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Bushfire, Heat Wave and Flooding Case Studies from Australia

Report from the International Panel of the WEATHER project funded by the European Commission's 7th framework programme

Melbourne, March 2012

Document details

This document should be cited as:

Chhetri, P., A. Hashemi, F. Basic, A. Manzoni and G. Jayatilleke (2012) Bushfire, Heat Wave and Flooding - Case Studies from Australia. Report from the International Panel of the WEATHER project funded by the European Commission's 7th framework programme. Melbourne, March 2012.

Document title:	Bushfire, Heat Wave and Flooding - Case Studies from Australia
Lead Author:	Prof. Prem Chhetri
Version:	1.0 (final)
Date:	March 2012
Status:	Public
Quality review:	Fraunhofer ISI
Accepted:	1.4.2012

The WEATHER project:

Full title: WEATHER – Weather Extremes: Impacts on Transport Systems and Hazards for European Regions.

Duration: November 1st 2009 to April 30th 2012

Funding: Call 2008-TPT-1, 7th framework program of the European Commission, Directorate General for Research and Technical Development

Contract.: Grant Agreement no. 233 783

Consortium:
Fraunhofer-Institute for Systems and Innovation Research (ISI), Karlsruhe – project coordinator
Fraunhofer-Institute for Transportation and Infrastructure Systems (IVI), Dresden
Centre for Research and Technology Hellas (CERTH), Helenic Institute for Transport (HIT), Thessaloniki
Société de Mathématiques Appliquées et de Sciences Humaines - International research Center on Environment and Development (SMASH-CIRED), Paris
Karlsruhe Institute for Technology (KIT), Institute for Industrial Production (IIP), Karlsruhe
Institute of Studies for the Integration of Systems (ISIS), Rome
HERRY Consult GmbH, Vienna
Agenzia Regionale Prevenzione e Ambiente dell'Emilia Romagna (ARPA-ER), Servizio Idro-Meteo-Clima (SIMC), Bologna
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Acknowledgements

The author acknowledges the expert contributions of researchers on the project as well as the feedback from the National Transport Commission. I would also like to thank to Dr Claus Doll from Fraunhofer-Institut für System- und Innovationsforschung (ISI) for his advice on scoping this study to fit to the overarching purpose of the WEATHER Project.

Executive Summary

Australia is a country subject to a vast array of climatic regimes. In recent years it has had continuous exposure to various weather events such as drought, prolonged periods of extreme temperatures (heat waves), bushfires, cyclones and floods. The intensity and likely frequency of these events is forecast to significantly increase over the next 20 to 50 years as a result of climate change. Australia's transport systems, physical and social infrastructure, will be exposed to greater disruption as a direct result of these weather events. Since Australia is predominately a commodity export driven country, any impact on the country's transport infrastructure directly impacts GDP and living standards. As a consequence, government agencies have been reviewing these major climatic events to develop a series of adaption strategies to assist in the preparedness of the nation, including transport systems, to cope with future weather events.

One of the major issues Australia faces in planning for its transport system to adapt to climate change is the fragmented nature of the sector.

The options which are open to government to facilitate adaption to climate change include:

1. Codes of practice
2. Operation and management plans
3. Conditional licenses/approval/accreditation
4. Fitness for purpose obligations

How Australia is responding and adapting to these recent major weather events is explored in this report through three case studies. These include:

- The 2009 Victorian 'Black Saturday' Bushfires
- Heatwaves in Victoria
- Flooding in Queensland and Victoria

The case studies explore the magnitude of damages to infrastructure assets and operations, user time losses and safety; the protection measures existing before the event and how effective these have been; and the adaptation strategies after the event and the policy instruments applied.

Victorian Bushfires

Damage

The bushfires significantly impacted transport infrastructure, shutting road and rail networks for extended periods and in particular, the capacity to resupply affected areas.

The total cost of the bushfires has been estimated at $AUD 4 billion, with road and rail services taking months before being normalised.

Existing protection measures

Some of the key existing measures in place were not well designed nor understood clearly enough to deal with the size and extent of extreme bushfire events. These include:

- The Wildfire Management Overlay (WMO) which detects areas where the strength of wildfire is considerable and can cause danger to life and assets. WMO's intention is to make certain that building development in areas subject to high fire risk includes appropriate fire protection measures.
- The 'Stay or Go' policy was revisited and modified to 'Prepare, Stay and Defend or Leave Early' to be clearer for future extreme bushfires.

Adaption strategies

Following the bushfires, a Royal Commission was held to attempt to avert future loss of life and infrastructure should such an event occur again. A core adaption strategy was increased preparedness to respond to such an event and the establishment of formal communication systems to forewarn those exposed to similar risk in the future, and response plans. The four options open to government have been applied as follows:

- *Codes of practice* – ensure all roads operated by VicRoads adhere to 1985 Codes of Practice
- *Operation and management plans* – development of Rail Operations Management System
- *Condition licenses* – introduction of Bushfire Management Overlay
- *Fitness for purpose obligations* – a State Planning Policy for Bushfire Prone Regions

Heatwaves

Damage

The cost of the 2009 heatwave is estimated at $AUD 800 million due to power outages and transport disruptions, resulting in 25% of metro train services being cancelled, rail lines buckling, bitumen on major highways bleeding, concrete slabs lifting and cracking and traffic signals malfunctioning. In addition, port facility productivity declined through vessel delays and reduced crane capacity.

Existing protection measures

There were few existing measures in place.

Adaption strategies

The four options put forward to government have been applied as follows:

- *Codes of practice* – none currently implemented.
- *Operation and management plans* – public transport providers have developed management plans for staff, passengers and standby contingency equipment to rapidly respond to issues at times of excessive heat.
- *Condition licenses* – enhancing and maintaining existing above and below rail infrastructure to cope with excessive heat.
- *Fitness for purpose obligations* - modernisation of transport infrastructure to be able to withstand future excess heat events, for example increasing replacement of wooden sleepers from 22,000 to 64,000 per year, additional rail ballast and changing to continuous welded joints.

Flooding - Queensland & Victoria Focus

Damage

The Queensland Floods are viewed as one of the most expensive disasters in Australia's history costing between $AUD 13 billion and $AUD 30 billion. Australia's coal exports were dramatically reduced as supply chains were cut dragging the national economy backwards. The Port of Brisbane was shut down for ten days and the channel depth reduced, costing nearly $AUD 500 million. Brisbane's entire public transport system was affected, the ferry network in particular being destroyed. Lost rail revenue was calculated at $AUD 26 million, infrastructure repairs an estimated $AUD 1 billion, and there was $AUD 213 million trucking industry loss.

Existing protection measures

There were existing plans and authorities responsible for management of flood related activities but there is general consensus that these were inadequate for extreme situations.

Adaption strategies

Of the four options open to government they have been applied as follows:

- *Codes of practice* – ensure safeguarding of existing transportation and logistics infrastructure through the Victorian Flood Management Strategy 1998, the Water Act1989 and the Emergency Management Act 1986, Dam Safety Management Guidelines, and Australian Government Emergency Management Planning (Floods).

- *Operation and management plans* – improve management of roads, bridges and dams by reviewing and updating existing guidelines, and provide assistance to local governments to enhance their ability to cope with extreme weather events
- *Condition licenses* – state road and water authorities to enhance and clearly define roles and responsibilities.
- *Fitness for purpose obligations* – authorised government agencies to provide timely information to the public and communities in preparation for floods, and to improve public awareness and education of those in risk areas.

Overall Remarks

The 2009 heatwave, the Queensland floods and Victorian floods, and bushfires all instigated high level government inquiries aimed at assessing the effectiveness of existing transportation provisions and the capacity of logistics infrastructure and management support systems in coping with extreme weather events, which are not uncommon in Australia but which seem to have become extreme and more frequent in recent decades. The general findings of these inquiries pointed out that existing transportation and infrastructure systems were not able to cope with disaster situations that are considered extreme although in each instance there were high levels of commitment, collective effort and goodwill of all stakeholders.

Furthermore, the analysis of such extreme events generally finds that post-event actions most likely result in only marginal improvements in resilience to such events unless a systematic and structured response, as recommended by the inquiring committees, is adopted. Additional to the above strategies that focus primarily on preparedness for event occurrence, is the acknowledgement that a further concerted effort is needed for mitigation and post-event recovery in the immediate and longer term. Plans need to be prepared for the execution of projects targeting upgrades and repairs to social, economic and logistics infrastructures with a view that they become more resilient in the future.

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1 Introduction

The overarching aim of this report is to provide an overview of the impacts of past extreme weather events on Australia's transportation systems. It reviews the mitigation or adaptation strategies and policies, proposed or adopted, to respond to those extreme weather events. More specifically, this report examines the potential implications of extreme weather events for transportation systems by reviewing previous impacts; the preparedness of government agencies for managing extreme events detrimental to logistics operations; and the approaches adopted to secure Australian transportation from such shifts in extreme weather conditions.

When considering extreme weather events it is important to consider the type and scale of events since they define the severity of the impact. The impacts are categorized as immediate, temporary, permanent or delayed. **Immediate** impacts are those occurring at the onset of the event, for example a loss of access due to rising flood levels or fire. **Temporary** impacts are those losses due to damage from the event and can be rectified in the short term, e.g. fallen trees). **Permanent** impacts are the degraded, damaged or destroyed infrastructures due to damage from water or fire, while **delayed** impacts could be the consequential economic costs from disrupted industries. The events considered in this document cover all four categories.

