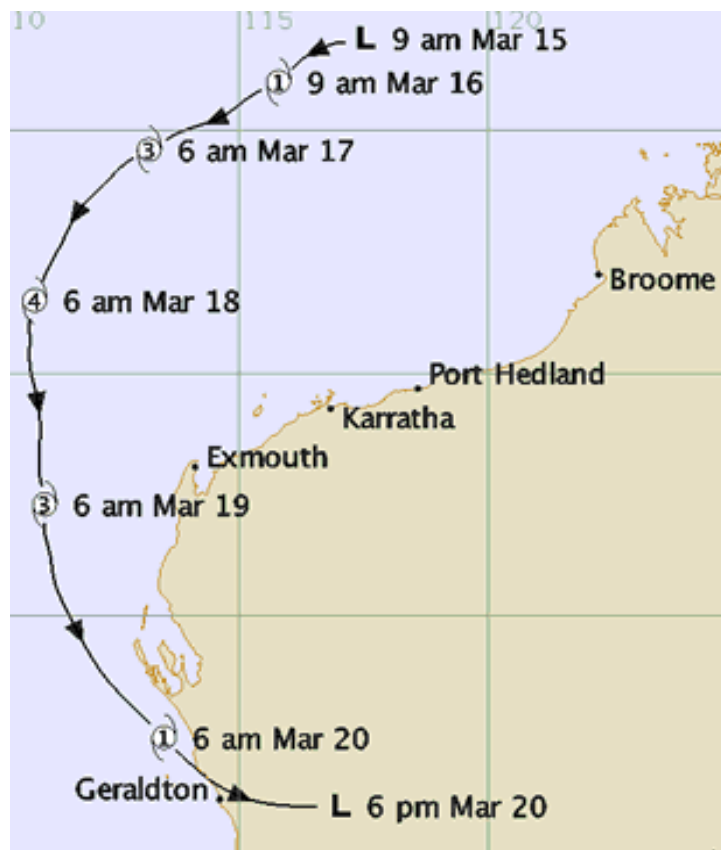


Figure 9: Track of Tropical Cyclone "Alpha".

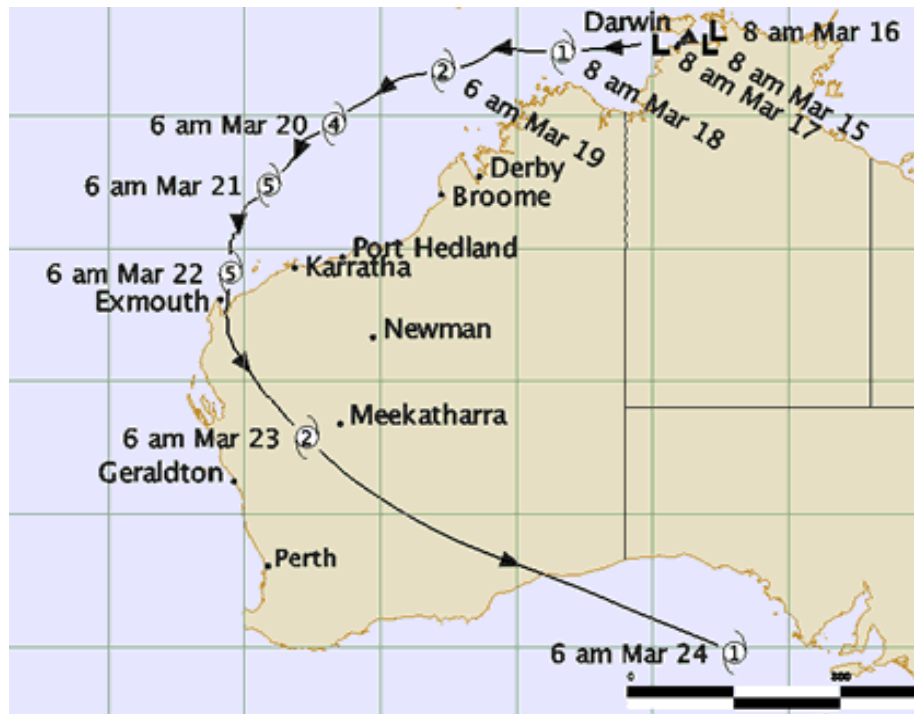


Figure 10: Track of Tropical Cyclone "Beta".

As a result of the two cyclones widespread flooding occurs across the state. The following summarises the flooding in various catchments:

- Major flooding occurs in the Avon River catchment including the townships of Beverley, York, Northam and Toodyay. Areas of York town will be inundated and there is a possibility of the banks at Northam overtopping and/or failing.
- Major flooding occurs in the Swan River catchment and major flood levels at Walyunga, Guildford and Barrack Street Jetty.
- Major flooding is expected in the Blackwood catchment at Bridgetown and Nannup several days after peaks are observed in Avon and Swan Rivers.
- Significant flooding occurs in the Onslow Coastal Rivers catchments resulting in the cutting of the North West Coastal Highway.
- Major flooding occurs in the Gascoyne River catchment including the township of Carnarvon with upstream catchment areas significantly impacted. The Great Northern Highway is cut at multiple locations.
- Significant overland flooding in the Goldfields district catchment results in major infrastructure damage. Significant impacts to East-West rail and road transport routes.
- Significant overland flooding in the Southern Interior catchments results in major infrastructure damage.
- Significant overland flooding in the South East Coastal and Eucla District catchments results in major infrastructure damage.

Heatwave

The heatwave scenario was developed by BOM and DOH and has approximately a 1% chance of occurrence in any given year.

The state has experienced a mild December and a cool start to January with regular sea breezes and maximums in the low 30's along the coast. On 3 January the wind changes to northeasterly and the temperature begins to rise. The northeasterly wind is expected to remain for the next seven days.

Forecasts indicate seven consecutive days in excess of 38°C in the metro area (Figure 11) with peak temperature in the mid-40s. Temperatures exceeding 40°C are also expected over a wide area from Geraldton to Albany and Esperance (Figure 12).

On 7 January the temperature reaches 41°C. A failure occurs at the Armadale substation leaving 30-40,000 customers without power, including schools and hospitals. The heat is also restricting power generation and resulting in vehicle movement bans. The restoration time for power is uncertain.

On 9 January the temperature reaches 46°C. A water main bursts on the corner of Albany and Brookton Highways. Smaller water pipes also burst in North Perth and Beeliar. The restoration time is uncertain. Power issues in the Armadale area are ongoing.

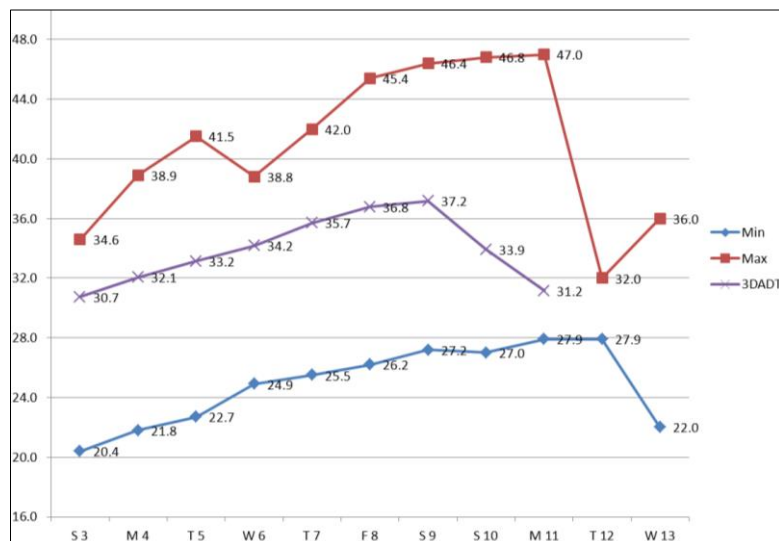


Figure 11: Temperature profile for the beginning of January at Perth Airport (Temperatures across the city and eastern suburbs is likely to be higher)

The 10 January the temperature peaks at 47°C resulting in disruption to public transport as speed restrictions are placed on the rail network. Further water pipes burst in Bentley and Yokine. A number of events are expected to take place during this period, including the Fringe World Festival, the Perth Scorchers 20/20 and the Hopman Cup.

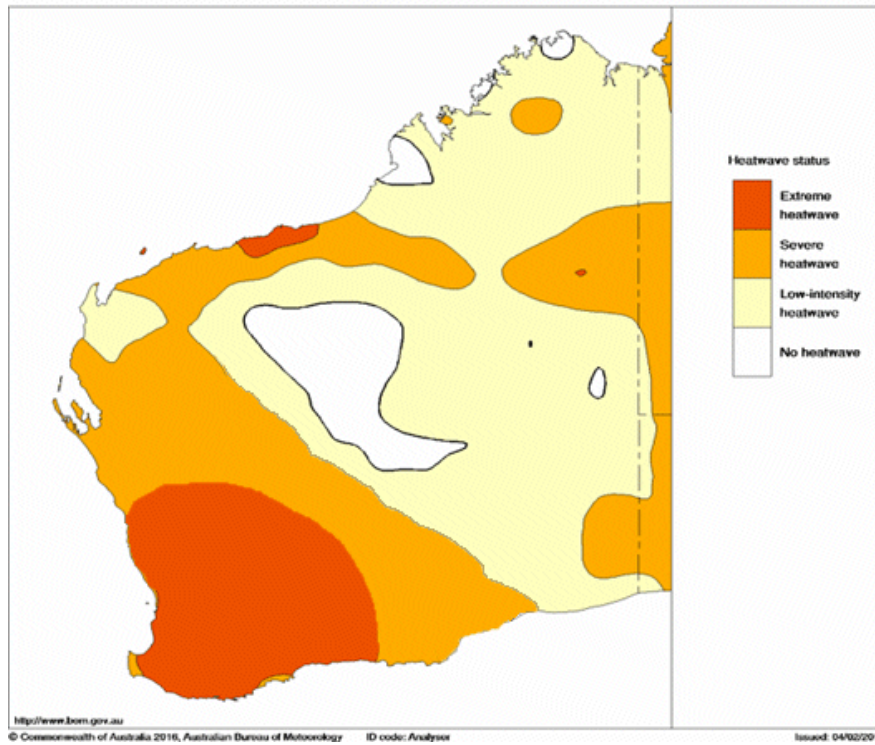


Figure 12: Indicative map of heatwave intensity.

