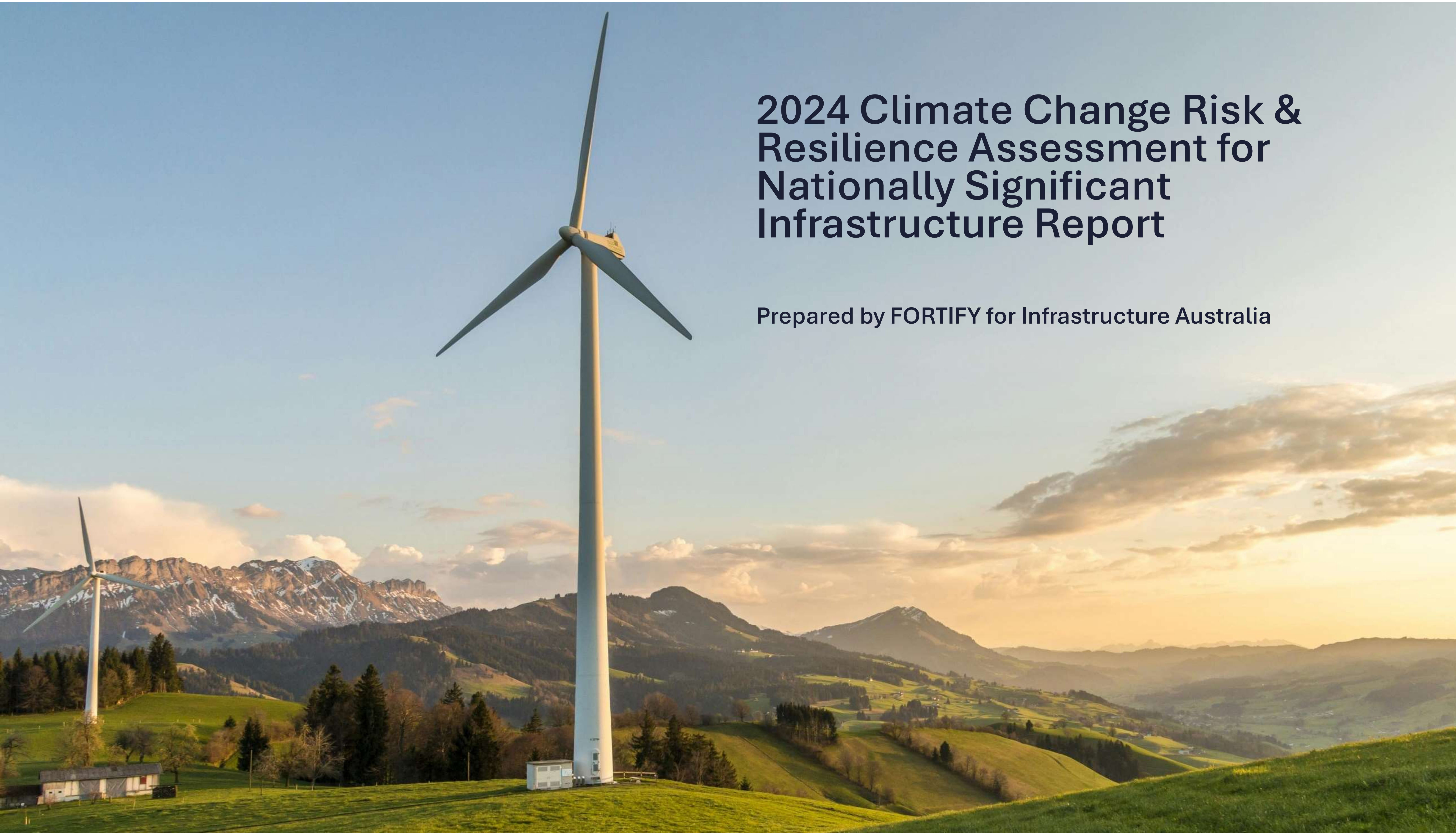

2024 Climate Change Risk & Resilience Assessment for Nationally Significant Infrastructure Report

Prepared by FORTIFY for Infrastructure Australia

CONTENTS

ACKNOWLEDGEMENT OF COUNTRY

We respectfully acknowledge the Gadigal people of the Eora Nation as the traditional custodians of the land on which we live and work. We honor their deep connection to this land, water, and environment, nurtured through generations of knowledge, resilience, and stewardship. Their understanding of living in harmony with nature is a profound reminder of the sustainable relationship we must seek in addressing today's climate challenges.

As we develop and implement climate change risk frameworks, we draw inspiration from the wisdom of Indigenous practices that have long safeguarded ecosystems. Recognizing that the climate crisis poses unprecedented risks to our environment, economy, and communities, it is essential to look to the time-honored traditions of conservation and respect for natural balance that Indigenous peoples exemplify. We are committed to integrating this spirit of stewardship into our strategies to ensure a resilient and sustainable future for all.

FORWARD

As a team we would like to thank Andrew Mather, our Mentor, who has given valuable guidance and encouragement throughout his involvement; his input is greatly appreciated.

We also extend our thanks to our colleagues and professional mentors who have nominated us to participate in the program. It has been highly beneficial and has exposed us to new ideas that we now put to use on a daily basis and has improved us as professionals and leaders.

We thank all of the people from Consult Australia involved in organising the course and the speakers and the various Judges from Infrastructure Australia, whom we hope enjoy this report.

Perhaps most of all we thank our friends and families for their enduring patience and support with us while writing this report.

EXECUTIVE SUMMARY

Natural disasters are costly

Damage and downtime of infrastructure can cost billions of dollars a year to the economy and can severely affect the day to day lives of people and communities who are acutely affected.

A key source of this damage and downtime is caused by natural disasters, some of which are expected to get worse over time as the effects of climate change cause more extreme weather events.

Funds for repair and resilience of infrastructure need to be prioritised

Investment in infrastructure can be made to improve the resilience to these natural disasters but it is difficult to decide where to best spend the available resources.

This is further important because the severity and frequency of some types of natural disasters is increasing as a result of climate change.

Infrastructure assets can be quantitatively prioritised using a ‘FortiFactor’

We propose a framework to assess the relative risk of a range of infrastructure assets in order to provide an easy metric, the “FortiFactor”, to form a first-pass assessment on where to allocate funds for detailed review and investment.

Improve existing open-source digital toolkits developed by leading researchers

This method is proposed to be developed into a web application, building off existing digital infrastructure which has been developed by Oxford University and various worldwide governments.

The aim of this tool is to provide user-friendly, visual breakdowns of large datasets to aid engineers and Ministers in rapid and informed decision making.

...and keep improving

Further to this, we discuss a range of potential features for inclusion in future iterations of the app.

"If [another] natural disaster were to occur, council would not have the available cash to respond," Stevens said in her report to councillors before last week's meeting, noting cash reserves had fallen from $19 million five years ago to zero in June.

Shoalhaven's natural disasters
Black Summer bushfires, from August 2019
Storms and floods, January 2020
Storm and flood, July 2020
Storm and flood, August 2020
Storm and flood, October 2020
Storms and floods, March 2021
Storms and floods, May 2021
Severe weather and flooding, November 2021
Severe weather and flooding, February 2022
Severe weather and flooding, June 2022
Flooding, September 2022
Severe weather and flooding, November 2023
East Coast flooding April 2024
Severe weather, June 2024"

The most disaster-prone council in NSW says it has run out of cash – Sydney Morning Herald, 6th November 2024

ABOUT THE TEAM

Our team name FORTIFY (**F**ramework for **O**ptimised **R**esilience and **T**argeted **I**nfrastructure **F**unding **Y**ields) is chosen to embody our collective goal of improving the resilience of the infrastructure assets which serve our communities and doing so in a cost-effective manner.

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MEng(Hons) MIEAust CPEng MIStructE APEC

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Henry Stone is a Senior Structural Engineer with over a decade of experience in the UK and Australia. Graduating with an MEng in Civil Engineering from Loughborough University in the UK, he began his career in London, where he worked on award winning, architecturally led projects across a range of sectors, progressing to senior roles involving project management and mentoring.

Subsequently, he worked as a Senior Forensic Structural Engineer investigating structural failures, writing expert witness reports and providing technical advice to support litigation.

Since moving to Australia in 2022, Henry has worked at Northrop, managing large-scale projects and teams, combining technical expertise with strong client relationships.

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Diploma of Civil Construction Design

Senior Civil Drafter, Arcadis

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Brandon Sayasane is a Senior Civil Drafter with under a decade of experience in design and drafting documentation with main skills in general civil engineering and creating CAD & Design systems and processes to be efficient.

Brandon has worked on multi-million-dollar projects such as Western Sydney Airport, Coffs Harbour Bypass and Torrens to Darlington.

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Mary Hadjiangeli is an emerging leader in the rail industry, dedicated to advancing Australia's next generation of infrastructure projects. With over eight years of structural engineering experience, she brings strong analytical and technical expertise to every endeavor. Mary is committed to exceeding client expectations across multidisciplinary projects through effective project management and a collaborative approach.

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Jisun Chang is a Senior Project Manager with experience delivering designs for major infrastructure projects in Australia. She graduated from the University of Sydney with a university medal in BEng (Civil) and B Project Management. Throughout university, she worked with Laing O'Rourke and the City of Sydney in risk management and scheduling respectively.

Working with Arup, she has supported multidisciplinary teams to deliver mega-design projects, including Martin Place Metro Station, Canberra Institute of Technology Woden Interchange, and Western Sydney Airport (WSA) Stations Systems, Trains, Operations and Maintenance (SSTOM).

1 INTRODUCTION

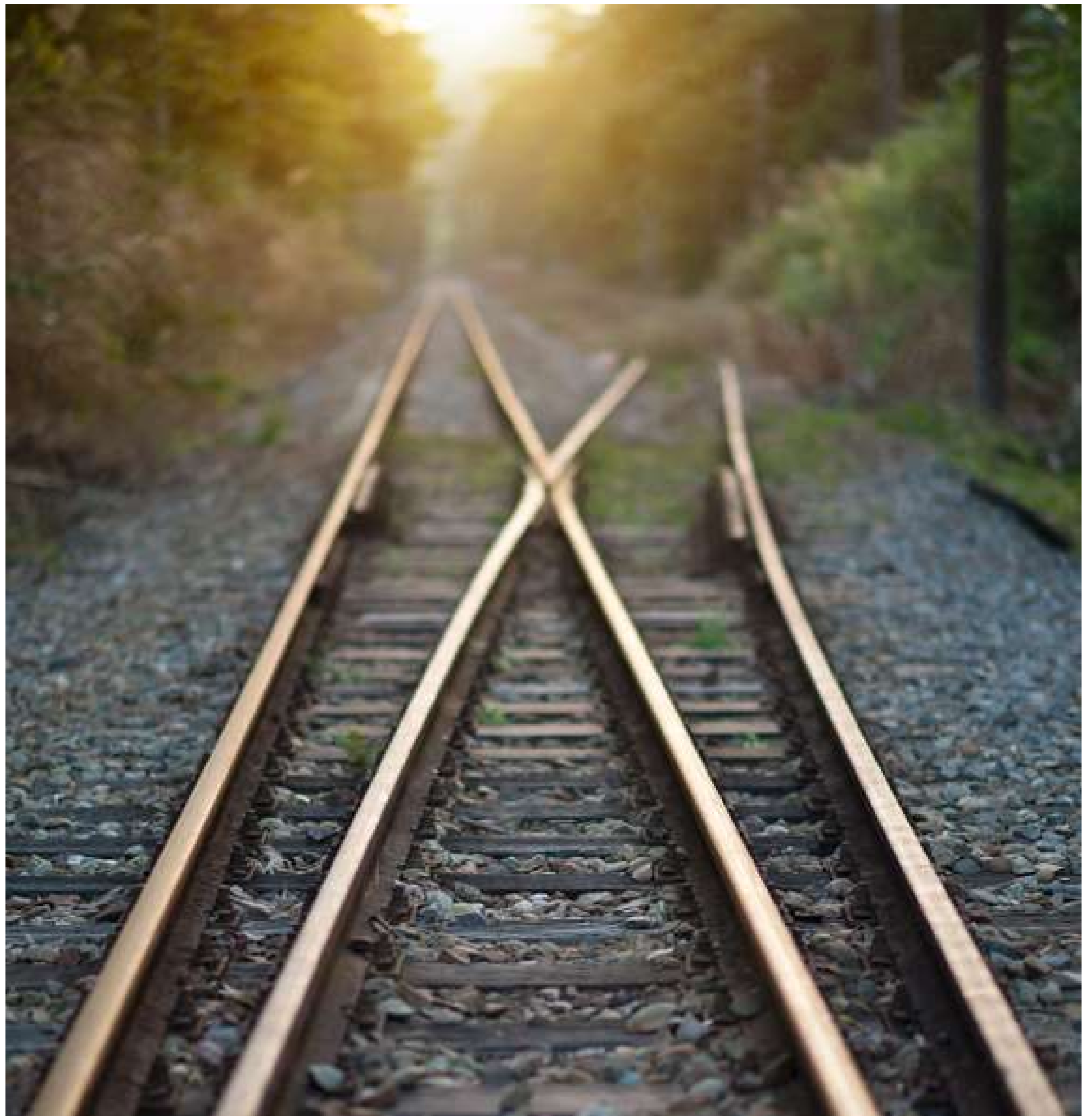
In recent years, the impacts of **climate change** have heightened the frequency and **severity of natural hazards**, revealing vulnerabilities within Australia's infrastructure networks and the associated social, environmental, and economic consequences. By 2050, the economic cost of these natural hazards is projected to exceed $39 billion annually, up from an average of over $18 billion per year, an **increase of $19 billion**. Given the critical role of infrastructure in national resilience, assessing and mitigating these risks has become a strategic priority for the Australian Government. This priority is outlined in the Infrastructure Policy Statement (November 2023) and is central to the government's ongoing infrastructure investment strategies.

The challenge, however, lies in establishing a **comprehensive national review on risk and resilience** across infrastructure sectors and hazard types. Data on these issues is often fragmented, inconsistent, and compiled using varying methodologies by diverse entities. Consequently, translating this data into coherent, actionable insights that can guide national policy and investment remains difficult.

This report seeks to address this gap by proposing a **structured framework and methodology** for assessing and comparing risks of a range of nationally significant infrastructure from natural hazards. The aim is to develop a lightweight system capable of evaluating **relative risk of various infrastructure assets** across spatial and temporal dimensions, ultimately providing robust, recommendations on where investment is most needed to enhance infrastructure resilience.

This initiative presents an opportunity to influence Infrastructure Australia's Audit efforts, advancing our understanding of infrastructure vulnerabilities and resilience on a local and national scale and providing a tool for elected representatives to make better-informed decisions when it comes to infrastructure resilience. With that in mind we have tailored the framework to have easily digestible conclusions suitable for advisers and ministers in order to **facilitate easy decision making in where to allocate funding** and reduce decision complexity from that of a busy. Multi-lane roundabout to a gentle fork in the road.

Understanding the impact of natural disasters on communities is essential, particularly for Aboriginal and Torres Strait Islander communities, who are often disproportionately affected by such events. These communities are not only vulnerable due to geographical and socio-economic factors but also have deep cultural ties to their land, which can be severely disrupted by natural disasters. Ensuring that the unique needs and perspectives of Aboriginal and Torres Strait Islander peoples are integrated into risk assessment frameworks is crucial to developing effective, inclusive resilience strategies that safeguard both cultural heritage and community well-being.



2 REPORT STRUCTURE

We aim to tell a story with this report and introduce information in the order that it becomes necessary. With that in mind we will discuss topics in the order in the graphic below.

3 RISK ASSESSMENT FRAMEWORK

3.1 Why do We Need a Risk Assessment Framework?

Infrastructure assets, encompassing roads, power plants, electrical transmission lines, and more, are critical to the stability and growth of communities and the broader economy. Ensuring the resilience of such infrastructure assets in the face of natural disasters is paramount to maintaining continuity in essential services.

To ensure the resilience of the infrastructure, it is necessary to assess where funding can be most efficiently allocated to get the greatest amount of risk reduction per dollar spent.

We propose a comprehensive risk assessment framework, aimed at evaluating the vulnerability of infrastructure to multiple hazards across various geographic scales. This framework incorporates the calculation of a "FortiFactor", considering the unique attributes of each asset and its exposure to natural hazards. The proposed approach is designed to align with established industry procedures to ensure reliability and comparability of the assessment results.

3.2 Requirements of a Risk Assessment Framework

The development of this risk assessment framework hinges on certain core requirements to ensure it is robust and flexible enough to cover a range of different contexts. The framework needs to be applicable across different geographic scales, as infrastructure assets may vary from local installations to assets serving larger regions. This multi-scale adaptability is necessary given the geographic variability in natural hazard occurrence, such as cyclones, earthquakes, and bushfires. Moreover, the framework should encompass various sectors of infrastructure, including roads, telecommunications, energy supply systems, and public buildings. The diversity of asset types means the methodology must be adaptable to account for differences in asset functionality and resilience characteristics.

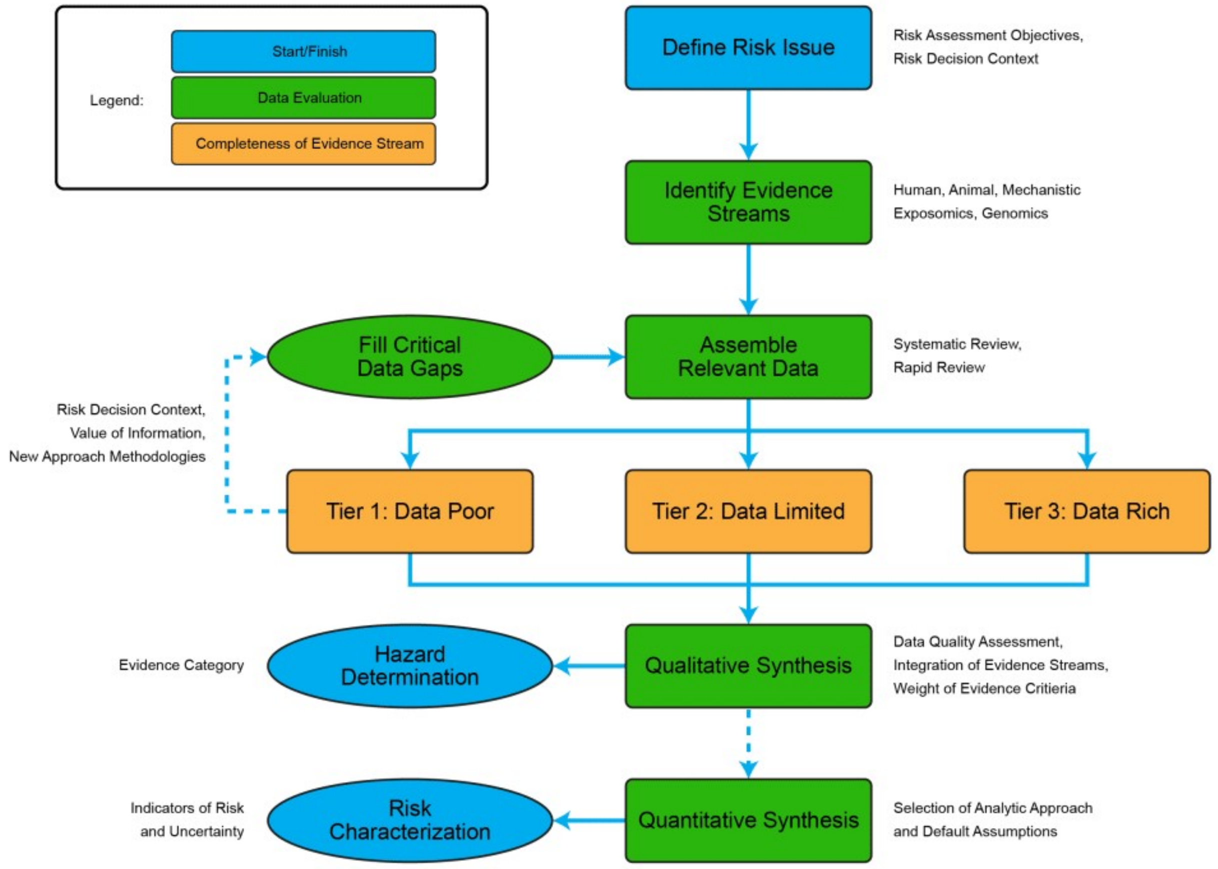
To create a meaningful comparison across assets and hazards, the framework is also required to align with similar established procedures, such as that which is outlined in Quantifying Climate Risks to Infrastructure Systems: A Comparative Review of Developments Across Infrastructure Sectors (Verschuur et al. 2024) and frameworks proposed by FEMA (Federal Emergency Management Agency) for hazard mitigation planning. Alignment with recognised procedures will support the standardisation of risk assessments and will facilitate benchmarking and comparison of results. Importantly, the framework integrates hazard parameters, exposure, and vulnerability to enable a holistic evaluation of risks, consistent with methods outlined in widely-referenced studies such as Cutter et al.'s Social Vulnerability Index and methodologies developed by the Global Facility for Disaster Reduction and Recovery (GFDRR).

3.3 Scope

This project poses a framework to assess the impact of natural disasters on infrastructure assets, and how the loss of those assets impacts communities. This does not make an attempt to assess the risks to non-infrastructure assets such as houses or commercial properties, though much of the functionality could be adapted to do so as part of further work, if required.

The metrics described in this report produce a means of comparative assessment between different assets. There is no attempt made to quantify the costs of any of the impacts.

