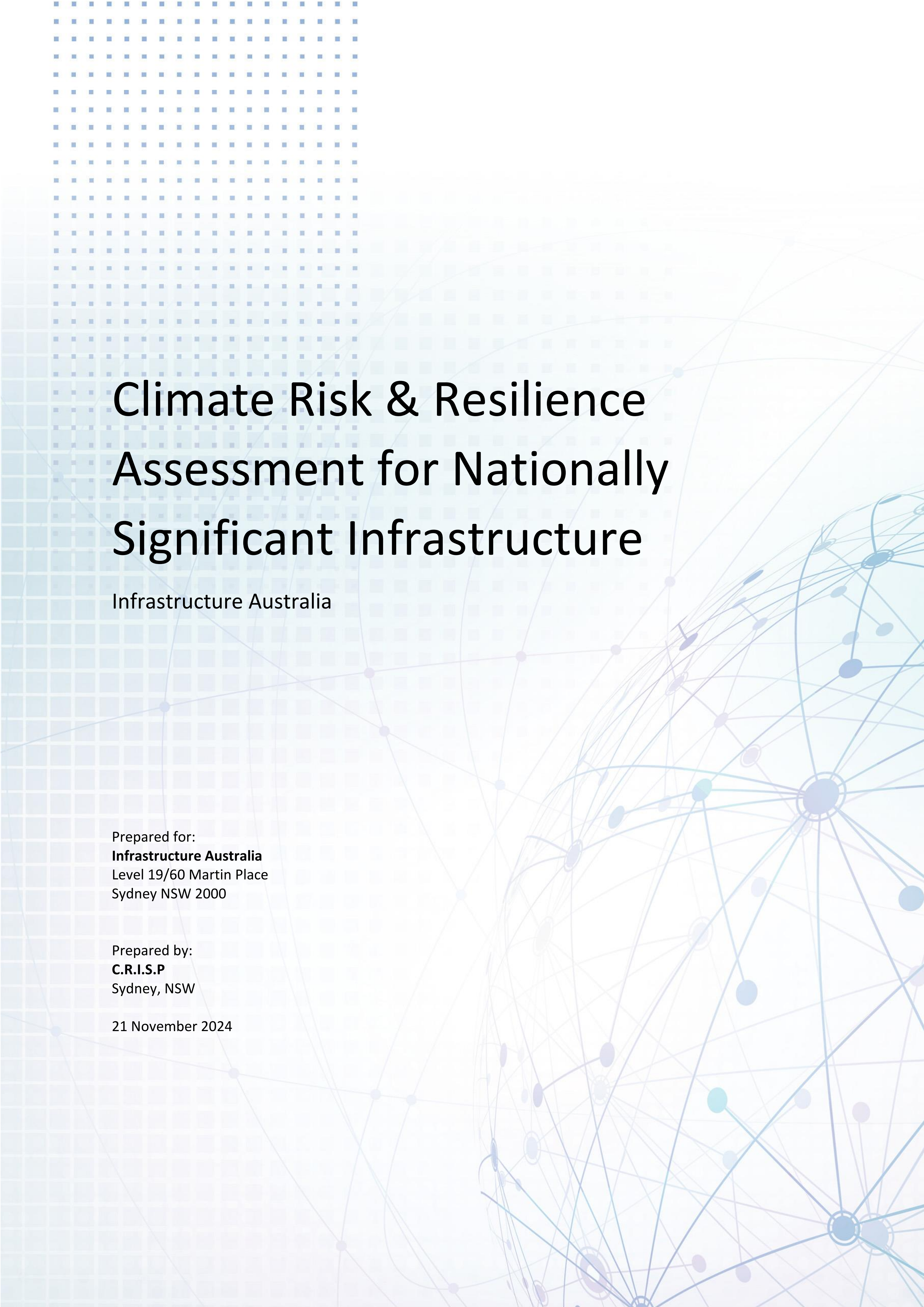
Climate Risk & Resilience Assessment for Nationally Significant Infrastructure

Infrastructure Australia



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Infrastructure Australia

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Acknowledgments

C.R.I.S.P acknowledges the Traditional Custodians throughout Australia and their continuing connection to land, water, culture and community, and pays respect to their Elders past and present.

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1.1 PROJECT BACKGROUND

1.1.1 Australia’s Investment in Climate-Resilient Infrastructure

The Australian Government has committed to investing over $110 billion in infrastructure projects over the next decade (2021–2031) as part of a broad initiative to strengthen the nation’s resilience and enhance its infrastructure capabilities (Infrastructure Australia, 2021). This investment underscores the government's dedication to building and upgrading critical infrastructure across various sectors, including transport, water, energy, and digital networks. The goal is to create infrastructure that not only supports Australia’s economic growth but also withstands the growing impacts of climate change.

Central to this initiative is the Infrastructure Priority List, which identifies over 200 nationally significant projects and initiatives worth more than $60 billion. These projects are strategically selected to address Australia’s most pressing infrastructure needs, with approximately 20% of new projects specifically designed to mitigate climate risks (Infrastructure Australia, 2021). These include flood control systems, bushfire-resistant structures, and upgrades to transport and energy networks to improve resilience to extreme weather events. The Priority List ensures that investment is directed toward projects that will have a lasting impact on Australia's sustainability and resilience.

In line with its focus on climate adaptation, the government has allocated over $15 billion specifically for climate resilience initiatives. This funding is intended to support infrastructure projects that mitigate and adapt to the increasing frequency and severity of climate-related events, such as bushfires, droughts, and floods. These projects not only protect vital infrastructure but also help to safeguard communities and reduce the long-term costs associated with climate impacts (Australian Government, 2023).

A critical target of this investment is the stabilisation of disaster recovery costs at 2019 levels. As climate-related events are expected to increase in both frequency and intensity, this goal reflects the government's proactive approach to managing future expenses by enhancing resilience now (Productivity Commission, 2022). Through strategic investments in climate-resilient infrastructure, Australia aims to minimise the financial burden of disaster recovery on future generations.

The economic benefits of investing in climate resilience are substantial. It is estimated that early investments in climate-resilient infrastructure could result in $1.8 trillion in savings by 2070 (CSIRO, 2023). These savings represent avoided costs associated with disaster recovery and repair, highlighting the long-term value of resilience investments for the Australian economy. By prioritising climate resilience now, Australia is working to ensure a more stable and sustainable future, reducing both the human and financial toll of climate-related events on communities and infrastructure systems.

1.2 REQUIREMENTS AND OBJECTIVES

The Australian Government approaches climate resilience of infrastructure assets through assessing systemic risks, interdependencies and vulnerabilities. Key to the success of this is adopting nationally consistent approach, collaborative planning, and data-driven decision making.

1.2.1 A Nationally Consistent Approach

A nationally consistent approach to climate resilience is critical to creating uniform standards for understanding and quantifying climate risks across Australia’s infrastructure. This approach involves developing standardised risk assessment frameworks that consider interconnections between various infrastructure systems, enabling asset owners and governments to better manage vulnerabilities.

1.2.2 Collaborative Planning

Effective infrastructure planning and decision-making are key requirements to achieving climate resilience. This requires diverse and inclusive collaboration across all sectors, including federal, state, and local governments, industries, communities, and asset owners. Such collaborative planning ensures that a wide range of perspectives is incorporated into resilience strategies, addressing unique vulnerabilities faced by different regions and sectors.

Improved decision-making frameworks are needed to facilitate this collaboration, focusing on enhanced transparency and accountability in infrastructure projects.

1.2.3 Data Quality

Data quality is another foundational element for Australia's climate resilience efforts. Reliable and comparable, high-quality data enables accurate climate risk assessments, which are essential for effective planning. Access to precise, up-to-date data on weather patterns, temperature changes, and other climate variables supports risk quantification and informs infrastructure designs that can withstand projected climate impacts.

2 Key Climate Risks to Infrastructure in Australia

Climate risk is defined as the probability of climate events occurring alongside an estimation of the potential outcomes. These risks are typically quantified as a combination of an event's consequences and the likelihood of occurrence. For infrastructure in Australia, these risks are particularly significant due to the country's diverse and challenging environmental conditions (Australian Government, 2023).

Climate risks are categorised into acute and chronic risks:

- Acute risks refer to sudden, extreme weather events that can cause immediate and substantial damage to infrastructure. These include heatwaves, storms, bushfires, cyclones and floods.
- Chronic risks involve long-term, gradual climate changes, and can slowly degrade infrastructure over time, resulting in higher maintenance costs and potentially reducing asset longevity. These include rising temperatures, sea-level rise, and altered precipitation pattern

Below is an overview of key climate risks impacting infrastructure in Australia.

2.1 EXTREME WEATHER EVENTS

Australia is experiencing an increase in the frequency and intensity of storms and cyclones, particularly affecting northern regions. Severe thunderstorms and hail events are also becoming more common, posing direct risks to infrastructure. Roads, buildings, energy systems, and other critical assets are vulnerable to damage from intense winds, flooding, and hail, which disrupts services and requires costly repairs (Infrastructure Australia, 2021). The unpredictability of such extreme weather events increases the difficulty in maintaining resilient infrastructure across affected areas.

2.2 HEATWAVES AND RISING TEMPERATURES

Heatwaves and rising temperatures are placing significant stress on infrastructure across Australia, especially in urban areas. Roads, rail systems, and buildings face increased degradation as extreme heat accelerates material wear, leading to higher maintenance needs. The energy sector is also impacted by surging demand during heatwaves, as more people rely on air conditioning, which can overload power grids and lead to blackouts (CSIRO, 2023). Infrastructure systems are thus under increased pressure to handle both structural impacts and operational demands during prolonged periods of high temperatures.

2.3 SEA-LEVEL RISE AND COASTAL EROSION

Sea-level rise and coastal erosion present a critical risk to Australia's coastal infrastructure, including ports, coastal roads, and low-lying residential areas. As sea levels continue to rise, there is a direct threat to the integrity and operation of these assets, which are increasingly vulnerable to storm surges and tidal flooding. Additionally, critical transport networks along the coast face inundation, potentially disrupting supply chains and limiting access to essential services (Australian Building Codes Board, 2022).

2.4 INCREASED BUSHFIRE RISK

The risk of bushfires has intensified with climate change, endangering energy and telecommunications networks that are essential for community functioning and emergency response. Bushfires can severely damage energy transmission lines and disrupt telecommunications towers, leading to widespread power outages and communication losses. Water supply systems can also be compromised as bushfires increase sediment loads and contaminate reservoirs (Infrastructure Australia, 2021).

2.5 DROUGHT AND REDUCED RAINFALL

Australia faces an increasing risk of drought and reduced rainfall, which puts pressure on water infrastructure and impacts hydroelectric power generation (Australian Government, 2023). Drought conditions decrease water availability, affecting reservoirs and the agricultural sector, which relies heavily on irrigation. This also impacts energy generation, as lower water levels reduce the operational capacity of hydroelectric plants.

2.6 FLOODING AND INLAND RIVER SYSTEM OVERFLOWS

Flooding, both in urban areas and along inland river systems, is becoming more frequent and severe, leading to overloaded drainage systems and damaged infrastructure (CSIRO, 2023). Urban flooding challenges stormwater infrastructure in cities, causing property damage, disrupting transport, and increasing public health risks. In rural areas, overflowing rivers can damage agricultural infrastructure, leading to crop loss and economic setbacks.

2.7 TELECOMMUNICATIONS AND DIGITAL INFRASTRUCTURE RISKS

Telecommunications infrastructure faces increased climate risks, particularly during natural disasters like storms, floods, and bushfires, which can disrupt network operations and sever communication lines. Loss of connectivity is a significant challenge during emergencies, as it impedes coordination between communities and emergency services.

2.8 ECONOMIC AND SOCIAL RISKS

The economic costs of infrastructure failure due to extreme climate events include both direct and indirect impacts. Direct costs arise from infrastructure damage and repair, while indirect costs relate to service disruptions, lost productivity, and decreased quality of life for affected communities. The cumulative impact of climate risks on infrastructure can lead to long-term economic instability if resilience measures aren’t prioritised.

3 Framework for Climate Risk Assessment

3.1 HAZARD, EXPOSURE AND VULNERABILITY (HEV) CLIMATE RISK ASSESSMENT FRAMEWORK

The HEV model is a widely recognised approach for quantifying climate risk to infrastructure assets. This model has been used in several disaster and vulnerability scenario modelling case studies within Australia. Examples include Geoscience Australia's National Hazard Impact and Risk Service which forecasts the impacts of tropical cyclones, earthquakes and severe winds on residential buildings and infrastructure in Australia and to identify regional high threat areas to allow for better-informed natural hazard mitigation and risk reduction strategies. Of particular interest was the case study produced by the department titled 'Assessing Queensland's vulnerability to Severe Wind and Tropical Cyclones' by Geoscience Australia 2021. This model breaks down risk assessment into three key components:

- Hazard: This involves assessing the frequency and intensity of climate events, such as storms, floods, and heatwaves, using data from climate models and historical weather patterns. Understanding hazard levels enables planners to gauge the likelihood and potential severity of various climate threats.
- Exposure: This measures how much an asset is exposed to specific climate hazards, taking into account geographic location, physical setting (e.g., coastal or urban), and operational conditions. High exposure levels indicate that an asset is more likely to encounter a specific climate event, increasing its overall risk.
- Vulnerability: Vulnerability reflects the sensitivity of an asset to climate hazards, determined by factors such as design standards, construction materials, maintenance practices, and operational processes. Older or inadequately designed infrastructure tends to be more vulnerable, which heightens the risk of damage during climate events.

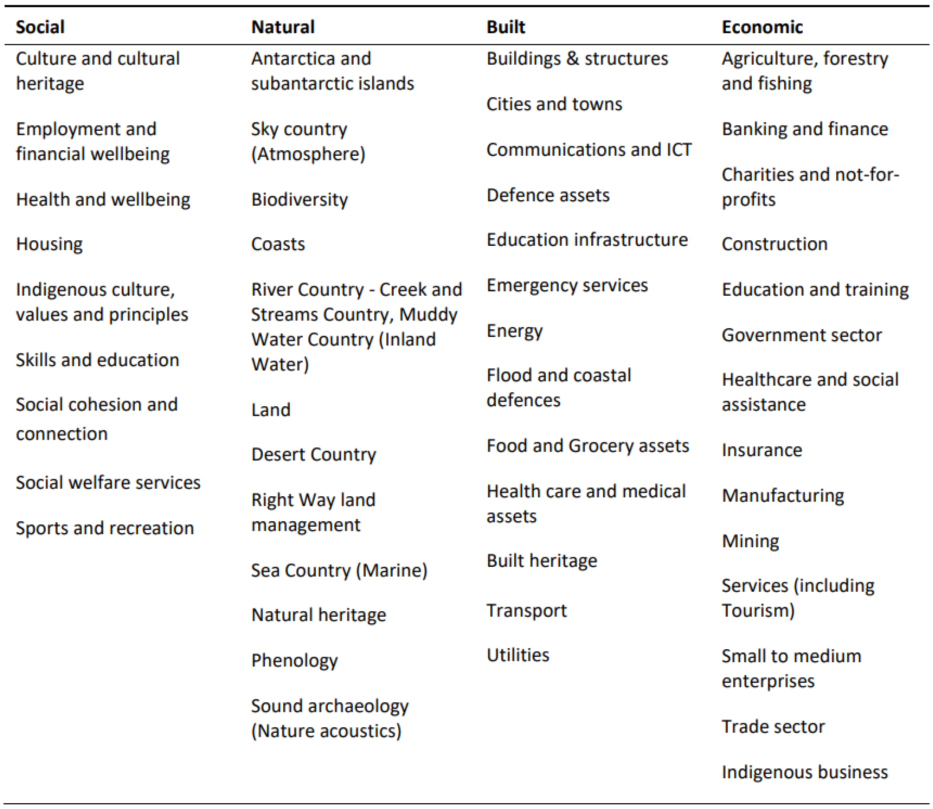
The combination of these three factors allows for a quantifiable measure of climate risk to infrastructure, calculated as Risk = Hazard x Exposure x Vulnerability (ISCA, 2023). This risk score provides a basis for identifying potential damage and service disruption, guiding targeted adaptation efforts.

This model has been adopted for the purposes of the report as the fundamental methodology and framework of this assessment. Variation of the HEV risk assessment framework to suit various quantitative risk interaction models will be discussed in Section 5.3. Scoring system accompanied with a modified HEV risk assessment framework will be discussed in Section 5.4. Available Australia datasets from relevant stakeholders including Geoscience Australia have been reviewed with findings summarised in Section 4. Due to the gaps and limitations of the existing Australia datasets, a case study has been carried out based on a published literature to evaluate the proposed scoring methodology in Section 6.6.

3.2 CRITICAL KEY INFRASTRUCTURE SECTORS

A key component of the Risk Assessment methodology is elements of risk – things of value to Australians that could be impacted, negatively or positively, by climate change. They can be highly subjective and values-based. Additionally, they may be impacted by hazards, and/ or play a role in the resilience of other assets to hazards ((Australian Government Department of Climate Change, Energy, the Environment and Water, 2023).

National Climate Risk Assessment Methodology (Australian Government Department of Climate Change, Energy, the Environment and Water, 2023) identified the elements at risk for Social, Built, Economic and Natural domains are in below figure.



Social	Natural	Built	Economic
Culture and cultural heritage	Antarctica and subantarctic islands	Buildings & structures	Agriculture, forestry and fishing
Employment and financial wellbeing	Sky country (Atmosphere)	Cities and towns	Banking and finance
Health and wellbeing	Biodiversity	Communications and ICT	Charities and not-for-profits
Housing	Coasts	Defence assets	Construction
Indigenous culture, values and principles	River Country - Creek and Streams Country, Muddy Water Country (Inland Water)	Education infrastructure	Education and training
Skills and education	Land	Emergency services	Government sector
Social cohesion and connection	Desert Country	Energy	Healthcare and social assistance
Social welfare services	Right Way land management	Flood and coastal defences	Insurance
Sports and recreation	Sea Country (Marine)	Food and Grocery assets	Manufacturing
	Natural heritage	Health care and medical assets	Mining
	Phenology	Built heritage	Services (including Tourism)
	Sound archaeology (Nature acoustics)	Transport	Small to medium enterprises
		Utilities	Trade sector
			Indigenous business

Figure 1 Identified elements at risk

Infrastructure assets and network falls under Built domain. Built domain is defined as human-made surroundings, structures, and any supporting infrastructure created using material, spatial, and human resources to facilitate life, health, work and play Australian Government Department of Climate Change, Energy, the Environment and Water, 2023).

Further screening of the critical key infrastructure sectors has been carried out by federal government and by each state. Queensland is one of the states leading the climate risk assessment in infrastructure assets and networks.

As identified in the Queensland Critical Infrastructure Disaster Risk Assessment (Queensland Fire and Emergency Services, 2024) the group has looked to adopt the following four key critical infrastructure sectors:

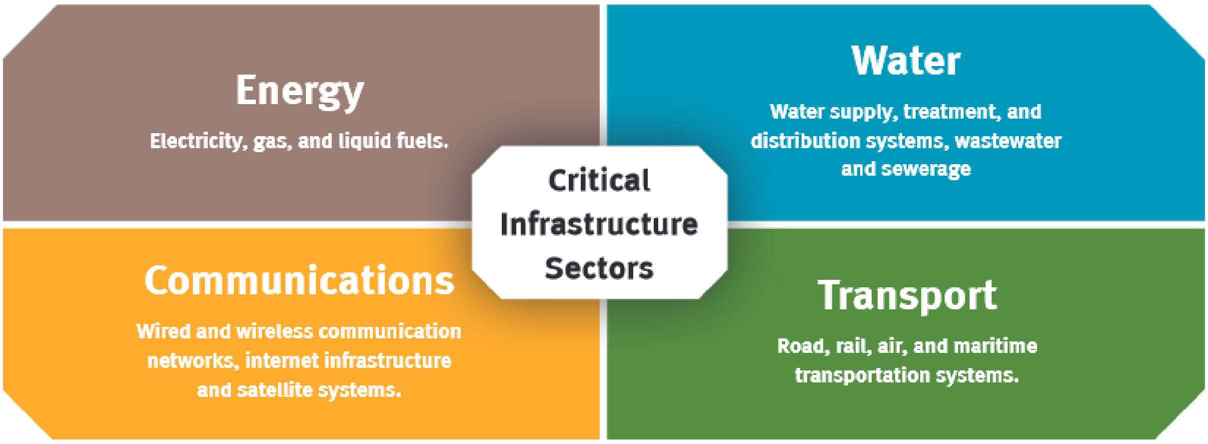


Figure 2 Four critical infrastructure sectors identified for assessment as part of the Queensland Critical Infrastructure Disaster Risk Assessment 2024

These sectors were identified as being the most critical infrastructure for the functioning of a community, with other critical infrastructure also dependent on these four sectors.

Review of global climate risk assessment in infrastructure domain indicates Energy, Water, Communications and Transport are the primary focus.

For the purposes of this reporting and assessment, we focus on the leading application of the HEV risk assessment framework in the Transport infrastructure sector inspired by Queensland Department of Transport and Main Roads (TMR). We expect similar approach has been developed by each state and can be agreed upon to document datasets for prioritise climate hazards, exposure and vulnerability by states. A similar approach with minor differences in taxonomy will be discussed in Section 3.5 which transform the risk assessment to consider multiple infrastructure sectors at a national level.

3.3 TMR RISK ASSESSMENT FRAMEWORK

The Risk assessment framework developed by the Department of Transport and Main Roads is a framework already developed and in-use by a leading state transport authority within Australia, utilises a national and local evidence based approach in assessing risk and has significant parallels to the nationally significant climate risks identified as part of the National Climate Risk Assessment – First Pass Assessment Report (Australian Government Department of Climate Change, Energy, the Environment and Water, 2024), refer to Table 1.

The State of Queensland Department of Transport and Main Roads has produced engineering policy and guidelines for Climate Change and Natural Hazards Risk Assessment of new and existing infrastructure assets throughout the state. This framework was developed in accordance with Australian Standard AS 5334 *Climate change adaptation for settlements and infrastructure – A risk-based approach* and its associated Risk Management Framework. The framework considers factors such as the asset design life, stakeholder inputs through a desktop risk assessment based on a review of project documentation, hazard mapping and in consideration of future climate projections. These hazards and risks are collated to be evaluated through a multidisciplinary workshop or process with representatives from the asset owner, Department of Transport and Main Roads and various specialist consultants.

The process generally includes the following steps:

- **Validation of preliminary climate change and natural hazards risks informed by a desktop assessment**
  - Identification of key climate variables (temperature, rainfall, extreme events), natural hazards and the climate variability that differentiates regional climate zones.
- **Identification of new climate change and natural hazards risks**
  - Development of potential climate change scenarios, based on the latest climate science, which describe how each variable may change over the design life of the proposed works.
  - Identification of broad climate and natural hazard risks that may impact on the proposed works
- **Allocation of preliminary risk ratings – Utilising a likelihood and consequence risk evaluation**
  - Completion of a climate and natural hazard risk assessment as part of the overall risk assessment process, with risk ratings evaluated using AS 5334 Risk Management Framework, including likelihood and consequence criteria
  - Consequence ratings are to be selected based on the highest rating for the risk categories. This risk assessment should also identify the likely timing of particular risks and opportunities
- **Identification of potential treatment options (as required)**
  - Identification of measures to mitigate, adapt or build resilience to the identified high and extreme climate and natural hazard risks

- Assessment of residual risks to the project, considering adaptation measures to treat all high and extreme risks

3.3.1 Use of Climate Projections and Timeframes

Climate risk assessments rely heavily on both historical data and future climate projections, which are primarily sourced from the Bureau of Meteorology (BOM) and the CSIRO. These organisations provide comprehensive datasets and projections across multiple climate scenarios, including changes in temperature, rainfall, sea-level rise, and extreme weather events. This data is essential for understanding how various climate risks may evolve, impacting infrastructure assets differently depending on the geographical and operational context (CSIRO, 2023).

Time horizons are a critical aspect of these assessments, with typical risk evaluations considering short-term (2030), medium-term (2050), and long-term (2100) projections. These intervals allow for a staged understanding of climate impacts, aiding in planning and adaptation across different stages of an asset's lifecycle. For modelling purposes, Representative Concentration Pathways (RCPs) are commonly used, particularly RCP 4.5 for moderate emissions and RCP 8.5 for high-emission scenarios. These scenarios enable researchers and asset managers to simulate climate impacts under various global emission levels, allowing them to anticipate the potential severity of climate-related risks and design infrastructure accordingly.

However, the impacts of climate change will be different across the different timeframes. In fact, the impacts could lead to considerably different trends (positive change vs negative impact) that may need to be considered for the asset.

If the forecast useful life for an asset is 20 years, at least two time-horizons must be selected with at least one being the final expected operating year of the asset or beyond. For example, if the asset life is 70 years, then 2050 and 2090 may be selected for an assessment.