The economic implication of extreme weather events such as bushfires, floods, landslides and cyclones on transportation and logistics systems is widely recognised. Natural disasters in Australia account for more than one billion dollars in annual damages to homes, businesses and infrastructure (Reeves et al., 2010). Costs include social displacement, maintenance, repair and replacement of critical infrastructure, costs associated with the restoration of ecological damage, and the incalculable costs of loss of life. It also increases the frequency and length of business closure or a relative reduction of throughput and work productivity. The direct impacts include the increased cost of storage, shipment delay, supply chain backlog, insurance claims and damage or loss of goods.

The report provides an updated and more accurate understanding of the dangers posed by the vagaries of extreme weather events on transport systems and infrastructure in Australia. It investigates the changes in practice and policy necessary to make Australian transportation systems more resilient to weather extremities. Specifically, this report presents a range of case studies of recent extreme weather events on the Australian continent to answer the following research questions:

- What is the order of damages to infrastructure assets and operations, user time losses and safety?

- Which protection measures existed before the event and how effective were they?
- How have adaptation strategies changed after the event and which policy instruments are applied or expected to be implemented.

The case studies of extreme weather events investigated in this report include:

- The 2009 Victorian ‘Black Saturday’ Bushfires
- Heatwaves in Victoria
- Flooding in Queensland and Victoria

2 Projected Future Climate of Australia

For any commercial business, exposure to extreme climatic events is influenced by a variety of interrelated factors including the physical location of business operations, the conditions under which the business operates, and business and community characteristics (Tierney, 2007).

The impacts of extreme climate events on transport systems can be both physical and social. It is expected that coastal storm surge, adverse winds and wave conditions will increase in intensity and frequency. The physical impacts of such conditions include: “increased runoff and siltation requiring increased dredging; disturbance and distribution of currently entrained heavy metals and other pollutants; increased high wind stoppages under Occupational Health and Safety requirements; delays to berthing and cargo handling; coastal flooding; and required engineering upgrades to wharfs, piers, gantries and other cargo handling equipment” (Australian Government, 2009 p. 120).

The impacts of extreme weather events on transportation services and logistics provisions such as navigation and berthing, goods handling, circulation and storage, vessel movements, the quality and lifespan of assets, services scheduling and delivery, and workforce health and well-being are ecologically severe and economically significant (International Finance Corporation, 2011). For many coastal ports it is likely that the compounded effects of mean sea level rise, high tides and increased storm surges will be the most significant risks of climate change (Wright, 2007). These impacts can result in business closure (temporary or permanent). An interruption to normal business functions can lead to a decline in financial measures such as value, return on investment and growth, or other measures of business success. Consequently, this can lead to a loss of jobs which will affect personal income, overall economic performance, and may lead to a range of related challenges within the general community.

ustralia has a variety of climatic regimes. It has a long history of coping with the uncertainty of extreme weather conditions where environmental and settlement systems are equally vulnerable to the climate change risks. Throughout its history, Australia has experienced continuous extreme weather events such as drought, bushfires, cyclones and floods. To understand the likely impacts of these extreme weather events on transport systems, it is first necessary to review the projected future climate of Australia. This has been investigated through the description of climate change scenarios developed by the Commonwealth Scientific and Industrial Research Organisation (CSIRO) and the Bureau of Meteorology (BOM).

Overall, the climate projections indicate an increase in intensity of cyclones and areas exposed to cyclone, increases in extreme rainfall and wind, in mean sea levels, in temperature ranges, in the numbers of hot days, in ocean swell, and increases in ocean acidification (CSIRO and BOM). Longer-term changes to average trends in climatic conditions as well as an increase in the strength and regularity of extreme weather events are predicted. For instance, CSIRO (2007) estimates that climate change might lead to a 60% increase in intensity of Category 3 to 5 severe storms (Table 1) by 2030 and 140% by 2070. The coastal areas of Queensland, northern coast of Western Australia and the Northern Territory are particularly vulnerable to cyclones.

Table 1: Definition of Severe Storms by Category (BoM (b), 2011)

Category	Maximum Mean Wind (km/h)	Typical Strongest Gust (km/h)	Central Pressure (hPa)	Typical Effects
1	63 - 88	< 125	> 985	Negligible house damage. Damage to some crops, trees and caravans. Craft may drag moorings
2	89 - 117	125 - 164	985 - 970	Minor house damage. Significant damage to signs, trees and caravans. Heavy damage to some crops. Risk of power failure. Small craft may break moorings.
3	118 - 159	165 - 224	970 - 955	Some roof and structural damage. Some caravans destroyed. Power failures likely. (e.g. *Winifred*)
4	160 - 199	225 - 279	955 - 930	Significant roofing loss and structural damage. Many caravans destroyed and blown away. Dangerous airborne debris. Widespread power failures. (e.g. *Tracy*, *Olivia*)
5	> 200	> 279	< 930	Extremely dangerous with widespread destruction. (e.g. *Vance*)

Australia as an island nation is posed in a unique situation where its economy, productivity, quality of life and standard of living largely rely on its foreign trade. Consequently, the maritime industry, ports and connected infrastructures in Australia are extremely important to the country's economic and social wellbeing. The value of Australia's 2011 imports/export trade was $AUD 460 billion (Australian Trade Commission, 2011). Essentially 31% of GDP is dependent on port and associated infrastructure operations. Any natural disaster impacting ports or infrastructure therefore has serious consequences for Australia. A map of Australia's key ports (Figure 1) shows their geographic dispersion and their importance by port volume activity.

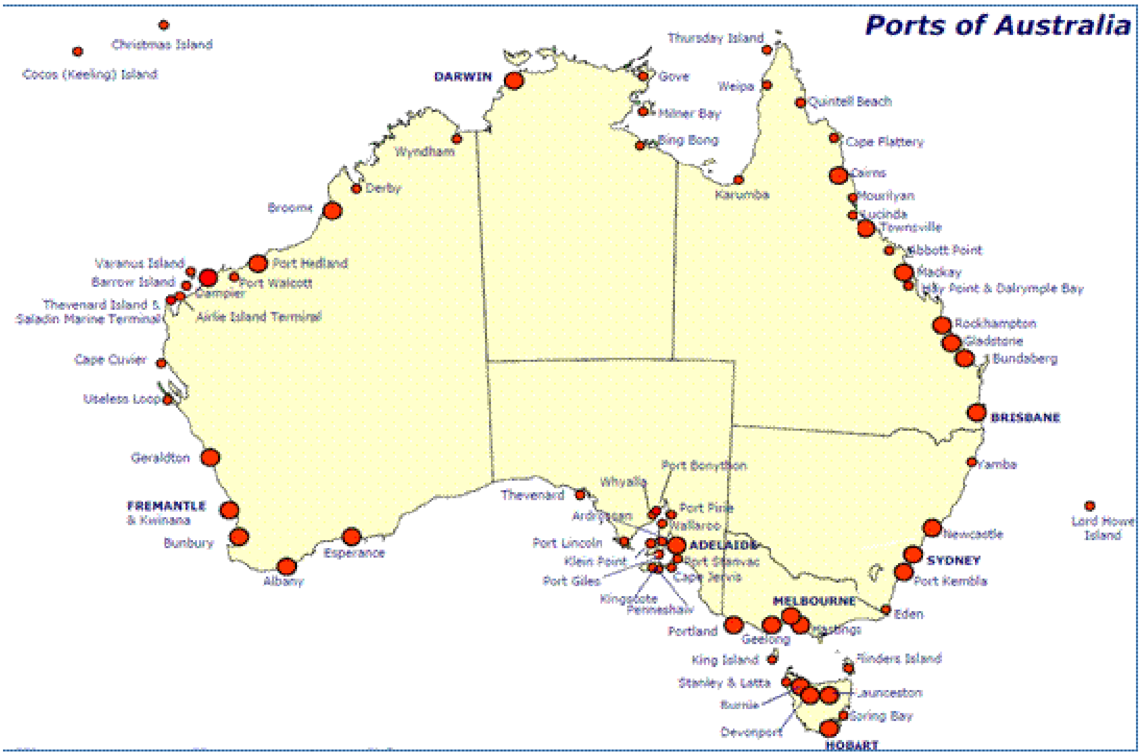

Figure 1: Australia's key ports (Ports Australia, 2009).

Supply chains including key ports such as Townsville, Dalrymple Bay, Hay Point, Abbott Point, Gladstone, Darwin, Dampier and Port Hedland, all in the northern half of Australia, are at a greater risk of experiencing more intense and frequent cyclones. A cyclone occurring within a 300 km radius of a port will cause business disruption and up to 48 hours of port downtime (GCCR, 2008). With the expected rise in temperatures by 2030 for northern Australia, cyclone event intensity will increase together with a potential expansion of cyclone activity to southern regions such as the Port of Brisbane. In the case of intermodal trans-shipment, the loading and unloading operations, which must cease when the maximum wind speed exceeds 36km/hour has the potential to cause severe disruptions to crane activity (GCCR, 2008).

There is still uncertainty on the magnitude of sea level rises and the frequency of extreme events over the forthcoming century. However, it is forecast that an 18cm sea level rise by 2100 will inundate low-lying transportation facilities such as coastal highways, railways, and ports (Warrick and Rahman, 1992). Other studies estimate a rise of 70cm (Welle, 2005) and an extreme as much as two to twelve metres (Hansen et al., 2007). Nonetheless, it is expected that as average temperatures increase, the economic impacts related to sea level rises and extreme events will also increase.