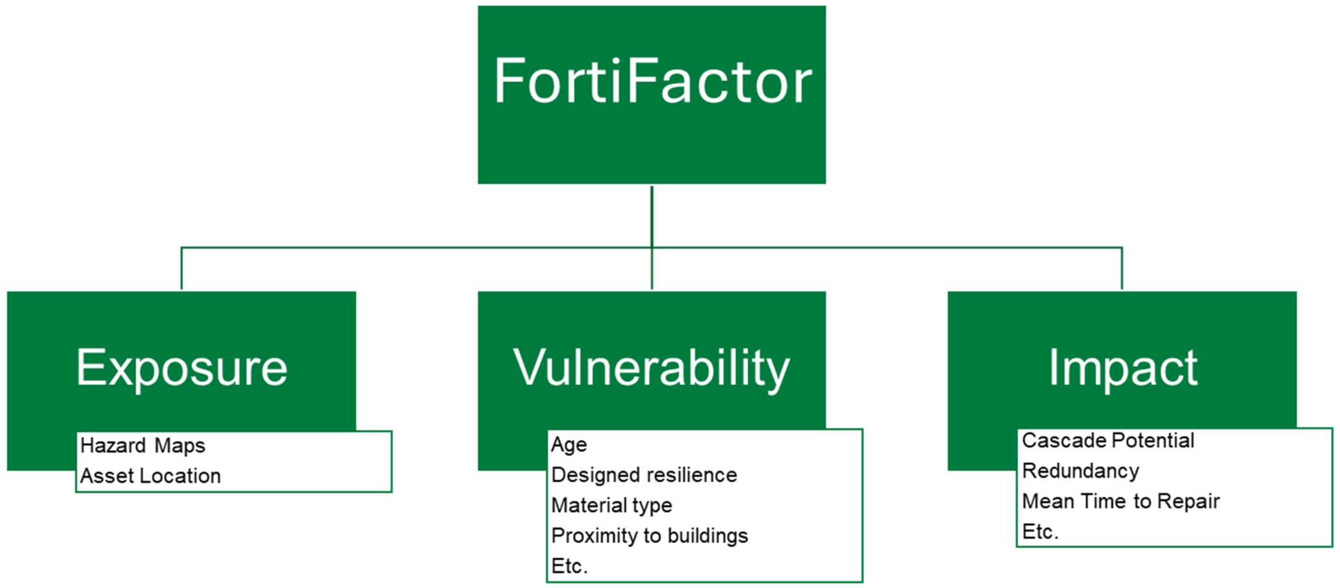
The Framework is developed with a view to assess the long-terms risks, over the timescale of investment decisions, and therefore does not apply to short time periods or respond to changing risk profiles while a disaster is ongoing.



3.4 Key Terms

The proposed solution involves calculating a relative risk factor or "FortiFactor" for each infrastructure asset, which provides a qualitative value representing the overall risk exposure of that asset. The FortiFactor will be used to prioritise interventions, guide resource allocation, and support decision-making for infrastructure resilience improvement.

To calculate the FortiFactor, values for exposure, vulnerability and impact are defined and multiplied together. To determine numerical parameters for each of these, a range of factors are taken into account as described In the rest of this chapter.



3.5 Assets

3.5.1 What Are Assets?

An asset, in the context of this risk assessment framework, refers to any piece of physical infrastructure that provides essential services to the community. Assets can include roads, power plants, electrical transmission lines, telecommunications facilities, public buildings such as fire stations, and other critical infrastructure. Each asset plays a key role in maintaining the functionality of societal systems, and its resilience directly affects the stability and continuity of these services. Understanding the characteristics of each asset, such as its construction, age, location, and functionality, is crucial for accurately assessing the risks it faces.

Things which aren't considered Assets in the context of this report are things which do not serve an infrastructure function, such as private houses, commercial properties, farmland, parks, stadia and warehouses. Though these also serve important functions for society, and their loss can be devastating to the individuals or companies who own them, their loss in the aftermath of a natural disaster is typically not an immediate concern for the wider population.

3.5.2 Why are Assets Important?

Infrastructure assets, are fundamental to the functioning of modern societies. Their importance is particularly pronounced in the context of natural disasters for several reasons:

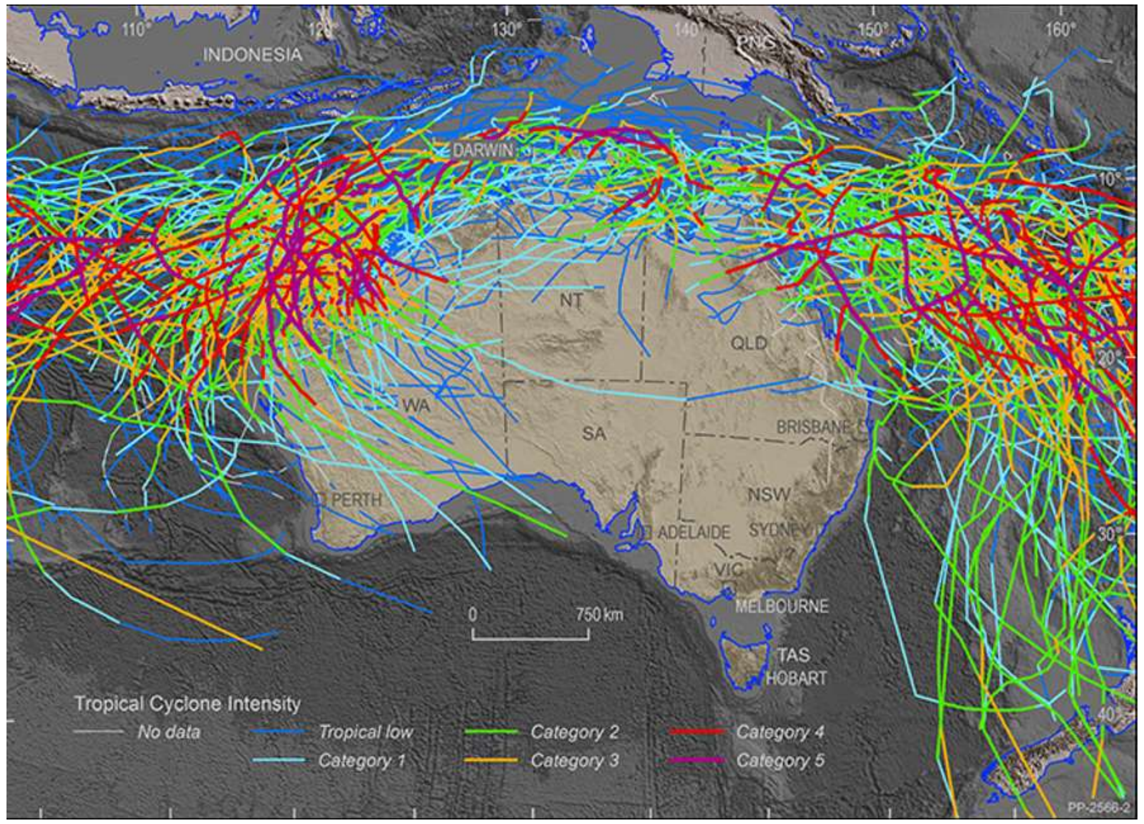
- Essential Services Provision: Infrastructure assets deliver critical services that support daily life and economic activities. During natural disasters, maintaining these services is vital for emergency response and recovery efforts. For instance, resilient infrastructure can serve as the first line of defense against shocks and disasters, supporting economic functions and providing critical services to communities.
- Economic Stability: The functionality of infrastructure assets underpins economic stability. Disruptions can lead to significant economic losses due to halted business operations, supply chain interruptions, and increased recovery costs. For example, natural disasters often reveal weaknesses in infrastructure systems, highlighting the importance of designing infrastructure to withstand extreme weather events.
- Public Safety and Health: Robust infrastructure ensures the safety and well-being of the population by providing access to healthcare, emergency services, and safe transportation routes during disasters. The United Kingdom's guidance emphasizes that resilience is the ability of assets, networks, and systems to anticipate, absorb, adapt to, and rapidly recover from a disruptive event.

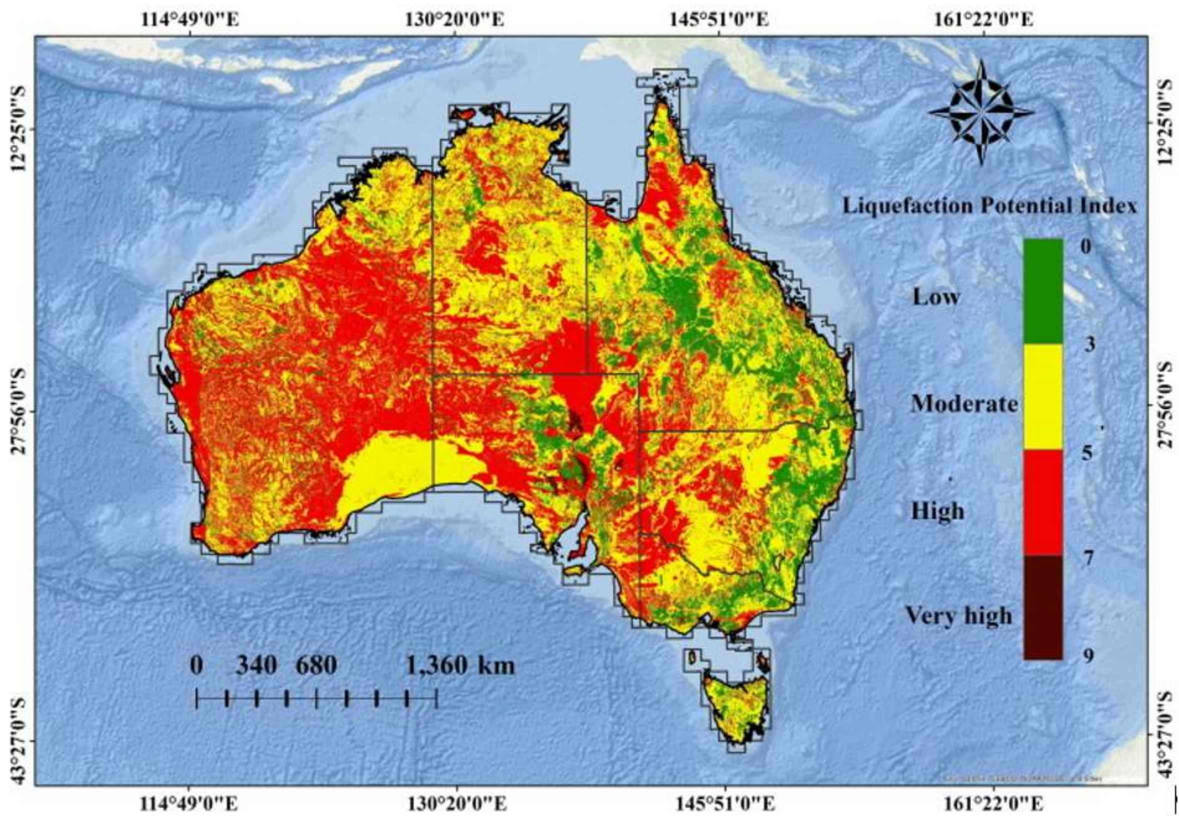
In summary, infrastructure assets are crucial in natural disaster contexts because they ensure the continuity of essential services, uphold economic stability, protect public safety and health, and enhance disaster mitigation and response capabilities.

3.6 Hazards

Hazards refer to the potential natural events or disasters that could negatively impact infrastructure assets. These include earthquakes, cyclones, bushfires, floods, and other environmental phenomena that pose a risk to the stability and function of critical infrastructure. Each hazard type has unique characteristics that can affect different types of assets in various ways, and it is important to evaluate these hazards specifically to determine the vulnerability and exposure of each asset. Understanding hazard frequency, intensity, and potential impact is fundamental to assessing the risks involved.

This report only looks at Hazards which might cause a natural disaster and does not make any comment on things like degradation of assets over time due to normal wear and tear or corrosion, for example, which are more of an operation and maintenance issue and are already addressed by existing codes and standards.





3.7 Vulnerability

Vulnerability represents the likelihood that an asset will suffer damage or lose functionality if it is exposed to a hazard. It depends on the inherent characteristics of the asset, such as its design, construction materials, age, and condition, as well as its ability to withstand specific types of hazards. For instance, an old bridge constructed with outdated standards may have higher vulnerability to earthquakes compared to a newly built bridge designed with modern seismic standards. The concept of vulnerability helps to determine which assets are most likely to experience damage during hazard events and to what extent.

3.7.1 Why is Vulnerability Important?

Vulnerability is an important metric because it combines the properties of the asset and the hazard to give an asset-specific measure of how different hazards will affect different assets. This is important in quantifying the overall risk of an asset because the consequences of certain hazards on certain assets can vary significantly.

3.8 Exposure

3.8.1 What is Exposure?

Exposure describes the degree to which an asset is susceptible to particular hazards based on its geographic location. It involves understanding whether an asset is located within an area likely to be affected by a specific type of natural hazard, such as bushfires, floods, earthquakes, or cyclones. The exposure of an asset is determined by its proximity to hazard-prone areas, and it can be quantified through data that cross-references hazard maps with asset locations. For example, an asset situated in a floodplain would have a higher exposure factor compared to one located in an area with no history of flooding.

3.9 Impact

3.9.1 What are Impacts

Impact refers to the consequences that arise from the loss or degradation of an asset's function due to hazard exposure. It encompasses both direct and indirect effects on the community and economy. Direct impacts could include disruptions in service, such as power outages or blocked transportation routes, while indirect impacts might involve economic losses due to reduced business activity or compromised access to emergency services. By assessing impact, it becomes possible to determine the broader societal and economic repercussions of asset failure, allowing for better prioritization of resilience measures.

3.9.2 Limitations on Data Availability

Some impacts are very complicated to assess and so cannot be included in this framework in a detailed manner. For example, cascade impact; the impacts caused by the loss of one infrastructure asset causing the loss of function of another infrastructure asset, which might cause the loss of further infrastructure assets, and so on, requires complicated analysis which is beyond the scope of this report. However, we discuss possibilities for further work later in the report. With that said, it is possible to capture this with an estimated number on a basic sliding scale as has been incorporated herein.

3.9.3 Impact on Aboriginal and Torres Strait Islanders

The impact of asset loss on Aboriginal and Torres Strait Islander communities can be disproportionately severe. Many of these communities are in remote or vulnerable areas with already limited infrastructure, making failures both far-reaching and long-lasting. Geographic isolation increases transportation costs and complicates logistical support, making restoration efforts particularly challenging. Limited redundancy means that losing one infrastructure component can lead to cascading failures, exacerbating the impact.

Loss of critical infrastructure severely affects access to essential services like healthcare, clean water, reliable energy, and communications. Healthcare services often rely on small clinics with limited capacity to handle sudden increases in demand. Power failures can disrupt medical equipment, refrigeration for medicines, and basic lighting, leading to significant care gaps. Clean water is another major concern, as many communities depend on fragile water systems vulnerable to disruptions, potentially causing health crises.

Many communities rely on isolated power systems, such as diesel generators, which are prone to fuel supply chain issues. Energy disruptions impact healthcare, schools, businesses, and everyday life. Communications infrastructure is similarly vulnerable; losing connectivity can further isolate communities, cutting them off from emergency services and vital information during crises.

These challenges underscore the importance of integrating culturally informed perspectives into resilience planning. Recognizing traditional knowledge and involving these communities in the planning process fosters trust, builds tailored solutions, and promotes equity. Addressing these specific vulnerabilities ensures more inclusive and effective resilience planning, helping to prevent these communities from being left behind.

4 FRAMEWORK

As discussed, the fundamental metric we propose to compare the impacts of hazards on assets is the FortiFactor, which is the sum of the exposures of each asset to each hazard multiplied by the impact of loss of each asset on the community. The following sections describe each of these parameters in detail.

4.1 Formula

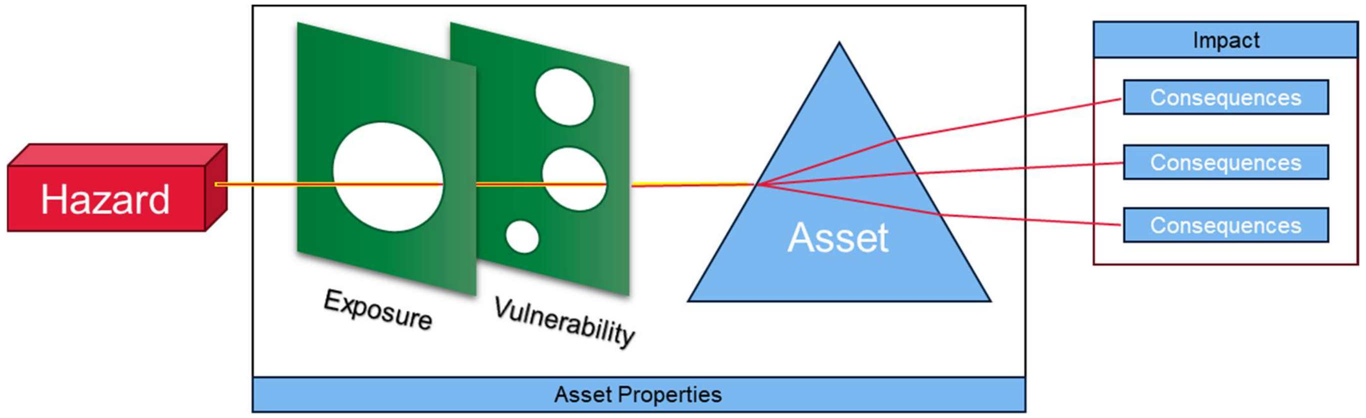
The calculation of the Fortifactor begins with the collection of data pertaining to the relevant parameters, including historical hazard data, projected future hazard data, asset-specific design details, and geographic information are compiled to provide a foundation for the risk assessment. For each asset, the FortiFactor is summarised as the following formula;

$$F = E \times V \times I \qquad \text{EQ.1}$$

Where:

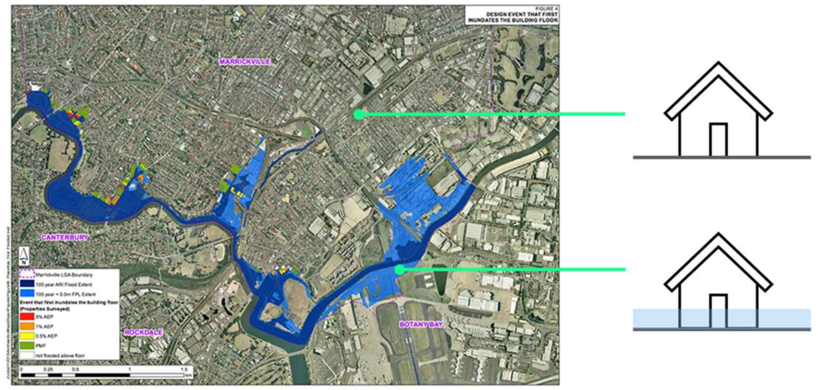
- F is the FortiFactor
- E is a function defining Exposure of the asset to the Hazard(s)
- V is a function defining Vulnerability of the Asset to the Hazard(s)
- I is a function defining Impact on the community as a result of loss of function of the asset

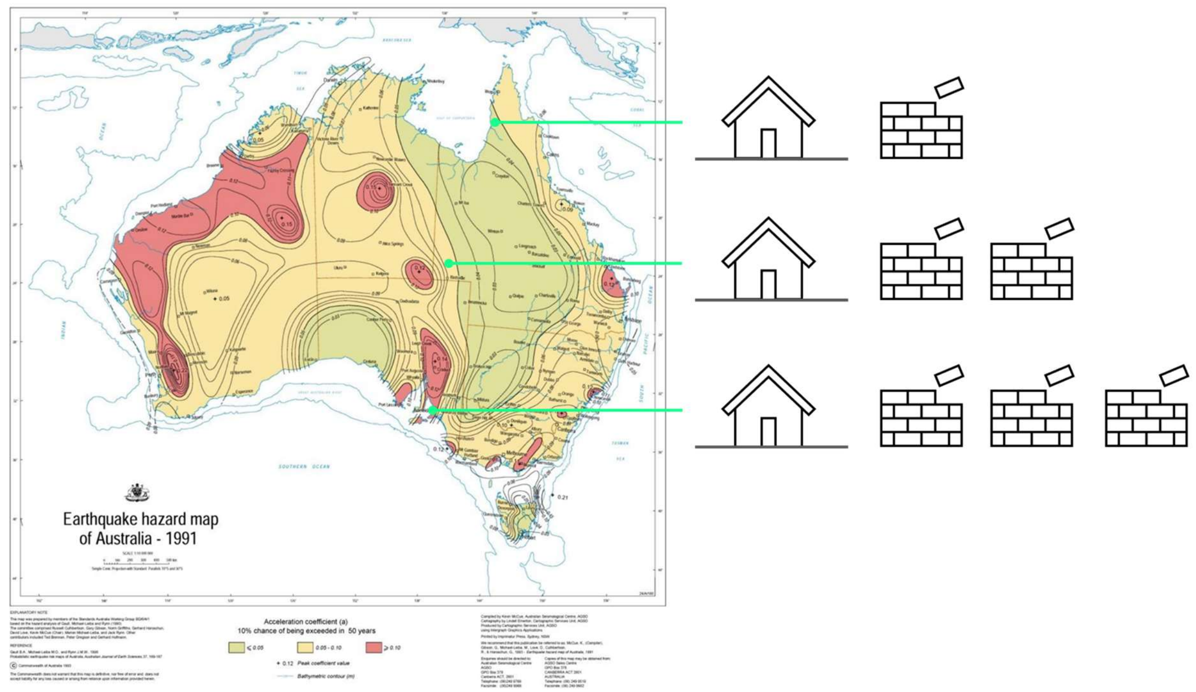
Some of these variables will be found by finding a default value relating to the Asset Class (A_c) and Hazard Class (H_c) and then modified by Modifying Variables which have information specific to the asset in question. In this manner a quick assessment can be made for all assets, then can be refined with asset specific data in further stages of investigation.