3.3.2 Climate and Hazard Identification (Hazard)

The identification of current and future hazards, under the influence of climate change to be considered under the framework should be based on leading agency research and information. However, the minimum climate and natural hazards that should be considered as part of the risk assessment are as follows:

Primary Variables (stresses)	Secondary Variables (shocks)
Air Temperatures	Precipitation
Humidity	Wind and Hail
Sea Surface Temperature	Bushfire
Precipitation	Coastal Inundation
Sea Level Rise	Cyclones/Storms
Wind and Hail	Flooding
Coastal Inundation	Heatwave
Drought	Landslides
Frost	Tsunami

Table 1 Minimum climate and natural hazards to be considered as part of the risk assessment

3.3.3 Hazard Likelihood, Consequence and Risk Rating (Vulnerability)

The framework adopts the AS 5334 *Climate change adaptation for settlements and infrastructure – A risk-based approach* matrices noted below:

Likelihood	Description	Recurrent or Event Risks	Long Term Risks
Almost Certain	Could occur several times per year	Has happened several times in the past year and in each of the previous 5 years or Could occur several times per year	Has a greater than 90% chance of occurring in the identified time period if the risk is not mitigated
Likely	May arise about once per year	Has happened at least once in the past year and in each of the previous 5 years or May arise about once per year	Has a 60-90% chance of occurring in the identified time period if the risk is not mitigated
Moderate	Maybe a couple of times in a generation	Has happened during the past 5 years but not in every year or May arise once in 25 years	Has a 40-60% chance of occurring in the identified time period if the risk is not mitigated
Unlikely	Maybe once in a generation	May have occurred once in the last 5 years or May arise once in 25 to 50 years	Has a 10-30% chance of occurring in the future if the risk is not mitigated
Very Unlikely (Rare)	Maybe once in a lifetime	Has not occurred in the past 5 years or Unlikely during the next 50 years	May occur in exceptional circumstances, i.e., less than 10% chance of occurring in the identified time period if the risk is not mitigated

Table 2 Likelihood Criteria (AS5334:2013 Climate change adaptation for settlements and infrastructure)

Consequence	Adaptive Capacity	Infrastructure, Service	Social / Cultural	Governance	Financial	Environmental	Economy
Insignificant	No Change	No infrastructure damage, no change to service	No adverse human health effects	No changes to management required	Little financial loss or increase in operating expenses	No adverse effects on the natural environment	No effects on the broader economy
Minor	Minor decrease to the adaptive capacity of the asset. Capacity easily restored.	Localised infrastructure service disruption. No permanent damage. Some minor restoration work required. Early renewal of infrastructure by 10-20%. Need for new/modified ancilary equipment	Short-term disruption to employees, customers or neighbours. Slight adverse human health effects or general amenity issues	General concern raised by regulators, requiring response action	Additional operational costs. Financial loss small, <10%	Minimal effects on the natural environment	Minor effect on the broader economy due to disruption of service provided by the asset
Moderate	Some change in adaptive capacity. Renewal or repair may need new design to improve adaptive capacity.	Limited infrastructure damage and loss of service. Damage recoverable by maintenace and minor repair. Early renewal of infrastructure by 20-50%	Frequent disruptions to employees, customers or neighbours. Adverse human health effects	Investigation by regulators. Changes to management actions required.	Moderate financial loss 10-50%	Some damage to the environment, including local ecosystems. Some remedial action may be required	High impact on the local economy, with some effect on the wider economy
Major	Major loss in adaptive capacity. Renewal or repair would need new design to improve adaptive capacity	Extensive infrastructure damage requiring major repair. Major loss of infrastructure service. Early renewal of infrastructure by 50-90%	Permanent physical injuries and fatalities may occur. Severe disruptions to employees, customers or neighbours	Notices issued by regulators for corrective actions. Changes required in management. Senior management. Responsibility questionable	Major financial loss 50-90%	Significant effect on the environment and local ecosystems. Remedial action likely to be required	Serious effect on the local economy spreading to the wider economy
Catastropic	Capacity destroyed, redesign required when repairing or renewing asset	Significant permanent damage and/or complete loss of the infrastructure	Severe adverse human health effects, leading to multiple events of total disability or fatalities.	Major policy shifts. Change to legislative requirements	Extreme financial loss >90%	Very significant loss to the environment. May include loss of species, habitats or ecosystems.	Major effect on the local, regional and state economies

Consequence	Adaptive Capacity	Infrastructure, Service	Social / Cultural	Governance	Financial	Environmental	Economy
		and the infrastructure service. Loss of infrastructure support and translocation of service to other sites. Early renewal of infrastructure by 90%	Total disruption to employees, customers or neighbours. Emergency response at a major level			Extensive remedial action essential to prevent further degredation. Restoration likely to be required	

Table 3 Consequence Criteria (AS5334:2013 Climate change adaptation for settlements and infrastructure)

Likelihood	Insignificant	Minor	Moderate	Major	Catastrophic
Almost Certain	Low	Medium	High	Extreme	Extreme
Likely	Low	Medium	Medium	High	Extreme
Moderate	Low	Low	Medium	High	Extreme
Unlikely	Low	Low	Medium	Medium	High
Very Unlikely (Rare)	Low	Low	Low	Medium	Medium

Table 4 Risk Rating Matrix (AS5334:2013 Climate change adaptation for settlements and infrastructure)

3.4 OTHER CONSIDERATIONS FOR DEVELOPING A HIGH-LEVEL AUSTRALIA NATIONAL RISK ASSESSMENT FRAMEWORK

At a national level, the HEV risk assessment framework can be tailored to consider the following aspects.

3.4.1 Residual Risk Classification

Australia's climate risk framework uses a classification system to categorise infrastructure assets based on their risk level. This system includes four classes (Infrastructure Australia, 2021).:

- Low Risk (Class 1): Infrastructure with minimal or no immediate impact from climate risks, typically requiring only standard maintenance and regular ongoing monitoring.
- Moderate Risk (Class 2): Assets that face moderate climate risks and may require enhanced design standards or moderate adaptation measures to ensure continued functionality.
- High Risk (Class 3): Infrastructure with significant exposure to climate risks, necessitating immediate adaptation efforts, such as major design alterations or relocations, to mitigate vulnerability.
- Critical Risk (Class 4): Assets at severe risk of failure due to climate impacts. For these high-stakes assets, extensive redesign, relocation, or even abandonment may be necessary to protect safety and investment.

3.4.2 Residual Risk Prioritisation

The Climate Risk Prioritisation Matrix is used to evaluate and rank risks based on their likelihood and potential impact. This enables asset managers and policymakers to allocate resources effectively by assessing risks across economic, social, and operational dimensions. The matrix prioritises risks as follows:

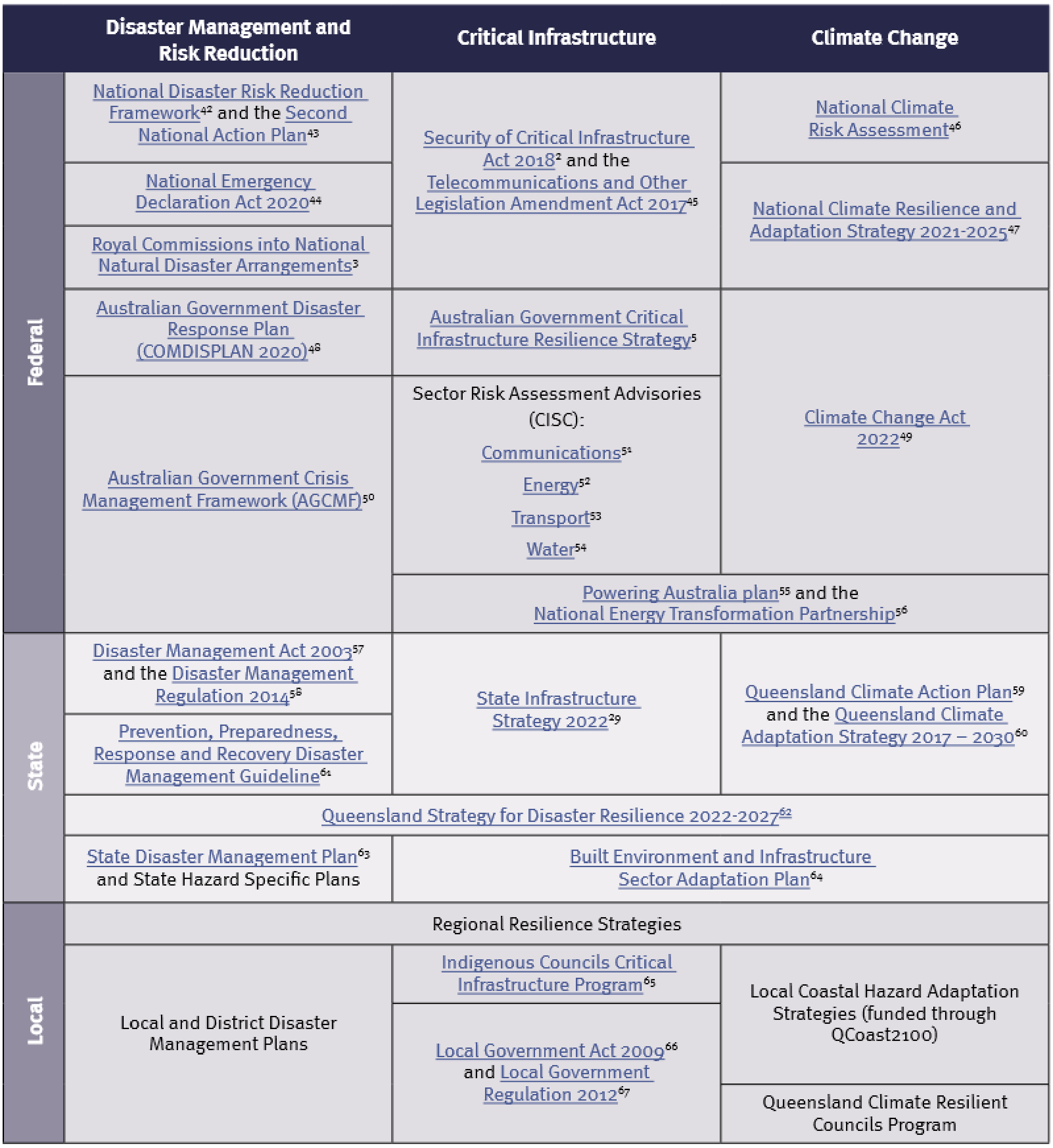
- High Probability, High Impact: These are critical risks that demand immediate attention and mitigation measures to protect infrastructure and maintain service continuity.
- Low Probability, High Impact: These risks, while less likely to occur, can have severe consequences and therefore require contingency planning to ensure preparedness.
- Low Probability, Low Impact: Risks that are less likely and less severe may not need immediate action but should be monitored over time in case conditions change.

By applying this prioritisation matrix, Australia's climate resilience framework provides a structured approach to addressing climate risks systematically, ensuring that resources are allocated efficiently, and critical infrastructure is safeguarded against both current and future climate challenges.

3.4.3 Management of Residual Risk

The application of a risk management framework will allow the categorisation and accurate identification of risk prioritisation via an analysis utilising the HEV model. This will assist government and leading authorities to tailor their planning approaches to build appropriate mitigation and resilience strategies aimed to reduce residual risk across all levels. The application of this approach can lead to enhanced support arrangements between disaster groups and supporting agencies to managing risks.

Our framework currently considers the national approach to managing the resilience of infrastructure against climate change further work has been undertaken as part of the Queensland Emergency Risk Management Framework to establish shared risk management and passage of residual risk across Local, District and State levels. This will need to be reviewed with all federal and state legislation to ensure critical infrastructure resilience to climate change.



<table>
<tr><th></th><th>Disaster Management and Risk Reduction</th><th>Critical Infrastructure</th><th>Climate Change</th></tr>
<tr><td rowspan="6">Federal</td><td>National Disaster Risk Reduction Framework[42] and the Second National Action Plan[43]</td><td rowspan="3">Security of Critical Infrastructure Act 2018[2] and the Telecommunications and Other Legislation Amendment Act 2017[45]</td><td>National Climate Risk Assessment[46]</td></tr>
<tr><td>National Emergency Declaration Act 2020[44]</td><td rowspan="2">National Climate Resilience and Adaptation Strategy 2021-2025[47]</td></tr>
<tr><td>Royal Commissions into National Natural Disaster Arrangements[3]</td></tr>
<tr><td>Australian Government Disaster Response Plan (COMDISPLAN 2020)[48]</td><td>Australian Government Critical Infrastructure Resilience Strategy[5]</td><td rowspan="2">Climate Change Act 2022[49]</td></tr>
<tr><td rowspan="2">Australian Government Crisis Management Framework (AGCMF)[50]</td><td>Sector Risk Assessment Advisories (CISC):
Communications[51]
Energy[52]
Transport[53]
Water[54]</td></tr>
<tr><td colspan="2">Powering Australia plan[55] and the National Energy Transformation Partnership[56]</td></tr>
<tr><td rowspan="4">State</td><td>Disaster Management Act 2003[57] and the Disaster Management Regulation 2014[58]</td><td rowspan="2">State Infrastructure Strategy 2022[29]</td><td rowspan="2">Queensland Climate Action Plan[59] and the Queensland Climate Adaptation Strategy 2017 – 2030[60]</td></tr>
<tr><td>Prevention, Preparedness, Response and Recovery Disaster Management Guideline[61]</td></tr>
<tr><td colspan="3">Queensland Strategy for Disaster Resilience 2022-2027[62]</td></tr>
<tr><td>State Disaster Management Plan[63] and State Hazard Specific Plans</td><td colspan="2">Built Environment and Infrastructure Sector Adaptation Plan[64]</td></tr>
<tr><td rowspan="4">Local</td><td colspan="3">Regional Resilience Strategies</td></tr>
<tr><td rowspan="3">Local and District Disaster Management Plans</td><td>Indigenous Councils Critical Infrastructure Program[65]</td><td rowspan="2">Local Coastal Hazard Adaptation Strategies (funded through QCoast2100)</td></tr>
<tr><td rowspan="2">Local Government Act 2009[66] and Local Government Regulation 2012[67]</td></tr>
<tr><td>Queensland Climate Resilient Councils Program</td></tr>
</table>

Figure 3 Key legislation and policy documentation - Queensland Critical Infrastructure Disaster Risk Assessment 2024

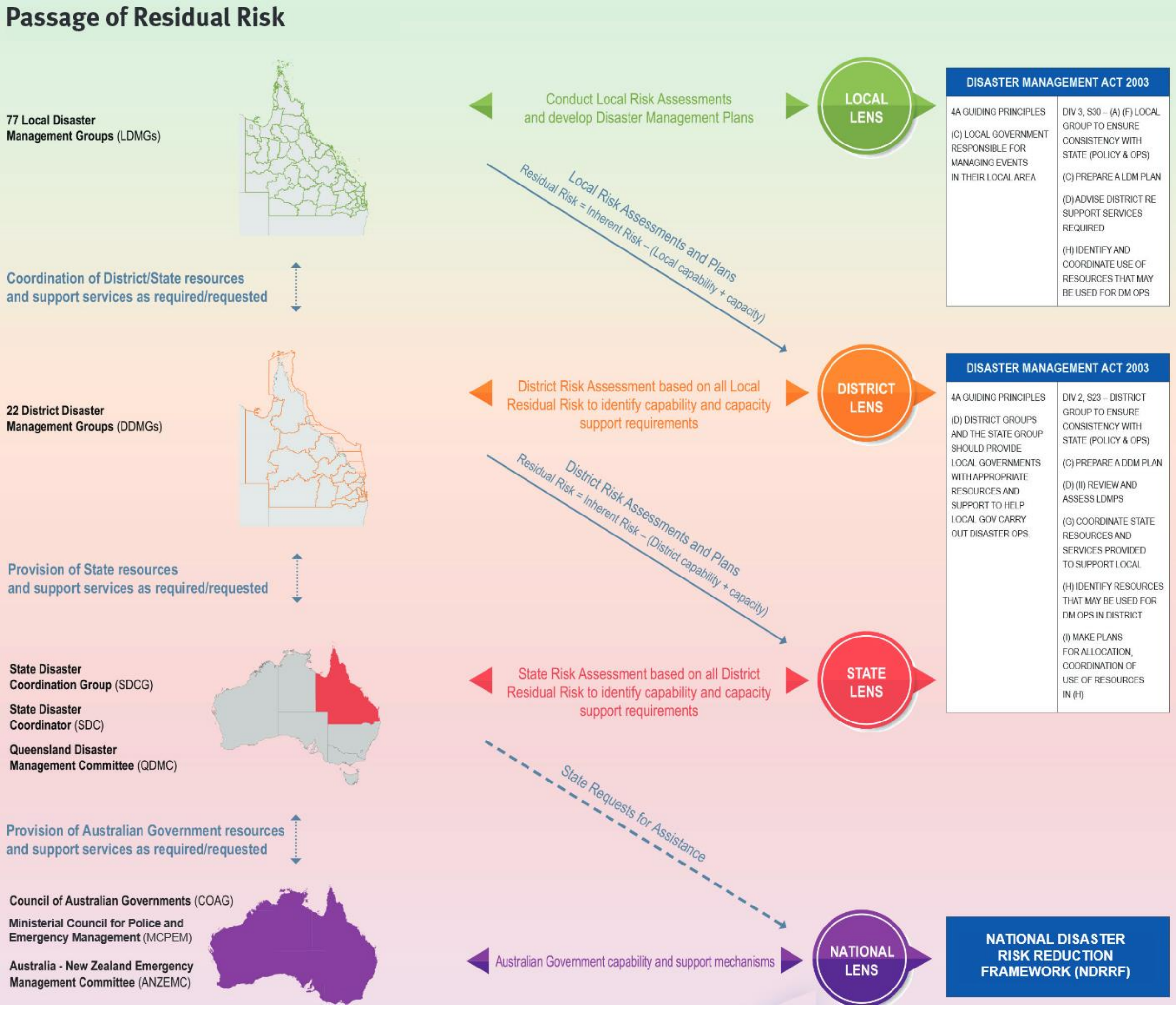
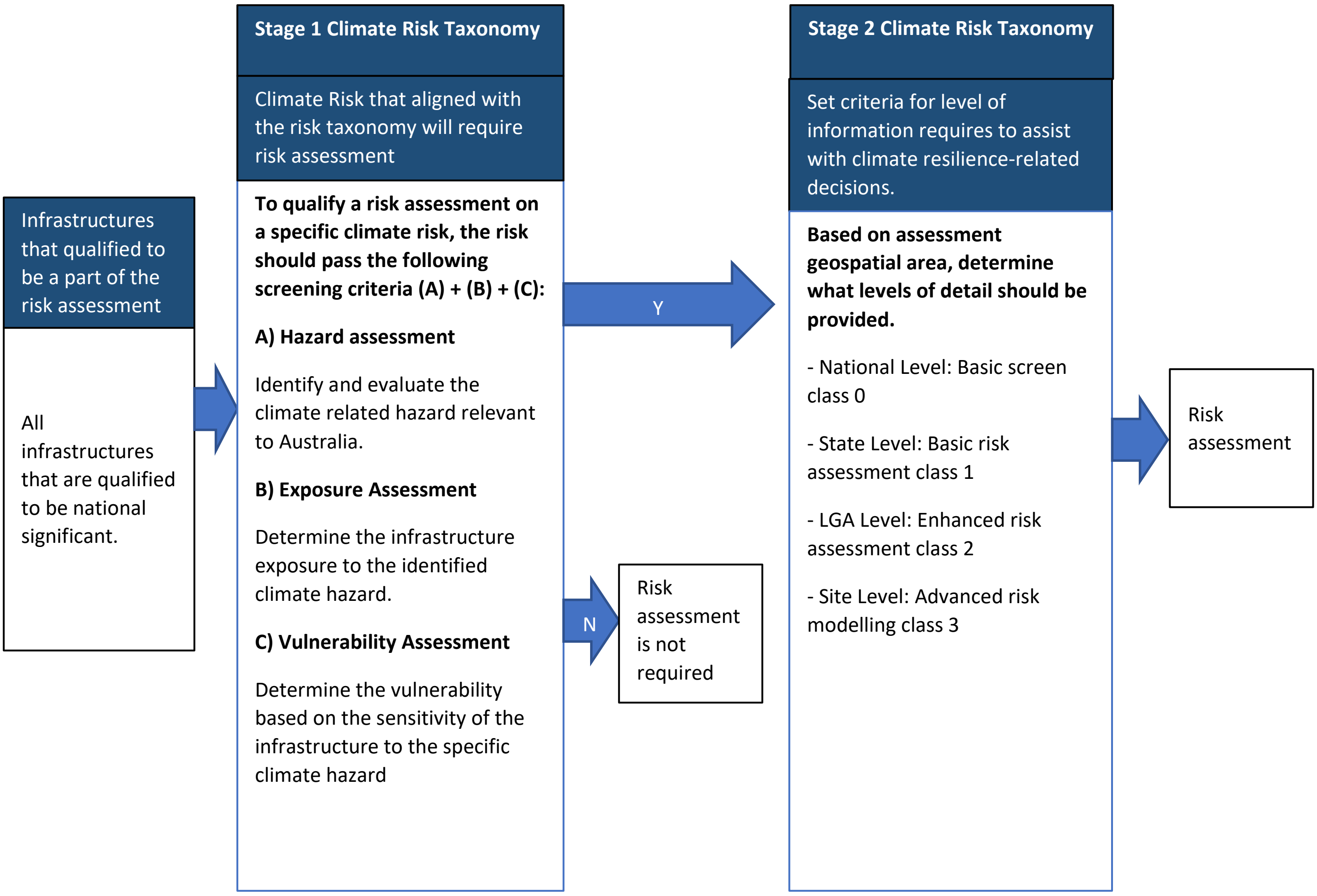


Figure 4 Passage of Residual Risk – Local/District/State/National - The Queensland Emergency Risk Management Framework

3.5 CLIMATE RISK TAXONOMY

The climate risk taxonomy for various infrastructure sectors subject to identified climate risks is highly dependent on expert advice. Despite abundant research and publications available for reference, it is imperative to form a federal level working group consisting of specialists from critical infrastructure sectors, such as asset operators, subject matter experts, asset owners, and climate science specialists, including the Bureau of Meteorology.

Based on the research, our approach is to adopt a two-stage taxonomy following the HEV risk assessment framework proposed in Section 3.1. Stage 1 of the climate risk taxonomy establishes a framework to filter out the type(s) of hazards to which an identified infrastructure asset or network is sensitive. Stage 2 taxonomy collect datasets to enable end-user to make informed decisions on building resilience in infrastructure assets and networks.



Infrastructures that qualified to be a part of the risk assessment

All infrastructures that are qualified to be national significant.

Stage 1 Climate Risk Taxonomy

Climate Risk that aligned with the risk taxonomy will require risk assessment

To qualify a risk assessment on a specific climate risk, the risk should pass the following screening criteria (A) + (B) + (C):

A) Hazard assessment

Identify and evaluate the climate related hazard relevant to Australia.

B) Exposure Assessment

Determine the infrastructure exposure to the identified climate hazard.

C) Vulnerability Assessment

Determine the vulnerability based on the sensitivity of the infrastructure to the specific climate hazard

Risk assessment is not required

Stage 2 Climate Risk Taxonomy

Set criteria for level of information requires to assist with climate resilience-related decisions.

Based on assessment geospatial area, determine what levels of detail should be provided.

- National Level: Basic screen class 0

- State Level: Basic risk assessment class 1

- LGA Level: Enhanced risk assessment class 2

- Site Level: Advanced risk modelling class 3

Risk assessment

Figure 5 Two-stage taxonomy process flow chart

3.5.1 Stage 1 Climate Risk Taxonomy

The purpose of developing the climate risk taxonomy is to establish a consistent framework for determining whether infrastructure is subject to climate risk. For infrastructure to be classified as exposed to climate risk, it must meet three criteria: **hazard**, **exposure**, and **vulnerability**, built into the taxonomy. If the infrastructure meets these criteria, a risk assessment for the specific climate hazard is to be conducted. This pre-screening approach aims to reduce the scope required for detailed risk assessments by filtering out relevant risks for each infrastructure asset and network.

		Is the climate-related hazard likely to affect the infrastructure	Does this infrastructure depend on other assets or networks, whose failure could lead to its own failure	Roads	Railways	Airports	Ports
Primary variables (stress)	Air temperature	Yes/No	Yes/No	Yes	Yes	Yes	No
	Humidity	Yes/No	Yes/No	No	No	No	No
	Sea surface temperature	Yes/No	Yes/No	No	No	Yes	Yes
	Precipitation	Yes/No	Yes/No	Yes	Yes	Yes	Yes
	Seal level rise	Yes/No	Yes/No	Yes	Yes	Yes	Yes
	Wind and hail	Yes/No	Yes/No	Yes	Yes	Yes	Yes
	Coastal inundation	Yes/No	Yes/No	Yes	Yes	Yes	Yes
	Drought	Yes/No	Yes/No	Yes	Yes	Yes	No
	Frost	Yes/No	Yes/No	No	No	No	No
Secondary variables (shocks)	Precipitation	Yes/No	Yes/No	Yes	Yes	Yes	Yes
	Wind and hail	Yes/No	Yes/No	Yes	Yes	Yes	Yes
	Bushfire	Yes/No	Yes/No	Yes	Yes	Yes	No
	Coastal inundation	Yes/No	Yes/No	Yes	Yes	Yes	Yes
	Cyclones/storms	Yes/No	Yes/No	Yes	Yes	Yes	Yes
	Flooding	Yes/No	Yes/No	Yes	Yes	Yes	Yes
	Heatwave	Yes/No	Yes/No	Yes	Yes	Yes	No
	Earthquake	Yes/No	Yes/No	Yes	Yes	Yes	Yes
	Tsunami	Yes/No	Yes/No	Yes	Yes	Yes	Yes
Note: Yes - Significant adverse effect possible (in worst case of occurrence) No - No significant adverse effect possible (in worst case of occurrence) Uncertain - Uncertain if significant adverse effect is possible							

Table 5 Stage 1 Climate Risk Taxonomy for National Significant Infrastructures

The process generally involves the following steps:

- **Step 1: Hazard assessment**

  The initial step involves identifying and evaluating the climate-related hazards relevant to Australia. This requires determining the type of hazard and assessing its likelihood of becoming a significant climate risk for the future. To achieve this, the climate and natural hazards (refer to Table 1 in Section 3.3.2) should be assessed for all national infrastructures.

- **Step 2: Exposure assessment**

  The next step involves determining the infrastructure's exposure to the identified hazards, including its interconnectivity with other infrastructure systems.

  The process includes:

Q1: Is the occurrence of the climate-related hazard possible for the investigation infrastructure?	
Yes ->	To be considered in the climate risk assessment
No ->	Do not need to be considered in the climate risk assessment
Q2: Is the infrastructure related to other infrastructure assets/networks, failure of that assets/networks will result in failure of the investigation infrastructure?	
Yes ->	Carry out risk assessment on that infrastructure assets/networks
No ->	No action is required

Table 6 Climate Risk Taxonomy Exposure Assessment Table

- **Step 3: Vulnerability Assessment**

  After completion of Steps 1 and 2, the hazard(s) that the investigation infrastructure is exposed to should be confirmed. It is then further filtered out based on the possibility of significant adverse effects for the infrastructure.

  We have developed the following table to determine whether a specific climate-related hazard could result in significant adverse effects on the infrastructure. Hazards that are not expected to impact the infrastructure do not need to proceed to the risk assessment stage.

  Currently, the taxonomy is tailored to transportation infrastructure. However, the methodology can be extended to other sectors and infrastructure types. This section outlines the taxonomy design logic and process steps, demonstrating how the framework functions and can be applied in broader contexts.

		Roads	Railways	Airports	Ports
Primary variables (stress)	Air temperature	Yes	Yes	Yes	No
	Humidity	No	No	No	No
	Sea surface temperature	No	No	Yes	Yes
	Precipitation	Yes	Yes	Yes	Yes
	Sea level rise	Yes	Yes	Yes	Yes
	Wind and hail	Yes	Yes	Yes	Yes
	Coastal inundation	Yes	Yes	Yes	Yes
	Drought	Yes	Yes	Yes	No
	Frost	No	No	No	No

		Roads	Railways	Airports	Ports
Secondary variables (shocks)	Precipitation	Yes	Yes	Yes	Yes
	Wind and hail	Yes	Yes	Yes	Yes
	Bushfire	Yes	Yes	Yes	No
	Coastal inundation	Yes	Yes	Yes	Yes
	Cyclones/storms	Yes	Yes	Yes	Yes
	Flooding	Yes	Yes	Yes	Yes
	Heatwave	Yes	Yes	Yes	No
	Earthquake	Yes	Yes	Yes	Yes
	Tsunami	Yes	Yes	Yes	Yes
Note: Yes - Significant adverse effect possible (in worst case of occurrence) No - No significant adverse effect possible (in worst case of occurrence) Uncertain - Uncertain if significant adverse effect is possible					

Table 7 Climate Risk Taxonomy Vulnerability Assessment Table

3.5.2 Stage 2 Climate Risk Sub-taxonomy

Stage 2 climate risk sub-taxonomy should be developed to for each climate hazards listed in Table 1. The purpose of developing the Stage 2 climate risk taxonomy is to set criteria of level of details of information required for each screening class to collect datasets that feeds into the following appropriate risk assessment framework and scoring system for area of investigation. The sub-taxonomy is developed inspired by the sub-taxonomy developed by ARUP for building structures (Almufti & Zuloaga, 2024). The difference is that ARUP taxonomy is developed for building structures under climate risk, whilst this report modified and utilised their taxonomy specifically in infrastructure.

