Prepared for
Infrastructure Victoria
ABN: 83 184 746 995

AECOM

Climate Change Consequences Study

Assessment of the impacts of climate change on Victoria's infrastructure

15-Aug-2023

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Phase 2 Project Report

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Client: Infrastructure Victoria

ABN: 83 184 746 995

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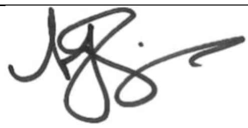
10	15-Aug-2023	Reissue of final report noting lack of flood overlays in Mornington Peninsula Shire Council	Adam Davis Technical Practice Leader, Sustainability & Resilience, ANZ	

Table of Contents

Acronyms

Table 1 List of Acronyms

Acronym	Description
AAP	Victorian Government's system-based Adaptation Action Plans
AEP	Annual Exceedance Probability
AMAF	Asset Management Accountability Framework
BMO	Bushfire Management Overlays
DELWP	Department of Environment, Land, Water and Planning
DNSP	Distribution Network Service Provider
DTF	Department of Treasury and Finance
EMV	Emergency Management Victoria
ESA	Equivalent Standard Axle
ESCI	Electricity Sector Climate Information
EV	Electric Vehicles
FO	Floodway Overlays
IPCC	Intergovernmental Panel on Climate Change
ITS	Intelligent Transport System
LIAF	Local Infrastructure Assistance Fund
LSIO	Land Subject to Inundation Overlays
MCA	Multi-Criteria Analysis
P&E	Plant and Equipment
POEL	Private Overhead Electric Line
RAS	Regional Climate Change Adaptation Strategies
RCP	Representative Concentration Pathways
REFCL	Rapid Earth Fault Current Limiter
SBO	Special Building Overlays
SES	State Emergency Service
SRN	Sector Resilience Network
T&D	Transmission and Distribution infrastructure
UFZ	Urban Flood Zone
VHBA	Victorian Health Building Authority
VMIA	Victorian Managed Insurance Authority
WOVG	Whole of Victorian Government

Glossary

Table 2 Glossary

Key term	Definition
Adaptation (to climate change)	In human systems, the process of adjustment to actual or expected climate and its effects, to moderate harm or exploit beneficial opportunities. In natural systems, the process of adjustment to actual climate and its effects; human intervention may facilitate adjustment to expected climate and its effects (IPCC, 2022). Adaptation actions may include physical changes to an asset to achieve or facilitate adaptation including changes/upgrades to technology and equipment, design standards for particular project elements, operational actions, or natural resource management actions (e.g., assisted colonisation, mixed-provenance plantings, restoration of key connectivity pathways to enable movement).
Adaptive capacity	The ability of institutions, systems, humans and other organisms to adjust to potential damage, to take advantage of opportunities, or to respond to consequences of environmental variability and change (IPCC, 2022). It includes adjustments in both behaviour and in resources and technologies (PIARC, 2015).
Cascading impacts	Occur when an extreme hazard generates a sequence of secondary events in natural and human systems that result in physical, natural, social or economic disruption, whereby the resulting impact is significantly larger than the initial impact (IPCC, 2022).
Climate change	A change in the state of the climate that persists for an extended period, typically decades or longer (IPCC, 2022). Climate change may be due to natural variability or a result of human activity.
Climate projections	Simulated response of the climate system (including variables such as temperature, precipitation, wind, solar radiation, sea level) to a scenario of future emissions or concentrations of greenhouse gases and changes in land use, generally derived using climate models. Climate projections depend on an emission scenario, in turn based on assumptions concerning factors such as future socioeconomic and technological developments that may or may not be realised (IPCC, 2022).
Climate variables	Factors that determine and govern the climate. Main factors include rain, atmospheric pressure, wind, humidity and temperature (PIARC, 2015). Changes in climate variables (such as temperature) can lead to changes in climate hazards (such as heatwaves).
Compound events	The combination of multiple drivers and/or hazards that contributes to societal and/or environmental risk (IPCC, 2022).
Consequence	Outcome of an event affecting objectives. A consequence can be certain or uncertain and can have positive or negative direct or indirect effects on objectives. Any consequence can escalate through cascading and cumulative effects (IS0, 2018).

Key term	Definition
Exposure	The presence of people, livelihoods, species or ecosystems, environmental services and resources, infrastructure, or economic, social, or cultural assets in places that could be adversely affected (IPCC, 2022).
Extreme weather event	An event that is rare at a particular place and time of year. The characteristics of what is called extreme weather may vary from place to place (IPCC, 2022).
Greenhouse gases	Gaseous constituents of the atmosphere that absorb and emit radiation at specific wavelengths within the spectrum of radiation emitted by the Earth's ocean and land surface, by the atmosphere itself, and by clouds. This property causes the greenhouse effect. Water vapour, carbon dioxide, nitrous oxide, methane and ozone are the primary greenhouse gases in the Earth's atmosphere (IPCC, 2022).
Hazard (climate hazard)	The potential occurrence of a natural or human-induced physical event or trend or physical impact that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, ecosystems, and environmental resources (IPCC, 2022).
Infrastructure	The designed and built set of physical systems and corresponding institutional arrangements that mediate between people, their communities, and the broader environment to provide services that support economic growth, health, quality of life, and safety (IPCC, 2022).
Likelihood	The chance of something happening (ISO, 2018).
Mitigation (of climate change)	Actions taken globally, nationally and individually to reduce greenhouse gas emissions and/or increase the amounts of greenhouse gases removed from the atmosphere by greenhouse sinks (IPCC, 2022).
Representative Concentration Pathways (RCPs)	Scenarios that include time series of emissions and concentrations of greenhouse gases and aerosols and chemically active gases, as well as land use/land cover. The word representative signifies that each RCP provides only one of many possible scenarios. The term pathway emphasises the fact that not only the long-term concentration levels, but also the trajectory taken over time to reach that outcome are of interest (IPCC, 2022).
Resilience (climate resilience)	The capacity of interconnected social, economic and ecological systems to cope with a hazardous event, trend or disturbance, responding or reorganising in ways that maintain their essential function, identity and structure (IPCC, 2022).
Risk	The effect of uncertainty on objectives. An effect is a deviation from the expected, and may be positive and/or negative. Risk is often expressed in terms of a combination of the consequences of an event (including changes in circumstances) and the associated likelihood of occurrence (ISO, 2018).
Sensitivity	The degree to which a system is affected, either adversely or beneficially, by climate variability or change. The effect may be direct (e.g. a change in crop yield in response to a change in temperature) or indirect (e.g. damages caused by an increase in the frequency of flooding) (IPCC, 2022)
Vulnerability	The degree to which a system is susceptible to, or unable to cope with, adverse effects of hazards, including climate change, variability and extremes (PIARC, 2015).

Acknowledgement of First Nations Australians

AECOM proudly acknowledges First Nations Australians including the Aboriginal communities of Victoria and their rich culture whilst paying respect to their Elders past and present.

We acknowledge Aboriginal and Torres Strait Islander peoples as Australia's first peoples and as the Traditional Custodians of the land and water on which we live, work and play.

We recognise and value the ongoing contribution of Aboriginal and Torres Strait Islander people and communities to Victorian life and how this enriches our society more broadly. We embrace self-determination and reconciliation, working towards equality of outcomes, ensuring an equitable voice and developing partnerships to improve the values we cherish across our cities, towns, and built environment.

Executive Summary

Victoria's climate is projected to become warmer and drier with more extreme weather events including heatwaves, intense rainfall and extreme fire weather. These events, together with longer term changes in climate, will continue to impact infrastructure across all sectors and regions in Victoria, ultimately affecting the communities and industries it supports.

Infrastructure Victoria engaged AECOM to conduct a Climate Change Consequences study (the study) to assess the impacts of climate change on Victoria's infrastructure. The study was established to build on the Victorian Government's existing climate adaptation work. This includes development of seven system-based Adaptation Action Plans (AAPs), which guide government action to build climate resilience, and six Regional Adaptation Strategies (RASs), which address climate change challenges and opportunities in Victoria's regions.

The study is focused on two key research questions:

1. How will a changing climate affect Victoria's infrastructure?
2. What additional actions can the Victorian Government take to build on existing adaptation efforts and better adapt Victorian Government-owned and regulated infrastructure to a changing climate?

Methodology

Recognising the far-reaching nature of the topic of climate change and infrastructure, a two-phase approach was undertaken to validate the outcomes of the study. The methodology undertaken across the two phases is summarised in Figure 1.

Phase 1 of the study involved a high-level risk assessment of climate impacts across key infrastructure sectors, considering socio-economic and environmental impacts, as well as cross-sectoral impacts. Phase 2 focused on further analysis of selected asset categories and climate risks shortlisted in Phase 1, to explore current and potential future adaptation actions in depth.

Adaptation actions were identified through the review of government and industry literature, and input from sector specialists and project stakeholders. Stakeholder engagement was undertaken to validate the project findings and support the development of recommendations.

The intent of the mapping exercise undertaken in Phase 2 was to identify regions where types of infrastructure are exposed to climate hazards, rather than identify specific assets at risk. It is therefore a 'first pass' and more detailed, site specific analysis of risks are required.

Scope

The focus of the study is climate change adaptation action across Victorian Government-owned and regulated infrastructure. Phase 1 of the study included a screening process to narrow the project scope from a high-level, whole-of-economy risk assessment to allow a detailed analysis of three shortlisted risks and asset categories in Phase 2, namely:

- Damage to, or degradation of electricity transmission and distribution (T&D) assets due to extreme weather events
- Damage to public hospital building structures due to extreme weather events
- Damage to roads or disruption of access due to extreme weather events.

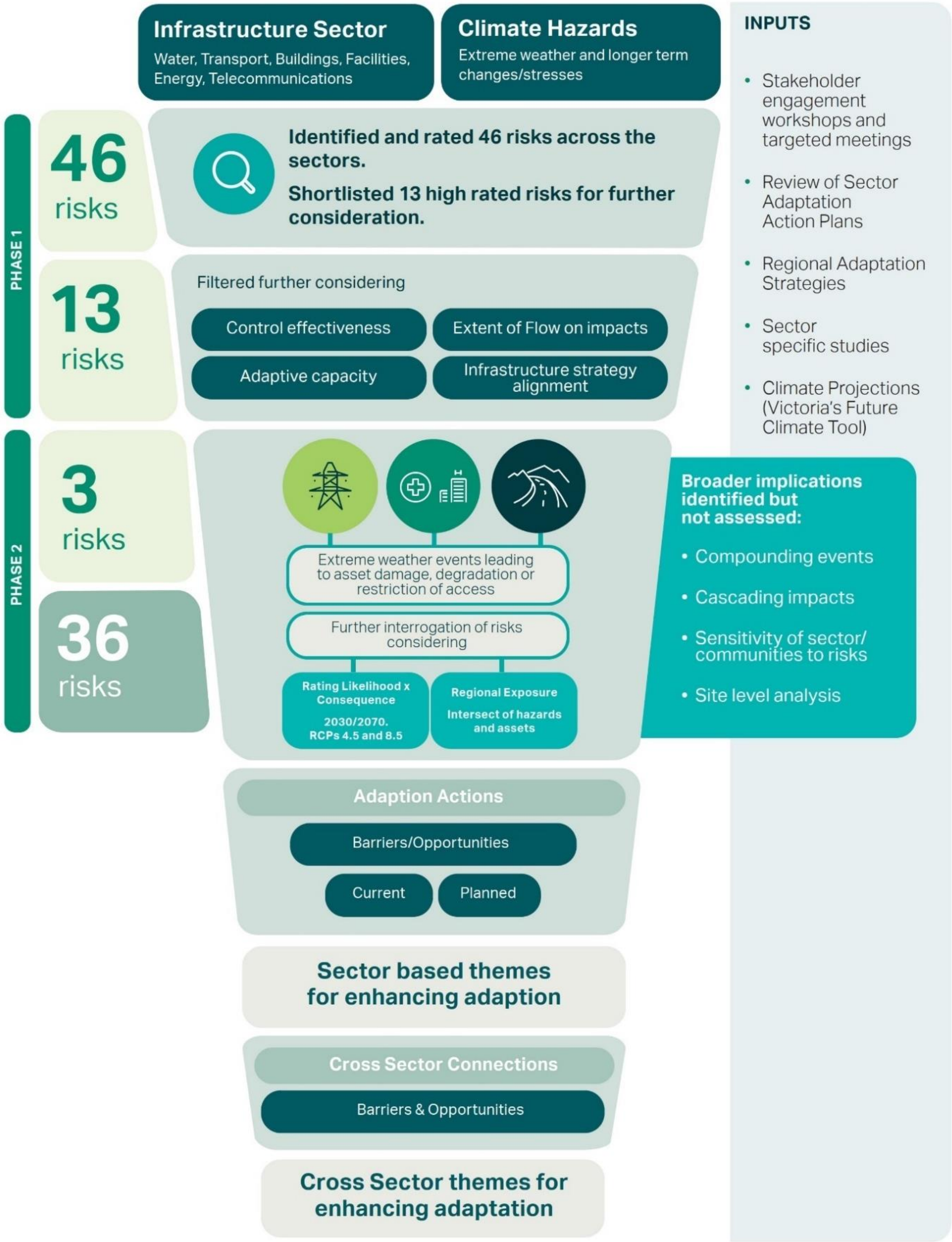


Figure 1 Summary of study methodology to assess the impacts of climate change on Victoria's infrastructure

Key risk profiles

The three shortlisted risks and asset categories were considered alongside extreme weather events to develop a list of more specific risk statements. A total of 36 detailed risks were identified across the three asset categories. These were rated according to likelihood (i.e. the chance of something happening) and consequence (i.e. the most probable outcome) under a low and high emissions scenario for both 2030 and 2070.

The risk assessment found that each sector's assets and infrastructure are already impacted by extreme weather events across Victoria. Climate change is expected to influence these risks, further increasing their frequency and/or severity, or exposing previously unaffected assets to risks (e.g., due changing flood risk profiles).

Regional exposure to risks

The study confirmed that the effects of the three shortlisted climate risks will not be experienced evenly across the state. The degree to which infrastructure is exposed to a hazard and the vulnerability to its effects are key considerations in determining the potential scale of impacts each climate risk may have. While broader vulnerability related issues (e.g. sensitivity and adaptive capacity of infrastructure and the communities they service) were noted in the analysis, the study focused on the relative exposure of assets to the climate hazards driving the shortlisted risks across Victoria's regions, as summarised in Table 3.

Table 3 Summary of regions with greatest exposure of assets to climate hazards

Hazards	Regions with greatest exposure of assets to specific climate hazards
Electricity transmission and distribution	
Bushfires	Gippsland, Hume Barwon South West, Gippsland and Hume (Substations)
Extreme Heat	Grampians, Loddon Mallee
Extreme Rainfall and Flooding	Greater Melbourne, Gippsland (Substations)
Extreme Wind	Hume, Greater Melbourne
Public hospitals	
Bushfires	Loddon Mallee, Greater Melbourne, Hume
Extreme Heat	Grampians, Loddon Mallee
Extreme Rainfall and Flooding	Greater Melbourne, Loddon Mallee, Hume
Road network	
Bushfires	Gippsland, Loddon Mallee, Barwon South West
Extreme Rainfall and Flooding	Hume, Loddon Mallee
Landslides	Barwon South West

Broader context of climate risks

To provide a more complete picture of the complexities associated with the risks and sectors within the study's scope, the analysis took a cross sector view of the challenges of climate change. This included identifying the cascading impacts between the three sectors, such as:

- Failure of electricity network disrupting intelligent transport systems
- Obstruction of roads restricting access to support response and recovery activities
- Increased demand on the road network to relocate patients from a damaged hospital.

The analysis also considered the effects of compounding events. Examples of demand related scenarios which have compounding impacts include increased traffic due to emergency response or repair activities, and surges in demand due to increases in heat-related presentations, and injuries and illness associated with extreme weather events .

Adapting to climate risks

There has been significant work undertaken, at multiple scales, to enhance the resilience of infrastructure in Victoria to the impacts of climate change. Key work relevant to the three shortlisted risks and asset categories includes the development of the AAPs and RASs, the Electricity Distribution Network Resilience Review (DELWP, 2022f) and sector-specific guidance such as the Victorian Health Building Authority's *Guidelines for Sustainability in Health Care Capital Works* (VHBA, 2021).

The study recognises that there are many proven physical adaptation actions available to manage climate risks to each sector. The report provides examples of actions that address the priority risks, however site specific investigations are required to determine the applicability of actions on a case-by-case basis.

Adaptation themes were identified for each asset category within scope, as listed in Table 4. These themes were developed following a comprehensive review and analysis of existing and planned adaptation controls and measures, together with key findings from the stakeholder engagement activities and consultation with subject matter experts. For each theme, the report documents current and planned controls, barriers to adaptation, together with opportunities and suggested actions to enhance adaptation.

Table 4 Adaptation themes by asset category

Adaptation theme
Electricity transmission and distribution
Adaptation theme #1: Building resilience of T&D network infrastructure
Adaptation theme #2: Enhancing guidance to support decision making
Adaptation theme #3: Strengthening T&D emergency response and recovery
Public hospitals
Adaptation Theme #4: Prioritisation and detailed investigation of vulnerability at the site level
Adaptation Theme #5: Strengthening existing sector processes to support climate adaptation decision-making and implementation
Road network
Adaptation theme #6: Prioritisation and detailed investigation of vulnerability at the site level
Adaptation theme #7: Enhancing guidance to support decision making
Adaptation theme #8: Strengthening road network emergency response and recovery

Barriers and opportunities

The AAPs provide a solid basis for adaptation action within each sector. Recognising that climate change adaptation is a long term commitment, barriers and opportunities to further build resilience in each of the three asset categories remain. Examples include opportunities to incorporate new technologies in building electricity transmission and distribution network resilience and to further develop Victoria's approach to managing landslide risks to the road network.

In addition, the study has identified barriers and opportunities which are common to all asset categories. These include:

- A need to prioritise sites for detailed investigation of climate risks, to assess local exposure and vulnerability of assets to climate hazards, and identify appropriate site-specific physical adaptation measures and timing for implementation.

- An opportunity to enhance systems and processes to better support adaptation decision-making and action.
- Opportunities to enhance consistency and standardisation in conducting cost benefit analyses, to help build the case for investment in adaptation.

Enhancing adaptation

For each sector, proposed adaptation actions were identified, building on the commitments in the AAPs and RASs. Acknowledging the cross sector implications of climate risks, actions that support adaptation across multiple sectors were also identified.

The proposed actions were prioritised for implementation into three categories: act now (i.e. within the current adaptation action planning cycle), act by 2026 (i.e. incorporate into the next round of adaptation planning, for roll out from 2026), or undertake further research. The proposed priority adaptation actions (i.e. act now) are summarised in Table 5, categorised into physical actions and policy or strategy-based actions.

Table 5 Priority additional adaptation actions

Adaptation action	Physical actions	Policy / strategy based actions
Electricity transmission and distribution		
E1 Prioritise sections of the electricity T&D network to undergo site specific assessment of climate risks	x	-
E3 Embed adaptation design principles into the design of new and upgraded/renewed infrastructure	x	-
E4 Enhance shared agreement on priorities for emergency restoration and recovery	-	x
E5 Include self-healing networks in the proposed adaptation design principles for new and upgraded infrastructure	x	-
Public hospitals		
H1 Prioritise hospitals for site specific assessment of climate risks and development of priority actions	x	-
H2 Supplement the Victorian Health Building Authority sustainability guidelines with tools to support climate adaptation decision making and implementation	-	x
Road network		
R1 Prioritise sections of the road network for site specific assessment of climate risks and development of priority actions	x	-
R2 Embed adaptation principles into proactive/preventative maintenance and road rehabilitation	x	-
R3 Embed adaptation principles into the design of new and upgraded/renewed infrastructure	x	-
Cross-sectoral adaptation actions		
C2 Enhance standardised approaches to cost-benefit analysis	-	x

1.0 Introduction

1.1 Purpose

Infrastructure Victoria engaged AECOM to conduct a Climate Change Consequence study (the study) to assess the impacts of climate change on Victoria's infrastructure. The study is focused on two key research questions:

1. How will a changing climate affect Victoria's infrastructure?
2. What additional actions can the Victorian Government take to build on existing adaptation efforts and better adapt Victorian Government-owned and regulated infrastructure to a changing climate?

The study was established to contribute to the Victorian Government's existing climate adaptation work. Building Victoria's Climate Resilience, released in February 2022, sets out the government's approach to adapting and building resilience to the changing climate (DELWP, 2022b). It was released alongside seven system-based Adaptation Action Plans (AAPs) which aim to build resilience in areas vulnerable to climate change impacts and/or essential to ensure Victoria is prepared: built environment, education and training, health and human services, natural environment, primary production, transport, and the water cycle (DELWP, 2022c).

The AAPs will be updated every five years until 2050 to ensure Victoria is resilient as the climate changes. This study aims to help inform future iterations of the AAPs, focusing on climate adaptation impacts and challenges as they relate to infrastructure for a selection of sectors.

This report outlines the methodology and approach, risk assessment, stakeholder engagement and adaptation analysis undertaken throughout the study and recommends additional sector-specific adaptation measures that the Victorian Government can action to continue to address climate-related risks to infrastructure into the future.

1.2 Scope

The focus of this study is climate change adaptation action across Victorian Government-owned and regulated infrastructure. The asset ownership of infrastructure, including regulated and public corporations, is complex and can involve privately owned and operated assets. These ownership and operational variations have not been considered in detail in this study. However, it is recognised, for example within the energy sector, that while some arrangements are national, the Victorian Government can influence regulatory and policy settings, particularly where energy infrastructure is also regulated through safety and licensing.

It is recognised that the two questions within the scope of this research are far-reaching, hence the project sought to progress an understanding toward these questions by refining the scope according to two phases:

- Phase 1 of the study involved a high-level risk assessment of climate impacts across key infrastructure sectors, considering socio-economic and environmental impacts, as well as cross-sectoral impacts.
- Phase 2 focused on further analysis of selected asset categories and climate risks shortlisted in Phase 1, to explore current and potential future adaptation actions in depth.

The study has been developed according to a specific scope to allow for a detailed analysis of the relevant adaptation actions and potential case studies within a time limited project. Phase 1, therefore, included a screening process to narrow the scope of analysis from a high-level, whole-of-economy risk assessment to allow for in-depth analysis of selected risks and asset categories in Phase 2.

A total of 46 risks were initially identified in Phase 1, these were refined via further analysis and stakeholder engagement, as outlined in Section 3.0, to limit the scope of adaptation analysis in Phase 2 to the three risks and asset categories detailed in Table 6.

Table 6 Shortlisted risks and asset types for Phase 2 analysis

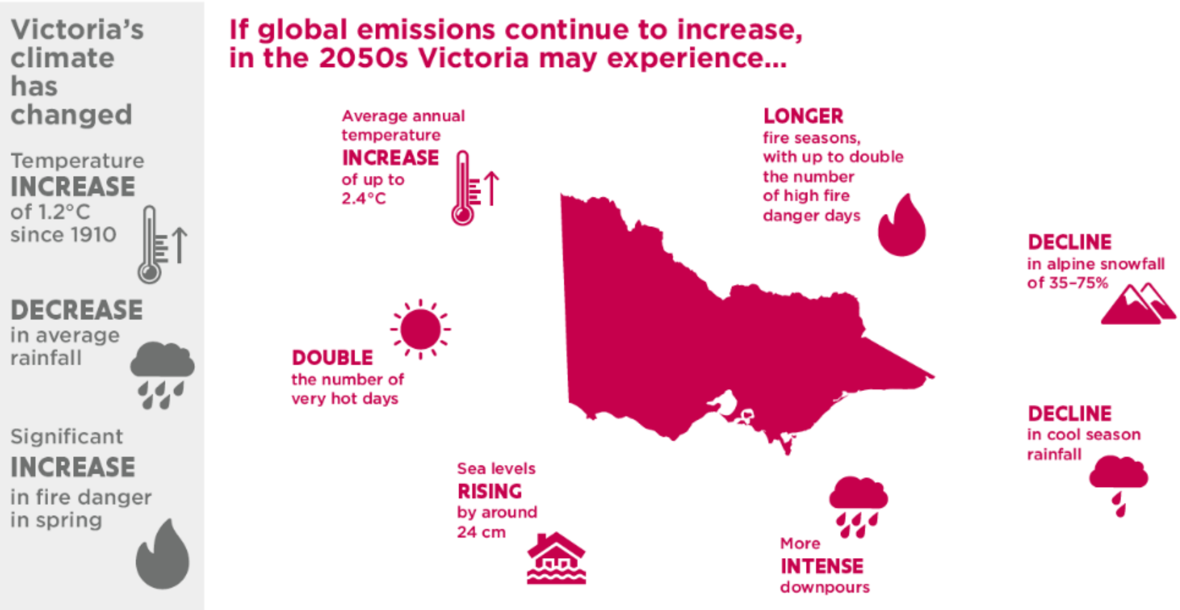
Sector - Infrastructure type	Risk statement	Asset type
Utilities – Electricity network	Damage to, or degradation of electricity transmission and distribution assets due to extreme weather events	Transmission lines/towers, distribution lines, transmission substations
Built Environment – Public hospitals	Damage to public hospital building structures due to extreme weather events (excluding facades)[1]	Hospitals building structures and plant and equipment attached to building structures (metro, regional)
Transport – Road network	Damage to roads or disruption of access due to extreme weather events	Declared roads including freeways (including tollway) and arterial roads (including highways)

In order to broadly align with the Victorian Government's system-focused approach to adaptation action, this study has taken a sector-focused approach to assessing climate risks and potential adaptation actions. However, it is recognised that the different sectors are highly interdependent. A key focus for this study has therefore been to identify cross-sectoral dependencies and impacts for the three shortlisted risks and asset categories areas. This is outlined in more detail in Section 7.0.

[1] Note, the risks associated with "Damage to building facades due to changes in temperature, wind conditions, exposure to fire or sea spray" were screened out in Phase 1 of the study.

2.0 Victoria’s changing climate

Climate change is affecting Victoria’s communities, economy and environment. It has already begun to cause irreversible damage, and strong and sustained action is needed to limit its future impacts (IPCC, 2022). Victoria's climate has become warmer and drier in recent decades and will continue to change in the future under the influence of both natural variability and global warming (DELWP, 2022a). Temperatures have increased by 1.2°C since 1910, fire seasons are more prolonged and intense, and while there has been a decrease in average annual rainfall, extreme rainfall events have increased (DELWP, 2022a). Figure 2 illustrates the projected changes to Victoria's climate in 2050.



Under high emissions, compared to 1986-2005. Updated from Victoria’s Climate Science Report 2019

Figure 2 Victoria’s climate change projections in 2050 (DELWP, 2022a)

Extreme weather events, such as floods, bushfires, storms and heatwaves, are projected to become more frequent and intense, increasing the vulnerability of Victoria’s community, services and built assets to a range of risks (DELWP, 2022b). In addition, these events are becoming increasing unpredictable – often overlapping or occurring in quick succession (DELWP, 2019a), reducing opportunities for recovery and undermining resilience. A high emissions scenario, where emissions continue to rise and global temperatures average 3°C or more above preindustrial levels, would be devastating for Victoria, posing severe risks to properties, infrastructure, ecosystems as well as to human health, livelihoods, and communities (Australian Academy of Science, 2021).

The increased frequency and intensity of extreme events occurring with climate change will impact infrastructure across all sectors and regions, and the effectiveness of current engineering solutions to these events (Cresswell et al, 2021). These impacts will be varied, some direct (e.g., damage, loss of capacity or faster degradation), and others indirect (e.g., disruption of activity due to failure of utilities or transport routes or increased demand on emergency services). Ultimately, they will affect the community and industries the infrastructure supports, with the implications felt unevenly across society. It is acknowledged that there is significant need for, and commitment to, action from government as existing policies and regulations are revisited to ensure they encompass events increasingly likely to occur in the lifetime of infrastructure (Cresswell et al, 2021).

Victoria's Climate Change Act 2017 provides the legislative foundation to manage climate risks and drive the transition to net zero emissions. *Victoria's Infrastructure Strategy 2021-2051* (Infrastructure Victoria, 2021) and the *Victorian Climate Change Strategy* (DELWP, 2021a) both set directions for action on greenhouse gas emissions reduction and climate adaptation.

3.0 Methodology

This section outlines the risk analysis framework, climate projections, hazards and variables which have informed this study, as well as the analysis undertaken. The analysis has been informed by extensive stakeholder engagement, detailed in Section 3.5.

3.1 Risk analysis framework

The assessment and management of climate risks to infrastructure sits within a more complex system of considerations that can ultimately support climate-resilient development. The Intergovernmental Panel on Climate Change (IPCC) illustrate the complex interactions between the climate system, ecosystems and human society in Figure 3.

The left-hand side of the diagram shows that society causes climate change which, in turn, impacts human society and ecosystems. Human society and ecosystems can adapt to and/or mitigate climate change, while human society also impacts ecosystems and can restore or conserve them. Sitting within the three systems is the 'risk propeller', which illustrates that risks emerge from the overlap of climate hazards and the vulnerability and exposure of human systems and ecosystems.

Under the banner of climate-resilient development, the right-hand side of Figure 3 illustrates the actions that can reduce climate risks and strengthen resilience, therefore reducing the impacts of future climate change on human society and ecosystems.

This study has focussed on the elements of the risk propeller in Figure 3 – i.e. the overlap of climate hazards, vulnerability and exposure.

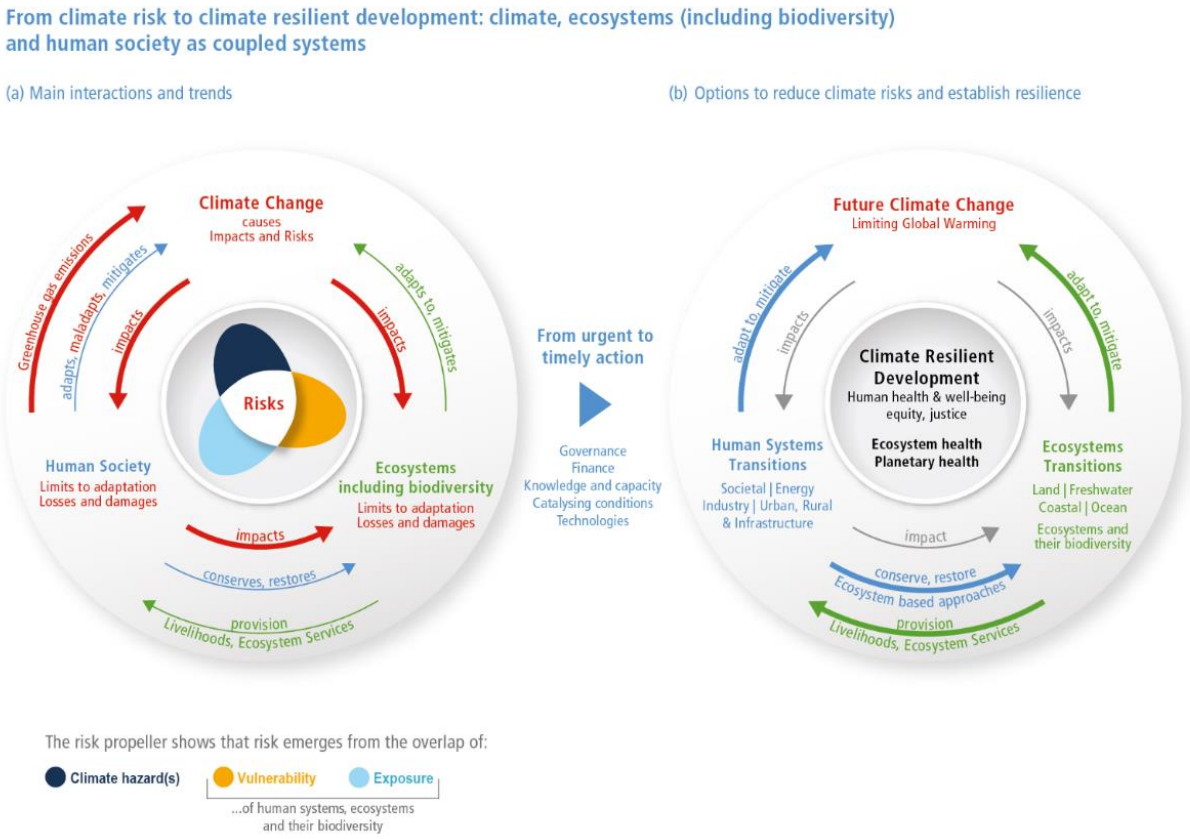


Figure 3 Interaction between climate hazards, exposure and vulnerability resulting in risk (IPCC, 2022)

In the context of infrastructure, climate risk is a function of climate hazards (for example, floods or heatwaves), the degree to which infrastructure is exposed to a hazard and the vulnerability to its effects. Vulnerability and exposure are influenced by socio-economic and cultural processes (including climate change adaptation and mitigation actions, and governance processes), which can increase or decrease the consequences of exposure to a hazard (Ministry for the Environment, 2019). Recognising that the vulnerability of infrastructure is highly dependent on site-specific factors that are beyond the scope of this state-wide study, the risk analysis has focussed on the assessment of climate hazards and the exposure of infrastructure at a regional level. However, supporting commentary is provided in the report on factors that may influence the site-specific vulnerability of infrastructure (e.g. the condition or design of infrastructure, the role it plays in the broader system and the communities it supports).

This study has taken a two-phase approach to the assessment and analysis of the climate risks facing Victorian infrastructure:

- Phase 1: high-level climate risk assessment across key infrastructure sectors, to shortlist assets and risks for more detailed assessment.
- Phase 2: further analysis and assessment of risk statements related to extreme weather events for shortlisted assets, to identify additional high priority adaptation actions.

The level of risk associated with different infrastructure types and climate impacts has been assessed using a combination of likelihood and consequence for each potential impact. In this study, likelihood ratings (i.e. the chance of something happening) range from rare to almost certain. In rating the consequence (i.e. the most probable outcome), consideration was given to the following themes: financial, local growth and economy, public health, infrastructure, governance, community and lifestyle, and environment and sustainability.

The risk framework (including consequence and likelihood assumptions and risk matrix) used in this study are outlined in Appendix A. The risk framework was based on the 2007 Infrastructure and Climate Change Risk Assessment for Victoria study, prepared for the Victorian Government, and risk criteria examples provided by the Victorian Managed Insurance Authority (VMIA, 2021 and CSIRO, 2007).

3.2 Climate projections, hazards and variables

To inform the assessment of climate hazards, the study has primarily used Victorian Climate Projections 2019 datasets (CSIRO, 2020b), developed in partnership between the Victorian Government and CSIRO's Climate Science Centre, to estimate likely changes up to 2070. Datasets were sourced from the Victoria's Future Climate Tool, an interactive online mapping tool that helps visualise future climate projections for Victoria (DELWP, 2019b). This data source has been supplemented by the Electricity Sector Climate Information Project (ESCI, 2022), a collaboration between CSIRO, the Bureau of Meteorology and the Australian Energy Market Operator.

It is acknowledged that the IPCC (2022a) have released a *Sixth Assessment Report (AR6)* which includes updated global and regional climate change projections. However, these projections are yet to be downscaled to Victoria. This study has therefore used the most up-to-date Victorian projections.

To help deal with the uncertainty surrounding the intensity of future climate change, the IPCC has outlined four scenarios to explore potential future concentrations of greenhouse gases in the atmosphere, called Representative Concentration Pathways (RCPs), ranging from high concentrations (RCP8.5) to very low concentrations (RCP2.6).[2] Each RCP reflects a different concentration of global greenhouse gas emissions reached by 2100, based on assumptions of different combinations of possible future economic, technological, demographic, policy and institutional trajectories (Department of the Environment, 2013).

The risk assessment conducted in this study uses low emissions (RCP4.5) and high emissions (RCP8.5) scenarios to provide contrasting possible climate futures to assess climate risk for infrastructure. See Table 7 for further details.

Table 7 Features of the Representative Concentration Pathways

[2] It is acknowledged that the IPCC AR6 has adopted Shared Socioeconomic Pathways as inputs to the development of climate projections, rather than the RCPs used in AR5. This study has continued to use RCPs for consistency with existing Victorian climate projections.

RCP	Likely 2080–2100 global average temperature (°C above pre-industrial levels)	Global greenhouse gas emissions pathway
8.5	3.2 to 5.4	Ongoing high greenhouse gas emissions
4.5	1.7 to 3.2	Emissions peak around 2040

Climate change projections for both high and low emissions scenarios have been considered over short-term (2030) and long-term (2070) periods – noting that while low emissions scenarios (RCP4.5) have been assessed, over the past two decades emissions have been tracking at RCP8.5 (Schwalm et al, 2020).

Climate projections drawn from the Victoria's Future Climate Tool are based on the Multi Model Mean climate model, which is the mean of all six climate models included in the tool. This model is useful for a high-level regional assessment, as undertaken in this study, but is not appropriate for a detailed analysis of risk in specific areas, where it is important to consider the full range of possible changes, including any 'worst case' scenarios which may need to be managed or mitigated (VMIA, 2019).

The range of climate change hazards and variables considered in the analysis are summarised in Table 8. The table also includes commentary on the spatial data that was used to inform this Phase 2 analysis. Appendix B includes further detail on the GIS data sources.

Table 8 Climate hazards and variables considered in the analysis

Hazards	Related climate variables	Commentary on spatial data
Extreme events (i.e. acute shocks)		
Extreme heat – Hot days	Daily maximum temperature Number of days over 35°C Number of days over 40°C	Spatial data related to the number of hot days (days over 35°C) and very hot days (days over 40°C) were extracted from the Victoria's Future Climate Tool. This included data for 2030 and 2070, for both the RCP4.5 and RCP8.5 greenhouse gas emissions scenarios.
Extreme heat – Heatwave	Warm spells	
Extreme rainfall flooding	Increase in rainfall intensity	Statewide flood modelling of current and projected future flood hazards is a significant undertaking beyond the scope of this study. To represent the potential areas at risk of flooding due to extreme rainfall events, Victorian planning overlays and zones were used. The specific overlays used were Special Building Overlays (SBO), Land Subject to Inundation Overlays (LSIO), Floodway Overlays (FO) and Urban Flood Zone (UFZ). Recognising this is effectively a representation of historic areas at risk of flooding, sensitivity testing was undertaken by identifying assets that were within 50 m or 100 m of the flood overlays. This attempts to identify assets that have the potential to become exposed to floods as the intensity of rainfall events increases and flood hazard profiles change.
Coastal flooding	Storm surge Sea level rise	Hazard extents were extracted from the Victoria's Future Climate Tool representing potential areas exposed to sea level rise related inundation and storm surge related inundation. This data includes sea level rise projections for 2030 and 2070, for both the RCP4.5 and RCP8.5 greenhouse gas emissions scenarios.