Table 2: Climate change variables and scenarios (Collated from CSIRO and BOM (a,b,c,d) Projections)

<table>
<tr><th>Climate change variable</th><th>2030</th><th>2070</th></tr>
<tr><td>Sea level rise</td><td>The worst case scenario projects an increase of 0.149m rise in mean sea level; however it tends to spatially vary across Australia.</td><td>The worst case scenario projects an increase of 0.471m rise in mean sea level.</td></tr>
<tr><td>Storm Surge</td><td>Storm surge studies for parts of the Victorian and Queensland coasts reveal the possibility of major upsurge in flood due to higher mean sea level and more extreme weather events.</td><td></td></tr>
<tr><td>Temperature</td><td>The best estimate of annual warming over Australia by 2030 is around 1.0ºC, with warmings of around 0.7-0.9ºC in coastal regions and 1-1.2ºC inland regions.</td><td>Average warming over inland Australia ranges from around 1.8ºC for the B1 (low emissions) scenario to around 3.4ºC for the A1FI (high emissions) scenario.</td></tr>
<tr><td>Extremely hot days
(over 35°C)</td><td>This number of extreme hots days varies across different regions in Australia. Some major cities are listed below:
<table>
<tr><th></th><th>Alice Springs</th><th>Sydney</th><th>Melbour-ne</th><th>Perth</th></tr>
<tr><td>Current</td><td>90</td><td>3.5</td><td>9</td><td>28</td></tr>
<tr><td>Low emissions</td><td>102</td><td>4.1</td><td>11</td><td>33</td></tr>
<tr><td>High emissi-ons</td><td>118</td><td>5.1</td><td>13</td><td>39</td></tr>
</table></td><td>This number of extreme hots days varies across different regions in Australia. Some major cities are listed below:
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<tr><th></th><th>Alice Springs</th><th>Sydney</th><th>Melbourne</th><th>Perth</th></tr>
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<tr><td>Low emissi-ons</td><td>132</td><td>6</td><td>15</td><td>44</td></tr>
<tr><td>High emissi-ons</td><td>182</td><td>12</td><td>26</td><td>67</td></tr>
</table></td></tr>
<tr><td>Rainfall</td><td>Annual rainfall variation shows
- Little change in the far north
- Decreases of 2% to 5% elsewhere.</td><td>- In the low emissions scenario is -20% to +10% in central, eastern and northern areas, with a best estimate of little change in the far north. The range of change in southern areas is from a 20% decrease to little change, with best estimate of around a 7.5% decrease.
- In the high emissions scenario is -30% to +20% in central, eastern and northern areas, with a best estimate of little change in the far north grading to around a 10% decrease in the south-west. In southern areas is from a 30% decrease to a 5% increase, with best estimate of around a 10% decrease.</td></tr>
</table>

The projected patterns and trends relevant to climate change variables and scenarios for Australia, by the CSIRO and BOM, are summarised in Table 2. Note however, that the projections vary because different models are used and there is still conjecture at the downscaled level. Table 2

2.1 Impact on the Transport System

A wide range of road, rail, maritime and air transport infrastructure is likely to be affected by climate change. The physical effects of climate change, identified in the Department of Climate Change and Energy Efficiency report by Maddocks (2011), that set major challenges for transport infrastructure and associated services include higher temperatures and increased solar radiation, rising sea levels, increasing prevalence of bushfire events, including lightning strikes, extreme winds and heavy rainfall, storm surges and increases in storm severity (Table 3). This will result in augmented degradation of roads, buckling of rail tracks, and damage to ports and airports. In case of minor impact, the effects of climate change may be resolved by additional maintenance and repair. In case of major events, some infrastructure may become permanently unusable and need replacing. Table 3 presents the various scenarios.

Table 3: The likely impact of climate change on transport infrastructure (Maddocks, 2011)

Risk Scenario	Climate variable	Impact	Consequences	Likelihood	Region	Risk 2070	Risk Scenario
Degradation of roads	Increase in temperature and heatwaves Increased solar radiation Increase in extreme rainfall events Increased drought frequency and decrease in soil moisture	Degradation of road surface caused by heat, solar radiation Degradation of road foundations and drainage assets by increased ground movement with drying soils followed by high ground water events Flood damage to road surface and foundations Increased landslip and embankment failure	Increased maintenance and replacement costs Short term loss of access Financial impacts on councils and road authorities Community anger / fracture	High	All	Moderate to high	Degradation of roads
Rail track movement and damage	Increase in temperature and heatwaves	Degradation and buckling of rail tracks caused by heat	Interruption to rail services Rail safety risks Increased maintenance and replacement costs	High	All	High	Rail track movement and damage
Airports damage and service interruption	Increase in temperature and heatwaves Increased solar radiation Increase in extreme rainfall events and sea level rise Increase in extreme wind Increased high bushfire risk days	Tarmac degradation Damage and accelerated degradation of airport infrastructure Reduced visibility from bushfire smoke and dust storms Coastal airports damaged from storm surge and sea level rise inundation	Increased maintenance and replacement costs Interruption to services Potential accidents	High	All	Moderate to high	Airports damage and service interruption
Storm and flood damage to trans-	Increase in extreme rainfall events Increase in extreme wind intensity	Damage to buildings and infrastructure due to flooding, debris, fallen trees, winds Widespread bridge damage Tunnel flooding	Cost of rebuilding Short term loss of transport and bridge access Higher insurance and maintenance costs	High	All	Moderate to high	Storm and flood damage to transport infrastructure

port infra-structure			Community anger				
Coastal flooding and storm surge	Sea level rise Increase in extreme rainfall events Increase in extreme wind intensity	Damage to road and rail transport infra-structure adjacent to coast Degradation and failure of tunnel and bridge structures close to coast Degradation and corrosion due to salt infiltration in groundwater Damage to ports and jetties including water overtopping of sea wall protection	Cost of rebuilding or moving roads and transport Permanent loss of use of road and rail transport in flooded/at risk areas Higher insurance and main-tenance costs Community anger / fracture	High	All	High	Coastal flooding and storm surge

2.2 Tools for Government to Facilitate Adaption Measures

One of the issues Australia faces in planning for its transport infrastructure to adapt to climate change is the fragmented nature of that sector. Each State Government regulates for roads, rail, ports and air transport within its jurisdiction and assigns responsibilities for planning, funding, construction, operation and maintenance to government departments. The authorities for these functions vary between states. The fragmentation however, is slowly changing with the advent of a single national regulator for rail safety, heavy vehicles, and marine.

- The existing regulatory framework applicable to transport infrastructure has obstacles which hinder the adaption to climate change. Key obstacles identified in the Department of Climate Change and Energy Efficiency report (Maddocks, 2011, p xiii) include:
  "Lack of explicit or implicit recognition of the need to adapt to climate change
- Regulatory framework only applies to new infrastructure and does not apply to existing infrastructure
- Lack of harmonisation and fragmentation of approach within jurisdictions and between jurisdictions
- Inadequate, inconsistent or out-dated information regarding climate change risks
- Implementation is ineffective
- Enforcement mechanisms are weak or too costly to pursue"

The options open to government to facilitate adaption to climate change are summarised in Table 4.

Table 4: Options open to government to facilitate adaptation to climate change (Maddocks, 2011)

Tool	Usefulness for Climate Change Adaptation	Ideal Circumstances for Use
Codes of practice	Can be useful to make sure that climate change risks are calculated as part of continuing management and operation of current infrastructure	Codes of practice are typically not mandatory. Therefore, the use of codes to address climate change risks are ideally suited to sectors where the degree of voluntary compliance is relatively high and/or where it is in the entities' interests to comply.
Operation and management plans	A requirement can be imposed to require future plans to specifically account for climate change risks	Plans that account for climate change risks could be useful for a large range of infrastructure categories. They will be most effective in cases where a regulatory framework continues to apply to the infrastructure after it has been constructed, thereby providing regulatory oversight to ensure that the plans are dynamic, keep pace with climate change risks and are effectively implemented.
Conditional licenses/ approval/ accreditation	Licenses, approval or accreditation can be restricted to sufficient review and management of climate change risks	The use of conditions to require assessment of climate change risks in relation to licenses, approval or accreditation is most viable in the context of regimes where licensing, approval or accreditation regimes already exist. Ideally, mechanisms to monitor and enforce such conditions should also exist.
Fitness for purpose obligations	Can be used to make sure that the infrastructure has been designed in a way that it can deal with existing and upcoming climate change risks	Fitness for purpose obligations is useful in relation to relatively certain and foreseeable climate change risks. These obligations can be imposed to ensure that the design, construction and installation of infrastructure take account of these risks. They will need to be complemented by effective enforcement mechanisms.

3 Australian Case Studies

This section presents three case studies of extreme weather events with particular focus on the scale of damage to infrastructure assets and operations, user time losses and safety; the protection measures and their effectiveness; and the adaptation strategies applied or envisaged to reduce the level of risk.

3.1 The 2009 Victorian Black Saturday Bushfire

3.1.1 Background

Bushfire is a significant public health and safety issue. Fatal injuries and destruction of properties from bushfires continue to be a significant problem in Australia. The last week of January 2009 was one of the most extreme and protracted heatwaves ever for the Australian state of Victoria. For three consecutive days, the temperature in Melbourne was above 43°C (the first time in recorded history). It was forecast that on Saturday 7th February the temperature would be in the low 40°C's, accompanied by strong winds (Nguyen, 2010). The Country Fire Authority (CFA) and the Department of Sustainability and Environment (DSE), the state's primary bushfire agencies, warned that forests and grasslands were at their driest condition since the disastrous Ash Wednesday fires of 1983.