Storm

The storm scenario was developed by BOM and DFES and has approximately a 1% chance of occurrence in any given year.

Over the Australia Day weekend, the state experiences a number of warm season severe thunderstorm cells, which produce heavy rainfall, hail and severe wind gusts in excess of 125 km/hr (Figure 13). The storm cells develop and weaken over time and at varying rates. These changes may lead people to think the storm is over when further cells are yet to pass through.

The day before Australia Day storm cells track over the Midwest and northern Wheatbelt (Figure 13).

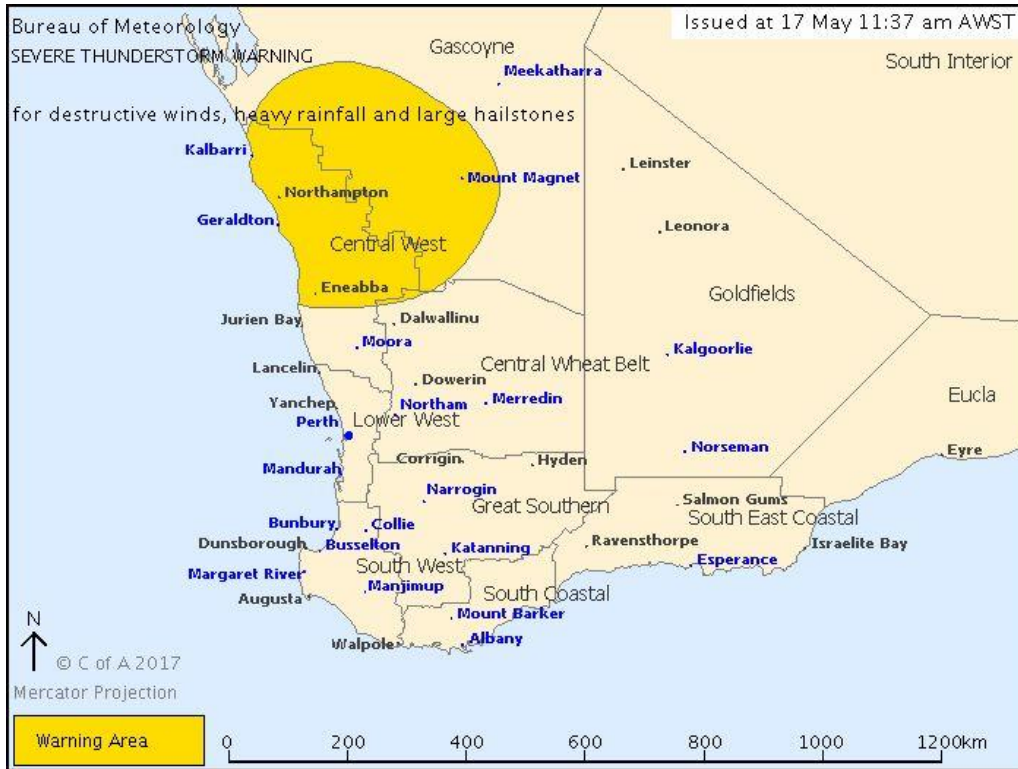


Figure 13: Thunderstorm warning areas for the 25th of January.

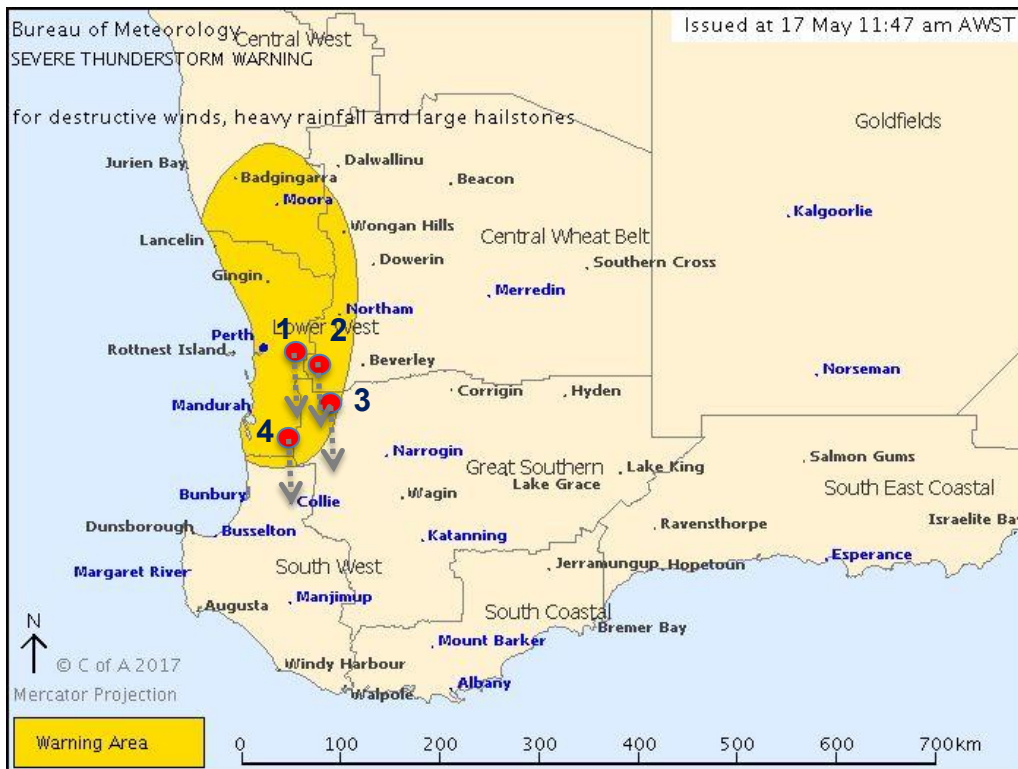


Figure 14: Thunderstorm warning areas for the 26th of January.

On Australia Day storm cells move over the Perth metropolitan area (Figure 14). Cells pass over the Perth central business district (CBD), Perth Airport, Perth Hills and Mandurah/Peel area. A tornado also touches down in the CBD.

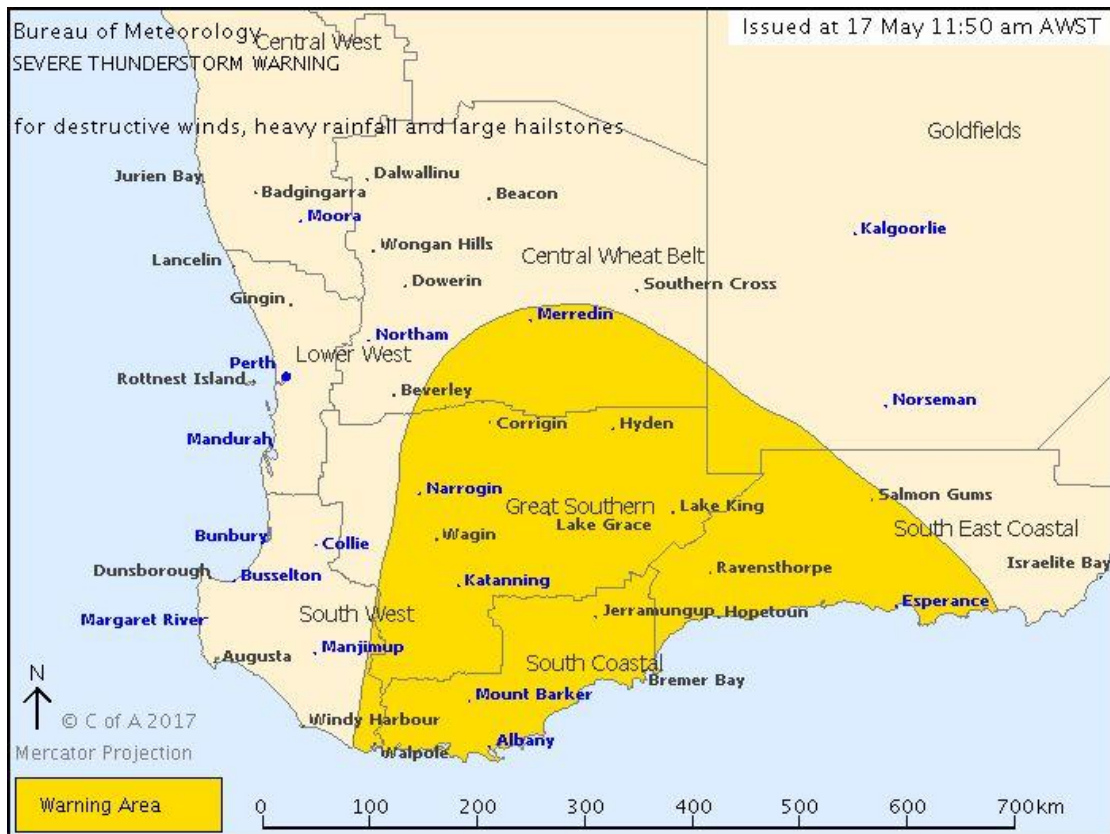


Figure 15: Thunderstorm warning areas for the 27th of January.