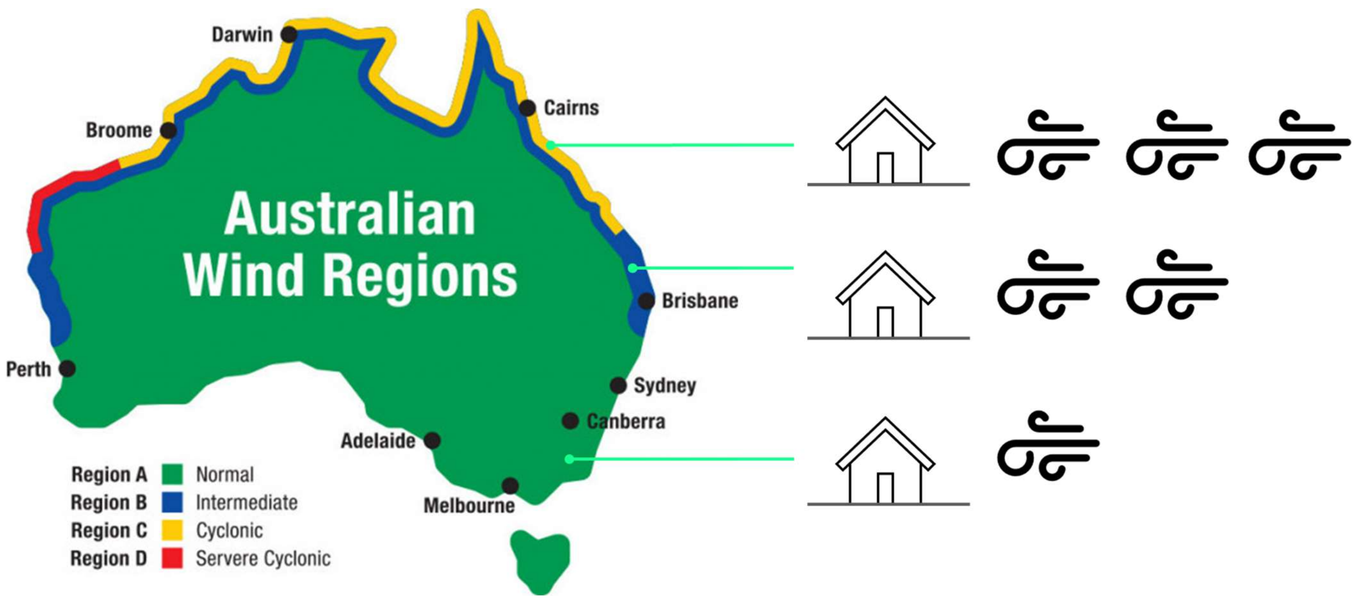


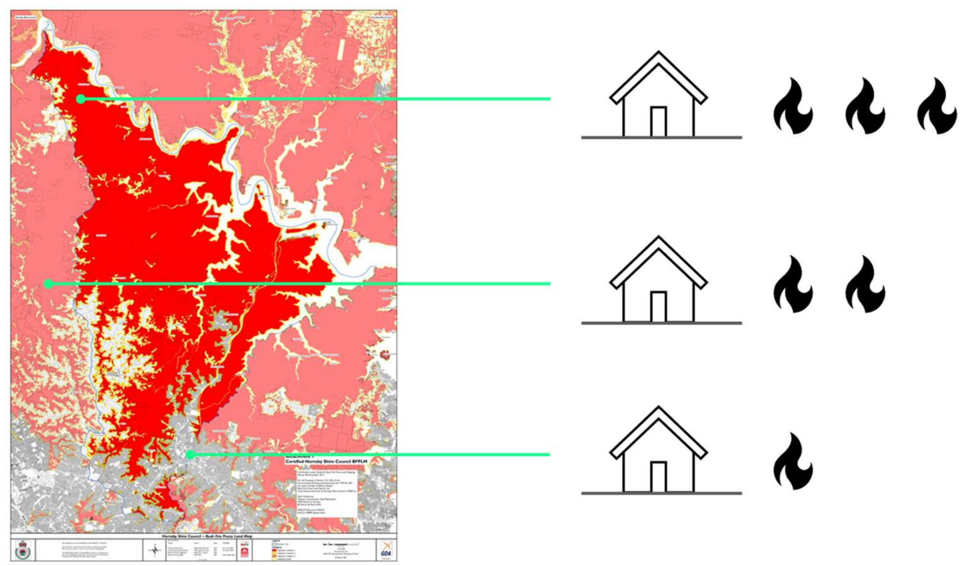
4.2 Exposure

Exposure is the measure of whether an Asset will in a location where a hazard event may occur. We have not included the ability to add modifiers to this metric in our implementation, though this could be done in future work. As such, there is not a formula for Exposure. Instead, Exposure is a value which is determined by cross referencing the geographic location of an asset to the various sources of Hazard data available and assigning a value for Exposure for each Asset. As such, each specific asset will have a different exposure value for each Hazard class, which will be used in future calculations.









4.3 Vulnerability

Vulnerability is the measure of how likely an asset is to be damaged by a given hazard if that hazard occurs in a location where it could affect the asset. Different asset classes have different vulnerabilities to different types of hazard. As such, for each asset there will be a range of different values for V, one for each Hazard.

The vulnerability of an asset may differ from that of the default values in the Asset Class; to capture this, the vulnerability may be modified by multiplying it by a range of further variables, $v_{i \ldots n}$, which will either increase or decrease the vulnerability of a specific asset. These variables are discussed in more detail later but may include things like materials used in the construction of the asset, age of the asset, whether the asset is designed to meet certain codes and historical data on whether it has been adversely affected by Hazards.

$$V(A) = \sum_{H_c=1}^{H_c=\max} \left(V_c(H_c) \times \prod_{v=1}^{v=\max} v_i(H_c) \right) \qquad \text{EQ.2}$$

Where;

- V(A) is the vulnerability of the specific asset
- $V_c(H_c)$ is the Vulnerability based on default class values of H_c, Hazard class and A_c, Asset class.
- $\Pi\, v_i(H_c)$ denotes the product of all modifier variables $v_{i \ldots \max}$ relevant to the Asset class and Hazard Class
- Both V_c and v_i can be shown as 2D arrays (tables) because the vulnerability varies depending on the specific Hazard class and Asset in question as per the below;

$$V_c = \begin{bmatrix} V_{c,11} & V_{c,12} & V_{c,13} & \cdots & V_{c,1H_c} \\ V_{c,21} & V_{c,22} & V_{c,23} & \cdots & V_{c,2H_c} \\ V_{c,31} & V_{c,32} & V_{c,33} & \cdots & V_{c,3H_c} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ V_{c,A_c1} & V_{c,A_c2} & V_{c,A_c3} & \cdots & V_{c,A_cH_c} \end{bmatrix} =$$

	Roads	Railways	Airports	Ports/Harbours	Bridges	Road Tunnels	Power Plants	Electrical Transmission lines	O+G pipelines	Refineries/storage	Solar power stations	Irrigation systems	Cellular towers	fibreoptic networks	datacentres	broadcasting systems	Healthcare Facilities	Fire Stations	Police Stations
Earthquake	4	4	4	4	8	2	6	4	4	4	4	1	4	1	4	4	4	4	4
Flooding	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
Cyclone/Storm	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Tsunami	10	10	10	10	10	10	10	10	8	10	10	10	10	10	10	10	10	10	10
Volcanic Erruption	10	10	10	10	10	10	10	10	8	10	10	10	10	10	10	10	10	10	10
Landslide	10	10	10	10	10	10	10	10	8	10	10	10	10	10	10	10	10	10	10
Bushfire	2	4	8	8	4	1	6	10	10	10	10	2	10	4	4	4	10	10	10
Drought	0	0	0	0	0	0	0	0	0	0	0	10	0	0	0	0	0	6	0
Tornado	0	2	6	6	8	10	10	10	10	10	10	2	10	2	10	10	10	10	10
Heatwave	1	1	2	2	1	1	6	1	1	1	1	1	1	1	1	1	4	8	1
Avelanche	10	10	10	10	10	10	10	10	8	10	10	10	10	10	10	10	10	10	10
Blizzards	10	10	8	4	10	1	1	1	1	1	1	1	1	1	1	1	4	4	4
Cold snap	2	2	8	2	2	1	1	1	1	1	1	1	1	1	1	1	4	4	4

Vulnerability Synthetic data for illustrative purposes

4.4 Impact

Impact is a property which we define as belonging solely to the asset, independent of exposure, vulnerability or hazard. As such, this is essentially a single term dependent on the data of the Asset to be assessed on a case by case basis.

In a first-pass implementation, default values may be used depending on the asset class; ie substation vs. Airport. However, because of the large difference in individual assets of the same class this is a crude approach subject to significant amounts of error; for example, the impact as a result of the loss of function of Sydney Kingsford Smith airport would be far more significant than the loss of a smaller, regional airport.

$$I(A) = I_c(A_c) \times \prod_{j=1}^{j=\max} i_j(A) \tag{EQ.3}$$

Where;

- I(A) is the impact of the loss of the specific asset
- $I_c(A_c)$ is the Impact of the loss of the asset based on just the asset class only
- $\Pi\ i_j$ is the product of all the modifier variables relating to the asset

$$I_c = \begin{bmatrix} I_{c1} & I_{c2} & I_{c3} & \cdots & I_{cn} \end{bmatrix} =$$

	Roads	Railways	Airports	Ports/Harbours	Bridges	Road Tunnels	Power Plants	Electrical Transmission lines	O+G pipelines	Refineries/storage	Solar power stations	Irrigation systems	Cellular towers	fibreoptic networks	datacentres	broadcasting systems	Healthcare Facilities	Fire Stations	Police Stations
Earthquake																			
Flooding																			
Cyclone/Storm																			
Tsunami																			
Volcanic Eruption																			
Landslide																			
Bushfire	4	4	5	4	5	5	5	4	4	3	2	2	2	2	2	2	3	3	3
Drought																			
Tornado																			
Heatwave																			
Avelanche																			
Blizzards																			
Cold snap																			

Impact Synthetic data for illustrative purposes

4.5 Master Formula

In conclusion, taking the above formulae and substituting these into the summary formula presented initially we present the below to define the FortiFactor.

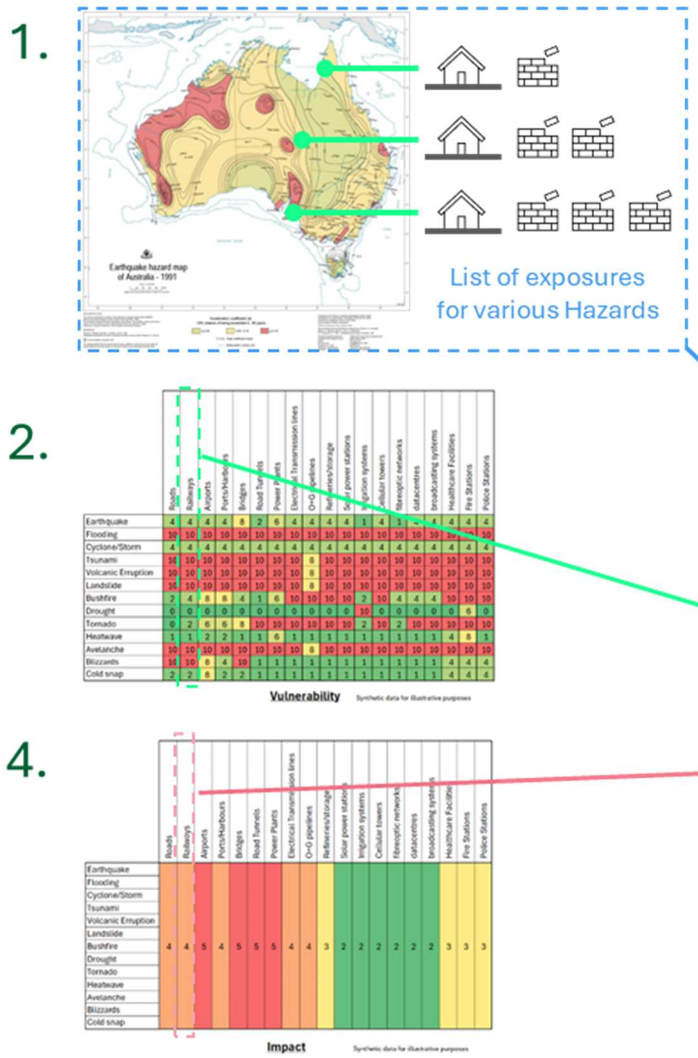
The master formula includes a Calibration factor, which adjusts the weighting of different hazards. This factor can vary for each hazard class, allowing for the relative importance of hazards to be calibrated effectively.

$$\boxed{F} = \boxed{E} \times \left(\sum_{H_c=1}^{H_c=\max} \left(\boxed{V_c(H_c)} \times \boxed{\prod_{v=1}^{v=\max} v_i(H_c)} \right) \right) \times \left(\boxed{I_c(A_c)} \times \boxed{\prod_{j=1}^{j=\max} i_j(A)} \right)$$

EQ.4

STEPS

1. Exposure from various hazard maps.
2. Vulnerability based only on classes.
3. Vulnerability modifiers based on asset-specific data.
4. Impact based on asset class only.
5. Impact modifiers based on asset specific data.
6. Sum products of E,V,I to give FortiFactor



			3.						5.				6.
			v_i = vulnerability modifiers for Martin Place Metro Station (blank = not used)						i_j = Impact Modifiers for Martin Place Metro Station (blank = not used)				
	E = Exposure (determined from map data)	Vc = Vulnerability based on asset class only	v_1, age	v_2, designed resiliance	v_3, material type	v_4, proximity to buildings	Π of $v_{1\to max}$	Ic = Impact based on the class of the asset only	i_1, cascade potential	I_2, Redundancy	i_3, Mean Time To Repair	Π of $v_{1\to max}$	E x V x I x all modifers)
Earthquake	2	2	0.5	0.5	0.5	2	0.3						0.015625
Flooding	3	5	1	0.2	1	1	0.2						0.0375
Cyclone/Storm	2	2	0.8	0.5	1	0.5	0.2						0.01
Tsunami	4	5	1	1	1	1	1						1.25
Volcanic Erruption	0	5	1	1	1	1	1						0
Landslide	0	5	1	1	1	1	1						0
Bushfire	0	2	1	1	1	1	1	4	2	0.3	0.3	0.1	0
Drought	0	0	1	1	1	1	1						0
Tornado	0	1	1	1	1	1	1						0
Heatwave	5	0.5	1	1	1	0.8	0.8						0.1
Avelanche	0	5	1	1	1	1	1						0
Blizzards	0	5	1	1	1	1	1						0
Cold snap	0	1	1	1	1	1	1						0
									∑ = FortiFactor =				1.413125

Martin Place Metro

Synthetic data for illustrative purposes

4.6 Modifier Variables

The examples above use “modifier variables” to add detail specific to the asset. There are two key reasons why we have implemented this approach;

It allows for analysis of the asset based on limited data such as the Asset Class, which are trivial to determine and store in the dataset. Which allows for a rudimentary analysis which can be easily applied to all assets.

It allows for an unlimited number of modifiers which can be added to assets as data becomes available. In this manner, if a new modifier variable is added to the system, its value can be set to equal 1 for all assets where a determination of the value for the variable has not yet been made.

EXAMPLE*; if the system has been used for some amount of time and then the engineers running the system decide that it is important to include data about how the amount of people who use the asset each week, then this can be input into the system and data can be input for assets where the variables are known and the rest of the assets can be added as equal to 1.*

The examples in this report have a limited number of variables for the sake of brevity, but other modifier variables could be implemented as per the suggestions in the list below;

- Vulnerability modifiers
    - Age of asset or time until design life reached (may affect condition/strength)
    - Design standards used (ie older codes less conservative)
    - materials used (ie timber vs concrete may affect bushfire)
    - Proximity to nearby buildings at risk of collapse
    - Soil type (may affect resilience to earthquakes)
    - Maintenance History (regular maintenance may reduce vulnerability)
- Impact modifiers
    - Occupancy (ie train lines which have high throughput may yield a larger impact)
    - Redundancy and Criticality (availability of alternative assets to mitigate disruptions)
    - Local population resilience (if locals are well prepared to respond to emergencies)

In the case of the Impact score, a single baseline score and single set of modifiers have been applied for the asset irrespective of the hazard classes. However, modifiers may be asset and hazard specific. For example, for the Mean Time to Repair (MTTR) Impact modifier may be more severe in the case of a bushfire than for a heatwave. Using any combination of impact modifiers, the relative impact calculations can become as detailed and as it needs to be. However, unless a highly detailed assessment is undertaken for a specific function, a uni-dimensional impact modifier across all hazard classes may be sufficient.

4.6.1 Data Format of Modifier Variables

Modifier variables may theoretically be implemented as either a value for each asset, or even an array, so that a different value can be provided for each type of Hazard. For example, it may be the case that the mean time to repair (MTR) for a road might be quite quick for a flood, but if it has suffered a landslide, it may take weeks or months to repair.

For example, in the Illustration for the master formula on the previous page the vulnerability modifiers (brown) are presented as an array and the impact modifiers are presented as a single value (cyan).

4.7 Section Summary

The framework that we have proposed to evaluate the resilience of infrastructure assets across various scales and sectors is a complex yet vital undertaking. By calculating a FortiFactor for each asset, our framework allows for a standardised assessment of vulnerability and exposure to natural hazards, and the impact that the loss of those assets may have on the communities affected guiding. Once populated with data, this framework will provide a tool for resource allocation and prioritizing resilience improvements. Aligning this framework with established procedures and leveraging a comprehensive set of parameters ensures its applicability and reliability, ultimately contributing to the safeguarding of infrastructure assets against future risks.

5 WORKED EXAMPLE – SYDNEY HARBOUR BRIDGE

5.1 Exposure

Exposure is given a score of between 0 and 10 based on existing geospatial and meteorological data.

For example:

The earthquake rating may be taken from the earthquake hazard map included in AS1170.4 Structural Design Actions – Earthquake. Alternatively, it may be taken from an open-source data set provided by Geoscience Australia (e.g. Australian Seismic Site Conditions Map). They key is that exposure figures are relative.

Heatwave, cold snaps and blizzard exposures are taken from meteorological climate forecasting data sets, e.g. from from the US National Oceanic and Atmospheric Administration (NOAA) National Centres for Environmental Information (NCEI) which compile historical datasets from global weather stations.
Alternatively, an intermediary data source that has already digesting the raw data may be used instead. E.g. a combination of average temperature data from the Bureau of Meteorology as well as the Interactive Climate Projections Map developed by the NSW Government ([Interactive climate change projections map | AdaptNSW)](#)

The below table shows the exposure scores used for the location of this asset across a range of Hazard Classes.