Hazards	Related climate variables	Commentary on spatial data
Coastal erosion – Short term	Storm surge Sea level rise	Sections of the coastline at high or very high susceptibility to coastal erosion were identified using data from Victorian Coastal Inundation Dataset. This represents locations where coastal erosion has the greatest potential to occur as sea levels rise, or the intensity of coastal storm events increase.
Extreme wind	Wind speed, severe convective wind gusts	Coarse scale historic spatial data was drawn from the ESCI Project. The ESCI Project identified that work is yet to be undertaken to develop climate projections building on the historic data generated from the project. This is complicated by the fact that while there is some indication of a potential increase in extreme wind events, there are low confidence levels associated with these projections (Dowdy A. et al, 2021).
Bushfire	Number of severe fire danger days which is influenced by average temperature, average rainfall, evaporation and wind speed	The Victorian Bushfire Management Overlay (BMO) was used. It represents locations of Very High or Extreme bushfire hazard. Climate change is projected to increase the frequency and intensity of fire weather conditions (i.e. severe fire danger days). However, the extent, or locations at risk, are largely determined by the terrain and vegetation and therefore, for this study, are considered unlikely to change. The BMO was used in place of the Bushfire Prone Area overlay, as the BMO provides a focus on the locations at highest risk of fire.
Landslides	No specific variable. Occurrence is influenced by many factors including rainfall, bushfire	Locations with landslide susceptibility rated High or Very High were extracted from the Geomorphology of Victoria dataset (GMU250). Climate change is projected to increase the frequency and intensity of extreme rainfall and fire weather conditions which can influence the frequency at which landslides may occur. However, the extent or locations at risk are largely determined by the terrain, vegetation or current management practices or controls and therefore, for this study, are considered unlikely to change.
Longer term changes in climate (i.e. chronic stresses)		
Coastal erosion – Long term	Sea level rise	Refer to the commentary above for Coastal erosion-short term.
Reductions in average rainfall	Average annual rainfall	These hazards were not assessed spatially as part of the Phase 2 analysis.
Increase in elevation of groundwater	Sea level rise	

3.3 Phase 1 analysis

3.3.1 High-level climate risk and consequence assessment

A high-level climate risk and consequence assessment was undertaken, using a qualitative process to develop a preliminary understanding of climate risk across key infrastructure sectors. The objectives of the high-level assessment were to:

- Assess the risk to broad infrastructure categories against climate change hazards

- Identify climate risks and asset types considered high risk, for potential further investigation
- Identify gaps in research, where relevant

The high-level risk assessment built on the *Infrastructure and Climate Change Risk Assessment for Victoria report* (CSIRO, Maunsell & Phillips Fox, 2007), which considered five infrastructure sectors: buildings and facilities, energy, telecommunications, transport, and water. The risk assessment also incorporated information on climate change risks and opportunities outlined in the first iteration of the Victorian Government's Adaptation Action Plans (AAPs), released in 2022 (DELWP, 2022c).

This assessment resulted in 46 key climate-related risks relevant to Victoria's government-owned and regulated infrastructure in the built environment, energy, telecommunications, transport and water sectors. The assessment has taken a sector approach, but it is recognised that the different sectors are highly interdependent.

Each risk was given a preliminary risk assessment using the framework outlined in Appendix A. The risks were rated under a high emissions (RCP8.5) scenario for both 2030 and 2070.

3.3.2 Risk screening

The high-level risk assessment was tested via a series of workshops aiming to gain consensus on the climate risks and asset types that should be considered high risk. This resulted in 13 risks being shortlisted for further analysis. See Section 3.5 for further detail on the project's stakeholder engagement process.

A multi-criteria analysis (MCA) was conducted following the workshops to interrogate the 15 shortlisted risks and identify three risks and asset categories to form the scope of Phase 2. The factors considered in the MCA were:

- Risk rating (2030) – prioritising risks that were rated high in both the initial high-level risk assessment and during the workshop.
- Effectiveness of controls – prioritising risks that have fewer effective controls currently in place.
- Extent of flow on impacts – prioritising risks with a high level of direct or indirect impacts on other sectors.
- Adaptive capacity – prioritising risks where there is limited redundancy (i.e. backups in case of failure) or those where recovery would take a long time.
- *Victoria's Infrastructure Strategy 2021–2051* (Infrastructure Victoria, 2021) and the system-focused AAPs – prioritising risks where there were potential gaps to be further explored (DELWP, 2022d).

Following completion of the MCA, the following three risks and asset types were agreed for further investigation in Phase 2 of the project:

- Utilities – Electricity network – Damage to, or degradation of electricity transmission and distribution assets due to extreme weather events.
- Built environment – Public hospitals – Damage to public hospital building structures due to extreme weather events.
- Transport – Road network – Damage to roads or disruption of access due to extreme weather events.

Risks related to the water-sector were identified among the 'Top 5' risks following the MCA. However, due to the significant work being undertaken in this space, particularly in the sector-specific AAP and the Draft Urban Water Strategy, the analysis focused on the electricity sector.

Consideration was given to the role of different asset types in preserving life and supporting emergency response to extreme weather events. This was a key factor in refining the asset category of 'buildings' under the built environment sector, to focus on hospital buildings.

While rail infrastructure supports critical public and commercial transport services, risks to rail were not included in the scope. A factor in this decision was the ability for the road network to provide an alternative (i.e. adaptive capacity) should rail services be interrupted.

While the risk screening process refined the scope of the study, it is acknowledged that these three risks are not the only critical risks or critical infrastructure categories in Victoria, Rather, this process enabled detailed assessments of selected categories and risks to be undertaken in Phase 2.

3.4 Phase 2 analysis

3.4.1 Detailed risk assessment

Building on the methodology adopted in Phase 1, Phase 2 of the study considered additional elements in relation to the three shortlisted risks and asset types to focus the development of potential adaptation actions.

The additional elements considered in the Phase 2 risk assessment are listed in Table 9. This resulted in the development of 36 risk statements relevant to the three shortlisted risks and asset types, detailed in full in the risk register in Appendix A.

Table 9 Elements considered in Phase 2 climate risk assessment

Element	Description
Risk identification	
Development of risk statements	Each of the relevant climate hazards were considered to develop a list of more specific risk statements (outlined in Appendix A). Direct and indirect impacts were identified for each risk statement.
Risk analysis	
Rating risks	Using the risk framework included in Appendix A, the likelihood and consequence of each risk was rated, and then combined to determine an overall risk rating. In rating risks, consideration was given to historic occurrences of the risk as well as climate projections. To determine priority risks, the risk rating was then combined with regional exposure and the following factors considered in Phase 1: • Adaptive capacity • Extent of flow on impacts • Control effectiveness. It is acknowledged that the direct and flow on consequences of risks may affect multiple consequence categories set out in the risk framework (i.e. financial, local growth and economy, public health, infrastructure, governance, community and lifestyle, and environment and sustainability). The risk rating for the study was focused on the category with the greatest direct consequence.
Regional exposure	To provide insight into how the risks may be experienced differently across Victoria, quantitative consideration of the exposure of the assets to climate hazards was undertaken using GIS analysis. State-wide data was collected on the three infrastructure types that were the focus of the study. This data was then compared to data sets representing the climate hazards. An explanation of the climate hazard data used in the assessment is included in Table 8. The intent of the mapping was to identify regions where types of infrastructure are exposed to climate hazards, rather than identify specific assets at risk. It is therefore a 'first pass' and more detailed, site specific analysis of risks are required.
Risk treatment	
Existing and planned controls	Drawing on the system-focused AAPs, RASs and sector-specific knowledge or studies, existing and planned adaptation actions were

Element	Description
	identified, and opportunities for any additional adaptation actions explored with stakeholders.
Additional adaptation actions	Focusing on the most urgent risks, additional adaptation actions were identified across three categories: physical actions, policy / strategy-based actions and emergency management actions.

3.4.2 Identifying adaptation options

A key outcome of the study is the identification of additional adaptation actions to address the priority risks. The following was undertaken to identify adaptation actions:

- Review of industry / sector-based literature. Examples included*: Climate Change Impacts on the Useful life of Infrastructure* (IPWEA, 2018); *Mitigation Ideas - A Resource for Reducing Risk to Natural Hazards* (FEMA, 2013) and *Potential Impacts of Climate Change on U.S. Transportation* (Transportation Research Board, 2008).
- Input from sector-specialist team members and AECOM technical staff. Our project team has drawn on the knowledge of technical specialists representing the power, health care building and transport sectors. This was achieved through internal workshops, targeted meetings and review of draft materials.
- Input from project stakeholders. This was achieved through a combination of workshops and targeted meetings with select stakeholders. More detail on the stakeholder engagement process is included in the following subsection.

The recommended additional adaptation actions are numbered, including a letter reflecting the sector (i.e. E – Electricity transmission and distribution infrastructure, H – Public hospitals, R – Road network and C – Cross sector).

3.5 Stakeholder engagement

Stakeholder engagement has formed a critical part of the evidence gathering for this project. Analysis was tested through two workshop series in April and June 2022, coinciding with the two phases of research. These were complemented by one-on-one meetings with key stakeholders across the Victorian Government and peak bodies.

Workshops were attended by a total of around 90 participants, with an average attendance of 19 participants in each. Attendees were from a wide spectrum of organisations including government departments, academia, regulators, infrastructure operators and think tanks.

The workshops provided an efficient way to access information from the broad network of stakeholders that could interrogate the findings of the detailed risk analysis. AECOM collaborated with Infrastructure Victoria to determine the format, content and participants for two sets of three, two-hour, sector-specific workshops, as outlined in Table 10.

Table 10 Workshop coverage and objectives

Workshop	Sectors covered	Objectives
Phase 1	• Built environment • Transport • Utilities	• Review sector-specific risks to infrastructure and relative risk ratings • Review current risk controls and adaptation actions • Identify cross-sector impacts
Phase 2	• Public hospitals • Road network	• Identify compounding risks/events, adaptive capacity, cascading impacts and impacts from transition to net zero emissions

	• Electricity network	• Review existing and planned adaptation actions, including physical solutions, policies/strategies and emergency management actions • Identify additional physical and policy adaptation actions to address identified risks • Identify datasets and information to input into the analysis of potential adaptation actions

Following the workshops, a summary of outcomes was made available to participants to provide another opportunity to gain endorsement of the project's outcomes and recommendations prior to preparing the final Project Report. The main discussion themes and insights provided by stakeholders in the workshops have been incorporated into the analysis and findings presented in this report.

3.6 Implications for Indigenous communities and infrastructure

Aboriginal and Torres Strait Islander communities have over 60,000 years' experience living in and adapting to Australia's environment and climate. Their knowledge of how to manage Australia's unique environment has been passed down through generations. Since colonisation, much of this knowledge has been maligned and ignored by governments. Working in collaboration with Aboriginal communities and incorporating their knowledge of our environment into adaptation projects is vital to ensure their success and avoid maladaptation (IPCC, 2022).

It is acknowledged that Aboriginal and Torres Strait Islander peoples and communities have their own established and respected values and protocols, and unique ways of expressing those values. What is of upmost importance is the building of relationships before engaging in business to gain trust and respect going forward and ensure that the right environment for two-way dialogue is created.

This study investigates the impacts of climate change on Victorian Government-owned and regulated infrastructure across the state in order to identify high-priority adaptation actions. Due to the breadth of this study, it does not focus on any specific locations in Victoria. However, it is evident that there is a flow on impact to vulnerable Aboriginal and Torres Strait Islander communities as a result of climate change. We acknowledge the need to engage with Aboriginal and Torres Strait Islander communities to develop the most effective and inclusive solutions at a local level.

3.7 Assumptions and limitations

The following assumptions and limitations are noted:

- The impact of earthquakes were not considered in the study. Although earthquakes are not directly caused by climate conditions, they may become more common due to increased climate-related stresses on tectonic plates. Droughts, heavy rainfall and the melting of Antarctic glaciers may all trigger increased earthquake activity in Victoria. This is in addition to regular seismic activity, where Australia experiences an earthquake with a magnitude of 6 or higher on average every six to ten years (Quigley, 2021). But while climate change may affect the likelihood of quakes, we lack the data to accurately predict their occurrence due to the numerous complicating factors related to the causes of earthquakes (Buis, 2019). As a result, this risk assessment acknowledges their danger and a potential increase due to climate change but has excluded them from this analysis. Further research is required, particularly into the potential appearance of neotectonic faults in Victoria, to properly evaluate the risk of climate change induced earthquakes (Quigley, 2021).
- The study focuses on infrastructure and risks determined through the consultation process undertaken in Phase 1. It is important to note that this study is not intended to be a comprehensive assessment of all climate risks to each sector. For example, the impacts of climate change on the following are not included in the scope of the study: energy demand; electricity generation capacity; health impacts on humans and therefore demand for hospital services; and impacts to intelligent transport systems (ITS). In addition, only the shortlisted climate hazards have been for the sector elements considered (i.e. the impacts of extreme events were the focus of the study, rather than longer-term stresses).

- While the study provides commentary on the regional differences in exposure to climate hazards, the study has not assessed the current adequacy of the infrastructure and services across the state. For example, it has not assessed whether or not additional infrastructure is required in a region to address any current shortfalls in projected demand, or if current design standards are adequate for the future climate.
- The study includes a state-wide assessment that was conducted in the context of other government-driven activities. For example, in the energy sector, the Electricity Distribution Network Resilience Review in response to the severe storms in June and October 2021 was being finalised while this study was being undertaken (DELWP, 2022f). There are also significant challenges associated with broader energy supply issues, including potential power outages and rapidly increasing energy costs. While the findings of the 2021 review will be applicable to building the resilience of electricity distribution infrastructure, the challenges associated with the broader management of electricity demand and supply are outside the scope of this study.
- The GIS data used in the analysis looks at hazard areas at a regional scale. In addition, planning overlays are designed to inform planning decisions, rather than being detailed enough to inform design decisions. The currency and completeness of flood overlays included in the planning scheme vary across the state, for example there are no flood overlays for the Mornington Peninsula Shire Council. In addition, some assets outside the mapped hazard areas may be at risk of flooding or fire. Actual hazard extents may differ due to changes in land use (i.e. changes in impervious surfaces, or vegetation coverage). It is recommended that site-specific analysis of hazards and infrastructure is conducted to determine the precise vulnerability to hazards.
- Concurrence of multiple hazards has been acknowledged as a compounding event in the study. However, no attempt has been made to determine the likelihood or consequences of the simultaneous occurrence of multiple hazards (i.e. extreme heat and fire, or extreme wind and extreme heat).
- The focus of the study is on Victorian Government-owned or regulated infrastructure. The sensitivity or adaptive capacity of this infrastructure (or the communities serviced by the infrastructure) will be influenced by connecting local government and/or privately owned infrastructure, both of which are outside the scope of this study.
- Infrastructure plays an important role in supporting communities and businesses. It is acknowledged that the more resilient communities are in the broadest definition (i.e., well resourced, strong interpersonal connections on the local level, educated and informed of hazards and how to prepare and respond etc.), the greater their adaptative capacity to cope with failure of infrastructure, or other stresses. Community-level resilience building is an important consideration of broader adaptation planning but is beyond the scope of this study.

4.0 Electricity transmission and distribution

Extensive work has been conducted in the electricity sector to date to build resilience to extreme weather events following the 2009 Black Saturday bushfires, which resulted in the implementation of the Victorian Bushfires Royal Commission (Parliament of Victoria, 2010). More recently, the Victorian Government investigated long-term reforms to Victoria's distribution network following prolonged power outages caused by severe storms in June and October 2021 through the Electricity Distribution Network Resilience Review (EDNRR) (DELWP, 2022f). The Panel's recommendations from the Review include a comprehensive set of reforms designed to reduce both the likelihood and impact of prolonged power outages, such as those experienced in parts of Victoria following the 2021 storms. These recommendations are currently being reviewed by the Victorian Government and it is expected that a formal response will be issued in late 2022, or early 2023. The study acknowledges the work carried out in the Resilience Review, noting that the intention is for the recommendations made in this study to complement that work.

The Australian Energy Market Operator (AEMO, 2022) published the *2022 Integrated System Plan* (ISP) in June 2022, a whole system plan for the transformation of the National Electricity Market (NEM) in its shift toward renewable energy. The ISP outlines the development trends for the electricity sector over the next 30 years stating that a "once-in-a-century" transformation is underway in how electricity is generated and consumed in east and south east Australia. In the ISP's *Step Change* scenario, considered to represent the most likely pace of energy transformation in reaching net zero by 2050, the renewable share of total annual generation would rise from approximately 28% in 2020-21 to 83% in 2030-31 (consistent with the Commonwealth Government's policy), to 96% by 2040, and 98% by 2050. For transmission and distribution (T&D) network infrastructure, this calls for a large restructuring of the current systems in place to cater for:

- Almost double the electricity delivered to approximately 320 terawatt hours (TWh) per year.
- Coal-fired generation withdrawing faster than announced, with 60% of capacity withdrawn by 2030.
- Nine times the utility-scale variable renewable electricity capacity.
- Nearly five times the distributed solar photovoltaic (PV) capacity, and substantial growth in distributed storage.

Extreme weather-related risks and longer-term changes in climate exacerbate existing stresses on the electricity sector and can impede the immediate response to disaster events. Climate change will influence these risks by increasing their frequency or severity, or exposing previously unaffected assets to risks (e.g., changing flood risk profiles). Examples of the broader risks posed by climate change to the electricity sector include:

<u>Impacts to Demand or Generation (i.e. Supply)</u>

- Increasing the frequency of electrical blackouts due to demand exceeding supply during extreme heat events.
- Disrupting electricity generation assets due to adverse environmental conditions including extreme wind, fire weather, dust storms, or lack of water availability.
- Reducing efficiency of generation assets due to increased temperatures.

Damaging, or degrading, electricity generation assets due to extreme weather events (heat, flood, fire, storms).

Example of hazard: Extreme wind causing mass power outages

There have been many recent examples of extreme weather events damaging the electrical transmission and distribution (T&D) network in Victoria.

One such example occurred in January 2020 when six large transmission towers collapsed and a seventh tower severely damaged, in strong winds exceeding 125 km/h (Clayton, 2020). More than 20,000 properties across the state were affected by blackouts. Many businesses were affected by the outages including the Portland Alcoa aluminium smelter. The event also caused the Heywood interconnector between Victoria and South Australia to be impacted (Clayton, 2020).

Impacts to Transmission and Distribution Infrastructure

- Damaging or degrading transmission and distribution infrastructure due to extreme weather events.
- Destabilising transmission and distribution structure foundations due to flood or drought induced changes in ground conditions.
- Weakening structures making them more prone to failure and even collapse in an extreme storm event.
- Increasing arcing faults and pole fire on electricity transmission lines due to build-up of pollution.
- Flooding electrical substations and battery banks due to extreme rainfall events.
- Changing the prevalence or distribution of termite and other pests that damage timber network assets due to changes in temperature and rainfall.
- Reducing efficiency of transmission and distribution assets due to increased temperatures.

Impacts to Operational Activities

- Increasing health and safety risks to operation and maintenance staff due to exposure to extreme weather events.
- Restricting maintenance activities due to increasing length of fire seasons.
- Reducing performance of underground cables due to reducing soil moisture content and increasing ground temperature.
- Increasing whole of life costs, including maintenance costs, reduction in asset performance and shortening of asset lifespans due to combined increase in frequency and intensity of climate impacts.

The analysis is focused on the risks associated with damage to, or degradation of electricity T&D assets due to extreme weather events. This section describes the analysis of this specific risk, including differences in regional exposure across Victoria. This analysis is followed by commentary on the broader context of climate risks impacting electricity T&D infrastructure, including factors that will support a more detailed site-specific analysis.

4.1 Key risk profile

The risks associated with damage to, or degradation of electricity T&D assets due to extreme weather events were broken down to consider multiple climate hazards and elements which typically impact the assets. The hazards assessed were:

- Extreme temperatures, including heatwaves
- Bushfires
- Extreme rainfall and flooding
- Storms including extreme wind and lightning.

The specific T&D assets that were considered include: electricity transmission lines and towers; distribution lines and towers (i.e. poles and wires); and substations (including switchyards and zone, transmission and terminal substations). This combination of hazards and assets led to the identification of 14 risks. In the 2030 low emissions scenario, three risks were rated high and five were rated medium. The spread of the risk ratings changed in the 2030 high emissions scenario, with five risks rated high and five rated medium. In the 2070 timeframe, the spread of risk ratings changed significantly between the two emissions scenarios. In the low emissions scenario, there were 5 high rated risks and seven medium risks. This changed to 10 high rated risks and four medium rated risks in the high emissions scenario. Detail on the risk ratings (i.e. likelihood and consequence ratings) is provided in Appendix A.

The most significant risks were rated high in both timeframes (i.e., 2030 and 2070) under the high emissions scenario (i.e. RCP 8.5):

1. Extreme temperatures (including heatwaves) leading to derating or sagging of electricity transmission lines
2. Storms, including extreme wind or lightning, leading to degradation and failure of electricity transmission lines or towers
3. Bushfire or grassfire leading to degradation and failure of electricity transmission lines or towers
4. Storms, including extreme wind or lightning, leading to failure of electricity distribution lines
5. Bushfire or grassfire leading to damage and failure of transmission substations.

There are no specific design guidance mandated on this sector, instead it's up to the designer or individual requirements from utilities to set expected ambient conditions which equipment ratings should not exceed. Design ratings are typically informed by historic BoM data, rather than considering future climate projections. It is understood that, based on this approach, older assets are likely rated to 35°C, with newer assets rated to higher temperatures (i.e. 40°C)[3]. Lines can also expand and sag during extreme heat events, increasing the potential for interaction with vegetation depending on the arc distance between cables.

Fires can cause similar heat-related impacts, derating transmission lines due to radiant heat or weakening towers. Additionally, both large bushfires and localised grassfires can damage and destroy vulnerable distribution assets, such as wooden electricity poles. Storms, specifically strong wind and lightning, present issues to T&D infrastructure. Extreme wind may lead to towers being blown down, as recent Electricity Sector Climate Information project noted that there have been approximately 11 wind-related transmission tower failures events in 40 years across Victoria (ESCI, 2022). Lightning may cause circuit breakers to open disrupting supply. Depending on the charge this may be resolved by a reset, otherwise, replacement of equipment would be required.

Climate projections indicate the frequency, intensity and duration of extreme heat and fire danger days will increase, along with more intense rainfall events. These changes in climate are anticipated to increase the frequency or severity of the impacts on T&D infrastructure. This is reflected in the overall increase in the number of high risks, and reduction in the number of low risks under the later timeframes and higher greenhouse gas emissions scenario. For example, the buckling of transmission towers due to extreme heat is rated high under the 2070 high emissions scenario, but medium under the other three scenarios. Similarly, the flooding of substations is rated high in both 2030 and 2070 but only under the high emissions scenarios.

4.2 Regional exposure to risks

The risk to electricity transmission and distribution assets will not be experienced evenly across Victoria. Factors contributing to this include differing exposure of assets to climate hazards and the relative vulnerability of the assets and the communities they serve. This section provides commentary on how the exposure differs across six regions focussing on the hazards causing the most significant risks to electricity T&D assets: extreme heat, bushfire and storms. Discussion of vulnerability-related factors that may influence the risk profile of individual assets or towns is included in subsection 4.3.

Regions with greatest exposure of electricity T&D assets to climate hazards

Bushfires	Gippsland, Hume Barwon South West, Gippsland and Hume (Substations)
Extreme Heat	Grampians, Loddon Mallee
Extreme Rainfall and Flooding	Greater Melbourne, Gippsland (Substations)
Extreme Wind	Hume, Greater Melbourne

While extreme temperatures will occur across Victoria, the northern parts of the state are projected to be exposed to the hottest conditions (refer to Figure 4). For example, in 2070 under a high emissions scenario Mildura is projected to have 23 days a year with a maximum temperature above 40°C

[3] Based on the experience of AECOM subject matter specialists.

(compared to a historic average of 12) and Horsham, 11 days a year (compared to 2). This may place electricity T&D assets in northern Loddon Mallee and northern Grampians at greatest risk of being impacted by extreme heat.

Across Victoria, T&D assets in Gippsland and Hume are in locations at greatest risk of bushfires (refer to Figure 5). The likelihood of bushfires damaging distribution structures is reduced by existing controls including vegetation clearance, as well as the materials used in towers. Despite such controls, heat from fires may cause derating (in a similar way to high ambient temperatures during extreme heat days) or damage to lines. Wooden transmission poles are more susceptible to damage from fire. In Victoria, it is reported that 74% of all poles in-service are timber poles, and at least 50% of them were installed over 40 years ago (ESV, 2019).

Analysis undertaken as part of the ESCI project indicated limited trends in the data related to extreme wind events that are likely to cause damage to T&D infrastructure. It also noted that work is yet to be undertaken to apply climate projections to the data generated from the project (ESCI, 2022). This is complicated by the fact that while there is some indication of a potential increase in extreme wind events, there are low confidence levels associated with these projections (Dowdy A. et al, 2021). Historic data from the ESCI study shows that the regions that have experienced extreme wind conditions most frequently include Hume and eastern Greater Melbourne.

Across the state, there are 22 substations exposed to bushfire risk, of which six are in Gippsland, five in Barwon South West, three each in Grampians, Hume and Greater Melbourne, and two in Loddon Mallee (refer to Figure 7). There are also 17 substations potentially exposed to flood risk. These represent substations whose property boundary intersects the flood overlays. Nine are located in Greater Melbourne, three in Gippsland and two in Grampians. An additional three substations are located in close proximity to flood overlays. These substations may be exposed to flood waters as increases in the intensity of rainfall events change the extent or depth of flood hazards at the local scale.

For each of the identified substations, further analysis at the site level would be required to determine what structures, plant or equipment on the property may be at risk from fire or flooding. For example, some assets in a flood zone may already be built to be resilient to flood waters (i.e., elevated), or changes in the landform and drainage on, or adjacent to, the site may prevent water from entering the site and inundating assets. Existing clearance of vegetation and material selection at sites will influence the potential risk of damage from bushfire or grassfire events.

When considering the combined exposure of each region to extreme heat, bushfire and storm hazards, Loddon Mallee, Grampians and Hume may be considered the regions most exposed to the risks of damage to, or degradation of, electricity T&D assets due to extreme weather event. While these regions may have the greatest level of exposure, they are also experiencing significant investment in renewable energy generation. This investment presents opportunities to build new T&D infrastructure that is more resilient to projected changes in climate and reduce the network's sensitivity to outages. For example, greater flexibility may be designed into the network to enable segments of the network to be isolated should an outage occur and power be rerouted (e.g. self-healing), rather than an outage causing a more significant impact on the supply of power throughout the network.

For each of the locations identified as exposed to the climate hazards, and therefore potentially at risk, further analysis is required at the subregional or site level to determine the specifics of the infrastructure's vulnerability or resilience to extreme heat, bushfire or storm-related risks. Factors that may influence the vulnerability of T&D infrastructure at the subregional, or site level include:

<u>Sensitivity factors</u>

- The design of infrastructure: for example, a substation may be designed in a way that has critical assets elevated above projected flood levels, or levees / flood walls that prevent water entering the site.
- The age and condition of infrastructure: older assets may be designed to older standards making them more vulnerable to increasingly higher temperatures. Assets that are in poor condition may be more susceptible to failure when under stress (i.e., extreme heat or wind).

- Embedded or distributed generation: this provides redundancy and reduces reliance on the main network. For full islanded capability in the event of separation from the main grid, battery systems with grid forming capabilities are required to sustain the power quality requirements. In 2014, a battery system was successfully commissioned in the AusNet network to demonstrate an effective method of managing temporary feeder disconnection in times of need such as line maintenance and bushfire prevention (Goman, 2016).
- The criticality of specific assets and the customers or communities they serve: failure of an asset that supports a significant number of customers, or high-value industry may be deemed more sensitive.

Adaptive capacity factors:

- Provision of back-up generation for critical assets will limit the impact of short-term disruptions to electricity supply.
- Ease of access to repair, enabling a quick recovery of supply: T&D outages that occur in remote areas, areas with difficult terrain (e.g., steep slopes) or where access can be restricted by fallen vegetation (e.g., due to fires or storms) can delay efforts to repair assets and restore electricity services.
- Social factors: access to resources and strong social connectedness can significantly influence the degree to which an event will affect a community, and how quickly they are able to recover. For example, a community with high relative socio-economic disadvantage may not have the resources to invest in back-up energy generation capacity, rent temporary accommodation or promptly undertake repairs following damage from an event.

Estimated value of electrical transmission and distribution assets exposed to fire and flood hazards

Based on GIS analysis of the exposure of electrical T&D assets to bushfire and flooding hazards, focussing on substations, there is $54m of value at risk of flooding due to a 1 in 20 year flood event (representing 3 substations), $107m at risk due to a 1 in 50 year flood event and $214m (6 substations) at risk due to a 1 in 100 year flood event (12 substations). Note these values are based on an average value per substation and may not represent the actual value of the specific substations exposed to the risk of flooding. They have been calculated by SGS and AECOM using AEMO estimates and climate intelligence data sourced from Climatics (AEMO, 2021 and Climatics, 2022)

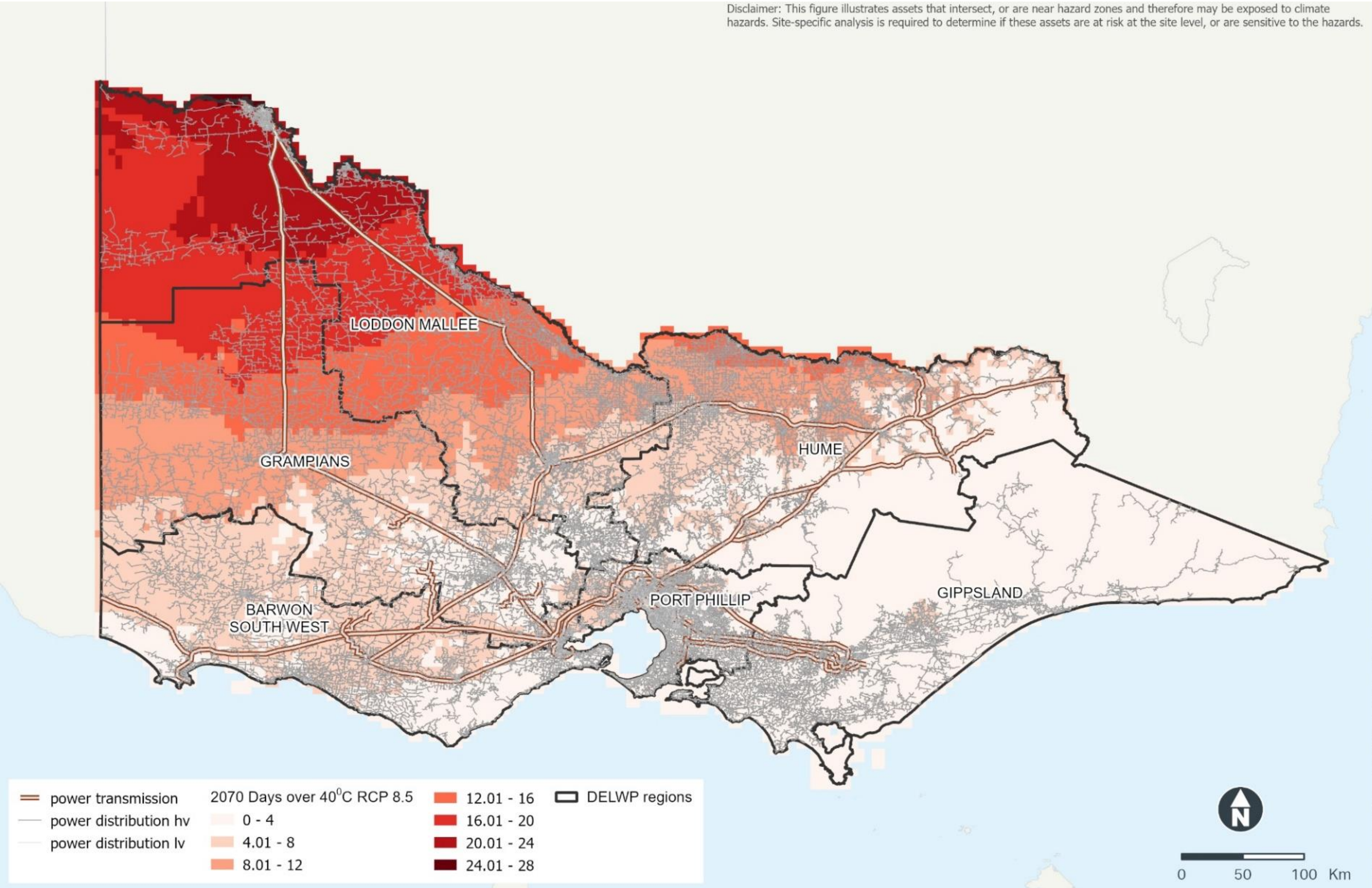


Figure 4 Transmission and distribution lines exposed to extreme heat – Projected days with maximum temperatures over 40°C in 2070 (RCP 8.5)

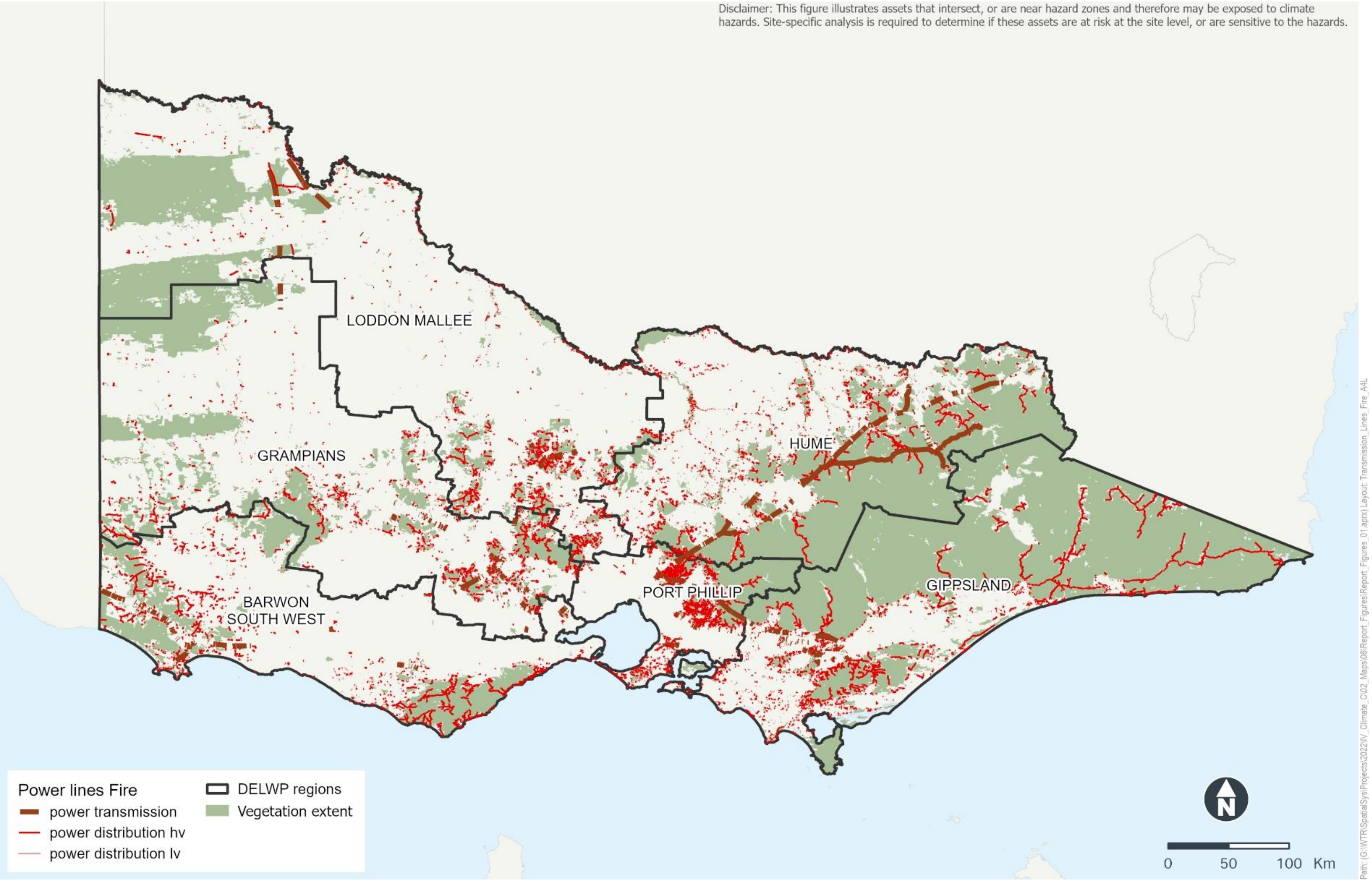


Figure 5 Transmission and distribution lines exposed to bushfire risk (i.e. Bushfire Management Overlay)

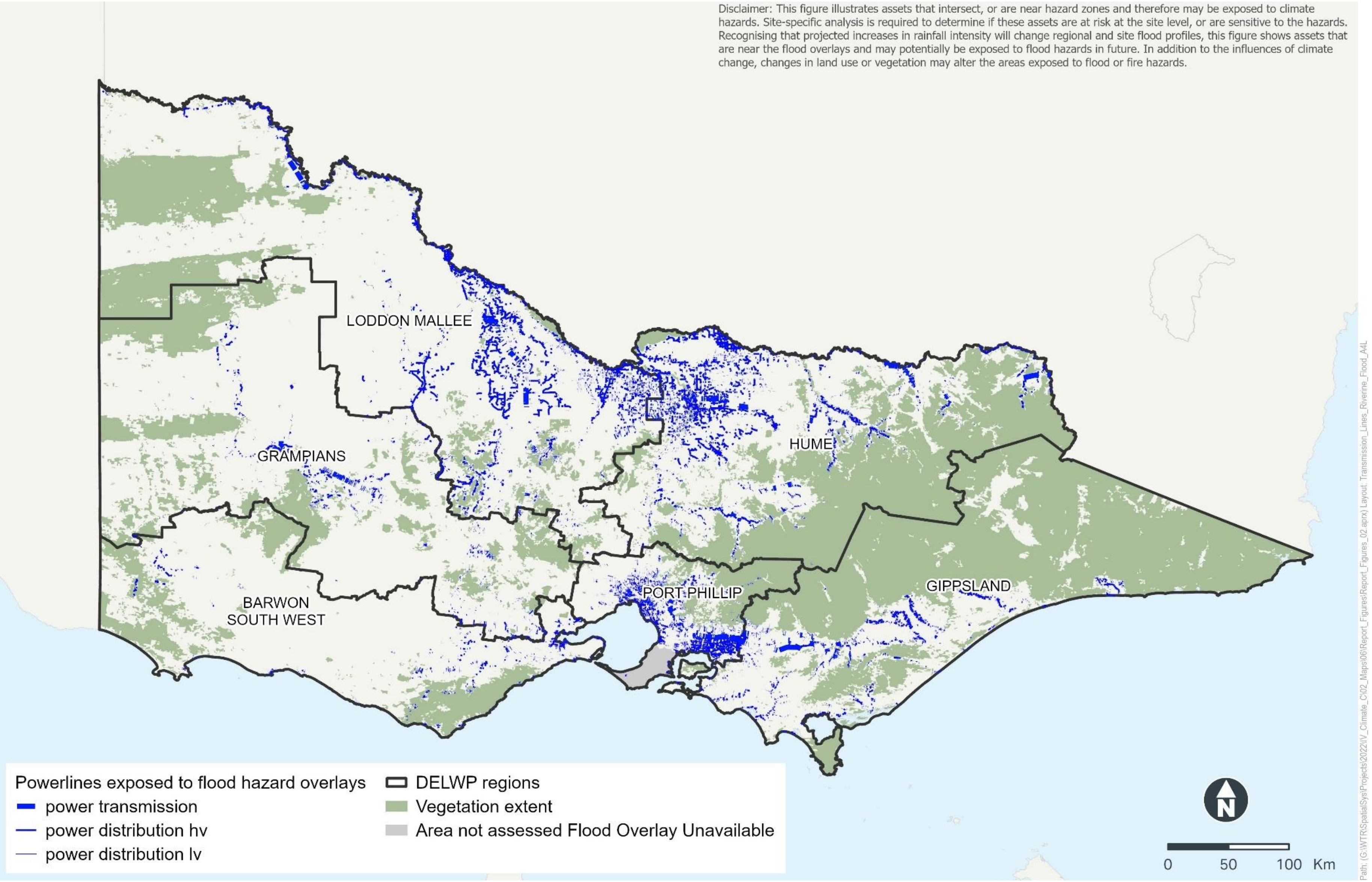


Figure 6 Transmission and distribution lines exposed to flood hazard (i.e. flood hazard overlays)

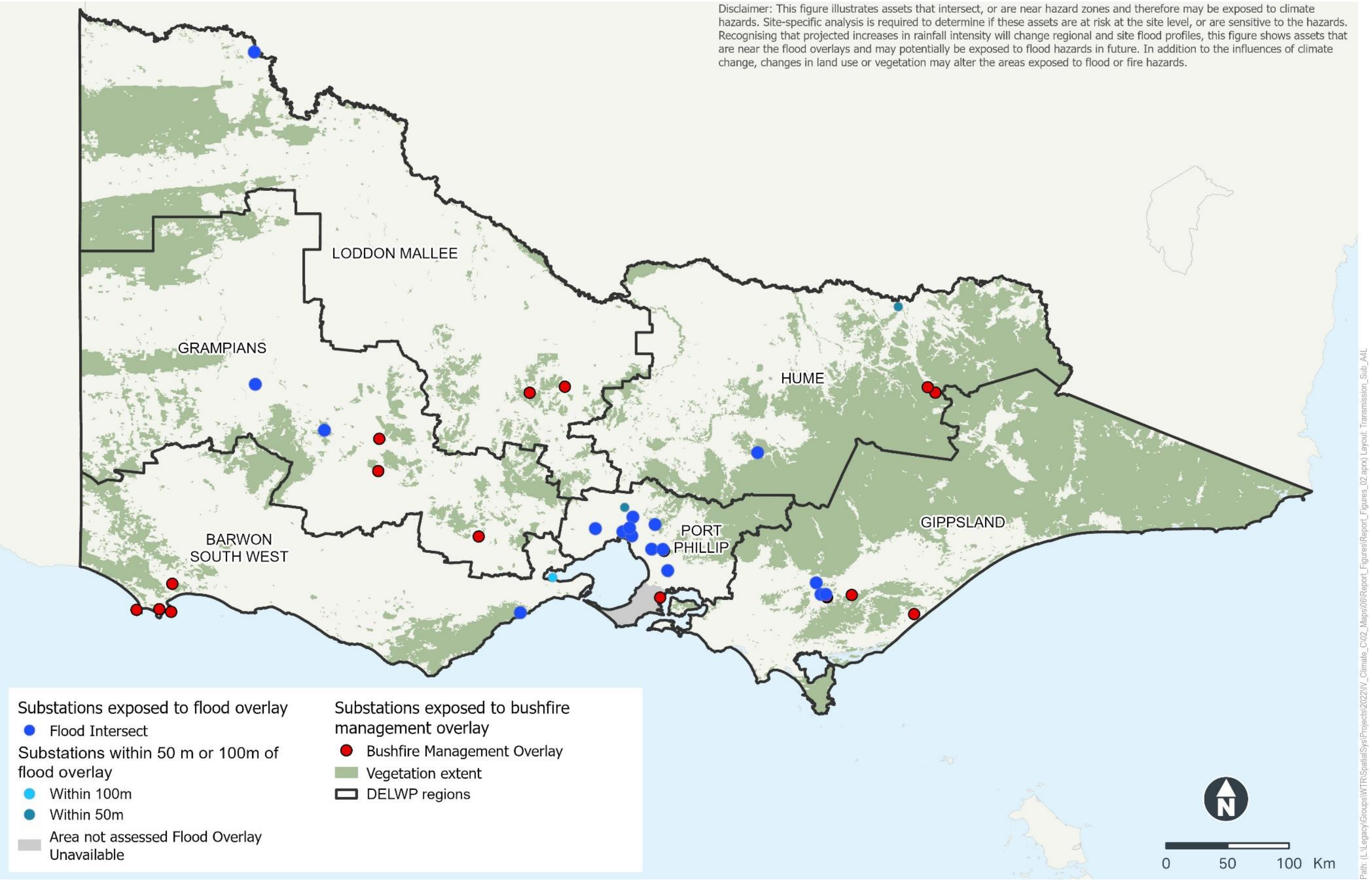


Figure 7 Substations exposed to flood and bushfire hazards

4.3 Broader context of climate risks

The analysis discussed in subsection 4.1 identified and rated the direct impacts of extreme weather on T&D infrastructure. To provide a more complete picture of the complexities associated with the risk of damage to, or degradation of electricity T&D infrastructure, consideration needs to be given to compounding events and cascading impacts.