In many parts of the state, temperatures reached 40°C by 11.00am, increasing to the mid-40°C's soon after. Several areas experienced record-breaking maximums. In Melbourne for example, the temperature reached 46.4°C (VBRC, 2009). Multiple bushfires ignited throughout the state and as the powerful winds of the morning changed to an intense storm by the afternoon the fires increased greatly. Three hundred and sixteen of these grass, scrub or forest fires were attended or patrolled by CFA and DSE. Figure 2 shows the major locations of bushfire incidents. One hundred and seventy three people perished that day, with the majority of deaths occurring in the peri-urban areas/towns of Melbourne such as Kinglake and Marysville. These towns are known for offering a lifestyle change referred to as the 'tree-change' movement because of their popularity, being situated along tourism corridors and surrounded by national and state parks and reserves. However, they are connected through only a sparse road and rail network (Figure 3).

Figure 2: Major sites of bushfire in Victoria (Carson-Wikipedia, 2009)

Figure 3: Photos depicting the scale of damage and the intensity of bushfire (Top left: Hamintor n.d. Top right: Hargest n.d, Bottom: Black Saturday)

3.1.2 Impacts and Adaption Measures

The 2009 Victorian Black Saturday bushfires is an example of an extreme weather event that had catastrophic impacts on transportation systems and logistics operations. In addition to the loss of life and community displacement, the bushfires destroyed valuable assets and parts of the transportation system resulting in numerous towns, businesses and private houses being disconnected from the supply chain network for many days/weeks. An in-depth investigation into the bushfires provided the evidential base for formulating a range of legislative provisions, manifested in changes to the land use planning system through to the adoption of the Bushfire Management Overlay and the creation of a new Rail Operations Management System. The perception and understanding of the risk and the effectiveness of communication channels were found to be fundamental to the successful implementation of risk reduction and mitigation strategies. The strategies devised were for more effective geo-targeted bushfire safety programs to adjust to the needs of vulnerable groups, to build resiliency through awareness, and to ameliorate the community well-being.

Table 5 gives a summary analysis of the costs and impacts on assets and logistics operations, and presents the mitigation/adaptation measures put in place after this catastrophic event. The table shows the immense impact to transport systems including devastated rail and road infrastructure and a complete severing of the road network, resulting in acute disruptions in supply chain and hindering disaster relief efforts in the affected areas. Substantial mitigation and adaptation efforts however were initiated to ensure that the tragedy of such a scale can be avoided or managed in the best possible and most efficient way in future.

Table 5: Costs and impacts on assets and logistics operations and adopted mitigation/adaptation measures

	Costs and impacts on assets and operations	Mitigation/adaptation measures
Impacts and costs	A total of 173 people died in the Black Saturday bushfires. 73 people died in Ash Wednesday fires (1983). Of the 173 people who died, 113 perished inside their homes and a further 27 just outside them. 11 died in cars fleeing the fires with a further 10 dying on roadways, while many people successfully escaped approaching flames by car (Bushfire CRC, 2009). Three of the ?ve rail corridors were shut down by the 7 February 'Black Saturday' bush?res. Loss of Access/Escape routes during the bushfire, resulted in people being trapped and restricted operations of emergency services. Access to roads (e.g. around Marysville) were cut to unsafe roads (risk of falling trees across the road) 51 townships were directly impacted, over 2,000 homes destroyed, along with many businesses, schools and kindergartens Estimated cost of the fires to be more than $AUD 4 billion (Victorian Bushfire Royal Commission (a), 2009) The Victorian Managed Insurance Agency estimated total value of claims for lost or damaged assets and infrastructure is $AUD 76.7 million, the majority of the losses sustained being associated with the Kilmore East and Murrindindi fires (Victorian Bushfire Royal Commission (b), 2009: Appendix A, pg 344).	Australian Government contributed $465 million towards the reconstruction and recovery efforts to address the psycho-social, economic, infrastructure, and environmental impacts (Australian Government, 2009) The pre-existing Wildfire Management Overlay (WMO) detects areas where the strength of wildfire is considerable and probable to cause a danger to life and assets. WMO's intention is to make sure development in areas subject to high fire risk includes appropriate fire protection measures. The WMO was revised to improve safety as recommended by the Royal Commission and is now called the Bushfire Management Overlay (BMO) (Department of Planning and Community Development, 2011). The BMO requires that new developments implement appropriate bushfire protection measures including where the building is located on the site, emergency access and fire-fighting water supply. The BMO includes a statutory provision in Planning Schemes for high risk areas where the provisions apply to specific land.(Department of Planning and Community Development, 2011) Stay Or Go policy is now more accurately described by its full title, 'Prepare, Stay and Defend or Leave Early'. (Victorian Bushfire Royal Commission, 2009a)
Speed restrictions, delays and cancellation	Of 11,834 scheduled services over these two months, 515 were technically 'cancelled' although all but 41 were replaced by road coaches (20 of these couldn't be replaced as roads were cut off by bush?res). Fire destroyed 3000 sleepers in the Camperdown areas on the Warrnambool line. The damage was greater in the north-east with 1200 sleepers, the Wandong Station platform and two rail bridges destroyed.	VicRoads implement a systematic statewide program of bushfire risk evaluation for all roads for which it is responsible, to endure conformity with the obligations I s.43 of the Country Fire Authority Act 1958 and with the objectives expressed in the VicRoads 1985 Code of Practice.
Damage and destruction	Fires swept through the township of Wandong, destroying the station's platform, pit, 1200 sleepers and two rail bridges on the Seymour line. Fire also burned more than 3000 sleepers on the Warrnambool line near Camperdown. More than $AUD 1 million worth of damage was caused to V/Line infrastructure. (V/Line, 2009)	A new Rail Operations Management System (ROMS) is established with the ability to undertake simulations of a number of scenarios across rail network, including the loss of individual carriages and lines and to assist in the areas of ?eet management, timetabling and staff management(V/LINE, 2009).

3.2 Heat Waves

3.2.1 Background

A heat wave is a condition of severe, extensive and prolonged exposure to high ambient temperatures. Ambient heat impact on infrastructure is rarely considered to hold the same importance as other high impact events such as bushfires or cyclone because it is not as immediate in effect, but the impact of heat stress can be significant for human health, workplace health and safety as well as temperature sensitive components of transport systems.

From 27 January to 8 February 2009 south eastern Australia experienced an intense heatwave which in comparison with previous events, was regarded as one of Australia’s most intense periods of high temperatures (Reeves et al, 2010).

It followed 13 years of drought (below average rainfall) and in that 2009 period the heatwave accounted for an estimated 500 deaths in Adelaide and Melbourne and resulted in financial losses from mainly power outages, disruptions in transport services and poor responses to needs. The estimated the cost of the heat wave was $AUD 800 million. Governments, councils, hospitals, emergency organisations and the community showed a highly unprepared response to a heatwave of such extreme (Reeves et al., 2010).

Southern Australian urban areas have suffered from extreme and widespread heatwave events previously (e.g. 1908 and 1939) but the recent events happening in the first decade of this century have been extraordinarily extensive, long-term and severe compared to previous ones. The 2009 heatwave broke previous records with daily maximum temperatures 12°C - 15°C above the seasonal average of 28°C – 32°C for successive days. New daily maximum temperature extremes were observed for Adelaide (45.7°C) and Melbourne (46.4°C). Adelaide had eight consecutive days over 40°C and Melbourne suffered an unprecedented run of three days above 43°C. Night-time temperatures for both Adelaide and Melbourne were also unusually high. This heat build-up was made worse by exceptionally low surface moisture, a consequence of an extended drought over the previous 13 years (Reeves et al., 2010)..

The likelihood of similar meteorological conditions to the 2009 heatwave occurring in future decades is difficult to estimate. However, CSIRO predicts that for both cities the number of days with maximum temperatures over 35°C may increase by 25 per cent by 2030 and double by 2070.

Hennessy et al (2008), in ‘An assessment of the impact of climate change on the nature and frequency of exceptional climatic events’ finds that the extent and frequency of exceptionally hot years have been increasing rapidly over recent decades and the trend is expected to continue. While the report was primarily drafted for a national review of drought policy, the analysis and projections are relevant for transportation. Using international mid-range emissions scenarios, Figure 4 provides temperature, rainfall and evaporation projections relevant to the potentially destructive impacts of fire and temperature events.

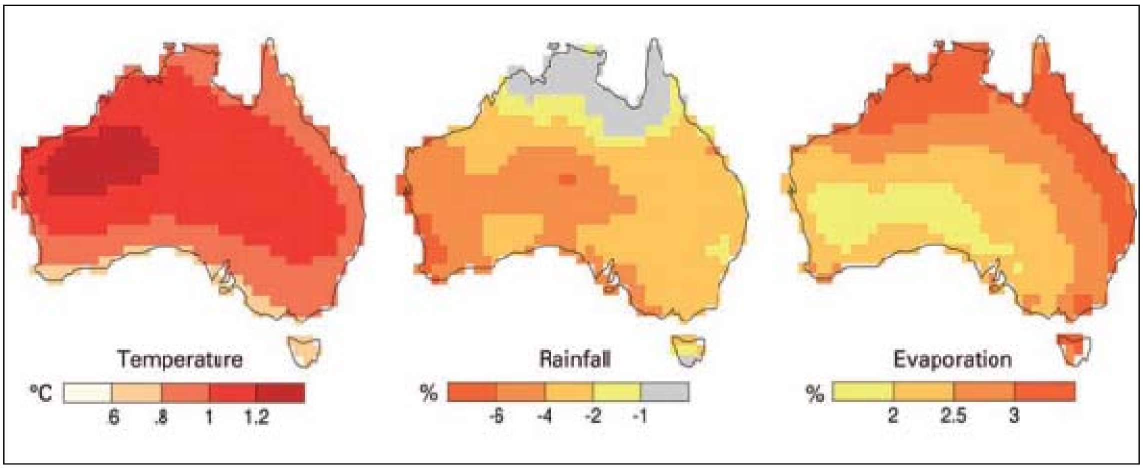

Figure 4: Temperature, Rainfall and Evaporation Projections by 2030. Median projected changes in annual-average temperature, rainfall and potential evaporation by 2030, relative to 1990, for the mid-range A1B emission scenario (Hennessy et al., 2008)

3.2.2 Impacts and Adaptation Measures

Record-breaking daytime temperatures, cumulative days of heat and continuing high temperatures at night are problematic for critical infrastructure. Melbourne's transport infrastructure showed varying levels of impact to these heatwave conditions. For airports the impacts appear minimal; for trams and sea ports the impacts were relatively minor while the impact on roads was moderate and the train system was moderate-high(Figure 5).