The day after Australia Day similar storm cells move over the South and East including the Great Southern and parts of the Wheatbelt (Figure 15).

The storm systems cause widespread power outages for up to four weeks. Significant flash flooding causes traffic management and public transport issues and threats to personal safety particularly at Australia Day events (e.g. Swan foreshore). Surface flooding along the Swan River also occurs from the down-draught of storm cells.

Tsunami

The tsunami scenario was developed by BOM and DFES and has approximately a 0.01% chance of occurrence in any given year.

It is April school holidays and the Monday after ANZAC weekend. After a front with heavy rainfall over the southwest on the previous weekend, it is a lovely sunny day.

At 5:00am, an earthquake of magnitude 8.5 strikes near Cilicap, Western Java. A tsunami watch is issued for Australia indicating a potential tsunami threat for WA. A tsunami warning is then issued for WA (Wallal to Kalbarri) for threat to the marine environment. The expected tsunami arrival time is 9:15am at Carnarvon and 9:45am at Port Hedland.

A little while later, the magnitude of the earthquake is upgraded to 9.3. A revised tsunami warning is issued for WA with the threat is upgraded to include land inundation (Figure 16; Figure 17).

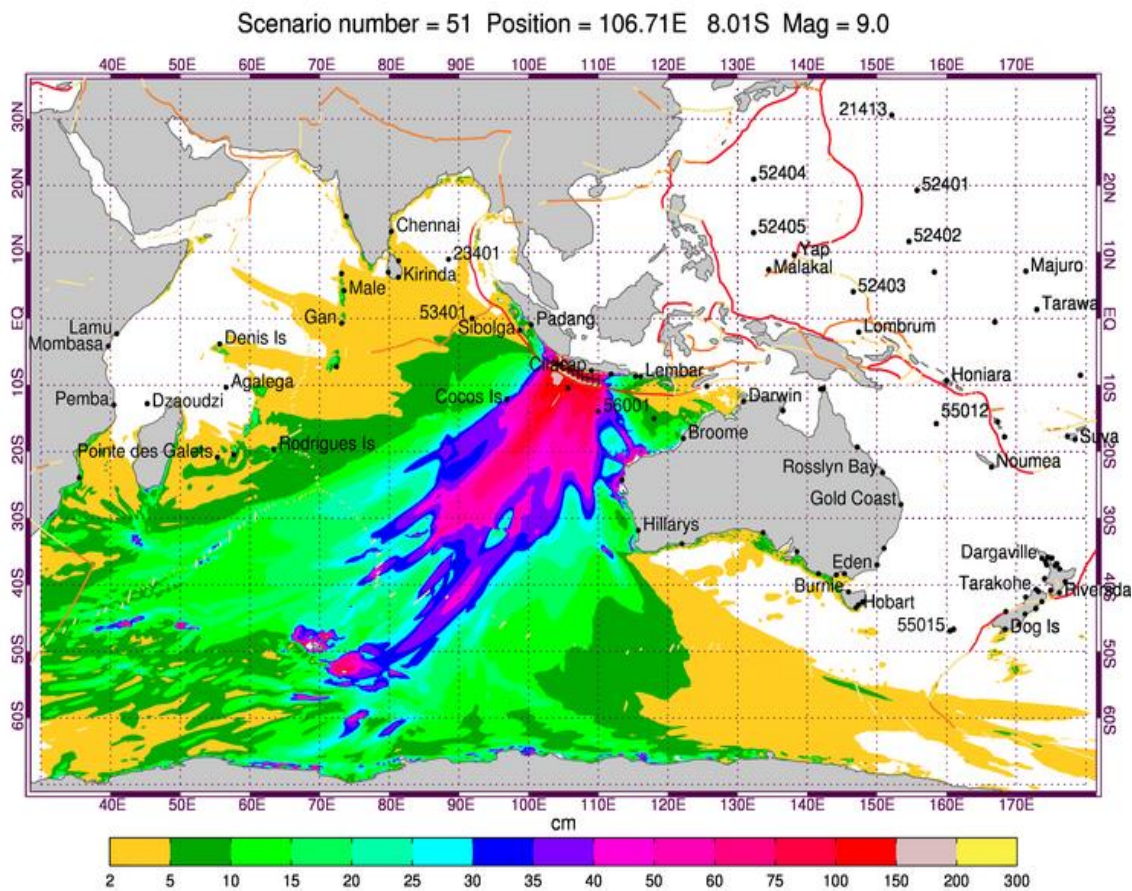


Figure 16: Indication of wave energy and wave distribution from the tsunami. Scale is indicative of wave height (in cm) in deep water. Image supplied by BOM WA.

The West Australian coast from the Northern Territory to Bremer Bay is expected to be affected with estimated times of arrival between 8:45 and 9:45am (Table 5).

Table 5: Estimated time of arrival for the tsunami scenario.

Area	Estimated time of arrival of first wave
Lancelin/Jurien Bay	After 8:45 am
Geraldton/Cape Leeuwin/Perth/Mandurah	9:15 am
Denham/Augusta	After 9:30 am
Albany/Bunbury/Busselton	9:45am

Major land inundation, flooding, dangerous rips, waves and strong currents are expected. The most susceptible regions (in terms of inundation and population) are predicted to be Geraldton, Fremantle and the Southwest including Geographe Bay, Bunbury and Dunsborough.

Evacuation orders are put in place for some communities and advice is issued to go to higher ground (at least ten metres above sea level), or if possible to move at least one kilometre away from all beaches, marinas, harbours and coastal estuaries.

THERE IS A LAND AND MARINE TSUNAMI WARNING CURRENT FOR WESTERN AUSTRALIA.

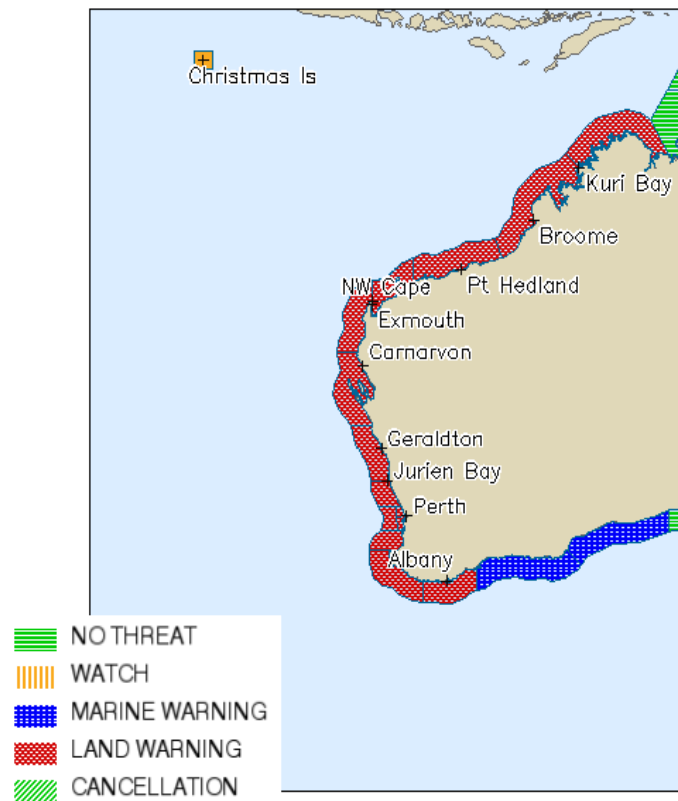


Figure 17: Land and marine threat to Western Australia from the tsunami scenario. Image supplied by BOM WA.

3 Risk profile

A total of 435 risk statements were assessed for the seven hazards across the five NERAG impact areas – economy, people, public administration, environment and social setting. The risk statements were assessed using the tailored *NERAG 2015* consequence criteria table for the state (Appendix B). The consequence levels are based on gross state product (\$239.7 billion) and the population of WA (2.623 million).

Of the risk statements assessed, none are extreme risks, 4.6% are high, 18.9% are medium, 50.3% are low and 26.2% are very low. Figure 18 shows a breakdown of the risk levels per hazard. The bushfire, heatwave and storm scenarios are dominated by low risks and cyclone and tsunami by low and very low risks. While the majority (50.3%) of the risks have been assessed as low, all hazards have some high risks, with earthquake and flood having the greatest number.