Compounding events refer to the combination of multiple drivers or hazards that contribute to societal or environmental risk associated with damaged T&D infrastructure. These events are listed in Figure 8, grouped under the themes of Demand and Supply; Infrastructure and Operations. Examples of demand-related scenarios which have compounding impacts include the increased reliance on electricity for communication, heating, transport and point-of-sale transactions. This increased reliance on electricity means that disruptions to the supply of electricity will impact a greater volume of daily activities. Compounding events may also include the occurrence of multiple hazards simultaneously, or in quick succession, for example, a bushfire during a heatwave, or extreme rainfall following a bushfire event.

Cascading impacts relate to the sequence of secondary events that flow on from the initial direct impact of a risk. These may be physical, natural, social or economic impacts that, when combined, are greater than the initial direct impact of the risk. Figure 8 lists cascading impacts associated with damage to T&D infrastructure. Each impact includes a reference to the relevant consequence theme, as per the risk framework used in this assessment (refer to Appendix A). Examples of cascading impacts from damage to electricity T&D lines and corresponding consequence themes include starting a fire causing ‘Health’ or ‘Environmental’ impacts; and disruption of communication systems restricting the ability to communicate with at-risk or affected communities causing ‘Safety’ concerns.

In undertaking a more detailed assessment of risk (i.e. a site level risk assessment), consideration of compounding and cascading events can aid the identification of failure chains and interconnections with other systems. The consideration of cascading impacts can also provide a deeper understanding of the consequences of the risk. This can be beneficial in determining the benefits of avoided damages to justify investment in adaptation action to manage risks. For example, the benefits will extend beyond the avoidance of direct costs associated with repair and reinstatement of services to broader societal benefits including avoided: health consequences; environmental damages or disruption to economic activity.

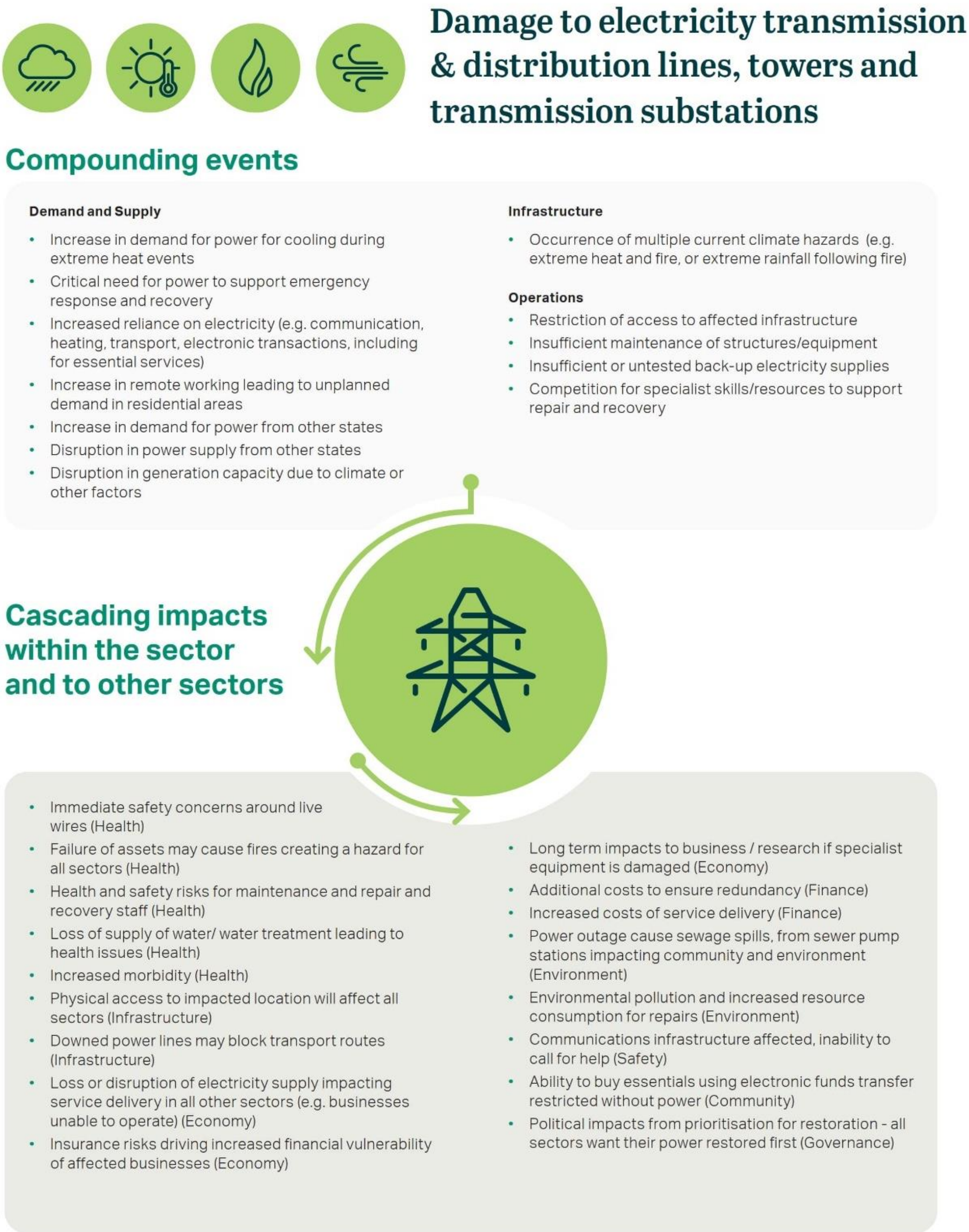


Figure 8 Broader context associated with the risk of damage to electricity infrastructure due to extreme weather events

4.4 Case study: Impact of extreme weather on electrical T&D infrastructure

4.4.1 What happened during the June 2021 storms?

On the 9th of June, 2021, an extreme storm that caused heavy rain, lightning and severe wind impacted across eastern and central Victoria, notably Gippsland and the Yarra Ranges. The storm caused flooding which damaged the Yallourn power station and coal mine in the Latrobe Valley which supplies up to 22% of Victoria's energy (DELWP, 2022e). The power station was therefore operating at only 20% of standard capacity (ABC, 2021).

AEMO advised that power supply was sufficient across the state, despite the substantial reduction in generation from Yallourn. However, it was the distribution network that was greatly impacted. Hundreds of trees fell, damaging distribution lines, as well as homes, and causing widespread blackouts. Five days later, on the 14th of June, over 25,000 homes were still without power across Victoria, 3,000 of which were advised that they would be without energy supply until the 10th of July, over a month after the storm initially hit (ABC News, 2021a).

AusNet, the distribution network business in most of Victoria's east, reported that at its peak, around 230,000 customers were without power – around 30% of its total customer base, heavily impacting its network (AusNet, 2021). Restoration could not begin immediately due to continuing bad weather and inaccessibility of some areas it covered, such as Mt Dandenong (AusNet 2021). According to the EDNRR, all network damage arising from the June 2021 storms was repaired by 5 July 2021, nearly a month later (DELWP, 2022). Residents were frustrated with communication that seemed to initially underestimate the extent of the damage, with significant revisions to restoration times (ABC News, 2021b). A year on, impacts from the storm are persisting. In Kalorama, where 44 houses were destroyed in the storm, electricity and telecommunications issues plague the town and much of the region. Power (41%) and internet (31%) outages occur more frequently than before the storm (Paul and Rizmal, 2022).

4.4.2 How is this relevant to Victoria's future planning?

This storm was a catalyst for a review established by the Victorian Government regarding the resilience of the electricity distribution network. The EDNRR's independent Expert Panel outlined recommendations for improving investment in network resilience, as well as community resilience to future power outages, such as through improved communication by providers. The Panel sets out recommendations into short (by 2025), medium (from 2025) and long-term (2026 onwards) priorities, setting a framework to oversee structural investment as well as regulatory and potentially legislative change to ensure that prolonged outages such as those seen in June 2021 are not seen again. It is expected that the Victorian Government will respond to the Panel's recommendations in 2022, or early 2023. Any regulatory or legislative change implemented as a result of this review would affect Victoria's electricity distribution network planning in the future (DELWP, 2022f).

Events like the June 2021 storm are likely to occur again in future. They highlight the need for energy and telecommunications infrastructure to be made more resilient, with the prolonged service disruptions remaining a frustration for many Dandenong Ranges communities. There were also lessons to be learnt from the recovery effort, in particular AusNet's initial assessment of the damage. By underestimating the severity of the destruction, AusNet were unable to provide customers with an accurate estimate of how quickly services may be returned.

4.5 Adapting to climate risks

There has been significant work undertaken, at multiple scales, to enhance the resilience of electricity T&D network infrastructure in Victoria to the impacts of climate change. Key work includes the development of the *Built Environment Climate Change Adaptation Action Plan* 2022-2026, the Regional Adaptation Strategies and the previously mentioned EDNRR as a result of the outages caused by the June and October 2021 storm events. Initial work at the national level includes the Electricity Sector Climate Information project which was to help the electricity sector build its capacity to assess climate risks.

There are many effective adaptation actions that can, and are, being implemented to manage the risks associated with damage to, or degradation of electricity T&D assets due to extreme weather events. A summary of adaptation actions that address the highest rated risks to the network is provided in Table 11. These actions are not intended to be an exhaustive list of actions and may not be applicable for use on all assets, or in all locations. However, they demonstrate specific physical measures that can be taken to build the resilience of the T&D networks and the communities they serve.

Table 11 Summary of physical adaptation actions to manage the priority risks of extreme weather events damaging electricity T&D network infrastructure

Climate hazards	Risks	Physical adaptation actions
Extreme temperatures, including heatwaves	Extreme temperatures (including heatwaves) leading to derating or sagging of electricity transmission lines	• Existing lines could be re-rated every 5–10 years using the current rating methodology, reflecting the increasing ambient temperatures • Implications of climate change should be considered when planning new lines, as the safe carrying capacity will drop over time as temperatures rise
Storms, including extreme wind or lightning	Storms, including extreme wind or lightning, leading to degradation and failure of electricity transmission lines or towers Storms, including extreme wind or lightning, leading to failure of electricity distribution lines	• Ongoing clearance and management of vegetation to minimise contact with the electricity network • Foundation and structural design of towers to account for higher wind loading and changing ground conditions in future • Primary equipment solutions include adding strain structures to T&D towers, reinforcing towers, adding intermediate structures to divide wind-span, and tower replacement • System adaptation solutions may include new lines on alternative routes, local generation for demand centres, and stand-alone power systems
Bushfire	Bushfire or grassfire leading to degradation and failure of electricity transmission lines or towers Bushfire or grassfire leading to damage and failure of transmission substations	• Ongoing clearance and management of fire breaks to minimise contact between vegetation and the electricity network • Selection of materials or coatings that are resistant to fire or radiant heat • Fire consequence mapping • Underground assets to protect from exposure to fire and reduce powerline bushfire ignitions Additional controls specific to distribution lines • By lowering the energy release in certain types of powerline faults within milliseconds, Rapid Earth Fault Current Limiters (REFCL) rapidly reduce the risk of arcing and igniting bushfires • Automatic Circuit Reclosers have the ability to immediately detect and turn off power at a fault on high fire risk days

Following a comprehensive review and analysis of existing adaptation controls and measures, together with key findings from the stakeholder engagement activities and consultation with subject matter experts, three adaptation themes have emerged as potential areas for further enhancing electricity T&D infrastructure resilience, namely:

- Building resilience of T&D network infrastructure.
- Enhancing guidance to support decision making.
- Strengthening T&D emergency response and recovery.

In the following sections, key current and planned adaptation actions relevant to these themes will be highlighted, and barriers to adaptation, opportunities and suggested actions to enhance adaptation will be discussed. Where applicable, comparable recommendations referenced in the *Built Environment Climate Change Adaptation Action Plan 2022-2026* and the EDNRR will be drawn out for discussion, with differentiating factors highlighted.

4.6 Adaptation theme #1: Building resilience of T&D network infrastructure

4.6.1 Current and planned controls

As owners, operators or controllers of transmission or distribution systems, Distribution Network Service Providers (DNSPs) play a vital role in maintaining and enhancing network resilience (AEMO, 2022). The design, construction, operation and maintenance of assets is critical to resilience building. Site selection for T&D infrastructure is dependent on a number of factors, including physical and topographical impacts such as soil type, potential for flooding, adequacy of drainage and area for control of storm water runoff, and potential soil erosion and sediment control. Planning controls including overlays and permits, together with design standards and building codes, set the requirements for the design and construction of T&D infrastructure.

Regular inspection and maintenance of assets is required to ensure their condition is in line with policies and strict regulations audited by Energy Safe Victoria. For example, stakeholders highlighted in workshop discussions that recent modelling and flood plain analysis by Powercor identified four substations that are below the 1% annual exceedance probability line (which defines land with a 1% chance of experiencing a flood each year) and have been flagged for upgrades. In addition to modelling and analysis, several DNSPs across the state are investing in digital asset inspection technologies to assist in data collection and the long-term planning of asset management programs.

At a strategic level, eight critical infrastructure sectors, including the energy sector, prepare annual Sector Resilience Plans under *Victoria's Critical Infrastructure Resilience Strategy* (EMV, 2015). *Victoria's Critical Infrastructure All Sectors Resilience Report 2021* acknowledges that key risks to the energy sector include severe weather events (storm, flood, extreme temperatures, drought and fires). Resilience improvement initiatives proposed by the Energy Sector Resilience Network in 2021-22 prioritise climate change adaptation to improve resilience to risks linked to climate change. Reviews of energy infrastructure and supply resilience are reported annually in the *Energy Sector Resilience Plan* and *Energy Summer Preparedness Plan*.

To minimise bushfire risk and ensure that power supplies are sustained in affected communities, the following controls have been put in place:

- Maintain clearance and management of fire breaks is required to minimise contact between vegetation and the electricity network. Fire consequence mapping was conducted following the Black Saturday bushfires in 2009.
- The Victorian Government established the Rapid Earth Fault Current Limiter (REFCL) (DELWP, 2022g) program in 2017 to improve safety across Victoria's electricity network. By lowering the energy release in certain types of powerline faults within milliseconds, REFCLs rapidly reduce the risk of arcing and igniting bushfires. Through the program, which is due to be completed in 2023, REFCLs have been installed on 22 kilovolt powerlines at 45 substations across Victoria to detect and suppress faults.

- Automatic Circuit Reclosers have the ability to immediately detect and turn off power at a fault on high fire risk days, and have been installed on all 12.7 kilovolt, single-wire earth return powerlines in Victoria (DELWP, 2022g).
- The undergrounding of assets to reduce powerline bushfires ignitions and increase community safety is driven through the Victorian Government's Private Overhead Electric Line scheme (DELWP, 2022h). The scheme targets areas which were most affected during the summer 2019-20 bushfires in addition to High Bushfire Risk Areas.

The Regional Adaptation Strategies (RASs) are locally developed and led and supported by the Victorian Government to address the challenges and opportunities that climate change will bring to Victoria's regions. Each RAS has its own locally relevant and unique adaptation actions. The following controls from specific RASs have been highlighted as examples:

- Gippsland's RAS aims to assess the vulnerability of key regional infrastructure by working with responsible agencies and asset owners to collaboratively develop an understanding of asset interdependence and the impacts of failure on surrounding and dependent infrastructure and systems. Responsible agencies will be required to develop a greater understanding of higher-risk areas and implement adaptation measures to reduce risk.
- Loddon Mallee's RAS aims to improve ageing public assets to withstand an increase in extreme weather events. Actions include conducting audits in ageing infrastructure and identifying opportunities to replace damaged or end-of-life public assets with alternative technologies.

4.6.2 Barriers and opportunities

The stakeholder engagement process identified barriers and opportunities for the sector to build the resilience of electricity transmission and distribution assets to extreme weather events, and the impacts of climate change more broadly.

The scope of the national regulatory framework was raised by stakeholders as a key barrier to building network resilience, in that it does not embed resilience as an objective. The National Electricity Rules require DNSPs to improve the reliability of supply but do not include a regulatory mechanism to encourage proactive investments in network resilience. The EDNRR (DELWP, 2022f) has recognised this gap, recommending that the Victorian Government work with the Australian Energy Regulator to formally amend the regulatory framework from the next regulatory period, i.e. 2026 onwards.

The EDNRR acknowledges that the 2026 timeframe is too distant and that action to improve network resilience is required now. The Review's first recommendation is therefore to develop a Victorian Network Resilience Investment Strategy so that actions to drive distributor investments in resilience can start immediately. The recommendation includes specific actions to identify locations at high risk of climate change impacts, conduct geospatial risk analysis and identify preferred investment solutions, among others (DELWP, 2022f).

This recommendation demonstrates a robust strategy to drive investment in resilient solutions for the distribution network. However, there is an opportunity to expand this approach to include transmission networks. There is also an opportunity to consider the urgency of implementation, identifying options that can be factored into the DNSPs' asset renewal strategy.

The Victorian Government's priority adaptation actions for electricity infrastructure over the next five years (2022-26) are embedded within the *Built Environment Climate Change Adaptation Action Plan*, the system which comprises cities and towns together with supporting infrastructure and services – including energy (DELWP, 2021b). The Plan outlines an action to strengthen energy infrastructure resilience via the EDNRR, using existing frameworks such as *Victoria's Critical infrastructure All Sectors Resilience Report*. In addition to the recommendations already outlined, the EDNRR recommends that distribution businesses strengthen electricity system resilience by taking an all-hazards approach to risk mitigation. If implemented, this would require distribution businesses to develop a Network Resilience Plan at least every five years to determine the need for investments and solutions in the most high-risk locations in the electricity distribution network (DELWP, 2022f).

Considering the criticality of the electricity network, and the scope of the two aforementioned plans, there is an opportunity to develop a targeted plan to cater to both transmission and distribution infrastructure and address the holistic needs of the electricity network.

4.6.3 Enhancing adaptation

E1 Prioritise sections of the electricity T&D network to undergo site-specific assessment of climate risks

Building on the critical work that DNSPs undertake to maintain their assets, it is recommended that they conduct detailed assessments of climate risk at the asset or site level. The prioritisation process for selecting assets to assess should consider the exposure of assets to hazards, criticality of assets (including consideration of isolation potential and socio-economic factors), age of assets and planned timing for reinvestment. This may assist in enabling a detailed understanding of risks to be considered in the design of renewed assets. Input to the prioritisation process from AEMO may also assist in enabling consideration of planned changes to the network.

The detailed assessments should consider all climate risks to the assets in the priority locations. The asset level assessments should identify adaptation options for implementation as well as the urgency of implementation (i.e. should they be prioritised for immediate investment or factored into asset renewal). Action E1 aligns with recommendation 1 of the EDNRR (specifically, the recommendations to identify locations at high risk of climate change impacts, conduct geospatial risk analysis and identify preferred investment solutions), but with scope expanded to include transmission assets as well as distribution network infrastructure. It is recommended as an immediate priority to enhance the resilience of T&D network infrastructure across Victoria.

The prioritisation activity should be coordinated with the oversight of the Victorian Government to ensure that this critical process is undertaken, and documented in the sector-specific climate change adaptation plan recommended in action E2.

E2 Develop a climate change adaptation plan at the T&D network level

Considering the criticality of the electricity T&D network in supporting all other sectors of the economy, it is recommended that a climate change adaptation plan be developed specifically at the network level. The purpose of developing a sector-specific adaptation plan is to provide a shared document to support decision-making by DNSPs.

The plan could bring together the findings and recommendations from the multiple studies undertaken in this sector (e.g. the EDNRR and the Electricity Sector Climate Information (ESCI) project). This could be achieved by either expanding the scope of the five-yearly Network Resilience Plan proposed by the EDNRR to include the transmission network or by developing a new Adaptation Action Plan at the network level. It is recommended that this action be implemented as a matter of priority. The Victorian Government should coordinate the development of the plan seeking input from the industry stakeholders, to be incorporated into the next round of adaptation action planning.

4.7 Adaptation theme #2: Enhancing guidance to support decision making

4.7.1 Current and planned controls

As a complementary measure to the Powerline Bushfire Safety Program which was launched in 2011 following the Victorian Bushfires Royal Commission into the Black Saturday Fires, the Victorian Government introduced the f-factor Incentive Scheme in 2012 as a regulatory instrument under the National Electricity (Victoria) Act 2005. The scheme is designed to incentivise electricity network businesses to focus on areas and times of the year where powerline ignitions pose the greatest bushfire risk. It incentivises delivery of operational improvements and efficient investment in network assets to reduce risk to the community.

Gippsland’s RAS includes the aim to build back better following significant natural events. This could be achieved by identifying and maximising opportunities to replace impacted infrastructure with more resilient designs which are fit for purpose. These efforts are complemented by the aim of ensuring agencies responsible for key regional infrastructure develop a greater understanding of locations and assets at higher risk and implement adaptation measures to reduce risk.

4.7.2 Barriers and opportunities

In Victoria, electricity T&D assets are privately owned and maintained by DNSPs. While the Australian Energy Regulator is the authority that enforces the rules established by the Australian Energy Market Commission, individual DNSPs can differ in their approach to delivery. DNSPs have their own design and construction guidelines, which are influenced by company drivers and investment requirements. In the rapidly developing network transition, with new technology development and climate change impacts, it was identified in the stakeholder engagement discussions that the decision-making process for climate adaptation can be challenging, varying between companies, and potentially slow to implement. This presents an opportunity for the Victorian Government, in consultation with stakeholders, to develop a set of standardised adaptation design guidelines to promote consistency and standardisation.

4.7.3 Enhancing adaptation

E3 Embed adaptation design principles into the design of new and upgraded/renewed infrastructure

There is an opportunity for the development of adaptation design guidelines that could be used by DNSPs to support greater alignment in building resilience across the sector. These guidelines can then assist DNSPs to embed climate resilience considerations into the design of new infrastructure or when upgrading/renewing infrastructure. These guidelines could also be included as requirements to support the development of projects funded by government (e.g. stand-alone power systems and microgrids). Examples of adaptation design principles relevant to electrical transmission and distribution infrastructure are provided in Figure 9.

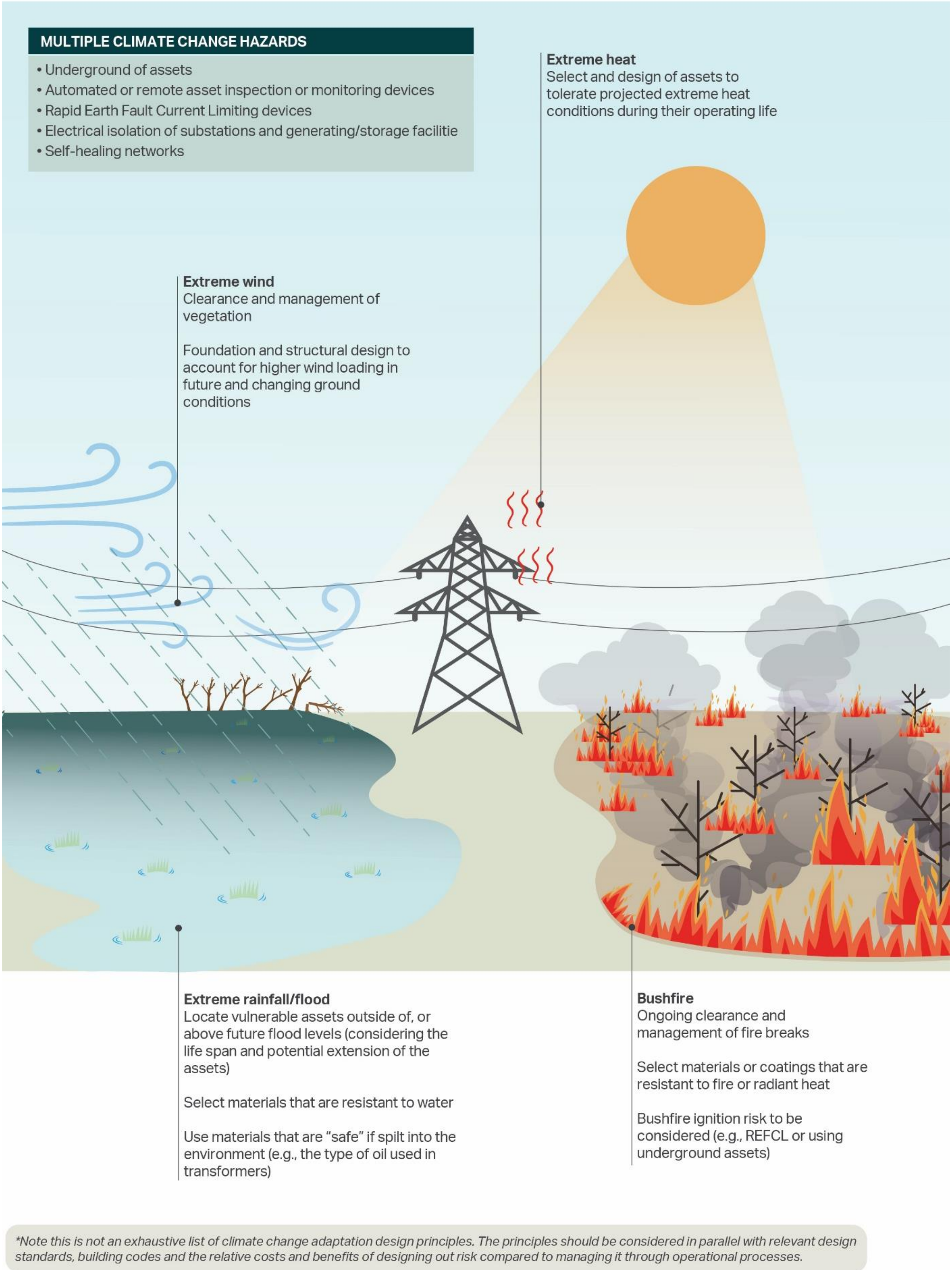


Figure 9 Design principles to manage the risks of extreme weather events damaging electrical T&D infrastructure [Adapted from ESCI, 2022, and SCRC, 2020].

4.8 Adaptation theme #3: Strengthening T&D emergency response and recovery

4.8.1 Current and planned controls

There are a number of emergency management controls in Victoria that support the response and recovery from events that disrupt electricity transmission and distribution. Emergency Management Victoria (EMV) leads emergency management in Victoria, maximising the ability of the emergency management sector to work together and to strengthen the capacity of communities to plan for, withstand, respond to and recover from emergencies.

EMV supports the Emergency Management Commissioner (EMC) to lead and coordinate emergency preparedness, response and recovery across Victoria's emergency management sector in conjunction with communities, government, agencies and business. In 2018, an amendment to the Emergency Management Act required the EMC to prepare a state emergency management plan. The plan recognises that Victoria has three operational tiers (municipal, regional and state) to ensure emergency management arrangements are scalable. At a regional level, the RASs speak to the importance of enhancing emergency management and preparedness to disasters, and increasing critical infrastructure resilience to the impacts of significant events.

Established under the Energy Safe Victoria Act 2005, Energy Safe Victoria is the regulator responsible for electricity safety in the state, auditing the design, construction and maintenance of electricity networks. The regulator also conducts comprehensive public awareness safety campaigns to educate the community on the potential dangers of electricity, including due to extreme weather events.

4.8.2 Barriers and opportunities

The stakeholder engagement process identified barriers and opportunities for the sector to strengthen T&D emergency response and recovery. Workshop discussions pointed to gaps in central emergency management coordination following the outages caused by the 2021 storms, leading to challenges in prioritising recovery and service restoration efforts and in communicating to customers about the likely ongoing impact of outages. The discussion acknowledged that improvements had subsequently been put in place through the first phase of the EDNRR, which made recommendations for operational improvements and information sharing during energy emergencies. Actions to implement these recommendations were underway by the end of 2021.

The EDNRR's final recommendations further targeted this barrier, calling for new obligations on distribution businesses to improve the prioritisation of power restoration following an outage and for improved communication with customers. Considering the criticality of the network to emergency response and recovery services in extreme weather events, and the impact on communities of prolonged power outages, the Victorian Government can play a key role in coordinating efforts across the various organisations involved, to build resilience across the T&D network.

It is assumed that a significant proportion of electricity networks in Australia are aging and do not have automated or intelligent controls to manage emergency outages. These include technologies such as self-healing networks, which use sensing, control and communications technology to automatically reroute power for critical infrastructure while isolating the fault. The intelligent control also limits the requirement for technicians to attend the site to determine the cause of the fault, vital for being able to restore power in areas impacted by extreme weather events such as floods, bushfires and storms.

Self-healing networks have been used internationally for almost a decade, with pilot projects being implemented in the United States in 2013 (SEL, 2022) and the Netherlands in 2014 (Coster and Kerstens, 2014). Jemena, an electricity network operator in Melbourne's northern and western suburbs, rolled out a multi-year plan in early 2022 to create a self-healing electricity network with an anticipated completion date in 2024 (Chirgwin, 2022).

The intelligent control system requires well connected infrastructure networks to support the ability to automate the rerouting of power. A smart network with the ability to anticipate, respond to and isolate damage could mitigate the impact of power disturbance events and speed up recovery. Investment in new renewable generation and supporting T&D infrastructure presents opportunities for the broader network. More distributed generation and a more interconnected network can support the ability to automate the isolation of faults and rerouting of power, minimising disruptions to customers.

4.8.3 Enhancing adaptation

E4 Enhance shared agreement on priorities for emergency restoration and recovery

The Victorian Government can play a key role in coordinating efforts across the various organisations involved to enhance centralised agreement on priorities for emergency restoration and recovery efforts, and enable deployment of responses in a timely manner. This process could be coordinated as a part of, or embedded in, the development of the annual Sector Resilience Plans to enable a regular review of priorities.

This action will align with EDNRR recommendations which seek to introduce new obligations on distribution businesses to improve prioritisation of power restoration following outages.

E5 Include self-healing networks in the proposed adaptation design principles for new and upgraded infrastructure

It is recommended that the adaptation design principles for the design of new and upgraded infrastructure (Action E3) include requirements for the implementation of self-healing networks, to have intelligent protection systems with the ability to be centrally, remotely and automatically controlled.

Examples of the technology installed in the aforementioned case studies are listed below. These examples are for distribution networks, which may provide the most value from implementation in Victoria. The implementation of similar technology for the transmission network would also benefit the broader reliability of the electricity network:

- Jemena deployed an advanced distribution management system platform with a fault location, isolation, and service restoration system (Chirgwin, 2022).
- Dutch Distribution Network Operator Stedin worked with Schneider Electric to install underground self-healing networks in Rotterdam. This included intelligent fault passage indicators, remote-controlled ring main units and a completely self-healing distribution feeder (Coster and Kerstens, 2014).
- Mississippi Power partnered with Schweitzer Engineering Laboratories to commission a Distribution Network Automation solution to create a robust, self-healing network that incorporated Advanced Recloser Controls in a Real-Time Automation Controller-based distribution automation control solution (SEL, 2022).

4.9 Summary of proposed adaptation actions

Table 12 summarises the proposed adaptation actions in response to the risk of damage to, or degradation of electricity transmission and distribution assets due to extreme weather events.

For each action a suggested timing for implementation has been indicated. These are either, act now (i.e. within the current adaptation action planning cycle), act by 2026 (i.e. incorporate into the next round of adaptation planning, for roll out from 2026), or undertake further research.

Progressing these adaptation actions can help to determine which physical adaptation measures, summarised in Section 4.5, could be deployed in different parts of the network to help build electricity T&D infrastructure resilience.

Table 12 Proposed adaptation actions to address the risk of damage to, or degradation of electricity transmission and distribution assets due to extreme weather events

Adaptation actions	Act now	Act by 2026	Further research
Physical actions			
E1 Prioritise sections of the electricity network to undergo site specific assessment of climate risks	x	-	-
E3 Embed adaptation design principles into the design of new and upgraded/renewed infrastructure	x	-	-
E5 Include self-healing networks in the proposed adaptation design principles for new and upgraded infrastructure	x	-	-
Policies / Strategy based actions			
E2 Develop a climate change adaptation plan at the T&D network level	-	x	-
E4 Enhance centralised agreement on priorities for emergency restoration and recovery	x	-	-

5.0 Public hospitals

The COVID-19 pandemic has presented an ongoing challenge to an already stretched Victorian public health system (VHA, 2021). Across Victoria, there are approximately 150 public hospitals and healthcare services that provide a range of different services at a variety of scales (Department of Health, 2022). The services provided by hospitals range from emergency, trauma and intensive care, medical and surgical services, mental health and rehabilitation. Some facilities provide specialist care, for example the Victorian Comprehensive Cancer Centre, Monash Children's Hospital and The Royal Dental Hospital. While there are hospitals and healthcare services located in all regions of Victoria, due to the specialist nature of some facilities not all facilities are 'interchangeable'. For example, if the services of one hospital are disrupted, it may be that the next closest hospital is not able to provide a like for like replacement of the affected services. In addition to the varying scale of assets, the age and condition of hospitals varies across the state, with the typical design life span of structures exceeding 70 years.

Extreme weather events currently present a range of risks to public hospitals and the broader health system, adding additional stresses. Many of these risks will be influenced by climate change, either increasing their frequency or severity (e.g., fire events), or exposing previously unaffected assets to risks (e.g., changing flood risk profiles). Examples of the broader risks posed by climate change to hospitals include:

Impacts to Demand or Supply

- Surges in demand due to increases in heat-related presentations, and injuries and illness associated with extreme weather events, including family violence injuries
- Increasing demand for mental health services due to increased stress associated with more frequent or intense extreme weather events
- Restricted ability to access staff as they may not be able to access workplaces, or may be directly impacted by a hazard event.

Impacts to Hospital Infrastructure

- Damage to building structures due to extreme weather events
- Reducing asset performance or efficiency as temperatures or humidity exceeds the design thresholds of building infrastructure
- Damaging facades of buildings due to extreme weather events including wind and heat.