	E = Exposure (from map data)
Earthquake	4
Flooding	6
Cyclone/Storm	4
Tsunami	8
Volcanic Eruption	0
Landslide	0
Bushfire	0
Drought	0
Tornado	0
Heatwave	10
Avalanche	0
Blizzards	0
Cold snap	0

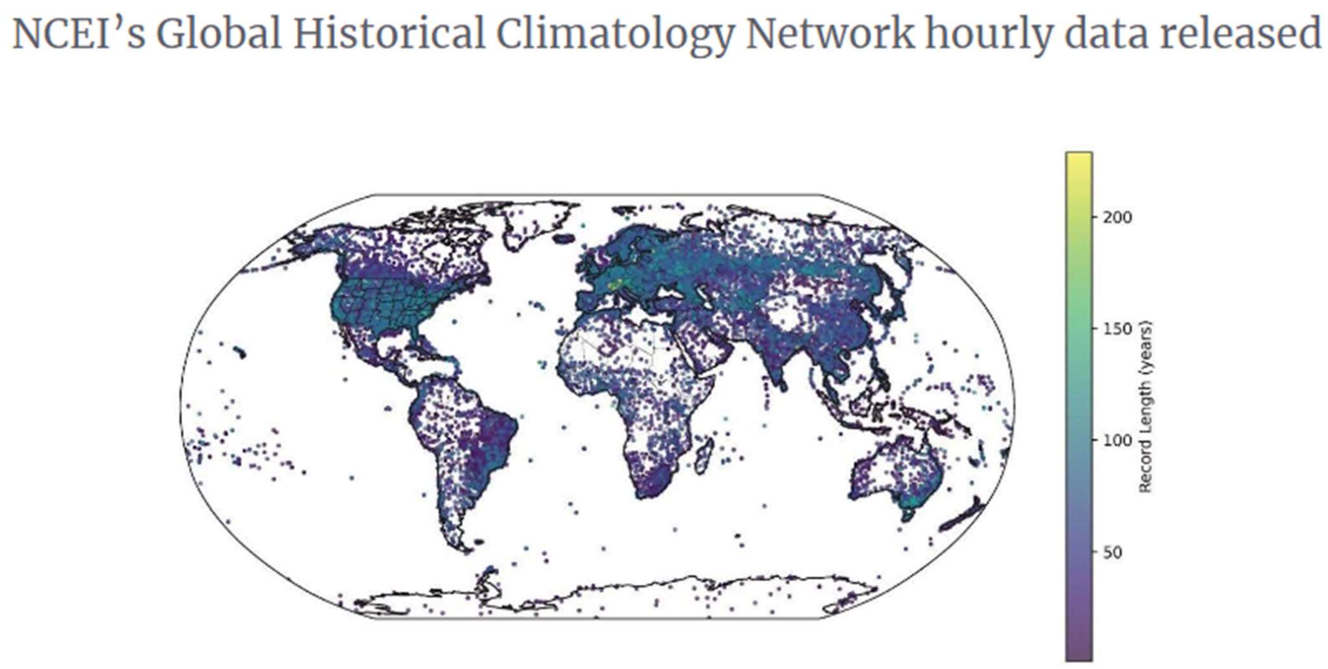


Fig: Map indicating the duration of records for land-based meteorological stations. (NOAA). There is plentiful raw measurements to derive values from

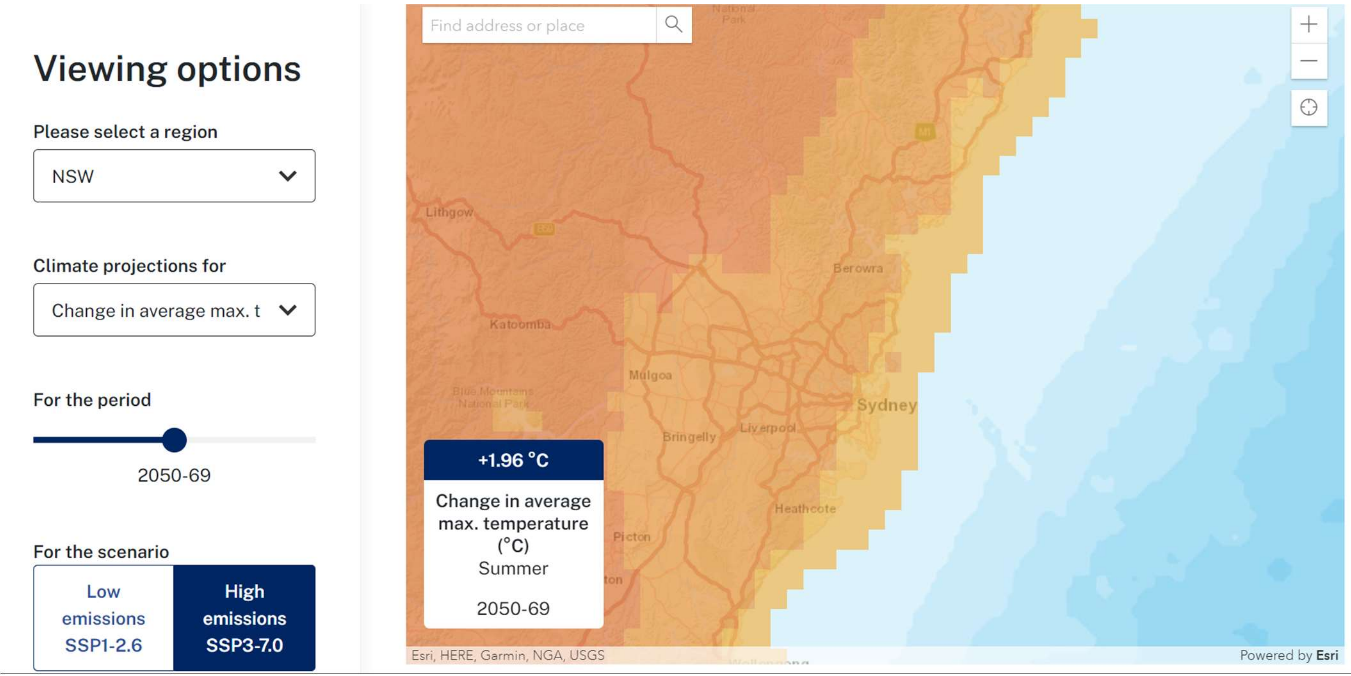


Fig: Interactive climate projections map for change in baseline temperature ([Interactive climate change projections map | AdaptNSW).](#) There are many sources which have both summary and forecast meteorological data.

5.2 Vulnerability

Each asset class is given a baseline vulnerability score for each hazard class. This baseline method is used as an initial 'broad wash' approach. For this example, the 'bridges' asset class is selected.

	Roads	Railways	Airports	Ports/Harbours	Bridges	Road Tunnels	Power Plants	Electrical Transmission lines	O+G pipelines	Refineries/storage	Renewable energy (onshore)	Irrigation systems	Cellular towers	Fibreoptic networks	Datacentres	Broadcasting systems	Healthcare Facilities	Fire Stations	Police Stations
Earthquake	4	4	4	4	8	2	6	4	4	4	4	1	4	1	4	4	4	4	4
Flooding	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
Cyclone/Storm	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Tsunami	10	10	10	9	10	9	10	10	8	10	10	10	10	9	10	10	10	9	10
Volcanic Eruption	10	10	10	9	10	9	10	10	8	10	10	10	10	9	10	10	10	9	10
Landslide	10	10	10	9	10	9	10	10	8	10	10	10	10	9	10	10	10	9	10
Bushfire	2	4	8	8	4	1	6	10	10	10	10	2	10	4	4	4	10	10	10
Drought	0	0	0	0	0	0	0	0	0	0	0	10	0	0	0	0	0	6	0
Tornado	0	2	6	6	8	10	10	10	10	10	10	2	10	2	10	10	10	10	10
Heatwave	1	1	2	2	1	1	6	1	1	1	1	1	1	1	1	1	4	8	1
Avelanche	10	10	10	10	10	10	10	10	8	10	10	10	10	10	10	10	10	10	10
Blizzards	10	10	8	4	10	1	1	1	1	1	1	1	1	1	1	1	4	4	4
Cold snap	2	2	8	2	2	1	1	1	1	1	1	1	1	1	1	1	4	4	4

	V = Vulnerability	v_i = Vulnerability modifiers (blank = not used)				**V, including modifiers**
	Bridges	v1, age	v2, designed resilience	v3, material type	v4, proximity to other assets	
Earthquake	4	0.5	0.5	0.5	2	1.0
Flooding	5		0.2			1.0
Cyclone/Storm	2	0.8	0.5		0.5	0.4
Tsunami	5					5.0
Volcanic Eruption	5					5.0
Landslide	5					5.0
Bushfire	2					2.0
Drought	0					0.0
Tornado	4					4.0
Heatwave	0.5				0.8	0.4
Avalanche	5					5.0
Blizzards	5					5.0
Cold snap	1					1.0

It is evident that each asset is unique and that a generic score alone would not accurately reflect the vulnerability of the specific asset. Vulnerability modifiers are applied to adjust the vulnerability score for factors including:

Age

Designed resilience

Material type

Proximity to other assets

If not used, the default value for all modifiers is 1, preserving the general vulnerability score. A score less than one reduces vulnerability, and a score greater than 1 increases vulnerability.

5.3 Impact

Each asset class is given a baseline impact score, considering the core function of an asset. This is not dependent on the hazard class

	Impact																		
	Roads	Railways	Airports	Ports/Harbours	Bridges	Tunnels	Power Plants	Electrical Transmission lines	O+G pipelines	Refineries/storage	Renewable energy (onshore)	Irrigation systems	Cellular towers	Fibreoptic networks	Datacentres	Broadcasting systems	Healthcare Facilities	Fire Stations	Police Stations
Earthquake																			
Flooding																			
Cyclone/Storm																			
Tsunami																			
Volcanic Eruption																			
Landslide																			
Bushfire	8	10	9	8	10	10	9	8	8	6	4	3	4	4	4	5	6	6	7
Drought																			
Tornado																			
Heatwave																			
Avelanche																			
Blizzards																			
Cold snap																			

	Impact	I_i = Impact Modifiers (blank = not used)			
	Bridges	I1, cascade potential	I2, Redundancy	I3, Mean Time To Repair	**I, including modifiers**
Earthquake					
Flooding					
Cyclone/Storm					
Tsunami					
Volcanic Eruption					
Landslide					
Bushfire	5	4.00	0.50	0.25	2.5
Drought					
Tornado					
Heatwave					
Avalanche					
Blizzards					
Cold snap					

Similar to the exposure score, modifiers are used to tailor the score to the specific asset. Modifiers include:

- Cascade potential; an attempt to quantify the knock-on impacts of this asset from being damaged
- Redundancy; whether there is a nearby asset or service that can deliver the same function should this asset be damaged
- Mean Time to Repair; an asset that can be recovered to functionality in a day will have a lower impact than one that will take weeks or months to repair.

Where not used, the default modifier score is 1

5.4 FortiFactor

The FortiFactor is determined for each hazard class by multiplying E x V x I for the hazard.

The total FortiFactor for the hazard is the sum of all hazard class fort factors.

In the case of the Sydney Harbour Bridge, the FortifFactor score is 556.

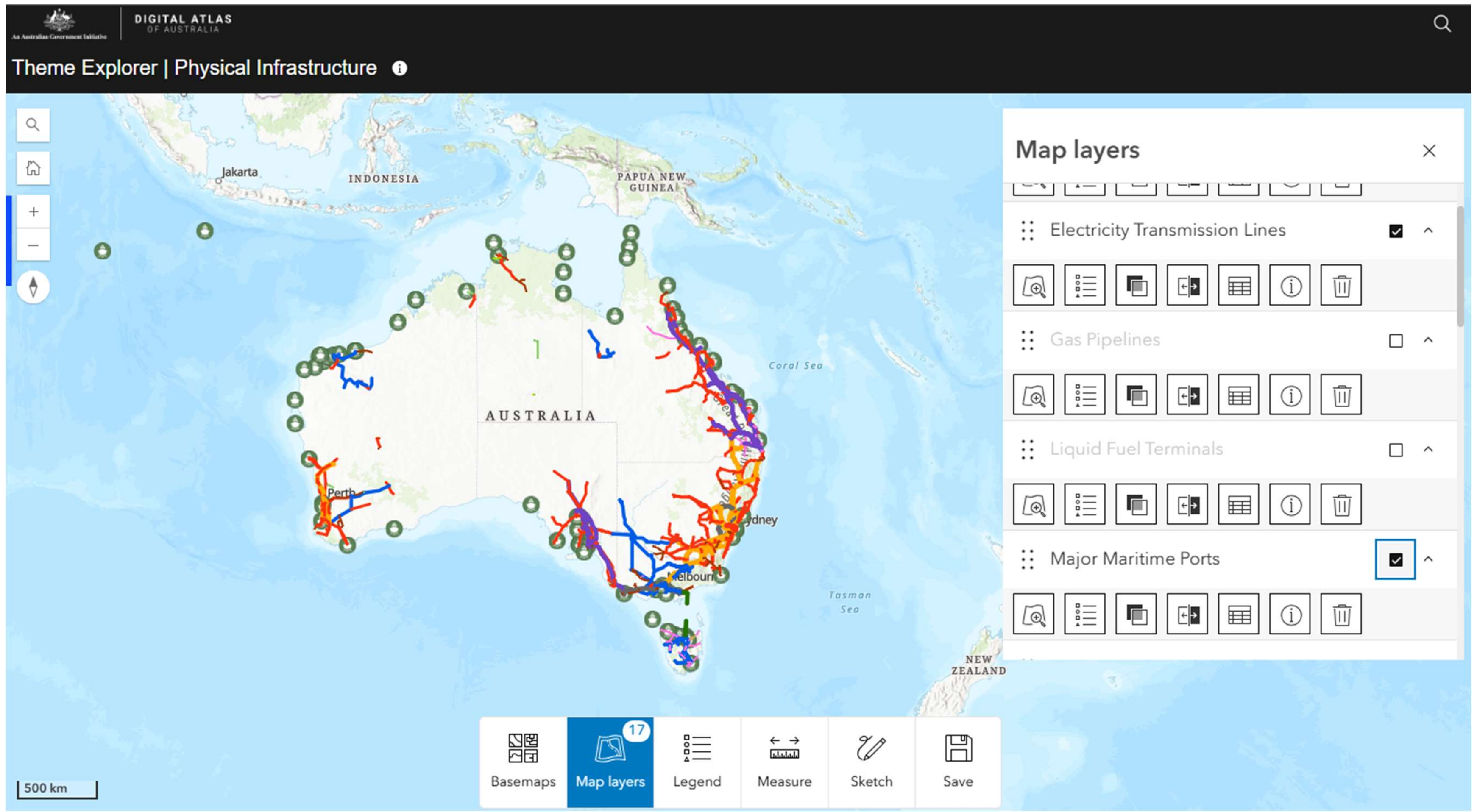
		Vulnerability	vi = Vulnerability modifiers (blank = not used)					Impact	Ii = Impact Modifiers (blank = not used)				
	E = Exposure	Bridges	v1, age	v2, designed resilience	v3, material type	v4, proximity to buildings	V = Vulnerability, including modifiers	Bridges	I1, cascade potential	I2, Redundancy	I3, Mean Time To Repair	I = Impact, including modifiers	Fortifactor, F = E x V x I (including modifiers)
Earthquake	4	8	0.5	0.5	0.5	2	2	5.00	4.00	0.50	0.25	2.50	40
Flooding	6	10		0.2			2						60
Cyclone/Storm	4	4	0.8	0.5		0.5	1						16
Tsunami	8	10					10						400
Volcanic Erruption	0	10					10						0
Landslide	0	10					10						0
Bushfire	0	4					4						0
Drought	0	0					0						0
Tornado	0	8					8						0
Heatwave	10	1				0.8	1						40
Avelanche	0	10					10						0
Blizzards	0	10					10						0
Cold snap	0	2					2						0
													556

6 DATA SOURCES

The following section presents a number of data sources which are used to inform the risk assessment. Data sources are described and reviewed, and their specific usefulness is stated. In the following section, these data sources are analysed.

6.1 Digital Atlas of Australia

Description	Geospatial platform with national datasets on transport networks and physical infrastructure, including roads, railways, and ports.
Strengths	Broad coverage of physical infrastructure across Australia. Interactive and accessible to diverse users. Integrates multiple government datasets.
Weakness	Limited hazard-specific data. Sparse real-time updates. Focuses on infrastructure layout, not resilience metrics.
Areas for Improvement	Add real-time updates, especially during hazard events. Integrate hazard and climate risk layers for better resilience planning.
Availability	Public
Uses	National infrastructure mapping for policy and planning. Emergency preparedness for transport networks. Identifying regions at risk during natural hazards.
Data used for our system	Exposure, Vulnerability
URL	https://digital.atlas.gov.au/



6.2 National Exposure Information System (NEXIS)

Description

Aggregates exposure data on residential, commercial, industrial buildings, and agricultural assets across Australia.

Strengths

Comprehensive sectoral exposure data.

High utility for estimating property and asset exposure.

Useful for analyzing population and property density across regions.

Weakness

Limited availability of real-time or frequently updated data.

Data aggregated at high levels, limiting granularity.

Lacks specific resilience metrics for infrastructure.

Areas for Improvement

Include more granular data, particularly for high-risk areas.

Enhance resilience indicators for different infrastructure types.

Availability

Public

Uses

Risk assessment for property and infrastructure.

Population density studies for urban planning.

Agricultural asset risk analysis.

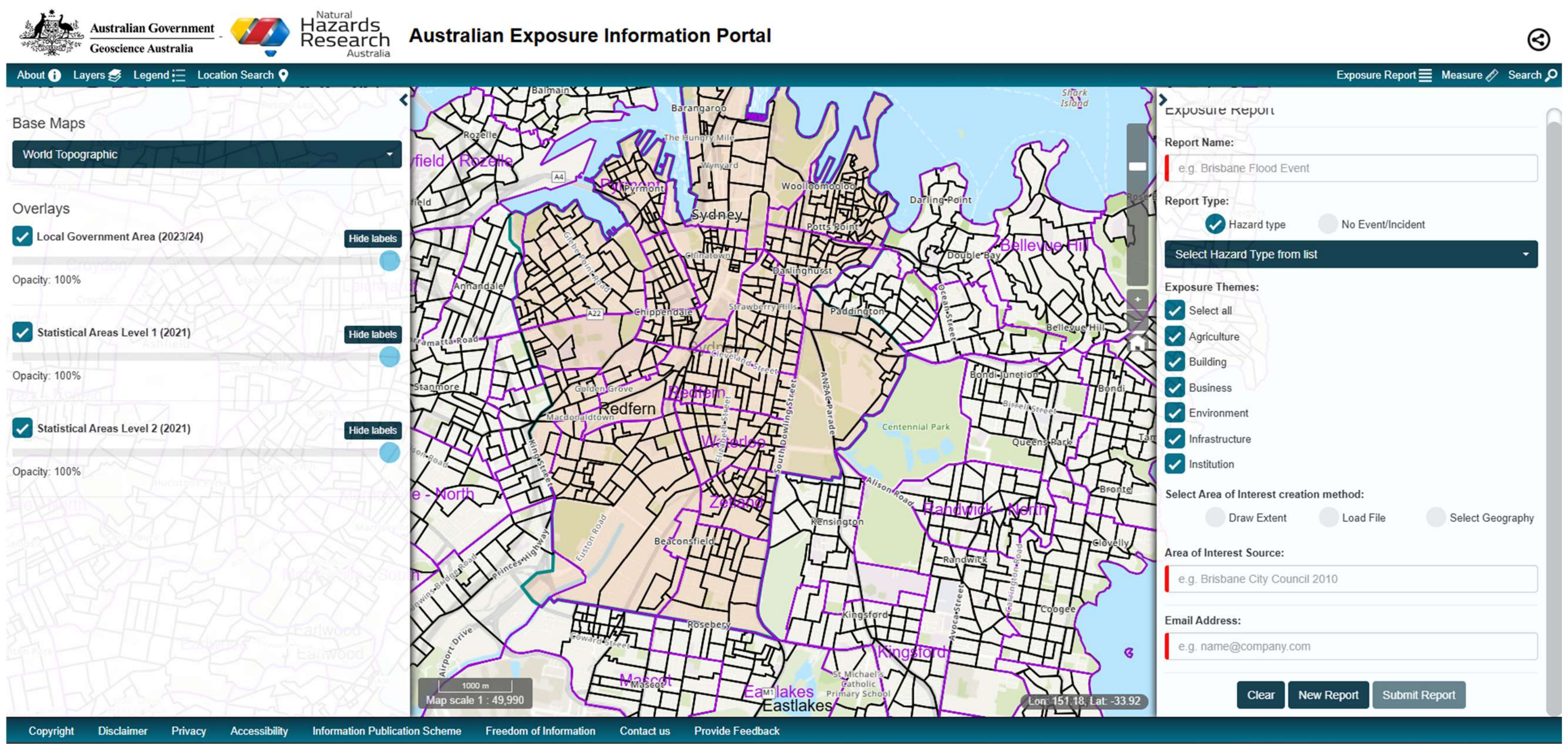
Data used for our system

Impact

URL

https://portal.aeip.ga.gov.au/

https://www.ga.gov.au/scientific-topics/national-location-information/nexis



6.3 Climate Risk Map of Australia

Description Interactive map showing climate-vulnerable areas with different emission scenarios, hazard types, and timeframes.

Strengths Detailed climate vulnerability data.

Interactive, allowing customizable risk views.

Includes future climate scenarios for planning.

Weakness Limited infrastructure-specific data.

Does not account for direct infrastructure impacts.

Does not include economic or social impact metrics.

Areas for Improvement Add layers showing infrastructure resilience against projected risks.

Integrate socio-economic vulnerability indicators.

Availability Public

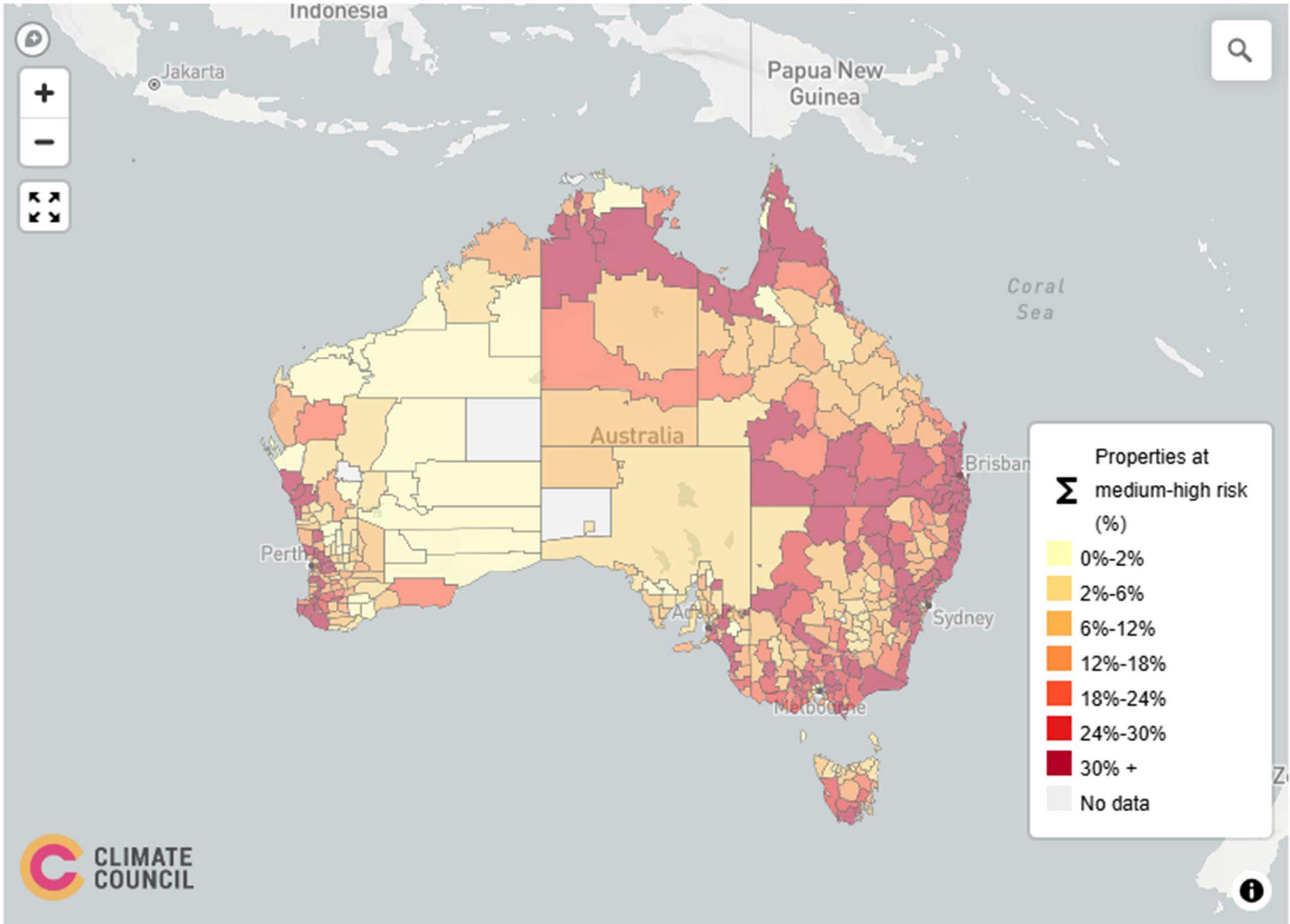
Uses Future planning for climate resilience.