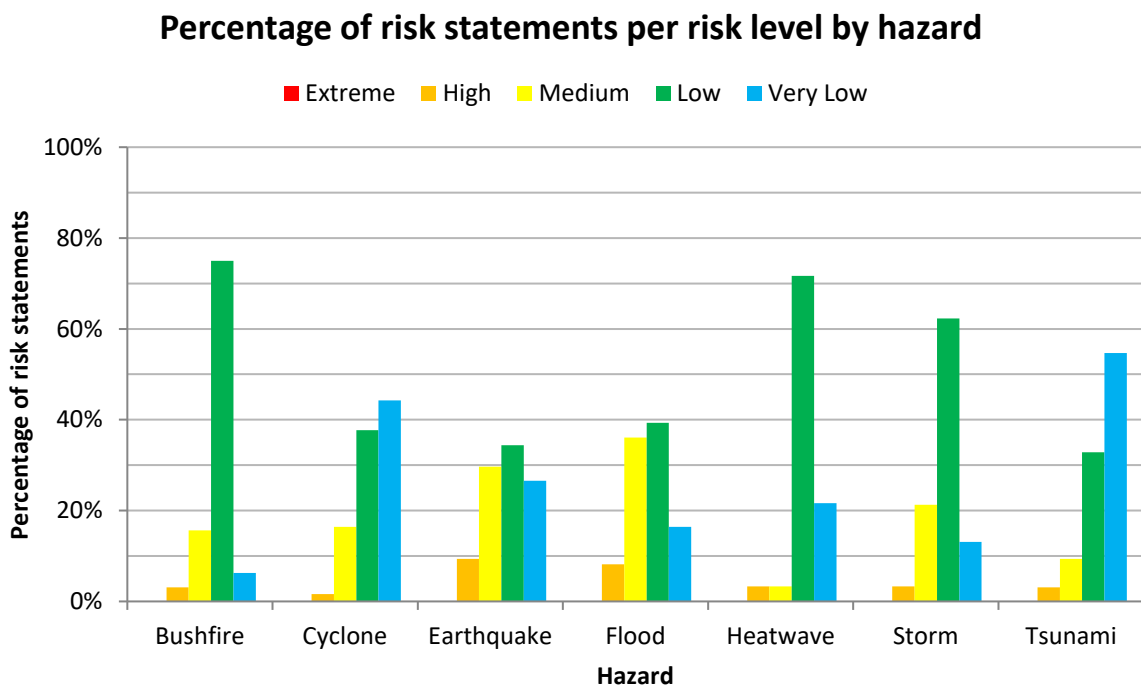


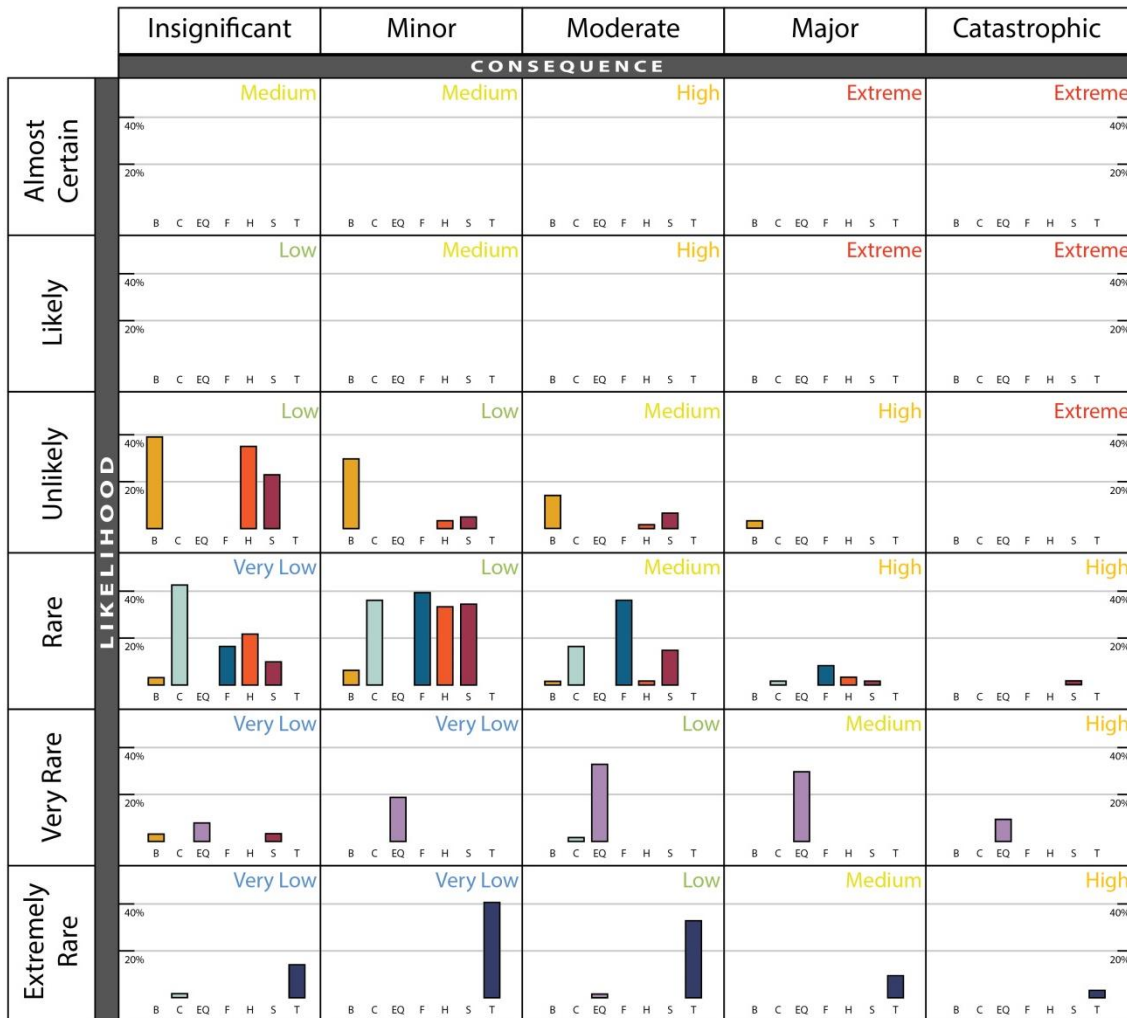
Figure 18: Percentage of risk statements in each risk level for each hazard.

Figure 19 (over page) shows the percentage of risk statements for each hazard as they sit on the *NERAG 2015* risk matrix. The matrix is used to categorise risk statements by their likelihood, consequence and risk level. The likelihood of the seven hazards ranges between unlikely to extremely rare with tsunami being the most infrequent hazard to occur with an annual chance of occurrence of 0.01%. This matrix reveals that many of the low and very low risks are a result of a minor or insignificant consequence level.

Figure 19 also clearly highlights risks and hazards which have catastrophic consequences. These are consequences that could have a potential to strain or outstrip the state’s resources. There are nine statements (2% of all statements) that have catastrophic consequences which relate to the earthquake, storm and tsunami scenarios. These particular statements concern disruption to business activities, damage to private and

commercial buildings, death and injury, disruption of Department for Child Protection and Family Support (CPFS) service provision and impacts to the aviation sector.

State Risk Profile



Legend

- Bushfire (B)
- Cyclone (C)
- Earthquake (EQ)
- Flood (F)
- Heatwave (H)
- Storm (S)
- Tsunami (T)

Key

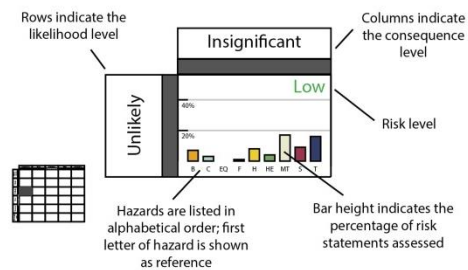


Figure 19: Percentage of risk statements for each hazard assessed across the state categorised by their likelihood, consequence and risk level.

Of the 435 statements, 20 are rated as high risk. The following tables contain these statements by hazard and their relevant impact areas.

Bushfire: Four major bushfires across WA:

PUBLIC
ADMINISTRATION



- will impact DFES services, impacting their ability to maintain core services.
- will impact on Parks & Wildlife services, impacting their ability to maintain core services.

Cyclone: A category 5 cyclone making landfall just west of Karratha:

ECONOMY



- will impact natural resource industries (mining, oil, gas) infrastructure and/or operations, resulting in a lack of production, recovery costs and/or financial losses.

Earthquake: A magnitude 6.4 earthquake off the coast of Perth:

ECONOMY



- will impact private buildings and contents, resulting in financial losses.
- will impact commercial buildings and contents, resulting in financial losses.
- will disrupt business activities, resulting in financial losses.

PEOPLE



- will impact the health of people and cause death(s).
- will impact the health of people and cause injury and/or serious illness.

PUBLIC
ADMINISTRATION



- will impact CPFS, impacting their ability to maintain core services.

Flood: Widespread flooding across WA:

ECONOMY



- will impact commercial buildings, contents and services, resulting in financial losses.
- will disrupt major freight routes, resulting in financial losses.
- will disrupt business activities, resulting in financial losses.

PUBLIC
ADMINISTRATION



- will impact DFES services, impacting their ability to maintain core services.
- will require recovery works to be undertaken by Local Governments, impacting their ability to deliver core services.

Heatwave: A prolonged heatwave across WA:

PEOPLE



- will impact the health of people and cause death(s).
- will impact the health of people and cause injury and/or serious illness.

Storm: A significant storm across SW and Midwest WA:

ECONOMY



- will impact commercial buildings and contents, resulting in financial losses.
- will impact the aviation sector (e.g. damage to infrastructure, disruption to services), resulting in recovery costs and/or financial losses.

Tsunami: A tsunami along the WA coast:

ECONOMY



- will impact commercial buildings and contents, resulting in financial losses.
- will disrupt business activities, resulting in financial losses.

4 Analysis of risks

The assessed risks have been grouped into categories to identify determine common themes and determine if certain areas and sectors are at higher risk. The nine themes identified are: agency core service delivery; agriculture; built environment; business and industry; community wellbeing; environment; health; transport and utilities. Each theme is discussed below and the data are displayed in tabular form.

In the following tables, risk statements are represented by showing the hazard name under the assigned risk level. Where a number follows the hazard name, more than one statement from that hazard fits into that category and risk level. There may also be more than one statement for a hazard in a category.

The colour coding in these tables follows the impact areas: pink – economy; orange – public administration; blue – people; purple – social setting; green – environment.

Agency core service delivery

The greatest risks to government services stem from the bushfire, earthquake and flood scenarios (5 high risks - Table 6). The impact to DFES and P&W from the bushfire scenario could result in these agencies having to temporarily halt some core services, with the majority of their organisations focused on the event. This would be more problematic for DFES as they would have limited resources available if another incident were to take place. The ability to meet the response demand for smaller fires would be impacted. The larger fires would become the priority with interstate assistance likely needed. P&W would maintain core services which are not directly related to fire response; however, a significant amount of resources would be required – potentially half of their current staff.