Impacts to Operational Activities

- Disrupting utilities (e.g., power, water and telecommunications) and transport access to facilities due to extreme weather events
- Health and safety risks to staff due to exposure to extreme weather events or more agitated patients
- Reducing amenity within buildings due to extreme heat or smoky conditions caused by large scale fires

Increasing the pressure on hospitals

Climate change is projected to increase the frequency and intensity of many extreme weather events. Recent examples of extreme weather events that have led to significant increases in the demand for health services include:

- The 4-day heatwave in January 2009 led to significant increases in emergency department presentations and ambulance cases during the event, which ultimately lead to 374 deaths. Sadly, this was closely followed days later by the catastrophic Black Saturday bushfires (DHS, 2009).
- In November 2016, Melbourne experienced a thunderstorm asthma event that caused hundreds of hospital admissions and thousands of emergency department presentations. It is anticipated that climate change will increase the likelihood of similar events reoccurring (PHRP, 2018).

- Increasing energy and water demand and operating costs due to hotter and drier conditions
- Reducing amenity of landscaping due to hotter and drier weather conditions
- Increasing whole of life costs, including maintenance costs and shortening of asset lifespans due to more frequent exposure to harsher weather conditions (i.e., heat, wind, rain, fire).

This analysis is focused on the risks associated with damage to public hospital building structures due to extreme weather events. This section discusses the analysis of this specific risk, including differences in regional exposure across Victoria. This analysis is followed by commentary on the broader factors that will influence the impacts associated with this risk and support a more detailed site-specific analysis.

5.1 Key risk profile

The risk associated with damage to public hospital building structures due to extreme weather events was broken down to consider multiple climate hazards and elements on a typical hospital site. The hazards assessed were:

- Extreme temperatures, including heatwaves.
- Extreme rainfall and flooding.
- Coastal storm surge and coastal erosion.
- Bushfires.

For this analysis, the focus of impacts to hospital facilities was on the hospital 'building envelope', plant and equipment (P&E) attached to hospital buildings, multi-level carparking structures and onsite road or pedestrian access and at grade carparking. This combination of hazards and assets led to the identification of 12 risks. The spread of the risk ratings was largely consistent across the two 2030 low emissions scenarios and the 2070 low emissions scenario with only two high rated risks and only one risk increasing from Low to medium in the 2070 low emissions scenario. Under the 2070 high emissions scenario, the number of high rated risks increased to five. Detail on the risk ratings (i.e. likelihood and consequence ratings) is provided in Appendix A.

The highest rated risks were extreme rainfall related flooding leading to both damage to hospital building structures and damage to P&E attached to hospital facilities. These risks were both rated high in 2030 and 2070 under both the low (RCP 4.5) and high (RCP 8.5) emissions scenarios. The next most significant risks (medium in all scenarios, except the 2070 high emissions scenario) were extreme temperatures damaging P&E and extreme rainfall-related flooding leading to obstruction of, or damage to onsite car parks, road or pedestrian access. More extreme temperatures may restrict the ability of older facilities to maintain required indoor environmental conditions or, in the case of older facilities with naturally ventilated substations or switchrooms, may result in temporary loss of power supply or damage to electrical infrastructure.

Should flood waters inundate a hospital or surround a facility for an extended period of time, this is also likely to lead to significant damage. This damage may be as a result of impacts to structural integrity of buildings, damage to electrical infrastructure located below freeboard, or contaminants carried in flood water requiring extensive remediation of damaged facilities.

Climate projections indicate the frequency, intensity and duration of extreme heat will increase, along with more intense rainfall events (DELWP 2022a). These changes in climate are anticipated to increase the frequency or severity of the impacts on hospital facilities. This is reflected in the overall increase in the number of high risks, and reduction in the number of low risks in 2070 under the high emissions scenario.

Recent economic impacts of extreme weather on Victorian Hospitals

VMIA data from the past 15 years shows a growing number of flood related insurance claims, with 12 affected Victorian hospitals seeking claims in the 2017/18 season. On average over the 15 years, there have been three flood related claims per year with a direct economic impact of approximately $507,600 per event. Using Deloitte (2017) hazard multipliers to include the average estimated indirect economic impacts for these events, the total damages can range between $5-11 million per event.

Major bushfire events have been less common over the same period, with five events having been recorded by VMIA, the largest being Black Saturday's $77 million (Parliament of Victoria, 2010) in infrastructure loss and damages.

Focussing on the hospitals identified as exposed to flood or fire hazards, it is estimated that annually, 2% of the capital value of these hospitals is at risk each year from bushfires and 1% of their capital value is at risk from flooding (Climatics, 2022).

5.2 Regional exposure to risks

This section provides commentary on how the exposure differs across the six regions focussing on the hazards causing the most significant risks to hospital facilities: extreme rainfall, extreme heat and bushfires. Our state-wide risk analysis has resulted in risk ratings that are less sensitive than if the analysis was undertaken at a site level. However, this report acknowledges that risks to hospital facilities will not be experienced evenly across the state. Factors contributing to this include differing exposure of assets to climate hazards and the relative sensitivity (i.e. the degree to which they are affected by climate variability) of the assets and the communities they serve. Discussion of vulnerability-related factors that may influence the risk profile of individual assets or towns is included in subsection 5.3.

Regions with greatest exposure of public hospitals to climate hazards

Bushfires	Loddon Mallee, Greater Melbourne, Hume
Extreme Heat	Grampians, Loddon Mallee
Extreme Rainfall	Greater Melbourne, Loddon Mallee, Hume

Across the state there are 20 public hospitals potentially exposed to flood risk from extreme rainfall events (refer to Figure 10). A further 14 are located within 50 metres of flood overlays and may become exposed as the extent of flood hazards changes due to increases in the intensity of extreme rainfall events. Of the 20 hospitals that are exposed now, eight are within the Greater Melbourne region, five in Loddon Mallee and four in Hume. Of the six regions, only Gippsland does not have any hospitals that intersect with (or are within 50 m of) current flood related planning overlays.

While extreme temperatures will occur across Victoria, the northern parts of the state are projected to be exposed to the hottest conditions. For example, in 2070 under a high emissions scenario Mildura is projected to have 23 days a year with a maximum temperature above 40°C (compared to historic average of 12) and Horsham, 11 days a year (compared to 2). This may place hospitals in northern Loddon Mallee and northern Grampians at greatest risk.

Across Victoria, 12 hospitals are in locations exposed to bushfire risk (refer to Figure 11). Three-quarters of these are within Loddon Mallee (four hospitals), Greater Melbourne (three hospitals) and Hume (two hospitals). There is one hospital at risk within each of the other three regions (Barwon South West, Gippsland and Grampians). The likelihood of bushfires damaging building structures is considered lower than flooding due to existing controls, including vegetation clearance around structures, that limit the ability of fire to interact with structures. Despite the clearance, 'ember attack' has the potential to cause damage to structures, while smoke from fires can cause significant indoor air quality issues for hospitals.

Exposure to coastal inundation was also considered in the analysis. Only one hospital was identified at potential risk of coastal inundation. This facility is located in Rosebud, Greater Melbourne, and is considered exposed under the end-of-century storm surge scenario (i.e. 82 cm sea level rise).

When considering the combined exposure of each region to extreme heat, extreme rainfall and bushfires, Loddon Mallee, Hume and Greater Melbourne are the regions most exposed to the risks of damage to hospital facilities due to extreme weather events.

For each of the hospitals identified as exposed to the climate hazards within scope for this study, and therefore potentially at risk, further analysis is required at the subregional or site level to determine the specifics of the vulnerability or resilience of structures and P&E to extreme heat, rainfall or related risks. Factors that may influence the vulnerability of hospital infrastructure at the subregional or site level include:

Sensitivity factors

- The design of infrastructure: For example, a hospital may be designed in a way that has critical assets (e.g. high voltage electrical systems, heating, ventilation and cooling systems) elevated above projected flood levels, or levees / flood walls that prevent water entering the site.
- The age and condition of infrastructure: Older assets may be designed to older standards making them more vulnerable to increasingly higher temperatures. Assets that are in poor condition may be more susceptible to failure when under stress (e.g. extreme heat or wind).
- The criticality of specific services and the communities they serve: Failure of a hospital that supports a large or remote population or provides a specialist service not replicated at other hospitals may be deemed to be a more sensitive part of the health system.
- The types of patients treated and complexities of being able to relocate them further away from family and friends.

Adaptive capacity factors:

- Provision of back-up generation for critical assets within hospitals will limit the impact on service cause by short-term disruptions to electricity supply.
- Ease of access to alternative services: If hospitals that provide a replicable service are located nearby, at the local level, adaptive capacity may be considered higher.
- Ease of access to repair, enabling a quick recovery of services: Hospitals in remote areas, or where there is significant damage to supporting infrastructure (e.g. roads, telecommunications, power or water) can experience delays in efforts to repair assets and restore hospital services.
- Social factors: Access to resources and strong social connectedness can significantly influence the degree to which an event will affect a community, and how quickly they are able to recover. For example, a community with high relative socio-economic disadvantage may not have the resources to access hospital services that are located further away. They may not have access to transport to travel greater distances or have the resources to stay in temporary accommodation closer to an alternative hospital.

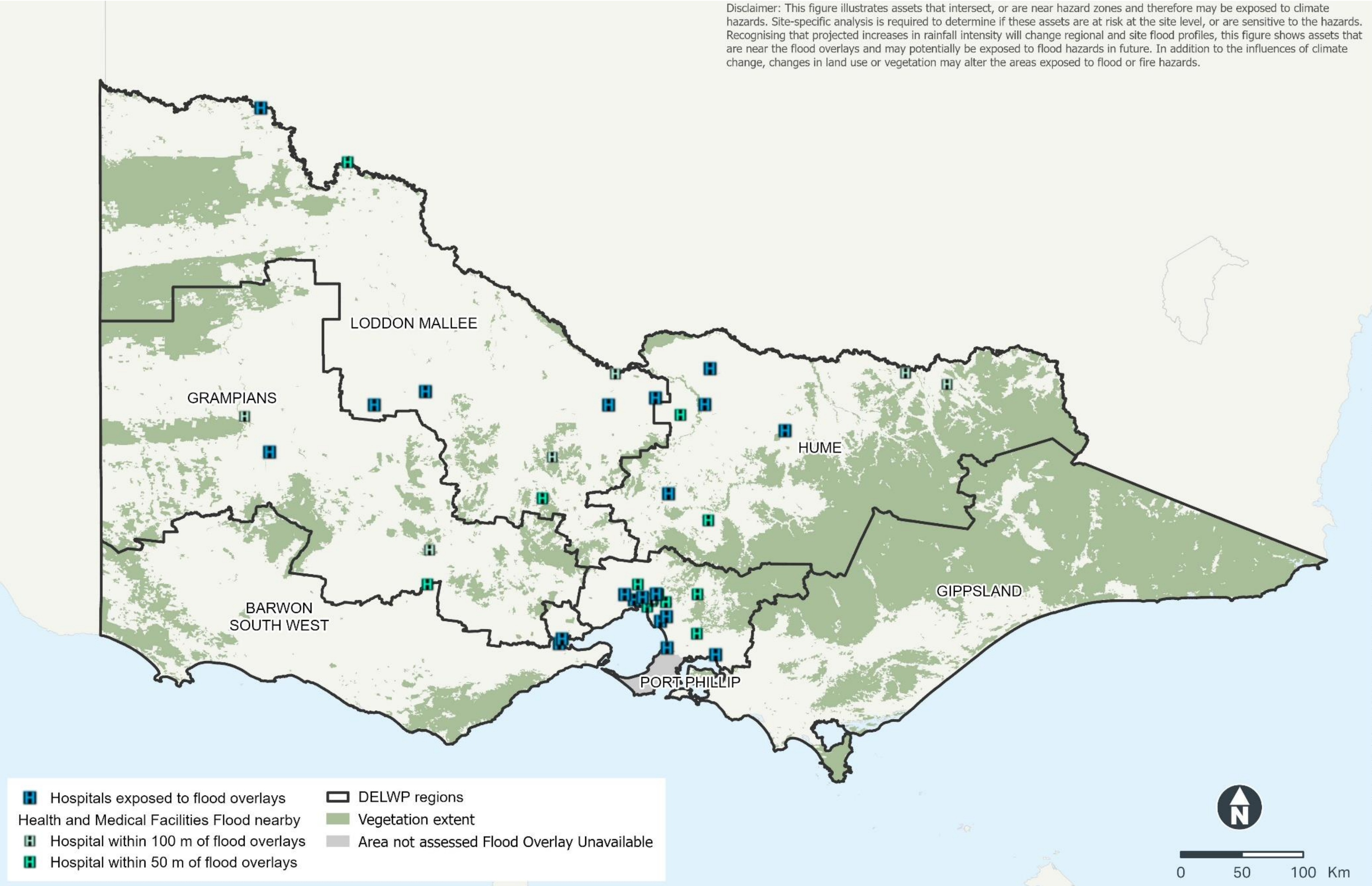


Figure 10 Public hospitals exposed to flood risk (i.e. flood overlays)

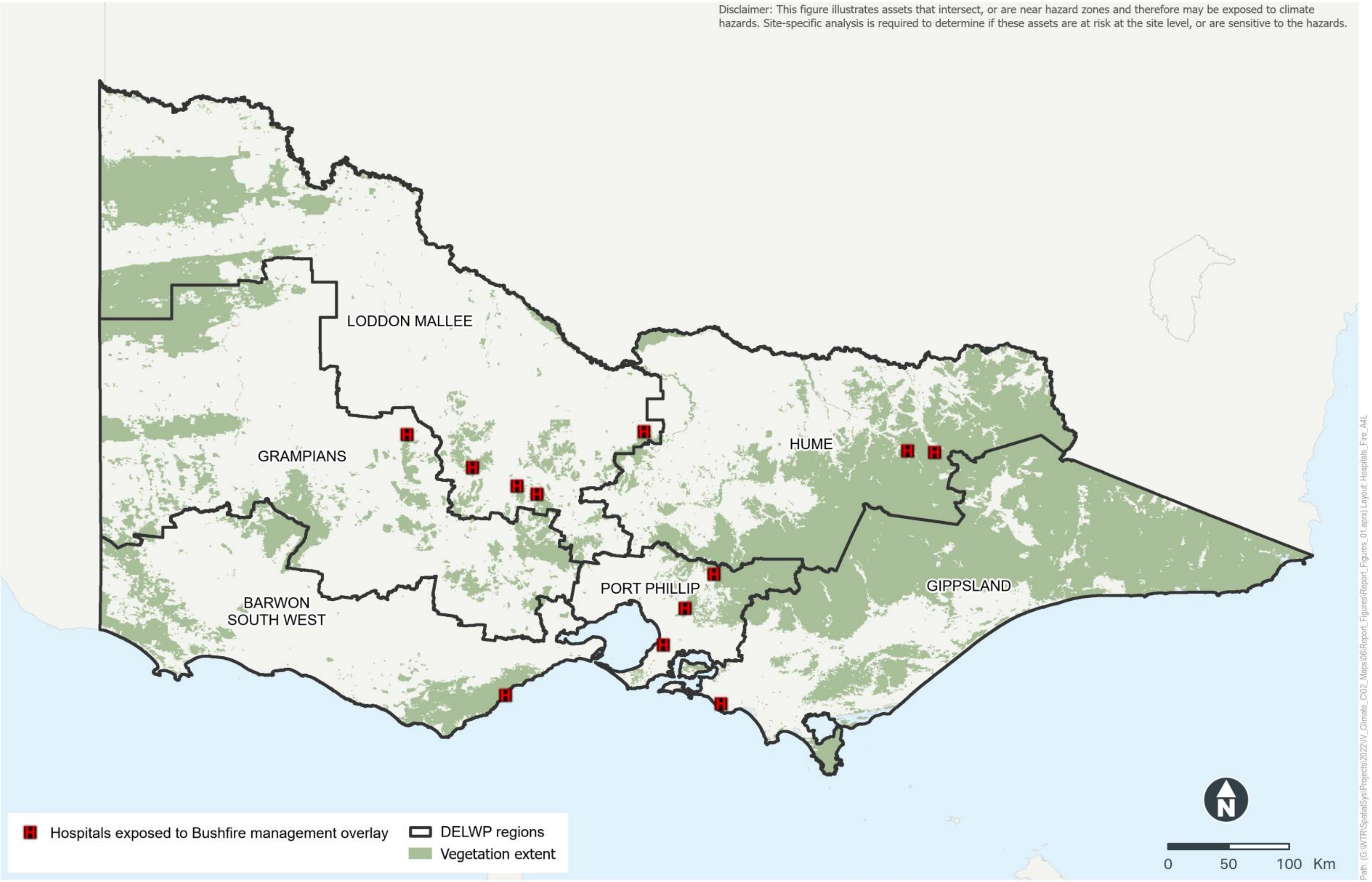


Figure 11 Public hospitals exposed to bushfire risk (i.e. Bushfire Management Overlay)

5.3 Broader context of climate risks

The analysis discussed in subsection 5.1 identified and rated the direct impacts of extreme weather on hospital facilities. To provide a more complete picture of the complexities associated with the risk of damage to hospital facilities, consideration needs to be given to compounding events and cascading impacts which will differ at each hospital.

Compounding events refer to the combination of multiple drivers or hazards that contribute to societal or environmental risk associated with damaged hospital facilities. These events are listed in Figure 12, grouped under the themes of Demand and Supply, Infrastructure and Operations. Examples of demand-related scenarios which have compounding impacts include increased presentations at hospitals due to more frequent extreme heat, or air quality issues associated with smoke from fires, or hotter temperatures. Disruption of road access to hospitals or supply chains may also have a compounding effect, restricting the ability to relocate patients from a damaged hospital, or bring in resources or personnel to respond to damage to hospital facilities following a fire or flood event.

Cascading impacts relate to the sequence of secondary events that flow on from the initial direct impact of a risk. These may be physical, natural, social or economic impacts that, when combined, are greater than the initial direct impact of the risk. Figure 12 lists cascading impacts associated with damage to hospital facilities. Each impact includes a reference to the relevant consequence theme, as per the risk framework used in this assessment (refer to Appendix A). Examples of cascading impacts from damage to hospital facilities and corresponding consequence themes include inability of skilled medical staff to attend work if affected by climate hazards personally (Health), reduced healthcare outcomes of existing and planned/scheduled patients (Health), impacts to employment of medical staff and service providers that support the hospital, e.g. cleaning, catering and maintenance (Economic).

In undertaking a more detailed assessment of risk (i.e. a site level risk assessment), consideration of compounding and cascading events can aid the identification of failure chains and interconnections with other systems. The consideration of cascading impacts can also provide a deeper understanding of the consequences of the risk. This can aid the determination of benefits of avoided damages to justify investment in adaptation action to manage risks. For example, the benefits will extend beyond the avoidance of direct costs associated with repair and reinstatement of services to broader societal benefits including avoided: health consequences; economic impacts to employees or supporting businesses, disruptions to medical research and environmental damages.

Damage to hospitals structures and plant and equipment attached to structures

Compounding events

Demand and Supply

- Increase in demand for hospital services due to regional hazard event causing a large number of injuries
- Increase in demand for medical services due to more frequent extreme heat, poor air quality, exposure to smoke, change in disease vectors, family violence etc.
- Increase in demand for hospital services due to interruptions to other local hospital services or specialist facilities
- Restricted ability to access staff as they may not be able to access workplaces, or may be directly impacted by a hazard event, or may suffer increased stress as a result of more frequent events and demands on their services

Infrastructure

- Insufficient maintenance of structures/ equipment, or vulnerable design features (e.g. plant equipment located in basement)
- Increased reliance on electricity (i.e. for heating or transport)
- Increased onsite electricity generation or storage capacity
- Occurrence of multiple current climate hazards (e.g. extreme heat and fire, or extreme rainfall following fire)

Operations

- Disruption of power, communications and water supply restricting operations and emergency response
- Restriction of road access to the hospital site restricting operations and emergency response
- Disruption of supply chains (including fuel for emergency generators) and waste management services (clinical waste)
- Competition for specialist skills / resources to support repair and recovery

Cascading impacts within the sector and to other sectors

- Health impacts and injuries, increasing demand for health services at other facilities (including mental health) (Health)
- Restricted ability to assist response to emergency events (Health)
- Interruption to planned health services leading to long term adverse health outcomes (Health)
- Health impacts to frontline workers who may be exposed to extreme weather events / hazards (Health)
- Deteriorating physical and mental health of communities and medical service providers (Health)
- Longer travel time to reach alternative facilities leading to reduced healthcare outcomes (Health)
- Long term impacts to medical research or medical services if specialist equipment is damaged (Economy)
- If facilities close, disruption of supply chains supporting the hospital (i.e. cleaning service, catering, maintenance contractors etc.) (Economy)
- Environmental pollution and increased resource consumption for repairs (Environment)
- Insurance risks driving increased financial vulnerability of medical services (Finance)
- Increased costs of service delivery (Finance)
- Impacts to heritage values (if relevant to specific hospitals) (Community)
- Relocation of staff seeking new employment if facilities are closed as a result of damage (Community)
- Increased morbidity (Health)
- Increased risk of litigation (Governance)

Figure 12 Broader context associated with the risk of damage to hospital facilities due to extreme weather events

5.4 Case study: Impact of extreme weather on public hospital facilities

5.4.1 What happened during the 2011 floods?

Charlton, in Victoria's north-west, was significantly impacted by the January 2011 floods. The town's hospital was inundated with water at least 60 centimetres deep. The flood waters (contaminated by sewage) caused severe and mostly irreparable damage to the carpets, flooring, walls and medical equipment. The hospital functionally became a stranded asset (Gray, 2012). It was unusable following the damage caused by the floods and an emergency medical clinic was set up in the local basketball stadium (Veness, 2011).

Temporary care facilities were required to be established in the town until a new hospital was built following delivery of the 2015 Victorian Budget. The new hospital was built above the 2011 flood levels on the old Charlton Primary School site and incorporated flood resilience measures in the design (Baldasso Cortese, 2022, DHHS, 2015, Australian Tenders, 2016).

While the specific flood resilience measures applied at Charlton Hospital are not known, examples of flood resilience measures applied at other Victorian hospitals, as identified through the stakeholder consultation, include:

- Elevating critical and infrastructure above flood levels.
- Installing flood gates at key locations on the car park and hospital buildings.
- Realigning drainage systems.
- Creating flood barriers using landscaping around the buildings.

5.4.2 How is this relevant to Victoria's future planning?

Incidents of extreme rainfall will intensify and become more frequent, while annual rainfall volumes are projected to decrease as climate change continues to escalate. These events heighten the likelihood of flash flooding and larger-scale riverine flooding.

Many urban areas in Victoria are built adjacent to floodplains, and hospitals in these areas will be at increased risk of riverine flooding. In addition, as the climate changes, areas or assets not previously at risk of flooding may become threatened by more intense downpours. With 34 hospitals within, or close to flood hazard areas, it will be important to understand the specific vulnerability of each site and plan to manage the associated risks.

Investments in the renewal of existing hospitals, or the construction of new hospitals provide an opportunity to integrate adaptation features into the location or design of facilities. Embedding adaptation features into the scope of these investments is often the most cost-effective way to reduce the overall vulnerability of a hospital and the communities it serves.

5.5 Adapting to climate risks

There are many effective adaptation actions that can, and are, being implemented to manage the risks associated with extreme weather events damaging hospital facilities. As each hospital faces a unique set of risks based on its location and circumstances, the specific adaptation actions required will differ from facility to facility. Hospitals will need tailored adaptation actions to address the relevant risks.

A summary of physical adaptation actions that address the priority risks to hospital facilities is provided in Table 13. Due to its state-wide nature, this report is not intended to provide individual hospitals with set list of adaptation actions. The actions listed are not intended to be an exhaustive list and may not be applicable for use in all hospital facilities or locations. However, they demonstrate specific physical measures that can be taken to build the resilience of hospitals and the communities they serve.

Table 13 Summary of physical adaptation actions to manage the priority risks of extreme weather events damaging public hospital facilities

Climate hazards	Risks	Physical adaptation actions
 Extreme temperatures, including heatwaves	Extreme temperatures damaging plant and equipment attached to hospital facilities	• Shading of sensitive equipment may assist in managing this risk. Shade may be provided naturally (i.e. using vegetation) or artificially, using awnings or shade structures. • The use of lighter coloured materials, or materials with reflective coatings near sensitive equipment may also assist in reducing heat build-up. • Designing or locating equipment in a way that enables passive cooling (i.e. natural airflow) or providing air conditioning may also assist in managing this risk.
 Extreme rainfall and flooding	Extreme rainfall related flooding leading to both damage to hospital building structures and damage to plant and equipment attached to hospital facilities Extreme rainfall related flooding leading to obstruction of, or damage to onsite car parks, road or pedestrian access	• Locating structures, critical plant and equipment and services outside of, or above future flood levels. The determination of future flood levels should consider the climate projections at the end of the planned life of the asset. This may involve relocating critical equipment or services from their existing location to a higher position in the hospital (e.g. moving an electrical substation from the basement of a facility to the first floor). • Installing flood gates or door dams at key locations on a hospital building or car park. These may be removable structures that require the temporary storage of barriers as well the training of staff to enable their timely deployment prior to a forecast flood event. • Ensuring the design of drainage systems include allowance for increases in projected rainfall as well as allowances for blockage from debris. Drainage systems include the gutters and down pipes on structures as well as at grade drainage, pipes, culverts and retention basins and pumping systems. Water sensitive urban design may also assist in reducing runoff by minimising impervious surfaces. • For car parks and plant areas that may be exposed to flood water, use materials that are water resistant, or easy to clean up following exposure to flood waters (e.g. concrete, brick, aluminium, steel etc).

In addition to implementation of specific physical adaptation actions, there has been significant work undertaken to enhance the resilience of Victorian public hospital infrastructure to the impacts of climate change. The development of the *Health and Human Services Climate Change Adaptation Action Plan 2022-2026* (HHS-AAP) and the Regional Adaptation Strategies (RAS) provide important resources to guide and enhance climate resilience of hospitals and the broader health sector.

Following a comprehensive review and analysis of these documents, together with key findings from the stakeholder engagement activities and consultation with subject matter experts, two adaptation themes have emerged as potential areas for enhancing resilience:

- Prioritisation and detailed investigation of vulnerability at the site level.
- Strengthening existing sector processes to support climate adaptation decision-making and implementation.

In the following sections, key current and planned adaptation actions relevant to these themes will be highlighted, and barriers to adaptation, opportunities and suggested actions to enhance adaptation will be discussed. Where applicable, comparable recommendations referenced in the HHS-AAP and RASs will be drawn out for discussion, with points of differentiation and areas of value addition highlighted.

5.6 Adaptation Theme #4: Prioritisation and detailed investigation of vulnerability at the site level

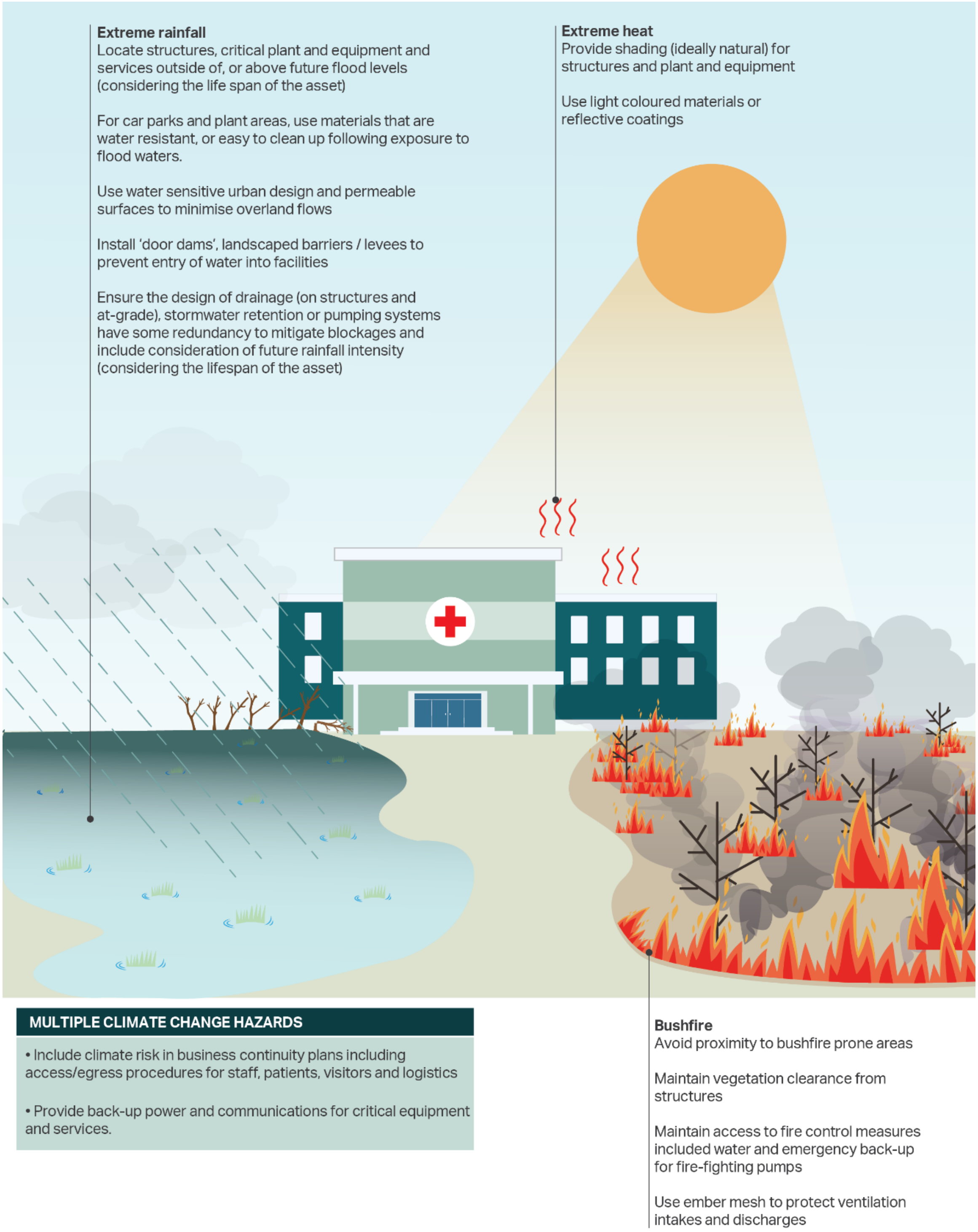
5.6.1 Current and planned controls

The HHS-AAP acknowledges existing work that has been undertaken to improve the resilience of health infrastructure to the impacts of climate change, as well as setting out planned actions. Examples of current adaptation actions include:

- The Victorian Health Building Authority (VHBA) has completed a climate risk hazard mapping assessment for public health infrastructure which is used to help drive planning (DELWP, 2021c).
- The VHBA is implementing a comprehensive works program to ensure emergency diesel generators in Victorian hospitals will operate automatically in response to a grid outage (DELWP, 2021c). Access to reliable back-up power supply is an important element of enhancing the resilience of critical facilities like hospitals.
- The VHBA *Guidelines for Sustainability in Health Care Capital Works* (VHBA, 2021) specify that during the design and delivery of healthcare buildings the implications of climate change are to be assessed and responses integrated. The guidelines provide a list of resilience responses for consideration. Examples of adaptation design principles are listed in Figure 13. The responses included in the VHBA guidelines are consistent with similar international health related guidance (i.e. *Smart Hospitals Toolkit* (Pan American Health Organization, 2017)) and more general building related adaptation guidance (i.e. *Climate Change Impacts on the Useful Life of Infrastructure* (IPWEA, 2018) and *Mitigation Ideas, A Resource for Reducing Risk to Natural Hazards* (FEMA, 2013).
- The VHBA *Engineering Guidelines for Healthcare Facilities: Volume 1: Fundamentals* (VHBA, 2020) specify that facilities built in bushfire-prone areas are to provide additional generating capacity, and those in remote and bushfire-prone areas should allow for sufficient on-site fuel storage to address potential resupply delays in emergencies.

The VHBA guidelines are supported by State level planning controls including the Victorian Planning Provisions, which restrict development in flood or fire hazard areas (DELWP, 2021i). In addition, the National Construction Code (NCC) and Building Code of Australia provide more general requirements for the development of safe and reliable building structures. Examples of topics where general requirements are provided by the NCC include, weather proofing, condensation management, energy efficiency (including extreme heat) and building in high wind and flood areas (Version 2019). The NCC has recently been reviewed with climate adaptation one of the topics of focus. The new NCC is to be adopted from May 2023.

Looking ahead, the HHS-AAP includes a number of actions aiming to increase the climate resilience of existing health infrastructure. This includes developing technical advice on improving infrastructure resilience, monitoring the implementation of adaptation initiatives and specifying climate resilience standards for health infrastructure grant programs.



**Note this is not an exhaustive list of climate change adaptation design principles. The principles should be considered in parallel with relevant design standards, building codes and the relative costs and benefits of designing out risk compared to managing it through operational processes.*

Figure 13 Adaptation Design principles addressing the risk of damage to hospital facilities due to extreme weather events [Adapted from VHBA Guidelines (2021), FEMA (2013), IPWEA (2018), Pan American Health Organisation (2017)].

5.6.2 Barriers and opportunities

The HHS-AAP will assist in enhancing resilience across the sector by embedding resilience in new and renewed infrastructure. However, it is not clear how the need for investment will be determined, nor how specific facilities may be prioritised. It is also unclear how specific preventative adaptation measures to manage existing or projected climate risks will be identified.

Victoria's *Critical Infrastructure All Sectors Resilience Report 2021* included an action to develop a three-year plan to capture health-related resilience improvement initiatives and opportunities proposed by key stakeholders (EMV, 2021). Once developed, implementation could be reviewed as a part of the annual resilience planning process.

The stakeholder engagement process identified a number of barriers that restrict the ability of the sector to address the risk of damage to hospitals due to extreme weather events, and the impacts of climate change more broadly. Inconsistent climate adaptation knowledge and expertise among health sector staff and the consultants who deliver infrastructure projects were noted as a challenge. Individual health services may not have the specialist knowledge to assess or develop solutions for climate-related challenges, relying instead on consultants and contractors to deliver this technical expertise. The success of adaptation outcomes is therefore influenced by the consultants providing the service.

The VBHA guidelines (VHBA, 2021) assist in addressing these challenges by providing an accessible resource with key information on the topic of climate resilience, helping to drive consistency across the sector. However, workshop discussions highlighted that each health service is acting alone, and with differing levels of knowledge about the vulnerability of specific hospitals to climate change. This may lead to duplication of effort where agencies are 'finding their own way', investigating issues or identifying solutions. In the workshops, it was suggested that there is an opportunity to develop a program of site-specific assessments of climate risk and priority actions, coordinated centrally to provide a line of sight on the relative vulnerability of individual hospitals across the public healthcare system.

The reliance of hospitals on external systems also presents a challenge to building the resilience of individual hospitals. While healthcare agencies have the ability to guide the design of infrastructure on the hospital site, it is ultimately reliant on external transport and utility services provided by other organisations. This includes:

- Power, water and telecommunications systems
- Road, or other public transport, networks
- Drainage infrastructure.

Knowledge of these systems, and collaborating with the responsible stakeholders that own and manage them, will enable a greater understanding of the vulnerabilities of a hospital and the development of more effective resilience plans.

5.6.3 Enhancing adaptation

H1 Prioritise hospitals for site specific assessment of climate risks and development of priority actions.

Building on the VHBA's *Guidelines for Sustainability in Health Care Capital Works* (VHBA, 2021), the prioritisation process should consider the criticality of services provided by the hospitals (with reference to VHBA classification of facilities based on criticality. Consideration should also be given to isolation potential and socio-economic factors, the scale of exposure to hazards (i.e. drawing on this study, and any previous VHBA assessments), the age of infrastructure and upcoming planned investments. Detailed assessments should broaden the scope beyond the impact to infrastructure, to include a holistic consideration of climate risks to the hospital's operations.

The outcomes of the assessment should include determination of priority risks to each facility, recommended adaptation actions and the timing for implementation of the actions. Some actions may be identified as urgent, while others may be integrated into future renewal works or asset replacement cycles (including replacement following damage from a hazard event).

This should be coordinated centrally, to provide efficiencies and consistency across health services. Centralised coordination may also identify common actions that could be more effectively implemented across multiple sites and/or health services. The findings of these assessments could also be used to inform future updates of the VHBA sustainability guidelines to address common issues or opportunities.

5.7 Adaptation Theme #5: Strengthening existing sector processes to support climate adaptation decision-making and implementation

5.7.1 Current and planned controls

The most effective way to enhance the long-term resilience of hospitals and the healthcare sector is to embed consideration of climate risk into existing systems and processes. This increases the likelihood of change in the sector when compared to having climate resilience seen as a separate area of consideration.

As mentioned previously, the HHS-AAP identifies that the climate resilience of existing health infrastructure will be increased by specifying climate resilience standards for health infrastructure grant programs and capital projects. In addition, the *Guidelines for Sustainability in Health Care Capital Works* (VHBA, 2021) provide guidance for the consideration of climate risks and the development of adaptation solutions to inform design and delivery of hospitals and healthcare infrastructure.

Emergency management is also an important element of building resilience. The HHS-AAP identifies that the state utilises the Emergo Train System to conduct hospital exercises to test and refine agency emergency management plans and procedures. This training also seeks to build relationships across health, emergency management and critical infrastructure sectors.

The Department of Treasury and Finance (DTF) plays an important role in supporting asset management across government. The DTF *Asset Management Accountability Framework* (AMAF) sets out mandatory requirements and general guidance for managing assets. This guidance should assist with supporting preparedness activities including preventative maintenance, with the aim of reducing the need for, often more expensive and disruptive, recovery activities.

At the regional level, the Gippsland RAS acknowledges the importance of leveraging existing processes by advising Health Service Boards to ensure they understand risk and consider vulnerability assessments in the development of Strategic Plans (DELWP, 2021f).

5.7.2 Barriers and opportunities

Resource availability was identified as a challenge during the stakeholder engagement process across both human and financial resources. The healthcare sector is a high-pressure working environment with increasing demand for services. Stakeholders emphasised that the COVID-19 pandemic has drained staff, services and resources over the last two years. This has impacted individual hospitals' ability to proactively plan for climate change. Additionally, inconsistency in knowledge amongst health sector staff presents a challenge to integrating climate resilience in the design and delivery of healthcare infrastructure. These factors can contribute to opportunities to build resilience being missed, including in smaller, more financially constrained capital projects. While these projects may be relatively small in capital value and have fewer human resources allocated to them, they can still be complex and present material opportunities to progressively build the resilience of hospitals.

As previously discussed, the VHBA guidelines (VHBA, 2021) provide a valuable resource to guide integration of climate resilience in healthcare infrastructure. The guidance details the implications of climate change for healthcare buildings, along with design responses to build resilience. However, it was noted in the stakeholder engagement workshops that there is an overwhelming amount of information and guidance being produced on climate risks and potential responses, in addition to the guidelines. The relevance of this information to health services is not always clear, and there can be inconsistencies in guidance and information. There is also a lack of methodologies and guidance for capturing costs and benefits of climate adaptation, making it challenging to build the case for investing in adaptation action amongst all the competing budget requirements of a hospital.

Access to consistent methodologies, frameworks and data to demonstrate long-term benefits of higher cost actions would assist health sector staff in the decision-making process, particularly where there are resource constraints. This information could make it easier to integrate consideration of climate resilience into business cases, project requirements and the assessment of proposed projects. The HHS-AAP acknowledges the need for consistency in adaptation processes, assessments and guidance across the sector. This includes actions to improve climate resilience in the health asset base by developing technical advice on climate infrastructure resilience and disseminating best-practice case studies.