Figure 6 shows a correlated temporal pattern between temperature and counts of urban passenger train cancellations per day with temperatures above 40°C tending to have larger numbers of cancellations, highlighting the sensitivity of the transportation systems to extreme weather conditions such as elevated temperatures.

Figure 5: Rail buckling and replacing old timber sleepers with concrete sleepers (Metcalfe et al. 2009)

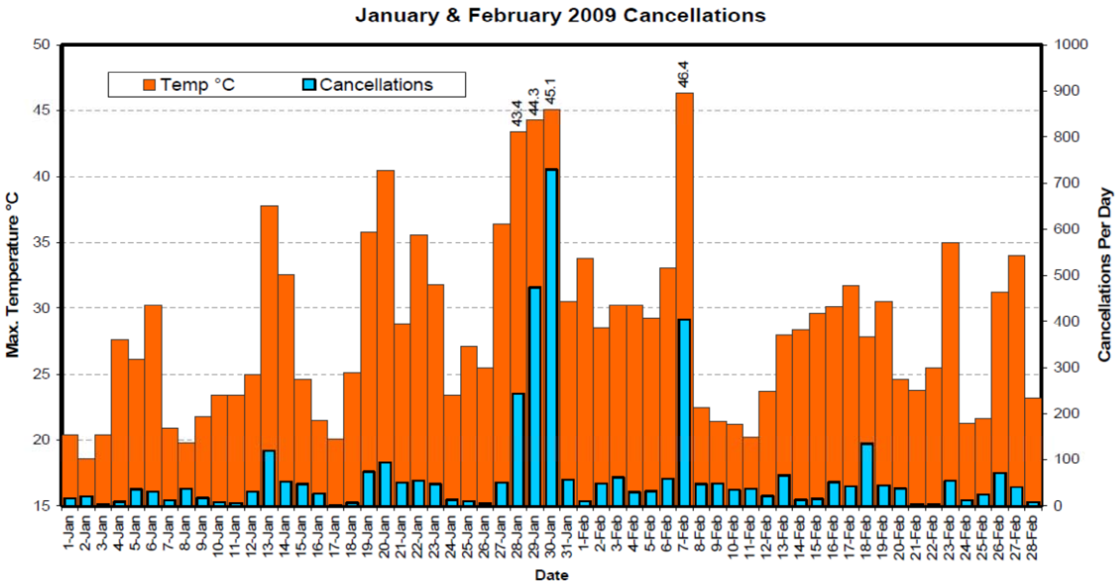

Figure 6: Temperature and cancellation record in January–February 2009 (Metcalfe et al. 2009)

Table 6 provides details of extreme heat events on transport operations and mitigation and adaption strategies.

Table 6: Impacts of extreme heat events on transport operations and mitigation/adaptation measures

Extreme Weather Events	Costs and impacts on assets and operations	Mitigation/adaptation measures
Modal Supply: Rail/Road/ Train and Tram	- Asset life of port infrastructure to decrease by 10 to 20 per cent. - Financial losses from the heatwave mainly resulted from power outages and transport service disruptions, as well as response costs, have been estimated at $AUD 800m. - In Melbourne on 30 January, train cancellations peaked when more than 24 per cent of services did not run. - Buckling, power failures, or failure of components such as air conditioners occurred. - Increased stop work for stevedores with more frequency and longer periods when weather reaches 38 degree (Celsius). - Impact of the heatwave on the tram subsector was minimal (Croucamp, 2009); whilst on trains it was much more severe. - On the three days of the initial heatwave peak, train service was on average 76 per cent, with only 64 per cent operating on the third day (Department of Transport 2009c). - More than 750 services out of 2400 were cancelled, that is, more than one-third of services (Connex media release). - There were 29 instances of reported rail buckling incidents (Osborne & McKeown 2009) that either slowed or disrupted service. - The heatwave caused buckling of the rail tracks buckled at Port Melbourne, Airport West and Royal Park. - 22 days of heat-related speed restrictions on at least one or more of V/Line's routes were imposed. - Impact of concern was on the physical comfort of tram passengers. The air-conditioning units in Comeng trains are not designed to operate above 34.5 °C (the remaining fleet consists of mainly Siemens and X'Trapolis trains which have units designed for about 42 °C). (Metcalfe et al. 2009), - The main direct impact on roads under its management was flushing or bleeding (patches of stickiness on the surface of roads made of bitumen and stone aggregate) at a number of places VicRoads. From 29 January to 7 February, 15 incidents of flushing were reported from three regions. Some of these occurred on major highways including Princes Highway East, Strzelecki Highway, Bass Highway Stage 5 and the South Gippsland Highway and a number of arterial roads. - Concrete slab footpaths lifted and cracked during the heatwave in a few places.	- Heatwaves are not a recognised emergency under the federal 'Natural Disaster Response and Recovery Arrangements'. Heatwaves is perceived not to require a planned response mechanism and that the existing generic template for disaster management is adequate. This prevents state governments being able to claim reimbursement for 50 per cent of certain response and recovery costs during a heatwave. - To reduce discomfort or improve thermoregulatory performance in a condition of heat stress, various adaptations such as increased water cooling, provision of extra shading, use of alternative time schedules for activities or shifting to alternative locations or operating regimes) were suggested. - The structural response to prevent track buckling is to replace old timber sleepers with concrete sleepers (Metcalfe et al., 2009). Increasing from 22,000 sleeper replacements to 64,000 per year. - More climate-appropriate design of residential and commercial buildings is suggested to cope with extreme heat events. - The practice of track being joined by 'fish plates', bolted at the side, has now been replaced by the use of continuous welded joints, which have no expansion gap. - On hot days drivers and workers are required as a part of heat policy to carry thermos flasks for carrying iced water on the job. - Tram depots are equipped with ice machines. At times of excess heat, work hours are reduced and outdoor workers are advised to stay under shade Yarra Trams. - Other measures include maintaining a standby train fleet (an extra 10 trains), bus contingency arrangements, interface between operations and infrastructure staff, and an increase in funding for maintenance. - Provision and compaction of additional ballast and track strengthening at 400 locations. - Field technicians deployed during hot weather for monitoring at high-risk locations. - Mobile track gangs with water to cool tracks during hot weather. - A/C units in the Comeng fleet have been serviced by cleaning condenser coils and radiators, and changing filters. - Changing filters at 2-week intervals instead of

	- Traffic signals at 124 intersections in metropolitan Melbourne and three in regional Victoria were reported to be malfunctioning not only due to excessive heat, but primarily due to failure of electrical supply (Croucamp 2009).	3-week intervals as before. - New fleet of X'Trapolis trains are being brought in, which have a higher heat tolerance level. - Sufficient A/C upgrade by 2010 so that all driving cabs will be fed from a new unit to ensure driver comfort and safety, and compliance with new Fatigue Management Plan FMP. - Leaving pantographs up on hot days for continuity of A/C operation and reducing load on A/C system. - Resetting carriage temperature to higher level to reduce A/C load. - Investigation for opportunity for Split Saloon Window operable during hot weather and automatic closing doors.
Intermodal - Seaports	- Roughly 5% of the 36-hectare terminal was cited to have been out of action during the heatwave, which contributed to a reduced working capacity. This problem was also experienced on berths and terminal roadways. - High temperature poses a potential risk for the loading and unloading of volatile substances such as petroleum and gas products - Vessel delays experienced due to the slowdown in loading/unloading operation. - - Movement of heavy machinery on bleeding pavements caused rutting and heaving, with waves forming on the surface. - There was a loss of 49.5 crane hours in January 2010, as compared to the 72 crane hours which were lost in January 2009.	- Fifteen per cent of the area of 36 hectare terminal has now been converted into concrete with further plan to gradually pave the entire terminal yard.
Intermodal - Airports	- The impact of the 2009 heatwave was barely felt at the airport. There was no business interruption and no flights were delayed or cancelled because of the heatwave.	

3.3 Flooding – Queensland and Victoria

3.3.1 Background

The Monsoon season in Queensland typically begins in December each year. In 2010/2011 Australia experienced an extremely strong La Niña effect, the second strongest in its history. La Niña is the positive phase of the El Niño Southern Oscillation which is the cooler than average sea surface temperatures (SSTs) in the central and eastern tropical Pacific Ocean which normally results in higher than average winter, spring and early summer rainfall over much of Australia. Ocean temperatures around Australia were near record high levels, there were more frequent low pressure systems over Australia and more humid conditions than usual, all accompanied by heavy monsoonal rainfalls. Excessive rainfall across much of eastern Australia in 2010/2011, together with record cyclone activity (Figure 7 and Figure 8) caused severe flooding and damage to transport and other infrastructure.