In the event of a magnitude 6.4 earthquake off the coast of Perth, modelling indicates that ~39,000 residential buildings would be in a complete damage state. A further ~260,000 residential buildings are expected to have slight to extensive damage. A large number of residents would be displaced, potentially for an extended period, as structural surveying would be required to determine which structures are habitable. As a result of this volume of displacement, the CPFS, who are responsible for welfare support, would be unable to deliver their core services in the short to midterm. A critical issue would be the sourcing of appropriate evacuation centres. Although there may be a range of large venues available, the structural integrity of such buildings would need to be established first. With the earthquake occurring in the winter, it is likely that weather conditions would further complicate the habitability of damaged homes.

The impact on local governments from state-wide flooding was assessed as a high risk. Their ability to maintain core services would be severely reduced due to the focus on recovery. As a large portion of the state would be impacted, resource sharing is likely to be limited. The impact on some local governments would be greater than others due to the severity of the flooding in their jurisdiction and their capacity to recover. DFES would also encounter a severe reduction in their core services as a result of the flood scenario. The geographic extent of the flooding would require multiple incident management teams in multiple districts running concurrently. In addition, a large number of responders would be

volunteers and endurance of the response may be affected. Serious consideration would be given for interstate assistance. Further to this, road access may impede the response in isolated and remote areas.

The earthquake scenario produces the greatest number of medium risks. A number of agencies, particularly local governments, Main Roads WA, DFES and the Department of Environment Regulation (DER) and would be impacted by the event such that it would severely reduce their ability to maintain core functions. These impacts are primarily a result of a prolonged disruption to services and the densely populated area of impact.

The volume of waste from the earthquake event would severely impair the ability to dispose of hazardous waste. The large number of buildings expected to suffer damage would lead to a large amount of waste. There is limited landfill capacity and this event would likely have a long term impact on local government waste management. In addition, as a small team, DER has limited capacity to respond to HAZMAT incidents. Two major incidents at any one time can be supported; however, multiple incidents would occur as the result of an earthquake. Issues including asbestos release, chemical spills, air quality and hazardous waste across a wide area of impact would overwhelm DER services and they would require assistance. They could potentially maintain licensing functions; however EM services and functions would likely be stretched, particularly due to environmental health aspects.

Of the other medium risks, Department of Agriculture and Food WA (DAFWA) services were most impacted by storm and flood; Main Roads WA by flood and earthquake; DFES and DER by tsunami and earthquake; CPFS by cyclone and storm; and WA Police by flood.

Table 6: Risks to agency core service delivery. Note: EQ = earthquake.

Agency core service delivery					
Category	Extreme	High	Medium	Low	Very Low
Government services		Bushfire (2) EQ Flood (2)	Bushfire (4) Cyclone EQ (6) Flood (3) Storm (3) Tsunami (2)	Bushfire (6) Cyclone (2) EQ (4) Flood (2) Heatwave (7) Storm (6) Tsunami (5)	Cyclone (6) EQ Flood Heatwave Tsunami (5)

Agriculture

Agriculture risks were low or very low, with the exception of one medium risk from flooding impacts to agricultural and horticultural infrastructure. The flood scenario occurs in late March, so grain crops would have been harvested and the costs resulting from inundation of grain storage facilities is expected to be low. Impacts would primarily result from erosion, loss of fences, and not being able access farms. Losses from the February 2017 flooding in Ravensthorpe are estimated at \$100,000 of uninsurable damage per farm from erosion, lost fences, and no access to paddocks. If 1000 of WA's 10,000 farms were impacted in a similar manner by the flooding, the resultant cost would be at least \$100 million.

In addition, the Carnarvon horticultural industry experienced \$10-12 million of losses following Cyclone Olwyn in 2010 from impacts to shade houses, irrigation and the recovery of top soil. Similar losses would be anticipated in this scenario, along with horticulture crops in the Swan Valley being impacted for an extended period.

Some of the hazards are spatially constrained by their nature or scenarios used. Agricultural infrastructure close to the coast is minimal, so damage to horticulture products and land from salt water inundation would be the only expected impact from tsunamis. The Pilbara is largely used as pastoral leases so impacts from the cyclone scenario would be insignificant (impacts from other cyclone tracks are presented in the flood scenario). The greatest impact from the bushfire scenario is likely to be to vineyard infrastructure, which could affect the following year's production. Likewise, grapes would be most at risk in the storm scenario.

Table 7: Risks to agriculture. Note: EQ = earthquake.

Agriculture					
Category	Extreme	High	Medium	Low	Very Low
<i>Impacts to agricultural and pastoral activities</i>			Flood	Bushfire (3) Flood Heatwave (2) Storm (3) Tsunami	Cyclone (3) EQ (3) Flood Heatwave Tsunami (2)

Built environment

The highest risks to the built environment are expected to come from the earthquake and tsunami scenarios. The earthquake is likely to cause catastrophic damage to a number of commercial buildings located in Fremantle, the Kwinana Industrial area and Cockburn Central. These areas in particular have a high concentration of commercial buildings and are expected to receive higher earthquake shaking intensity than other areas (Figure 7). A number of buildings in the Kwinana Industrial area were built in the 1970s, prior to the establishment of the national building code in 1988 and may be more susceptible to impacts. Service stations with broken pipelines were also mentioned as having a higher cost of repair than other commercial buildings. Buildings within the central business district (CBD) may also be impacted, even if they have not sustained significant damage themselves, due to the danger posed by damaged neighbouring buildings. The single high risk for damage to private buildings also arose from the earthquake scenario. Earthquake loss modelling by Geoscience Australia⁴ estimates that up to 30% of private buildings in the Perth area could sustain moderate to complete damage (Table 4). Combined with buildings that may sustain minor damage, the financial cost could exceed \$10 billion; the threshold to reach the catastrophic consequence level.

⁴ Wehner M., Ryu H., Corby N., Robinson D. and Edwards M. 2013. Earthquake Impacts Scenarios for Western Australia. Professional Opinion 2013/XX. Geoscience Australia: Canberra.

The tsunami scenario is anticipated to cause catastrophic impacts to commercial buildings, particularly those associated with marina and ports. Areas of concern are Hillarys Boat Harbour, the Fremantle Port area, Geraldton and Bunbury harbour area. Damage is thought to occur through the direct impacts of tsunami waves on buildings and from the inundation of salt water, sand and debris.

High risks to commercial buildings are also expected from the storm and flood scenarios, though with major consequences (\$1-10 billion losses). Hail damage to glass exteriors and windows from the storm cells would be significant. Associated tornadoes could damage and remove roofs from commercial buildings in the CBD. Buildings built before 1995 are more vulnerable due to changes in building codes; large multistorey buildings however are less vulnerable as they are designed for high wind loadings. The flood may cause impacts to commercial buildings, in particular to public buildings which are often located in low lying areas.

Medium risks for the cyclone scenario related to damage to commercial buildings around Karratha, close to where the cyclone makes landfall (Figure 6). Buildings in the industrial areas of Karratha house unused mining machinery and equipment which could be damaged along with the structures themselves.

Medium risks for residential building damage arose from the bushfire, cyclone, flood and storm scenarios. A Category 5 cyclone and the associated storm surge in Karratha would cause damage to residential buildings; although it is unlikely that every building in the town would be damaged or inundated. For the bushfire scenario, the majority of the houses that could be impacted would be in the Hovea and Dunsborough areas. Around 200 houses could be lost (~\$100 million) despite asset protection work which would be ongoing during the bushfires. Both the flood and storm were anticipated to cause approximately \$500 million of damages across the state.

Table 8: Risks to the built environment. Note: EQ = earthquake.

Built environment					
Category	Extreme	High	Medium	Low	Very Low
<i>Impacts to commercial buildings, contents and services</i>		EQ Flood Storm Tsunami	Cyclone	Bushfire Heatwave	
<i>Impacts to private buildings and contents</i>		EQ	Bushfire Cyclone Flood Storm	Tsunami	Heatwave

Business and industry

The greatest impacts to commercial activities stem from the earthquake, flood and tsunami scenarios. Earthquake and tsunami were assessed to have catastrophic economic consequences for the state of greater than \$9.5 billion in losses. As a result of the earthquake, damaged buildings that contained asbestos or buildings that could collapse would likely have a cordon around them for health and safety reasons. These cordons could restrict access to nearby businesses impacting commercial activities. Some larger businesses, or those with multiple office locations, might be able to continue without significant losses. As a result of building damage and trading loss, some businesses may close down; however others are likely to start up. It was anticipated that large sums of money would come into the state for the recovery and reconstruction effort, though this would likely occur over the long term.

The flood scenario has the potential to cause more than \$1 billion of losses or damages to businesses. One of the primary ways would be through impacts to the distribution of goods, both perishables (via road) and non-perishables (via rail). The flooding impacts to the east-west rail line and road network could result in delays of interstate deliveries for up to two weeks, or longer in some areas. Some businesses are vulnerable to cash flow interruptions and contracts could be lost if items do not arrive in time. The temporary loss of business could be recovered in time as stocks are replenished; however, smaller businesses may suffer as they are may not have the cash flow to survive. The transport of mining and agriculture products to export ports would also be impacted. In addition, the inundation of open pit mines may result in some losing production for over 12 months while they are being drained. Previous floods in Queensland resulted in large pits being offline for several years. The impact of flood to business premises by inundation or isolation would also contribute to disruption costs.

The tsunami scenario would result in a number of businesses along the coast requiring remediation of building interiors, during which they would likely need to close. Due to the extent of impacts along the whole WA coastline and the limited number of trades personnel available, larger businesses are likely to be prioritised for repair. When including port services in this category, the disruption to which can cost up to \$2.5 million per hour, the overall consequence was assessed as catastrophic (greater than \$9.5 billion).