Although not unique to this sector, insurance related constraints can present a challenge to enabling more resilient infrastructure to be rebuilt following an event. Insurance often only funds the 'like-for-like' replacement of an asset built to the current standards. However, if the current standards do not adequately account for projected changes in climate, this may present a missed opportunity to use the renewal of an asset to enhance its resilience. The concept of building back better following emergencies, to allow assets to be rebuilt to a more resilient standard, is included as a recommendation in *Victoria's Infrastructure Strategy 2021-2051* (Infrastructure Victoria, 2021).

Understanding the risk profile and any required adaptation actions of a particular site *prior* to a disaster event may enhance the likelihood of necessary actions being able to be incorporated into the renewal of assets once an event has occurred. This prior knowledge may be even more valuable as there can be short timeframes available to undertake recovery works, which do not allow time to investigate solutions which can boost resilience.

The Victorian Managed Insurance Authority (VMIA) provides information to support reducing risk and building resilience across the public assets it insures, which includes the healthcare sector. This information includes the 'Climate Change Risk Foundations' training course (VMIA, 2022) and supporting risk management guidelines. VMIA (2022a) also undertakes a Site Risk Survey program, providing specific advice to help identify risks and possible solutions at VMIA insured sites. The engineering risk assessment considers elements that are relevant to climate risks including natural hazards, risk management systems, building services and public safety.

5.7.3 Enhancing adaptation

H2 Supplement the Victorian Health Building Authority sustainability guidelines with tools to support climate adaptation decision making and implementation

VHBA's *Guidelines for Sustainability in Health Care Capital Works* (VHBA, 2021) could be enhanced by providing additional information to support the inclusion of climate adaptation measures in new or existing hospitals. This would support the identification and justification of climate adaptation initiatives that add initial cost, but provide whole-of-life value for money.

Provision of this information would build on existing actions in the HHS-AAP by developing technical advice and case studies specifically for hospitals, covering a range of scenarios with variables including size of capital projects, metro versus regional locations, and different climate hazards. Information on potential costs and benefits should also be included to support project assessment and business case development. In addition, undertaking evaluations of previous climate events which impacted health assets (e.g. a flood or fire event), and associated capital works undertaken in response to the events would present further opportunity to collect valuable insights on what the implications were for the facility concerned, what worked well and what opportunities to further improve resilience may exist.

H3 Consider enhancing assessment of climate risks in the Victorian Managed Insurance Authority's site risk surveys.

VMIA's survey process could be enhanced to more explicitly including consideration of climate change, prompting surveyors and site stakeholders to consider the implications of how a hotter, drier and more extreme climate may influence the risk profile of a site. For example, it would be valuable to identify whether allowances for climate change are included in the hazard models informing the assessment and how changes in climate may alter the hazard profile (i.e. the frequency or intensity of hazards), and therefore the site's risk profile, over time.

There may also be an opportunity to share common risk assessment findings with other sector processes including future Critical Infrastructure All Sectors Resilience Reports, updates of the VHBA sustainability guidelines and future sector Adaptation Action Plans.

5.8 Summary of proposed adaptation actions

Table 14 summarises the proposed adaptation actions to enhance management of the risk of damage to public hospital building structures due to extreme weather events.

A suggested timing for implementation has been indicated for each action. These are either act now (i.e. within the current adaptation action planning cycle), act by 2026 (i.e. incorporate into the next round of adaptation planning, for roll out from 2026), or undertake further research.

Progressing these adaptation actions can help to determine which adaptation measures, as summarised in Section 5.5, could be deployed at specific public hospitals to help build the resilience of the sector.

Table 14 Proposed adaptation actions to address the risk of damage to hospital structures due to extreme weather events

Adaptation actions	Act now	Act by 2026	Further research
Physical actions			
H1 Prioritise hospitals for site specific assessment of climate risks and development of priority actions	x	-	-
Policies / Strategy based actions			
H2 Supplement the Victorian Health Building Authority sustainability guidelines with tools to support decision making	x	-	-
H3 Consider enhancing assessment of climate risks in the Victorian Managed Insurance Authority's site risk surveys.	-	x	-

6.0 Road Network

Victoria's road network plays a critical role in supporting economic activity, supply chains for the movement of goods and services, and many aspects of our daily lives including access to work, education, healthcare and social and recreational activities. During times of crisis, the road network is also critical for the immediate response and longer-term recovery from disaster events including floods and bushfires. Crucially the road network itself can be directly damaged or obstructed by these extreme weather events, leading to extended periods of road closures which impact on the level of service provided by the infrastructure. Climate change will present broader risks to the road network including:

Impacts to Demand

- Evacuation in the event of an emergency
- Responding to emergency events

Impacts to Road Network Infrastructure

- Damaging, or obstructing bridges and tunnels due to inundation, water- or wind-borne debris or fire
- Degrading road pavements and surfacings due to increased average or extreme temperatures or increased solar radiation
- Flooding of roads due to rainfall overwhelming drainage structures resulting in damage to pavements and underlying embankments
- Damaging Intelligent Transport System (ITS) and other ancillary assets (e.g., noise walls, signage and barriers)

Impacts to Operational Activities

- Increasing occurrence of accidents due to water over roads (i.e., aquaplaning) or windy conditions
- Disruption to the operation of road based public and commercial transportation (e.g. buses and commercial passenger vehicles)
- Disruption of power or telecommunications outages preventing the operation of ITS and signalling
- Disruption to road construction activities
- Increasing whole of life costs, including maintenance costs, reduction in asset performance and shortening of asset lifespans.

Example of hazards: Landslides impacting roads in Victoria

Landslides are defined as the movement of mass rock, earth or debris down a slope (Victoria State Emergency Service, 2018). Landslides can be triggered by intense or prolonged rainfall as well as burst / leaking pipes and shocks or vibrations.

In 2016, significant prolonged rainfall followed recent bushfires in the Otway Ranges resulting in more than 100 landslides. This led to the closure of more than 20 km of the Great Ocean Road between Lorne and Wye River (Woods, 2016).

In addition to damaging infrastructure, these events caused access restrictions, impacting local communities and tourists.

This analysis is focussed on the risks associated with damage to roads and disruption of access due to extreme weather events. This section describes the analysis of this specific risk, including differences in regional exposure across Victoria. This is followed by commentary on the broader factors that will influence the impacts associated with this risk and support more detailed site specific analysis.

Elements or components that make up a road include:

- The pavement, including surfacing, base layers, subbase layers and the subgrade
- The road edges, including shoulders and verges
- Embankments, including fill materials below pavements and forming embankments as well as slope edge protection

- The drainage system, including open drains, pit and pipe systems and culverts and pipe crossings beneath roads
- Road furniture and other items including barriers, guard fences, kerbs, guide posts, signs etc.

Whilst there are a range of typical road/embankment compositions, in particular with differing shoulder and edge materials, the following image (Figure 14) presents a typical example.

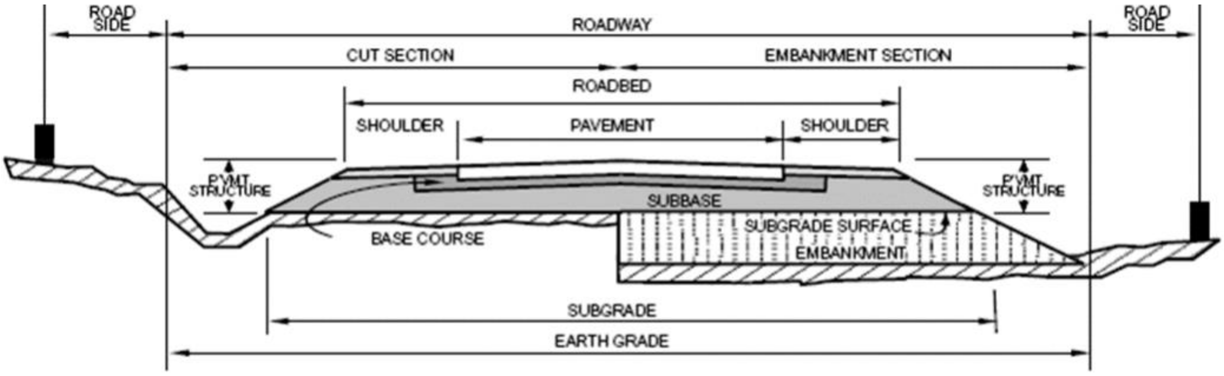


Figure 14 Overview of the typical components of a road (MDOT, 2020)

The different road components are made up of a range of material types and each element has different susceptibilities to damage in extreme fire, flood and landslide events. Some of the risks to the road network vary for different pavement types. The pavement types that comprise the majority of the declared road network in Victoria are summarised in Table 15.

Table 15 Summary of typical pavement types used in Victoria's road network[4]

Pavement type	Typical use on Victoria's road network	Typical design life[1] (Typical service life[2])
Unsealed Roads Flexible pavement comprising gravel materials only	May be used for some state owned assets in remote or low traffic areas, such as State Parks or for emergency access	15 to 20 years (>30 years)
Unbound Granular Flexible pavement comprising unbound crushed rock base and subbase with either a thin asphalt surface (say 30 to 50mm thick) or sprayed bitumen seal (say 10 to 20mm thick)	Typically used for main roads, tourist roads and highways in rural areas Possibly used for state roads passing through towns, particularly if there are no signalised intersections	20 years (> 40 years)
Deep Strength or Full Depth Asphalt Flexible pavement comprising a thick combined asphalt surface and base (say 150 to 350mm thick) overlying a subbase of either/both unbound crushed rock and/or bound/cement stabilised crushed rock)	Typically present for most freeways and most arterials and main roads in urban areas	20 to 30 years (> 50 years)

[4] Information based on experience of AECOM project subject matter specialist.

Pavement type	Typical use on Victoria's road network	Typical design life[1] (Typical service life[2])
Rigid Pavement Concrete base slab in the order of 200 to 250mm thick over a bound or unbound crushed rock subbase	Localised use for various roads, mostly in major urban centres Limited use on main road network in Victoria Commonly used in tunnels Often used in state owned land for crossovers off public roads into commercial and industrial access driveways	30 to 40 years (>50 years)

Note 1. Design life typically assumes an 85 to 95% probability that the pavement will reach this point without the need for significant rehabilitation
Note 2. Service Life is the actual life achieved by the pavement subject to good maintenance. Service life may be significantly shorter in pavements that are subject to inundation.

6.1 Key risk profile

The risks associated with damage to roads or disruption of access due to extreme weather events were broken down to consider multiple climate hazards and elements which typically impact the assets. The hazards assessed were:

- Extreme temperatures, including heatwaves
- Extreme rainfall and flooding
- Bushfire
- Coastal storm surge
- Coastal storm related erosion.

A total of 10 risks were identified. There was little variation in the spread of risk ratings across the scenarios and timeframes assessed. In the 2030 timeframe, four risks were rated medium and five were rated high, across both the low and high emissions scenarios. In the 2070 timeframe, the number of high risks increased under the high emissions scenario, but the total number of medium risks did not change. The minimal change in the profile of the risks across the scenarios is attributed to the state-wide scale of the assessment and the nature of the risk framework, where a shift from a likelihood rating of *Likely* to *Almost Certain,* did not change the overall risk rating from High. Detail on the risk ratings (i.e. likelihood and consequence ratings) is provided in Appendix A.

The most significant risks were rated high in both timeframes (i.e., 2030 and 2070) under the high emissions scenario (i.e. RCP 8.5):

1. Extreme rainfall-related flooding leading to damage to roads
2. Extreme rainfall-related flooding leading to obstruction or closure of roads caused by inundation or landslides
3. Extreme rainfall leading to washout or collapse of roads
4. Bushfire or grassfire leading to obstruction or closure of roads caused by smoke or fire safety risk
5. Coastal storm-related flooding or erosion leading to damage to roads.

Extreme rainfall-related flood events can cause significant damage to roads primarily through two mechanisms, inundation or washout.

Inundation of the road

Standing water on or beside road pavements can increase the moisture content and level of saturation in and under pavement layers and thus weaken pavement surfacings, base/subbase layers and the underlying subgrade including embankment fill materials. Pavement types, configurations and conditions most susceptible to damage or distress due to moisture ingress resulting from inundation are[5]:

- Unsealed pavements that are most susceptible to moisture infiltration and distress as the surface is not sealed. These pavements are generally easier to repair than other pavement types via regrading and gravel top ups
- Unbound granular pavements with thin asphalt or sprayed seal surfacing. These are likely to be the most common pavement type for most sealed roads in rural areas. In comparison, state owned main roads in urban areas are relatively much less susceptible to the impacts of inundation due to the greater thickness of bound pavement materials
- Asphalt or spray seal surfaced pavements with a cracked surface that is not well sealed, readily allowing water ingress, and possibly some soil ingress, into the pavement base/subbase layers. This can result in excessive pore pressures in the pavement when trafficked that can deteriorate or breakdown the base/subbase layers and/or soften the subgrade, any of which can increase distresses, increase maintenance, reduce serviceability and reduce the service life of the pavement. Pavements exhibiting shape loss such as rutting or depressions which can increase the depth and duration of water ponding after rain or flooding events and allow increased water infiltration into the pavement
- Roads with an inadequate or poorly maintained roadside drainage system
- Pavements without a suitable subsurface drainage system. Subsurface drainage systems are more likely to be provided on high classification or main roads and in urban areas and less likely to be used on low traffic sealed and unsealed roads in rural areas
- Earthwork materials (forming embankments below pavements) that are susceptible to moisture variation such as high plasticity clays (often described as 'expansive' or 'reactive)', or otherwise susceptible to piping erosion or dispersion.

Following inundation, where water cannot readily drain from within the pavement and subgrade prior to significant trafficking, the pavement may be subject to any of the following types of distresses:

- Cracking of the surface, due to weakening of the surfacing or pavement base layers
- Rutting (shape loss in wheel paths) due to weakening of the surfacing or pavement base layers
- Depressions (shape loss due to subgrade softening or swelling)
- Potholes into the pavement structure, due to saturation and weakening of the pavement base layers
- Other surface distresses such as delamination or breakdown of asphalt or seals, due to weakness of the surface layer or underlying pavement base layers
- Edge break of sealed surfaces and/or shoulder erosion resulting in edge drop offs, generally due to weakness in the shoulder materials and/or pavement edge.

The potential for the above distress types is much greater for sealed and unsealed unbound granular pavements compared to full depth/deep-strength asphalt and concrete pavements.

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[5] Information based on AECOM subject matter specialist experience and knowledge of the Austroads Guide to Pavement Technology.

Washout/erosion of road embankments and pavements, particularly around culverts

Intense rainfall events can lead to significant volumes of water needing to pass either alongside roads in edge drains or through culverts under roads, where present. If culverts are not large enough to handle the volume of water, and the velocity can be great enough, the material surrounding the culvert may be washed away leading to some or all of the road collapsing or also washing away.

Once waters subside roads may be covered in debris, drainage infrastructure blocked by debris and supporting subgrade may have softened. These factors will influence how quickly a road can be returned to normal levels of service without the risk of further damage occurring to the road once traffic resumes, or another heavy rainfall event occurs.

Landslide damage

Extreme, or prolonged rainfall events can trigger landslides in areas of steep terrain. Although landslides are often localised in area, significant time and resources can be required to clear and repair road infrastructure before the road can be reopened. This is particularly the case when engineering design and construction is required to remediate a slope adjacent to the road. The likelihood of landslides occurring can increase following a fire, where vegetation has been damaged, reducing its ability to secure the soil or rock. More often landslides obstruct roads, with service resuming once it is cleared, although in some cases landslides downslope of the road can lead to the collapse of a road. This is particularly prevalent when flood waters contribute to erosion at the toe (i.e. bottom) of a slope.

Bushfire damage

Bushfire events have led to significant road closures across Victoria (e.g. closure of the Princes Highway due to the 2019 Bunyip fires (Kulich, E, 2019)). While the fire event is less likely to physically damage the road pavement and earthworks structures itself, there is often damages to bridges and signage structures. Bushfires can also lead to closures of roads due to safety concerns impacting passenger and freight transport operations. Safety concerns related to bushfires include reduced visibility from smoke, the risk of trees damaged by fire (or wind) falling across roads, and the risk of people being directly exposed to the fire. Fire events can also contribute to the occurrence of other risks including obstruction of roads due to landslides when intense rainfall events saturate unprotected soils and trigger slope movement.

Coastal storm damage

Coastal storm related flooding or erosion can also damage roads. The impacts of coastal flooding may be similar to that described for flooding due to extreme rainfall events. Coastal erosion can also progressively undermine or destabilise roads causing significant damage. The loss of land adjacent to roads due to coastal erosion may also lead to extended closure of roads to avoid potential safety risks to road users.

Recent economic impacts of extreme weather on Victoria’s road network

Between 2008 and 2019 there have been more than $100m in flood-related road insurance claims across 19 individual claims. During this period, fire-related claims were significantly lower. The 2009-10 Black Saturday and the 2019-20 Black Summer bushfires were the most significant individual events over the period, with claims totalling around $10 million in both years (VMIA, 2022).

In addition to damages to roads, the Black Summer fires resulted in 1,500 signs and 14,000 guideposts being damaged or destroyed and 1,400 km of arterial roads being closed for traffic (VMIA, 2022; State Government of Victoria, 2021).

Example of coastal erosion hazard

The Port Campbell coastal cliffs are naturally regressing due to processes including weathering and marine erosion. It is estimated that the coast is receding at an average rate of 1 to 2 centimetres each year, achieved by occasional and localised rock falls that cause the cliff crest to retreat abruptly (for example 1 to 2 metres once a century, or 10 to 20 metres once in a thousand years) (Bird, 1993). The soft limestone along the Port Campbell coast is expected to recede at a faster rate with sea level rise (DCC, 2009).

Following the January 1990 collapse of the natural rock arch known as London Bridge (west of Port Campbell), a deviation of the Great Ocean Road around the twin inlets of 'The Murphys' was completed in September 1990 (VicRoads, 1991). By 2011, the head of both inlets had reached the old road alignment (Refer to red dotted line in the image below).

6.2 Regional exposure to risks

Regions with greatest exposure of road network assets to climate hazards

Bushfires	Gippsland, Loddon Mallee, Barwon South West
Landslides	Barwon South West
Extreme Rainfall and Flooding	Hume, Loddon Mallee

The risk to road network assets will not be experienced evenly across Victoria. Factors contributing to this include differing exposure of assets to climate hazards, pavement type, road classification and the relative vulnerability of the assets and the communities they serve. This section provides commentary on how the exposure differs across six regions focussing on the hazards causing the most significant risks to road network assets: extreme rainfall related flooding, landslides, bushfire and coastal flooding or erosion. Discussion of vulnerability-related factors that may influence the risk profile of individual assets or towns is included in subsection 6.3.

This study mapped the VicRoads declared road network (data provided by VicRoads) against planning overlays related to flood (refer to Figure 15) and fire (Figure 16), as well as areas susceptible to landslides (Figure 17). The majority of roads exposed to flood or fire hazard areas are classified as arterial other roads (63% of road length exposed to flooding and 71% exposed to bushfire)), followed by arterial highways (32% for floods and 26% for fires)).

The four regions with the greatest length of roads exposed to flooding, landslides and/or fire are:

- Gippsland – Approximately 46% of the length of the region's declared road network intersect the bushfire management overlay. Approximately 4% of the road network is within flood hazard areas. In addition, approximately 12% by length of the roads are in areas considered to have high or very high susceptibility to landslides. Coastal inundation is likely to be a risk to some roads in the region with the extent increasing with sea level rise (e.g., from 0.5% by length of roads in 2040 to 0.6% in 2070).

- Hume – This region has the highest percentage of road length exposed to flooding (14%) and second highest percentage of road length exposed to bushfire (29%). It is also the region with the greatest percentage of road length exposed to both fire and flood hazards (2%). The majority of the roads exposed to flooding surround Shepperton. The roads exposed to bushfire are mostly in the vegetated high country in the south and east / northeast of the region. 3% of the road length in Hume are in areas considered to have high sensitivity to landslides, although no roads are in areas of very high susceptibility.
- Loddon Mallee – Approximately 28% of the road length in the region are exposed to flood or fire hazard areas, evenly spread across both hazard types. Significant portions of the Loddon Highway from Serpentine to past Kerrang are exposed to flooding. Areas exposed to bushfire include the Calder Highway south of Mildura and the forested areas surrounding Bendigo.
- Barwon South West – Approximately 24% of the road length in Barwon South West are in areas exposed to bushfire hazards. These are predominantly in the Great Otway National Park and the National Parks in the region's west. This region has the greatest percentage of roads in areas at high or very high susceptibility to landslip (approximately 15% by length of the region's roads). These are mainly in the Otway Ranges and the Grampians (Gariwerd). Coastal inundation is also likely to be a risk to some roads in the region, with sea level rise projected to increase the percentage of roads at risk over time (e.g., 0.1% by length of roads at risk in 2040 increasing to 0.2% in 2070). Coastal erosion may also be a risk to a small number of roads (<0.1%).

Sensitivity factors influencing each region's vulnerability to risk include asset specific factors and community related factors. For example, Gippsland and Hume identified in their Regional Adaptation Strategies that isolation issues are a concern. Grampians and Loddon Mallee both identified car dependence as a challenge. High levels of car dependence has the potential to make communities in these regions more sensitive to disruptions of the road network from extreme weather events as they. Gippsland also identified that there is significant pressure on its existing road network due to growth in the region.

For each of the locations identified as exposed and therefore potentially at risk, further analysis is required at the site level to determine the specifics of the asset's vulnerability or site-specific resilience to flood, fire or landslide related risks. Some assets may already be built in such a way to minimise the likelihood of them being affected (i.e., elevated above flood hazards, implement sufficient drainage, implement sufficient vegetation management and stabilisation of slopes). Factors that may influence the vulnerability of road network assets at the subregional, or site level include:

<u>Sensitivity factors</u>

- The design of infrastructure: For example, a road may be designed so that the road surface and supporting infrastructure (e.g. barriers, signage, lighting etc) is elevated above projected flood levels, or flood protection infrastructure is in place to prevent water overtopping the road (e.g. drainage infrastructure is of adequate capacity).
- The age and condition of infrastructure: Older assets may be designed to previous standards applied at the time of construction, making them more vulnerable to projected climate extremes. Assets that are in poor condition may be more susceptible to failure when under stress (i.e. high velocity flood waters, or heavy grain freight travelling on roads with saturated subgrades).
- The type of road pavement in place: Unbound granular pavements with thin asphalt or spray sealed surfacings are more susceptible to damage or deterioration from inundation, erosion and washout than full depth asphalt or concrete pavements. Unsealed pavements are the most susceptible to damage.
- The criticality of specific assets and the customers or communities they serve: Failure of a road that supports a significant number of residents, or high value industry may be deemed more sensitive.

Adaptive capacity factors

- Alternative routes for road vehicles are often available in metropolitan areas, however may be less available in regional areas.
- The ability to repair damaged roads may be restricted by competition for resources, or remoteness. This may delay reinstating road access for communities or result in poor serviceability of a road prior to the repairs (e.g. rough or slippery road).
- The duration and scale of the event will also affect the time to repair. Repairs may be unable to commence until the climate hazard has passed and it is safe to access damaged roads.

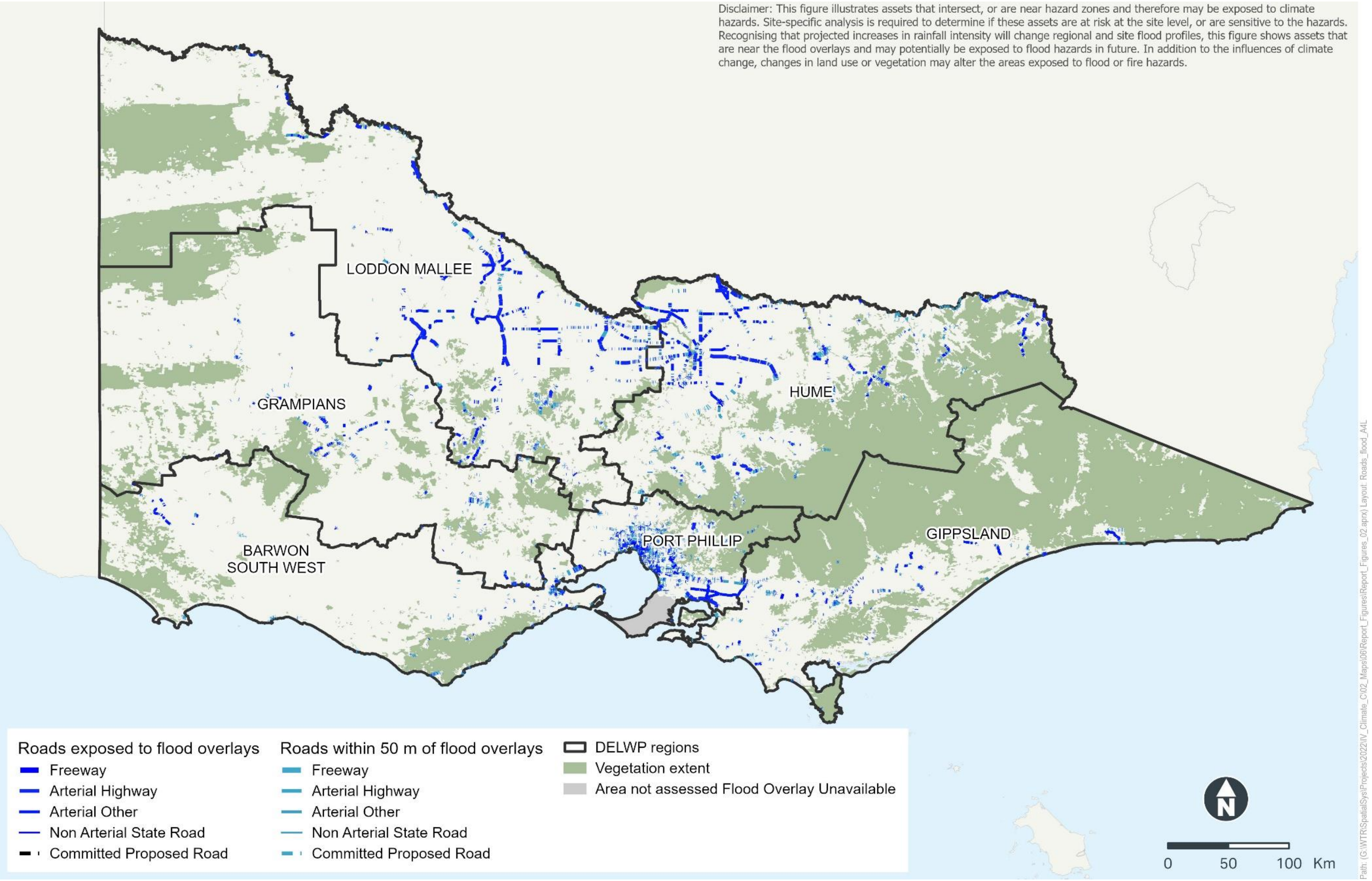

Figure 15 Roads exposed to flood risk (i.e. flood overlays)

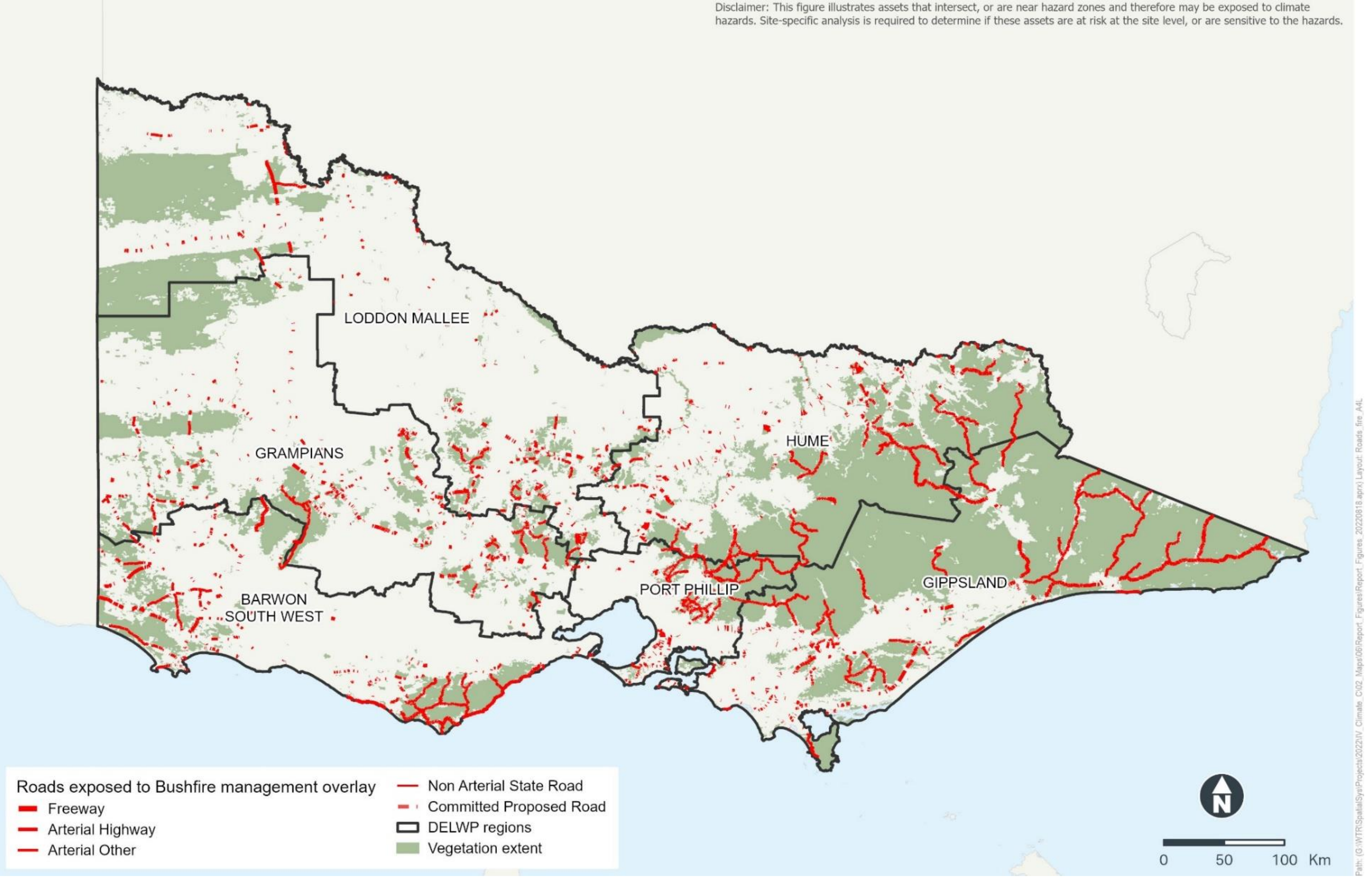

Figure 16 Roads exposed to bushfire risk (i.e. Bushfire Management Overlay)

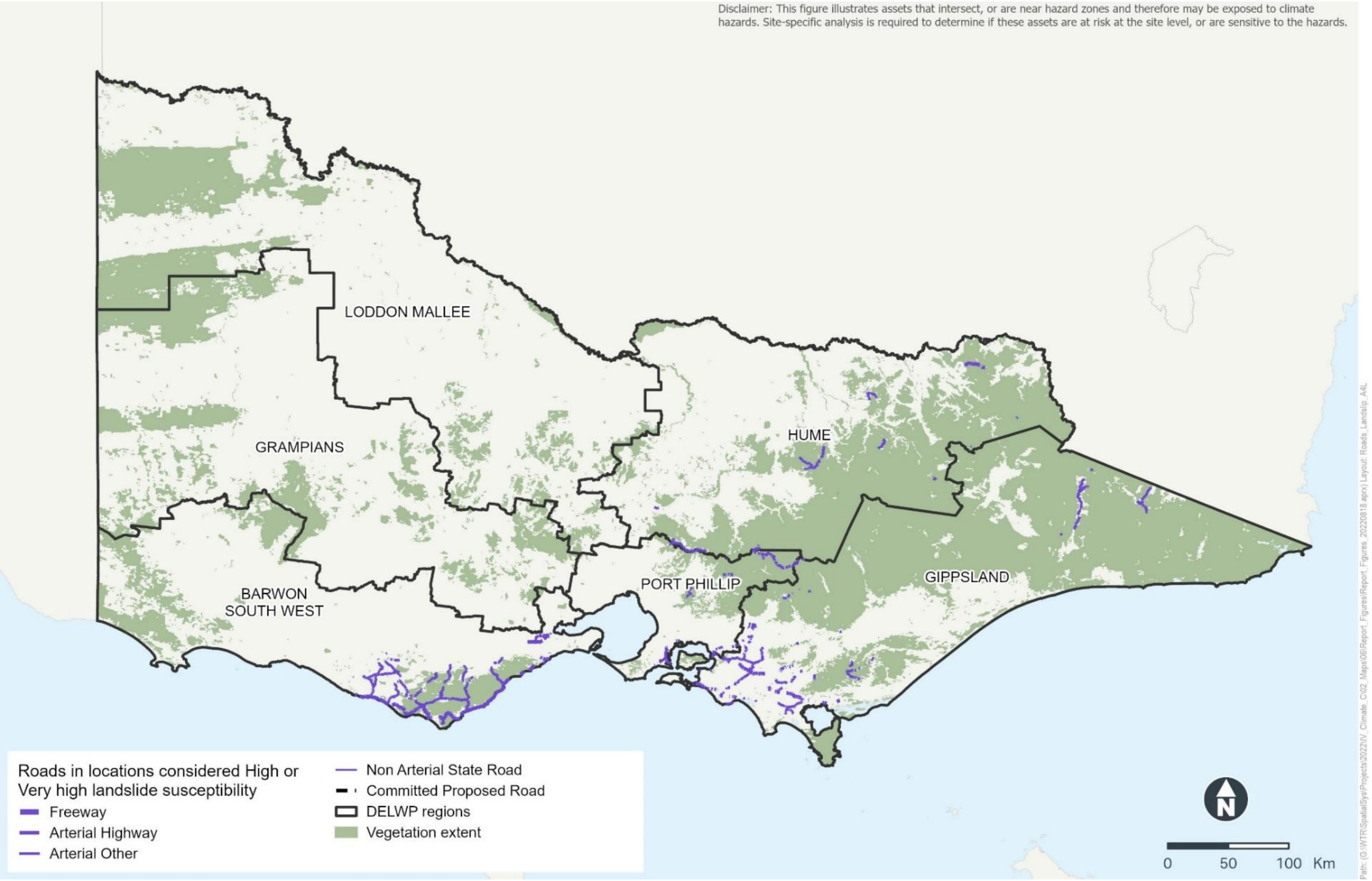

Figure 17 Roads exposed to landslide risk

6.3 Broader context of climate risks

The analysis discussed in subsection 6.1 identified and rated the direct impacts of extreme weather on road network assets. To provide a more complete picture of the complexities associated with the risk of damage and degradation of road infrastructure, consideration needs to be given to compounding events and cascading impacts.

Compounding events refer to the combination of multiple drivers or hazards that contribute to societal or environmental risk associated with damaged road network infrastructure. These events are listed in Figure 18, grouped under the themes of Demand and Supply, and Infrastructure and Operations. Examples of demand related scenarios which have compounding impacts include increased traffic due to emergency response or repair activities, or a failure of rail services leading to increased road based freight. Compounding events may also include the occurrence of multiple hazards simultaneously or in quick succession, for example an extreme rainfall event following a bushfire.

Cascading impacts relate to the sequence of secondary events that flow on from the initial direct impact of a risk. These may be physical, natural, social or economic impacts that, when combined, are greater than the initial direct impact of the risk. Figure 18 lists cascading impacts associated with damage to the road network. Each impact includes a reference to the relevant consequence theme, as per the risk framework used in this assessment (refer to Appendix A). Examples of cascading impacts from damage to road network assets and corresponding consequence themes include road disruptions adding extra pressure on vulnerable communities (Community); and increased operations, maintenance and repair costs (Finance).

In undertaking a more detailed assessment of risk (i.e. a site level risk assessment), consideration of compounding events and cascading impacts can aid the identification of failure chains and interconnections with other systems. The consideration of cascading impacts can also provide a deeper understanding of the consequences of the risk. This can be beneficial in determining the benefits of avoided damages to justify investment in adaptation action to manage risks. For example, the benefits will extend beyond the avoidance of direct costs associated with repair and reinstatement of services, to broader societal benefits including avoided: health consequences; environmental damages or disruption to economic activity.

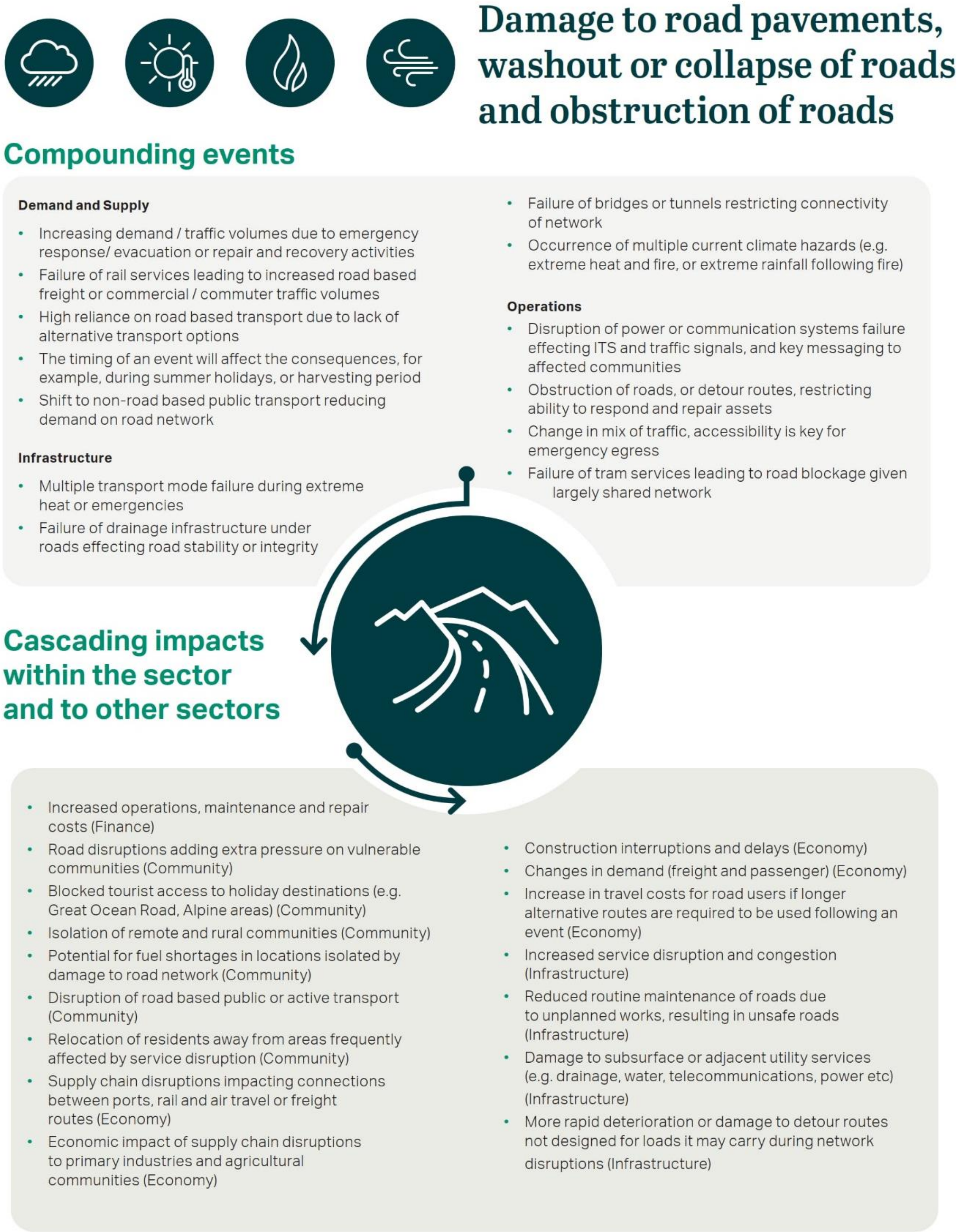

Figure 18 Broader context associated with the risk of damage to roads or disruption of access due to extreme weather events.