We have developed a sub-taxonomy for flood hazard, taxonomy for other climate hazard may be developed following a similar approach.

The level of screening is based on the assessment geospatial area, as below:

- National Level: Basic screen class 0
- State Level: Basic risk screening class 1
- LGA Level: Enhanced risk assessment class 2
- Site Level: Advanced risk modelling class 3

	Category	Basic Hazard Screening Class 0	Basic Risk Screening Class 1	Enhanced Risk Assessment Class 2	Advanced Risk Modelling Class 3
Hazard	Modelling approach	Deterministic or probabilistic analysis	Probabilistisc and statistical modelling		Advanced site-specific modelling including dynamic hydrology and unsteady flow hydraulics and compound flood modelling as necessary
	Spatial resolution	100m and above	30 to 90m	10 to 30m	1 to 3m
	Intensity metrics	Inundation classification (in or out of flood zone)	Inundation depth or proxy depths	Inundation depth	Inundation depth, velocity (if near river), duration (for downtime)
	Likelihood method	Single deterministic or intensity-based scenario (based on single return period)	At least one return period	Multiple return periods	Multiple return periods and risk realisations that capture uncertainty about the median intensity-based hazard values.
	Hazard-specific requirements	None	Moderate-resolution topography information and easily accessible rainfall intensity data	Moderate-resolution topography data, easily accessible rainfall data from local meteorological stations, nearby stream gauge data, and basic information about relevant flood defence infrastructure. If included in model, verify flood defences	High-resolution (e.g., LiDAR) topographic data, detailed and use/cover data, detailed stormwater infrastructure information such as storm drain networks and culverts, rainfall data from local meteorological stations, nearby stream gauge data, and nearby tide gauge data (if coastal). All should represent the "current" conditions reasonably. Verify site-specific stormwater conveyance capacity (e.g. size, location, inverts) for inclusion in hazard model.
Exposure	Known infrastructure/site characteristics	Geolocation / Spatial location	Geolocation (building footprint), RL of infrastructure	Geolocation (building footprint), RL of infrastructure	Geolocation (infrastructure footprint), RL of infrastructure, building materials/ construction methodologies etc.

	Category	Basic Hazard Screening Class 0	Basic Risk Screening Class 1	Enhanced Risk Assessment Class 2	Advanced Risk Modelling Class 3
Vulnerability	Hazard-specific requirements	n/a	None		Component fragilities from the literature or derived from physical testing, empirical observation, or engineering calculations.

Table 8 Stage 2 Climate Risk Sub-taxonomy

4 Data Collection, Availability and Gaps

4.1 EXTREME WEATHER EVENTS

4.1.1 Data Collection Findings

Data on extreme weather events, including storms, cyclones, and hail, is typically gathered through meteorological stations, remote sensing satellites, and climate modelling. The Bureau of Meteorology (BOM) provides records of past events, including cyclone tracks, storm intensities, and frequency. Advanced radar systems and satellite imagery provide real-time data on developing storms and hail events.

The BOM makes historical data and some live tracking of extreme weather events available to the public, including alerts and warnings for severe weather conditions. However, detailed datasets and comprehensive climate models are not freely available, with access only to researchers and government agencies (Bureau of Meteorology, 2023).

4.1.2 Assumptions and Limitations

One limitation of the above is that models may not accurately predict the exact timing, severity, or location of future events due to inherent uncertainties in weather modelling. Additionally, fine-resolution data specific to localities or short-term event predictions can be limited, creating challenges for local-level infrastructure planning.

4.2 HEATWAVES AND RISING TEMPERATURES

4.2.1 Data Collection Findings

Temperature data is collected through ground-based meteorological stations and satellite data. Historical temperature records, such as daily maximum and minimum temperatures, help model future heatwaves. The BOM and CSIRO provide climate projections and detailed models on rising temperatures and future heatwave scenarios.

Daily and historical temperature data, as well as heatwave warnings, are available to the public through the BOM. CSIRO's climate projection data is accessible, though advanced datasets are generally restricted or require permission (CSIRO, 2023).

4.2.2 Assumptions and Limitations

Detailed Urban Heat Island (UHI) data is often limited, with gaps in fine-scale, localised data that can inform infrastructure resilience at the community level. Additionally, limited data exists on the indirect impacts of heatwaves on infrastructure degradation, which makes it challenging to predict asset wear and design longevity.

4.3 SEA-LEVEL RISE AND COASTAL EROSION

4.3.1 Data Collection Findings

Sea-level data is collected using tide gauges, satellite altimetry, and coastal monitoring stations. The BOM and Geoscience Australia provide sea-level records and coastal erosion data. Tide gauge stations, combined with satellite measurements, allow for accurate tracking of changes in sea level over time.

Sea-level data is generally available to the public via the BOM and Geoscience Australia, with annual and decadal trend reports on sea-level rise. However, localised erosion data is less commonly available and is often collected in specific research studies or coastal engineering assessments (Geoscience Australia, 2023).

4.3.2 Assumptions and Limitations

Gaps exist in high-resolution coastal erosion and sediment movement data, which limit precise predictions of coastal retreat and impacts on infrastructure. Real-time erosion monitoring is also limited, making it difficult to provide up-to-date information for critical assets near coastlines.

4.4 INCREASED BUSHFIRE RISK

4.4.1 Data Collection Findings

Bushfire data is collected through remote sensing, ground observations, and climate modelling. Data on bushfire-prone areas, fire histories, and vegetation cover are provided by agencies such as the BOM and Geoscience Australia, along with state-based agencies.

Bushfire data, including real-time fire tracking, is available to the public through state-based fire services and BOM, which issues warnings and monitors fire conditions. However, more comprehensive data on bushfire risk modelling and vegetation-specific fuel loads may be restricted to researchers and policymakers (Australian Government, 2023).

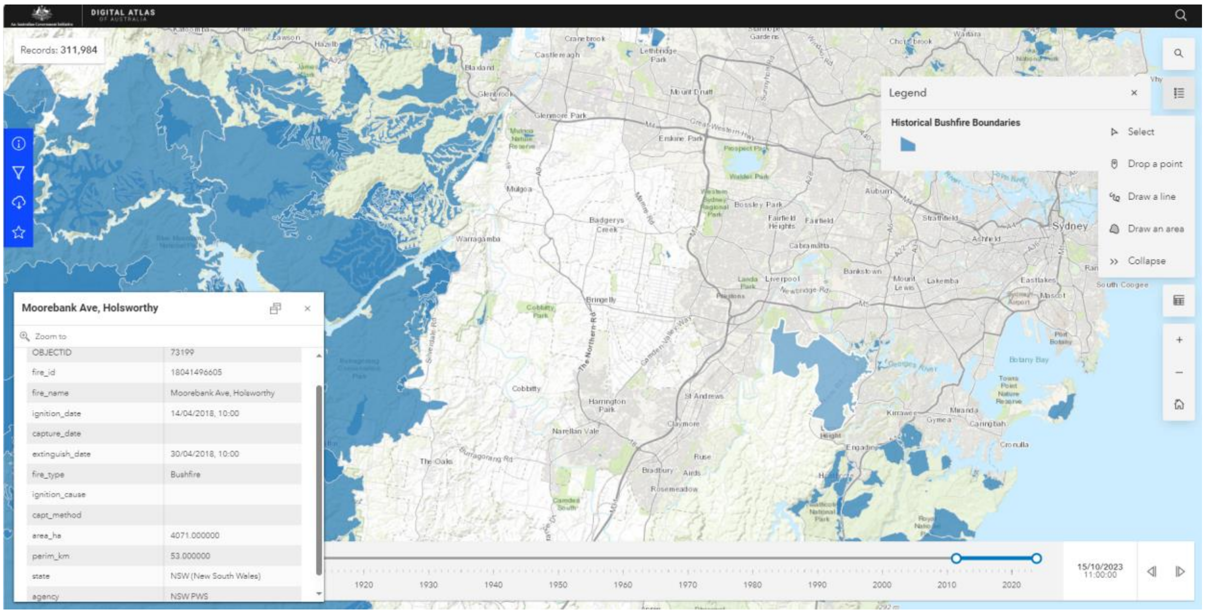
Below table includes all relevant data sources recording dates, locations, severity, and footprint for historic and recent bushfire events at a state or national level. The datasets at the national level have been calibrated. All datasets are publicly available. However, some characteristics of the datasets are missing, especially the severity of the bushfire events.

Extent	State	Historic	Recent	Format	Accessible		Remarks
State and Territory Fire Severity Dataset	NSW	Y	Y	Interactive Map	Y	Historical Fire Extent and Severity Mapping (FESM) | Dataset | SEED (nsw.gov.au)	
	VIC	Y	Y	Interactive Map	Y	Fire History Records of Fires across Victoria. - Dataset - Victorian Government Data Directory	
	SA	Y	Y	.kmz Dataset to be imported to Google Map Pro	Y	Bushfires and Prescribed Burns History - Dataset - data.sa.gov.au	
	WA	Y	N	.Geojson Dataset to be imported to Google Map Pro	N	DBCA Fire History (DBCA-060) - Datasets - data.wa.gov.au	
	NT	N	N	-	-	-	
	TAS	Y	Y	Interactive Map		LISTmap - Land Information System Tasmania (thelist.tas.gov.au)	
The National Indicative Aggregated Fire Extent Dataset		Y	N	Interactive Map & data files include .kml files	Y	Historical Bushfire Boundaries | Digital Atlas of Australia	Severity is not included

Extent	State	Historic	Recent	Format	Accessible		Remarks
		Y	N	Interactive Map		AUS GEEBAM Fire Severity Dataset (2019-2020) | Find Environmental Data (dcceew.gov.au)	2019-2020 Only

Table 9 Australian bushfire data sources

Historical bushfire boundaries are available on Digital Atlas of Australia, refer to Figure 6.



Moorebank Ave, Holsworthy

Zoom to

OBJECTID	73199
fire_id	18041496605
fire_name	Moorebank Ave, Holsworthy
ignition_date	14/04/2018, 10:00
capture_date	
extinguish_date	30/04/2018, 10:00
fire_type	Bushfire
ignition_cause	
capt_method	
area_ha	4071.000000
perim_km	53.000000
state	NSW (New South Wales)
agency	NSW PWS

Figure 6 Historical bushfire boundaries on Digital Atlas of Australia

An attempt was made by an Australian research group to develop a fire severity map that involved calibrating datasets from each Australian state in 2019 to 2020 to demonstrate the feasibility, methodology, and process to transform diverse bushfire data sources from each state to an interactive map with consistent data presentation at the Australian national level. Refer to Figure 7 for data calibration and Figure 8 for fire severity datasets at a national level.

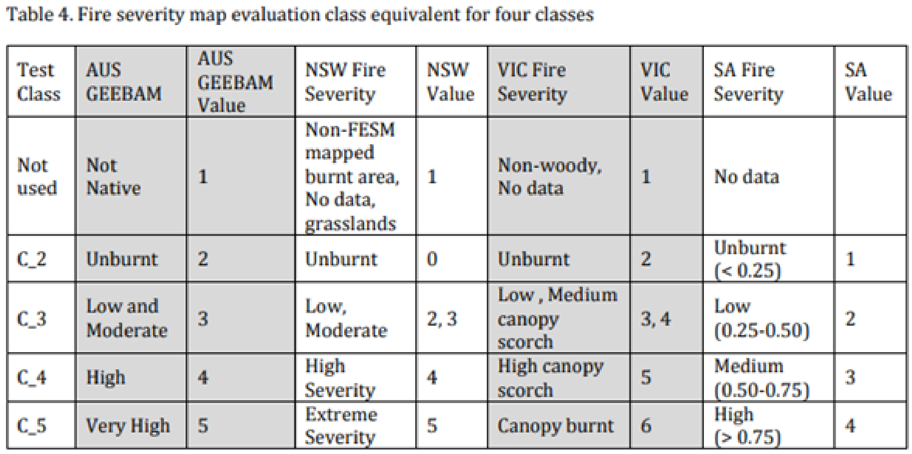


Table 4. Fire severity map evaluation class equivalent for four classes

Test Class	AUS GEEBAM	AUS GEEBAM Value	NSW Fire Severity	NSW Value	VIC Fire Severity	VIC Value	SA Fire Severity	SA Value
Not used	Not Native	1	Non-FESM mapped burnt area, No data, grasslands	1	Non-woody, No data	1	No data	
C_2	Unburnt	2	Unburnt	0	Unburnt	2	Unburnt (< 0.25)	1
C_3	Low and Moderate	3	Low, Moderate	2, 3	Low , Medium canopy scorch	3, 4	Low (0.25-0.50)	2
C_4	High	4	High Severity	4	High canopy scorch	5	Medium (0.50-0.75)	3
C_5	Very High	5	Extreme Severity	5	Canopy burnt	6	High (> 0.75)	4

Figure 7 Calibration of diverse datasets from states

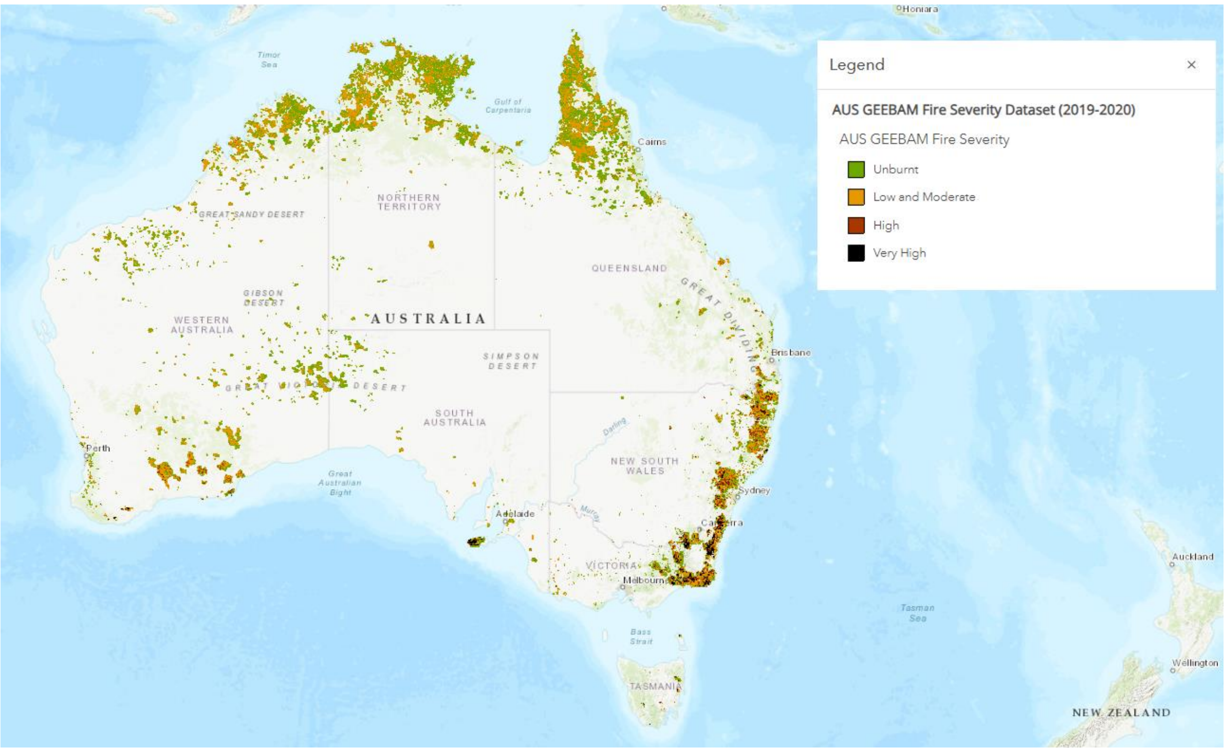


Figure 8 Interactive map showing fire severity datasets

4.4.2 Assumptions and Limitations

There is limited availability of real-time vegetation condition data, which would enhance early warning systems. Data on bushfire impacts on specific infrastructure assets, such as power lines, is also sparse, limiting predictive modelling for asset-specific resilience.

4.5 DROUGHT AND REDUCED RAINFALL

4.5.1 Data Collection Findings

Rainfall and drought conditions are monitored through rain gauges, satellite data, and soil moisture sensors. BOM provides data on rainfall patterns, drought status, and water availability projections. Soil moisture and evapotranspiration data are also collected to assess drought severity.

Drought information, rainfall records, and projections are available through BOM's website, and monthly drought reports are published. However, specific datasets on groundwater levels and soil moisture may have limited access for in-depth research applications (BOM, 2023).

4.5.2 Assumptions and Limitations

Gaps exist in localised soil moisture and groundwater data, which are critical for agricultural resilience and rural infrastructure planning. Additionally, limited predictive models account for compounding drought impacts on water infrastructure, which can affect long-term planning.

4.6 FLOODING AND INLAND RIVER SYSTEM OVERFLOWS

4.6.1 Data Collection Findings

Flood risks are monitored using hydrological models, river gauge data, and radar systems. The BOM provides real-time flood warnings and river levels, while Geoscience Australia offers flood hazard maps for historical flood-prone areas.

Flood data, including river height readings and flood forecasts, is available to the public via BOM. However, specific hydrological models and simulations used for flood risk assessments may require access permissions for use in planning (Geoscience Australia, 2023).

Flood behaviour is relatively well understood compared to other priority natural hazards. There is a range of widely accepted industry analytical tools and approaches to estimate and quantify flood behaviour in the study area, which provides a solid foundation for data collection.

Fundamental to the estimation of flood hazard on a floodplain is the estimation of flood depth, flood velocity, and the combination of depth and velocity. Flood hazard varies with flood severity (i.e. for the same location, the rarer the flood, the more severe the hazard) and with location within the floodplain for the same flood event. Sound floodplain management practice should consider a full range of design flood probabilities to provide an overview of the full risk profile for the subject floodplain. Similarly, the variability of flood hazard should be assessed across a range of flood probabilities, as well as spatially across the floodplain.

Geoscience Australia provides flood datasets at a national level via the Australian Flood Risk Information Portal, refer to Figure 9. The interactive map shows the study areas where flood study assessment reports have been made available. The flood study assessment reports have been categorised as flood studies with and without geospatial information. However, the flood study assessment reports were created for different purposes at given times. There are limitations in accessing information outside the calendar year under consideration, refer to Figure 10. In addition, different levels of flood assessment have been carried out and are not differentiated in the interactive map. Different levels of flood assessment were agreed upon and determined between government agencies and consultancies to ensure they were fit-for-purpose. Typically, the spatial resolution varies in different levels of flood assessment, i.e. 100x100m grids vs 10x10m grids.

It is noted that not all study areas showing the presence of flood study assessments provide a direct link to access the report due to ongoing discussions regarding copyright requirements for public download. For those without public download access, contact with the local council is required, refer to Figure 11 and Figure 12.

For the flood study assessment reports made available, flood assessments were typically carried out covering the annual exceedance probability (AEP) of 2%, 1%, and 0.2%.

In conclusion, although the information has been displayed in an interactive map format, it is not a true interactive map where users can directly access the native spatial data related to flood hazards, including the footprint of the study area, the levels of flood assessments, the year, AEP, and outcomes of flood depth, flood velocity, and their combination. Instead, the interactive map provides a directory of available past flood assessment reports in PDF format owned by government agencies. Extensive effort is required to review the collected flood assessment reports and assess whether they are fit-for-purpose for understanding the characteristics of the flood hazard and informing future management decisions at a state or national level, such as flood risk management, strategic and development-scale land-use planning, and flood emergency response planning.

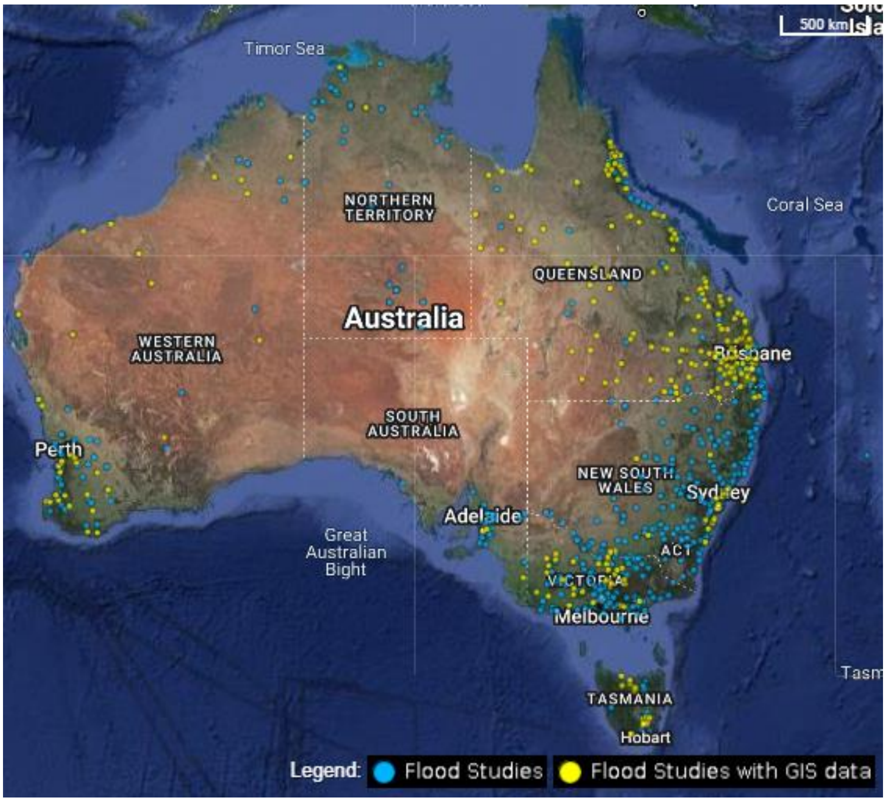
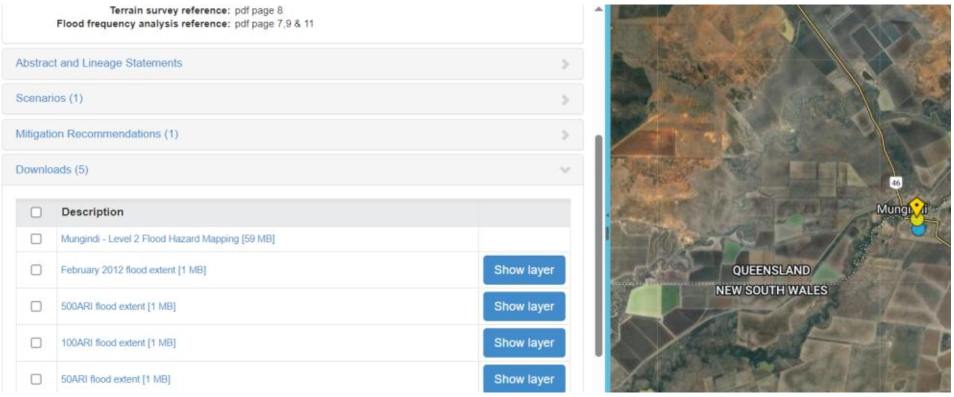


Figure 9 Australian flood risk information portal


Terrain survey reference: pdf page 8
Flood frequency analysis reference: pdf page 7,9 & 11

Abstract and Lineage Statements

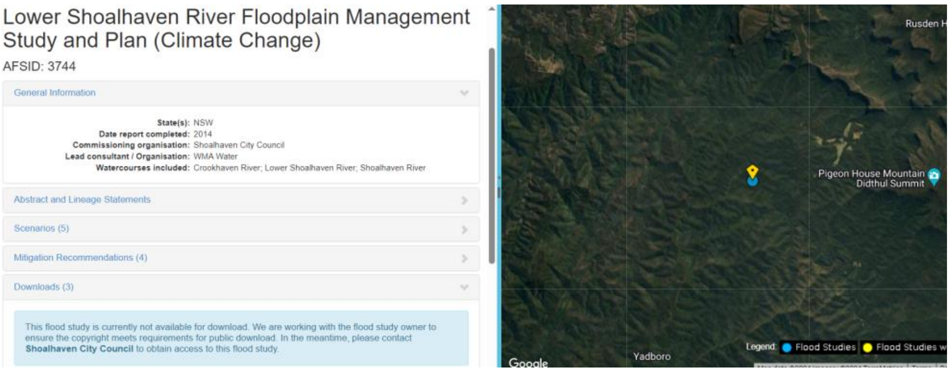
Scenarios (1)

Mitigation Recommendations (1)

Downloads (5)

☐	Description	
☐	Mungindi - Level 2 Flood Hazard Mapping [59 MB]	
☐	February 2012 flood extent [1 MB]	Show layer
☐	500ARI flood extent [1 MB]	Show layer
☐	100ARI flood extent [1 MB]	Show layer
☐	50ARI flood extent [1 MB]	Show layer

Figure 10 Available flood study with GIS data


Lower Shoalhaven River Floodplain Management Study and Plan (Climate Change)

AFSID: 3744

General Information

State(s): NSW
Date report completed: 2014
Commissioning organisation: Shoalhaven City Council
Lead consultant / Organisation: WMA Water
Watercourses included: Crookhaven River; Lower Shoalhaven River; Shoalhaven River

Abstract and Lineage Statements

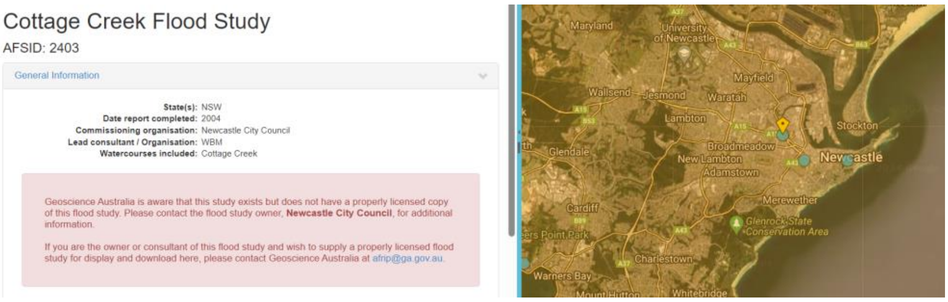
Scenarios (5)

Mitigation Recommendations (4)

Downloads (3)

This flood study is currently not available for download. We are working with the flood study owner to ensure the copyright meets requirements for public download. In the meantime, please contact **Shoalhaven City Council** to obtain access to this flood study.

Figure 11 Unavailable flood study



Cottage Creek Flood Study

AFSID: 2403

State(s): NSW
Date report completed: 2004
Commissioning organisation: Newcastle City Council
Lead consultant / Organisation: WBM
Watercourses included: Cottage Creek

Geoscience Australia is aware that this study exists but does not have a properly licensed copy of this flood study. Please contact the flood study owner, **Newcastle City Council**, for additional information.