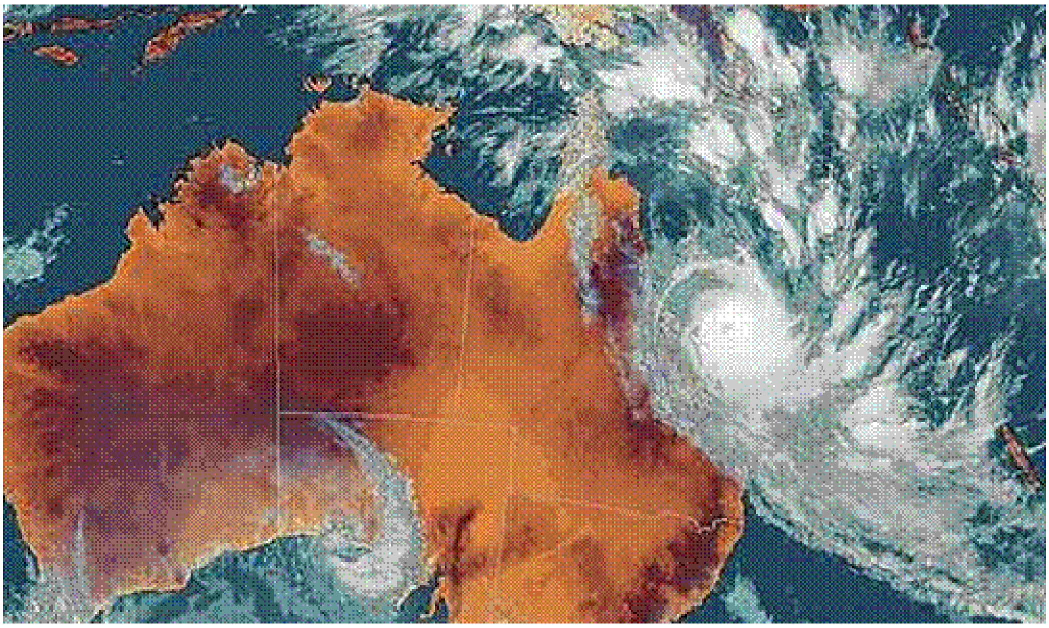

Figure 7: Image of Cyclone Yasi February 2011. Cyclone Yasi is one of the most powerful cyclones to have affected Queensland on record (BoM (a), 2011)

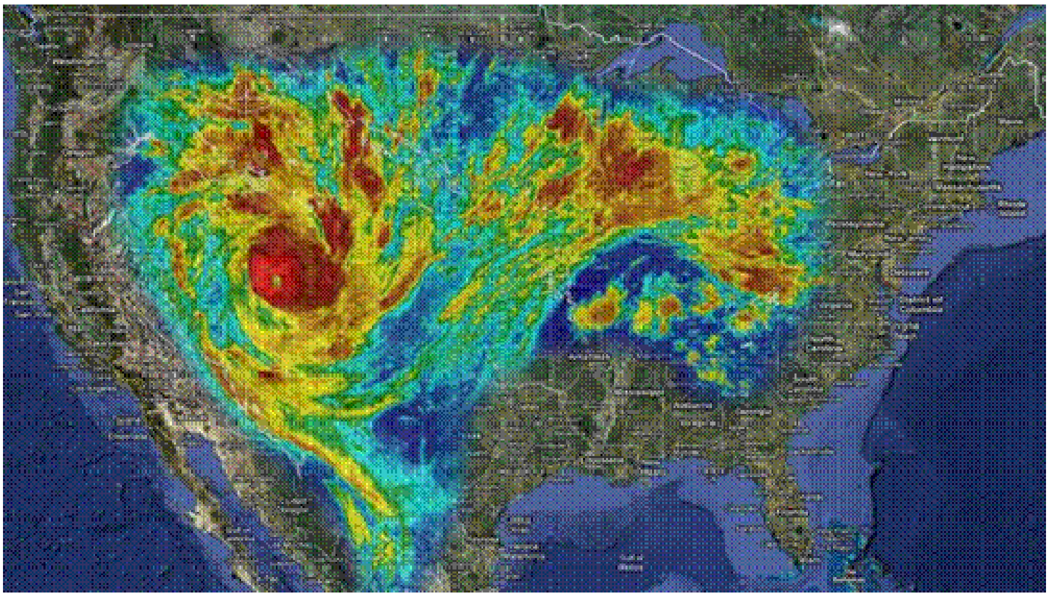

Figure 8: Map showing Tropical Cyclone Yasi superimposed over the USA to demonstrate the magnitude of the event (Archer and Mastrosavas, 2011)

3.3.2 Queensland

More than one quarter of the coal mines in Queensland's Bowen Basin had to stop operations and a further 60% were working under restrictions. Flooding stopped the production of coal but its transport was also disrupted because of damage to railways. Companies declared emergency conditions and ports were forced to run down coal stockpiles to meet demand. Export losses of over 1 million tonnes per week resulted in the mining sector earnings decreasing by $AUD 2.5 billion in total, of which $AUD 2 billion was due to lost coking coal production (PWC, 2011).

The Brisbane city flood gauge exceeded its major flood level on 12 January. Power had to be switched off to many parts of the central business district resulting in most businesses closing. Flooding also had a substantial impact on road conditions making some local roads inaccessible. Highways were cut off, roads were washed out and bridges were submerged in floodwaters. Communities living in rural and regional Queensland had difficulty in getting to the nearest town. The towns of Theodore and Condamine were fully evacuated and over 22 towns and more than 200,000 people were severely affected. Forty one local government areas were declared disaster areas with significant disruption to mining, agriculture and other industries (BOM, 2011d). Agricultural producers (e.g. milk, sugar) also struggled to transport supplies or livestock to or from properties.

3.3.3 Victoria

From September 2010 to February 2011, Victoria experienced some of the worst floods in the state's history. For four days from 12 October 2010 heavy rainfall caused flooding in the northern catchments, particularly along the Murray River, upstream of Lake Hume. The highest rainfalls were in the north east of the state, with many places recording in excess of 120mm for the four days. In November, heavy rain continued, particularly in the north east of the state, with Mt Hotham recording 94.4 millimetres (mm) in 24 hours (Comrie, 2011). The constant low pressure systems and unexpected tropical moisture made Victoria experience its wettest January on record. This triggered flood events that were more severe and widespread than those of September, affecting four times as many properties and over 100 towns, including the major regional centres of Charlton, Echuca, Horsham and Kerang. Between the 9th and 15th of January 2011, rainfall totals of 100 to 300mm were experienced across two-thirds of the state. The rainfall initially caused flash flooding across western and central parts of the state with subsequent major and moderate flooding spanning to the north, west and central Victoria. Approximately one-third of Victoria, including 70 local government areas, experienced some form of flooding or storm damage. The resulting costs and disruptions to regional, urban and rural communities were high (Comrie, 2011). The floods caused wide-ranging damage to local community infrastructure, such as public buildings and roads, essential services, such as water, electricity and telecommunications. There were also environmental and public health concerns (e.g. septic overflows). There were numerous disruptions to public transport and commercial freight services.

How Australian infrastructure was affected by the floods of 2010/2011 is shown by the number of major road closures in Figure 9 (each purple spots represents a major closure due to flood waters).

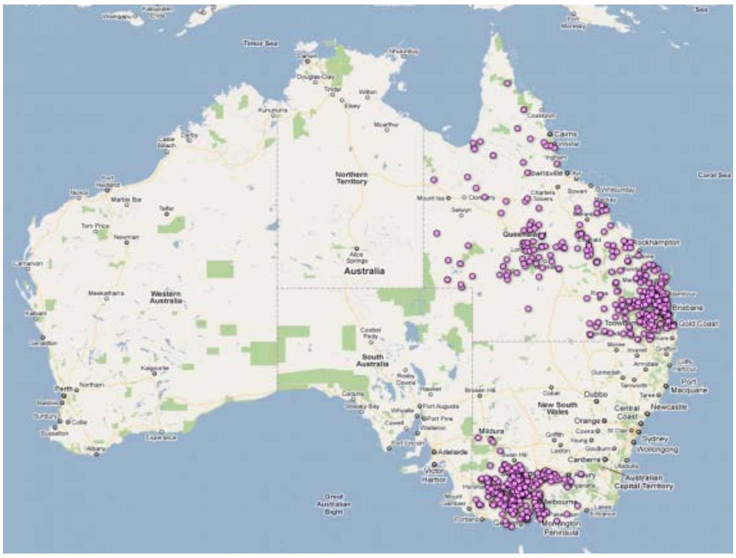

Figure 9: Major Road Closures due to floods 2010/2011 (map taken from Lost Press Marketing, 2011)

Figure 10: Flood impacts on road networks in Queensland (Dove, 2011)

Figure 11: Flood impacts on road networks in Victoria (Roads Collapsing, n.d)

3.4 Impact and Adaption Measures

3.4.1 Queensland

The 2011 floods are regarded as the 'the most expensive disaster in Australia's history' and that the government's task was to 'rebuild Queensland' (PWC, 2011, p. 2). Preliminary estimates are that flood damage alone could cut one per cent off national economic growth, a loss to the Australian economy of $AUD 13 billion (Sydney Morning Herald, 2011) while some other analysts suggest that the costs could be as high as $AUD 30 billion (ABC News, 2011). The Queensland Government estimates that the damage to local government roads, water supplies and waste facilities, buildings and airports is $AUD 2 billion dollars, and the total damage to public infrastructure across the state is between $AUD 5 and $AUD 6 billion dollars.