Impacts to the mining industry from the cyclone scenario were assessed as a high risk, with potential losses of up to \$9.5 billion. These losses were expected to stem from the costs associated with disruption to ships, which will need to remain anchored offshore during the event and the need to evacuate approximately 1500 people from Barrow Island. This would likely cause a delay in operations, incurring significant costs to the industry.

Similar impacts to the mining industry were assessed for the earthquake scenario, but due to the lower likelihood of the scenario, the risk level is medium. Facilities for chemical manufacturers, oil refineries, fertiliser manufacturers and alumina would be closed for an extended period. While the construction standards are unknown for many of these buildings, a large portion of the economic impacts are thought to stem from disruptions to operations and need to inspect all plant and equipment for structural damage.

Cyclone and tsunami would have the greatest impact on the marine industry, resulting in medium risks. The tsunami would impact multiple ports, as well as marine infrastructure,

along the coast. Limited opportunities to divert shipping to other ports would be exacerbated if ports are damaged. Losses of over \$950 million could be expected.

The impacts from the cyclone scenario are expected to cause significant damage to ports and channels, particularly those in the Pilbara, resulting in a medium risk. Wind strengths and the expected 12 metre storm surge in Karratha would have an impact on some infrastructure. The most significant cost could come from damage to a shipping channel and re-dredging that may be required. Re-dredging was estimated to cost up to \$500,000 and take months to complete, incurring disruption costs. Even if damage to infrastructure (a berth in particular) or the channel was not substantial, the expected disruption would last up to 20 days. Other port structures would require surveying before operations could continue.

Impacts to tourism were assessed to be low or very low risk. Tourist attractions and accommodation would likely experience damage, particularly during the earthquake scenario with the epicentre of the earthquake located just offshore of Rottnest Island, a prominent tourist destination. For most hazards, the decline in tourism was expected to be localised, and relatively short term, resulting in losses of less than \$100 million.

Table 9: Risks to business and industry. Note: EQ = earthquake.

Business and industry					
Category	Extreme	High	Medium	Low	Very Low
<i>Impacts to commercial activities</i>		EQ Flood Tsunami	Bushfire	Cyclone Heatwave Storm	
<i>Impacts to marine infrastructure and industry</i>			Cyclone Tsunami	Flood Storm	Bushfire EQ Heatwave
<i>Impacts to mining infrastructure and industry</i>		Cyclone	EQ Flood	Bushfire Heatwave Tsunami	Storm
<i>Impacts to tourism</i>				Bushfire EQ Flood Heatwave Storm	Cyclone Tsunami

Community Wellbeing

Community wellbeing is assessed for the state as a whole. It does not focus on those individuals who would be directly affected by the scenario events but rather the broader WA community.

The community wellbeing of the state was largely assessed to be at low or very low risk from the seven hazards. In most cases, it was expected that the state could use its existing resources to return the community to normal; or there would be only isolated or short term interruptions to services provided to the community.

Due to its lower likelihood of occurrence, the earthquake scenario produces medium risks with higher consequences than other hazards. There are an additional four earthquake statements that are low risk, but have moderate consequences worth noting.

A major consequence (medium risk) anticipated from the earthquake scenario is the loss of culturally significant facilities and/or heritage buildings. Widespread damage and permanent loss of heritage and cultural buildings would be expected as most heritage buildings are unreinforced masonry, the most susceptible building type. Heritage buildings in Fremantle were of particular concern due to the higher expected ground shaking in this area (Figure 7) and the knock-on impact to tourism that this may have. Other areas of Perth would also experience significant damage. The reconstruction cost of heritage buildings is very high due to the measures required to restore them safely to heritage standards. For hazards other than earthquake, there would be isolated losses of some heritage buildings and culturally significant facilities; however impacts to the community wellbeing were not anticipated to be widespread across the state.

Impacts to the community wellbeing as a result of earthquake damage to residential buildings were rated lower than for heritage buildings. However, this was still assessed with moderate consequences (low risk) as some people may permanently move from WA due to their homes being damaged.

Two other medium risks to the community wellbeing stem from impacts to home-based services and service providers such as NGOs, Meals on Wheels and Silver Chain. The earthquake has been assessed to create a major consequence, such that there is a severe reduction to services provided. Those who provide these services are likely to have been affected by the earthquake themselves and may not be able to attend work. Heatwave was also assessed to impact these services as many of those vulnerable to heatwave impacts are those who require home services. There may be limited capacity to redistribute resources in the face of high demand. Delays in public transport services as a result of the heatwave could also impact service providers.

The earthquake scenario was assessed to result in on-going reductions in the day to day services of facilities for vulnerable people (aged, childcare, disability) and in the availability of basic commercial products and services. Most aged care facilities are already at capacity so there would be issues absorbing residents into other facilities if some are damaged. Facilities work closely to relocate residents with reciprocating arrangements; however, in the case of the earthquake, unlike bushfire or storm, all metropolitan facilities may be in a similar situation without alternatives. There is the potential for ongoing issues for a prolonged period of time.

The availability of basic commercial products would be an issue initially as shop items will fall off shelves or spoil. Perishable items travelling by road are likely to be impacted and the movement of non-perishables by train would depend on the impact to rail infrastructure and operations. Nonetheless, supply chains tend to be resilient and alternative goods would be sourced with some delays. Speciality items, such as building materials, would likely be impacted over a longer period of time due to their sourcing from eastern states or abroad and the high demand after such an event.

The flood scenario is expected to result in a significant reduction in services provided in aboriginal communities. A number of communities will be isolated, as would any of their resident staff. Though supplies may have been stocked at the beginning of the wet season, these could be running low by late March. Emergency services may take over the provision of immediate services and supplies but this would not include aspects such as financial payments and community activities. Disruption would also occur to health services and commercial services as staff based in regional centres may have reduced access to communities.

The extensive flooding may also result in a loss of income and employment such that some of the affected may move interstate. This was mentioned with particular regard to mining and the flooding of open pit mines that result in temporary to prolonged mine closures.

Table 10: Risks to the community wellbeing. Note: EQ = earthquake.

Community Wellbeing					
Category	Extreme	High	Medium	Low	Very Low
<i>Administration of aboriginal communities</i>			Flood	Heatwave Storm	Bushfire Cyclone EQ Tsunami
<i>Availability of essential supplies</i>				Bushfire Cyclone EQ Flood Heatwave Storm	Tsunami
<i>Culturally significant facilities and customs</i>			EQ	Bushfire Flood (2) Heatwave Storm	Cyclone Tsunami
<i>Death/injury of animals</i>				Storm	Bushfire Cyclone EQ Flood Heatwave Tsunami
<i>Displacement or isolation of communities</i>				Bushfire (2) Cyclone EQ Flood (2)	Cyclone EQ Storm Tsunami (2)

Community Wellbeing					
Category	Extreme	High	Medium	Low	Very Low
				Heatwave (2) Storm	
<i>Educational facilities</i>				Bushfire Flood Storm	Cyclone EQ Heatwave Tsunami
<i>Facilities for vulnerable people</i>				Bushfire EQ Flood Heatwave Storm	Cyclone Tsunami
<i>Home care services</i>			EQ Heatwave	Bushfire Cyclone Flood Storm	Tsunami
<i>Impacts to people's health</i>				Bushfire Storm	Cyclone EQ Flood Heatwave Tsunami
<i>Loss of income</i>			Flood	Bushfire Heatwave Storm	Cyclone EQ Tsunami
<i>Residential building damage</i>				Bushfire EQ Heatwave Storm	Cyclone Flood Tsunami
<i>Social service providers</i>				Bushfire Heatwave Storm	Cyclone EQ Flood Tsunami

Environment

The majority of environment risks are low. Environmental damage may occur in some instances, but it is expected to be localised.

There are seven medium risks across the seven hazards. The only major consequence results from the earthquake scenario, as a result of land and airborne contamination. Asbestos and dust would be a significant issue, as many of the buildings vulnerable to collapse contain asbestos. The clean-up and monitoring of asbestos contamination would likely require a substantial effort. The potential contamination of the Swan and Canning Rivers from accidental chemical releases would require localised clean-up programs. Similarly if the waste water system is not operating, waste would likely be discharged into waterways, though its impact is generally diluted. A clean up may not be required, but monitoring would be undertaken.

Flood is expected to cause the most environmental risks as a result of debris and pollutants entering riverine or marine environments, coastal impacts and soil erosion. Pollutants would enter aquatic environments during the floods, but quantifying the impact on marine ecology is difficult. Large amounts of silt and decaying organic materials along with sediment disturbance and temperature changes can result in low dissolved oxygen levels in the water, which in turn can cause large fish kills after floods. Along the coast, minor damage is expected for ecosystem or species of national significance.

During the February 2017 flooding, there was erosion damage to ~20% of the impacted landscape. Soil erosion would certainly occur during this flood scenario, with any interventions primarily done for the benefit of farmers. A top soil replacement scheme was put into effect in the Gascoyne region following Cyclone Olwyn in 2015.

Large hail from the storms would impact wildlife in general, and significant endangered species. The environmentally sensitive ecosystem of the Dampier archipelago, particularly birds and reefs, would be vulnerable to cyclone impacts.

Table 11: Risks to the environment. Note: EQ = earthquake.