If you are the owner or consultant of this flood study and wish to supply a properly licensed flood study for display and download here, please contact Geoscience Australia at afrip@ga.gov.au.

Figure 12 Unavailable flood study

4.6.2 Assumptions and Limitations

Limited access to high-resolution floodplain data for certain areas affects the precision of flood risk modelling, especially in rapidly urbanising regions. There is also a lack of infrastructure interdependency data, which could model how floods impact interconnected systems, such as energy and transportation networks.

4.7 TELECOMMUNICATIONS AND DIGITAL INFRASTRUCTURE RISKS

4.7.1 Data Collection Findings

Data on climate impacts on telecommunications infrastructure is typically gathered through network monitoring, satellite communication systems, and ground-based sensors.

Limited public data is available on the direct impacts of climate risks on telecommunications infrastructure. While general outage information is accessible, comprehensive datasets on infrastructure performance under climate stressors are typically held by network operators (Infrastructure Australia, 2021).

4.7.2 Assumptions and Limitations

There is a lack of real-time resilience data on telecommunications infrastructure, particularly during multi-hazard events like floods and heatwaves. Limited data on infrastructure interdependencies also constrains accurate modelling of cascading failures across infrastructure networks.

4.8 ECONOMIC AND SOCIAL RISKS

4.8.1 Data Collection Findings

Economic and social risks due to climate impacts on infrastructure are assessed using economic modelling, census data, and climate projections. Government agencies and research institutions use these models to estimate financial impacts of infrastructure failure due to climate events.

Basic economic impact data related to climate events is available through government reports and studies. However, detailed cost-benefit analyses and economic risk models used for resilience planning are often proprietary or accessible only to policymakers and researchers (Productivity Commission, 2022).

4.8.2 Assumptions and Limitations

Gaps exist in long-term economic impact data specifically focused on infrastructure damage costs due to climate events. Data on indirect social impacts, such as displacement or reduced access to essential services, is also limited, complicating comprehensive economic assessments.

4.9 REVIEW OF GIS DATASETS AND INTERACTIVE MAPS

Below is a summary of the strengths and weaknesses encountered for datasets that were made available via interactive maps and/or via digital files in geospatial data formats such as the Digital Atlas of Australia:

4.9.1 Strengths

- Platforms such as the Digital Atlas of Australia offer a centralised platform for integrating and accessing vast spatial data
- Support collaboration across various levels of government, industry and community enhancing data-driven-decision making
- User-friendly method with tools for both novice and expert users to parse through vast datasets, enabling seamless data integration and analysis.
- It is an integrated tool that can visualise hazard and exposure levels.

4.9.2 Weaknesses:

- The tools are still in developmental stages, with some features and data sets not fully integrated
- Some data remains in isolated silos, making integration and utilisation challenging
- Requires significant upfront investment, coordination and alignment between all authorities for the tool to present useful information relevant to each interested stakeholder

4.9.3 Areas for Improvement

- Expand availability and quality of foundational data sets for comprehensive coverage.
- Enhance support for real-time data updates and integration from diverse sources.
- Further development to provide a centralised platform includes the calibrated spatial datasets of priority hazards and the exposure and vulnerability of physical infrastructure assets.
- A universal quantifying system is required for data collectors to follow to ensure consistent data quality and measurements.
- Timeliness should be reported as part of the data collection and publication. The intervals will affect the accuracy in future prediction.

4.9.4 Gaps and Limitations:

- Gaps in spatial enablement of certain data types, especially non-spatial formats like Excel or PDFs.
- Complexity in data-sharing agreements and jurisdictional boundaries limits full data integration and utilisation potential.
- Different quantification methods and standards have been adopted by state governments and private corporates.
- Inconsistency in design basis and fundamental modelling parameters
- Data quality varies and require sensible calibration.
- It is challenging to validation of historic data.

5 Methodology

Following the literature review of the risk assessment framework proposed by the academics, research of published climate risk assessment overseas, and the review of global and Australian data sources, two methodologies are proposed to demonstrate the feasibility of developing a standardised quantitative analysis system for multi-hazard cross-sectional geospatial risk and cascading risk. Both risk assessment frameworks are variations of the HEV risk assessment framework discussed in Section 3.1. The simplified analysis model to assess multi-hazard cross-sectional geospatial risk will be discussed in depth and will explore its application and suitability for the Australian local environment. Conversely, the methodology of assessing cascading risk will be briefly touched upon to demonstrate the opportunities for assessing complex risk interactions.

5.1 REFERENCE RESEARCH DOCUMENTS AND DATASETS

This section refers to the reference research documents as follows:

- IPCC AR6 Report
- National Climate Risk Assessment, Methodology
- National Climate Risk Assessment, First pass assessment report
- Australian Google Earth Engine Burnt Area Map, A rapid, national approach to fire severity mapping
- Australian Disaster Resilience Handbook Collection for Flood Hazard
- A global multi-hazard risk analysis of road and railway infrastructure assets
- A GIS-based framework for high-level climate change risk assessment of critical infrastructure
- TMR climate risk assessment
- Quantifying climate risks to infrastructure systems: A comparative review of developments across infrastructure sectors

This section refers to the database as follows. The global database refers to Table 1:

- Digital Atlas of Australia
- Geoscience Australia
- Australian Flood Risk Information Portal
- States bushfire database refer to Table 9

5.2 DATA AVAILABILITY

The outcome of the data review has been covered in Section 4. Data sources that are readily available to the public are identified in the subsequent sections to demonstrate the feasibility of integrating diverse data sources into the proposed risk assessment framework and the proposed analysis methodology and models.

In general, there are more readily available datasets for the coarse aggregates of the geographic regions. Hence, this section focuses on the review of global data and Australian national data. Refer to Section 4.4 and Section 4.6 with two examples of existing climate hazard data availability at a finer geographic scale in Australia to demonstrate the challenges, gaps, and limitations during the implementation of climate risk assessment at a finer level. The global data covers all risk framework components that were assessed in the research paper A Global Multi-Hazard Risk Analysis of Road and Railway Infrastructure Assets (EE Koks et al, 2019). The purpose of presenting it is to showcase the feasibility of accessing data on hazards, exposure, and vulnerability and processing that data for further climate risk assessment. Additionally, the paper compares and quantifies the global transportation asset exposure and potential damages under a wider range of hazards at the global level to assess the fiscal burden of damage from natural hazards and to quantify the potential benefits of adaptation action. The research team developed programmed tools to estimate the damage and reconstruction, and repair costs based on available global data.

Despite proving the feasibility of obtaining available global data to carry out the climate risk assessment, further work is required to fill in the gaps of the datasets at the Australian national level and at a finer geographic level to enable meaningful assessment of climate risk in the local environment.

Australian bushfire and flood datasets were reviewed in detail and presented in Section 4.4 and Section 4.6. For other top priority national climate hazards, fewer gaps are expected; however, a comprehensive data review is needed within the federal government department to assess the data quality and availability

5.2.1 Global Data References

Availability of global data adopted in the paper (provide reference) is listed in below table.

Risk Framework Component	Items	Platform	Accessibility
Hazards	Earthquakes	UNISDR Global Assessment Report 2015 data portal	Free access
	Tropical cyclones	UNISDR Global Assessment Report 2015 data portal	Free access
	Surface and river floods	Fanthom Global	Special request required, Use with permission
	Coastal floods	Joint Research Centre of European Commission	Free access
	Infrastructure (Road and railway)	OpenStreetMap	Free access
Exposure	Damage probability	Bespoke code-based analysis tool	Reference code available on GitHub
Vulnerability	Reconstruction/ repair costs	World Bank research	Free access

5.2.2 National Hazard Data for Australia

Refer to below table for a review of the primary data provider and data availability for the top ten priority climate hazards listed in the National Climate Risk Assessment, First Pass Assessment Report.

Top 10 priority hazards for Australia over the next century (Department of Climate Change, Energy, the Environment and Water, National Climate Risk Assessment First Pass Assessment Report)	Specific hazard with available data	Primary data provider	Data availability
Bushfires, grassfires and air pollution	Bushfires	State Government	Partially available
Changes in temperatures including extremes	Extreme temperatures	Bureau of Meteorology	Available

Top 10 priority hazards for Australia over the next century **(Department of Climate Change, Energy, the Environment and Water, National Climate Risk Assessment First Pass Assessment Report)**	**Specific hazard with available data**	**Primary data provider**	**Data availability**
Coastal and estuarine flooding	Storm surge	Bureau of Meteorology	Available
Coastal erosion and shoreline change	Coastal erosion	Geoscience Australia	Available
Convective storms including hail	Storms and hailstorm	Bureau of Meteorology	Available
Drought and changes in aridity	Drought	Bureau of Meteorology	Available
Extratropical storms	Extratropical storms	Bureau of Meteorology	Available
Ocean warming and acidification	Sea surface temperature	Bureau of Meteorology	Available
Riverine and flashing flooding	Floods	Consulting companies, local government, Geoscience Australia	Limited availability. Commercial arrangements, special requests, and terms of use may be required
Tropical Cyclones	Tropical cyclones	Geoscience Australia	Available

Following a literature review of the risk assessment framework proposed by academics, research of published climate risk assessment overseas, and the review of global and Australian data sources, two methodologies are proposed to demonstrate the feasibility of developing a standardised quantitative analysis system for multi-hazard cross-sectional geospatial risk and cascading risk. The simplified analysis model to assess multi-hazard cross-sectional geospatial risk will be discussed in depth and will explore its application and suitability for the Australian local environment. Conversely, the methodology of assessing cascading risk will be briefly touched upon to demonstrate the opportunities for assessing complex risk interactions.

5.2.3 Australian National Infrastructure Exposure Data and Vulnerability Rating

It is expected that sufficient data on existing infrastructure systems and assets are available within the Australian federal government system. Refer to Figure 13 for available transport data on OpenStreetMap.

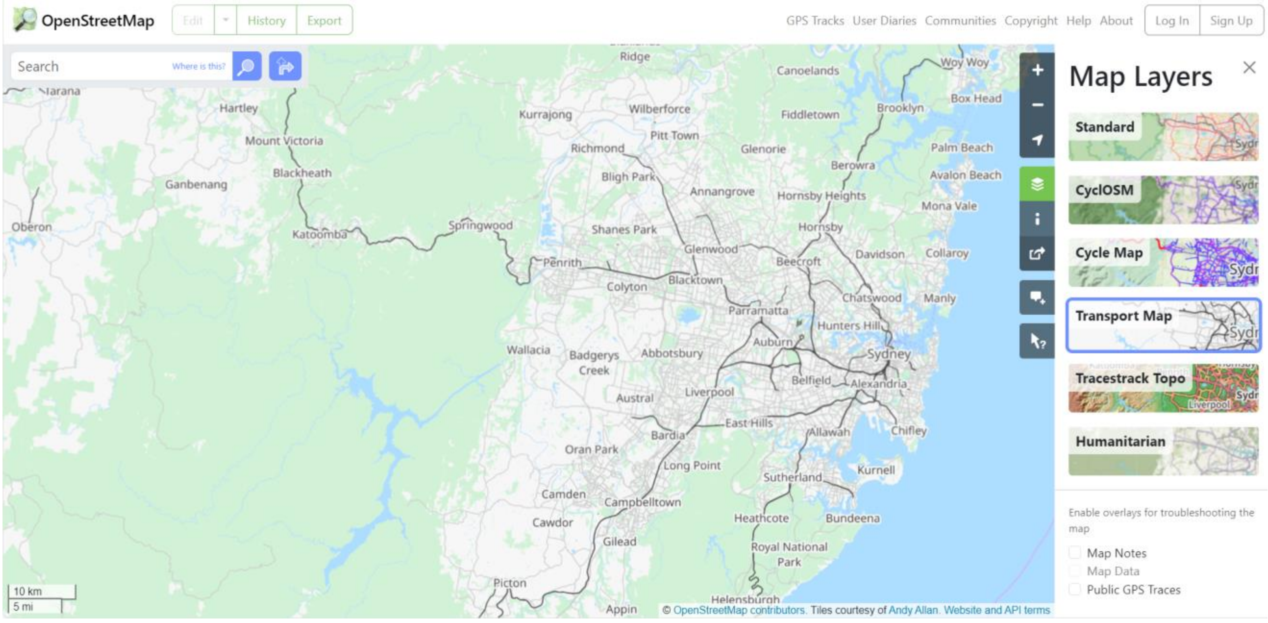


Figure 13 Available transport system data

It is expected that specialists in each climate hazard field have developed an industry-acknowledged vulnerability classification system that can be adopted to assign numerical ratings of vulnerability of an infrastructure asset impacted by a climate hazard. Refer to Figure 14 for the vulnerability classifications published by the Australian Disaster Resilience Handbook Collection for Flood Hazard (Australian Government Attorney-General's Department, 2017).

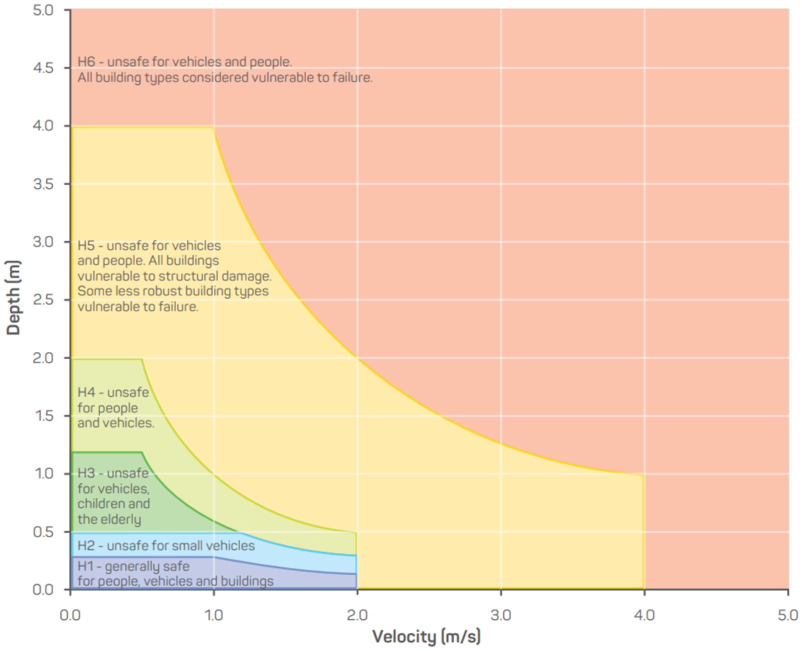


Figure 14 Flood hazard vulnerability classifications (Australian Government Attorney-General's Department, 2017)

5.3 RISK ANALYSIS MODEL

Two risk analysis models are proposed to attempt to address two typical cases of risk analysis: one is to assess multi-hazard cross-sectional geospatial risk, and the other is to assess cascading risk. Both factors in the climate change impact. The objective of multi-hazard cross-sectional geospatial risk analysis is to highlight possible climate change risk hotspots. This analysis approach helps to inform more detailed cascading failure studies by identifying cross-sectional risk hotspots.

5.3.1 Multi-hazard Cross Sectional Geospatial Risk Assessment Framework

A six-step risk assessment framework is proposed in the research paper A GIS-based framework for high-level climate change risk assessment of critical infrastructure (L Hawchar et al, 2020) This approach is GIS-based, facilitating modelling of geographical variability in both climate and asset vulnerability within a country. It permits the identification of potential climate change risk hotspots across a range of critical infrastructure sectors. Refer to Figure 15 for the six distinct steps.

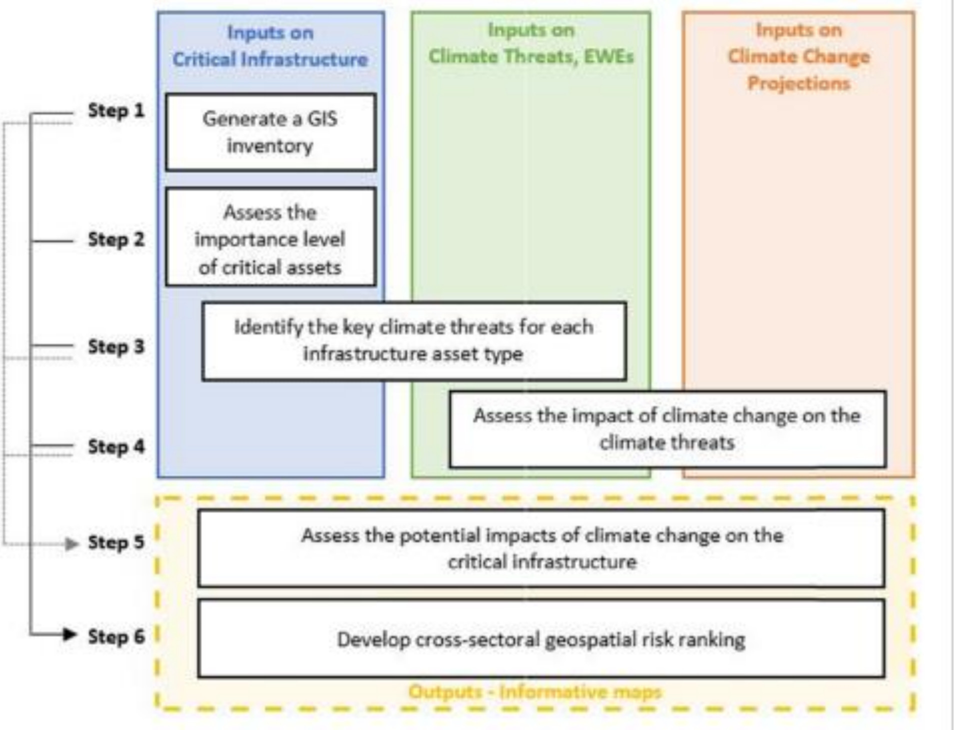


Figure 15 Flowchart of the high-level GIS-based assessment of critical infrastructure vulnerability to climate change (L Hawchar et al, 2020)

5.3.2 Cascading Risk Assessment Framework

The methodology to assess cascading risk identifies dependency models, such as systems maps and Bayesian Belief Networks, as ideal due to their ability to convey complex relationships and transform qualitative insights into semi-quantitative models. These models require substantial data input and generally target a few interconnected systems.

Dependency models enable detailed mapping of nodes (e.g., climate events) and conditional relationships, forming a network of interdependencies that estimate impacts by calculating expected values based on probabilities and impact magnitudes. This approach prioritises risks and is adaptable for organisations to assess specific system and asset interactions. Systems mapping complements the model by visualising intricate climate risk interactions, delivering a scalable and effective framework for comparative risk assessment. Refer to Figure 16 for the risk pathways.

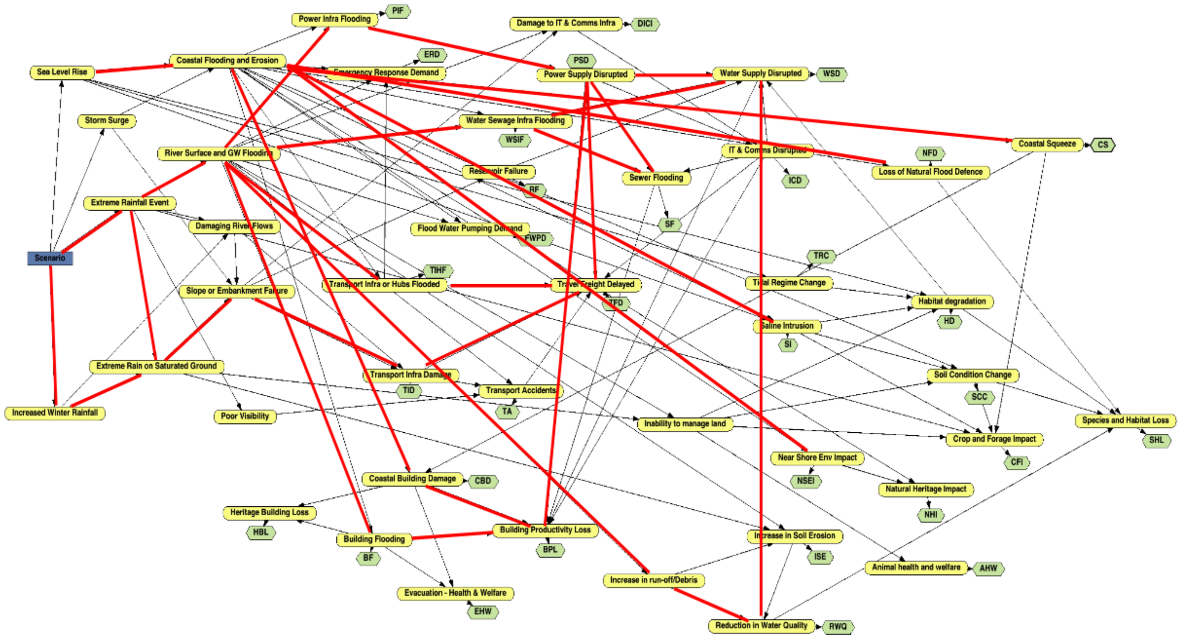


Figure 16 Risk pathways of cascading risks (WSP, 2020)

5.4 STANDARDISED SCORING SYSTEM

The risks analysis model for cascading risks is included to show the feasibility of expanding the analysis approach to address all complex risk interactions.

This section focuses on a standardised scoring system that calculates multi-hazard cross-sectional geospatial risk.

5.4.1 Assumptions and Limitations

- Importance index and vulnerability indices are highly simplified to suit the high-level analysis for demonstration at this stage of development.
- The level of granularity is sufficient to give an “order of magnitude” understanding of the overall level of risk, risk hotspots, and risk interactions. It is not for detailed analysis.
- The demonstration is at an aggregate/average national level but could be regionalised by using different input data (the model structure would remain the same) when available.
- Any of the models do not consider the sequences of events.
- Assessment on existing infrastructure assets and systems only. Modern design standards and practices can be future-proof.
- Model sensitivity to consider changes in spatial resolution and existing errors in datasets.
- Priority natural hazards have been identified.
- Sufficient datasets are available for different levels of geographic aggregation noting appropriate calibration of datasets is required and achievable.
- Global hazard data are available via the identified platforms in the research paper. This is a sign that there is well-acknowledged data collection and presentation for significant natural hazards. Therefore, it is reasonable to assume that under different spatial resolutions, i.e. national level, state/province level, region level, and site level, sufficient data can be made available via consistent and systematic approaches and collaboration between public and private sectors.

- Continuous efforts are required to expand the features of the proposed system. The current available global UNDRR Risk Viewer platform is a multiple agency effort to share spatial data information on global risk from natural hazards. It allows the public to visualise, download, or extract data on past hazardous events, human and economic hazard exposure, and risk from natural hazards. It covers major hazards, initial tropical cyclones, and earthquakes, and as it becomes available, information related to storm surges, droughts, floods, landslides, tsunamis, and volcanic eruptions.
- Climate risks to infrastructure systems can broadly be categorised into four tiers and summarised in Figure 17 (J Verschuur, 2024). The first tier involves quantifying the risk to individual assets, such as the physical asset damages from flooding of road segments or from heat to energy transmission. Within the second tier, network-wide effects are evaluated, considering damages to multiple components of the transportation system and their implications, such as the disruption of train services due to floods destroying railway lines. The third tier focuses on analysing interactions and dependencies between infrastructure networks, such as the flooding of a nearby electricity substation that leads to the disruption of an airport or water treatment plant. Finally, the fourth-tier entails assessing systemic risks associated with the indirect economic losses or other socio-economic impacts of infrastructure services. When moving to higher tiers, the spatial scale often increases, resulting in an amplification of impacts. However, capturing these higher tier effects also increases the complexity of quantitative modelling frameworks, and hence the ability to validate model results. We can refer to these three aspects as the key modelling trade-offs. The risk assessment framework and the analysis model are limited to quantifying the risk to individual assets. Factors and considerations are given to further explore the damages to multiple components of the infrastructure system and their implications.

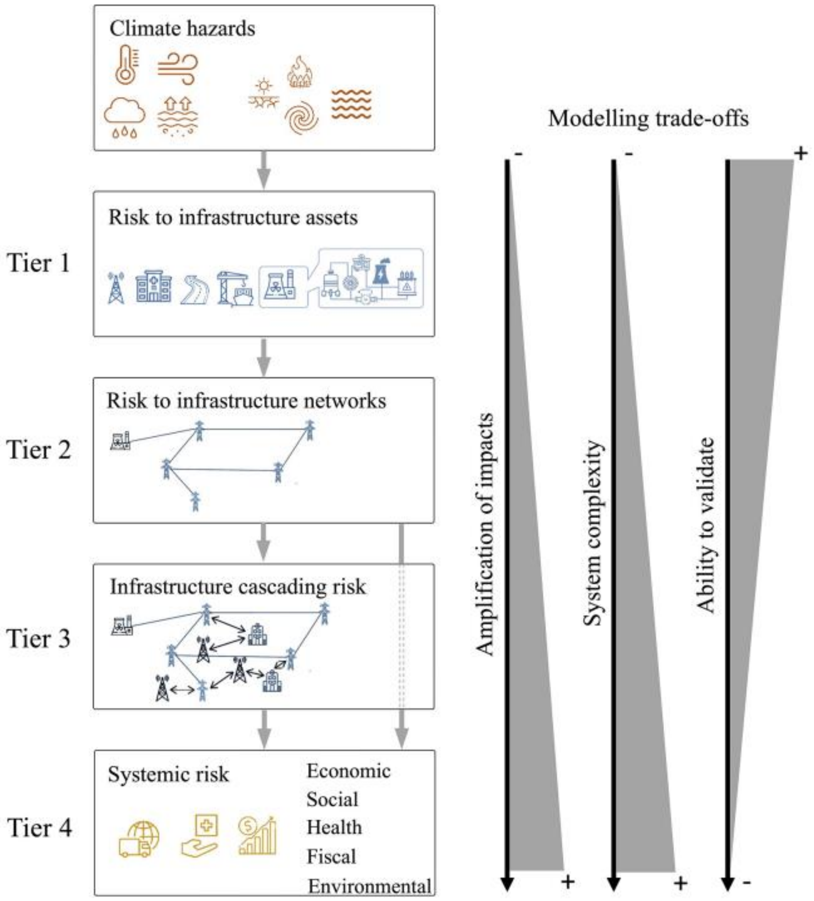


Figure 17 Four-tier framework of climate risks to infrastructure, including the three modelling trade-offs (J Verschuur et al, 2024)

5.4.2 Geographic Aggregation

Hazard Mapping

Spatial resolution is a key factor in reporting the representative 'order of magnitude' for mapping the climate hazards and the risks. It has been widely adopted by researchers to adopt grids of different sizes to suit geographical areas. It was also found that the risk assessment outcome is highly sensitive to changes in spatial resolution. A recent study on uncertainty in coastal flood risk assessment shows that a change in resolution from 10 to 100 m of the digital elevation map could change the estimated expected annual damages by 200%. Similar effects are expected for the risk assessment outcome, especially for risk assessments at a regional level or at a site level.

A direct comparison of hazard mapping on a global scale and at a national level is shown in Figure 18 to Figure 21.