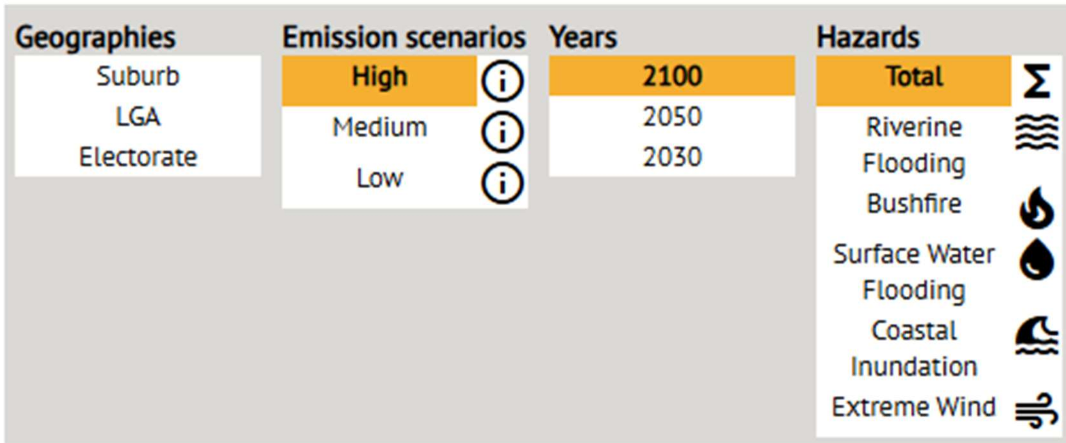
Local community impact assessments.

Visualization of climate risk across various emission scenarios.

Data used for our system Exposure, Vulnerability

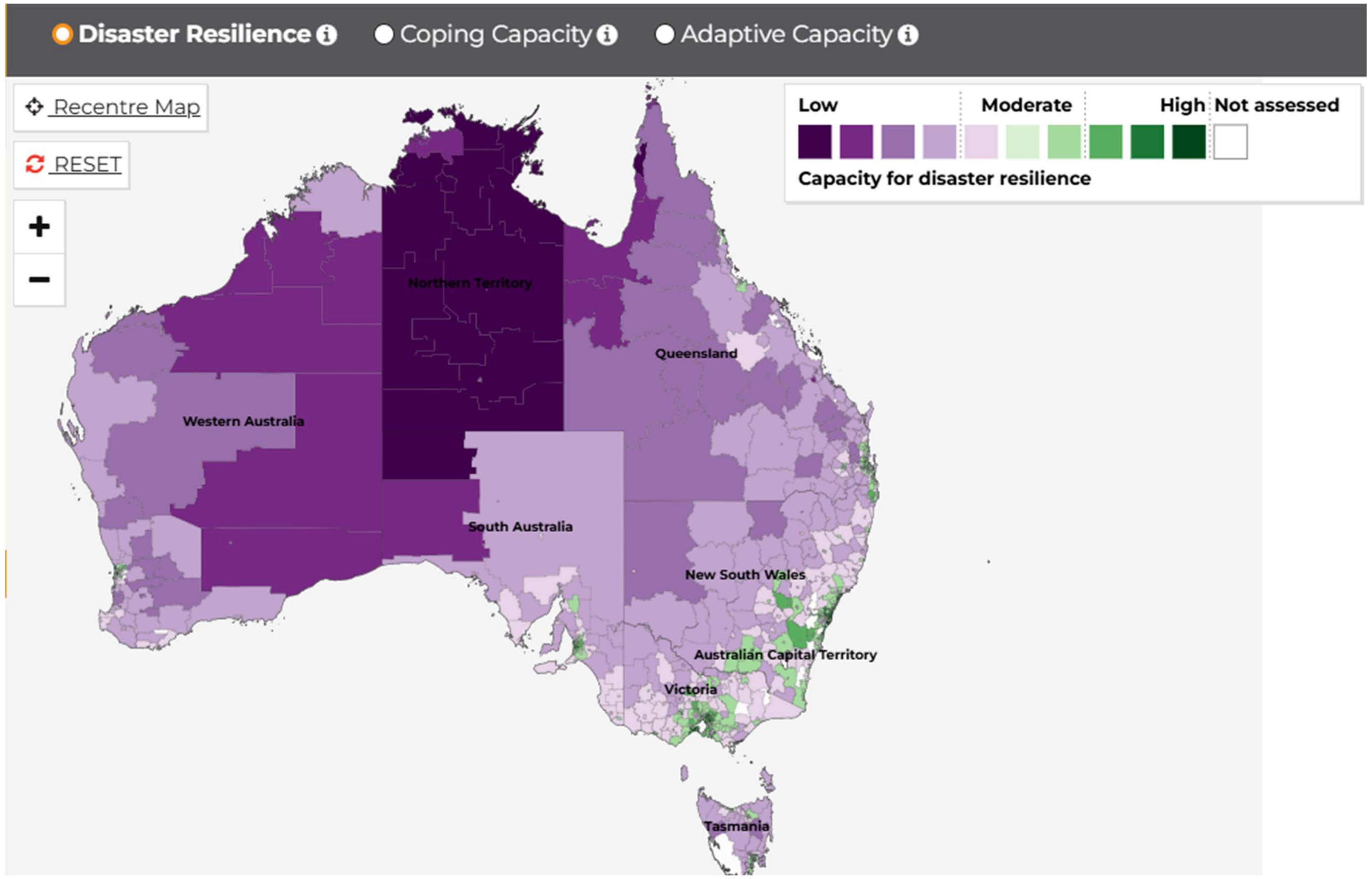
URL https://www.climatecouncil.org.au/resources/climate-risk-map/





6.4 Australian Disaster Resilience Index

Description	A national, standardized assessment of disaster resilience capacities in communities across Australia.
Strengths	Community resilience metrics are standardized and accessible. Captures multiple dimensions of community resilience. Useful for assessing resilience at local levels.
Weakness	Limited connection to physical infrastructure. Aggregated data does not specify asset-level impacts. No dynamic updates for recent events.
Areas for Improvement	Expand to assess infrastructure and community interdependencies. Add dynamic updates based on recent hazard events.
Availability	Public
Uses	Community resilience measurement. Identification of vulnerable communities for resource allocation. Disaster preparedness assessments.
Data used for our system	Vulnerability modifier for resilience, Impact modifier for Mean Time to Repair.
URL	https://adri.bnhcrc.com.au/#!/maps



6.5 Geoscience Australia Natural Hazards and Scenarios

Description

Mapping tool with data layers for hazards like cyclones, earthquakes, landslides, and bushfires, as well as various risk scenarios.

Strengths

Comprehensive coverage of multiple hazard types.

Interactive with scenario-based modeling.

Effective for understanding geographic hazard distribution.

Weakness

Limited socio-economic impact data.

Infrastructure-specific impacts are not detailed.

No provision for real-time data.

Areas for Improvement

Add layers for economic and infrastructure impacts.

Include resilience metrics for critical infrastructure assets.

Availability

Public

Uses

Geospatial mapping of hazard-prone regions.

Risk scenario analysis for policy formulation.

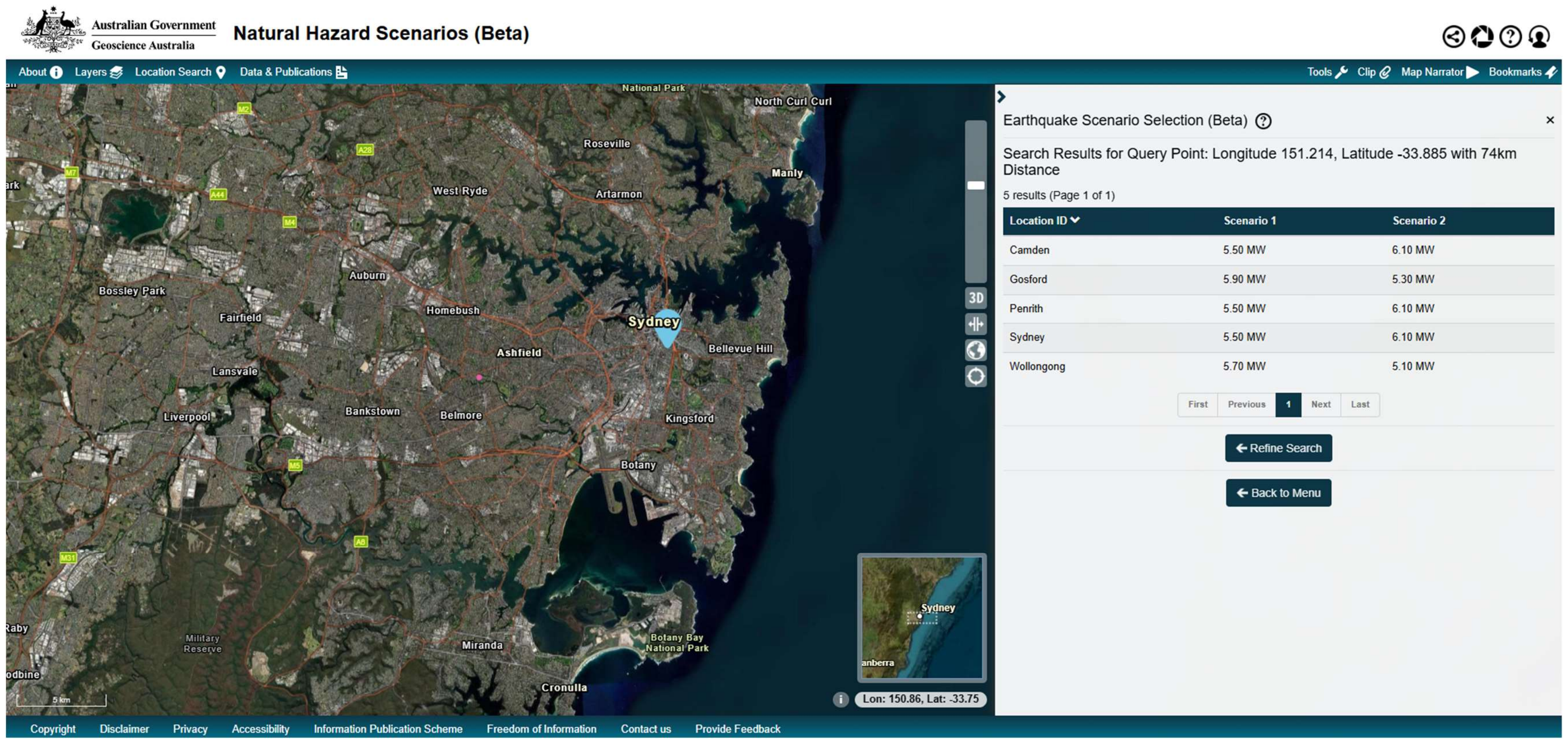
Educational use for hazard awareness.

Data used for our system

Exposure

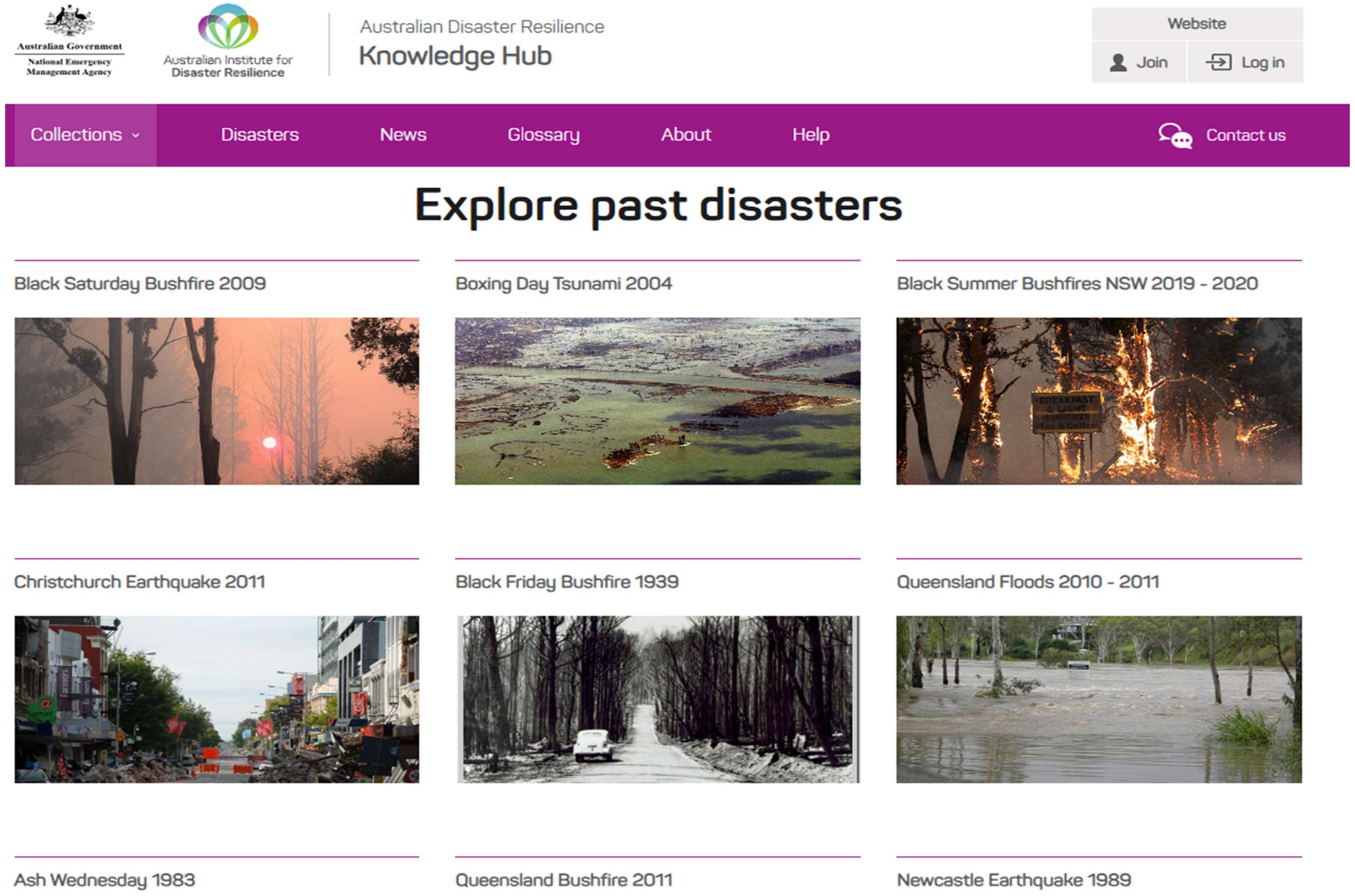
URL

https://portal.ga.gov.au/persona/hazards



6.6 Australian Disaster Resilience Knowledge Hub

Description	Contains historical data on disasters, including information on type, year, impacts, and location, along with disaster-related insights.
Strengths	Valuable historical insights on disaster impacts. Covers a wide range of disaster types and frequencies. Can be useful for trend analysis and comparison.
Weakness	Limited granularity on specific infrastructure impacts. Data may be outdated for dynamic risk assessment. Does not include predictive models.
Areas for Improvement	Link historical data with current infrastructure status for trends. - Add predictive models for anticipated future impacts.
Availability	Public
Uses	Historical disaster trend analysis. Community education and awareness about past events. Resource allocation based on past impact data.
Data used for our system	Exposure, Impact
URL	https://knowledge.aidr.org.au/collections/australian-disasters/



6.7 Australian Emergency Management Knowledge Hub

Description Dataset on historical disaster events, including impacts and geographic coordinates.

Strengths Covers diverse disaster types and locations.

Spatial data enables location-specific analysis.

Structured to include impacts, which aids resilience planning.

Weakness Limited to historical data, not predictive.

Lacks high-resolution temporal data.

Does not directly connect with current infrastructure assets.

Areas for Improvement Add predictive capabilities for future hazard events.

Integrate more detailed, asset-level impact data.

Availability Public

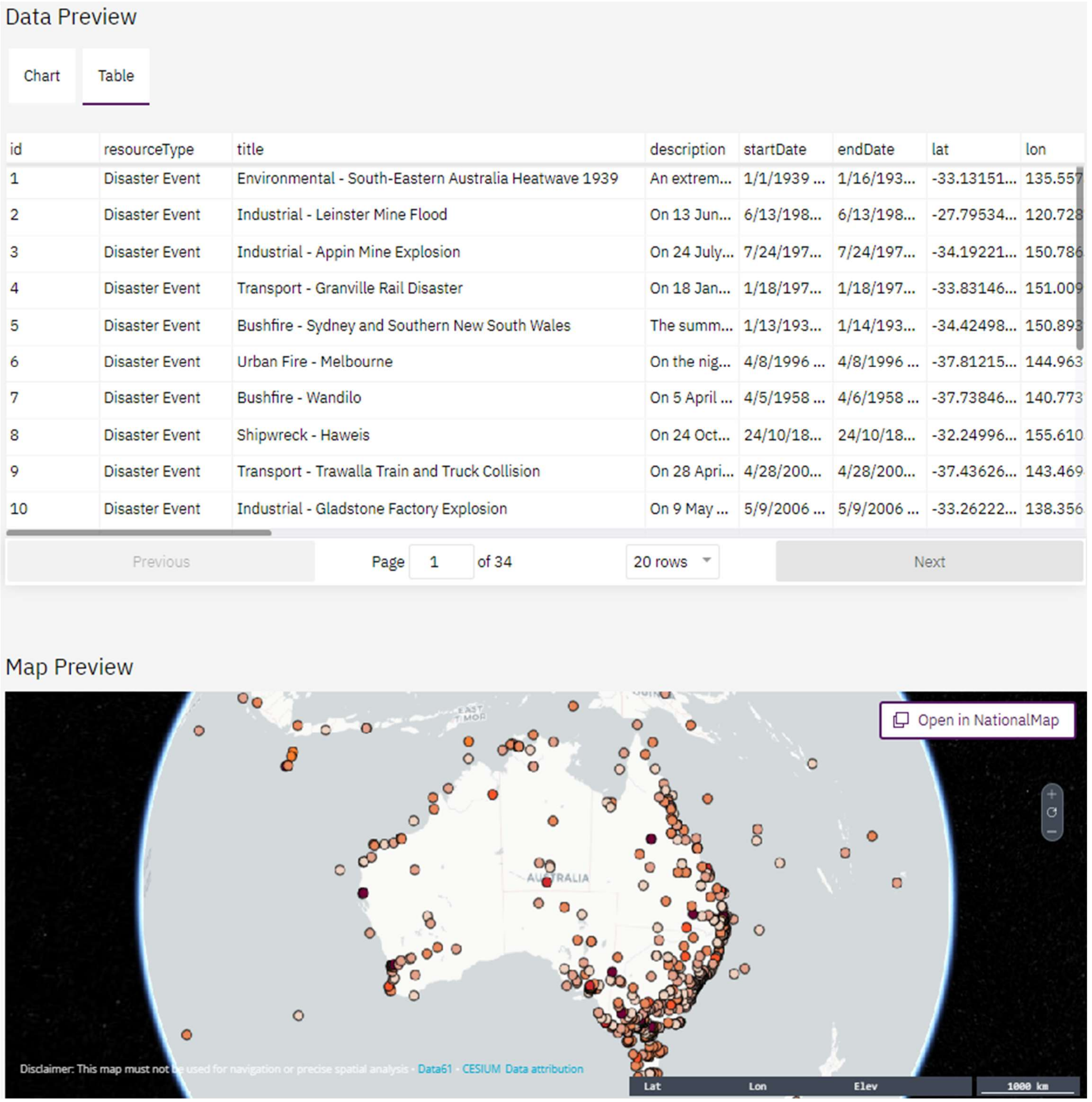
Uses Location-based disaster impact studies.

Emergency management and risk assessment.

Regional hazard planning for specific events.