6.4 Case study: Impact of extreme weather on the road network

6.4.1 What happened during the Black Summer bushfires?

On 29 December 2019, a small fire started approximately 30 km west of Mallacoota in Gippsland. The fire grew significantly and rapidly, and by 5.00pm on 30 December 2019 residents and visitors were advised it was too late to evacuate as fire had blocked the only road out of the town. Fallen trees had obstructed the road impacting on evacuation efforts, and fire danger prevented efforts to clear it. By 31 December 2019, 4,000 people remained in Mallacoota as fire reached the outskirts of the town. The majority of people took refuge on the beach as the fire advanced. Air and sea evacuations began on 3 January 2020, four days after the town had become inaccessible by road, with 2,000 people needing to be rescued (Australian Institute for Disaster Resilience, 2022).

Operations to return residents to the town began on 19 January 2020, and the town was only reconnected with the rest of the State when the Mallacoota-Genoa Road reopened on 4 February 2020, more than a month after it had been closed. The town was reconnected to the power grid on 8 February 2020 (Australian Institute for Disaster Resilience, 2022).

6.4.2 How is this relevant to Victoria's future planning?

The catastrophic Black Summer bushfires should be taken as a warning of what may come in the future. In Victoria alone, the Insurance Council of Australia (2021) estimated there were direct losses of $5.47 billion. As with many natural disasters, however, the indirect losses exceed the direct losses. Victoria needs to plan for longer and more severe bushfire seasons.

This case highlighted the importance of having safe road networks to flee bushfires. There is only one road in and out of Mallacoota, and it runs through bushland. Residents who did not escape by road in time retreated to the beach, and had to wait days with no power and limited food and water before being rescued by the Navy. Even then, some people could not escape because they were not able to bring animals on the boat. Physical recovery from the fire has been slow, with only 15 out of 200 houses being rebuilt as of April 2022 (Lucas, 2022).

Over the longer term, there is the risk that residents in bushfire-affected towns such as Mallacoota will leave the town and not return. A loss of resident population could subsequently affect critical industries and services that could leave bushfire affected towns unable to operate effectively.

6.5 Adapting to climate risks

There are many effective adaptation actions that can, and are, being implemented to manage the risks associated with damage or disruption to roads due to extreme weather events. A summary of adaptation actions that address the highest rated risks to the road network is provided in Table 16. These actions are not intended to be an exhaustive list of actions and may not be applicable for use in on all roads, or locations. However, they demonstrate specific physical measures that can be taken to build the resilience of the road network and the communities they serve.

Table 16 Summary of physical adaptation actions to manage the priority risks associated with damage to roads or disruption of access due to extreme weather events

Climate hazards	Risks	Physical adaptation actions
 Extreme rainfall and flooding	Extreme rainfall related flooding leading to road inundation and damage to road pavements and underlying earthworks	To reduce risk of inundation: • Locate new roads or realign existing roads outside flood hazard areas, or • Design new road levels to be above future flood levels • Design to accommodate or limit consolidation of foundation materials and embankments beneath pavements such that surface settlement that may occur will not reduce capacity of the road to accommodate design flood levels • Raise road surface levels of existing unsealed or flexible roads via overlay or other rehabilitation • Improve capacity of stormwater drainage system (i.e., bigger culverts, deeper table drains, cut off drains) to reduce risk of inundation or duration of inundation Where inundation cannot be avoided: • Consider alternative pavement materials which are resistant to moisture infiltration from flooding. Examples for new pavements or upgrade of existing pavements include: - sealed pavements instead of unsealed pavements - thin asphalt surfacing instead of sprayed seals - upgrade/rehabilitate existing granular sealed or unsealed pavements using foamed bitumen stabilisation or similar to provide a thicker bound base layer - deep strength/full depth asphalt type pavements instead of thin asphalt surfaced pavements - concrete pavements instead of asphalt pavements - cement bound subbase layers instead of unbound subbase layers • Embankment design to either reduce or accommodate water infiltration, considering: - selection of embankment materials that reduce flood water infiltration, such as low permeability and non-dispersive verge and fill materials - alternatively, allow flood water to permeate through embankments beneath the pavement in materials that are insensitive to moisture infiltration such as high permeability rockfill/gravel/sand layers or drainage blankets - provision of subsurface drainage systems to permit water that has entered into the pavement or embankment to drain away after the flooding has receded

Climate hazards	Risks	Physical adaptation actions
Extreme rainfall and flooding (…continued)		• Undertake increased frequency of road maintenance including: - increased frequency of condition monitoring for pavements in high risk flood areas with maintenance planning and condition thresholds specific to these areas, including prompt inspection following flood events - prompt sealing of cracks and patching of localised failures in asphalt or spray sealed surfaces - prompt resurfacing with asphalt to restore shape and improve crossfall in roads subject to ponding - proactive resurfacing of spray sealed or asphalt surfaced pavements prior to poor condition developing - cleaning out of debris and silt from roadside table drains, pipes/culverts, and flushing of subsurface drains
	Extreme rainfall leading to washout or collapse of roads	• Risk reduction and mitigation actions as per pavement inundation risks generally as above • Undertake ground improvement such as insitu stabilisation or other treatments beneath new roadways and embankments to strengthen insitu materials to make them more resistant to erosion or washout • Provision of erosion and scour resistant materials (i.e., rock beaching, rip-rap, concrete etc) on embankment slope faces and pavement shoulders that may be exposed to high velocity flows
	Extreme rainfall leading to landslide risk	The following actions may be used to manage landslide risk: • Reducing the angle of the slope (i.e. reducing the steepness of the slope) • Retain or enhance vegetation on slopes • Apply engineering controls for example spray concrete or anchored mesh • Enhance surface water drainage • Realigning the road to avoid the high risk slopes. • Emergency management communications are also important controls including informing the community of road closures and detour routes during fire events.
	Extreme rainfall related flooding leading to obstruction or closure of roads caused by inundation, washout or landslides	• Risk reduction and mitigation actions for extreme rainfall and flooding as provided in rows above for inundation, washout and landslide • Where inundation cannot be avoided, consider: - Provision of stormwater drainage systems with sufficient capacity to assist in reducing the likelihood of inundation occurring and the length of time the road is inundated Local provision of concrete causeways to increase trafficability, road availability and access for emergency vehicles and evacuation during and after flood events

Climate hazards	Risks	Physical adaptation actions
Bushfire	Bushfire or grassfire leading to obstruction or closure of roads caused by smoke or fire safety risk	• Maintenance of roadside vegetation is the most significant physical action relevant to managing this risk. This may include the monitoring of the health or condition of trees on roads sides that should they fall, have the potential to block the road. Selective removal of trees may be required to manage this risk. This may be complicated by requirements to maintain environmental values. • Emergency management communications are also important controls including informing the community of road closures and detour routes during fire events.
Coastal flooding and coastal erosion	Coastal storm related flooding or erosion leading to damage to roads.	• In addition to the actions listed for extreme rainfall flooding, coastal protection works may be required, for example: - Sea walls, although introducing these structures can have environmental impacts, as well as change the coastal processes and resulting erosion risk on adjacent coastlines - Coastal revegetation to stabilise the shoreline. • If coastal protection works are not feasible, or desirable, realigning the road to avoid high risk areas may be required.

In addition to the implementation of specific physical adaptation actions, there has been significant work undertaken, at multiple scales, to enhance the resilience of the road network in Victoria to the impacts of climate change. Key work includes the development of the *Transport Climate Change Adaptation Action Plan 2022-2026* (TS-AAP) and Regional Adaptation Strategies (RASs) together with existing standards and guidelines.

Following a comprehensive review and analysis of these documents, together with key findings from the stakeholder engagement activities and consultation with subject matter experts, three adaptation themes have emerged as potential areas for enhancing resilience:

- Prioritisation and detailed investigation of vulnerability at the site level.
- Enhancing guidance to support decision making.
- Strengthening road network emergency response and recovery.

In the following sections, key current and planned adaptation actions relevant to these themes are highlighted, and barriers to adaptation, opportunities and suggested actions to enhance adaptation are discussed. Where applicable, comparable recommendations referenced in the TS-AAP are drawn out for discussion, with differentiating factors highlighted.

Recent experience from Queensland Flood Recovery Projects*

The Queensland Government have dealt with significant flooding impacts on the road network in the past decade. Some key learnings and adaptive measures have been undertaken both for the design of new road pavements and the repair of existing pavements, in particular to reduce the moisture susceptibility of roads by providing more durable materials.

A hierarchy of treatments has evolved, with the most robust treatments being applied for higher classification roads. The hierarchy and typical treatments adopted can be summarised as follows (from least susceptible to most susceptible roads to flood events):

1. Sealed granular pavement (most susceptible to flooding)
2. Lightly bound pavement (addition of 1-2% cement to base and maybe subbase, increasingly common for new builds)
3. Foamed Bitumen Stabilisation with sealed surface (addition of bitumen to base and maybe subbase layers, common treatment for rehabilitation)
4. Foamed Bitumen Stabilisation with thick asphalt layers (least susceptible).

Queensland Department of Transport and Main Roads also has a preference for highly permeable verge materials on the low side to allow water to readily drain from pavements. Foam bitumen stabilisation has been tested during recent cyclone and flood events where the pavements have been reported as still being intact and do not need to be fully rehabilitated afterwards (PIARC 2019).

*This information is on anecdotal experience of AECOM Queensland pavement design team

6.6 Adaptation theme #6: Prioritisation and detailed investigation of vulnerability at the site level

6.6.1 Current and planned controls

The TS-AAP outlines actions to prioritise and investigate the vulnerability of transport assets, including Action 4 which sets out to audit parts of the transport system at highest risk and prioritise protection of assets, infrastructure and services. Activities in the TS-AAP that support Action 4 include:

- Identifying the assets and infrastructure most exposed to climate change.
- Prioritising high risk assets for maintenance and upgrades.
- Facilitating lower-priority or smaller-scale adaptation alternatives where adaptation options are not economically feasible or practicable on a large scale.

Specific RASs include locally relevant and unique adaptation actions relevant to this adaptation theme. The following have been highlighted as examples:

- Gippsland's RAS includes an action to assess the vulnerability of key regional built environment and transport assets and the impacts of failure. It also seeks to maximise opportunities to replace impacted infrastructure with more resilient designs in a bid to build back better following significant natural events (DELWP, 2021f).
- Loddon Mallee's RAS strives to improve ageing public assets to withstand an increase in extreme weather events by conducting audits and identifying opportunities to replace damaged or end-of-life public assets with alternative technology. It also encourages priority infrastructure projects in regional transport strategies to consider extreme weather events during the planning and design phases. The development of regional planning assessment to identify parts of the transport system that are vulnerable to being impacted by climate change is also considered. The RAS calls for planning to address insurance gaps or inform prioritisation for protecting vulnerable transport assets, infrastructure, and services (DELWP, 2021e).

6.6.2 Barriers and opportunities

Building the resilience of Victoria's road network is a large scale challenge requiring a combination of targeted projects as well as progressive enhancement through asset renewal. A systematic approach is required to prioritise sections of the road network for more detailed analysis to inform any future adaptation responses. Stakeholder consultation discussions indicated that there is currently no formal process to identify vulnerable parts of the road network, which are critical to the delivery of essential services, alternative services for other critical infrastructure sectors, and if disrupted would significantly impact on the social and economic wellbeing of the state. Instead, criticality of roads is considered more broadly based on the scale of roads (e.g., arterial, highway etc.). The implementation of TS-AAP Action 4 presents the opportunity to prioritise the highest risk, most vulnerable, and most critical parts of the network to then focus resources on conducting site specific, detailed assessments of climate risks and develop prioritised actions as a critical first step.

6.6.3 Enhancing adaptation

R1 Prioritise sections of the road network for site specific assessment of climate risks and development of priority actions

The prioritisation process should consider the criticality of the roads (including economic throughput, consideration of potential for isolation, and socio-economic factors), the scale of exposure to hazards (i.e. drawing on the geospatial mapping within this study and any previous assessments), the age of infrastructure, and planned timing for reinvestment. This could be further informed by intelligence from key stakeholders on sections of the road network which have previously been impacted by climate events. It is also an important step determining the vulnerability of key assets within the network and identification of the functionalities of the network impacted. For example essential transport functions, services or accessibility functions, and regular travel functions could be identified and assessed in the context of connectivity, quality of service, capacity and costs incurred due to identified climate risks. The assessments should consider all climate risks to the road and supporting assets in those locations (e.g., ITS, drainage, bridges and tunnels).

The outcomes of the assessment should include determination of priority risks to sections of the road network, recommend prioritised adaptation actions, the timing for implementation and the decision making processes that will support implementation. Some actions may be identified as urgent, while others may be able to be integrated into future renewal works or asset replacement cycles (including replacement following damage from a hazard event). The centralised coordination of this work may identify common actions that could be more effectively implemented at a regional level.

R1 builds on Action 4 of the TS-AAP, in proposing elements to consider when developing a prioritisation framework for transport assets and infrastructure. It is recommended as an immediate priority.

6.7 Adaptation theme #7: Enhancing guidance to support decision making

6.7.1 Current and planned controls

VicRoads' *Supplements* and *Codes of Practice* and Austroads' *Guide to Design* and *Impact of Climate Change on Road Performance* set the standard for designing road infrastructure to enhance resilience in the state. These include consideration of climate change via the following actions:

- Designing and maintenance of drainage structures.
- Locating and elevating roads and bridges away from flood hazards.
- Designing and maintaining pavements to manage heat risk.
- Utilising peak flow retardation devices (retarding basin, swales).
- Maintaining clearance of vegetation and vegetation management near assets.
- Implementing coastal stabilisation works and long-term relocation of roads away from the coast at select locations where there are historic issues or maintenance is required.
- Monitoring of condition of hillsides, noting that this is likely to be at select locations, rather than systematically across the state.

- Stabilising hillsides including the use of anchored mesh or another appropriate method (e.g., Great Ocean Road and Walhalla)
- Investing in preventing landslides as a part of the post COVID Building Works Package through the Landslip Prevention Program (Regional Roads Victoria, 2022).

Progress has been made across the sector to incorporate adaptation thinking into the project lifecycle and climate change risk assessment into decision making. The Department of Transport (DoT) has been factoring climate change into business case development, construction, operations and maintenance of road network assets, including consideration of the aforementioned standards and guidelines (DELWP, 2021d).

Looking to the future, the TS-AAP outlines actions to enhance adaptation decision-making, including Action 2 which sets out to strengthen adaptation planning and decision-making for transport services, assets and infrastructure. This will be achieved by developing stronger decision-making processes that consider climate change risks in all phases of asset and project lifecycles (e.g. procurement, design, construction and maintenance requirements and costs, and service levels).

Furthermore, TS-AAP Action 9 aims to develop funding models that can provide effective adaptation solutions for the transport system. This action includes undertaking cost-benefit analysis of adaptation options and measuring these against service levels, asset life and whole-of-life costs. DoT will also work with the Department of Treasury and Finance to develop methods to better embed climate change considerations in procurement, business cases, tender processes and lifecycle planning, including during renewal and maintenance activities, as outlined in Action 14.

6.7.2 Barriers and opportunities

Despite the availability of the standards and guidelines for designing road infrastructure to enhance resilience, in practice the decision-making process for how climate adaptation is considered can be inconsistent between operators. This presents an opportunity for the Victorian Government, in consultation with stakeholders, to develop a set of standardised adaptation design guidelines.

The 1997 Thredbo landslide disaster was the catalyst for a review of landslide risk and construction standards in New South Wales and more broadly across Australia. This included the Australian Geomechanics Society's *Landslide Risk Management Concepts and Guidelines* (AGS, 2000) and *Practice Note Guidelines for Landslide Risk Management* (AGS, 2007). In NSW the Roads Authority (then the Roads and Traffic Authority) based their *Guide to Slope Risk Analysis* on the approach suggested by the AGS (Stewart et al, 2002). This is supported through training to enable a consistent approach, including standardised risk assessment and reporting to feed into asset management planning and the allocation of funding. While VicRoads has developed the *Risk Management of Road Geotechnical Hazards Technical Note 96* (VicRoads, 2022), unlike NSW, there is no formal training to support its implementation[6].

This gap is compounded by the challenge of finding historical data on roads and locations which have been impacted by similar events in the past. Knowledge of previous landslide hazards can help to identify trends in the location and size of events, which may inform predictions of future issues and therefore preventative actions. GeoScience Australia, in their assessment of impacts of landslides in Australia (Leiba, 2011), explain that information regarding past landslides must be gleaned from written reports (often from the media or personal observations). Consequently, inventories of historic landslides that contain valuable information such as the location and size tend to be incomplete, missing, and/or held in local / regional offices or anecdotally by local staff.

Victoria's *State Landslide Hazard Plan* (Victoria SES, 2018) identifies this problem and recommends further work in Victoria to consolidate various inventories of landslide events, together with past risk assessments and susceptibility mapping, into a consolidated data set. With landslides in south east Australia likely to become more frequent and widespread because of predicted increases in rainfall intensity and bushfire activity (Nyman, 2019), there is an opportunity to further develop Victoria's approach to assessing and managing landslide risks to the road network.

Opportunities also exist to enhance guidance on managing climate risks associated with pavement assets. There is limited published guidance in Australia on the management of pavement assets in

[6] Based on the experience of AECOM subject matter specialists

flood prone areas. Several high level documents have been written by road authorities with regard to the risks and impacts related to extreme events resulting from climate change, however there is less detailed information available on specific requirements for maintenance, rehabilitation, as well as new pavement and road embankment design to address flood risk.

6.7.3 Enhancing adaptation

R2 Embed adaptation principles into proactive/preventative maintenance and road rehabilitation

Increased proactive rehabilitation of road pavement and roadside maintenance will assist in reducing the susceptibility of the road network to flood related damage and associated road closures. Greatest benefit will be achieved if maintenance and rehabilitation activities are targeted on areas at highest risk of flood damage, and on higher classification roads.

Adaptation action R2 is recommended as an immediate priority to promote consistency and standardisation of adaptation action to progressively enhance the resilience of Victoria’s road network.

Important proactive road maintenance activities to increase resistance to flood damage, as referenced in Table 16, include:

- Increased frequency of condition monitoring for pavements in high risk flood areas with maintenance planning and condition thresholds specific to these areas, including prompt inspection following flood events.
- Prompt sealing of cracks and patching of localised failures in asphalt or spray sealed surfaces.
- Prompt resurfacing with asphalt to restore shape and improve crossfall in roads subject to ponding.
- Proactive resurfacing of spray sealed or asphalt surfaced pavements prior to poor condition developing.
- Cleaning out of debris and silt from roadside table drains, pipes/culverts, and flushing of subsurface drains.

Pavement rehabilitation options for targeted road sections that assist in increasing the robustness of these areas include:

- Reactive repairs to areas impacted by flooding such as foamed bitumen stabilisation or locations of full depth asphalt pavement.
- Proactive upgrade of pavement structures to reduce potential erosion via measures as outlined in the physical adaptation action table (Table 16) with an example hierarchy given in Section 6.5 as adopted by the Queensland government.
- Improvements to functionality and capacity of stormwater drainage system.
- Modifications/protection treatments to embankments to provide increased resistance to water ingress and also erosion.

R3 Embed adaptation principles into the design of new and upgraded/renewed infrastructure

There is an opportunity to develop adaptation design guidelines to support greater alignment in building resilience across the sector. When building new infrastructure or upgrading/renewing infrastructure, it is recommended that adaptation features, including the principles set out in Figure 19, be embedded into the design.

These guidelines could support the development of projects funded by government. Additionally, these guidelines should provide direction regarding preventative maintenance (e.g. patching and resealing of road surfaces etc) which can assist in prolonging the life of assets, protecting the road surface as well as the subgrade of roads.

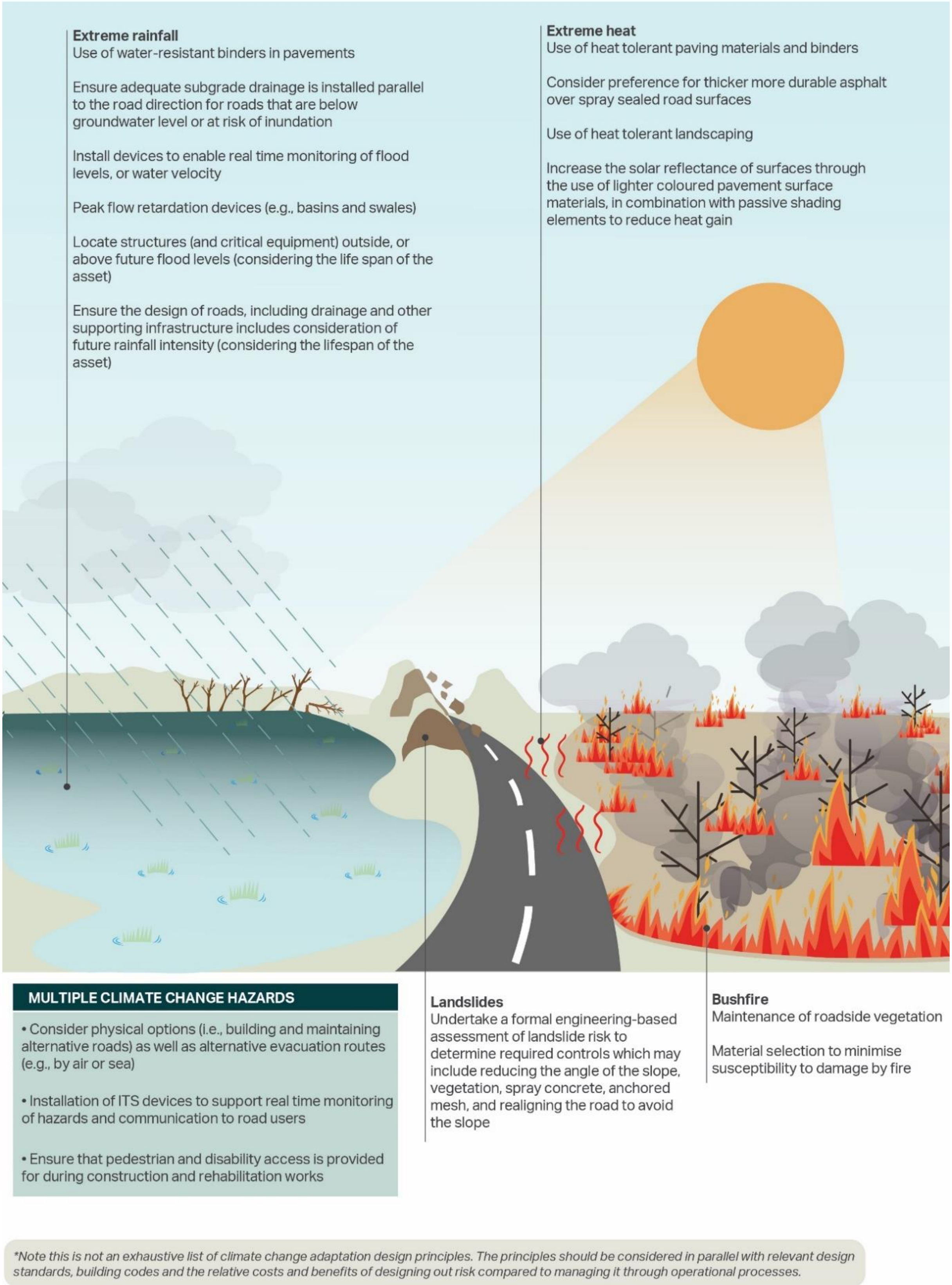

Figure 19 Adaptation design principles addressing the risk of damage to roads or disruption of access due to weather events

[Adapted from IPWEA (2018), National Academy of Science (2008), Transportation Research Board (2008), VicRoads (2015)].

R4 Enhance the approach to slope risk management in Victoria

Enhance Victoria's approach to assessing and managing landslide risks to the road network. Learnings could be adopted from the approach taken in NSW, including:

- supporting the industry with training on their application, and
- establishing a knowledge management process to capture the outcomes of assessments to prioritise actions and investment.

This approach would enable an open and transparent allocation of funds to landslide and slope management issues across the state, helping to support a more proactive, rather than reactive management approach.

6.8 Adaptation theme #8: Strengthening road network emergency response and recovery

6.8.1 Current and planned controls

Victoria's transport system is crucial in supporting emergency management activities. Building its capacity to help respond to and recover from emergencies is critical to building climate resilience. To enable this, operators of 'vital critical infrastructure' – which includes parts of the transport network (DELWP, 2021d) – have legislative risk management obligations, including resilience building, under Part 7A of the *Emergency Management Act 2013*.

Emergency response and recovery is a focus of the TS-AAP, with Action 3 seeking to increase the resilience of transport assets, infrastructure and services to climate change, in part by incorporating climate adaptation planning and principles into emergency management and disaster recovery responses. This action will be achieved by a number of supporting activities, including updating DoT's Emergency Management Framework, and continuing to include emergency management as a priority in DoT's risk assessment processes to identify emerging risks.

Some RASs outline regionally-focused adaptation actions to strengthen the emergency response and recovery of the road network. For example, Gippsland's RAS aims to establish reliable back-ups for essential infrastructure (including road networks for responders and the community) in emergency situations (DELWP, 2021f).

6.8.2 Barriers and opportunities

Building redundancy in the road network by identifying alternative routes for critical roads is crucial to maintaining resilience in the event of an emergency. DoT plays a critical role in assisting with the coordination of alternate transport routes during emergencies, including route selection, emergency traffic management and route conditions advice and control (EMV, 2022). It was identified in stakeholder engagement discussions that in the aftermath of an emergency, there is a risk that road networks will be damaged as a result of more frequent use as an alternative route.

Some alternative routes include unsealed local roads, which are not designed for frequent use, particularly by larger Gross Vehicle Mass capacities. From an economic cost perspective, more frequent use of alternate routes can result in additional rehabilitation costs for roads damaged by detouring vehicles, in addition to the costs to recover the main road affected by a climate hazard. From a social cost perspective, the implications of disruptions to supply chains and community activities also need to be considered.

6.8.3 Enhancing adaptation

R5 Enhance resilience of key alternative road-based routes

There is an opportunity for the Victorian Government to review and assess key alternative routes likely to carry heavier vehicles. From a planning and asset management perspective, once these key alternative routes are identified, it is recommended to increase their load carrying capacity via targeted strengthening rehabilitation treatments. This could be undertaken as part of scheduled preventative maintenance works to reduce risk of more rapid deterioration from increased traffic flows during emergency events.

For sites that are deemed as not being feasible to maintain existing roads-based evacuation routes, it is important to ensure that emergency management planning combines early warning to support road-based evacuation prior to an event, as well as access to air or sea resources to support timely alternative emergency evacuation methods.

6.9 Summary of proposed adaptation actions

Table 17 summarises the proposed adaptation actions to enhance the management of risk of damage to roads or disruption of access due to extreme weather events.

A suggested timing for implementation has been indicated for each action. These are either act now (i.e. within the current adaptation action planning cycle), act by 2026 (i.e. incorporate into the next round of adaptation planning, for roll out from 2026), or undertake further research.

Progressing these adaptation actions can help to determine which adaptation measures, as summarised in Section 6.5, could be used on specific roads to help build the resilience across the network.

Table 17 Proposed adaptation actions to address the risk of damage to roads or disruption of access due to extreme weather events

Action	Act now	Act by 2026	Further research
Physical actions			
R1 Prioritise sections of the road network for site specific assessment of climate risks and development of priority actions	x	-	-
R2 Embed adaptation principles into funding and targeting of proactive/preventative maintenance and road rehabilitation	x		
R3 Embed adaptation principles into the design of new and upgraded/renewed infrastructure	x	-	-
Policies / Strategy based actions			
R4 Enhance the formalised approach to slope risk management in Victoria	-	x	-
R5 Enhance resilience of key alternative road-based routes	-	x	-

7.0 Cross sector impacts

The impacts of climate hazards do not happen in isolation. Sections 4.0, 5.0 and 6.0 provided the broader context of factors that will influence the overall consequences of each of the risks assessed. Compounding and cascading factors play a role in influencing the resulting impacts within a sector and across sectors. Using the three asset types explored in this study (electricity, hospitals and roads), Figure 20 illustrates cross sector impacts between electrical T&D infrastructure, the road network and public hospitals. While many of the cross sector impacts ‘flow-on’ to hospitals (e.g., loss of power, loss of road access, increase in patient demand etc.), impacts to hospitals may lead to increases in demand for electricity to aid the response to an emergency. Damage to hospitals may also lead to increases in traffic on the road network to support the relocation of patients, or increase logistics demands to support the emergency response. The consideration of cross sector independencies may be further complicated by additional upstream and downstream dependencies.

It is important to explore these cross-sectoral issues when assessing the sensitivity of specific assets and when developing adaptation actions. This is because such consideration assists in understanding where the vulnerabilities in the broader system are and can help to prevent maladaptation. For example, a maladaptation could occur if investment in a physical adaptation solution protects a site from damage, but the site is unable to operate as a result of a loss of connecting services or access. It might be more effective, in some circumstances, to provide a lower level of physical protection and focus on enabling a quick recovery following an event, at which time services or access may also be restored.

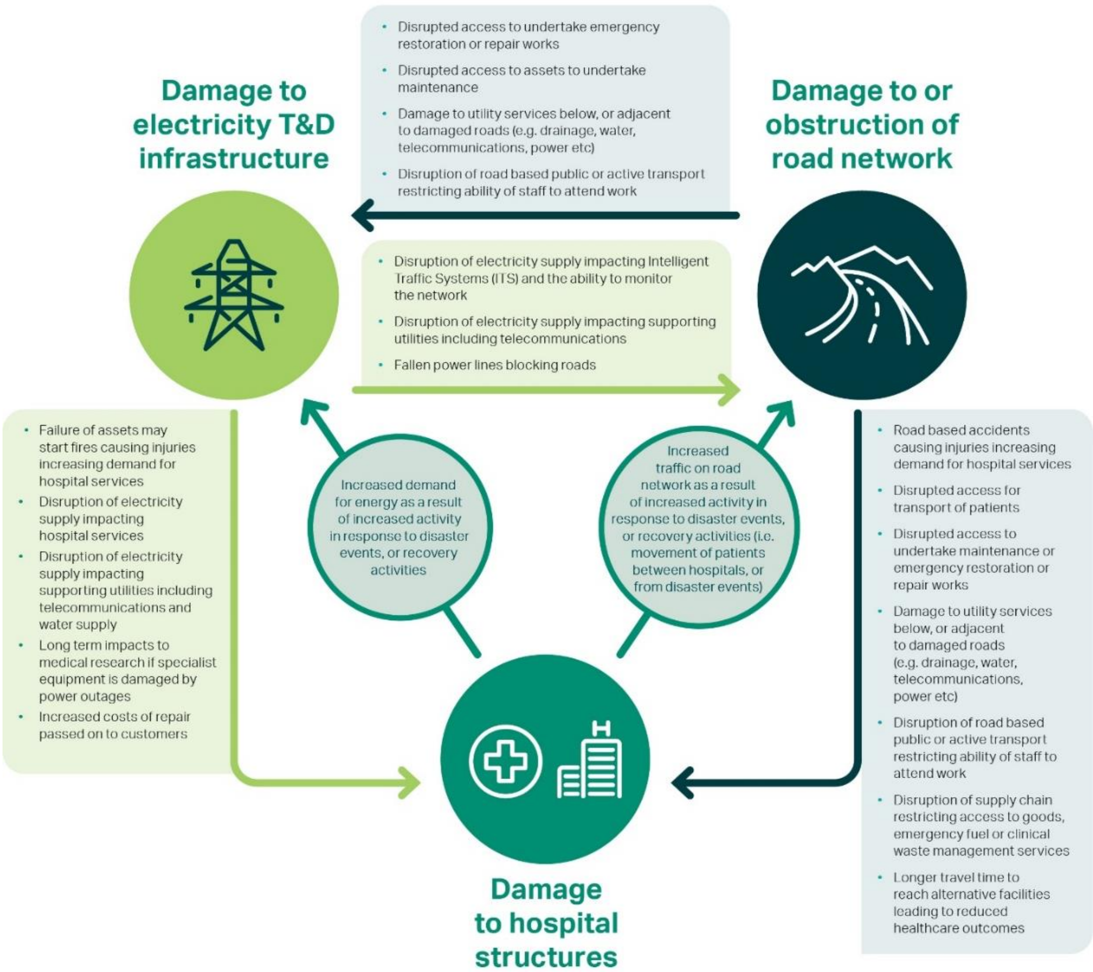

Figure 20 Example of cross sector impacts between the electricity T&D infrastructure, the road network and public hospitals (Note: the cross sector interdependencies which are identified will be influenced by additional compounding events or cascading impacts not included in the figure)

7.1 Adapting to climate risks

Sections 4.0, 5.0 and 6.0 have identified sector-specific priority risks and responding physical adaptation actions. Opportunities to enhance adaptation are also recommended for each sector. The physical adaptation actions may be supported by strategic planning responses that can provide cross sector benefits by locating critical infrastructure outside hazard areas. The importance of strategic planning is acknowledged in the *Built Environment Climate Change Adaptation Action Plan* (BE-AAP). Action 9 and Action 12 of the BE-AAP seek to incorporate spatial mapping of hazards, and consideration of projected changes in the profile of hazards due to climate change, into strategic planning for urban land use and critical infrastructure.

In the following sections (7.2 and 7.3), a cross sector view is applied to the discussion of barriers to adaptation and potential actions to enhance adaptation are recommended. Unlike Sections 4.0 to 6.0, a list of physical adaptation actions are not included in this cross sector discussion, as the physical actions relate to specific asset types (i.e. sectors).

7.2 Barriers and opportunities

Significant investment is required to build the resilience of Victoria’s infrastructure. Accessing funding to advance climate adaptation was identified as a barrier by stakeholders across multiple sectors. This included accessing funding to investigate the risks and identify appropriate solutions, as well as funding to undertake works to implement solutions. This can lead to a greater emphasis on recovery activities, rather than investing in preventative actions.

Building the business case for investment in adaptation requires detailed analysis of costs and benefits prior to a formal financial commitment. This involves the identification and evaluation of adaptation actions required to manage uncertainties, as relevant for business case development, procurement, delivery, evaluation and on-going management project investment objectives, as per the DTF *Investment Lifecycle and High Value High Risk Guidelines* (DTF, 2019).

Understanding the rising costs of climate hazards will support cost benefit analyses and enable informed and proactive planning for adaptation to minimise exposure to future cost impacts and disruptions. This could lead to co-benefits such as improved infrastructure condition and service reliability, greater business confidence, incentives for innovation, and ultimately better outcomes for communities (Deloitte Access Economics, 2021).

The costs of climate hazards associated with damage to infrastructure are identified as tangible (direct and indirect) costs and intangible costs (Bureau of Transport Economics, 2001; Productivity Commission, 2015). Examples of these costs are summarised below, with additional detail included in Appendix B:

- Direct costs have a market value, such as costs of replacing damaged assets due to a climate event. The Victorian Bushfires Royal Commission’s conservative cost estimate of the 2009 Black Saturday bushfire was over $4 billion, which included $77 million for lost or damaged public infrastructure such as roads, schools and community infrastructure (Parliament of Victoria, 2010). Estimated damage costs to telecommunications (Telstra - $15m), energy (Powercor - $729,000) and water assets (Melbourne Water - $5m) provide examples of the direct infrastructure costs of climate hazards.
- Indirect costs arise from the consequence of damages and destruction from disasters. The indirect economic impacts of a climate hazard can include clean-up, disruptions to infrastructure operations, loss of productivity and loss of income. Examples include telecommunication assets needing replacement (direct cost), resulting in disruption and additional costs from waiving service charges during the recovery (indirect cost).
- Intangible costs capture direct and indirect damages that cannot be easily priced or seen, such as social and environmental impacts. These can include health and wellbeing (including mental health), employment, education, environment and community factors. Deloitte (2016) found that lifetime mental health costs account for a large component of the overall economic cost of disasters, with $5.9b associated with mental health in the Queensland floods (2010-2011) and over $1b in the Black Saturday bushfires (2009).

Key barriers to developing a business case for adaptation action, highlighted during the stakeholder engagement process, were the lack of an agreed approach to quantifying resilience benefits and the availability of quality data to support informed decision-making on resilience investments. Examples of data gaps provided during workshop discussions included geospatial information on climate-related risks, and local-level climate projections to inform assessments of risk. Although the spatial resolution of the commonly used global climate models have improved greatly over time, the grid scales (with a typical atmospheric resolution of 200 km) limit representation of important regional and local-scale features such as topography (CSIRO, 2020). Analysis for this project has used Victorian Climate Projections 2019 datasets which present data from higher-resolution (5 km) modelling (CSIRO, 2020a).

It is acknowledged that there are a number of guidelines which provide comprehensive frameworks for infrastructure planning, assessment and evaluation to support decision-making in a consistent and coherent manner. Such guidelines include the DTF *Investment Lifecycle and High Value High Risk Guidelines* (DTF, 2019), *Australian Transport Assessment and Planning (ATAP) Guidelines* (ATAP, 2021), and *Infrastructure Australia Assessment Framework* (IA, 2017). These guidelines outline approaches to assess the risk and uncertainty of climate change throughout delivery and operation quantification of climate change events due to uncertainties. Planning for these changes can include the building of infrastructure to different standards (e.g. building a bridge to a higher flood specification), and early action on identified risks can result in rapid payback times where infrastructure resilience can pay for itself within 2-4 years (IA, 2017).

Notwithstanding these well-established guidance materials and approaches, it was highlighted through the stakeholder engagement process that there are complexities associated with the quantification of the benefits of adaptation actions to support cost benefit analysis. This particularly relates to the quantification and evaluation of indirect and intangible costs, and the quantification of upstream and downstream impacts across multiple sectors. This makes it challenging to build a business case for significant investments in infrastructure adaptation measures, and to access funding to maintain infrastructure. This can be compounded by funds being diverted towards emergency response and repair activities immediately following extreme events, which can impact on the allocation of funds towards preventative adaptation actions. It is estimated that 97% of all natural disaster spending in Australia occurs after an event on recovery, clean-up and asset repair while only 3% is spent on preventative measures before an event (ICA, 2021). The Australian Business Roundtable for Natural Disasters highlighted the benefit of resilience planning over recovery in their report *Building resilience to natural disasters in our states and territories* (Deloitte Access Economics, 2017).