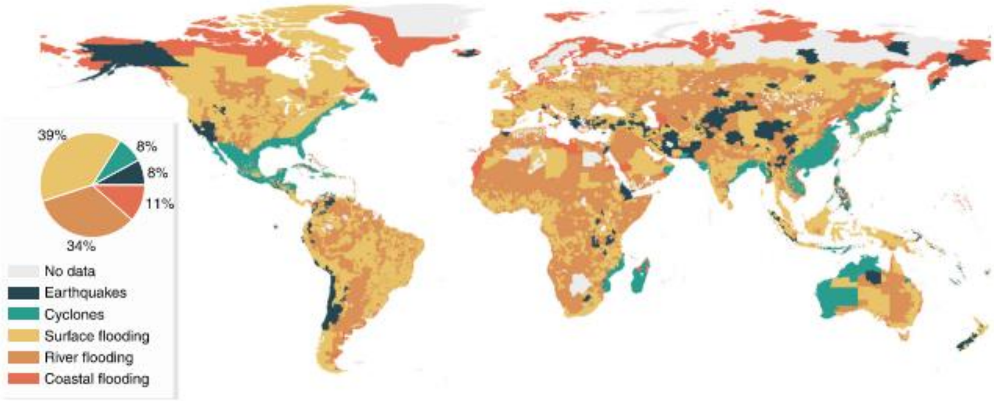


Figure 18 Dominant hazard per region at a global level (EE Koks et al, 2019)

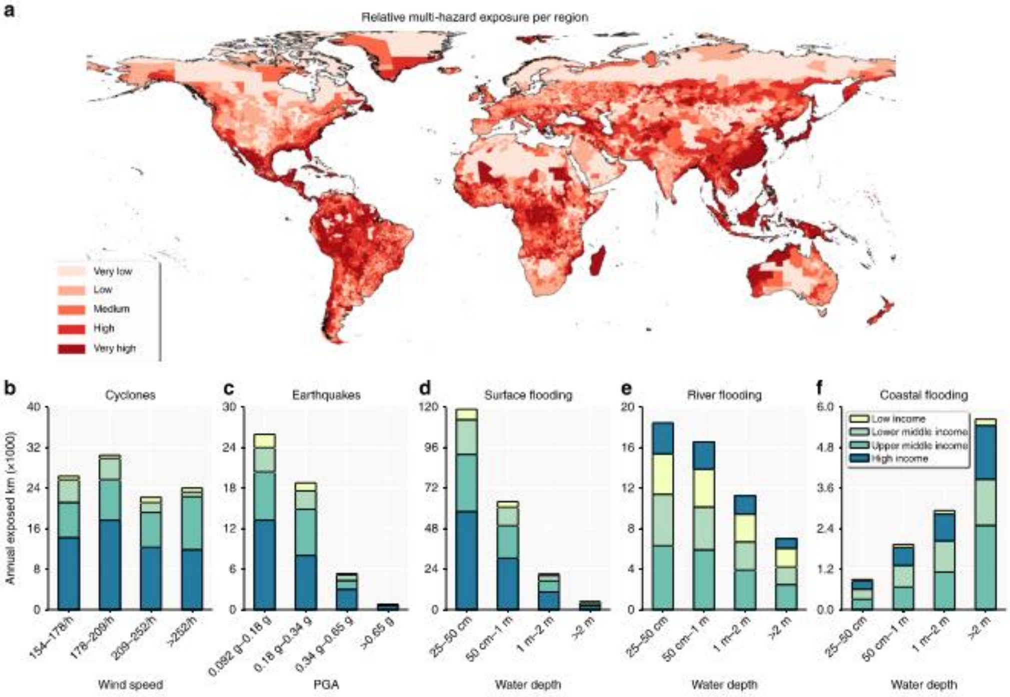


Figure 19 Global multi-hazard transport infrastructure exposure (EE Koks et al, 2019)

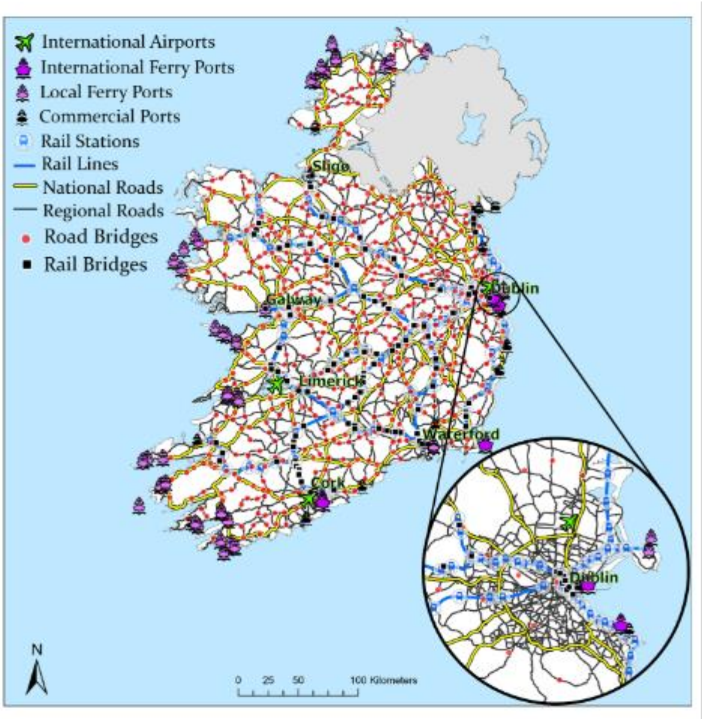


Figure 20 Map of the critical infrastructure assets of Irish transport sector (L Hawchar et al, 2020)

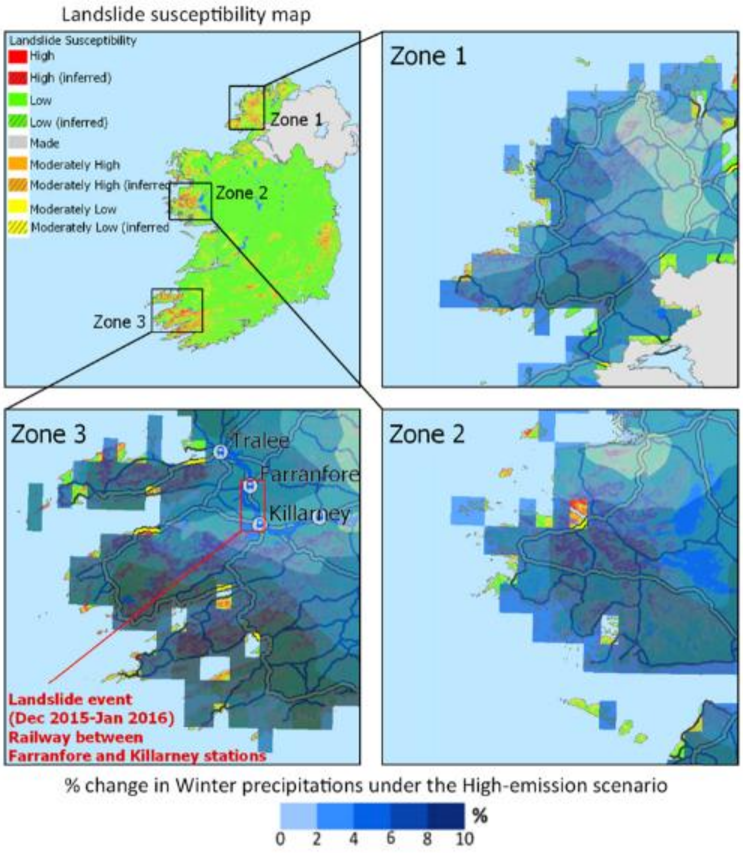


Figure 21 Assessment of the impact of climate change on Irish transport network vulnerability to landslide (L Hawchar et al, 2020)

Additional Information

Concluded from the research findings of the global multi-hazard risk analysis of road and railway infrastructure assets, additional information is recommended to be collected for the following assessments and screenings to develop the adaptation plan. They are:

- Income of the region.
- Year of construction.
- Design Standards.
- Historic insurance claims against damage caused by climate hazards.

5.4.3 Risk Interactions

Climate risks on infrastructure interact in different ways. The AR6 assessment introduces the dynamic nature of risk and their interactions. Following the order of increased complexities, they are:

- Unidirectional compound risks
- Bidirectional compound risks
- Cascade risks
- Aggregate risks

In the two proposed methodologies, one is suitable for assessing unidirectional compound risks, and the other is suitable for assessing cascade risks.

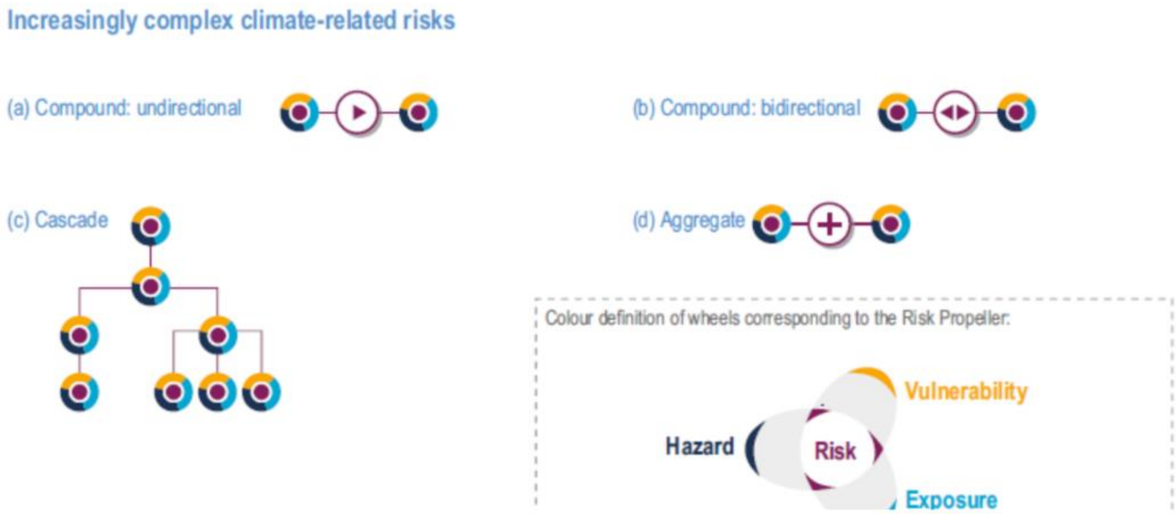


Figure 22 Risk interactions (O'Neill et al, 2022)

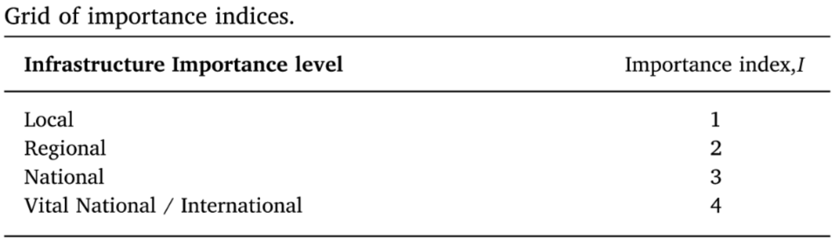
5.4.4 Risk Indices

The review of various climate risk assessment frameworks found that the majority of the methodology used to assess unidirectional compound risks adopts indices similar to importance indices and vulnerability indices to describe vulnerability. The differences are the terminology used to describe the same characteristic and the number of classes. They typically vary for assessing different infrastructure types. They also vary at different geographical levels. For example, a comparison of the taxonomy describing vulnerability in the research paper A GIS-Based Framework for High-Level Climate Change Risk Assessment of Critical Infrastructure and those in the TMR Climate Risk Assessment is summarised in Table 10. Therefore, it is for the working group and the specialists to finalise on the appropriate terminology and the number of classes that are suitable for all infrastructure types. For existing datasets, it is critical to agree on a methodology to calibrate the classifications and indices.

A GIS-based framework for high-level climate change risk assessment of critical infrastructure	TMR Climate Risk Assessment	A GIS-based framework for high-level climate change risk assessment of critical infrastructure	TMR Climate Risk Assessment
Infrastructure importance level and importance indices	Consequence (Indices not provided)	Relationship level between climate threat and infrastructure system and vulnerability indices	Likelihood (Indices not provided)
Local (1)	Insignificant	None (0)	Very Unlikely (Rare)
Regional (2)	Minor	Low (1)	Unlikely
National (3)	Moderate	Medium (2)	Moderate
Vital National / International (4)	Major	High (3)	Likely
	Catastrophic		Almost Certain

Table 10 Comparison of terminology and classifications

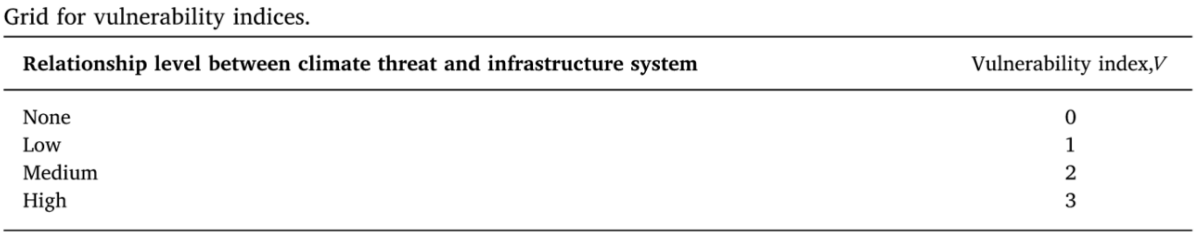
Figure 23 to Figure 25 show the proposed terminology and the number of classes to describe vulnerability in the research paper A GIS-Based Framework for High-Level Climate Change Risk Assessment of Critical Infrastructure (L Hawchar et al, 2020).



Grid of importance indices.

Infrastructure Importance level	Importance index,I
Local	1
Regional	2
National	3
Vital National / International	4

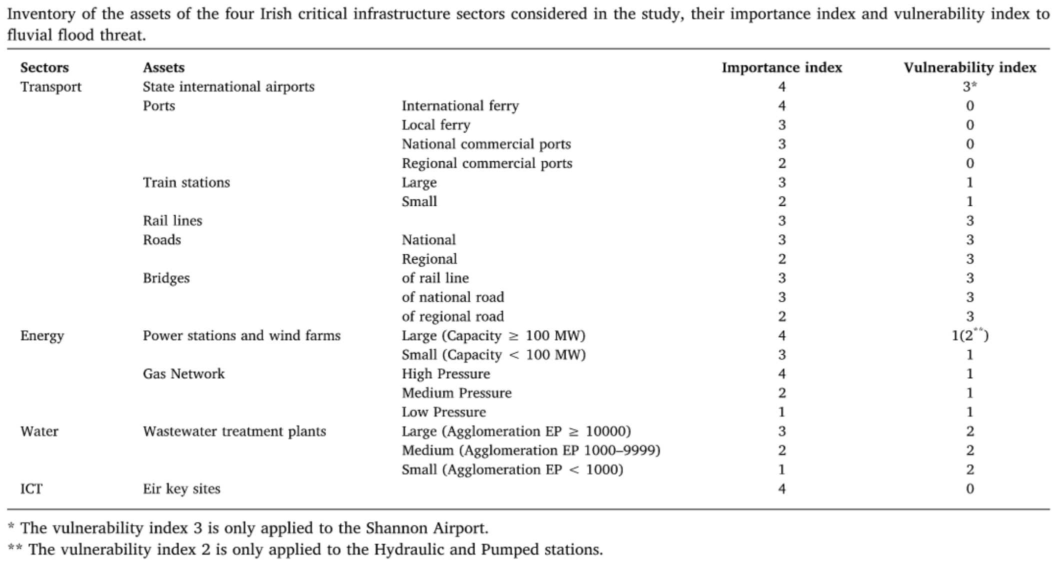
Figure 23 Importance indices (L Hawchar et al, 2020)



Grid for vulnerability indices.

Relationship level between climate threat and infrastructure system	Vulnerability index,V
None	0
Low	1
Medium	2
High	3

Figure 24 Vulnerability indices (L Hawchar et al, 2020)



Inventory of the assets of the four Irish critical infrastructure sectors considered in the study, their importance index and vulnerability index to fluvial flood threat.

Sectors	Assets		Importance index	Vulnerability index
Transport	State international airports		4	3*
	Ports	International ferry	4	0
		Local ferry	3	0
		National commercial ports	3	0
		Regional commercial ports	2	0
	Train stations	Large	3	1
		Small	2	1
	Rail lines		3	3
	Roads	National	3	3
		Regional	2	3
	Bridges	of rail line	3	3
		of national road	3	3
		of regional road	2	3
Energy	Power stations and wind farms	Large (Capacity ≥ 100 MW)	4	1(2**)
		Small (Capacity < 100 MW)	3	1
	Gas Network	High Pressure	4	1
		Medium Pressure	2	1
		Low Pressure	1	1
Water	Wastewater treatment plants	Large (Agglomeration EP ≥ 10000)	3	2
		Medium (Agglomeration EP 1000–9999)	2	2
		Small (Agglomeration EP < 1000)	1	2
ICT	Eir key sites		4	0

* The vulnerability index 3 is only applied to the Shannon Airport.

** The vulnerability index 2 is only applied to the Hydraulic and Pumped stations.

Figure 25 Inventory of the assets of the four Irish critical infrastructure sectors with importance index and vulnerability index to fluvial flood threat (L Hawchar et al, 2020)

5.4.5 Numerical Approach of Risk Assessment

A numerical approach proposed in the research paper A GIS-Based Framework for High-Level Climate Change Risk Assessment of Critical Infrastructure (L Hawchar et al, 2020) is applicable to Australia. Refer to Figure 26 and Table 11. R_{th} denotes relative risk index and is always a value between 0 and 1.

$$R_{th}^{(g)} = \frac{M_{th}^{(g)} - M_{th}^{min}}{M_{th}^{max} - M_{th}^{min}} \in [0,\, 1]$$

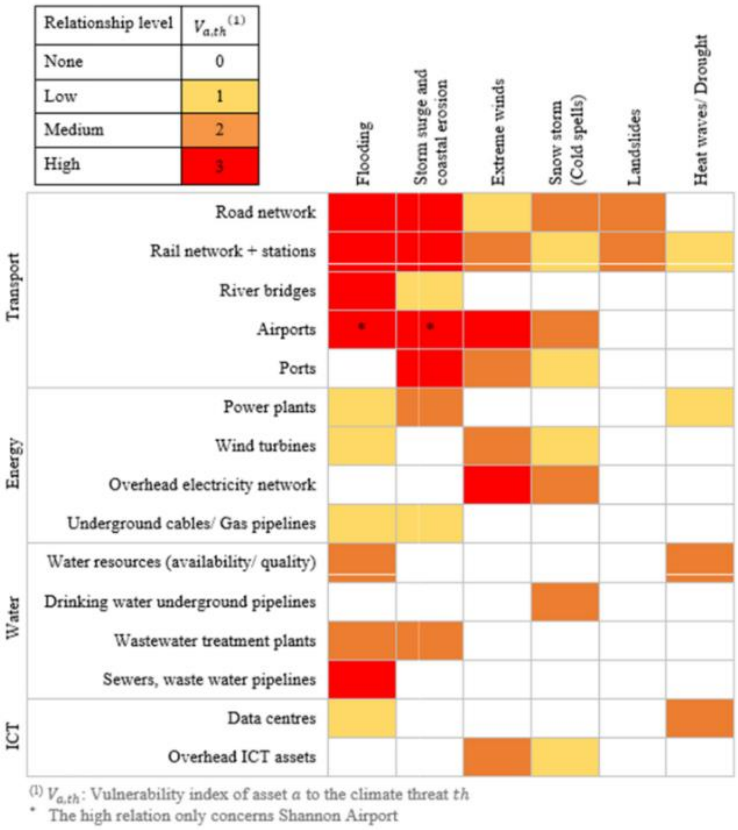
with

$$M_{th}^{(g)} = \sum_{a=1}^{n_a} (I_a.\ V_{a,th}).\ m_a^{(g)}$$

Figure 26 Numerical approach of risk assessment (L Hawchar et al, 2020)

Risk Framework Component	Quantitative Measurements	Definition
Hazard	th	A specific hazard
	Note hazards are typical expressed as severity and likelihood. The importance index and vulnerability index are named to differentiate the severity and likelihood between describing hazards and vulnerability.	
Exposure	$M_a^{(g)}$	A measurement index (ie number or length) of the asset type a within the grid g
	n_a	The total number of asset types in the study
Vulnerability	I_a	The importance index of asset a
	$V_{a,th}$	The vulnerability index of asset a Refer to Figure 22 for a worked example

Table 11 Definition of variables



Relationship level	$V_{a.th}$ ⁽¹⁾
None	0
Low	🟨 1
Medium	🟧 2
High	🟥 3

		Flooding	Storm surge and coastal erosion	Extreme winds	Snow storm (Cold spells)	Landslides	Heat waves/ Drought
Transport	Road network	🟥	🟥	🟨	🟧	🟧	
	Rail network + stations	🟥	🟥	🟧	🟨	🟧	🟨
	River bridges	🟥	🟨				
	Airports	🟥 *	🟥 *	🟥	🟧		
	Ports		🟥	🟧	🟨		
Energy	Power plants	🟨	🟧				🟨
	Wind turbines	🟨		🟧	🟨		
	Overhead electricity network			🟥	🟧		
	Underground cables/ Gas pipelines	🟨	🟨				
Water	Water resources (availability/ quality)	🟧					🟧
	Drinking water underground pipelines				🟧		
	Wastewater treatment plants	🟧	🟧				
	Sewers, waste water pipelines	🟥					
ICT	Data centres	🟨					🟧
	Overhead ICT assets			🟧	🟨		

⁽¹⁾ $V_{a.th}$: Vulnerability index of asset a to the climate threat th

* The high relation only concerns Shannon Airport

Figure 27 Key relationships between climate threats and Irish critical infrastructure assets (L Hawchar, 2020)

5.4.6 Weighting across different infrastructure types

The nature of climate-related impacts means that there are different units of importance level and vulnerability through which to assess different systems and subsectors within each system. The first pass risk assessment identified eight systems of national importance as follows:

- Defence and national security
- Economy, trade and finance
- First Nations values and knowledges
- Health and social support
- Infrastructure and built environment
- Natural environment
- Primary industry and food
- Regional and remote communities

Within Infrastructure and built environment, there are the following ten identified subsectors:

- Buildings and community infrastructure
- Transport and telecommunications
- Human heath, and medical and emergency services
- Water and wastewater management

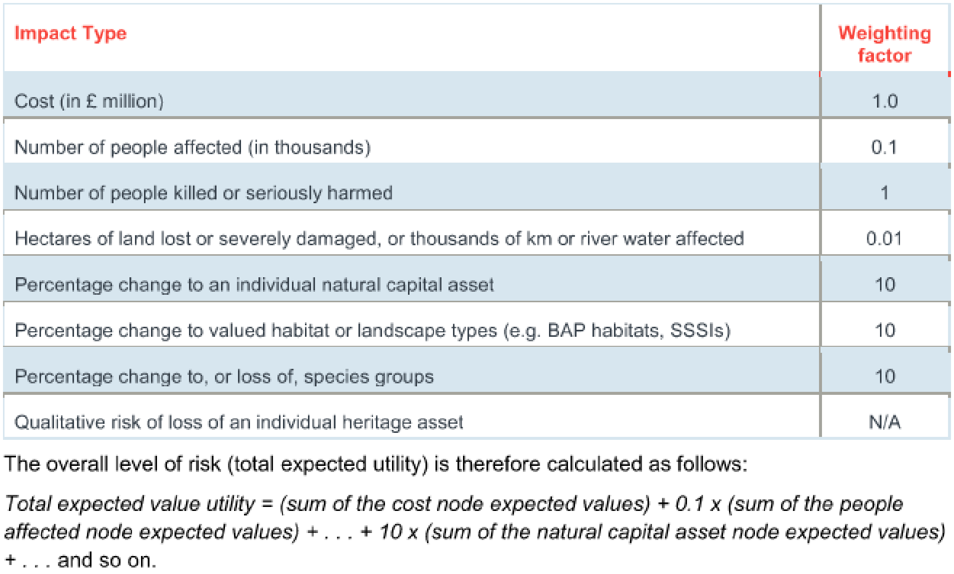
- Urban natural environments
- Critical and essential services infrastructure
- Supply chains
- Energy
- Circular economy and waste management
- Building liveability

The above subsectors can be further broken down into smaller aggregates such as:

- Road and railway infrastructure, including roads, railway system and bridges.
- Inland water transport, including navigation channels, locks and river ports.
- Airports
- Seaports
- Telecommunication infrastructure consists of a wide range of terrestrial (fixed and wireless) and satellite assets.
- Water infrastructure, including water supply, drainage and irrigation.
- Social infrastructure, including schools and hospitals.
- Energy generation, transmission and distribution

The finer granularity that any risk assessment aims to achieve for infrastructure assets and networks, the more complex it becomes to develop a consistent scoring system that considers the equivalent impact and severity of the natural hazards to infrastructure assets and networks of vastly different characteristics.

Refer to Figure 28 for an example of weighting factors that can be applied to calculate the expected value of climate hazard impact. Similar weighting factors are to be developed by the specialists to facilitate comparative analysis across different infrastructure types.



Impact Type	Weighting factor
Cost (in £ million)	1.0
Number of people affected (in thousands)	0.1
Number of people killed or seriously harmed	1
Hectares of land lost or severely damaged, or thousands of km or river water affected	0.01
Percentage change to an individual natural capital asset	10
Percentage change to valued habitat or landscape types (e.g. BAP habitats, SSSIs)	10
Percentage change to, or loss of, species groups	10
Qualitative risk of loss of an individual heritage asset	N/A

The overall level of risk (total expected utility) is therefore calculated as follows:

Total expected value utility = (sum of the cost node expected values) + 0.1 x (sum of the people affected node expected values) + . . . + 10 x (sum of the natural capital asset node expected values) + . . . and so on.