Data used for our system Exposure, Impact

URL https://data.gov.au/dataset/ds-dga-26e2ebff-6cd5-4631-9653-18b56526e354/details



id	resourceType	title	description	startDate	endDate	lat	lon
1	Disaster Event	Environmental - South-Eastern Australia Heatwave 1939	An extrem...	1/1/1939 ...	1/16/193...	-33.13151...	135.557
2	Disaster Event	Industrial - Leinster Mine Flood	On 13 Jun...	6/13/198...	6/13/198...	-27.79534...	120.728
3	Disaster Event	Industrial - Appin Mine Explosion	On 24 July...	7/24/197...	7/24/197...	-34.19221...	150.786
4	Disaster Event	Transport - Granville Rail Disaster	On 18 Jan...	1/18/197...	1/18/197...	-33.83146...	151.009
5	Disaster Event	Bushfire - Sydney and Southern New South Wales	The summ...	1/13/193...	1/14/193...	-34.42498...	150.893
6	Disaster Event	Urban Fire - Melbourne	On the nig...	4/8/1996 ...	4/8/1996 ...	-37.81215...	144.963
7	Disaster Event	Bushfire - Wandilo	On 5 April ...	4/5/1958 ...	4/6/1958 ...	-37.73846...	140.773
8	Disaster Event	Shipwreck - Haweis	On 24 Oct...	24/10/18...	24/10/18...	-32.24996...	155.610
9	Disaster Event	Transport - Trawalla Train and Truck Collision	On 28 Apri...	4/28/200...	4/28/200...	-37.43626...	143.469
10	Disaster Event	Industrial - Gladstone Factory Explosion	On 9 May ...	5/9/2006 ...	5/9/2006 ...	-33.26222...	138.356

6.8 Australian Flood Risk Information Portal (AFRIP)

Description

Provides a central repository for flood studies and associated spatial flood data.

Strengths

Essential for flood risk assessments and planning.

Consolidates various regional and local flood studies.

Includes spatial data valuable for flood-prone areas.

Weakness

Limited to flood data, missing other hazard types.

Lack of real-time flood impact data.

Regional studies may vary in methodology and detail.

Areas for Improvement

Broaden scope to incorporate multi-hazard flood risk.

Standardize methodologies across regional studies for consistency.

Availability

Public

Uses

Flood risk mapping for land planning.

Infrastructure resilience checks in flood-prone areas.

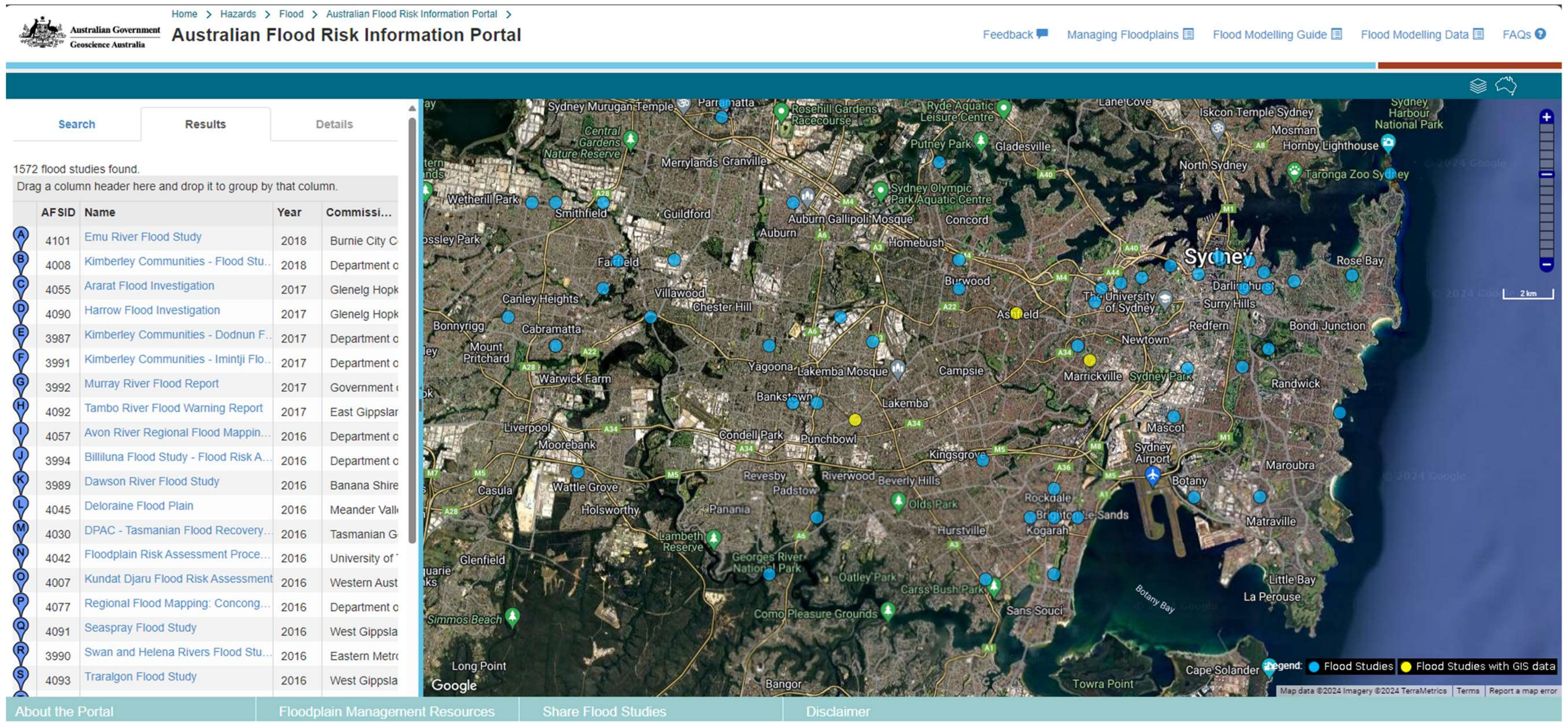
Long-term planning based on flood history.

Data used for our system

Exposure

URL

https://afrip.ga.gov.au/flood-study-web/#/search



6.9 Bushfire Boundaries Data

Description Interactive portal with national bushfire boundary data for assessing fire-prone regions.

Strengths Comprehensive spatial bushfire data.

Useful for identifying and monitoring bushfire zones.

Supports risk assessments for bushfire-prone infrastructure.

Weakness Limited to bushfire hazard, no multi-hazard data.

Lacks integration with other infrastructure risk data.

Not updated in real-time.

Areas for Improvement Incorporate multi-hazard data layers.

Add real-time updates for active fire monitoring.

Availability Public

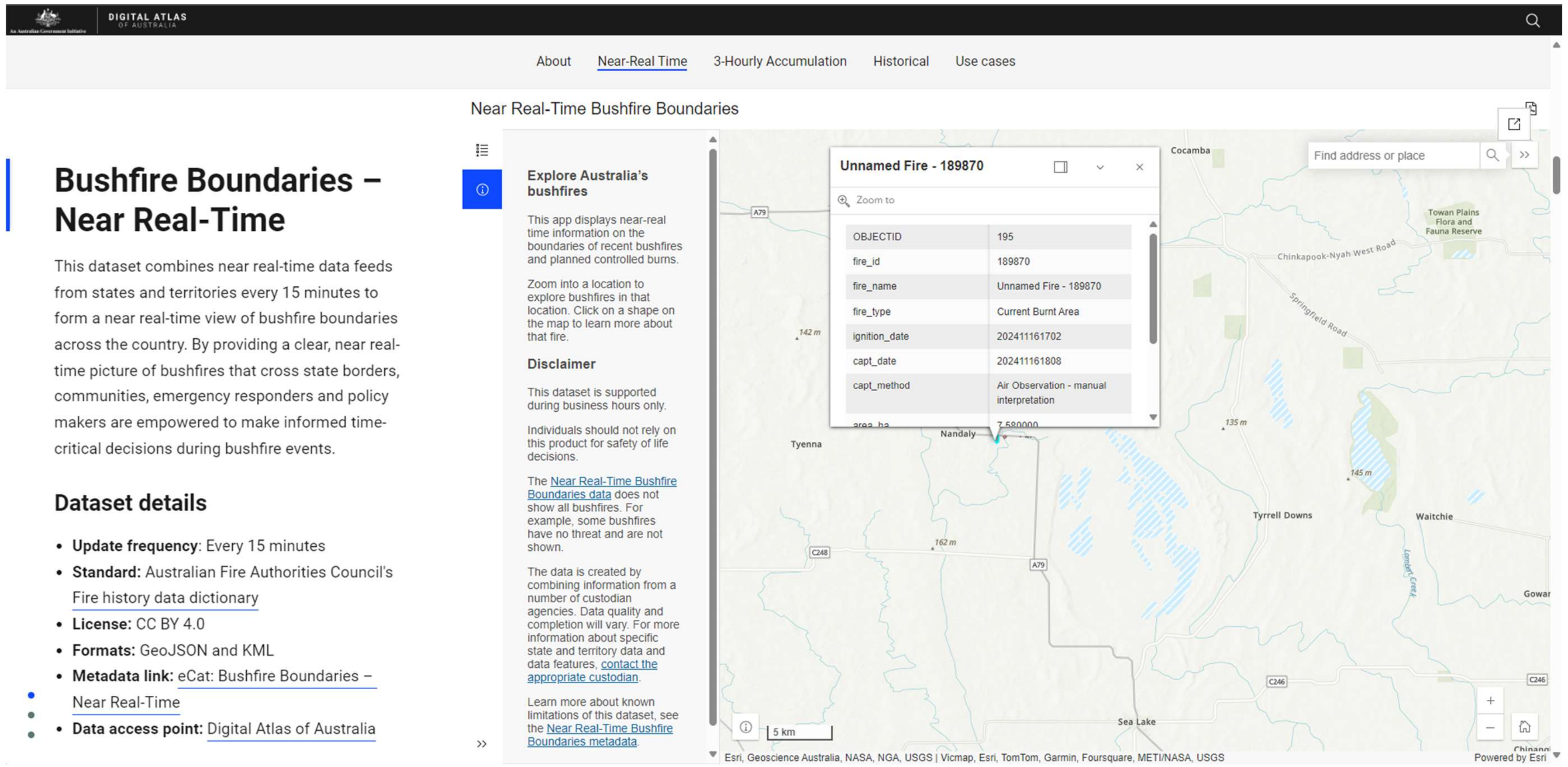
Uses Risk analysis for bushfire-prone regions.

Fire mitigation and preparedness planning.

Infrastructure protection in vulnerable zones.

Data used for our system Exposure

URL https://digital.atlas.gov.au/apps/d4739a49cea2459bbf665c67cc4d522d/explore



6.10 National Land Account

Description Data on land use and land cover, aiding in environmental impact assessments and understanding land change over time.

Strengths Covers diverse land use and environmental data.

Useful for assessing environmental resilience.

National scope with periodic updates.

Weakness Lacks direct linkage to infrastructure assets.

No hazard-specific resilience indicators.

Limited granularity for urban versus rural land types.

Areas for Improvement Add hazard-specific resilience indicators for land use.

Integrate infrastructure data for broader resilience analysis.

Availability Public

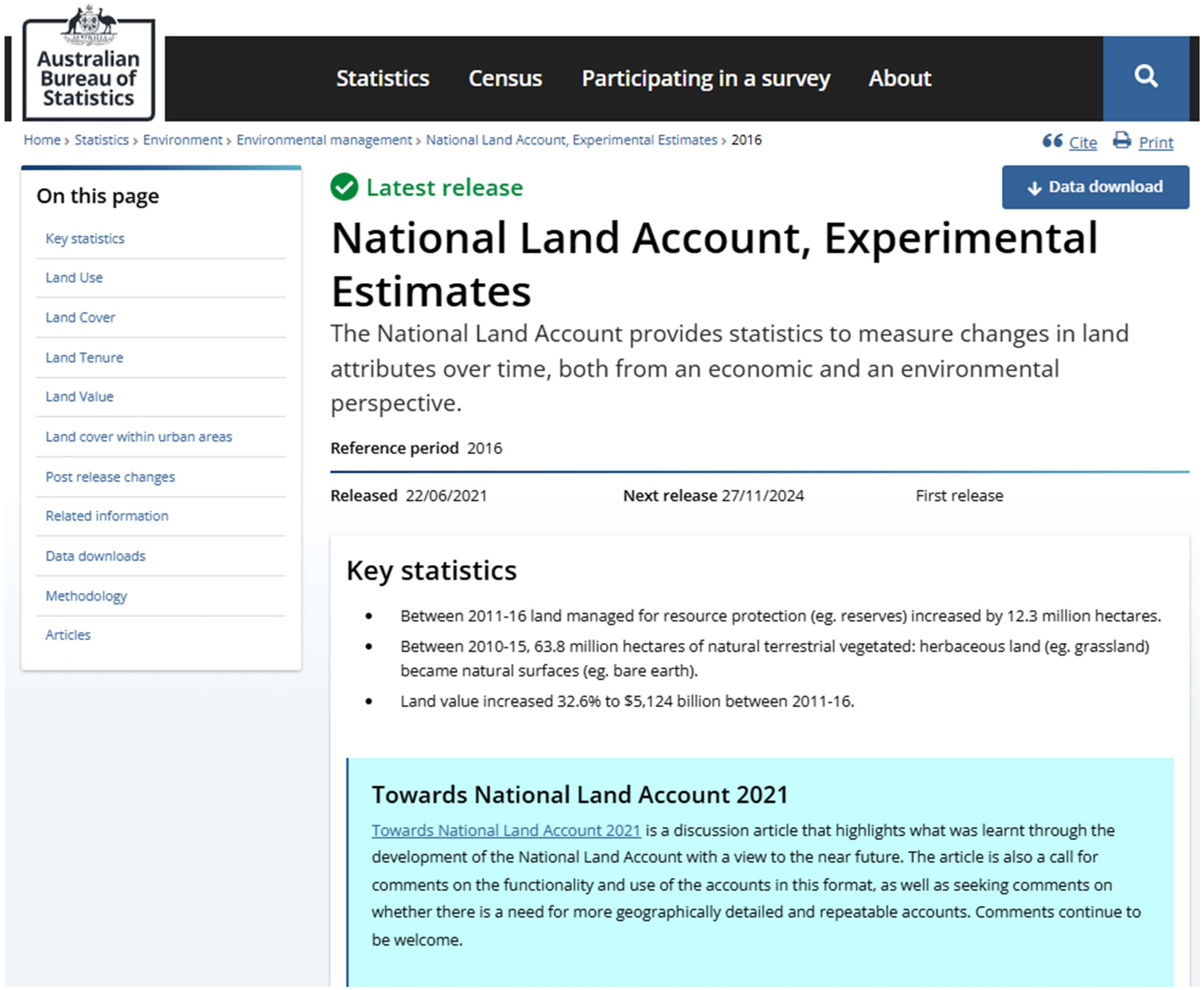
Uses Land-use planning and environmental impact assessments.

Monitoring of land use trends and changes.

Planning for urban and rural land resilience.

Data used for our system Exposure

URL https://www.abs.gov.au/statistics/environment/environmental-management/national-land-account-experimental-estimates/latest-release



6.11 Australian Rainfall and Runoff Data

Description National guidelines and data for flood hydrology, supporting infrastructure planning and flood design standards.

Strengths
- Standardized guidelines for flood management
- Key for infrastructure planning in flood-prone areas
- Provides consistent methodology for flood estimation

Weakness
- Limited regional specificity
- Does not cover other types of climate risks
- No infrastructure resilience metrics

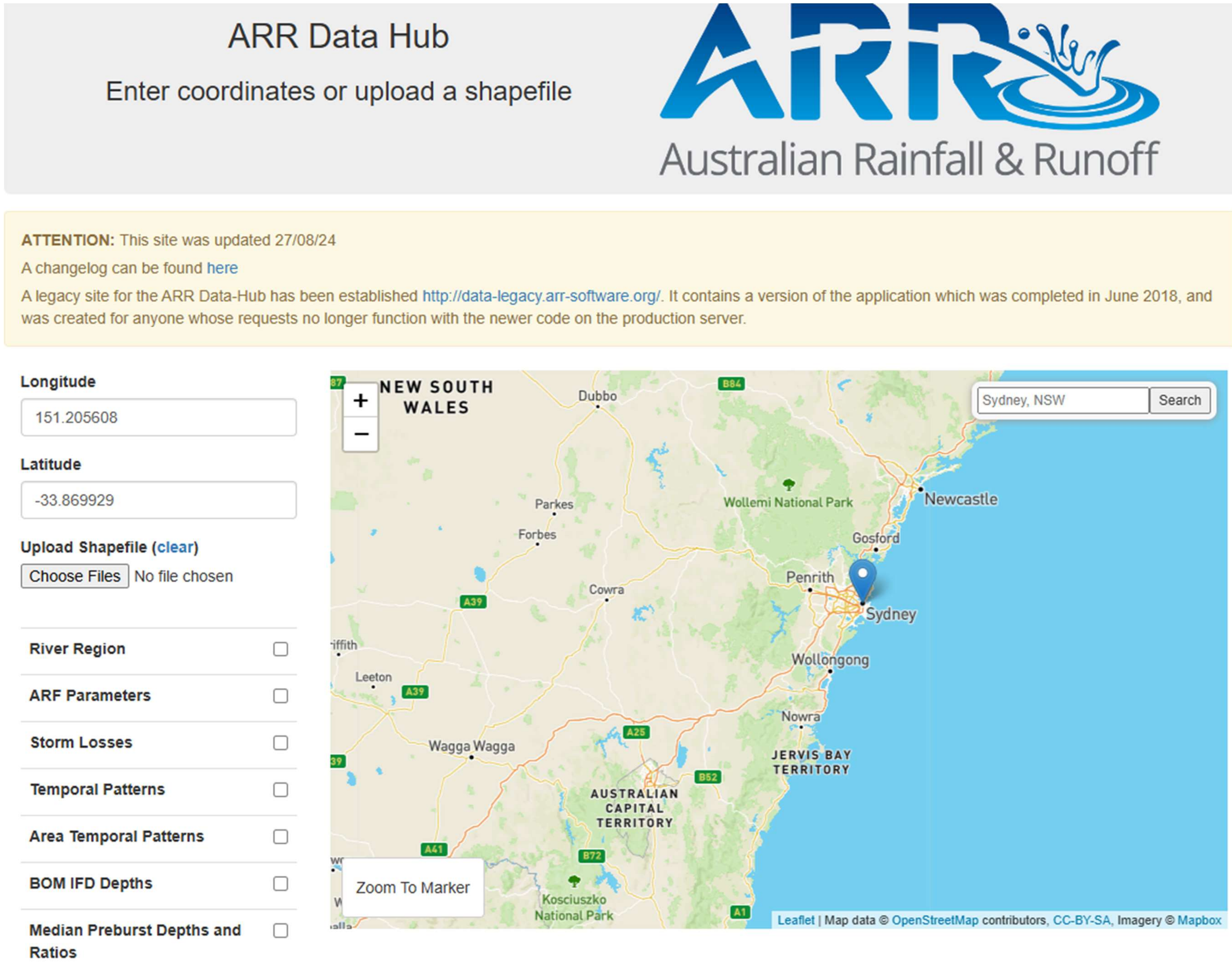
Areas for Improvement
- Enhance regional details for targeted flood resilience
- Add metrics on infrastructure performance under flood events

Availability Public

Uses Used for designing flood mitigation infrastructure, hydrological modeling, and policy compliance in flood-prone areas.