It was also identified in discussions with stakeholders that consistency and standardisation in conducting cost benefit analyses could be improved, particularly for indirect and intangible costs. In the electricity sector, for example, each service provider conducts their own assessment under the guidelines from the Australian Energy Market Commission, with potentially different drivers influencing the analysis and outcomes.

The BE-AAP responds in part to this barrier with a priority action to assess the use of economic tools in delivering climate change adaptation outcomes. Furthermore, the EDNRR has identified a cost benefit analysis of preferred investment solutions, to be undertaken by the Victorian Government, as a key step in its recommendation to develop a Network Resilience Investment Strategy. However, the challenges that asset owners and operators across all infrastructure sectors experience in building a case for investment in adaptation indicate there is an opportunity to provide additional guidance. Some of these challenges include:

- Estimation of how impacts may change as a result of climate projections.
- Identification of indirect and intangible benefits of actions.
- Inconsistency in approaches, baseline assumptions and use of scenarios.
- Inconsistency in the adoption of existing state and / or national guidance (i.e. *Infrastructure Australia's Assessment Framework*).
- Access to data to support the quantification of indirect and intangible benefits.

7.3 Enhancing adaptation

C1 Advance the development of downscaled climate and hazard projections

It is recommended that the Victorian Government, together with key stakeholders including CSIRO's Climate Science Centre, continue to advance the development of downscaled climate projections, particularly those related to extreme weather events, to support risk assessment and input into cost-benefit analysis of adaptation actions. This should prioritise the modelling of extreme wind events, building on the initial work undertaken by the Electricity Sector Climate Information project, which identified this as a gap in existing climate projections. The results from downscaling can complement the existing suite of data provided in the Victoria's Future Climate Tool.

This recommendation will complement existing actions within Adaptation Action Plans (including BE-AAP and TS-AAP) to extend the use of climate projection data and spatial mapping to inform land use and infrastructure planning, design and investment. Additionally, incorporating localised projection and spatial mapping data into site-specific assessments will enhance the quality of climate risk assessments and adaptation decision-making.

C2 Enhance standardised approaches to cost-benefit analysis

It is recommended that the Victorian Government demonstrates a standardised approach to cost benefit analyses for stakeholders to adapt for their own purposes, thereby supporting decision makers to build a case for investment in adaptation. This should include appreciation for the costs of climate hazards, consideration of indirect and intangible (e.g. social and environmental) costs and benefits, and expand the consideration of value for money when assessing the cost benefit of adaptation actions. Guidance should also be provided on valuing the benefits of preventative adaptation actions, versus responding through recovery activities.

This will enhance consistency of approach and methodologies in incorporating climate change considerations into decision-making (i.e., budgets, project planning and design, cabinet submissions, etc.). It will also complement existing actions within BE-AAP and TS-AAP to promote the use of economic tools to support delivery of adaptation outcomes and better embed climate change considerations throughout the infrastructure lifecycle.

7.4 Summary of recommended adaptation actions

Table 18 summarises the proposed adaptation actions to enhance adaptation across multiple sectors. For each action a suggested timing for implementation has been indicated. These are either act now (i.e. within the current adaptation action planning cycle), act by 2026 (i.e. incorporate into the next round of adaptation planning, for roll out from 2026), or undertake further research.

Table 18 Recommended adaptation actions to enhance climate adaptation across multiple sectors

Action	Act now	Act by 2026	Further research
Policies / Strategy based actions			
C1 Advance the development of downscaled climate and hazard projections	-	-	x
C2 Enhance standardised approaches to cost-benefit analysis	x	-	-

8.0 Conclusion

The objective of this study was to identify how climate change will affect Victoria's infrastructure and consider any additional actions the Victorian Government might take to build the resilience of state government-owned and regulated infrastructure.

The risk assessment undertaken in the study, including the GIS analysis of hazards, determined that extreme weather events have and will continue to adversely impact the three asset types that formed the focus of the study – electrical T&D infrastructure, public hospitals and the declared road network (which includes freeways, arterial roads and non-arterial state roads). The following key risks formed the basis of this study:

- Damage to, or degradation of electricity T&D assets due to extreme weather events
- Damage to public hospital building structures due to extreme weather events
- Damage to roads or disruption of access due to extreme weather events.

The study confirmed that the effects of the climate risks will not be experienced evenly across the state. The study identified the relative exposure of assets to climate hazard across Victoria's regions, as summarised in Table 19.

Table 19 Summary of regions with greatest exposure of assets to climate hazards

Hazards	Regions with greatest exposure of assets to specific climate hazards
Electricity transmission and distribution	
Bushfires	Gippsland, Hume Barwon South West, Gippsland and Hume (Substations)
Extreme Heat	Grampians, Loddon Mallee
Extreme Rainfall and Flooding	Greater Melbourne, Gippsland (Substations)
Extreme Wind	Hume, Greater Melbourne
Public hospitals	
Bushfires	Loddon Mallee, Greater Melbourne, Hume
Extreme Heat	Grampians, Loddon Mallee
Extreme Rainfall and Flooding	Greater Melbourne, Loddon Mallee, Hume
Road network	
Bushfires	Gippsland, Loddon Mallee, Barwon South West
Extreme Rainfall and Flooding	Hume, Loddon Mallee
Landslides	Barwon South West

The study acknowledges the existing climate adaptation work undertaken for each sector and region. The study has confirmed that there is significant action already underway as result of past extreme weather events, or through commitments for action outlined in the AAPs, and RASs.

Consideration was given to barriers and opportunities for climate change adaptation in each sector within the scope for this analysis, to identify potential additional actions to build on existing adaptation efforts. In addition, acknowledging the cross sector implications of climate risks, the study has identified actions that support adaptation across multiple sectors. The proposed priority adaptation actions are summarised in Table 20, categorised into physical actions and policy or strategy-based actions. These actions represent those that are considered priorities for action within the current adaptation action planning cycle (i.e. by 2026).

Table 20 Priority additional adaptation actions

Adaptation action	Physical actions	Policy / strategy based actions
Electricity transmission and distribution		
E1 Prioritise sections of the electricity T&D network to undergo site specific detailed assessment of climate risks	x	-
E3 Embed adaptation design principles into the design of new and upgraded/renewed infrastructure	x	-
E4 Enhance shared agreement on priorities for emergency restoration and recovery	-	x
E5 Self-healing networks	x	-
Public hospitals		
H1 Prioritise hospitals for site specific detailed assessment of climate risks and development of priority actions	x	-
H2 Supplement the Victorian Health Building Authority sustainability guidelines with tools to support climate adaptation decision making and implementation	-	x
Road network		
R1 Prioritise sections of the road network for site specific detailed assessment of climate risks and development of priority actions	x	-
R2 Embed adaptation principles into proactive/preventative maintenance and road rehabilitation	x	-
R3 Embed adaptation principles into the design of new and upgraded/renewed infrastructure	x	-
Cross-sectoral adaptation actions		
C2 Enhance standardised approaches to cost-benefit analysis	-	x

There are many existing concepts and approaches to building the resilience of the assets through physical adaptation actions. To determine the most effective location and timeframe for implementation, it will be important for each sector to prioritise locations and assets for more detailed site-specific assessments of climate risk.

There are opportunities within each sector, and across sectors, to enhance knowledge, frameworks and processes to progressively build the resilience of Victoria's infrastructure. Effective implementation of the proposed actions will require further stakeholder engagement to help develop consistency within and across sectors. This engagement could also support education and capacity building of infrastructure stakeholders.

References

ABC News, 2021. Yallourn power station evacuates mine due to potential flooding in Victoria's Latrobe Valley. 12 June 2021. https://www.abc.net.au/news/2021-06-12/yallourn-mine-evacuates-brown-coal-mine-due-to-floods/100210504

ABC News, 2021a. Thousands still without power as authorities reveal evidence of cracking at Yallourn power station mine. 14 June 2021. https://www.abc.net.au/news/2021-06-14/victoria-wild-weather-storm-floods-kaloroma/100212890

ABC News, 2021b. Melbourne residents hit by devastating storms told they will not have power for three more weeks. 17 June 2021. https://www.abc.net.au/news/2021-06-16/melbourne-residents-hit-by-devastating-storms-power-outages/100221326

AusNet Services, 2021. Cost pass through application – June 2021 storms (public version). https://www.aer.gov.au/system/files/AusNet%20Services%20-%202020-21%20Storms%20disaster%20event%20cost%20pass%20through%20-%20Application%20-%20November%202021.pdf

Australian Energy Market Operator (AEMO), 2021. 2021 Transmission Cost Report. https://aemo.com.au/-/media/files/major-publications/isp/2021/transmission-cost-report.pdf?la=en

Australian Energy Market Operator (AEMO), 2022. 2022 Integrated System Plan. https://aemo.com.au/-/media/files/major-publications/isp/2022/2022-documents/2022-integrated-system-plan-isp.pdf?la=en

Australian Geomechanics Society, 2000. Australian Geomechanics Society Landslide Risk Management Concepts and Guidelines.

Australian Geomechanics Society, 2007. Practice Note Guideline for Landslide Risk Management.

Agriculture Victoria, 2022. Victoria's Agriculture and Food Industries. https://agriculture.vic.gov.au/about/agriculture-in-victoria/victorias-agriculture-and-food-industries

Australian Academy of Science, 2021. The Risks to Australia of a 3°C Warmer World. https://www.science.org.au/files/userfiles/support/reports-and-plans/2021/risks-australia-three-deg-warmer-world-report.pdf

Australian Institute for Disaster Resilience, 2022. Black Summer bushfires, VIC, 2019-20 | Australian Disaster Resilience Knowledge Hub. https://knowledge.aidr.org.au/resources/black-summer-bushfires-vic-2019-20/

Australian Tenders, 2016. The Charlton Hospital Redevelopment. https://www.australiantenders.com.au/news/33/charlton-hospital-redevelopment/

Baldasso Cortese, 2022. Charlton. https://www.baldassocortese.com.au/charlton

Bird, Eric, 1993. The Coast of Victoria – The Shaping of Scenery' Melbourne University Press

Buis, Alan, 2019. Can Climate Affect Earthquakes, Or Are the Connections Shaky?. https://climate.nasa.gov/news/2926/can-climate-affect-earthquakes-or-are-the-connections-shaky/

Bureau of Transport Economics, 2001. Economic Costs of Natural Disasters in Australia. https://www.bitre.gov.au/sites/default/files/report_103.pdf

Chirgwin, Richard, 2022. Jemena sets "self-healing" network technology live. https://www.itnews.com.au/news/jemena-sets-self-healing-network-technology-live-577120

Clayton, Rachel, 2020. Destructive winds tear down power towers, trees and damage homes across Victoria. *ABC News*, 1 February 2020. https://www.abc.net.au/news/2020-02-01/wild-weather-victoria-continues-across-victoria/11920502

Climate Council, 2022. Uninsurable nation: Australia's most climate-vulnerable places. https://www.climatecouncil.org.au/wp-content/uploads/2022/05/CC_Report-Uninsurable-Nation_V5-FA_Low_Res_Single.pdf

Climatics, 2022. Climate intelligence sourced by SGS Economics and Planning from Climatics by Early Warning Network. https://www.earlywarningnetwork.com.au/services-climatics

Coster, Edward, and Wim Kerstens, 2014. Self-Healing Networks Come to the Netherlands. https://www.tdworld.com/grid-innovations/distribution/article/20964034/selfhealing-networks-come-to-the-netherlands

Cresswell, Ian, Terri Janke and Emma L. Johnston, 2021. Australia state of the environment 2021, independent report to the Australian Government Minister for the Environment. Canberra: Commonwealth of Australia. DOI:10.26194/f1rh-7r05.

CSIRO, Maunsell & Phillips Fox, 2007. Infrastructure and climate change risk assessment for Victoria: Report to the Victorian Government. Melbourne: Victorian Government.

CSIRO, 2020. Climate Change in Australia: Downscaling. https://www.climatechangeinaustralia.gov.au/en/learning-support/climate-models/downscaling/

CSIRO, 2020a. Climate Change in Australia: Constructing climate change projections – the CSIRO climate futures framework. https://www.climatechangeinaustralia.gov.au/en/projects/victorian-climate-projections-2019/vcp19-guidance/vcp19-constructing-projections/

CSIRO, 2020b. Victorian Climate Projections 2019. https://www.climatechangeinaustralia.gov.au/en/projects/victorian-climate-projections-2019/

Deloitte Access Economics, 2016. The economic cost of the social impact of natural disasters.

Deloitte Access Economics, 2017. Building resilience to natural disasters in our states and territories, The Australian Business Roundtable for Disaster Resilience and Safer Communities. https://www2.deloitte.com/content/dam/Deloitte/au/Documents/Economics/deloitte-au-economics-building-resilience-natural%20disasters-states-territories-161117.pdf

Deloitte Access Economics, 2021. Special report: Update to the economic costs of natural disasters in Australia, The Australian Business Roundtable for Disaster Resilience and Safer Communities. https://www2.deloitte.com/content/dam/Deloitte/au/Documents/Economics/deloitte-au-economics-abr-natural-disasters-061021.pdf

Department of Climate Change (DCC), 2009. Climate Change Risks to Australia's Coast - A First Pass National Assessment' Published by the Department of Climate Change, Commonwealth of Australia, 2009

Department of the Environment, 2013. Representative Concentration Pathways (RCPs). https://www.cawcr.gov.au/projects/Climatechange/wp-content/uploads/2016/11/ACCSP_RCP.pdf

Department of Environment, Land, Water and Planning, 2019. The economic impact of heatwaves on Victoria. www.climatechange.vic.gov.au/__data/assets/pdf_file/0011/413030/The-economic-impact-of-heatwaves-on-Victoria.pdf

Department of Environment, Land, Water and Planning, 2019a. Victoria's Climate Science Report 2019. https://www.climatechange.vic.gov.au/__data/assets/pdf_file/0029/442964/Victorias-Climate-Science-Report-2019.pdf

Department of Environment, Land, Water and Planning, 2019b. Victoria's Future Climate Tool. https://vicfutureclimatetool.indraweb.io/

Department of Environment, Land, Water and Planning, 2020. Grampians Region Adaptation Strategy 2021-25. Melbourne: State of Victoria.

Department of Environment, Land, Water and Planning, 2021. Climate Change Act 2017. https://www.climatechange.vic.gov.au/legislation/climate-change-act-2017

Department of Environment, Land, Water and Planning, 2021a. Victoria's climate change strategy. Melbourne: State of Victoria.

Department of Environment, Land, Water and Planning, 2021b. Built Environment Climate Change Adaptation Action Plan 2022-2026. Melbourne: State of Victoria.

Department of Environment, Land, Water and Planning, 2021c. Health and Human Services Climate Change Adaptation Action Plan 2022-2026. Melbourne: State of Victoria.

Department of Environment, Land, Water and Planning, 2021d. Transport Climate Change Adaptation Action Plan 2022-2026. Melbourne: State of Victoria.

Department of Environment, Land, Water and Planning, 2021e. Loddon Mallee Climate Ready Plan. Melbourne: State of Victoria.

Department of Environment, Land, Water and Planning, 2021f. Gippsland Regional Climate Change Adaptation Strategy. Melbourne: State of Victoria.

Department of Environment, Land, Water and Planning, 2021g. Hume Regional Climate Adaptation Strategy. Melbourne: State of Victoria.

Department of Environment, Land, Water and Planning, 2021h. Greater Melbourne Regional Climate Change Adaptation Strategy. Melbourne: State of Victoria.

Department of Environment, Land, Water and Planning, 2021i, Planning scheme structure. https://www.planning.vic.gov.au/schemes-and-amendments/planning-scheme-structure

Department of Environment, Land, Water and Planning, 2022. Independent Review of Victoria's Electricity and Gas Network Safety Framework. https://www.energy.vic.gov.au/electricity/electricity-network-framework-review

Department of Environment, Land, Water and Planning, 2022a. Victoria's changing climate. https://www.climatechange.vic.gov.au/victorias-changing-climate

Department of Environment, Land, Water and Planning, 2022b. Building Victoria's Climate Resilience. https://www.climatechange.vic.gov.au/__data/assets/pdf_file/0023/558140/BuildingVictoriaClimateResilience.pdf

Department of Environment, Land, Water and Planning, 2022c. Victorian Government action on climate change. https://www.climatechange.vic.gov.au/victorian-government-action-on-climate-change

Department of Environment, Land, Water and Planning, 2022d. Adaptation Action Plans. https://www.climatechange.vic.gov.au/building-victorias-climate-resilience/our-commitment-to-adapt-to-climate-change/adaptation-action-plans-a-major-step-forward-for-climate-resilience-in-victoria

Department of Environment, Land, Water and Planning, 2022e. Yallourn Power Station. https://www.vic.gov.au/yallourn-power-station

Department of Environment, Land, Water and Planning, 2022f. *Electricity Distribution Network Resilience Review 2022 (EDNRR). Final Recommendations Report*. https://www.energy.vic.gov.au/__data/assets/pdf_file/0039/578928/Network-Resilience-Review-Final-Recommendations-Report-FINAL.pdf

Department of Environment, Land, Water and Planning, 2022g. Network Assets Program. https://www.energy.vic.gov.au/safety-and-emergencies/powerline-bushfire-safety-program/network-assets-program

Department of Environment, Land, Water and Planning, 2022h. Powerline Replacement. https://www.energy.vic.gov.au/electricity/powerline-replacement-fund

Department of Health, 2022. Public Hospitals in Victoria. https://www.health.vic.gov.au/hospitals-and-health-services/public-hospitals-in-victoria

Department of Human Services (DHS), 2009. January 2009 Heatwave in Victoria: an Assessment of Health Impacts. Melbourne: State of Victoria.

Department of Health and Human Service, 2015. New Charlton Hospital Opens. http://www3.health.vic.gov.au/news/charlton-hospital.htm

Department of Treasury and Finance (DTF), 2016. Asset Management Accountability Framework. https://www.dtf.vic.gov.au/infrastructure-investment/asset-management-accountability-framework

Department of Treasury and Finance (DTF), 2019, Investment Lifecycle and High Value High Risk Guidelines. https://www.dtf.vic.gov.au/infrastructure-investment/investment-lifecycle-and-high-value-and-high-risk-guidelines

Dowdy, Andrew, Andrew Brown, Acacia Pepler, Marcus Thatcher, Tony Rafter, Jason Evans, Hua Ye, Chun-Hsu Su, Samuel Bell, and Christian Stassen, 2021. Extreme Temperature, Wind and Bushfire Weather Projections Using a Standardised Method. Bureau Research Report No.055. Melbourne: Bureau of Meteorology.

Electricity Sector Climate Information (ESCI), 2022. Electricity Sector Climate Information. https://www.climatechangeinaustralia.gov.au/en/projects/esci/about-esci/

Emergency Management Victoria, 2021. Victoria's Critical Infrastructure All Sectors Resilience Report 2021. https://www.emv.vic.gov.au/victorias-critical-infrastructure-all-sectors-resilience-report-2021

Emergency Management Victoria, 2022. Critical Transport core capability. https://www.emv.vic.gov.au/responsibilities/semp/roles-and-responsibilities/vpf-alignment/critical-transport

Energy Safe Victoria (ESV), 2019. The Condition of Power Poles in South West Victoria. https://esv.vic.gov.au/wp-content/uploads/2019/07/SWPowerPoles_FinalReport_20190725.pdf

FEMA, 2013. Mitigation Ideas: A Resource for Reducing Risk to Natural Hazards. https://www.fema.gov/sites/default/files/2020-06/fema-mitigation-ideas_02-13-2013.pdf

Forest Fire Management Victoria, 2022. Past bushfires: A chronology of major bushfires in Victoria from 2013 back to 1851. https://www.ffm.vic.gov.au/history-and-incidents/past-bushfires

Goman, Cara, 2016. Battery/Diesel Grid-connected Microgrids: A Case Study of Future Microgrid Capabilities - Microgrid Knowledge. https://microgridknowledge.com/batterydiesel-grid-connected-microgrids-a-case-study-of-future-microgrid-capabilities/

Gray, Darren, 2012. Flood-hit hospital replaced. *The Age,* 26 April 2012. https://www.theage.com.au/national/victoria/flood-hit-hospital-replaced-20120425-1xlmb.htmlInsurance Council of Australia, 2021. Insurance Catastrophe Resilience Report: 2020-21. https://insurancecouncil.com.au/wp-content/uploads/2021/09/ICA008_CatastropheReport_6.5_FA1_online.pdf

Infrastructure Victoria, 2021. Victoria's infrastructure strategy 2021-2051. Melbourne: Infrastructure Victoria.

Intergovernmental Panel on Climate Change, 2014. Climate Change 2014: Impacts, Adaptation and Vulnerability. https://www.ipcc.ch/site/assets/uploads/2018/03/ar5_wgII_spm_en-1.pdf

Intergovernmental Panel on Climate Change, 2022. Climate Change 2022: Impacts, Adaption and Vulnerability. https://report.ipcc.ch/ar6wg2/index.html

Intergovernmental Panel on Climate Change, 2022a. Sixth Assessment Report. https://www.ipcc.ch/report/ar6/wg2/

IPWEA, 2018. Practice Note 12.1: Climate Change Impacts on the Useful Life of Infrastructure. https://www.ipwea.org/resourcesnew/bookshop/pn12-1

ISO, 2018. 31000:2018, Risk management — Guidelines, https://www.iso.org/obp/ui/#iso:std:iso:31000:ed-2:v1:en

Kuhla, Kilian, Sven Norman Willner, Christian Otto, Tobias Geiger and Anders Levermann, 2021. Ripple resonance amplifies economic welfare loss from weather extremes. *Environmental Research Letters* 16, no. 11, 114010.

Kulich, Emily, 2019. Gippsland line to reopen tomorrow, roads remain closed. https://bawbawcitizen.com.au accessed 1 April 2022

Leiba, Dr. Marion, 2011. Impact of landslides in Australia to December 2011. Geoscience Australia

Lucas, Rachael, 2022. Mallacoota housing crisis depends two years on from Black Summer fires. *ABC News*, 3 April 2022. https://www.abc.net.au/news/2022-04-03/mallacoota-housing-crisis-deepens-black-summer-fires/100955180

Michigan Department of Transportation (MDOT), 2020. 2020 Standard Specifications for Construction. https://www.michigan.gov/mdot/-/media/Project/Websites/MDOT/Field-Services/FieldServices4/2020-Standard-Specifications-Construction.pdf

Ministry for the Environment, Arotakenga huringa āhuarangi, 2019. A framework for the national climate change risk assessment for Aotearoa New Zealand. https://environment.govt.nz/assets/Publications/Files/arotakenga-huringa-ahuarangi-framework-for-national-climate-change-risk-assessment-for-aotearoa-FINAL.pdf

Nyman, Petter, Ian Rutherford, Patrick Lane, Gary Sheridan, 2019. Debris flows in southeast Australia linked to drought, wildfire and the El-Nino-Southern Oscillation, The Geological Society of America

Pan American Health Organization, 2017. Smart Hospitals Toolkit. https://iris.paho.org/handle/10665.2/34977

Parliament of Victoria, 2010. 2009 Victorian Bushfires Royal Commission - Final Report. http://royalcommission.vic.gov.au/finaldocuments/summary/PF/VBRC_Summary_PF.pdf

Paul, Margaret, and Zalika Rizmal, 2022. Dandenong Ranges residents navigate insurance, building hurdles in storm recovery. *ABC News*, 7 June 2022. https://www.abc.net.au/news/2022-06-07/dandenong-ranges-melbourne-storm-recovery-homes-power-reception/101128940

PIARC, 2019, Adaptation Methodologies and Strategies for Increasing the Resilience of Roads to Climate Change – Case Study Approach, World Road Association, Paris.

Productivity Commission, 2012. Barriers to Effective Climate Change Adaptation. Inquiry Report no. 59. https://www.pc.gov.au/inquiries/completed/climate-change-adaptation/report

Productivity Commission, 2015. Natural Disaster Funding Arrangements. Inquiry Report no. 74. https://www.pc.gov.au/inquiries/completed/disaster-funding/report

Public Health Research & Practice (PHRP), 2018. Australia unprepared for climate change impact on allergies. https://www.phrp.com.au/media/media-releases/australia-unprepared-climate-change-impact-allergies/

Quigley, Mark, 2021. Melbourne earthquake: what exactly happened, and what's the best way to stay safe from aftershocks?. *The Conversation*, 22 September 2021. https://theconversation.com/melbourne-earthquake-what-exactly-happened-and-whats-the-best-way-to-stay-safe-from-aftershocks-168467

Regional Roads Victoria, 2022. Landslip Prevention Program, https://regionalroads.vic.gov.au/map/building-works-program/landslip-prevention-program

Schwalm, Christopher R., Spencer Glendon, and Philip B. Duffy, 2020. RCP8.5 tracks cumulative CO2 emissions. *Proceedings of the National Academy of Sciences of the United States of America* 117, no. 33, 19656–19657. https://doi.org/10.1073/pnas.2007117117

Schweitzer Engineering Laboratories (SEL), 2022. Self-Healing Network Restores Power Fast. https://selinc.com/solutions/success-stories/Self-Healing-Network-Restores-Power/

State Crisis and Resilience Council (SCRC), 2020. Emergency risks in Victoria. https://www.emv.vic.gov.au/publications/state-emergency-risk-assessment-reports/emergency-risks-in-victoria-july-2020

Stewart, I.E., Baynes, F.J., Lee, I.K., 2002. The RTA Guide to Slope Risk Analysis Version 3.1

The World Road Association (PIARC), 2015. International Climate Change Adaptation Framework for Road Infrastructure. https://www.piarc.org/ressources/publications/8/23557,SpecialProject-ClimateChange-EN.pdf

Transportation Research Board, 2008. Potential Impacts of Climate Change on U.S. Transportation. https://onlinepubs.trb.org/onlinepubs/sr/sr290.pdf

Veness, Kirsten, 2012. Flood damage closes Charlton Hospital. *ABC News*, 2 March 2011. https://www.abc.net.au/news/2011-03-02/flood-damage-closes-charlton-hospital/1963140

VicRoads, 1991. VicRoads Annual Report 1990-1991, VicRoads Corporate Affairs, 1991

VicRoads, 2015. Climate Change Risk Assessment.

VicRoads, 2022. Risk Management of Road Geotechnical Hazards, Technical Note 96, April 2022

Victorian Auditor General's Office, 2018. Protecting Victoria's Coastal Assets. https://www.audit.vic.gov.au/report/protecting-victorias-coastal-assets

Victorian Healthcare Association (VHA), 2021. Stabilising the system: Supporting Victoria's public health sector to manage sustained COVID-19 demand. https://vha.org.au/wp-content/uploads/2021/12/VHA-white-paper-Stabilising-the-system.pdf

Victorian Health Building Authority, 2020. Engineering guidelines for healthcare facilities: Volume 1 – Fundamentals for sustainability in health care capital works. Health Technical Guideline HTG-2020-001

Victorian Health Building Authority, 2021. Guidelines for sustainability in health care capital works. https://www.vhba.vic.gov.au/sites/default/files/2021-10/Sustainability-guidelines-for-capital-works-VHBA-Revised-October-2021.pdf

Victorian Health Building Authority, 2022. Frankston Hospital redevelopment. https://www.vhba.vic.gov.au/health/hospitals/frankston-hospital-redevelopment

Victorian Managed Insurance Agency, 2019. Victoria's Future Climate Tool – an introduction and guidance for risk management. https://www.climatechange.vic.gov.au/__data/assets/pdf_file/0022/526216/Victorias-Future-Climate-Tool-Guidance-for-Risk-Management-ACCESSIBLE-VERSION.pdf

Victorian Managed Insurance Authority, 2021. Risk Criteria Examples. https://www.vmia.vic.gov.au/tools-and-insights/risk-management-tools

Victorian Managed Insurance Authority, 2022. Climate Change Risk Foundations. https://www.vmia.vic.gov.au/training/our-offerings/climate-change-risk-foundations

Victorian Managed Insurance Authority, 2022a. Site Risk Survey Program. https://www.vmia.vic.gov.au/risk-advisory/site-risk-survey-program

Victoria State Emergency Service, 2018. State Landslide Hazard Plan. https://www.ses.vic.gov.au/documents/8655930/8998580/State+Landslide+Hazard+Plan+-+Version+1_September+2018_final.pdf

Victorian State Government, 2019. Victoria's Future Climate Tool. https://vicfutureclimatetool.indraweb.io/

State Government of Victoria, 2021. 2019-20 Eastern Victorian bushfires. https://www.vic.gov.au/2019-20-eastern-victorian-bushfires

Wittwer, Glyn, Kuo Li and Shenglang Yang, 2021. The Economic Impacts of the 2019-20 bushfires on Victoria. *Victoria's Economic Bulletin*, vol. 5. https://www.dtf.vic.gov.au/victorias-economic-bulletin-volume-5/economic-impacts-2019-20-bushfires-victoria

Woods, Emily, 2016. Great Ocean Road: Fear for more landslides as communities suffer amid road closures. *The Age*, 21 September 2016. https://www.theage.com.au/national/victoria/great-ocean-road-fear-for-more-landslides-as-communities-suffer-amid-road-closures-20160921-grkz9r.html

Appendix A

Risk Register and Risk Assessment Framework

Disclaimer: The risk register presented in this appendix was developed for the purpose of this Infrastructure Victoria study, reflecting the study's individual scope and detail.

This risk register does not represent an official Victorian Government Risk Register.

Risk ID	Category	Risk Statement	Climate hazards					Consequence category (driving the primary consequence)	2030 Low (RCP 4.5)			2030 High (RCP8.5)			2070 Low (RCP 4.5)			2070 High (RCP8.5)			2030 risk score (combination of 2030 L and 2030 H)	Regional exposure (1-Low, 2-Med, 3-High)						Adaptive Capacity (general state level comment)	Extent of Flow on Impacts	Control effectiveness Score	Average regional exposure score	Urgency rating
			Extreme temperatures (hot days)	Bushfire	Extreme rainfall and flooding	Coastal storm event (flooding / erosion)	Storms - extreme wind / hail / lightning)		L	C	Risk	L	C	Risk	L	C	Risk	L	C	Risk		Barwon South West	Gippsland	Grampians	Greater Melbourne	Hume	Loddon Mallee	Score	Score			
34.1	Utilities – Electricity	Extreme temperatures (or heatwaves) leading to derating or sagging of lines of electricity transmission lines	Y					Infrastructure	Almost Certain	Minor	Medium	Almost Certain	Moderate	High	Almost Certain	Moderate	High	Almost Certain	Moderate	High	5	1	1	3	2	2	3	2	3	2	2.0	14.0
34.2	Utilities – Electricity	Extreme temperatures (or heatwaves) leading to buckling of electricity transmission towers	Y					Infrastructure	Unlikely	Major	Medium	Unlikely	Major	Medium	Unlikely	Major	Medium	Possible	Major	High	4	1	1	3	2	2	3	2	3	2	2.0	13.0
34.3	Utilities – Electricity	Storms, including extreme wind or lightning, leading to degradation and failure of electricity transmission lines or towers					Y	Infrastructure	Possible	Major	High	Possible	Major	High	Possible	Major	High	Likely	Major	High	6	2	2	2	2	3	2	2	3	2	2.2	15.2
34.4	Utilities – Electricity	Bushfire or grassfire leading to degradation and failure of electricity transmission lines or towers		Y				Infrastructure	Unlikely	Major	Medium	Possible	Major	High	Possible	Major	High	Likely	Major	High	5	2	3	2	2	3	2	2	3	2	2.3	14.3
34.5	Utilities – Electricity	Extreme rainfall related flooding leading to damage to transmission towers (i.e. destabilisation or impact from water-borne debris)			Y			Infrastructure	Unlikely	Moderate	Low	Unlikely	Moderate	Low	Possible	Moderate	Medium	Possible	Moderate	Medium	2	1	3	2	2	2	3	2	3	2	2.2	11.2
34.6	Utilities – Electricity	Extreme temperatures (or heatwaves) leading to degradation and sagging of electricity distribution lines	Y					Infrastructure	Possible	Minor	Low	Possible	Minor	Low	Possible	Minor	Low	Likely	Minor	Medium	2	1	1	3	2	2	3	2	3	2	2.0	11.0
34.7	Utilities – Electricity	Storms, including extreme wind or lightning, leading to failure of electricity distribution lines					Y	Infrastructure	Likely	Major	High	Likely	Major	High	Likely	Major	High	Likely	Major	High	6	2	2	2	2	3	2	2	3	2	2.2	15.2
34.8	Utilities – Electricity	Bushfire or grassfire leading to failure of electricity distribution lines		Y				Infrastructure	Possible	Moderate	Medium	Possible	Moderate	Medium	Possible	Moderate	Medium	Almost Certain	Moderate	High	4	2	3	2	2	3	2	2	3	2	2.3	13.3
34.9	Utilities – Electricity	Extreme rainfall related flooding leading to damage to distribution pole (i.e. destabilisation or impact from water-borne debris)			Y			Infrastructure	Unlikely	Moderate	Low	Unlikely	Moderate	Low	Possible	Moderate	Medium	Possible	Moderate	Medium	2	1	1	1	1	3	2	2	3	2	1.5	10.5
34.10	Utilities – Electricity	Extreme temperatures (or heatwave) leading to damage and failure of transmission substations	Y					Infrastructure	Unlikely	Minor	Low	Possible	Moderate	Medium	Possible	Moderate	Medium	Likely	Moderate	High	3	1	1	3	2	2	3	2	3	2	2.0	12.0
34.11	Utilities – Electricity	Storms, including extreme wind or lightning, leading to damage and failure of transmission substations					Y	Infrastructure	Unlikely	Minor	Low	Possible	Moderate	Medium	Possible	Moderate	Medium	Likely	Moderate	High	3	2	2	2	2	3	2	2	3	2	2.2	12.2
34.12	Utilities – Electricity	Bushfire or grassfire leading to damage and failure of transmission substations		Y				Infrastructure	Possible	Major	High	Possible	Major	High	Possible	Major	High	Possible	Major	High	6	2	3	1	1	3	2	2	3	2	2.0	15.0
34.13	Utilities – Electricity	Extreme rainfall related flooding leading to damage and failure of transmission substations			Y			Infrastructure	Unlikely	Major	Medium	Unlikely	Major	Medium	Unlikely	Major	Medium	Possible	Major	High	4	0	2	0	2	0	2	2	3	2	1.0	12.0
34.14	Utilities – Electricity	Coastal storm related flooding or erosion leading to degradation, damage and failure of transmission substations				Y		Infrastructure	Rare	Major	Low	Rare	Major	Low	Rare	Major	Low	Unlikely	Major	Medium	2	0	0	0	0	0	0	2	3	2	0.0	9.0

Risk ID	Category	Risk Statement	Climate hazards					Consequence category (driving the primary consequence)	2030 Low (RCP 4.5)			2030 High (RCP8.5)			2070 Low (RCP 4.5)			2070 High (RCP8.5)			2030 risk score (combination of 2030 L and 2030 H)	Regional exposure (1-Low, 2-Med, 3-High)						Adaptive Capacity (general state level comment)	Extent of Flow on Impacts	Control effectiveness Score	Average regional exposure score	Urgency rating
			Extreme temperatures (hot days)	Bushfire	Extreme rainfall and flooding	Coastal storm event (flooding / erosion)	Storms - extreme wind / hail / lightning)		L	C	Risk	L	C	Risk	L	C	Risk	L	C	Risk		Barwon South West	Gippsland	Grampians	Greater Melbourne	Hume	Loddon Mallee	Score	Score			
24.1	Built Environment – Buildings	Bushfire events leading to damage to hospital structures		Y				Infrastructure	Rare	Major	Low	Rare	Major	Low	Rare	Major	Low	Unlikely	Major	Medium	2	1	1	1	2	2	2	3	3	2	1.5	11.5
24.2	Built Environment – Buildings	Extreme rainfall related flooding leading to damage to hospital structures			Y			Infrastructure	Possible	Major	High	Possible	Major	High	Possible	Major	High	Likely	Major	High	6	1	0	1	3	3	3	3	3	2	1.8	15.8
24.3	Built Environment – Buildings	Coastal storm related flooding or erosion leading to damage to hospital structures				Y		Infrastructure	Rare	Major	Low	Rare	Major	Low	Rare	Major	Low	Rare	Major	Low	2	0	0	0	1	0	0	3	3	2	0.2	10.2
24.4	Built Environment – Buildings	Extreme rainfall related flooding leading to damage to hospital plant and equipment attached to structures (e.g. HVAC)			Y			Infrastructure	Possible	Major	High	Possible	Major	High	Possible	Major	High	Likely	Major	High	6	1	0	1	3	3	3	2	3	2	1.8	14.8
24.5	Built Environment – Buildings	Bushfire events leading to damage to hospital plant and equipment attached to structures (e.g. HVAC)		Y				Infrastructure	Rare	Major	Low	Rare	Major	Low	Rare	Major	Low	Unlikely	Major	Medium	2	1	1	1	2	2	2	2	3	2	1.5	10.5
24.6	Built Environment – Buildings	Extreme temperatures (or heatwaves) leading to damage to hospital plant and equipment attached to structures (e.g. HVAC)	Y					Infrastructure	Possible	Moderate	Medium	Possible	Moderate	Medium	Possible	Moderate	Medium	Likely	Moderate	High	4	1	1	3	2	2	3	2	3	2	2.0	13.0
24.7	Built Environment – Buildings	Coastal storm related flooding or erosion leading to damage to hospital plant and equipment attached to structures (e.g. HVAC)				Y		Infrastructure	Rare	Major	Low	Rare	Major	Low	Rare	Major	Low	Rare	Major	Low	2	0	0	0	1	0	0	2	3	2	0.2	9.2
24.8	Built Environment – Buildings	Extreme rainfall related flooding leading to damage to hospital multi-level carparking structures			Y			Infrastructure	Unlikely	Moderate	Low	Unlikely	Moderate	Low	Possible	Moderate	Medium	Likely	Moderate	High	2	1	0	1	3	3	3	3	3	2	1.8	11.8
24.9	Built Environment – Buildings	Bushfire events leading to damage to hospital multi-level car parking structures		Y				Infrastructure	Rare	Moderate	Insignificant	Rare	Moderate	Insignificant	Rare	Moderate	Insignificant	Possible	Moderate	Medium	0	1	1	1	2	2	2	3	3	2	1.5	9.5
24.10	Built Environment – Buildings	Coastal storm related flooding or erosion leading to damage to hospital multi-level carparking structures				Y		Infrastructure	Rare	Moderate	Insignificant	Rare	Moderate	Insignificant	Rare	Moderate	Insignificant	Rare	Moderate	Insignificant	0	0	0	0	1	0	0	3	3	2	0.2	8.2
24.11	Built Environment – Buildings	Extreme rainfall related flooding leading to obstruction of, or damage to, onsite car parks, roads and pedestrian access			Y			Infrastructure	Possible	Moderate	Medium	Possible	Moderate	Medium	Possible	Moderate	Medium	Likely	Moderate	High	4	1	0	1	3	3	3	2	2	2	1.8	11.8
24.12	Built Environment – Buildings	Coastal storm related flooding or erosion leading to obstruction of, or damage to, onsite carparks, roads or pedestrian access				Y		Infrastructure	Rare	Moderate	Insignificant	Rare	Moderate	Insignificant	Rare	Moderate	Insignificant	Rare	Moderate	Insignificant	0	0	0	0	1	0	0	3	3	2	0.2	8.2