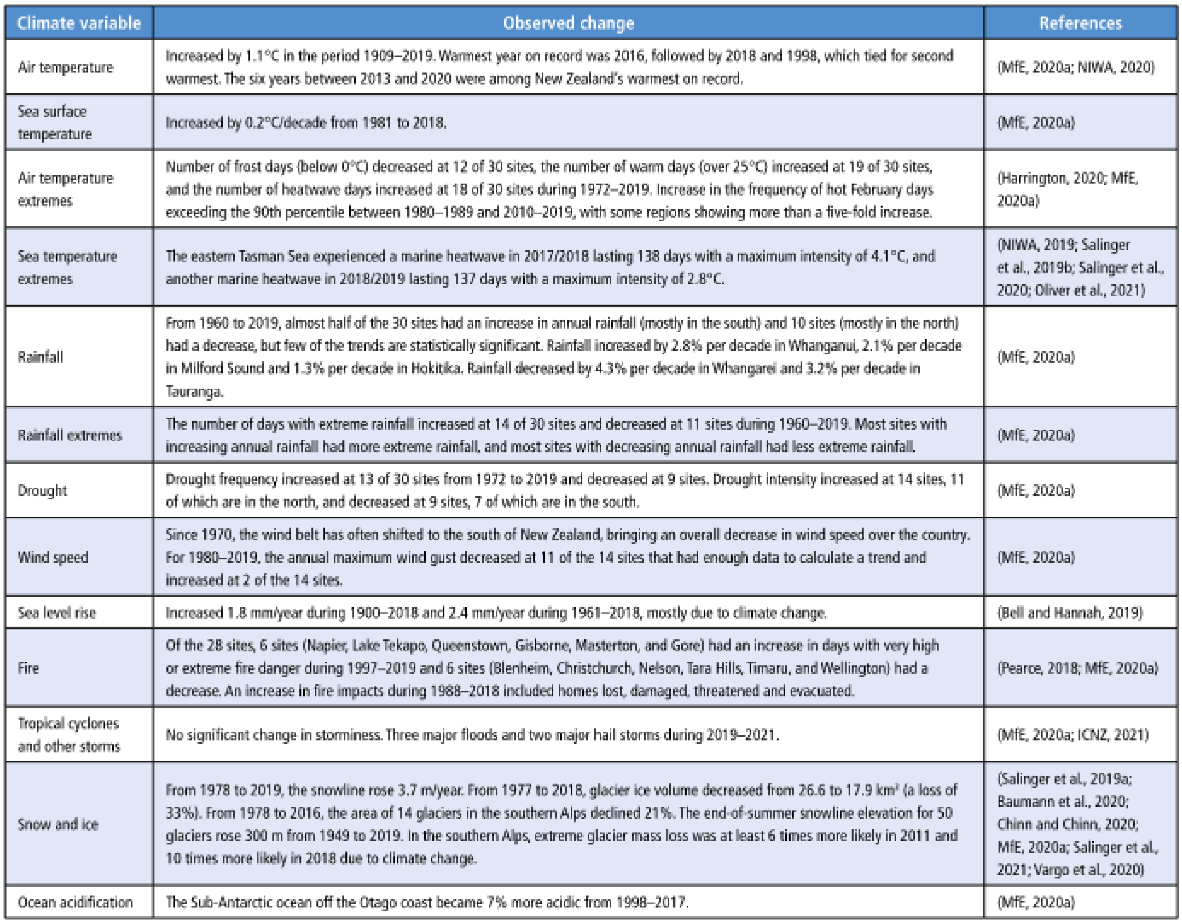
Figure 28 An example of weighting factors to remove vast differences in asset or network characteristics (WSP, 2020)

5.4.7 Climate Change Factors

The future climate can be simulated using the IPCC Special Report (IPCC, 2022) on Emissions Scenarios A1B, A2, and B1 and the Representative Concentration Pathways (RCP) 2.6, 4.5, and 8.5 emission scenarios. RCP 2.6 represents low emissions, RCP 4.5 medium emissions, and RCP 8.5 high emissions. Refer to Figure 29 and Figure 30 for observed climate change for Australia and Figure 31 and Figure 32 for projected climate change for Australia. Similar predictions for climate change for other countries are available in the IPCC AR6 report. An example of projected changes in mean annual runoff for 2046–2075 relative to 1976–2005 for RCP 8.5 from hydrological modelling with future climate projections is shown in Figure 33. It is expected that the specialists have developed or will develop similar projected changes for other climate hazards. Refer to Figure 34 and Figure 35 for risk assessment results following the proposed methodology and analysis model of gridded maps of relative fluvial flood risk to the four Irish critical infrastructure sectors and projected change (%) in autumn rainfall, for the high-emission scenario.

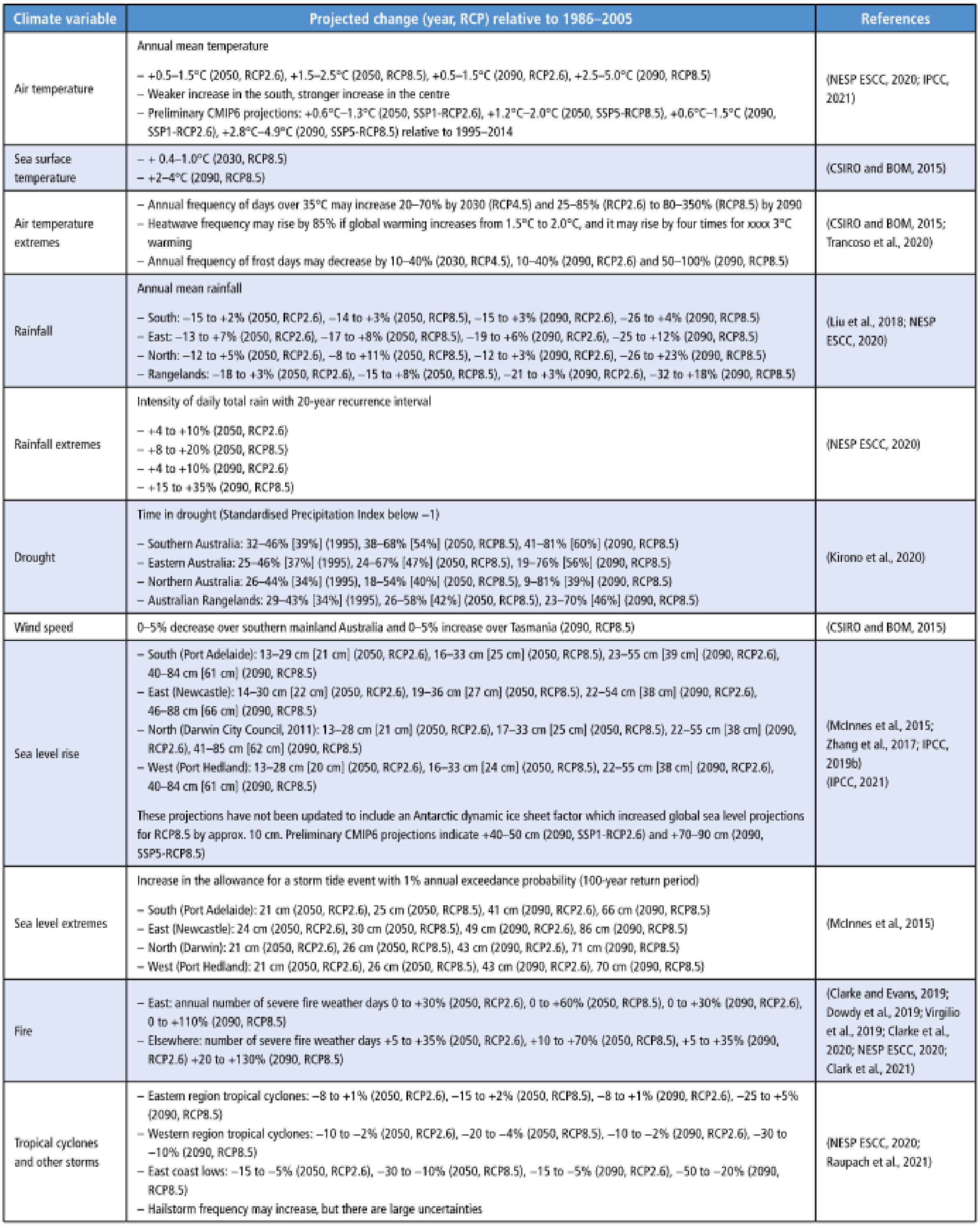
Climate variable	Observed change	References
Air temperature over land	Increased by 1.4°C from 1910 to 2019, with 2019 being the warmest year; 9 of the 10 warmest on record have occurred since 2005; clear anthropogenic attribution.	(BoM and CSIRO, 2020; Trewin et al., 2020; BoM, 2021a; Gutiérrez et al., 2021)
Sea surface temperature	Increased by 1.0°C from 1900 to 2019 (0.09°C/decade), with an increase of 0.16°C–0.20°C/decade since 1950 in the southeast. Eight of the 10 warmest years on record have occurred since 2010.	(BoM and CSIRO, 2020)
Air temperature extremes over land	More extremely hot days and fewer extremely cold days in most regions. Weaker warming trends in minimum temperatures in southeast Australia compared to elsewhere during 1960–2016. Frost frequency in southeast and southwest Australia has been relatively unchanged since the 1980s. Very high monthly maximum or minimum temperatures that occurred around 2% of the time in the past (1960–1989) now occur 11–12% of the time (2005–2019). Multi-day heatwave events have increased in frequency and duration across many regions since 1950. In 2019, the national average maximum temperature exceeded the 99th percentile on 43 days (more than triple the number in any of the years prior to 2000) and exceeded 39°C on 33 days (more than the number observed from 1960 to 2018 combined).	(Perkins-Kirkpatrick et al., 2016; Alexander and Arblaster, 2017; Pepler et al., 2018; BoM and CSIRO, 2020; Perkins-Kirkpatrick and Lewis, 2020; Trancoso et al., 2020)
Sea temperature extremes	Intense marine heatwave in 2011 near western Australia (peak intensity 4°C, duration 100 days). The likelihood of an event of this duration is estimated to be about five times higher than under pre-industrial conditions. Marine heatwave over northern Australia in 2016 (peak intensity 1.5°C, duration 200 days). Marine heatwave in the Tasman Sea and around southeast mainland Australia and Tasmania from September 2015 to May 2016 (peak intensity 2.5°C, duration 250 days)—likelihood of an event of this intensity and duration has increased about 50-fold. Marine heatwave in the Tasman Sea from November 2017 to March 2018 (peak intensity 3°C, duration 100 days). Marine heatwave on the GBR in 2020 (peak intensity 1.2°C, duration 90 days)	(BoM and CSIRO, 2018; BoM, 2020; Laufkötter et al., 2020; Oliver et al., 2021)
Rainfall	Northern Australian rainfall has increased since the 1970s, with an attributable human influence. April to October rainfall has decreased 16% since the 1970s in southwestern Australia (partly due to human influence) and 12% from 2000–2019 in south-eastern Australia. The lowest recorded average rainfall in Australia occurred in 2019.	(Delworth and Zeng, 2014; Knutson and Zeng, 2018; Dey et al., 2019; BoM and CSIRO, 2020; BoM, 2021a)
Rainfall extremes	Hourly extreme rainfall intensities increased by 10–20% in many locations between 1966 to1989 and 1990 to 2013. Daily rainfall associated with thunderstorms increased 13–24% from 1979 to 2016, particularly in northern Australia. Daily rainfall intensity increased in the northwest from 1950 to 2005 and in the east from 1911 to 2014 and decreased in the southwest and Tasmania from 1911 to 2010.	(Donat et al., 2016; Alexander and Arblaster, 2017; Evans et al., 2017; Guerreiro et al., 2018; Dey et al., 2019; BoM and CSIRO, 2020; Bruyère et al., 2020; Dowdy, 2020; Dunn et al., 2020; Gutiérrez et al., 2021)
Drought	Major Australian droughts occurred in 1895–1902, 1914–1915, 1937–1945, 1965–1968, 1982–1983, 1997–2009 and 2017–2019. Fewer droughts have occurred across most of northern and central Australia since the 1970s, and more droughts have occurred in the southwest since the 1970s; drought trends in the southeast have been mixed since the late 1990s.	(Gallant et al., 2013; Delworth and Zeng, 2014; Alexander and Arblaster, 2017; Dai and Zhao, 2017; Knutson and Zeng, 2018; Dey et al., 2019; Spinoni et al., 2019; Dunn et al., 2020; Rauniyar and Power, 2020; BoM, 2021b; Seneviratne et al., 2021)
Wind speed	Wind speed decreased 0.067 m/s/decade over land in the period 1941–2016, with a decrease of 0.062 m/s/decade over land from 1979 to 2015, and a decrease of 0.05–0.10 m/s/decade over land from 1988 to 2019. Wind speed increased 0.02 m/s/year across the Southern Ocean during 1985–2018.	(Troccoli et al., 2012; Young and Ribal, 2019; Blunden and Arndt, 2020; Azorin-Molina et al., 2021)
Sea level rise	Relative SLR was 3.4 mm/year from 1993 to 2019, which includes the influence of internal variability (e.g., ENSO) and anthropogenic greenhouse gases.	(Watson, 2020)
Fire	An increase in the number of extreme fire weather days from July 1950 to June 1985 compared to July 1985 to June 2020, especially in the south and east, partly attributed to climate change. More dangerous conditions for extreme pyro convection events since 1979, particularly in south-eastern Australia. Extreme fire weather in 2019–2020 was at least 30% more likely due to climate change.	(Dowdy and Pepler, 2018; BoM and CSIRO, 2020; van Oldenborgh et al., 2021)
Tropical cyclones and other storms	Fewer tropical cyclones since 1982, with a 22% reduction in translation speed over Australian land areas in the period1949–2016. No significant trend in the number of East Coast Lows. From 1979 to 2016, thunderstorms and dry lightning decreased in spring and summer in northern and central Australia, decreased in the north in autumn, and increased in the southeast in all seasons. Convective rainfall intensity per thunderstorm increased by about 20% in the north and 10% in the south. An increase in the frequency of large to giant hail events across southeastern Queensland and northeastern and eastern New South Wales in the most recent decade. Seven major hail storms over eastern Australia from 2014 to 2020 and three major floods over eastern Australia from 2019 to 2021.	(Pepler et al., 2015b; Ji et al., 2018; Kossin, 2018; BoM and CSIRO, 2020; Dowdy, 2020; ICA, 2021; Bruyère et al., 2020)
Snow	At Spencers Creek (1830 m elevation) in NSW, annual maximum snow depth decreased 10% and length of snow season decreased 5% during 2000–2013 relative to 1954–1999. At Rocky Valley Dam (1650 m elevation) in Victoria, annual maximum snow depth decreased 5.7 cm/decade from 1954 to 2011. At Mt Hotham, Mt Buller and Falls Creek (1638–1760 m elevation), annual maximum snow depth decreased 15%/decade from 1988 to 2013.	(Bhend et al., 2012; Fiddes et al., 2015; Pepler et al., 2015a; BoM and CSIRO, 2020)
Ocean acidification	Average pH of surface waters has decreased since the 1880s by about 0.1 (over 30% increase in acidity).	(BoM and CSIRO, 2020)

Figure 29 Observed climate change for Australia (IPCC, 2022)



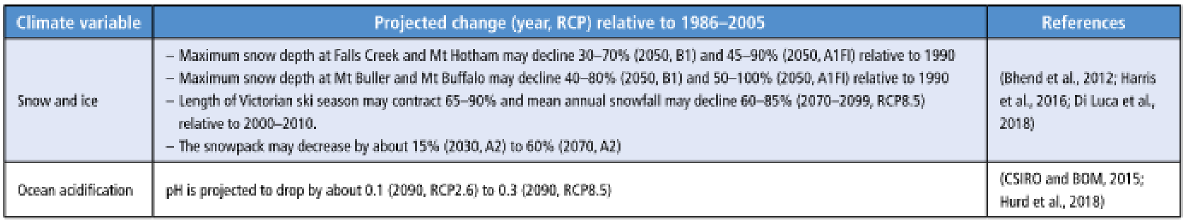
Climate variable	Observed change	References
Air temperature	Increased by 1.1°C in the period 1909–2019. Warmest year on record was 2016, followed by 2018 and 1998, which tied for second warmest. The six years between 2013 and 2020 were among New Zealand's warmest on record.	(MfE, 2020a; NIWA, 2020)
Sea surface temperature	Increased by 0.2°C/decade from 1981 to 2018.	(MfE, 2020a)
Air temperature extremes	Number of frost days (below 0°C) decreased at 12 of 30 sites, the number of warm days (over 25°C) increased at 19 of 30 sites, and the number of heatwave days increased at 18 of 30 sites during 1972–2019. Increase in the frequency of hot February days exceeding the 90th percentile between 1980–1989 and 2010–2019, with some regions showing more than a five-fold increase.	(Harrington, 2020; MfE, 2020a)
Sea temperature extremes	The eastern Tasman Sea experienced a marine heatwave in 2017/2018 lasting 138 days with a maximum intensity of 4.1°C, and another marine heatwave in 2018/2019 lasting 137 days with a maximum intensity of 2.8°C.	(NIWA, 2019; Salinger et al., 2019b; Salinger et al., 2020; Oliver et al., 2021)
Rainfall	From 1960 to 2019, almost half of the 30 sites had an increase in annual rainfall (mostly in the south) and 10 sites (mostly in the north) had a decrease, but few of the trends are statistically significant. Rainfall increased by 2.8% per decade in Whanganui, 2.1% per decade in Milford Sound and 1.3% per decade in Hokitika. Rainfall decreased by 4.3% per decade in Whangarei and 3.2% per decade in Tauranga.	(MfE, 2020a)
Rainfall extremes	The number of days with extreme rainfall increased at 14 of 30 sites and decreased at 11 sites during 1960–2019. Most sites with increasing annual rainfall had more extreme rainfall, and most sites with decreasing annual rainfall had less extreme rainfall.	(MfE, 2020a)
Drought	Drought frequency increased at 13 of 30 sites from 1972 to 2019 and decreased at 9 sites. Drought intensity increased at 14 sites, 11 of which are in the north, and decreased at 9 sites, 7 of which are in the south.	(MfE, 2020a)
Wind speed	Since 1970, the wind belt has often shifted to the south of New Zealand, bringing an overall decrease in wind speed over the country. For 1980–2019, the annual maximum wind gust decreased at 11 of the 14 sites that had enough data to calculate a trend and increased at 2 of the 14 sites.	(MfE, 2020a)
Sea level rise	Increased 1.8 mm/year during 1900–2018 and 2.4 mm/year during 1961–2018, mostly due to climate change.	(Bell and Hannah, 2019)
Fire	Of the 28 sites, 6 sites (Napier, Lake Tekapo, Queenstown, Gisborne, Masterton, and Gore) had an increase in days with very high or extreme fire danger during 1997–2019 and 6 sites (Blenheim, Christchurch, Nelson, Tara Hills, Timaru, and Wellington) had a decrease. An increase in fire impacts during 1988–2018 included homes lost, damaged, threatened and evacuated.	(Pearce, 2018; MfE, 2020a)
Tropical cyclones and other storms	No significant change in storminess. Three major floods and two major hail storms during 2019–2021.	(MfE, 2020a; ICNZ, 2021)
Snow and ice	From 1978 to 2019, the snowline rose 3.7 m/year. From 1977 to 2018, glacier ice volume decreased from 26.6 to 17.9 km^3 (a loss of 33%). From 1978 to 2016, the area of 14 glaciers in the southern Alps declined 21%. The end-of-summer snowline elevation for 50 glaciers rose 300 m from 1949 to 2019. In the southern Alps, extreme glacier mass loss was at least 6 times more likely in 2011 and 10 times more likely in 2018 due to climate change.	(Salinger et al., 2019a; Baumann et al., 2020; Chinn and Chinn, 2020; MfE, 2020a; Salinger et al., 2021; Vargo et al., 2020)
Ocean acidification	The Sub-Antarctic ocean off the Otago coast became 7% more acidic from 1998–2017.	(MfE, 2020a)

Figure 30 Observed climate change for Australia continued (IPCC, 2022)



Climate variable	Projected change (year, RCP) relative to 1986–2005	References
Air temperature	Annual mean temperature – +0.5–1.5°C (2050, RCP2.6), +1.5–2.5°C (2050, RCP8.5), +0.5–1.5°C (2090, RCP2.6), +2.5–5.0°C (2090, RCP8.5) – Weaker increase in the south, stronger increase in the centre – Preliminary CMIP6 projections: +0.6°C–1.3°C (2050, SSP1-RCP2.6), +1.2°C–2.0°C (2050, SSP5-RCP8.5), +0.6°C–1.5°C (2090, SSP1-RCP2.6), +2.8°C–4.9°C (2090, SSP5-RCP8.5) relative to 1995–2014	(NESP ESCC, 2020; IPCC, 2021)
Sea surface temperature	– + 0.4–1.0°C (2030, RCP8.5) – +2–4°C (2090, RCP8.5)	(CSIRO and BOM, 2015)
Air temperature extremes	– Annual frequency of days over 35°C may increase 20–70% by 2030 (RCP4.5) and 25–85% (RCP2.6) to 80–350% (RCP8.5) by 2090 – Heatwave frequency may rise by 85% if global warming increases from 1.5°C to 2.0°C, and it may rise by four times for xxxx 3°C warming – Annual frequency of frost days may decrease by 10–40% (2030, RCP4.5), 10–40% (2090, RCP2.6) and 50–100% (2090, RCP8.5)	(CSIRO and BOM, 2015; Trancoso et al., 2020)
Rainfall	Annual mean rainfall – South: –15 to +2% (2050, RCP2.6), –14 to +3% (2050, RCP8.5), –15 to +3% (2090, RCP2.6), –26 to +4% (2090, RCP8.5) – East: –13 to +7% (2050, RCP2.6), –17 to +8% (2050, RCP8.5), –19 to +6% (2090, RCP2.6), –25 to +12% (2090, RCP8.5) – North: –12 to +5% (2050, RCP2.6), –8 to +11% (2050, RCP8.5), –12 to +3% (2090, RCP2.6), –26 to +23% (2090, RCP8.5) – Rangelands: –18 to +3% (2050, RCP2.6), –15 to +8% (2050, RCP8.5), –21 to +3% (2090, RCP2.6), –32 to +18% (2090, RCP8.5)	(Liu et al., 2018; NESP ESCC, 2020)
Rainfall extremes	Intensity of daily total rain with 20-year recurrence interval – +4 to +10% (2050, RCP2.6) – +8 to +20% (2050, RCP8.5) – +4 to +10% (2090, RCP2.6) – +15 to +35% (2090, RCP8.5)	(NESP ESCC, 2020)
Drought	Time in drought (Standardised Precipitation Index below –1) – Southern Australia: 32–46% [39%] (1995), 38–68% [54%] (2050, RCP8.5), 41–81% [60%] (2090, RCP8.5) – Eastern Australia: 25–46% [37%] (1995), 24–67% [47%] (2050, RCP8.5), 19–76% [56%] (2090, RCP8.5) – Northern Australia: 26–44% [34%] (1995), 18–54% [40%] (2050, RCP8.5), 9–81% [39%] (2090, RCP8.5) – Australian Rangelands: 29–43% [34%] (1995), 26–58% [42%] (2050, RCP8.5), 23–70% [46%] (2090, RCP8.5)	(Kirono et al., 2020)
Wind speed	0–5% decrease over southern mainland Australia and 0–5% increase over Tasmania (2090, RCP8.5)	(CSIRO and BOM, 2015)
Sea level rise	– South (Port Adelaide): 13–29 cm [21 cm] (2050, RCP2.6), 16–33 cm [25 cm] (2050, RCP8.5), 23–55 cm [39 cm] (2090, RCP2.6), 40–84 cm [61 cm] (2090, RCP8.5) – East (Newcastle): 14–30 cm [22 cm] (2050, RCP2.6), 19–36 cm [27 cm] (2050, RCP8.5), 22–54 cm [38 cm] (2090, RCP2.6), 46–88 cm [66 cm] (2090, RCP8.5) – North (Darwin City Council, 2011): 13–28 cm [21 cm] (2050, RCP2.6), 17–33 cm [25 cm] (2050, RCP8.5), 22–55 cm [38 cm] (2090, RCP2.6), 41–85 cm [62 cm] (2090, RCP8.5) – West (Port Hedland): 13–28 cm [20 cm] (2050, RCP2.6), 16–33 cm [24 cm] (2050, RCP8.5), 22–55 cm [38 cm] (2090, RCP2.6), 40–84 cm [61 cm] (2090, RCP8.5) These projections have not been updated to include an Antarctic dynamic ice sheet factor which increased global sea level projections for RCP8.5 by approx. 10 cm. Preliminary CMIP6 projections indicate +40–50 cm (2090, SSP1-RCP2.6) and +70–90 cm (2090, SSP5-RCP8.5)	(McInnes et al., 2015; Zhang et al., 2017; IPCC, 2019b) (IPCC, 2021)
Sea level extremes	Increase in the allowance for a storm tide event with 1% annual exceedance probability (100-year return period) – South (Port Adelaide): 21 cm (2050, RCP2.6), 25 cm (2050, RCP8.5), 41 cm (2090, RCP2.6), 66 cm (2090, RCP8.5) – East (Newcastle): 24 cm (2050, RCP2.6), 30 cm (2050, RCP8.5), 49 cm (2090, RCP2.6), 86 cm (2090, RCP8.5) – North (Darwin): 21 cm (2050, RCP2.6), 26 cm (2050, RCP8.5), 43 cm (2090, RCP2.6), 71 cm (2090, RCP8.5) – West (Port Hedland): 21 cm (2050, RCP2.6), 26 cm (2050, RCP8.5), 43 cm (2090, RCP2.6), 70 cm (2090, RCP8.5)	(McInnes et al., 2015)
Fire	– East: annual number of severe fire weather days 0 to +30% (2050, RCP2.6), 0 to +60% (2050, RCP8.5), 0 to +30% (2090, RCP2.6), 0 to +110% (2090, RCP8.5) – Elsewhere: number of severe fire weather days +5 to +35% (2050, RCP2.6), +10 to +70% (2050, RCP8.5), +5 to +35% (2090, RCP2.6) +20 to +130% (2090, RCP8.5)	(Clarke and Evans, 2019; Dowdy et al., 2019; Virgilio et al., 2019; Clarke et al., 2020; NESP ESCC, 2020; Clark et al., 2021)
Tropical cyclones and other storms	– Eastern region tropical cyclones: –8 to +1% (2050, RCP2.6), –15 to +2% (2050, RCP8.5), –8 to +1% (2090, RCP2.6), –25 to +5% (2090, RCP8.5) – Western region tropical cyclones: –10 to –2% (2050, RCP2.6), –20 to –4% (2050, RCP8.5), –10 to –2% (2090, RCP2.6), –30 to –10% (2090, RCP8.5) – East coast lows: –15 to –5% (2050, RCP2.6), –30 to –10% (2050, RCP8.5), –15 to –5% (2090, RCP2.6), –50 to –20% (2090, RCP8.5) – Hailstorm frequency may increase, but there are large uncertainties	(NESP ESCC, 2020; Raupach et al., 2021)

Figure 31 Projected climate change for Australia (IPCC, 2022)



Climate variable	Projected change (year, RCP) relative to 1986–2005	References
Snow and ice	– Maximum snow depth at Falls Creek and Mt Hotham may decline 30–70% (2050, B1) and 45–90% (2050, A1FI) relative to 1990 – Maximum snow depth at Mt Buller and Mt Buffalo may decline 40–80% (2050, B1) and 50–100% (2050, A1FI) relative to 1990 – Length of Victorian ski season may contract 65–90% and mean annual snowfall may decline 60–85% (2070–2099, RCP8.5) relative to 2000–2010. – The snowpack may decrease by about 15% (2030, A2) to 60% (2070, A2)	(Bhend et al., 2012; Harris et al., 2016; Di Luca et al., 2018)
Ocean acidification	pH is projected to drop by about 0.1 (2090, RCP2.6) to 0.3 (2090, RCP8.5)	(CSIRO and BOM, 2015; Hurd et al., 2018)

Figure 32 Projected climate change for Australia continued (IPCC, 2022)