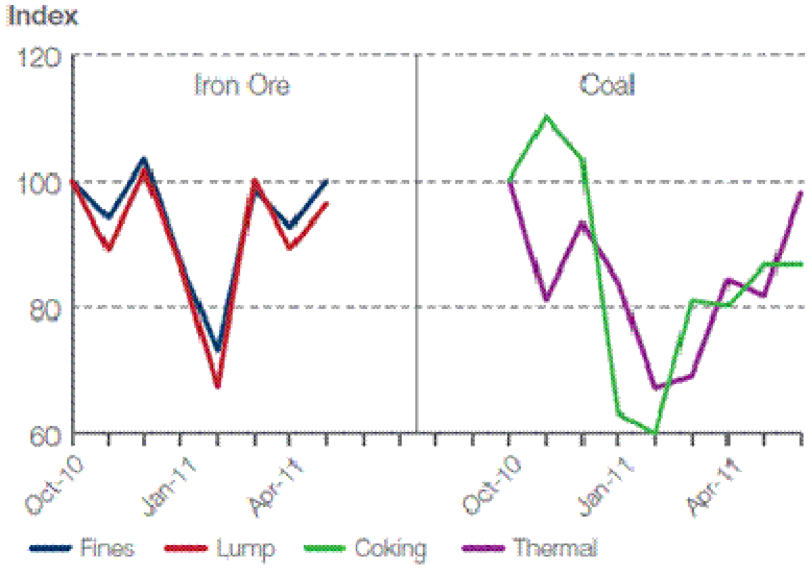

Figure 12: Export Volumes (Oct'10=100, nsa) (Australian Bureau of Statistics, 2011)

Figure 13: Images of destruction to Queensland rail lines – 2011 floods (Top left: Queensland floods, 2011a, Top right: Queensland floods, 2011b, Bottom left: Toowoomba Range damage, 2011, Bottom right: Mechielsen L. 2011

Australia's coal and bulk mineral exports were severely impacted by the floods and cyclones in Queensland and cyclones in northern Western Australia (Figure 12). The disruption to production and transport was enough to drag the Australian economy backwards in the first quarter of 2011. In Queensland, the mining sector earnings were estimated to have fallen by $AUD 2.5 billion, with $AUD 2 billion attributed to losses in coal production alone. After the cyclones and flooding, iron ore exports quickly returned to normal while the impact on coal was more prolonged because of the longer term nature of damaged infrastructure (Figure 13) where mine pits were flooded, heavy machinery submerged and rail lines washed away.

The Queensland Floods Commission of Inquiry has released an interim report outlining strategies ensuring groups are well prepared each year in the lead up to the wet season. Based on forecasts and scenarios the water reserves in dams will be set according to perceived risk. Management Plans will be established so that should an event occur, management can act decisively, the public is informed of risks and know what to do and how to respond, emergency services are properly resourced with the right equipment and those overseeing are fully trained and well informed, keeping ahead of perceived threats through scenario modelling.

There is an acknowledgement that these types of events occur, so one of the primary Brisbane mitigation strategies is to use dam water store or release mechanisms as a tool to reduce flood risk. However, flash flooding is rapid thus warranting a rapid response so the major focus of mitigation is in moving people and assets from exposed locations and then resupplying them. This is easier when those at risk have prior warning, knowledge of scenarios, and have clear response plans such as those below.

- Southeast Queensland Water – prior to September 30th each year ensure all parties are adequately prepared for the entire wet season and any flood event by:
  - Flood operation centre fully prepared with equipment, staff rostering, communications, modelling and information on operations and risk.
  - Adequate number of critical trained staff (e.g. Flood Engineers) available during wet season.
- Dam levels are reduced to 75% with an adjustment trigger established if the BOM forecasts a wet event.
- Review of all operation manuals with expert independent peer review and clear clarification and definition of strategies.
- Provide a structured management plan for recording information, observations, situations and conversations which will include:
  - Meteorological observations, situation analysis and forecasts
  - Current operating procedures
  - Strategy, aims and objectives of the flood engineers
  - Actual and expected releases
  - Any other comments.
- Establish an independent steering committee with oversight of modelling work to be reviewed by a technical committee which ensures the strategy remains current and provides for a simulation of future possible scenarios.

3.4.2 State Disaster Framework

Every area susceptible to flooding must have a disaster management plan, councils must publicise the plan and those who are required to work to it must understand it.

The public is to be made aware of the plan and those contributing to its application must be fully trained and kept informed.

A communication system such as phone texting (SMS) should be established to warn people in areas susceptible to flooding. The people within those regions should be aware of the required response. Sirens can also be used to sound flood warnings.

Operators of dams should be compliant with the requirements of the Queensland Dam Safety Management Guidelines (DERM February 2002), the ANCOLD Guidelines on Dam Safety Management (August 2003), and the Australian Government Emergency Management Planning for Floods Affected by Dams (2009).

The Department of Transport and Main Roads, as the primary provider of information about road conditions to the public, has to continue to develop accurate road condition reports and distribute them to the public and other agencies (Queensland Floods Commission of Inquiry, 2011).

Until the All Hazards Information Management System is in operation the status of requests for assistance should be tracked by other means and used to keep local disaster management groups informed of the progress on requests for assistance.

During floods, councils should quickly provide people in affected areas with advice on evacuation routes and the location of evacuation centres (Queensland Floods Commission of Inquiry, 2011).

Table 7 provides details of some of the costs and impacts of the flood on Queensland and on transportation.

Table 7: Costs and impacts of flooding on Queensland and transportation

Extreme Weather Events	Costs and impacts on assets and operations	Mitigation/adaptation measures
Impacts Queensland **Impacts** Brisbane	- Thirty-five people died in the floods. - More than 78 per cent of the state (an area, bigger than France and Germany combined, was declared a disaster zone, with over 2.5 million people affected. - Some 29,000 homes and businesses suffered some form of inundation. - The Queensland Reconstruction Authority has estimated that the cost of flooding events alone will be in excess of $AUD 5 billion (Queensland Floods Commission of Inquiry, 2011). - During the flood peak, 14,100 Brisbane properties were affected, with 1,203 houses suffered inundation, 66 Businesses were also severely affected: 1879 were partially inundated and 557 were completely inundated. - A significant portion of Brisbane's floating 'River Walk' and several privately and publicly owned jetties were washed into Moreton Bay. - Significant delay or sizeable detours for some road users and holiday travellers. Significant disruptions in online services on road closure due to difficulty accessing roads in remote areas, swiftness of rise and fall of water, thus information were out-dated very quickly, limited internet and mobile phone coverage and some confusion on the use of local name of roads.	- Development of Bruce Highway Upgrade Strategy (BHUS), Brisbane to Cairns, to improve efficiency, safety, reliability and flood immunity. This highway provides critical linkages for east-west freight movements, to 11 coastal ports and between inland production areas and towns / will deliver improved flood resilience, improved highway safety and remove existing constraints on connectivity to key gateways. - The Cross River Rail (CRR) Plan
Intermodal Seaports and airports	- Port of Brisbane was shut down from 11 January until Friday 21 January. Importantly, the port infrastructure was not damaged. - Sediment and material of about an extra 1.2 million m3 deposited into the port's channel and shipping berths, with official depths reduced by almost a metre in some areas. - Financial losses in transport revenue for 2010-11 are estimated around $AUD 467.4 million with $AUD 37.4 million revenue lost reported for ports. A decrease of about 6.4 per cent in total throughput in the Queensland port system in 2010-11 was recorded. - No disruption reported in flights at Brisbane Airport and its infrastructure was undamaged.	
Modal Road/rail/bus	- Inbound bus services to city were temporary ceased during the flooding. - Several railway lines were closed. The lost revenue for rail industry is estimated to be 26 million Australian	

	dollars and the repair bill could be over $AUD 1 billion - Heavy damages for road comparing to other infrastructure in Queensland were reported. Sections of highways were blocked or washed away by the rising water. The Queensland trucking industry was worth $AUD 7.0 billion, with $AUD 213.6 million being lost in revenue due to the floods. - Brisbane River transport infrastructure such as CityCat and Ferry Network was substantially destroyed	

3.4.3 Victoria

The long term average cost of flood damage in Victoria is estimated at $AUD 350 million per annum. This covers the direct physical damage to property and assets, and indirect damage arising from disruption to normal social and economic activities (Comrie, 2011). The estimated total cost of the 2011 floods is estimated at $AUD 1.3 billion, possibly increasing as further damage assessments arrive. For example, VicRoads found new damage to some roads previously repaired. Specific transport infrastructure damage is provided in Table 8.

Table 8: Victorian Floods Transportation Sector Damages 2011 (Victorian Floods Review, 2012)

Issue	Quantum
State-controlled bridges damaged	68
State-controlled (arterial) roads damaged	647
Railway bridges damaged	49
Railway bridges damaged	$AUD 4M
Railway track damaged (washaways)	66
Railway track damaged (washaways)	$AUD 10M
Local-controlled bridges damaged	$AUD 1M
Local-controlled roads damaged	2,876 km
Local-controlled roads damaged	$AUD 116M

The review of the 2010–11 Flood Warnings and Response inquiry made 93 recommendations on:

- *“the adequacy of flood predictions and modelling*

- *the timeliness and effectiveness of warnings and public information, emergency services command and control arrangements*
- *the adequacy of evacuations of people most at-risk, including those in health and aged care facilities*
- *the adequacy of clean-up and recovery arrangements*
- *the adequacy of service delivery by federal, state and local governments*
- *the adequacy of funding provided by state and federal governments for emergency grants, and community resilience".*

While not all recommendations are specifically targeted at the transport sector, they have an indirect effect by maximising warning coverage, improve flood modelling, minimise disruptions to services, and ensuring a rapid response to normalise services (Ryan, 2011).