			Climate hazards						2030 Low (RCP 4.5)			2030 High (RCP8.5)			2070 Low (RCP 4.5)			2070 High (RCP8.5)				Regional exposure (1-Low, 2-Med, 3-High)						Adaptive Capacity (general state level comment)	Extent of Flow on Impacts			
Risk ID	Category	Risk Statement	Extreme temperatures (hot days)	Bushfire	Extreme rainfall and flooding	Coastal storm event (flooding / erosion)	Storms - extreme wind / hail / lightning)	Consequence category (driving the primary consequence)	L	C	Risk	L	C	Risk	L	C	Risk	L	C	Risk	2030 risk score (combination of 2030 L and 2030 H)	Barwon South West	Gippsland	Grampians	Greater Melbourne	Hume	Loddon Mallee	Score	Score	Control effectiveness Score	Average regional exposure score	Urgency rating
8.1	Transport - Roads	Extreme temperatures (or heatwave) leading to damage to road surfaces	Y					Infrastructure	Likely	Minor	Medium	Likely	Minor	Medium	Likely	Minor	Medium	Almost Certain	Minor	Medium	4	1	1	3	2	2	3	2	3	2	2.0	13.0
8.2	Transport - Roads	Extreme rainfall related flooding leading to damage to road surfaces			Y			Infrastructure	Likely	Moderate	High	Likely	Moderate	High	Likely	Moderate	High	Almost Certain	Moderate	High	6	1	1	1	1	3	3	2	3	2	1.7	14.7
8.3	Transport - Roads	Bushfire or grassfire leading to damage to road surfaces		Y				Infrastructure	Possible	Minor	Low	Possible	Minor	Low	Possible	Minor	Low	Likely	Minor	Medium	2	3	3	2	2	3	2	2	3	2	2.5	11.5
8.4	Transport - Roads	Coastal storm related flooding or erosion leading to damage to road surfaces				Y		Infrastructure	Likely	Moderate	High	Likely	Moderate	High	Likely	Moderate	High	Almost Certain	Moderate	High	6	2	2	0	1	0	0	2	3	2	0.8	13.8
8.5	Transport - Roads	Extreme rainfall related flooding leading to damage to obstruction or closure of roads caused by inundation or landslip			Y			Infrastructure	Likely	Moderate	High	Likely	Moderate	High	Likely	Moderate	High	Almost Certain	Moderate	High	6	1	2	1	1	2	0	2	3	2	1.2	14.2
8.6	Transport - Roads	Coastal storm related flooding leading to obstruction or closure of roads caused by inundation or landslip				Y		Infrastructure	Possible	Moderate	Medium	Possible	Moderate	Medium	Possible	Moderate	Medium	Possible	Moderate	Medium	4	2	2	0	1	0	0	2	3	2	0.8	11.8
8.7	Transport - Roads	Bushfire or grassfire leading to obstruction or closure of roads caused by smoke or fire safety risk		Y				Infrastructure	Likely	Moderate	High	Likely	Moderate	High	Likely	Moderate	High	Almost Certain	Moderate	High	6	2	3	2	2	3	2	2	3	2	2.3	15.3
8.8	Transport - Roads	Storms, including extreme wind, leading to obstruction or closure of roads caused by fallen trees					Y	Infrastructure	Likely	Minor	Medium	Likely	Minor	Medium	Likely	Minor	Medium	Almost Certain	Moderate	High	4	2	3	2	2	3	2	2	3	2	2.3	13.3
8.9	Transport - Roads	Extreme rainfall leading to washout or collapse of roads			Y			Infrastructure	Possible	Major	High	Possible	Major	High	Possible	Major	High	Likely	Major	High	6	1	1	1	1	3	3	3	3	2	1.7	15.7
8.10	Transport - Roads	Coastal storm related erosion leading to collapse of roads				Y		Infrastructure	Unlikely	Major	Medium	Unlikely	Major	Medium	Unlikely	Major	Medium	Unlikely	Major	Medium	4	2	2	0	1	0	0	3	3	2	0.8	12.8

Likelihood definitions

Rating	Description
Almost certain	Has a greater than 90% chance of occurring in the assets' lifespan if the risk is not mitigated
Likely	Has a 60<90% chance of occurring in the assets' lifespan if the risk is not mitigated
Possible	Has a 30<60% chance of occurring in the assets' lifespan if the risk is not mitigated
Unlikely	Has a 10<30% chance of occurring in the assets' lifespan if the risk is not mitigated
Rare	Has a <10% chance of occurring in the assets' lifespan if the risk is not mitigated

*(Victorian Managed Insurance Authority, 2022) and (Coast Adapt, 2017)

Consequence definitions

Consequence and success criteria	Financial	Local growth and economy	Public health	Infrastructure	Governance	Community and lifestyle	Environment and sustainability
Severe	Direct loss or opportunity cost of more than $200M.	Full service or business performance disruption >1 weeks, partial disruption (months).	Severe adverse human health effects – leading to multiple events of total disability or fatalities.	Asset(s) completely damaged and/or large scale engineering works required for reinstating. Permanent damage and/or loss of infrastructure service across state. Retreat of infrastructure support and translocation of residential and commercial development.	Major policy shifts. Change to legislative requirements. Full change of management control.	The region would be seen as very unattractive, moribund and unable to support its community. Widespread and permanent loss of objects of cultural / heritage significance.	Major widespread loss of environmental amenity and progressive irrecoverable environmental damage
Major	Direct loss or opportunity cost of between $50M-$200M.	Full service or business performance disruption 2–7 days, sustained partial disruption (weeks).	Permanent physical injuries and fatalities may occur from an individual event.	Extensive structural damage to the asset(s) requiring extensive repair and significant engineering stabilisation work. Major disruption in the service of the asset – such as permanent loss of regional infrastructure services.	Notices issued by regulators for corrective actions. Changes required in management. Senior management responsibility questionable.	Severe and widespread decline in services and quality of life within the community. Widespread damage or localised permanent loss of objects of identified cultural / heritage significance.	Severe loss of environmental amenity and a danger of continuing environmental damage
Moderate	Direct loss or opportunity between $10 - $50M.	Full service or business performance disruption <2 days, consistent partial disruption (weeks).	Adverse human health effects, including mental health impacts.	Widespread (state) infrastructure damage and loss of service. Partial loss of local infrastructure. Moderate damage to some part of the structure of the asset(s) - damage recoverable by maintenance, repair and engineering stabilisation work. Moderate disruption in the service of the asset.	Investigation by regulators. Changes to management actions required.	General appreciable decline in quality of life. Localised damage to objects of cultural / heritage significance.	Isolated but significant instances of environmental damage that might be reversed with intensive efforts
Minor	Direct loss or opportunity between $2 - $10 M. Additional operational costs.	Part service or business performance disruption 1 day, limited partial disruption (days).	Slight adverse human health effects or general amenity issues. Minor mental health impacts.	Limited damage to some part of the asset(s) and require some small scale stabilisation work resulting in minor/localised service disruption. Some minor restoration work required. Need for new/modified ancillary equipment	General concern raised by regulators requiring response action.	Isolated but noticeable examples of decline in quality of life. Minor damage to objects of cultural / heritage significance.	Minor instances of environmental damage that could be reversed
Insignificant	Direct loss or opportunity cost of less than $1M.	Intermittent part service or business performance disruption, isolated partial disruption (days/hours).	No adverse human health effects or complaint.	Little disruption in service but no structural damage to the asset(s).	No changes to management required.	There would be minor areas in which the region was unable to maintain its current quality of life. Minor repairable damage to objects of cultural / heritage significance.	No environmental damage

(Victorian Managed Insurance Authority, 2022), (CSIRO, Maunsell & Phillips Fox, 2007) and (Australian Greenhouse Office 2006)

Risk matrix

		Consequence				
		Insignificant	Minor	Moderate	Major	Severe
Likelihood	Almost certain	Low	Medium	High	Extreme	Extreme
	Likely	Low	Medium	High	High	Extreme
	Possible	Insignificant	Low	Medium	High	High
	Unlikely	Insignificant	Low	Low	Medium	Medium
	Rare	Insignificant	significa	Insignificant	Low	Low

*(Victorian Managed Insurance Authority, 2022)

Rating criteria for urgency scoring

Risk Rating	Score	Comment / Description
High	3	Refer to the risk framework
Medium	2	
Low	1	
Insignificant	0	

Effectiveness of controls	Score	Comment / Description
Substantially effective	1	Existing controls address risk, are in operation and are applied consistently. Management is confident that the controls are effective and reliable. Ongoing monitoring is required.
Partially effective	2	Controls are only partially effective, require ongoing monitoring and may need to be redesigned, improved or supplemented.
Largely ineffective	3	Management cannot be confident that any degree of risk modification is being achieved. Controls need to be redesigned.

Extent of flow on impacts	Score	Comment / Description
High	3	Direct flow-on impacts to four or more sectors
Medium	2	Direct flow on impacts to up to three sectors
Low	1	Direct flow on impacts limited to two sectors

Adaptive Capacity	Score	Comment / Description
High	1	Service can be returned relatively quickly (hours), or alternative solutions such as redundancies are readily available
Medium	2	Service return within days, or some alternative redundancy solutions are available
Low	3	Return of asset service significantly delayed, no alternative redundancy solutions are readily available.

Appendix B

GIS data sources

Appendix B GIS data sources

Asset Data

Sector/Asset	Title of dataset	Author	Year published	Source of data set
Hospitals (public hospitals and healthcare facilities)	Foundation Facilities Points – Health and medical Facilities	Commonwealth of Australia (Geoscience Australia)	2021	https://data.gov.au/dataset/ds-ga-d9f88f7b-2bec-476b-b907-ef01109f8b3a/details?q=
Declared Road Network	VicRoads Declared Roads	Department of Transport	2021	https://vicroadsopendata-vicroadsmaps.opendata.arcgis.com/datasets/3f769db44819485caad22eb25197ee6d_0/explore?location=-36.482113%2C145.123575%2C7.93
Electricity Transmission and distribution lines	Overhead distribution and transmission powerlines - Vicmap Infrastructure	Department of Environment, Land, Water & Planning	2021	https://discover.data.vic.gov.au/dataset/overhead-distribution-and-transmission-powerlines-vicmap-infrastructure
Substations	Foundation Electricity Infrastructure	Commonwealth of Australia (Geoscience Australia)	2021	https://ecat.ga.gov.au/geonetwork/srv/api/records/fd46e23f-484d-4b40-8f10-9de3ed57fb1f

Hazard Data

Hazards	Title of dataset	Author	Year published	Source of data set
Extreme heat	Hot Days (max above) 35°C - RCP4.5 (medium emissions) Hot Days (max above) 35°C - RCP8.5 (high emissions) Hot Days (max above) 40°C - RCP4.5 (medium emissions) Hot Days (max above) 40°C - RCP8.5 (high emissions)	DELWP Derived from the Victorian Climate Projections 2019 (VCP19) data products.	2019	Victoria's Future Climate Tool https://vicfutureclimatetool.indraweb.io/
Extreme rainfall flooding	Vicmap Planning - Planning Scheme Overlay Polygon	Department of Environment, Land, Water & Planning	2022	https://discover.data.vic.gov.au/dataset/planning-scheme-overlay-vicmap-planning
Coastal flooding	SLR47CM_ST_2070	Department of Environment, Land, Water & Planning	2022	https://discover.data.vic.gov.au/dataset/victorian-coastal-inundation-sea-level-rise-storm-tide-2070
	SLR20CM_ST_2040	Department of Environment, Land, Water & Planning	2022	https://discover.data.vic.gov.au/dataset/victorian-coastal-inundation-sea-level-rise-storm-tide-2040
Bushfire	Vicmap Planning - Planning Scheme Overlay Polygon	Department of Environment, Land, Water & Planning	2022	https://discover.data.vic.gov.au/dataset/planning-scheme-overlay-vicmap-planning
Landslides	Geomorphology of Victoria	Department of Environment, Land, Water & Planning	2022	https://discover.data.vic.gov.au/dataset/geomorphology-of-victoria1
Coastal erosion	Victorian Coastal Hazard 2017 Erosion Vulnerability Results	Department of Environment, Water, Land and Planning	2018	Statewide Victorian Coastal Hazard 2017 Study wide data geodatabase https://corp-gis.mapshare.vic.gov.au/arcgis/rest/services/CoastKit/CHAErosion/MapServer/1

Appendix C

Considering the costs of damages from climate hazards

Appendix C Considering the costs of damages from climate hazards

Understanding the rising costs of climate hazards enables investments in adaptation to be better targeted to reduce the vulnerability of assets and minimise disruptions to the community and economy. Building the business case for resilience and a low emissions future is an important step to reducing climate hazards and associated costs, contributing to co-benefits around improved service reliability, greater business confidence, incentives for innovation and ultimately better outcomes for communities (Deloitte Access Economics, 2021).

The costs of climate hazards associated with the damage to infrastructure, increasing due to rising exposure and vulnerability to climate hazards, are generally identified as tangible and intangible costs (Bureau of Transport Economics, 2001; Productivity Commission, 2015). Section 7.1 of the report provides definitions of tangible costs (including direct and indirect costs) and intangible costs. Figure 21 provides examples of each type of cost.

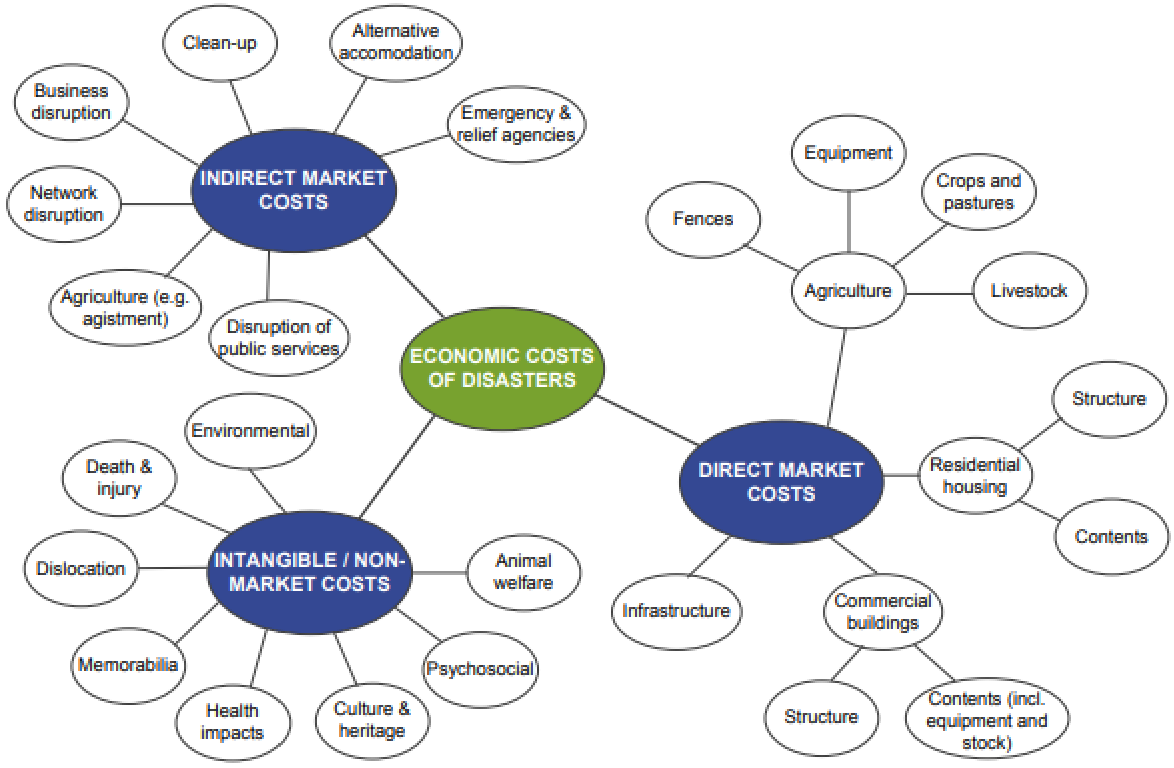

Figure 21 Total costs of climate hazards (Productivity Commission, 2015)

Each cost component should be considered separately before aggregating the costs to calculate the total cost of a disaster. Deloitte Access Economics (2017) estimated approximate multipliers to use to calculate intangible costs for Australia, based on the insurance losses. The ratio of total economic cost to insurance losses by disaster type are documented in Table 21.

Table 21 **Multiplier for total economic cost (intangible and uninsured losses) (Deloitte Access Economics, 2017)**

Disaster Type	Multiplier
Storm	4.9
Cyclone	9.5
Flood	21.7
Earthquake	7.3
Bushfire	4.9
Hail	4.9

This table shows that for each dollar paid by insurers to customers following damage from a storm, $4.90 in tangible and intangible costs is expected to have been caused by the storm. The relatively common natural disasters in Victoria, hail, bushfire and storms, all caused around $4.90 in total damage for each dollar that was claimed on insurance. Flood damage multipliers are more than four times greater than those for other common Victorian disasters, with one dollar paid out in insurance claims for each $21.70 in damage. This high multiplier is due in part to insurance policies that frequently exclude flood cover, so insurance payouts are a lower percentage of total damages.

Direct costs of climate hazards

The Insurance Council of Australia's (ICA) 2020-21 Insurance Catastrophe Resilience Report estimates the yearly economic cost of Australian disasters between 2006-16 at $18.2 billion (ICA, 2021). This is expected to more than double by 2050 to $39 billion in real terms. It is estimated that 97% of all natural disaster spending occurs after an event on recovery, clean-up and asset repair while only 3% is spent on preventative measures before an event.

According to the ICA, the Black Summer of 2019/20, including fires and subsequent storms and hail, incurred a total of $5.47 billion in insurance claims across all affected areas on the east coast of Australia. Of these, 87% were for personal property and 13% for commercial property. This represents the bulk of the $9 billion in natural disaster claims since 2018 (ICA, 2021).

The Victorian Bushfires Royal Commission's (Parliament of Victoria, 2010) conservative cost estimate of the 2009 Black Saturday bushfire was over $4 billion, which included $77 million for lost or damaged public infrastructure such as roads, schools and community infrastructure. Estimated damage costs to telecommunications (Telstra - $15m), energy (Powercor - $729,000) and water assets (Melbourne Water - $5m) provide an overview of the direct infrastructure costs of climate hazards.

Bushfire

The ICA estimated the total insurance loss attributed to the 2019/20 bushfires nationwide to be $2.3 billion with over 38,000 claims (ICA, 2021). Regional and rural Victoria, which contributes nearly 20% of state's economy and one-third of the of state's exports, was particularly hit hard by the fires.

As noted earlier, bushfires are expected to get more intense and more frequent and cover a larger area as the climate changes and summers become hotter. The Black Summer (2019-20) bushfires burned an area more than three times the total of the Black Saturday bushfire (2009). If carbon emissions remain high (reaching 3°C above pre-industrial levels just after 2060), Deloitte Access Economics estimates that by 2060, 50% of bushfire related costs will be due to climate change – at least $36.5 billion a year across Australia (Deloitte Access Economics, 2021).

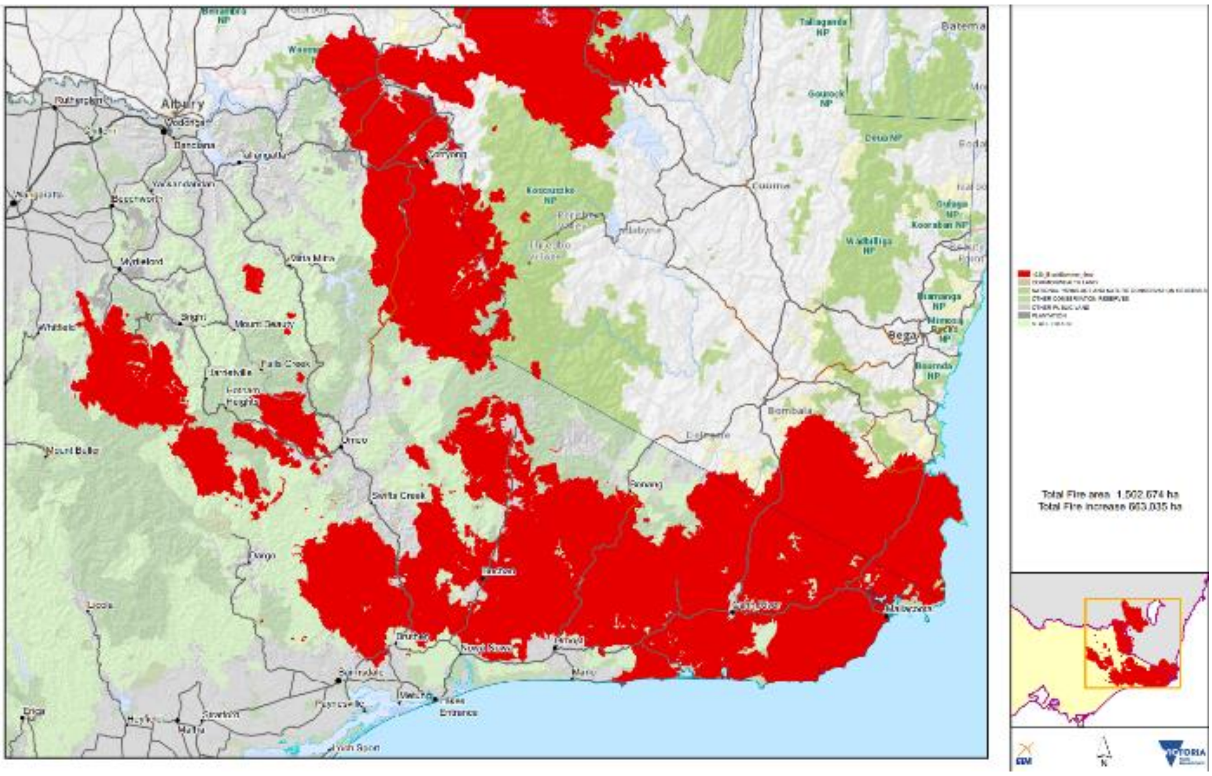

Figure 22 Area burned in Black Summer bushfires 2019-20 (Forest Fire Management Victoria, 2022)

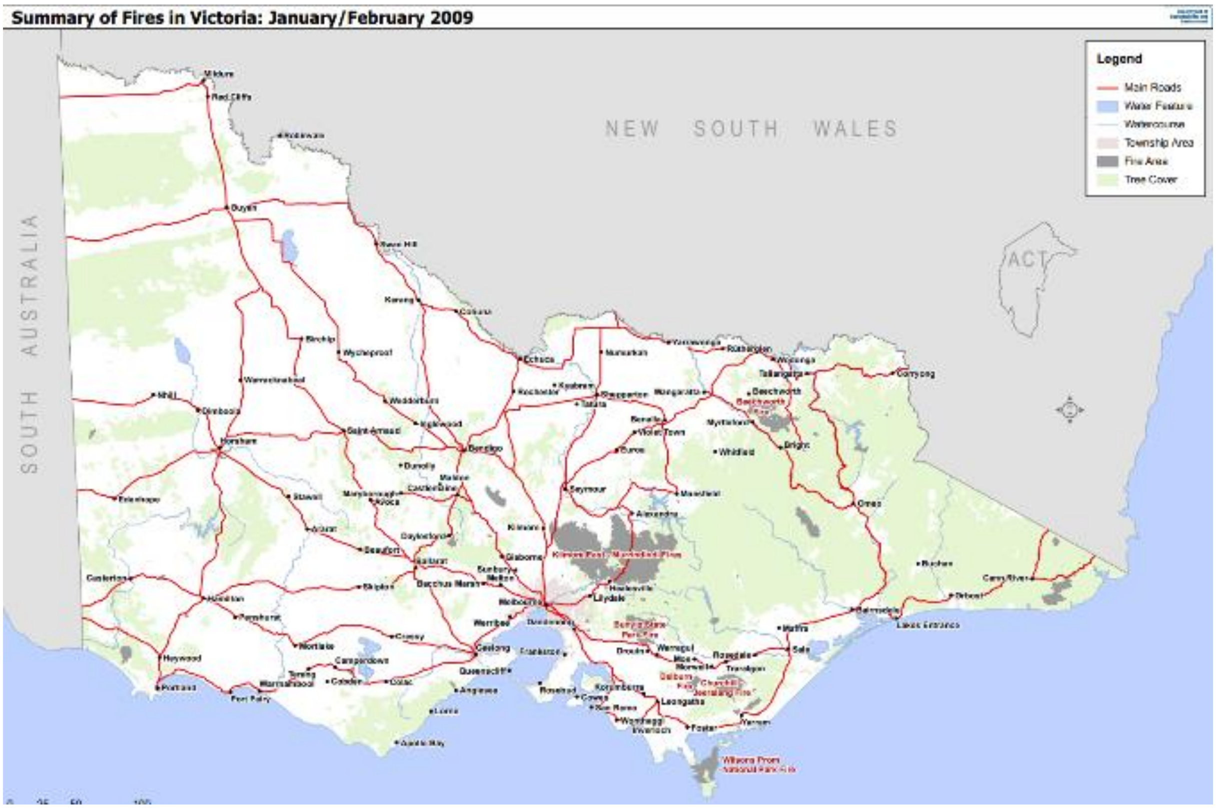

Figure 23 Area burned in Black Saturday bushfires 2009 (Forest Fire Management Victoria, 2022)

Extreme heat

DELWP estimates that on average heatwaves cost Victoria $87 million per year, expected to rise to $179 million by 2030 (DELWP, 2019). The industries that experience the most costly impacts are construction, in which outdoor work stops completely when the temperature gets too high, and agriculture, where extreme heat damages crop yields and affects the health of animals. The health sector is also at risk during very extreme events, with transport and water industries affected to a lesser extent. An extreme heatwave event in Victoria costs the construction industry $103 million in lost productivity. Heatwaves are expected to increase in frequency over time, more so if emissions continue to grow.

Floods

According to the ICA, the Victorian floods and related storm events in early June 2021 across eastern and central Victoria incurred a total of $230m in insurance claims, of which $188m were personal and $41.8m commercial (ICA, 2021). Insurance policies often exclude flood damage, hence this will be a significant underestimate of actual damage. Deloitte estimated that the actual flood damage is likely to be higher (multiplier of 21.7 for insured losses). By 2060, 31% of flood costs would be due to climate change under a high emissions scenario (Deloitte Access Economics, 2021).

The increased likelihood of severe storms may flood power stations and damage transmission lines and structures, potentially generating significant increases in the cost of power supply and infrastructure maintenance (CSIRO, 2007). Increased frequency and intensity of extreme rainfall events may cause significant flood damage to roads, rail, bridge, airport and port and especially tunnel infrastructure (CSIRO, 2007).

Buildings such as hospitals that are inundated with floodwaters can, at a minimum, be expected to be unusable for some months after flooding. Where the building is repairable, it will take some time to allow the building to dry out, replace permanently damaged items and equipment. If the floodwaters are moving at high velocity, these alone can force additional damage to buildings, knocking out walls or leaving buildings structurally unsound, in which case they may need to be rebuilt rather than repaired.

If the building is at risk of being inundated in a future flood, it may not be worthwhile to repair. Instead, managed retreat of the asset may be required (refer to call out box), for example, the building may need to be rebuilt on higher ground, away from floodwaters.

Coastal inundation

Over the long term, assets affected by coastal inundation face the greatest potential cost of all hazards. Unless collective action is taken to protect shorelines against erosion and inundation (e.g. seawalls or beach renourishment - both of which are temporary measures that can have unintended consequences), affected assets may not be rebuilt in the same location and may require managed retreat to avoid safety and environmental impacts from damaged property.

While insurance covers storm damage, as sea levels rise, areas at high risk of coastal inundation and other hazards may become uninsurable, which is where projected annual damage costs are equivalent to 1% or more of the property replacement cost. The Climate Council predicts that by 2030, 2.6% of properties in Victoria will be uninsurable (Climate Council, 2022).

Introducing Managed Retreat

The Productivity Commission (2012) defines '**managed retreat**' as involving active intervention by the government to relocate built assets and set aside undeveloped land for retreat from a high-risk area to a lower-risk area.

This can be implemented gradually over time (e.g. Byron Bay, NSW, where planning regulations require development to be relocated or removed once erosion reaches a set point) or en masse after a natural disaster (e.g. Grantham, QLD, where eligible property owners were able to voluntarily relocate following the 2010-11 floods).

Managed retreat can be facilitated through the acquisition of land by governments, either voluntarily or through compulsory measures.

With increasing frequency of climate hazards and growing interest, lessons need to be learned from interstate and overseas to understand this concept.

Indirect economic impacts and social costs

The indirect economic impacts of a climate hazard can include clean-up and disruptions to infrastructure operations and loss of income. Examples include telecommunication assets needing replacement (direct), resulting in disruption and additional costs from waiving service charges during the recovery, or reputational damage and ongoing loss of customers (indirect). Depending on the hazard event, the indirect cost may exceed the direct impact such as the 'flow on' costs from a storm's extended power cut where customers need to find temporary transport or accommodation. These flow on effects may have a significant impact on the wider economy, but some impacts are difficult to measure. This section provides commentary on examples associated with damage to infrastructure from climate change hazards.

Lower wages in areas hit by disaster

Department of Treasury and Finance (DTF) examined the impact the 2019/20 Victorian bushfires had on the affected regions, namely north east Victoria and East Gippsland, as well as the state as a whole (Wittwer et al, 2021). It predicted that the capital loss in these regions, while significant, caused far greater secondary effects throughout the state. For example, it modelled the effects of capital loss (the capital that was destroyed in the fires) as reducing real wages in the future. The higher cost of insurance compounds this effect too, reducing real consumption so that it may never fully recover. Moreover, tourism, a critical industry in Victoria, was affected even in regions not hit by the bushfires or other natural disasters, which had significant impacts on the wider Victorian economy.

Disruption of telecommunications, transport and trade that economies and society rely upon

Critical infrastructure affected by natural hazards have interdependencies, according to Emergency Management Victoria's *All Sectors Resilience Report* (EMV, 2021). 330,000 Victorians lost power in the 9 June 2021 storm and flood event. The restoration of power was delayed due to flooded and damaged roads, where extensive debris impaired the deployment of services to repair affected infrastructure, and extended power cuts prevented recovery attempts. Telecommunications infrastructure was damaged too, interrupting critical communication which could have eased the pressure on affected areas. As these events become more common and severe further into the 21st century, these interdependent vulnerabilities will become more exposed, amplifying the economic consequences by obstructing recovery efforts.

Impacts on supply chains

The ripple effects of overlapping natural hazards sometimes cause ripple effects which magnify their total impact. Ripple effects on both temporal and spatial factors may cause the aggregate output loss of each event to exceed the initial loss costs by up to 21% (Kuhla et al, 2021). This effect is found to be more significant in relatively high-income economies, like Victoria's, such that two events with aggregate output losses of $10b could cause a total loss of over $12b. This is in large part due to resulting disruptions to supply chains. As covered by DTF (Wittwer et al, 2021), destruction of capital results in less productive labour and production losses, applying pressure to manufacturers who now have to compete in a higher demand environment for their inputs. These costs are inevitably passed onto consumers, diminishing consumption. When two of these events overlap, the pressure is amplified and the effect on consumption is magnified.

Impacts on freight supply chains are also evident where roads are cut off for prolonged periods (i.e. due to flood or landslide events). This has effects on the increased price of products and services. The food supply chain is uniquely exposed to the effects of climate change and is a good case study to view the broad impacts hazard events can have on Victoria's economy. Victoria produced $17.83b of food and fibre products in 2019-20, $14.5b of which was exported (Agriculture Victoria, 2022). At every stage of the supply chain, climate change is applying increased pressure. Specifically, increased heatwaves, fires and floods will damage crops, put livestock under stress, and cause an overall reduction to the quality, quantity and value of agricultural output. In the storage and processing stage, floods, fire, heat and moisture affect grain storage, which puts it at risk, as well as amplifying the impact on the production stage, with much of it going to feed livestock. Moreover, there is an increased need for refrigeration which will further reduce the value added at this link of the supply chain. Lastly, at the consumption stage, changing demand profiles of consumers, at national, corporate and individual level, both domestically and abroad, for less carbon intensive food produce is applying additional pressure to the earlier stages of the chain.

Intangible economic impacts

Increased awareness and appreciation of, and research into, social and environmental cost factors is improving our understanding of some intangible economic impacts of climate hazards. However, they are generally still difficult to determine as they may take time to appear or are quite difficult to quantify and measure. These can include health and wellbeing (including mental health), employment, education, environment and community factors. As seen in Figure 24, social costs account for the most significant component of flood and bushfire events across Australia (Deloitte Access Economics, 2021).

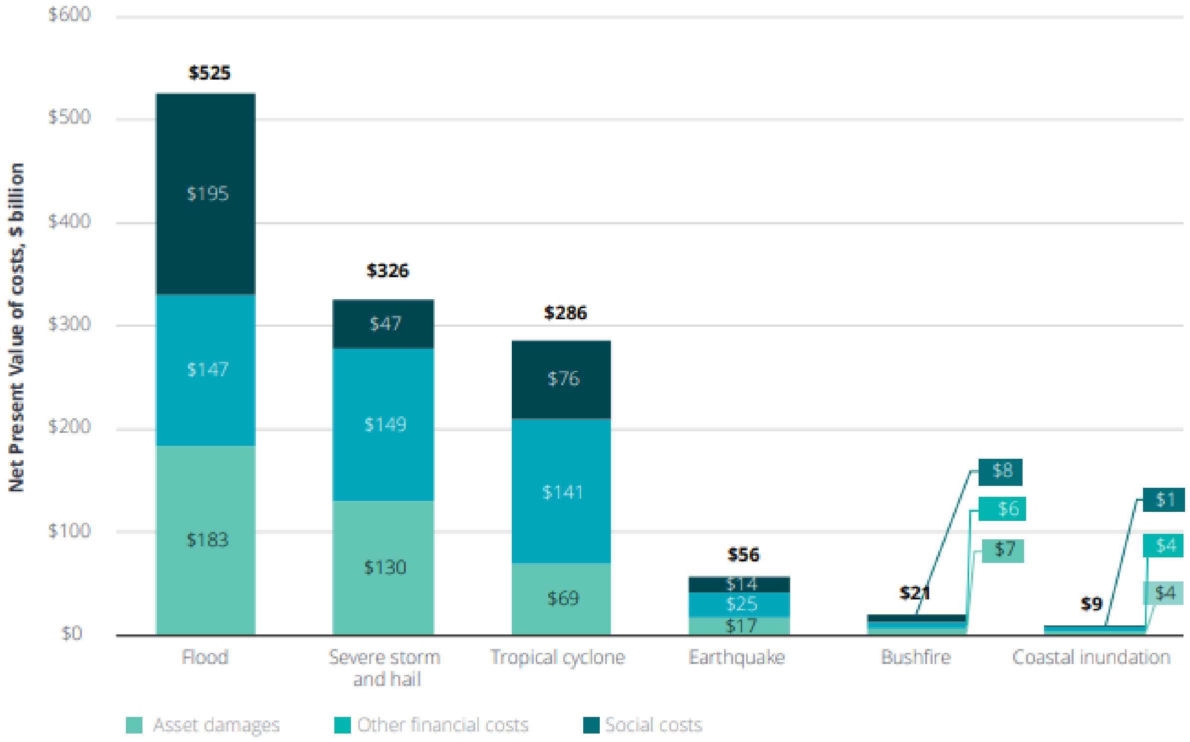

Figure 24 Value of economic costs and the components under low emissions scenario by natural disaster type, Australia, $b (Deloitte Access Economics, 2021)

Health and wellbeing

Between 1987 and 2016, natural disasters had caused 971 deaths and 4,300 injuries, with 24,000 people made homeless and more than 9 million people affected in Australia (Deloitte Access Economics, 2017). Increasing population and exposure to climate risk is placing greater pressure on state health services (Productivity Commission, 2015) which are currently under extreme pressure with the ongoing effects of the pandemic. Deloitte states that climate related impacts can lead to increases in (Deloitte Access Economics, 2021):

- Stress
- Family violence
- Mental health issues
- Alcohol consumption
- Injuries
- Fatalities
- Prevalence of chronic and non-communicable diseases

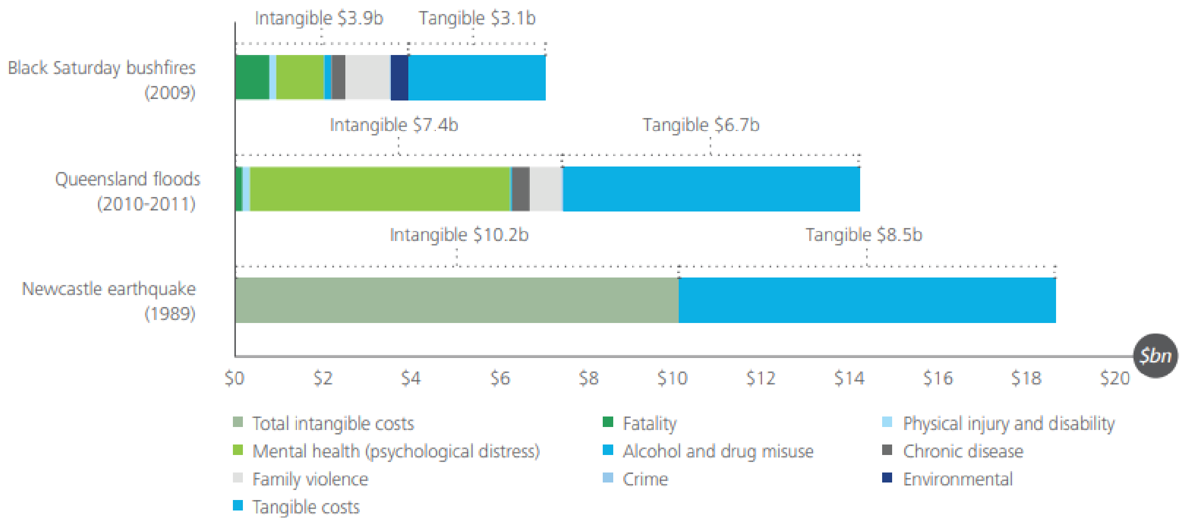

Figure 25 Total economic cost of Queensland floods, Black Saturday bushfires and Newcastle earthquake (Deloitte Access Economics, 2016)

As shown in Figure 25, lifetime mental health costs accounted for a large component of the overall economic cost of extreme weather events, with $5.9b associated with mental health in the Queensland floods and over $1b for the Black Saturday bushfires. This range of health and wellbeing factors are not as clear as direct impacts but make up a considerable disruption to business and family life, productivity loss and flow-on fiscal impacts on health services and the state budget.

Long term viability of rural towns

The cumulative impacts of climate hazards such as floods, bushfires and severe storms can have a significant financial, economic and emotional toll on areas at high risk, particularly in rural areas. A town hit by repeated disasters may face difficulty in getting insurance. Residents may be too distraught to rebuild. Businesses may lack the labour or resources to re-establish in the local area. If the population of a town declines following a disaster, it may be harder to retain services such as schools, hospitals, local police or a post office. As services decline, more residents and businesses may choose to leave. Over the longer term, towns in high climate risk areas may gradually become unviable (Productivity Commission, 2012).