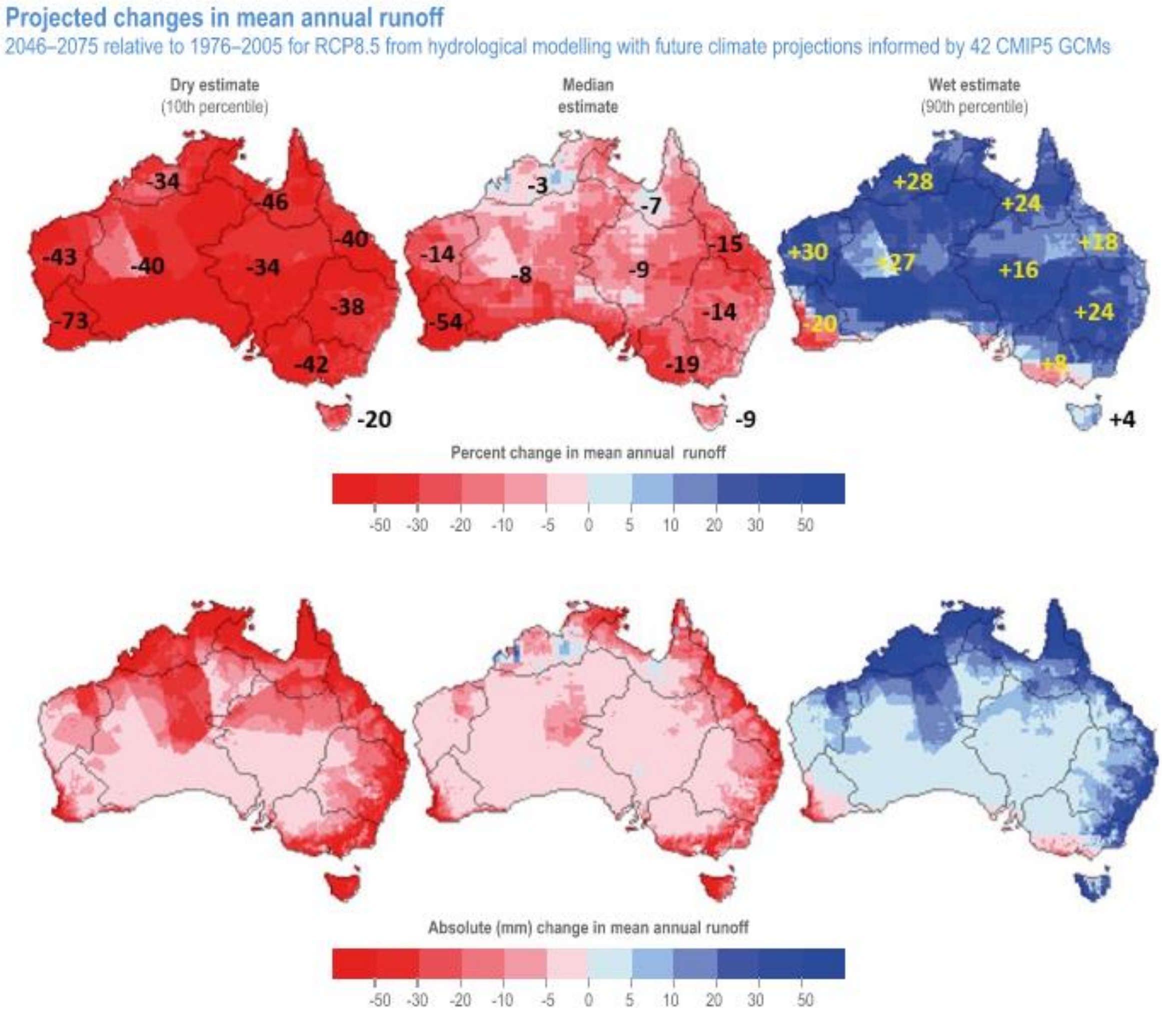


Figure 33 Projected changes in mean annual runoff for 2046-2075 relative to 1976-2005 for RCP8.5 from hydrological modelling with future climate projections (IPCC, 2022)

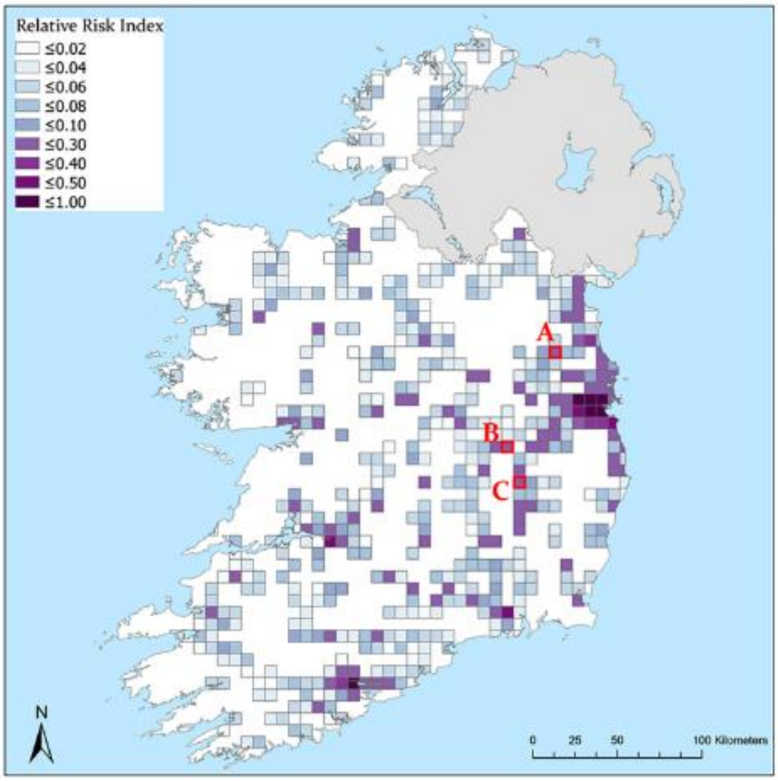


Figure 34 Gridded map of relative fluvial flood risk to the four Irish critical infrastructure sectors (L Hawchar, 2020)

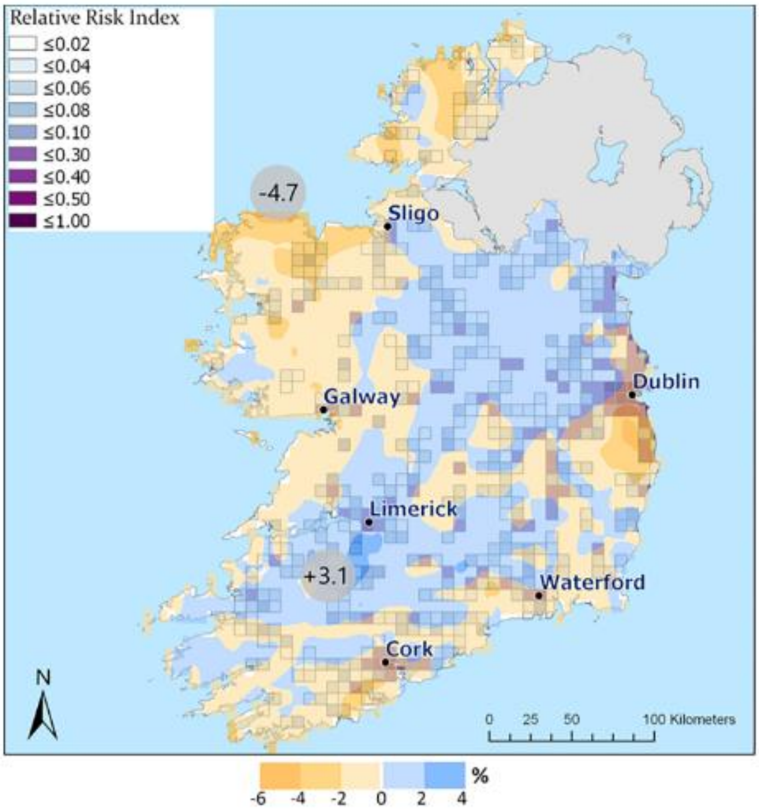


Figure 35 Gridded map of relative fluvial flood risk to the four Irish critical infrastructure sectors and projected change (%) in autumn rainfall, for high-emission scenario (L Hawchar, 2020)

5.5 FURTHER WORKS

Further works from larger specialised working groups are required to overcome practical challenges, such as insight into system functionality, asset-level vulnerability quantification, accurate existing hazard modelling, high-resolution climate change predictions, quantification of consequences of failure, and details of uncertainties at each step of the modelling process.

Further works are required to identify the full list of data providers to ensure comprehensive datasets become available for continuous evolution of the proposed risk assessment. For instance, for obtaining the global data for the UNISDR Global Assessment Report 2015 data portal, it is a joint effort by leading scientific institutions, governments, UN agencies, and development banks, the private sector, and non-governmental organisations.

Further works from researchers are required to consider multiple critical infrastructure sectors, with a view to better understanding the important cascading failures across critical infrastructure sectors.

Further works are required to develop a comprehensive quantitative approach to fully consider the interactions between bidirectional compound risks and aggregate risks.

6 In practice application/ Proof of Concept

This section is to demonstrate the practicality of adopting proposed two-stage taxonomy, HEV risk assessment framework and standardised scoring system in a selected geographical area.

6.1 OPERATING PLATFORM

A GIS based interactive map tool is used, that can show the geographical extents of an area with an ability to toggle the layers representing various attributes.

The overall climate risk assessment configuration presented a part of this report consists of a series of interdependent risk frameworks. The frameworks provide the user a structured approach in where the outputs are cascaded to the subsequent method for further evaluation and tiering for determining appropriate level of screening.

6.2 ASSURANCE OF THE FRAMEWORK

This proof-of-concept provides the assurance that the model results are reliable and valid based on the following rationale:

1. Integrating established risk assessment frameworks into a working configuration where the series of risk assessments work together to provide valuable insights on climate change and natural hazards.
2. Adoption of established and tested methodology such as TMR risk assessment to quantify and classify risks.
3. Considering of both current and future climate scenarios to inform long-term planning.
4. Providing actionable insights for prioritizing infrastructure investments
5. Scalable and replicable process that can be applied to a larger geographic areas or different infrastructure sectors.

By applying this framework, government agencies can get a clear picture and understanding of climate risks related to their infrastructure assets. This enables to make informed choices to allocate resources for enhancing resilience.

6.3 CENTRAL IDEA OF THE FRAMEWORK

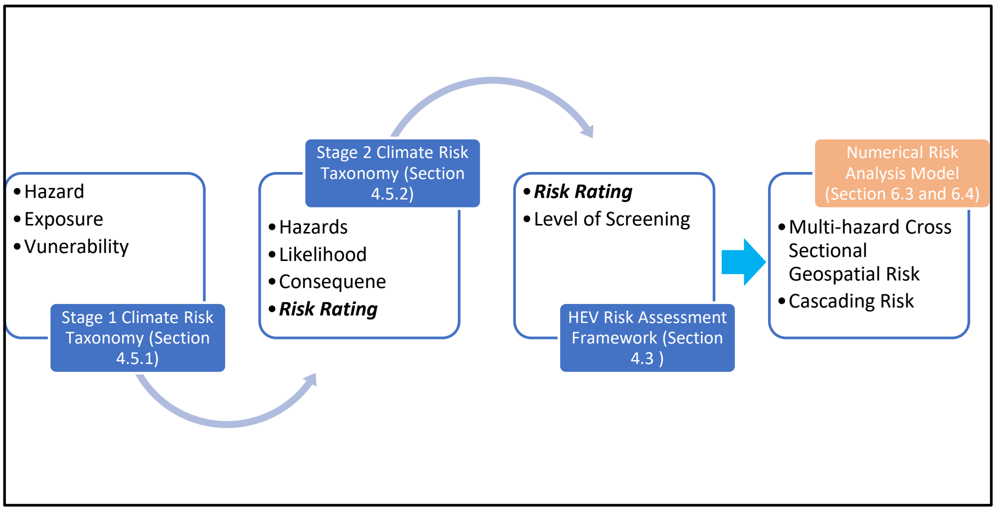


Figure 36 Configuration of Risk Assessment Framework and Dependencies

The framework for climate risk assessment consists of three inter-related assessment processes, refer to Figure 36. They are:

- Two-stage Climate Risk Taxonomy as per Section 3.5**Error! Reference source not found.** of this report
- HEV Risk Assessment Framework such as TMR Risk Assessment Framework as per Section 3.1 of this report
- Modified HEV Risk Assessment Framework and Standardised Quantitative Scoring System as per section 5.3 and 5.4 of this report

Above distinct steps of the risk assessment process have transferable and interrelated metrics enabling them to work together as a series of assessments. Conceptually, the output/results from one method forms an input to another method.

Initially, a Stage 1 Climate Risk Taxonomy enables pre-screening of the hazards that the infrastructure is specifically exposed to and as such makes the detailed risk assessment specific or targeted. The hazard, likelihood and exposure assessment are performed as per Section 3.5.2. This determination from Stage 1 confirms the scope of the detailed risk assessments required in Stage 2.

In Stage 2, datasets of hazards, exposure and vulnerability meeting the proposed taxonomy are made available by relevant stakeholders. The datasets will then be processed through a suitable HEV risk assessment framework such as TMR Risk Assessment framework to determine the vulnerability indices of one or more infrastructure assets and networks impacted by climate hazards. Subsequently, the resultant datasets of hazards, exposure and vulnerability will be calculated using a standardised numerical analysis model to transform climate risks into relative risk indices. Lastly, an interactive map or other visualisation tools allow incorporating the metadata consisting of the relative risk indices and all additional information into the database and become the foundation for postprocessing and presenting climate risk assessment outcome to end users.

6.4 OUTPUTS OF THE RISK ASSESSMENT FRAMEWORK

The outputs from the above-described interrelated configuration of risk assessment framework are tabulated as below:

Risk Assessment Framework	Outputs
Stage 1 Climate Risk Taxonomy	Preliminary Hazards Identification and assessment. Scope of Stage 2 assessment.
Stage 2 Climate Risk Taxonomy	Datasets of hazards, exposure and vulnerability meeting the allocated screening class.
HEV Risk Assessment Framework such as TMR Risk Assessment	Risk rating or indices of vulnerability.
Quantitative Risk Analysis Model	Relative risk indices and metadata that can be incorporated into an interactive map or other visualisation tools.

Table 12 Outputs from the Risk Assessment Frameworks

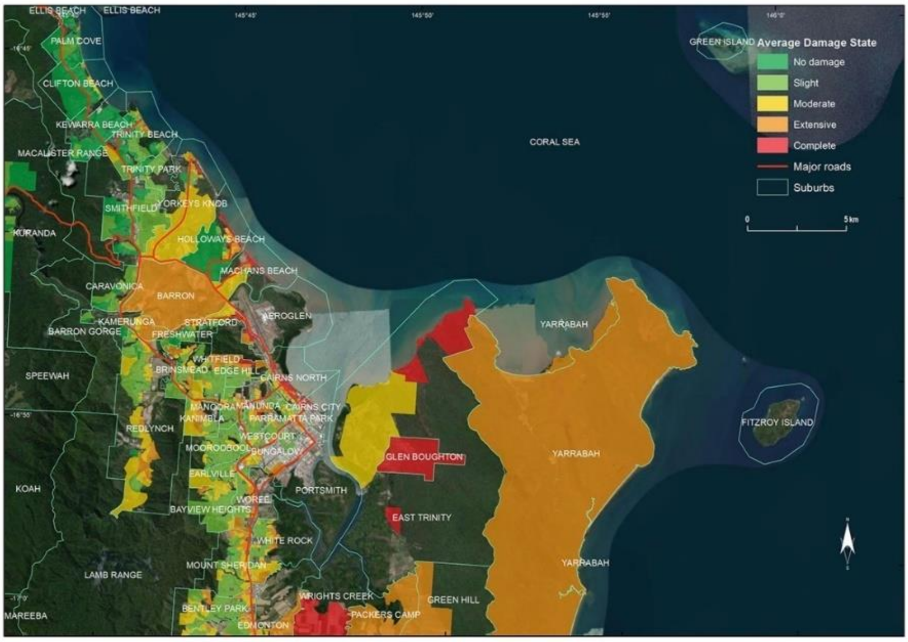
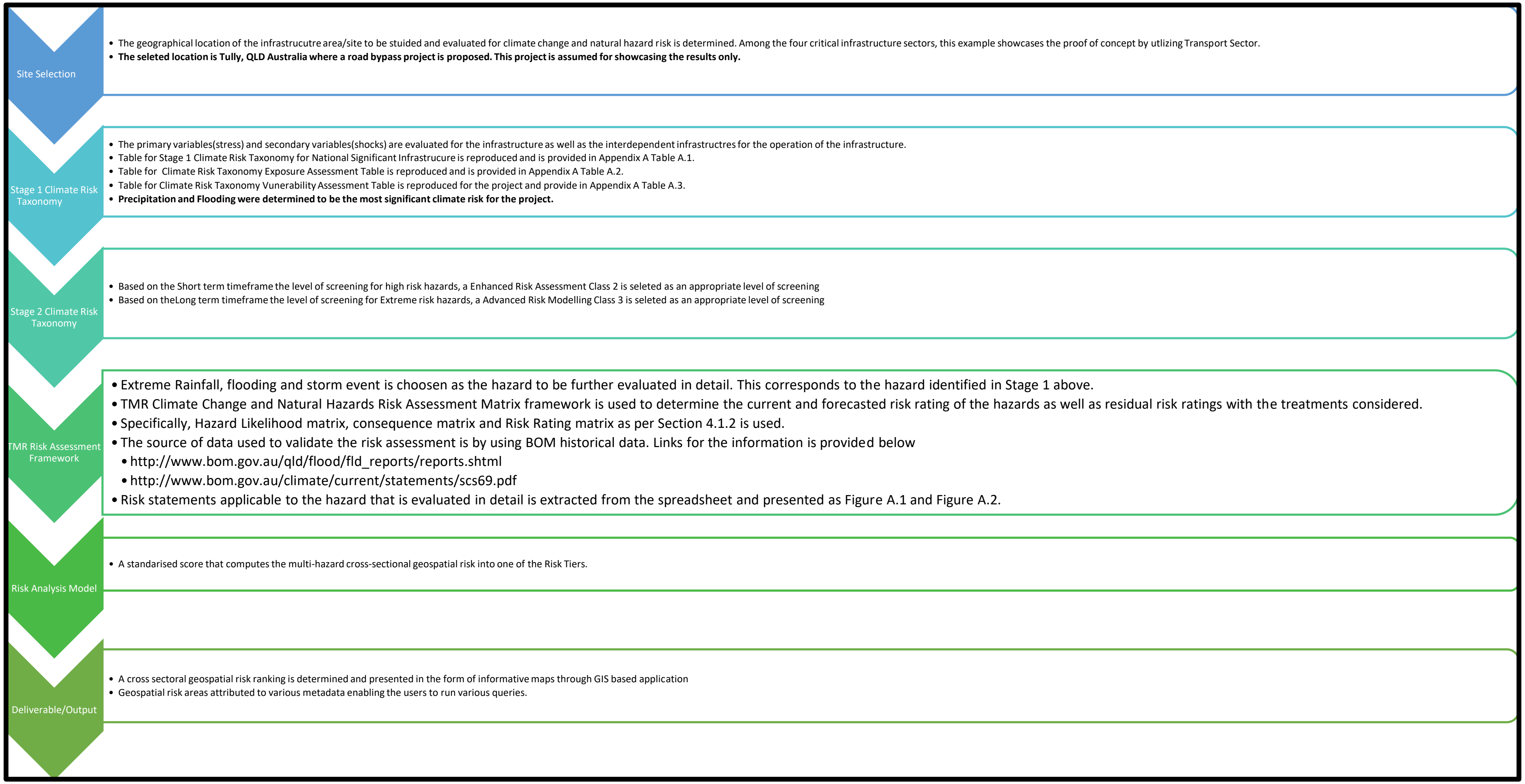


Figure 37 GIS based geospatial risk map.

6.5 IN PRACTICE APPLICATION/ PROOF OF CONCEPT

The section below illustrates the functioning of the risk assessment framework applied to a geographical area. This is presented in the form of a flow chart with appropriate cross-referencing to sources or Appendices as applicable.



Site Selection

- The geographical location of the infrastrucutre area/site to be stuided and evaluated for climate change and natural hazard risk is determined. Among the four critical infrastructure sectors, this example showcases the proof of concept by utlizing Transport Sector.
- **The seleted location is Tully, QLD Australia where a road bypass project is proposed. This project is assumed for showcasing the results only.**

Stage 1 Climate Risk Taxonomy

- The primary variables(stress) and secondary variables(shocks) are evaluated for the infrastructure as well as the interdependent infrastructres for the operation of the infrastructure.
- Table for Stage 1 Climate Risk Taxonomy for National Significant Infrastrucure is reproduced and is provided in Appendix A Table A.1.
- Table for Climate Risk Taxonomy Exposure Assessment Table is reproduced and is provided in Appendix A Table A.2.
- Table for Climate Risk Taxonomy Vunerability Assessment Table is reproduced for the project and provide in Appendix A Table A.3.
- **Precipitation and Flooding were determined to be the most significant climate risk for the project.**

Stage 2 Climate Risk Taxonomy

- Based on the Short term timeframe the level of screening for high risk hazards, a Enhanced Risk Assessment Class 2 is seleted as an appropriate level of screening
- Based on theLong term timeframe the level of screening for Extreme risk hazards, a Advanced Risk Modelling Class 3 is seleted as an appropriate level of screening

TMR Risk Assessment Framework

- Extreme Rainfall, flooding and storm event is choosen as the hazard to be further evaluated in detail. This corresponds to the hazard identified in Stage 1 above.
- TMR Climate Change and Natural Hazards Risk Assessment Matrix framework is used to determine the current and forecasted risk rating of the hazards as well as residual risk ratings with the treatments considered.
- Specifically, Hazard Likelihood matrix, consequence matrix and Risk Rating matrix as per Section 4.1.2 is used.
- The source of data used to validate the risk assessment is by using BOM historical data. Links for the information is provided below
  - http://www.bom.gov.au/qld/flood/fld_reports/reports.shtml
  - http://www.bom.gov.au/climate/current/statements/scs69.pdf
- Risk statements applicable to the hazard that is evaluated in detail is extracted from the spreadsheet and presented as Figure A.1 and Figure A.2.

Risk Analysis Model

- A standarised score that computes the multi-hazard cross-sectional geospatial risk into one of the Risk Tiers.

Deliverable/Output

- A cross sectoral geospatial risk ranking is determined and presented in the form of informative maps through GIS based application
- Geospatial risk areas attributed to various metadata enabling the users to run various queries.

Figure 38 Flow Chart showcasing the Proof-of Concept for an assumed project located at Tully, QLD Australia

		Is the climate-related hazard likely to affect the infrastructure (Road)	Does this infrastructure depend on other assets or networks, whose failure could lead to its own failure
Primary variables (stress)	Air temperature	No	No
	Humidity	No	No
	Sea surface temperature	No	No
	Precipitation	**Yes**	**Yes**
	Seal level rise	No	No
	Wind and hail	No	No
	Coastal inundation	No	No
	Drought	No	No
	Frost	No	No
Secondary variables (shocks)	Precipitation	**Yes**	**Yes**
	Wind and hail	No	No
	Bushfire	No	/No
	Coastal inundation	No	No
	Cyclones/storms	No	No
	Flooding	**Yes**	**Yes**
	Heatwave	No	No
	Earthquake	No	No
	Tsunami	No	No

Table 13 Stage 1 Climate Risk Taxonomy for National Significant Infrastructures

Q1: Is the occurrence of the climate-related hazard possible for the investigation infrastructure?	
Yes ->	**To be considered in the climate risk assessment**
~~**No ->**~~	~~Do not need to be considered in the climate risk assessment~~
Q2: Is the infrastructure related to other infrastructure assets/networks, failure of that assets/networks will result in failure of the investigation infrastructure?	
Yes ->	**Carry out risk assessment on that infrastructure assets/networks**
~~**No ->**~~	~~No action is required~~

Table 14 Climate Risk Taxonomy Exposure Assessment Table

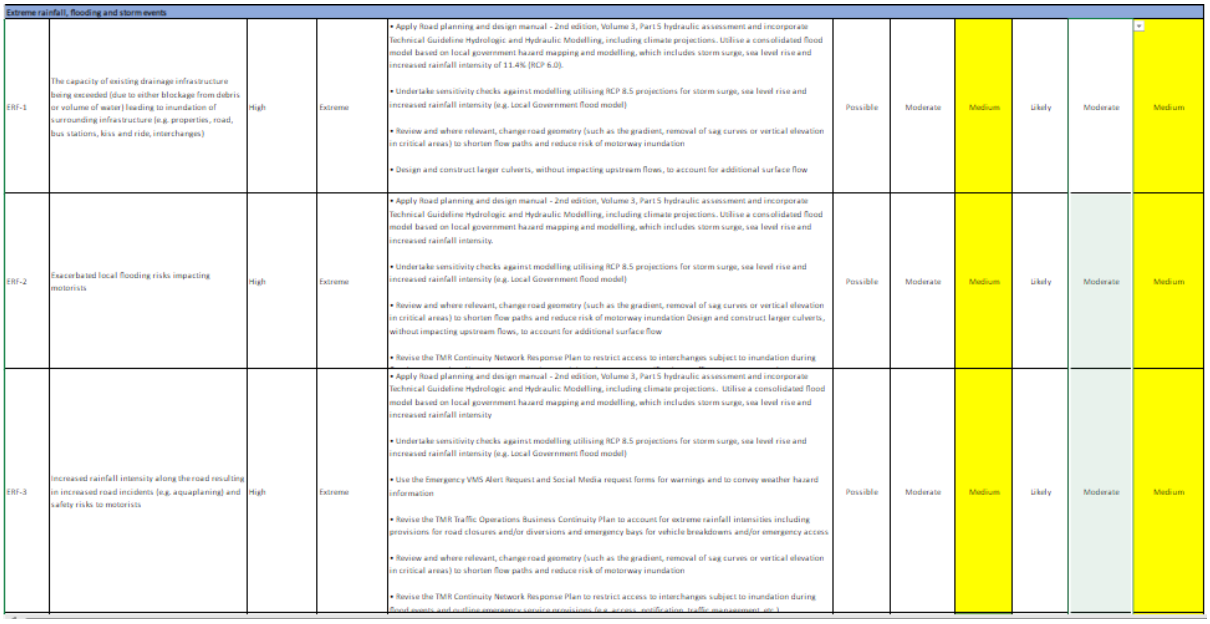
		Roads
Primary variables (stress)	Air temperature	No
	Humidity	No
	Sea surface temperature	No
	Precipitation	Yes
	Seal level rise	No
	Wind and hail	No
	Coastal inundation	No
	Drought	No
	Frost	No

Secondary variables (shocks)	Precipitation	Yes
	Wind and hail	No
	Bushfire	No
	Coastal inundation	No
	Cyclones/storms	No
	Flooding	Yes
	Heatwave	No
	Earthquake	No
	Tsunami	No