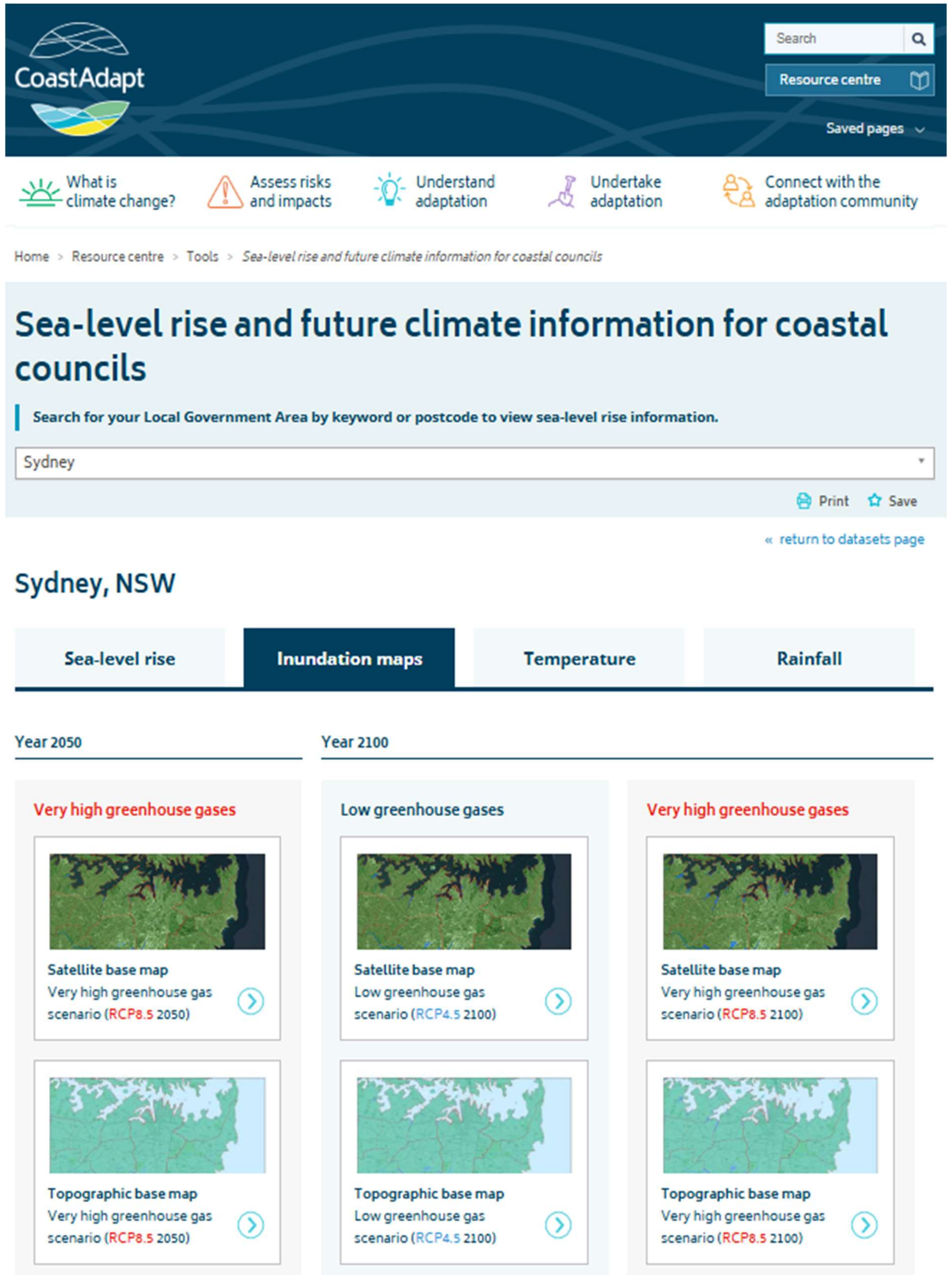
Data used for our system Exposure

URL
https://arr.ga.gov.au/
https://rffe.arr-software.org/
https://data.arr-software.org/



6.12 Coast Adapt (National Datasets for Coastal Vulnerability

Description	Covers data on coastal erosion, sea level rise, and vulnerability of coastal infrastructure and communities.
Strengths	- Essential for assessing coastal risks - Accounts for projected sea-level rise impacts - Useful for long-term infrastructure planning in coastal zones
Weakness	- Limited integration with inland hazard data - Lacks real-time updates on coastal conditions - Not highly granular for local analyses
Areas for Improvement	- Increase spatial granularity for urban coastal areas - Add real-time monitoring for high-risk coastal zones
Availability	Public
Uses	Supports coastal infrastructure planning, risk assessments for sea-level rise, and long-term adaptation strategies for coastal regions.
Data used for our system	Exposure
URL	https://coastadapt.com.au/



6.13 The Importance of Indigenous Knowledge

Case Study: The Gundagai Flood of 1852

The Gundagai flood of 1852 remains one of Australia's most devastating natural disasters, claiming the lives of 89 people and destroying much of the town. Long before the flood, the Indigenous Wiradjuri people, who had lived in the region for thousands of years, had warned the local European settlers and authorities about the vulnerability of the town's location. The Wiradjuri knew the Murrumbidgee River's flooding patterns and had historically avoided building near the floodplain. However, despite their knowledge and warnings, the council and settlers ignored their advice and proceeded to establish the town on the flood-prone land. This oversight highlighted a critical failure to integrate Indigenous knowledge into urban planning, leading to the catastrophic consequences when the floodwaters surged in 1852.

The Gundagai flood underscores the importance of consulting with Indigenous communities during infrastructure planning. The Indigenous peoples' deep connection to the land and their understanding of natural events, such as floods, can provide invaluable insights into safer site selection and resilient infrastructure development. This failure to listen to local knowledge resulted in a disaster that might have been mitigated through collaborative planning. The lesson learned from Gundagai is not only about disaster risk reduction but also about respecting and integrating the cultural knowledge of Indigenous communities. Incorporating their perspectives into modern planning processes not only helps protect lives and property but also fosters cultural respect and healing. The Gundagai tragedy, therefore, serves as a poignant reminder of the need to value Indigenous knowledge in sustainable and resilient infrastructure planning.

- McGrath, A. (2001). *Gundagai: A history of the town and district*. Gundagai Historical Society.
- Weatherhead, J. (2018). "Learning from the Past: The Gundagai Flood and Indigenous Knowledge." *Australian Journal of Environmental Planning*, 34(2), 45-59.
- Australian Bureau of Meteorology. (2020). *History of Major Flood Events in Australia*. Retrieved from https://www.bom.gov.au.

7 DATA SOURCE ANALYSIS

7.1 Strengths

7.1.1 Broad National and Sectoral Coverage

Many of these data sources, such as the Digital Atlas of Australia and the National Exposure Information System (NEXIS), offer extensive coverage of physical infrastructure across multiple sectors. By providing data on essential infrastructure like transportation networks, buildings, and agricultural assets, these sources support assessments on a national scale . Such extensive data enables a variety of applications, from exposure analysis and risk identification to resilience planning for high-risk assets. This broad scope of national data can be invaluable in supporting infrastructure and policy planning, especially when addressing resilience gaps across different sectors.

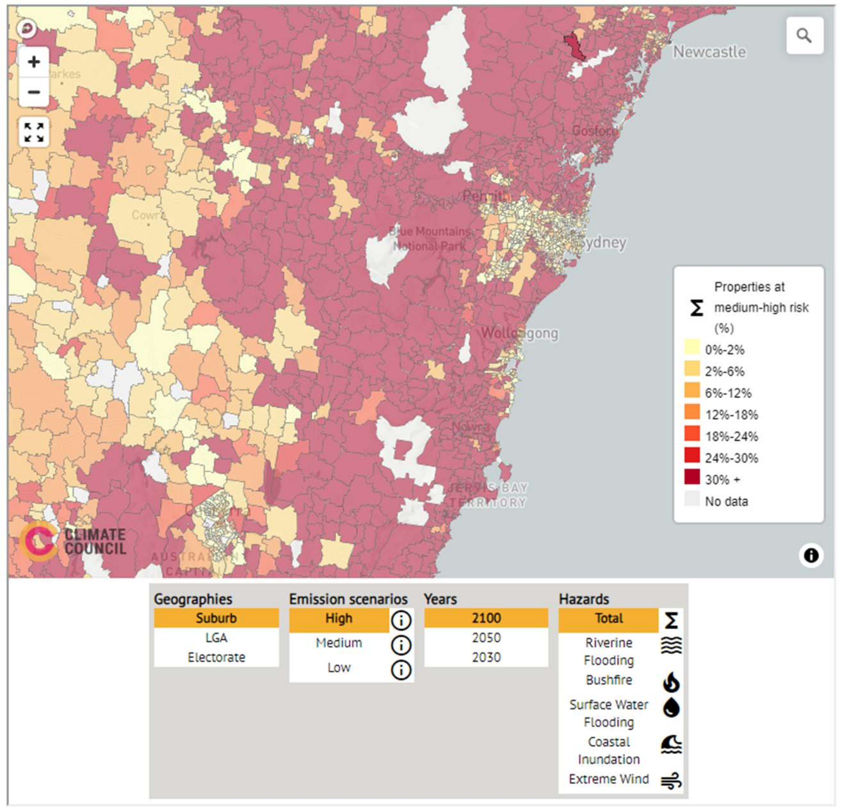
An additional advantage of these sources is the Standardisation of data formats, which can facilitate seamless integration across different platforms. This consistency in format and structure helps streamline national and sectoral analyses, making it easier for planners and policymakers to draw insights from cross-sectoral datasets. Additionally, the wide coverage includes both urban and regional holistic analysis of infrastructure resilience across both densely populated cities and less-developed rural areas. This breadth ensures that risk assessments and resilience planning can be adapted to various geographic contexts, supporting targeted initiatives where vulnerabilities are most pronounced.

7.1.2 Interactive and Spatial Analysis Tools

Tools like the Climate Risk Map of Australia, Geoscience Australia's Natural Hazards Portal, and the Australian Disaster Resilience Index provide users with powerful spatial analysis capabilities. By enabling visualizations that map hazard exposure and resilience levels across different regions, these tools support more detailed, region-specific assessments of natural hazards. The interactive nature of these tools makes them accessible to a wide range of users, from emergency responders and local planners to the broader public, fostering better community engagement and awareness of local risks.

Additionally, many of these platforms allow users to customize viewing layers, which lets them focus on specific types of data according to their unique needs. This customization is highly beneficial for tailoring analyses to particular areas or hazard types, such as flood zones or bushfire-prone regions, making it easier to conduct detailed studies of vulnerabilities within specific areas. Furthermore, the compatibility of these tools with other geospatial data platforms supports advanced analyses, as users can integrate multiple data sources for a comprehensive understanding of cross-sectoral risks and infrastructure needs.

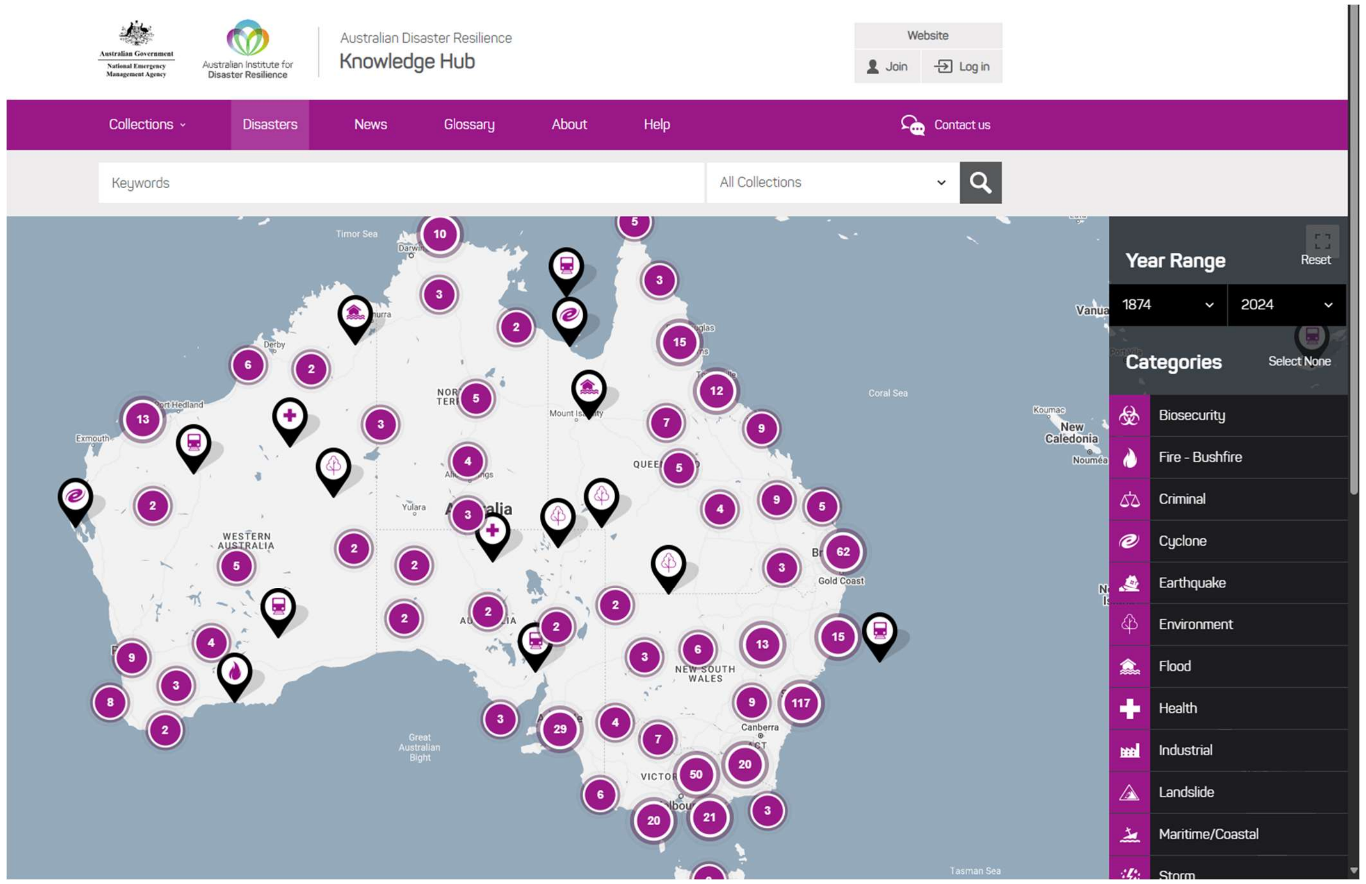
CLIMATE RISK MAP



7.1.3 Availability of Historical and Hazard-Specific Data

Several databases, including the Australian Disaster Resilience Knowledge Hub and the Natural Hazards and Scenarios Mapping Tool, offer valuable historical data on disasters that have occurred throughout Australia. This historical information enables users to identify patterns and trends in disaster frequency and intensity, which can be instrumental in tracking climate change impacts and assessing the long-term effects of these events on communities and infrastructure. The availability of hazard-specific data, such as records on past bushfires, cyclones, and floods, is essential for identifying high-risk areas and informing preventive measures that can mitigate future risks.

Longitudinal data in these databases also supports temporal analysis, allowing researchers to examine how hazard impacts have changed over time. This insight can be vital for designing adaptive strategies that evolve alongside shifting climate and environmental conditions. Additionally, the databases often include details about the specific impacts of each hazard, such as damage to critical infrastructure, which can guide future investments in resilience efforts for the most affected sectors.



7.2 Weaknesses

7.2.1 Data Fragmentation and Inconsistency

A significant limitation of these data sources is the inconsistency in data collection methodologies, geographic coverage, and update frequencies, leading to fragmented data that complicates the creation of a cohesive national resilience framework . For example, datasets may be designed with unique goals or agency priorities in mind, which often results in data that is incompatible or difficult to integrate with other sources. This fragmentation affects the reliability and comparability of insights drawn from multiple datasets, making it challenging to construct comprehensive resilience strategies that account for risks across different regions and sectors.

Furthermore, differences in update cycles among sources can lead to outdated information, particularly when some datasets are updated only periodically. This is a significant barrier for real-time risk assessments, especially in rapidly evolving hazards like bushfires and floods, where delayed information may undermine timely decision-making. As each dataset has unique standards and collection frequencies, merging these sources into a unified national framework is an ongoing challenge, requiring substantial Standardisation efforts across agencies and sectors.

7.2.2 Lack of Granular Infrastructure Impact Data

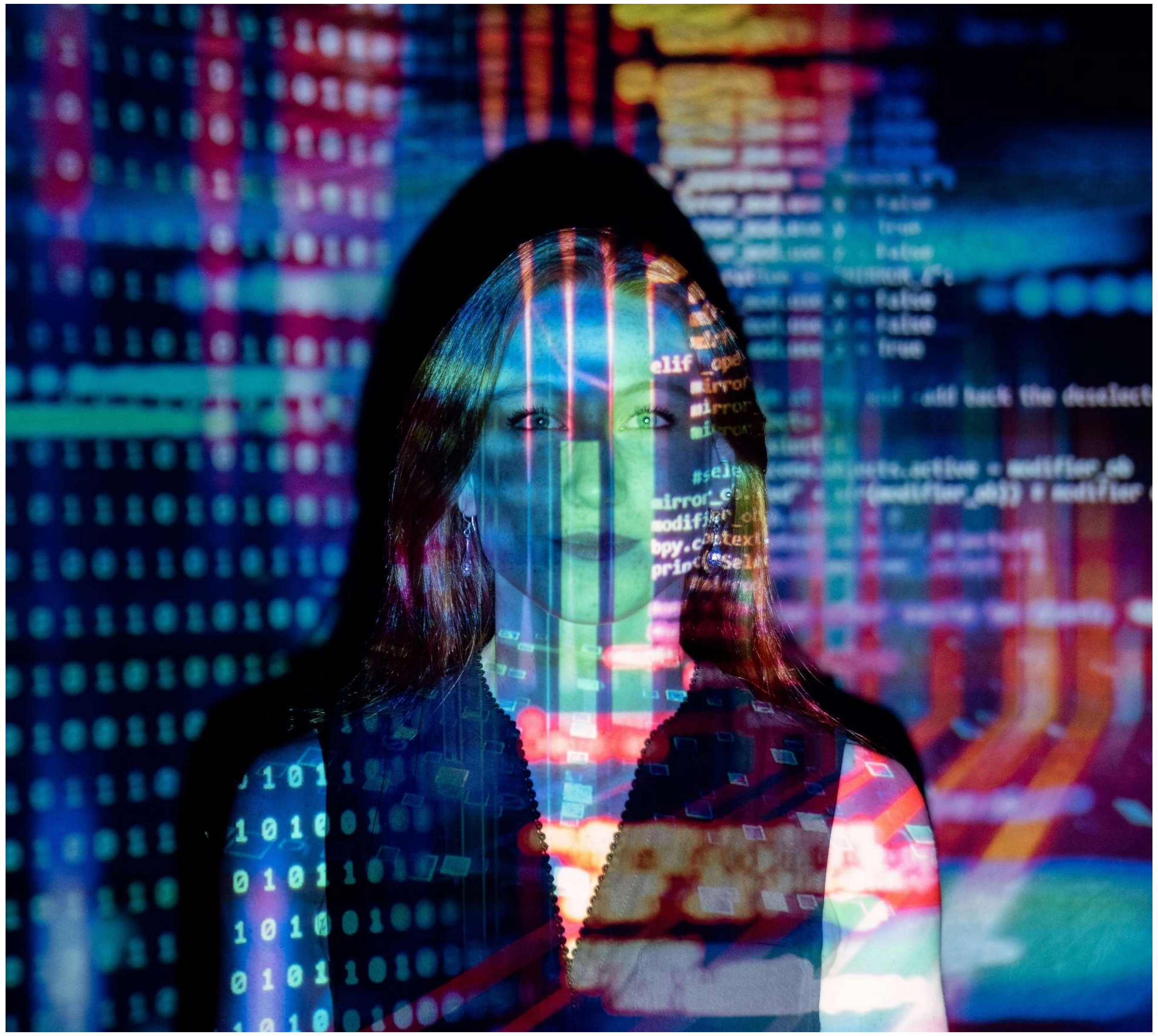
Many data sources provide only general information on hazard impacts, lacking the granular, asset-specific data needed to evaluate infrastructure resilience accurately. This absence of infrastructure-specific vulnerability data limits the ability to assess the robustness of individual infrastructure components, such as roads, bridges, and utilities, under particular hazard conditions. For effective resilience planning, it is essential to understand how different infrastructure assets respond to hazards, but current datasets often do not provide this level of detail.

The general nature of available data reduces the precision of predictive models used for risk assessment, particularly in hazard-prone regions where infrastructure vulnerabilities vary greatly. Without asset-level data, it becomes challenging to create targeted resilience strategies tailored to specific vulnerabilities in critical infrastructure networks. Furthermore, infrastructure resilience planning efforts may overlook certain risks or fail to allocate resources effectively, as the lack of detailed vulnerability metrics makes it difficult to prioritize investments based on asset-specific risk levels.

7.2.3 Limited Real-Time Data Integration

A notable limitation across these sources is the lack of integration with real-time data, especially critical for rapidly changing hazards like bushfires, floods, and severe storms. Most datasets are updated periodically, limiting their application in dynamic, time-sensitive assessments where real-time data would be invaluable for emergency response and immediate decision-making. In situations where hazards evolve quickly, such as fast-spreading bushfires, delays in data updates can significantly hinder effective risk assessment and resource allocation.

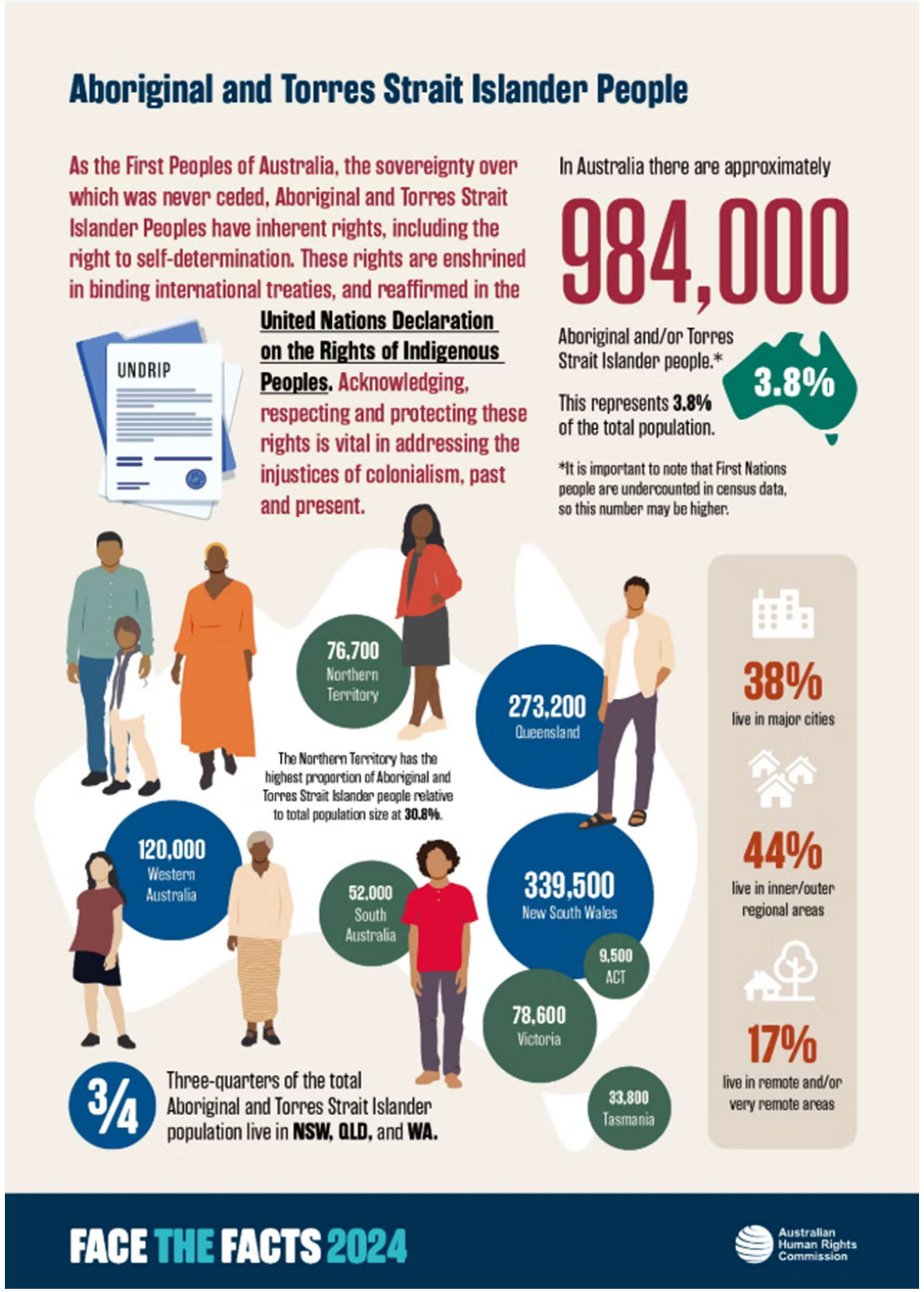
The scarcity of real-time data poses challenges for local and state governments, as well as emergency management agencies, who rely on timely information to coordinate response efforts. Real-time monitoring solutions, such as satellite data and IoT sensors, are available but are often costly, restricting their accessibility for smaller communities or agencies with limited budgets. Without consistent integration of real-time data, these sources cannot fully support the urgent needs of on-the-ground responders or help communities prepare adequately for rapidly approaching hazards.