Environment					
Category	Extreme	High	Medium	Low	Very Low
<i>Coastal impacts</i>			Flood	Bushfire Cyclone Heatwave Tsunami	EQ Storm
<i>Contamination from toxic substances</i>			EQ	Bushfire Flood Heatwave Tsunami	Cyclone Storm
<i>Debris or pollutants entering the riverine or marine environment</i>			Flood	Bushfire Cyclone EQ Heatwave Storm Tsunami	
<i>Flora and fauna</i>			Cyclone Storm (2)	Bushfire (3) Cyclone EQ (2) Flood (3) Heatwave (3) Storm	Cyclone EQ Tsunami (3)
<i>Soil erosion</i>			Flood	Bushfire Heatwave Tsunami	Cyclone EQ Storm

Health

The greatest risks to people's health are from deaths, injuries and illnesses directly attributable to the hazard scenarios. All seven natural hazards have the potential to result in deaths, with earthquake, heatwave and tsunami anticipated to lead to the greatest number of deaths. The earthquake scenario could result in catastrophic consequences, estimated as having a 50% chance of at least 263 deaths. This estimate was based on figures provided by Geoscience Australia using the ATC-13 methodology⁵. Heatwave and tsunami were expected to result in at least 27 deaths; however, the lower likelihood of an occurrence of a tsunami brings its risk level to medium.

Injuries and illnesses are a high risk for earthquake and heatwave, and a medium risk for all other hazards. For the earthquake scenario, the capacity of DFES urban search and rescue (USAR) would be stretched. In addition, there are 14 USAR trained paramedics in WA; therefore it is likely that interstate assistance would be required. This could take up to 24 hours to arrange and as a result some injuries may worsen. In the case of heatwave, pre-existing conditions are often exacerbated within vulnerable groups of the community. An increased number of presentations would be expected in the emergency room; however it may not be easy to attribute these impacts to the heatwave event itself. In addition, a number of heat related illnesses would likely go unreported, particularly by vulnerable groups who are less likely to ask for help (e.g. elderly living at home).

Earthquake is expected to place the greatest demand on health services, resulting in medium risks. The severity of this issue would likely depend on the damage received to health facilities, which would impact their ability to deal with a large volume of patients. Of particular concern are certain specialist areas such as surgery and high dependency units. Royal Perth and Fremantle Hospitals are expected to be impacted the most by the shaking (building age and location); but it was assumed that all tertiary facilities, including private facilities, would be impacted to some extent. Outer metropolitan area facilities may function but would already be at capacity. Patient transfers around the greater metropolitan area could be affected by a lack of available facilities and transport disruptions. For these reasons, WA health services would likely encounter a severe reduction in the delivery of their core functions. This limitation has the added potential to lead to a further death, directly attributable to the earthquake event.

Flood, earthquake and storm are expected to place the greatest demand on emergency services (primarily medical transport), resulting in the potential for a further death directly attributable to the emergency event. For all three hazards, this is mainly due to limited access to persons as a result of damage or inundation of critical infrastructure. In the earthquake scenario, a large number of resources would be required due to the high volume of injuries. A focus on earthquake-related injuries may prevent other daily incidents from being prioritised.

The impact on St John Ambulance (SJA) services is greatest from earthquake and flood. In these events, core services would be maintained by bringing in personnel to assist but there is likely to be some reduction in services. There is a large SJA volunteer base in the greater

⁵ Wehner M., Ryu H., Corby N., Robinson D. and Edwards M. 2013. Earthquake Impacts Scenarios for Western Australia. Professional Opinion 2013/XX. Geoscience Australia: Canberra.

metropolitan area from which to draw on. However, in the earthquake scenario, this volunteer base may be personally impacted affecting their ability to respond. Additionally, volunteers often play multiple roles which may conflict during an earthquake event (e.g. community paramedic vs. firefighter). Even if a sufficient number of personnel are available to assist, there may be a lack of equipment, such as ambulances. In the flood scenario, it is unlikely that SJA would experience a surge in calls. However they would be required to assist in moving people around (e.g. to evacuation centres) which would require significant effort. Services may be further restricted by access issues.

Table 12: Risks to health. Note: EQ = earthquake.

Health					
Category	Extreme	High	Medium	Low	Very Low
<i>Deaths</i>		EQ Heatwave	Bushfire Cyclone Flood Storm Tsunami		
<i>Emergency services</i>			EQ Flood Storm	Bushfire Cyclone Heatwave Tsunami	
<i>Emergency services</i>			EQ Flood	Bushfire Cyclone Heatwave Storm Tsunami	
<i>Health services</i>			EQ	Bushfire Cyclone Heatwave Storm Tsunami	Flood
<i>Health services</i>			EQ Flood	Bushfire Heatwave Storm Tsunami	Cyclone
<i>Injuries and illnesses</i>		EQ Heatwave	Bushfire Cyclone Flood Storm Tsunami		

Transport

The highest risks for transport come from the damage to aviation infrastructure from the storm scenario and the disruption to transportation routes from the flood scenario.

The storm scenario is expected to cause catastrophic damage (greater than \$9.5 billion) to aviation infrastructure, particularly at Perth Airport. There are assets valued in the billions of dollars at the airport that are vulnerable to hail. The removal of these assets from their regular aviation services could potentially result in long term economic failures within the aviation industry, with a flow on impact to dependent industries. Lightning is also a concern, as outside operations at the airport would be stopped for health and safety reasons. This would likely cause delays resulting in further financial losses.

The flood would cause significant impacts and disruption on the road network, particularly the main north-south and east-west freight routes. This disruption to the road network would affect freight and supplies coming into the state as well as the transport of mining products to export ports. In addition to disruption costs, the flood scenario would also cause physical damage to the road network and associated bridges. The February 2017 flooding provided a basis for the assessment, where the widespread and extensive damage to the road network and bridges cost an estimated \$100 million. Given the state-wide nature of the scenario, similar or greater damage is expected. In a similar manner, the storm scenario would cause maintenance issues across the road network with the possibility of more significant washouts from flash flooding in some areas and debris clearing required in most areas (medium risk).

While earthquake and tsunami present lower risks than flood in terms of disruption to transport routes, both have the same consequence level (major). They would cause considerable disruption to freight routes, in particular ports and road bridges. Port infrastructure (Fremantle Ports in particular) could sustain damage during the earthquake requiring repair and delaying operations. Disruption costs are currently estimated to be \$2.5 million per hour. Similar, the Fremantle bridges would require inspection, if not restoration, following the earthquake. The cost of disruption of the road bridge is estimated at \$300,000 per day.

The tsunami scenario could reduce the safety margin of ships entering shipping channels due to potential infilling of channels with sediment and debris. Closure and delays in port operations would result in significant financial losses. However, the closure of large ports would likely be short term and would therefore not significantly affect service delivery at ports and some marinas. The strong winds and storm surge associated with the cyclone could also impact ports in the north of the state causing disruption; assessed as a medium risk. If a channel is damaged from the storm surge, re-dredging could be required which may take months to complete. In general, expected disruption could be up to 20 days to repair any damage and undertake structural surveys of port infrastructure if required.

The cyclone scenario is expected to impact rail facilities at ports required for mineral loading and private rail lines linking mines to the port towns. Extra costs associated with utilising road transport as an alternative are not understood and have not been accounted for. Another risk worth consideration is the impact of the earthquake scenario on the rail network. Though rated as a low risk due to the scenario's likelihood, significant damage to the Public Transport Centre in East Perth could render all public transport trains inoperable as the control centre is onsite. The heritage listed building is known to not adhere to the current

building code and it could be inaccessible if damaged or deemed unsafe to enter. Damage to rail infrastructure across the city, tracks and signals, is also likely.

Table 13: Risks to transportation. Note: EQ = earthquake.

Transport					
Category	Extreme	High	Medium	Low	Very Low
<i>Disruption to aviation services</i>			Storm	Bushfire Cyclone EQ Flood Tsunami	Heatwave
<i>Disruption to transport routes</i>		Flood	Cyclone EQ Tsunami	Bushfire Heatwave Storm	
<i>Impacts to aviation</i>		Storm	Cyclone EQ	Bushfire	Flood Heatwave Tsunami
<i>Impacts to bridges or their approaches</i>			Flood	Bushfire Cyclone EQ Heatwave Storm	Tsunami
<i>Impacts to port and marina services</i>				Cyclone Flood Storm	Bushfire EQ Heatwave Tsunami
<i>Impacts to rail infrastructure</i>			Cyclone	Bushfire EQ Flood Storm	Heatwave Tsunami

Transport

Category	Extreme	High	Medium	Low	Very Low
<i>Impacts to road infrastructure</i>			Flood Storm	Bushfire Cyclone EQ Heatwave Tsunami	

Utilities

The highest risks to utilities relate primarily to the service delivery of the utility rather than repairs costs of damaged assets. Exceptions relate to the flood and earthquake scenarios which may have the potential to result in a moderate level of financial impact to power and communications infrastructure respectively. While the earthquake scenario is a rare event, the potential level of damage could result in major consequences for power utilities.

Of all of the utilities, power supply infrastructure and services are most at risk. While all hazard scenarios, with the exception of tsunami and cyclone, have the potential to create moderate level impacts to power supply service delivery, the earthquake scenario is the only scenario expected to affect power infrastructure significantly. The primary concern for earthquake impacts surrounds generation plants at Kwinana, substations in areas with high levels of shaking (Figure 7) and poles in areas of possible liquefaction. The level of shaking may also result in the tripping of a safety system causing short term but widespread loss of power. The scenario is likely to impact underground infrastructure which will take longer to repair than above ground equipment, leading to longer outages. For hazards other than earthquake, the level of risk is primarily related to the length of time it may take to restore all services. This is particularly relevant for bushfire where exclusion areas may slow restoration times. In addition, the response to the events may cause planned maintenance to be postponed which is likely to take several months to reschedule.

The highest risk to the natural gas supply relates to the earthquake scenario. The earthquake would likely result in gas leaks which could restrict access to certain areas and impact the operation of key facilities, such as hospitals. The economic impact of damage to the ATCO Gas network in Perth was assessed as a medium risk (major consequence), as the majority of the network would be affected. Some disruption is also possible from the tsunami and cyclone scenarios due to the dependence on offshore infrastructure.