Table 15 Climate Risk Taxonomy Vulnerability Assessment Table

Extreme rainfall, flooding and storm events									
ERF-1	Increased incidence of extreme rainfall events and subsequent flooding resulting in:	The capacity of existing drainage infrastructure being exceeded (due to either blockage from debris or volume of water) leading to inundation of surrounding infrastructure (e.g. properties, road, bus stations, kiss and ride, interchanges)	Direct	Likely	Major	High	Almost Certain	Major	Extreme
ERF-2		Exacerbated local flooding risks impacting motorists	Direct	Likely	Major	High	Almost Certain	Major	Extreme
ERF-3		Increased rainfall intensity along the road resulting in increased road incidents (e.g. aquaplaning) and safety risks to motorists	Direct	Likely	Major	High	Almost Certain	Major	Extreme
ERF-4		An increased safety risk and disruption to the users of the cycle / pedestrian network due to inundation of infrastructure	Direct	Likely	Moderate	Medium	Almost Certain	Moderate	High
ERF-5		Water damage to electrical infrastructure (ramp metering, signals and variable speed limit signs) resulting in disruption of road operation	Direct	Likely	Moderate	Medium	Almost Certain	Moderate	High
ERF-6		Erosion of infrastructure foundations resulting in the exposure of concrete (e.g. road base, drainage infrastructure, pier supports), particularly along river and creek crossings	Direct	Likely	Moderate	Medium	Almost Certain	Moderate	High
ERF-7		Increased risk of landslip (e.g. weakened verges and decreased slope stability) in surrounding areas resulting in damage to infrastructure	Direct	Likely	Moderate	Medium	Almost Certain	Moderate	High
ERF-8		Accelerated degradation of assets from increased rainfall intensities and prolonged flooding resulting in increased maintenance and operational costs and repairs	Direct	Likely	Moderate	Medium	Almost Certain	Moderate	High
ERF-9		Increased risk of additional scour and erosional impacts on surrounding waterways and the associated environmental impacts (e.g. water quality, ecological implications for species)	Direct	Likely	Moderate	Medium	Almost Certain	Moderate	High
ERF-10		Increased stormwater flow from surrounding developed areas contributing to additional water volumes in drainage lines and other stormwater infrastructure (e.g. culverts) resulting in additional localised flooding impacts	Indirect	Likely	Major	High	Almost Certain	Major	Extreme
ERF-11		Localised ponding leading to an increased attraction for animals resulting in increased hazards for fauna / automobile accidents.	Indirect	Likely	Major	High	Almost Certain	Major	Extreme
ERF-12		Power outages at substations disrupting supply to electrical and communications systems impacting operation of the road	Indirect	Likely	Moderate	Medium	Almost Certain	Moderate	High
ERF-13		Surrounding areas being inundated, resulting in an increase of motorists using the road as an escape route and potential decrease in safety along the road due to increased traffic in a hazard event	Indirect	Likely	Major	High	Almost Certain	Major	Extreme

Table 16 Risk Assessment of Extreme Rainfall, flooding and storm events



Extreme rainfall, flooding and storm events										
ERF-1	The capacity of existing drainage infrastructure being exceeded (due to either blockage from debris or volume of water) leading to inundation of surrounding infrastructure (e.g. properties, road, bus stations, kiss and ride, interchanges)	High	Extreme	• Apply Road planning and design manual - 2nd edition, Volume 3, Part 5 hydraulic assessment and incorporate Technical Guideline Hydrologic and Hydraulic Modelling, including climate projections. Utilise a consolidated flood model based on local government hazard mapping and modelling, which includes storm surge, sea level rise and increased rainfall intensity of 11.4% (RCP 6.0). • Undertake sensitivity checks against modelling utilising RCP 8.5 projections for storm surge, sea level rise and increased rainfall intensity (e.g. Local Government flood model) • Review and where relevant, change road geometry (such as the gradient, removal of sag curves or vertical elevation in critical areas) to shorten flow paths and reduce risk of motorway inundation • Design and construct larger culverts, without impacting upstream flows, to account for additional surface flow	Possible	Moderate	Medium	Likely	Moderate	Medium
ERF-2	Exacerbated local flooding risks impacting motorists	High	Extreme	• Apply Road planning and design manual - 2nd edition, Volume 3, Part 5 hydraulic assessment and incorporate Technical Guideline Hydrologic and Hydraulic Modelling, including climate projections. Utilise a consolidated flood model based on local government hazard mapping and modelling, which includes storm surge, sea level rise and increased rainfall intensity. • Undertake sensitivity checks against modelling utilising RCP 8.5 projections for storm surge, sea level rise and increased rainfall intensity (e.g. Local Government flood model) • Review and where relevant, change road geometry (such as the gradient, removal of sag curves or vertical elevation in critical areas) to shorten flow paths and reduce risk of motorway inundation Design and construct larger culverts, without impacting upstream flows, to account for additional surface flow • Revise the TMR Continuity Network Response Plan to restrict access to interchanges subject to inundation during	Possible	Moderate	Medium	Likely	Moderate	Medium
ERF-3	Increased rainfall intensity along the road resulting in increased road incidents (e.g. aquaplaning) and safety risks to motorists	High	Extreme	• Apply Road planning and design manual - 2nd edition, Volume 3, Part 5 hydraulic assessment and incorporate Technical Guideline Hydrologic and Hydraulic Modelling, including climate projections. Utilise a consolidated flood model based on local government hazard mapping and modelling, which includes storm surge, sea level rise and increased rainfall intensity • Undertake sensitivity checks against modelling utilising RCP 8.5 projections for storm surge, sea level rise and increased rainfall intensity (e.g. Local Government flood model) • Use the Emergency VMS Alert Request and Social Media request forms for warnings and to convey weather hazard information • Revise the TMR Traffic Operations Business Continuity Plan to account for extreme rainfall intensities including provisions for road closures and/or diversions and emergency bays for vehicle breakdowns and/or emergency access • Review and where relevant, change road geometry (such as the gradient, removal of sag curves or vertical elevation in critical areas) to shorten flow paths and reduce risk of motorway inundation • Revise the TMR Continuity Network Response Plan to restrict access to interchanges subject to inundation during flood events and outline emergency service provisions (e.g. access, notification, traffic management, etc.)	Possible	Moderate	Medium	Likely	Moderate	Medium

Table 17 Residual Risk Assessment of Extreme Rainfall, flooding and storm events, shown for few risk statements.

Above results will be processed via the numerical analysis model to enable both the relative risks presented in the form of a heat map and hot spots thereby indicating the level of risk that exists for the area under the study.

The platform categorises the area depending upon the risk score and allocates the spatial area into different layers. The layering of the area enables the user to extract data or run queries based on various interest or curiosities. One of the layering in the tool is to have different layers representing high priority climate risk areas and critical infrastructure assets.
The tool will further enable government agencies/users to retrieve meta data corresponding to the guidelines provided in the taxonomy and estimated costs for projects in the pipeline to enhance resilience for climate risks.

The platform allows the user to output easy to read and communicate tabulated data or reports for high-risk projects based on region/sector/project value by making filtering choices within the tool.

6.6 CASE STUDY

Figure 39 to Figure 45 showcases the step-by-step application of the high-level GIS-based approach following a modified HEV risk assessment framework assessing relative fluvial flood risk to the four Irish critical infrastructure sectors (Transport, Energy, Water and Telecommunication) in paper A GIS-based framework for high-level climate change risk assessment of critical infrastructure (L Hawchar et al, 2020). This is to justify that the proposed concept in this report has the potential to suit risk assessment at a national level for Australia. Refer to the published paper for more information.

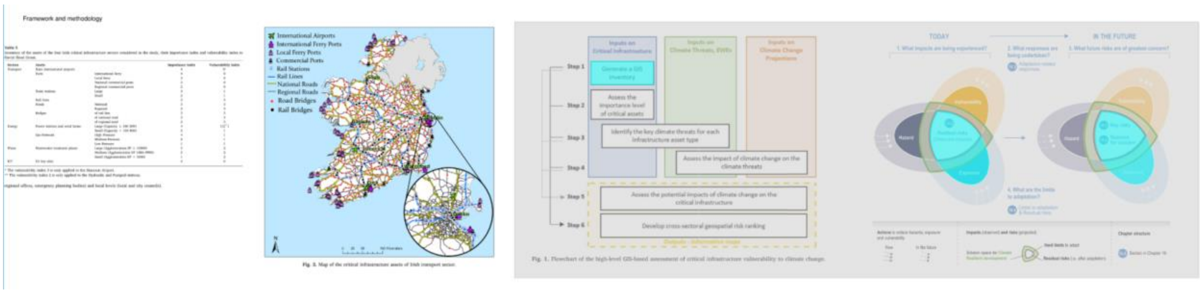


Figure 39 Generate a GIS inventory

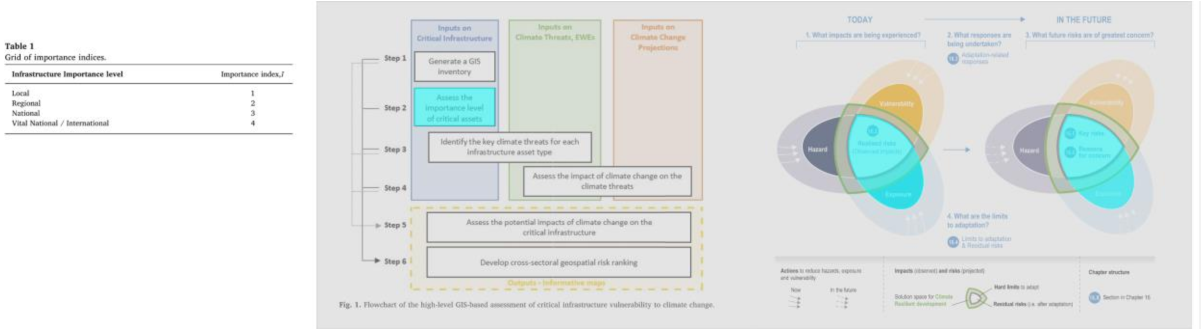


Table 1
Grid of importance indices.

Infrastructure Importance level	Importance index,*I*
Local	1
Regional	2
National	3
Vital National / International	4

Figure 40 Assess the importance level of critical assets

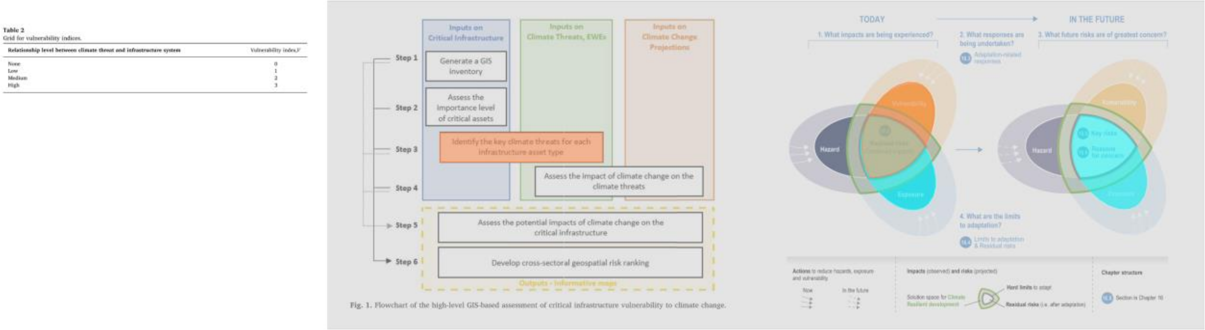


Table 2
Grid for vulnerability indices.

Relationship level between climate threat and infrastructure system	Vulnerability index,*V*
None	0
Low	1
Medium	2
High	3

Figure 41 Identify the key climate threats for each infrastructure asset type

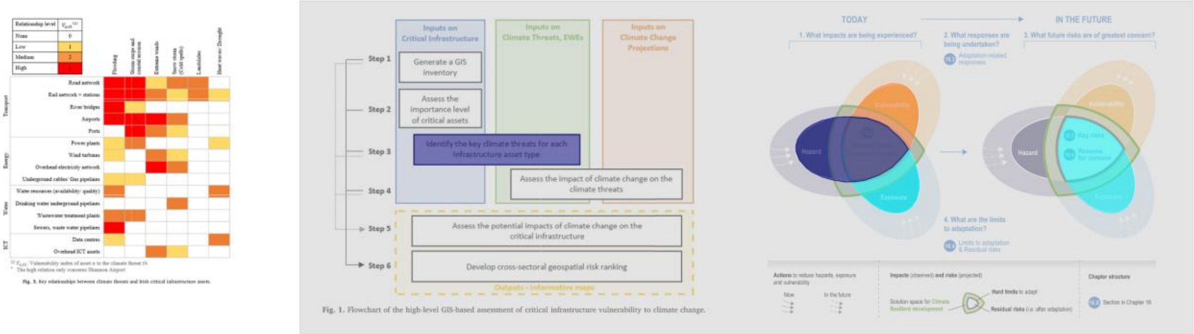


Fig. 3. Key relationships between climate threats and Irish critical infrastructure assets.

Fig. 1. Flowchart of the high-level GIS-based assessment of critical infrastructure vulnerability to climate change.

Figure 42 Assess the impact of climate change on the climate threats

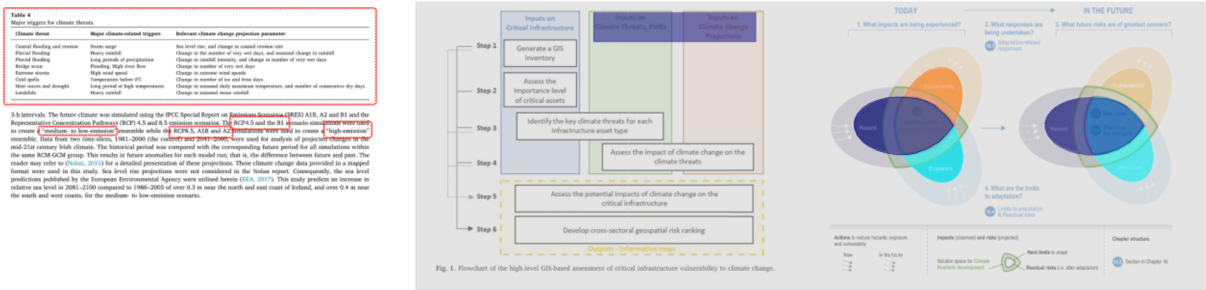


Table 4
Major triggers for climate threats.

Climate threat	Major climate-related triggers	Relevant climate change projection parameter
Coastal flooding and erosion	Storm surge	Sea level rise, and change in coastal erosion rate
Fluvial flooding	Heavy rainfall	Change in the number of very wet days, and seasonal change in rainfall
Pluvial flooding	Long periods of precipitation	Change in rainfall intensity, and change in number of very wet days
Bridge scour	Flooding, High river flow	Change in number of very wet days
Extreme storms	High wind speed	Change in extreme wind speeds
Cold spells	Temperature below 0°C	Change in number of ice and frost days
Heat waves and drought	Long period of high temperatures	Change in seasonal daily maximum temperature, and number of consecutive dry days
Landslide	Heavy rainfall	Change in seasonal mean rainfall

3-h intervals. The future climate was simulated using the IPCC Special Report on Emissions Scenarios (SRES) A1B, A2 and B1 and the Representative Concentration Pathways (RCP) 4.5 and 8.5 emission scenarios. The RCP4.5 and the B1 scenario simulations were used to create a "medium- to low-emission" ensemble while the RCP8.5, A1B and A2 simulations were used to create a "high-emission" ensemble. Data from two time-slices, 1981–2000 (the control) and 2041–2060, were used for analysis of projected changes in the mid-21st century Irish climate. The historical period was compared with the corresponding future period for all simulations within the same RCM-GCM group. This results in future anomalies for each model run; that is, the difference between future and past. The reader may refer to (Nolan, 2015) for a detailed presentation of these projections. These climate change data provided in a mapped format were used in this study. Sea level rise projections were not considered in the Nolan report. Consequently, the sea level predictions published by the European Environmental Agency were utilised herein (EEA, 2017). This study predicts an increase in relative sea level in 2081–2100 compared to 1986–2005 of over 0.3 m near the north and east coast of Ireland, and over 0.4 m near the south and west coasts, for the medium- to low-emission scenario.

Fig. 1. Flowchart of the high-level GIS-based assessment of critical infrastructure vulnerability to climate change.

Figure 43 Inputs on climate change projections

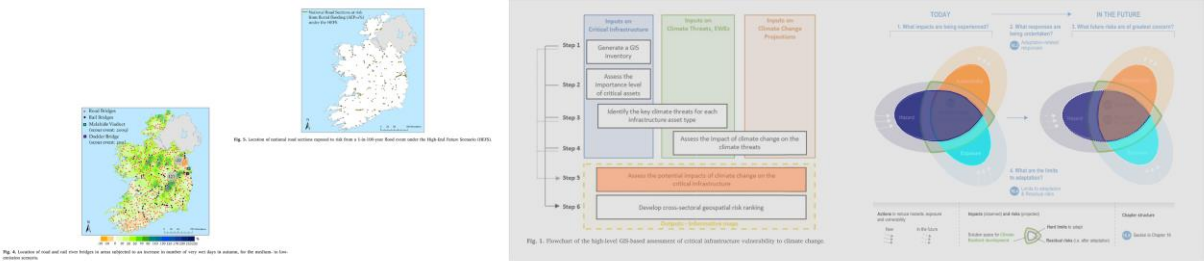


Fig. 4. Location of road and rail river bridges in areas subjected to an increase in number of very wet days in autumn, for the medium- to low-emission scenario.

Fig. 5. Location of national road sections exposed to risk from a 1-in-100-year flood event under the High-End Future Scenario (HEFS).

Fig. 1. Flowchart of the high-level GIS-based assessment of critical infrastructure vulnerability to climate change.

Figure 44 Assess the potential impacts of climate change on the critical infrastructure

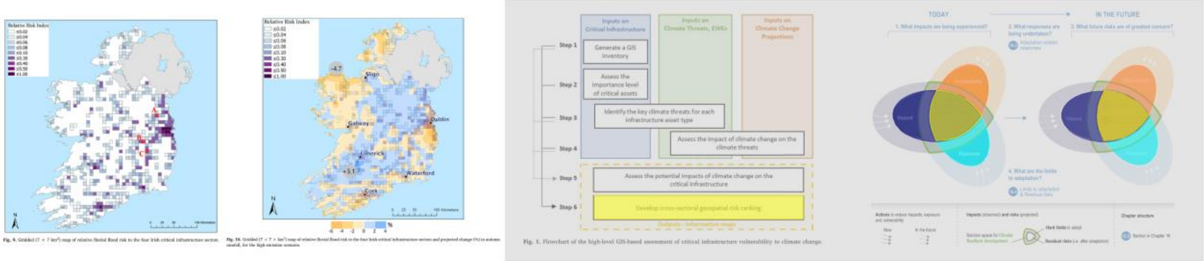


Fig. 9. Gridded (7 × 7 km²) map of relative fluvial flood risk to the four Irish critical infrastructure sectors.

Fig. 10. Gridded (7 × 7 × km²) map of relative fluvial flood risk to the four Irish critical infrastructure sectors and projected change (%) in autumn rainfall, for the high-emission scenario.

Fig. 1. Flowchart of the high-level GIS-based assessment of critical infrastructure vulnerability to climate change.

Figure 45 Develop cross-sectional geospatial risk ranking

7 Challenges and Recommendations

7.1 CLIMATE RESILIENCE CHALLENGES FOR INFRASTRUCTURE ASSETS

Government faces significant challenges in enhancing infrastructure climate resilience due to Australia's diverse climate, aging infrastructure, coordination complexities, and socio-economic disparities. Below is a detailed examination of these key challenges, highlighting their implications for infrastructure planning and resilience.

7.1.1 Variability of Climate Hazards Across Australia

One of the primary challenges in planning for climate resilience is the variability of climate hazards across Australia's vast geography, with different regions facing distinct climate risks.

This variability necessitates localised resilience strategies tailored to the unique risks of each region, complicating national-level planning efforts (Infrastructure Australia, 2021). This then creates challenges in achieving a nationally consistent yet adaptable approach to climate resilience across all regions.

7.1.2 Limitations of Climate Modelling

Climate modelling is a crucial tool for infrastructure planning, yet it has inherent limitations that restrict its effectiveness in predicting the precise timing, severity, and frequency of future climate events. Models, such as those produced by the CSIRO and BOM, provide valuable projections but cannot offer exact forecasts, leaving uncertainties in planning for climate resilience. These limitations challenge infrastructure decision-makers, who must navigate the uncertainty of future climate scenarios while making long-term investments in resilience (Australian Government, 2023).

7.1.3 Short-Term Focus in Economic Decision-Making

Short-term economic decision-making often prioritises immediate financial gains over long-term resilience against climate risks, posing a significant challenge for infrastructure planning. Many infrastructure projects are driven by cost-efficiency and short-term economic benefits, potentially overlooking future climate-related vulnerabilities. This focus on short-term returns can hinder investments in resilient infrastructure, leading to higher long-term costs associated with repairs, maintenance, and climate-related damage (Productivity Commission, 2022).

7.1.4 Aging and Legacy Infrastructure

Much of Australia's critical infrastructure is aging and was built to historical standards that do not account for modern climate risks. Bridges, roads, water systems, and energy grids are particularly vulnerable, as they were not designed to withstand today's extreme weather conditions, such as heatwaves, severe storms, and flooding. Retrofitting and upgrading these assets to meet current climate resilience standards is costly and logistically challenging, especially for infrastructure in rural or remote areas (Infrastructure Australia, 2021).

7.1.5 Complexity in Coordination and Capacity Constraints

Developing climate-resilient infrastructure requires coordination across multiple levels of government, regulatory bodies, and industry stakeholders, each with differing priorities, regulations, and capacities. Implementing climate resilience reforms necessitates navigating this complex governance structure, which can lead to delays and inconsistencies. Additionally, the infrastructure sector faces capacity constraints and a need for large-scale upskilling of staff to manage and implement resilience projects effectively (Australian Government, 2023).

7.1.6 Limited Data and Modelling Tools

The effectiveness of climate resilience planning is constrained by limited data and modelling tools. Accurate data on climate risks, asset vulnerabilities, and infrastructure interdependencies are often challenging to access, making comprehensive risk assessments difficult. Existing modelling tools may also fail to capture multi-hazard risks (e.g., heatwaves followed by flooding) or the complex interdependencies between infrastructure systems, such as the reliance of telecommunications on energy networks (Infrastructure Australia, 2021).

7.1.7 Unequal Distribution of Risks and Impacts

Climate risks are unevenly distributed across Australia, with vulnerable communities disproportionately affected by climate impacts. These communities often face greater challenges in accessing resilient infrastructure, such as flood defences, reliable energy sources, and communication networks. Additionally, limited resources and support make it harder for these areas to recover from climate-related disruptions (Productivity Commission, 2022).

7.1.8 Public Perception and Awareness

A lack of public awareness and understanding of climate risks to infrastructure poses another barrier to climate resilience. Many Australians are unaware of the long-term benefits of resilient infrastructure or the costs of inaction. This lack of awareness can reduce public support for resilience investments and hinder policy implementation, as communities may not recognise the value of upfront investments in resilience measures (Australian Government, 2023).

7.2 RECOMMENDATIONS TO IMPROVE CLIMATE RESOLIENCE

To improve infrastructure climate resilience in Australia, a comprehensive set of recommendations has been proposed, addressing various stages of infrastructure planning, design, and management. These recommendations aim to create a unified, resilient infrastructure framework capable of withstanding the diverse and increasing impacts of climate change across Australia.

7.2.1 Mandating Climate Risk Assessments

Integrating climate risk assessments into the planning, design, and approval processes for all infrastructure projects is a foundational step toward resilience. This includes both new and existing infrastructure and requires a thorough understanding of current and future climate hazards, exposure levels, and potential vulnerabilities. By mandating these assessments, asset managers and developers can make informed decisions on infrastructure design and location, ensuring that long-term climate risks are addressed early in the planning process. The Infrastructure Sustainability Council of Australia (ISCA) advocates for such integration, stressing that climate risk assessments should be standardised to help identify regional climate impacts and build localised resilience (ISCA, 2023).

7.2.2 Implementing a Risk Classification System

A standardised risk classification system across sectors would enhance infrastructure resilience by categorising risks based on severity, thereby guiding resource allocation and prioritisation. This system would classify infrastructure into risk categories such as low, moderate, high, and critical, enabling planners to focus efforts on assets most vulnerable to climate impacts. By categorising risks, government agencies and asset owners can prioritise resilience investments and effectively allocate resources where they are needed most. This approach aligns with Infrastructure Australia's calls for a risk-based framework that supports proactive and targeted adaptation (Infrastructure Australia, 2021).

7.2.3 Climate-Resilient Design Standards

Adopting climate-resilient design standards for all new infrastructure projects is essential in adapting to changing climate patterns. These standards should reflect future projections, including increased temperatures, more intense storms, and rising sea levels, ensuring that infrastructure is capable of withstanding these projected changes. Implementing climate-resilient standards will reduce the need for costly retrofits and improve the long-term sustainability of new infrastructure projects (Australian Building Codes Board, 2022).

7.2.4 Establishing a Coordinated National Resilience Strategy

A coordinated national approach to resilience planning is essential to unify efforts across Australia. This strategy should involve collaboration between federal, state, and local governments, as well as private sector stakeholders and communities, to ensure consistent resilience planning. A national strategy can provide a clear framework that aligns local efforts with broader resilience goals, facilitating efficient resource sharing and avoiding duplicated efforts. This coordination is critical for managing infrastructure interdependencies and building a resilient national infrastructure network (Australian Government, 2023).

7.2.5 Advanced Climate Modelling and Real-Time Monitoring

Developing advanced climate modelling and real-time monitoring tools would significantly improve Australia's capacity to predict climate risks and inform resilience strategies. By integrating real-time data from climate models and sensors, asset managers can better understand how various climate factors affect infrastructure systems. Real-time monitoring allows for rapid response during extreme events and aids in assessing infrastructure health post-event, while advanced climate models provide the necessary data to inform long-term planning. Enhancing these capabilities supports proactive resilience planning, as recommended by both CSIRO and the Bureau of Meteorology, who emphasise the importance of real-time data for managing climate variability (CSIRO, 2023).

7.2.6 Incentivising Investment in Resilient Infrastructure

To encourage the development of climate-resilient infrastructure, financial incentives should be introduced. Governments can promote investment in resilience by offering tax incentives, subsidies, and resilience bonds, which lower the financial barriers for both public and private sector stakeholders. By creating a favourable investment climate, these incentives support both innovation and widespread adoption of resilient infrastructure practices (Productivity Commission, 2022).

7.2.7 Regulatory Reforms

Updating regulatory frameworks to enforce resilience standards across sectors is crucial for implementing consistent climate resilience practices nationwide. These reforms should include revising building codes, engineering standards, and environmental regulations to ensure that resilience is built into infrastructure projects from the start. Updated standards must consider evolving climate risks, requiring infrastructure to meet both current and future resilience needs. A standardised regulatory framework provides a strong foundation for resilient infrastructure and aligns with Infrastructure Australia's emphasis on enforceable resilience standards (Infrastructure Australia, 2021).

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Other references refer to Section 5.1