To assist with road related mitigation strategies, Office of the Emergency Services Commissioner (2009) has produced an Emergency Management Manual for the Victorian Road Agency summarised below.

Prevention/Mitigation/Risk Reduction Activities

- *"improve the safety level of country and city roads*
- *encourage vehicle manufacturers to provide occupant safety features (eg extra air bags)*
- *maximise ongoing compliance with vehicle roadworthiness requirements*
- *coordinate road safety programs with community groups and other agencies*
- *plan for the management of incidents on major arterial roads with other agencies, including diversion routes for the different classes of vehicles".*

Response Activities

- *"assist with the management of road links during emergencies, including route selection, emergency traffic management, escorting, route conditions advice and control*
- *provide support advice on engineering and transport matters*
- *provide support for engineering and transport services for emergency response activities*
- *provide road closure and condition information to the public".*

Recovery Activities

- *"restoration of VicRoads roads and bridges and assist local councils for the same*
- *central contact point for access to transport and engineering expertise*
- *provide road closure and condition information to the public."*

4 Concluding remarks

This report presented an account of three major extreme weather events on Australian's transportation systems in Australia; the 2009 Victorian Black Saturday bushfire, the 2009 heat waves in Melbourne and Adelaide, and the floods of 2010/2011 in Queensland and Victoria. It is argued that there was an ill-preparedness of government agencies and others for the management of extreme events which have proven to be less effective and in some cases detrimental for providing logistics operations and supply chain functions. The responses to the extreme events and the subsequent adaptation and mitigation strategies were examined with particular reference to the implications for the transport systems in Australia. It is concluded that there is a co-dependency between bushfires, heatwaves, droughts and floods (ATSE 2008; CSIRO 2007) and their compounded effect impacts on transportation systems and logistics infrastructure.

Whilst Australia is aware of the potential impacts of climate change on the transport system, in most cases the adaption strategy is dependent on the type and severity of the impact of the climatic event and occurs predominately retrospectively once the event has been experienced. This is particularly true for the more severe climatic events which statistically are considered to have a low probability of occurrence. On these occasions however, the immediate focus is on developing a rapid response following the event and rectification later. The experience has usually resulted in strategies for being better prepared and better informed about what to do and when to do it, with various government agencies usually taking on a greater role for communication and public awareness in the lead up to these events in high risk areas. In addition, new infrastructure constructed in areas deemed at risk following a climatic event is subject to greater planning approval and licensing standards than historically. This can be concluded through the case studies summarised below.

4.1 Victorian Bushfires

Damage

The bushfires significantly impacted on the affected areas transport infrastructure shutting road and rail networks for extended periods in particular the capacity to resupply affected areas. The total cost of the bushfires has been estimated at four billion dollars with road and rail services taking months before they normalised.

Existing protection measures

Some of the key existing measures in place were not designed or clear enough to deal with the size and extent of extreme bushfire events, these include:

- WMO identifies areas where the intensity of wildfire is significant and likely to pose a threat to life and property. The purpose of a WMO is to ensure that building development in areas subject to high fire risk includes appropriate fire protection measures.
- ‘Stay or Go’ policy revisited and adapted to a ‘Prepare, Stay and Defend or Leave Early’ policy with more clarity for future extreme bushfires.

Adaption strategies

Following the bushfires a Royal Commission was held to attempt to avert the future loss of life and infrastructure should such a bushfire event occur again. A core adaption strategy was increased preparedness to respond to such an event and the establishment of formal communication systems to forewarn those exposed to similar risk in the future, and to have clear response plans. Of the four options open to government they have been applied as follows:

- *Codes of practice* – ensure all roads operated by VicRoads adhere to 1985 Codes of Practice
- *Operation and management plans* – development of Rail Operations Management System
- *Condition licenses* – introduction of Bushfire Management Overlay
- *Fitness for purpose obligations* – a State Planning Policy for Bushfire Prone Regions

4.2 Heatwaves

Damage

The cost of 2009 heatwave is estimated at $AUD 800 million due to power outages and transport disruptions resulting in 25% of metro train services were cancelled, road bitumen on major highways began bleeding, concrete slabs lifting and cracking and traffic signals malfunctioning. In addition port facilities productivity declined through vessel delays and reduced crane capacity.

Existing protection measures

There was little existing in place.

Adaption strategies

Of the four options open to government they have been applied as follows:

- *Codes of practice* – none currently implemented.
- *Operation and management plans* – public transport providers have developed management plans for staff, passengers and standby contingency equipment to rapidly respond to issues at times of excessive heat.
- *Condition licenses* – enhancing and maintaining existing above and below rail infrastructure to cope with times of excessive heat.
- *Fitness for purpose obligations* - modernisation of transport infrastructure to be able to withstand future excess heat events, for example increasing replacement of wooden sleeper from 22,000 to 64,000 per year, additional rail ballast and changing to continuous welded joints.

4.3 Flooding

Damage

The Queensland Floods are viewed as one of the most expensive disasters in Australia's history costing between 13 and 30 billion dollars. Australia's coal exports were dramatically reduced as supply chains were cut dragging the national economy backwards. Port of Brisbane was shut down for ten days and the channel depth reduced costing nearly $AUD 500 million. Brisbane's entire public transport system was affected, in particular the ferry network being destroyed. Lost rail revenue is calculated to be $AUD 26 million and a billion dollars to repair infrastructure and the trucking industry lost $AUD 213 million dollars.

The Victorian floods affected approximately one third of the state and caused damage to local infrastructures in regional, urban and rural communities as well as public health concerns. The average long term cost of flood damage is $AUD 350 million

Existing protection measures

There are state Acts and government guidelines in place but generally regarded as inadequate in situations of extreme weather events.

Adaption strategies

Of the four options open to government they have been applied as follows:

- *Codes of practice* – ensure safeguarding of existing transportation and logistics infrastructure through the Victorian Flood Management Strategy 1998, the Water Act1989 and the Emergency Management Act 1986, Dam Safety Management Guidelines, and Australian Government Emergency Management Planning (Floods).
- *Operation and management plans* – improve management of roads, bridges and dams by reviewing and updating existing guidelines, and provide assistance to local governments to enhance their ability to cope with extreme weather events
- *Condition licenses* – state road and water authorities to enhance and clearly define roles and responsibilities.
- *Fitness for purpose obligations* – authorised government agencies to provide timely information to the public and communities in preparation for floods, and to improve public awareness and education of those in risk areas.

4.4 Overall remark on policy responses, adaption strategies and implementation

The 2009 heatwave, the Queensland floods and Victorian floods, and bushfires all instigated high level government inquiries aimed at assessing the effectiveness of existing transportation provisions and the capacity of logistics infrastructure and management support systems in coping with extreme weather events, which are not uncommon in Australia but which seem to have become extreme and more frequent in recent decades. The general findings of these inquiries pointed out that existing transportation and infrastructure systems were not able to cope with disaster situations that are considered extreme although in each instance there were high levels of commitment, collective effort and goodwill of all stakeholders.

The findings also indicated that there is a significant opportunity to improve all aspects of existing disaster management planning, in situ policy response and post disaster recovery. Typically, the recommendations from post-event inquiries have led to Governments instigating legislative changes to develop and implement policies that enhance community resilience to extreme weather events in the future. Findings and the lessons learnt from these events highlighted the urgency for actions to improve communication amongst stakeholders, improve and increase the visibility of information flow, and called for more centralised command structures responsible for collaborating and coordinating the efforts of various authorities at different levels of government. A more centralised and standardised planning framework for reporting, monitoring and evaluating management practices and policy responses to extreme weather events is strongly recommended. Consequently, disaster mitigation plans, adaptation strategies, and data sharing agreements that involve the integration of National, State and Local government have been carried out in recent years. There is also recognition of the need to strengthen and better support local efforts and to provide advance notification and early warnings to communities at greater risk. Community preparedness has been identified as an important consideration in bushfire preparation activities and needs to be improved in some jurisdictions. This can be achieved through public education and community awareness programs. Such education would also clarify the roles and responsibilities of stakeholders, and include public information campaigns to educate more vulnerable communities, seen as those at greater risk, to be prepared to respond to different incident threshold levels. The 'Staying and Defending or Leaving Early', also called 'Stay or Go' policy, which has received particular attention of the 2009 Victorian Bushfires Royal Commission, has been reviewed and revisited. The early warning system put in place in Victoria has also been redeveloped for more effective and consistent planning and preparation for all hazards. In addition, the use of social media as early warning tools has also been trialled in some jurisdictions.

Furthermore, the analysis of such extreme events generally finds that post-event actions most likely result in only marginal improvements in resilience to such events unless a systematic and structured response, as recommended by the inquiring committees, is adopted. Additional to the above strategies that focus primarily on preparedness for event occurrence, is the acknowledgement that a further concerted effort is needed for mitigation and post-event recovery in the immediate and longer term. Plans need to be prepared for the execution of projects targeting upgrades and repairs to social, economic and logistics infrastructures with a view that they become more resilient in the future. To some extent this has already started with governments allocating extra funding in their budgets that will enable achieving this vision and associated management objectives.

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