Economic impacts to communications infrastructure were assessed as low or very low risk for all hazards with the exception of flood (medium risk). This is likely the result of a high level of redundancy at individual infrastructure sites such as portable or permanent backup generators. For the flood scenario, potential long term impacts are expected due to need to replace fibre cables and the possible inundation of some exchanges. Impacts to the delivery of communication services in these scenarios are more substantial. Storm, flood and bushfire would likely require interstate resources for restoration.

The flood scenario presents the greatest risk to the water supply and sewerage system infrastructure and services and has the potential to cause a medium level of risk to sewerage service delivery. This is because wastewater systems are typically located in low lying areas. The amount of work required to repair systems across a large area (Figure 9 and Figure 10) would result in high workloads and necessitate the deployment of additional staff to regional areas. It is worth noting that despite the low risk rating of both systems for earthquake, such an event could create moderate level impacts.

Table 14: Risks to utilities. Note: EQ = earthquake.

Utilities					
Category	Extreme	High	Medium	Low	Very Low
<i>Disruption to supply of natural gas</i>				Bushfire EQ	Cyclone Flood Heatwave Storm Tsunami
<i>Impacts to communication infrastructure</i>			Flood	Bushfire Cyclone Storm	EQ Heatwave Tsunami
<i>Impacts to communication service delivery</i>			Bushfire Flood Storm	Cyclone EQ Heatwave Tsunami	
<i>Impacts to natural gas distribution</i>			EQ	Bushfire Cyclone Heatwave	Flood Storm Tsunami
<i>Impacts to power supply infrastructure</i>			EQ	Bushfire Cyclone Flood Heatwave Storm Tsunami	
<i>Impacts to power supply service delivery</i>			Bushfire EQ Flood Heatwave Storm	Cyclone Tsunami	
<i>Impacts to sewerage service delivery</i>			Flood	Bushfire EQ Heatwave Storm	Cyclone Tsunami
<i>Impacts to sewerage systems</i>				Bushfire EQ Flood Heatwave	Cyclone Storm Tsunami

Utilities

Category	Extreme	High	Medium	Low	Very Low
<i>Impacts to water supply infrastructure</i>				Bushfire Cyclone EQ Flood Heatwave Storm	Tsunami
<i>Impacts to water supply service delivery</i>				Bushfire Cyclone EQ Flood Heatwave Storm	Tsunami

5 Comparison to 2013 risks

In 2013, the SEMC coordinated the first risk assessment workshop series to analyse the risks from these same seven natural hazards using the 2010 National Emergency Risk Assessment Guidelines (NERAG). While there are some similarities, the results of the two series vary. These variances are primarily due to the different criteria and methodology used, and notably, a greater maturity of our understanding of risk.

The first workshop series used the 2010 NERAG, which contains six categories (people, economy, environment, infrastructure, public administration and social setting); while the most recent workshops used the 2015 NERAG. Some of the significant changes in the 2015 version are: no infrastructure category; the people category is limited to deaths and injuries; and the economy category is based on the whole economy not government revenue alone. Aspects of the public administration, social setting and environment categories have also been refined. Consequently, the comparison of risks across the two series becomes difficult as risks for the same element (e.g. displacement of people) are assessed with different consequence criteria.

In addition to the criteria changes, the workshop series differed in their formats. In 2013, the impact categories were assessed in separate workshop tables to maximise participants' time and inputs. As a result, the data between tables was hard to normalise. One significant and positive change to the workshops has been running the assessment as a large group (between 15-35 participants) and assessing all categories collectively. This format has provided a balanced view across the categories and has relieved the issue of expertise being on one table and not another.

As our collective understanding of risk has improved over the last four years, another aspect that has changed is how the impacts to the social setting are perceived. The social setting category encompasses community and community-based services and cultural, emotional and psychological aspects of society. In 2013, many of the social setting risks were assessed as having major or catastrophic impacts in 2013. Comparatively in 2017, there is only one major consequence and it addresses the permanent loss of culturally important heritage buildings. It appears that there is a greater appreciation of the scale of the assessment, measuring how the entire state community is impacted rather than the particular individuals involved. An additional factor may be that there have been a few relatively large emergency events in WA in the last four years, which while significant, have not had a notable impact on the majority of the State's community.

Among the high risks that have remained constant across the two assessments are the impact of heatwave to people's health and the effect of flooding on the state's economy. Widespread flooding is expected to result in longer-term disruption to transport networks and resource sector operations, potentially slowing the state's productive capacity. Beyond these similarities, the 2017 assessments provide a substantially more robust and advanced picture of the State's risk profile.

Appendix A: Agencies involved in risk assessment

As the workshops took place before 1 July 2017 when some WA government departments were amalgamated, the agencies are referred to by their name prior to this date.

Association of Volunteer Bush Fire Brigades
Bethanie Group
Building Commission - Department of Commerce
Bureau of Meteorology
City of Perth
City of South Perth
Department for Child Protection and Family Support
Department of Agriculture and Food WA
Department of Defence
Department of Environment Regulation
Department of Fire and Emergency Services
Department of Health
Department of Parks and Wildlife
Department of Planning
Department of the Premier and Cabinet
Department of Transport, Marine Safety
Department of Water
Geoscience Australia
Horizon Power
Main Roads WA
Office of Bushfire Risk Management
Office of Emergency Management
Public Utilities Office
Red Cross
St John Ambulance
Surf Life Saving WA
Telstra
Tourism WA
WA Local Government Association
WA Police
Water Corporation
Western Australian Council of Social Services
Western Power

Appendix B: State consequence table

	Insignificant	Minor	Moderate	Major	Catastrophic
People*					
Mortality	Not Applicable	At least 1 death	At least 3 deaths	At least 27 deaths	At least 263 deaths
Injuries / Illness	Less than 3 serious injuries or any minor injuries	1 person critically injured with long-term or permanent incapacitation or more than 3 serious injuries	More than 3 critical injuries with long-term or permanent incapacitation or more than 27 serious injuries	More than 27 critical injuries with long-term or permanent incapacitation or more than 263 serious injuries	More than 263 critical injuries with long-term or permanent incapacitation or more than 2624 serious injuries
Economy					
Loss in economic activity and/or asset value	Decline of economic activity and/or loss of asset value less than \$9,588,000	Decline of economic activity and/or loss of asset value between \$9,588,000 and \$95,880,000	Decline of economic activity and/or loss of asset value between \$95,880,000 and \$958,800,000	Decline of economic activity and/or loss of asset value between \$958,800,000 and \$9,588,000,000	Decline of economic activity and/or loss of asset value greater than \$9,588,000,000
Impact on important industry	Inconsequential business sector disruption	Significant industry or business sector is impacted by the emergency event, resulting in short-term (i.e. less than one year) profit reductions	Significant industry or business sector is significantly impacted by the emergency event, resulting in medium-term (i.e. more than one year) profit reductions	Significant structural adjustment required by identified industry to respond and recover from emergency event	Failure of a significant industry or sector
Environment**					
Loss of species and/or landscapes	No damage to ecosystems at any level	<ul style="list-style-type: none"> Minor damage to ecosystem/species of state significance Significant damage to ecosystem/species of district/local significance 	<ul style="list-style-type: none"> Minor damage to ecosystem/species of national significance Significant damage to ecosystem/species of state significance Severe damage to ecosystem/species of district/local significance 	<ul style="list-style-type: none"> Significant damage to ecosystem/species of national significance Severe damage to ecosystem/species of state significance Permanent destruction to ecosystem/species of district/local significance 	Permanent destruction to ecosystem/species of national, state and district/local significance
Loss of community environmental value	Inconsequential damage to item of interest	Minor damage to item of interest	Significant damage to item of interest	Severe damage to item of interest	Permanent destruction to item of interest
Public Administration					
Governance Functions	Governing bodies' delivery of core functions is unaffected or within normal parameters	Governing bodies encounter limited reduction in delivery of core functions	<ul style="list-style-type: none"> Governing bodies encounter significant reduction in the delivery of core functions Governing bodies are required to divert some available resources to deliver core functions or seek assistance external to the state to deliver some of their core functions 	<ul style="list-style-type: none"> Governing bodies encounter severe reduction in the delivery of core functions Governing bodies are required to divert a significant amount of available resources to deliver core functions or seek assistance external to the state to deliver the majority of their core functions 	Governing bodies are unable to deliver their core functions
Social Setting					
Community wellbeing	• State community social fabric is disrupted	• State community social fabric is damaged	• State community social fabric is broken	• State community social fabric is significantly broken	• State community social fabric is irreparably broken
	• Existing resources sufficient to return the state community to normal function	• Some resources external to the state required to return the state community to normal function	• Significant resources external to the state required to return the state community to normal function	• Extraordinary resources external to the state are required to return the state community to functioning effectively	• State community ceases to function effectively, breaks down
	• No permanent dispersal	• No permanent dispersal	• Some permanent dispersal outside of the state	• Significant permanent dispersal outside of the state	• Community disperses in its entirety
Community Services	Inconsequential / short term impacts	Isolated / temporary reductions	Ongoing reductions	Reduced quality of life	State community unable to support itself
Culturally important objects	Minor damage to objects of cultural significance	Damage to objects of identified cultural significance	Damage or localised widespread damage to objects of identified cultural significance	Widespread damage or localised permanent loss of objects of identified cultural significance	Widespread and permanent loss of objects of identified cultural significance
Culturally important activities	Minor delay to a culturally important event	Delay to or reduced scope of a culturally important event	Delay to a major culturally important event	Temporary cancellation or significant delay to a major culturally important event	Permanent cancellation of a major culturally important activity

*Criteria for people have been rounded up to the nearest whole number.

**Environmental damage descriptors are over page.

Where there are dot points, only one point needs to be met for that consequence level