7.2.4 Insufficient Representation of Remote and Indigenous Lands

A considerable gap exists in data coverage for remote and Indigenous territories, as many datasets lack comprehensive data for these areas. This is particularly concerning because remote regions, including Indigenous lands, often face unique vulnerabilities to natural hazards and are typically less equipped to respond and recover quickly. As a result, resilience assessments that do not include these regions may overlook critical risks, leading to under-resourced or ineffective mitigation efforts.

Moreover, resilience planning that lacks cultural context and Indigenous perspectives can miss vital historical and local knowledge related to land stewardship. Indigenous communities have longstanding connections to the land and a deep understanding of local environmental patterns, making their insights essential for culturally inclusive and sustainable resilience strategies. Without this knowledge, resilience efforts risk being incomplete, less effective, and potentially unsustainable in the long term, as they may fail to address the specific needs and values of Indigenous communities. Additionally, the lack of detailed spatial data on remote areas means that resilience efforts often concentrate on urban centers, potentially neglecting more vulnerable populations in sparsely populated regions who face significant barriers in preparing for and recovering from natural hazards.



7.3 Key Gaps and Limitations in Data

7.3.1 Infrastructure-Specific Resilience Indicators

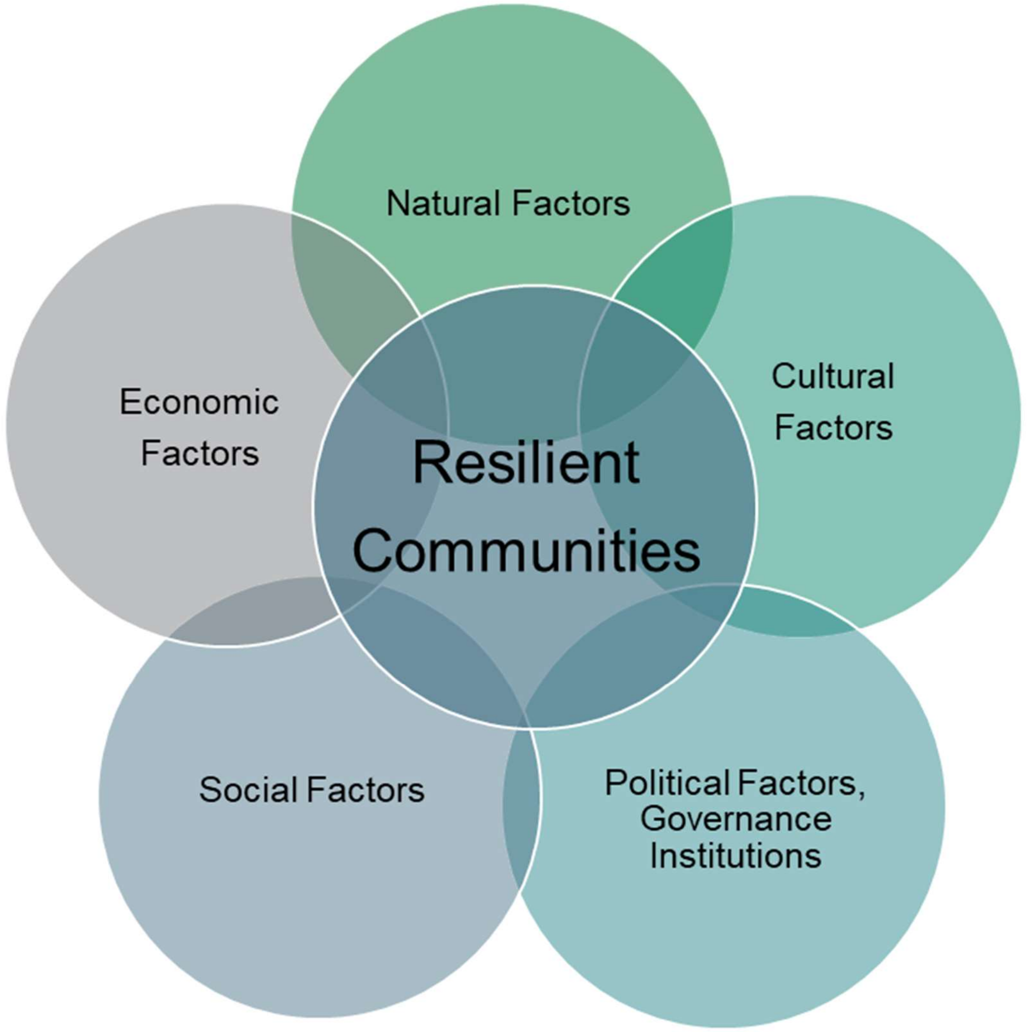
While there is substantial data on natural hazards and general exposure, few datasets contain detailed indicators directly linking infrastructure resilience—such as structural robustness or recovery capacity—with specific hazard scenarios. This gap complicates efforts to evaluate and strengthen the resilience of individual infrastructure assets, as there is limited information on how different assets might respond under various hazard conditions. For instance, while datasets like the National Exposure Information System (NEXIS) provide general exposure data, they lack insights into the resilience attributes of specific infrastructure types, such as the earthquake resistance of buildings.

The absence of such resilience indicators means that current resilience planning efforts often rely on assumptions rather than data-backed insights, limiting the precision of risk management strategies. Without infrastructure-specific metrics, it is challenging to conduct comparative analyses across different asset types, making it difficult to prioritize resources effectively or identify critical assets requiring immediate resilience enhancements.

7.3.2 Socio-Economic and Community Resilience Data

While sources like the Australian Disaster Resilience Index provide a high-level view of community resilience, there is a lack of detailed data on the socio-economic impacts of infrastructure failures on specific communities. Such data is critical for understanding how disruptions affect vulnerable populations, who may rely more heavily on certain services or face greater challenges in recovery. Without linking infrastructure resilience to socio-economic impacts, it is difficult to fully assess risks, including economic losses, health impacts, and social disruptions.

This gap limits planners' ability to address community-specific needs, such as ensuring the resilience of essential services in lower-income or remote areas. It also hinders modeling the long-term effects of infrastructure failures on local economies and public health, which are crucial for building inclusive resilience plans that account for broader societal needs.



7.3.3 Aboriginal and Indigenous Data Integration

Indigenous communities and their territories are often underrepresented in existing resilience and hazard assessment datasets, which creates significant gaps in resilience planning for these areas. Indigenous lands face unique vulnerabilities to natural hazards, and Indigenous communities hold vital knowledge about local land management and environmental stewardship. However, current datasets frequently lack this cultural and historical context, resulting in resilience planning efforts that may be less effective or sustainable for these communities .

The exclusion of Indigenous perspectives and data limits the inclusivity of resilience strategies and may lead to plans that are out of alignment with Indigenous values and practices. Indigenous knowledge offers valuable insights into land-use practices and risk mitigation strategies that are deeply rooted in local ecosystems, which can enhance the sustainability of resilience efforts. By integrating Indigenous knowledge, resilience planning could better address the unique needs and cultural values of these communities, promoting more comprehensive and equitable resilience solutions. Without this integration, however, resilience efforts risk perpetuating historical inequities, as Indigenous communities may be left underprepared for hazards despite their deep understanding of local environmental conditions.

7.3.4 Limited Hazard Interdependencies

Existing datasets often analyze hazards in isolation, focusing on individual risks such as flooding, bushfires, or cyclones without accounting for how these hazards might interact to create compound or cascading effects. This limited scope hinders the ability to develop resilience strategies that account for complex, multi-hazard scenarios, which are becoming increasingly common due to climate change and other environmental factors. For instance, bushfire-affected areas may face elevated flood risks due to vegetation loss, yet few datasets capture these compound risk dynamics in a way that would allow planners to develop integrated, multi-hazard resilience plans.

The lack of data on hazard interdependencies complicates efforts to conduct holistic risk assessments, as it becomes difficult to understand how different hazards might jointly impact infrastructure, communities, and natural systems. This limitation can lead to resilience plans that are less adaptive and versatile, reducing their effectiveness in real-world conditions where hazards often interact in unpredictable ways. Additionally, ignoring multi-hazard risks may result in unforeseen vulnerabilities, as resilience strategies may fail to account for the compound effects that exacerbate damage or hinder recovery. Addressing these gaps by incorporating multi-hazard analysis into resilience planning could significantly strengthen preparedness and mitigation strategies, helping communities anticipate and respond to the increasingly complex nature of hazard events.

7.4 Data Gaps

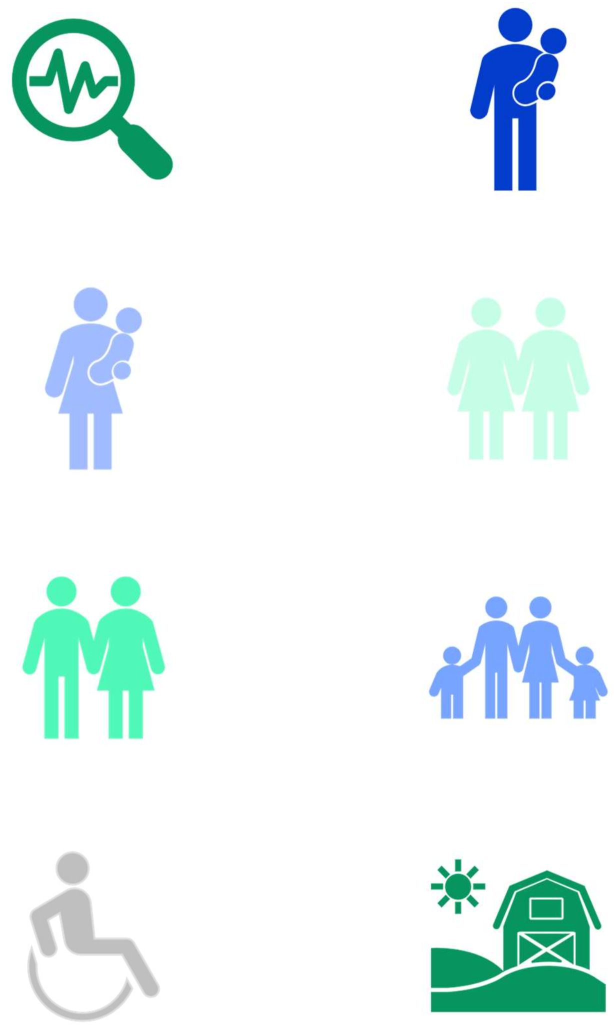
7.4.1 Identified Gaps

Temporal Data Gaps: Regularly updated, real-time hazard data is essential for dynamic assessments, especially for hazards like bushfires or floods where conditions can change rapidly. The lack of timely information hinders effective disaster response and preparedness, leaving communities and infrastructure more vulnerable. Real-time data also supports predictive modeling, enabling proactive rather than reactive risk management strategies.

Indigenous Community Data Integration: Existing data sources often exclude Indigenous lands and perspectives, missing crucial knowledge and historical context in assessing regional risks and resilience This exclusion not only diminishes the effectiveness of resilience frameworks but also marginalizes the contributions of Indigenous communities. Better integration would allow planners to leverage traditional ecological knowledge, providing more comprehensive and sustainable solutions.

Granular Infrastructure Vulnerability Data: Most sources lack detailed vulnerability metrics for individual infrastructure components, limiting asset-specific resilience assessment. The absence of this data creates gaps in understanding how specific assets perform under different hazard scenarios. This limits targeted mitigation efforts and can result in inefficiencies in resilience investment allocation.

Lack of Socio-Economic Context: There is a limited linkage between infrastructure failure, socio-economic impacts, and long-term resilience, especially in socio-economically vulnerable communities. This gap complicates efforts to prioritize regions for intervention and support. Without socio-economic data, it is challenging to quantify the broader economic and social consequences of disasters, reducing the ability to advocate for targeted resources.



7.5 Recommendations

7.5.1 Invest in Real-Time and Dynamic Data Integration

Improving real-time data availability—particularly for time-sensitive hazards like bushfires and flooding—would enhance the accuracy of risk assessments . Real-time monitoring technologies, such as IoT sensors and remote sensing, can detect rapid environmental changes, enabling quicker responses. Additionally, these systems can support continuous updates to hazard models, ensuring planners work with the most accurate datasets available.

7.5.2 Strengthen Indigenous Collaboration and Data Representation

Engage Indigenous communities as data partners to integrate Aboriginal land and heritage data into national frameworks. This collaboration should extend beyond data collection to involve Indigenous leaders in decision-making processes. By fostering mutual respect and inclusion, resilience planning can address cultural and ecological considerations more effectively, resulting in inclusive, community-driven solutions.

7.5.3 Enhance Data Standardisation and Interoperability

Standardize data formats and collection methodologies across sectors to improve data integration and allow for seamless, cross-sectoral analysis. Establishing interoperability standards between agencies would also help consolidate disparate datasets into a unified platform, improving accessibility and usability. Furthermore, standardized data can enhance international collaboration on climate and hazard resilience initiatives.

7.5.4 Develop Infrastructure-Specific Vulnerability Indicators

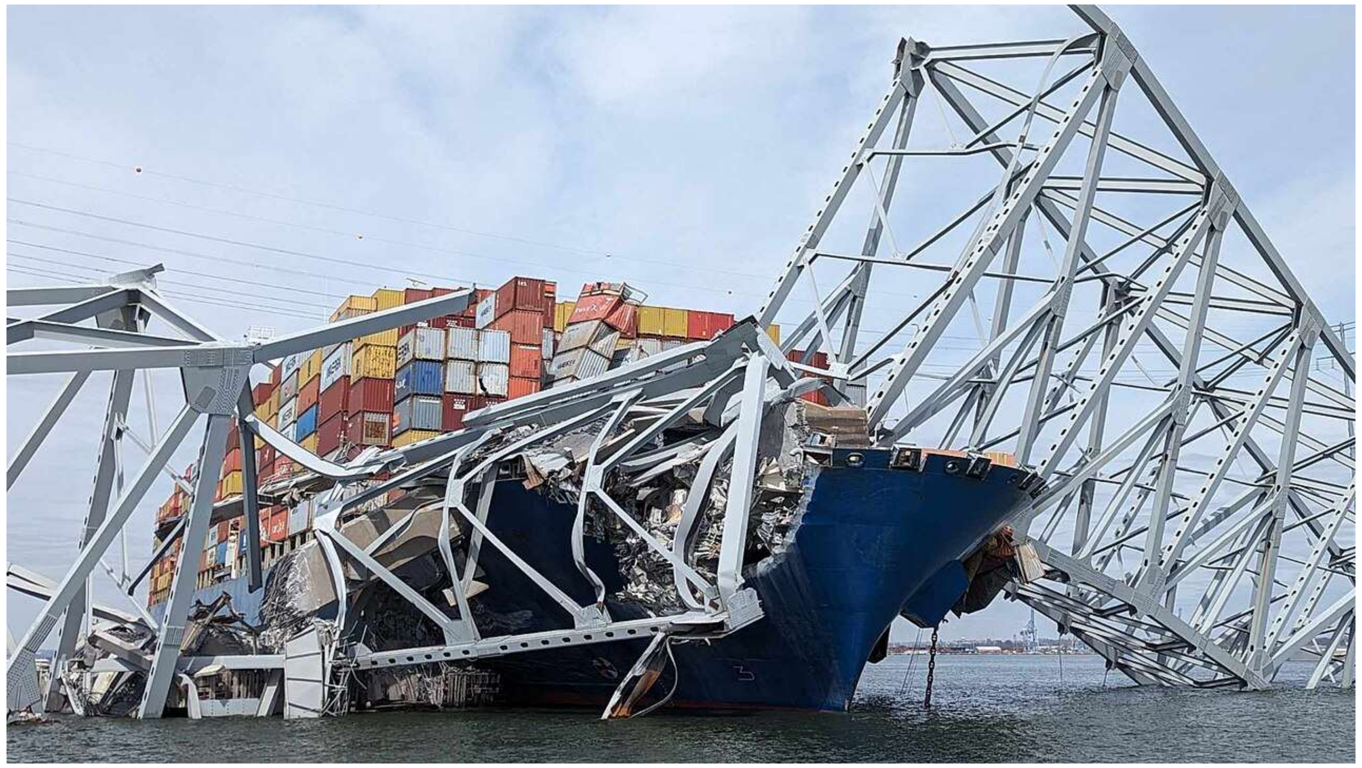
Collaborate with engineering and infrastructure experts to establish resilience indicators for infrastructure assets (e.g., flood resilience ratings for roads or bridges). Such indicators can provide a standardized measure of infrastructure robustness, making comparisons across regions and asset types more effective. These indicators can also inform future design standards, improving resilience in new infrastructure projects.

7.5.5 Incorporate Socio-Economic Impact Layers

Adding socio-economic data (e.g., economic activity, income levels) to resilience frameworks can help identify vulnerable communities and quantify the economic consequences of infrastructure failure. Including demographic data, such as population density and age distribution, can further refine risk assessments and enable targeted resource allocation. This holistic approach can significantly enhance the social equity of resilience planning.

7.5.6 Explore Compound Hazard Scenarios

Analyzing combined hazard effects (e.g., fire followed by flood) will better simulate real-world scenarios, supporting the development of multi-hazard resilience strategies. Compound hazard modeling can uncover cascading risks, such as how infrastructure damage from one hazard exacerbates vulnerability to another.



7.6 Summary of data sources

The above data sources provide essential insights for assessing the risks and resilience of Australian infrastructure against natural hazards. Collectively, they provide the raw data necessary to form a broad understanding of how various natural hazards such as bushfires, floods, and cyclones impact infrastructure, communities, and the environment. However, several critical challenges limit the effectiveness of these data sources. Chief among these are the lack of real-time data, inconsistent methodologies across different datasets, and a scarcity of resilience-specific metrics, particularly for assessing the robustness of infrastructure under hazard conditions. Addressing these limitations is crucial for enhancing the utility of these data sources, especially as they relate to cohesive national resilience planning.

Another prominent challenge is the focus on urban and metropolitan areas, which leaves rural and Indigenous lands underrepresented in hazard and resilience assessments. This gap is particularly concerning given that infrastructure in these remote areas often faces heightened vulnerability to natural hazards, yet may receive less attention in national resilience planning efforts. Moreover, integrating socio-economic data with hazard data could provide a deeper understanding of the broader impacts of natural hazards on communities and local economies, which would be highly beneficial for comprehensive resilience planning.

8 IMPLEMENTATION

8.1 Add to An Existing World-Leading Toolkit

FORTIFY propose that Infrastructure Australia build upon the work of international resilience experts.

The “Global Resilience Index (GRI) Risk Viewer” is an open-source map-based platform developed by researchers at the University of Oxford. Whilst it shows both the effect of natural hazards on population and assets, there are specific features that are of interest to assessing infrastructure risk. Link: https://global.infrastructureresilience.org/

Features of interest to FORTIFY is that it draws upon a range of open-source data sources to present;

- Hazards that may affect an area, and the scale of intensity
- It incorporates forecast hazard profiles after incorporating for the impact of climate change
- Geographically mapped infrastructure assets, typically represented in short segments. (expressed as ‘Exposure’).
- Calculates infrastructure risk based on a back-end formula and presents the information in colour-coded format
- Low latency and intuitive user-interface

8.1.1 Oxford GRI Risk Viewer is a Cumulation of work across multiple governments

The Oxford rendition of the GRI viewer itself is an iteration of earlier tools and research developed through the UK Foreign and Commonwealth Development Office (FCDO) as part of a project with the Government of Jamaica (GoJ) under the Coalition for Climate Resilient Investment’s (CCRI) work on "Systemic Resilience" in collaboration with the Green Climate Fund, and also through the High-Volume Transport Applied Research project.

Similarly, earlier versions of the tool piloted in Argentina and South-East Asia were funded by the Disaster Risk Financing and Insurance Program (DRFIP) of the World Bank with support from the Japan—World Bank Program for Mainstreaming DRM in Developing Countries, which is financed by the Government of Japan and managed by the Global Facility for Disaster Reduction and Recovery (GFDRR) through the Tokyo Disaster Risk Management Hub.

It would be a sensible allocation of funds, a net benefit for the global community and expand potential for access to a world-wide network of researchers if any work by IA built upon this tool.

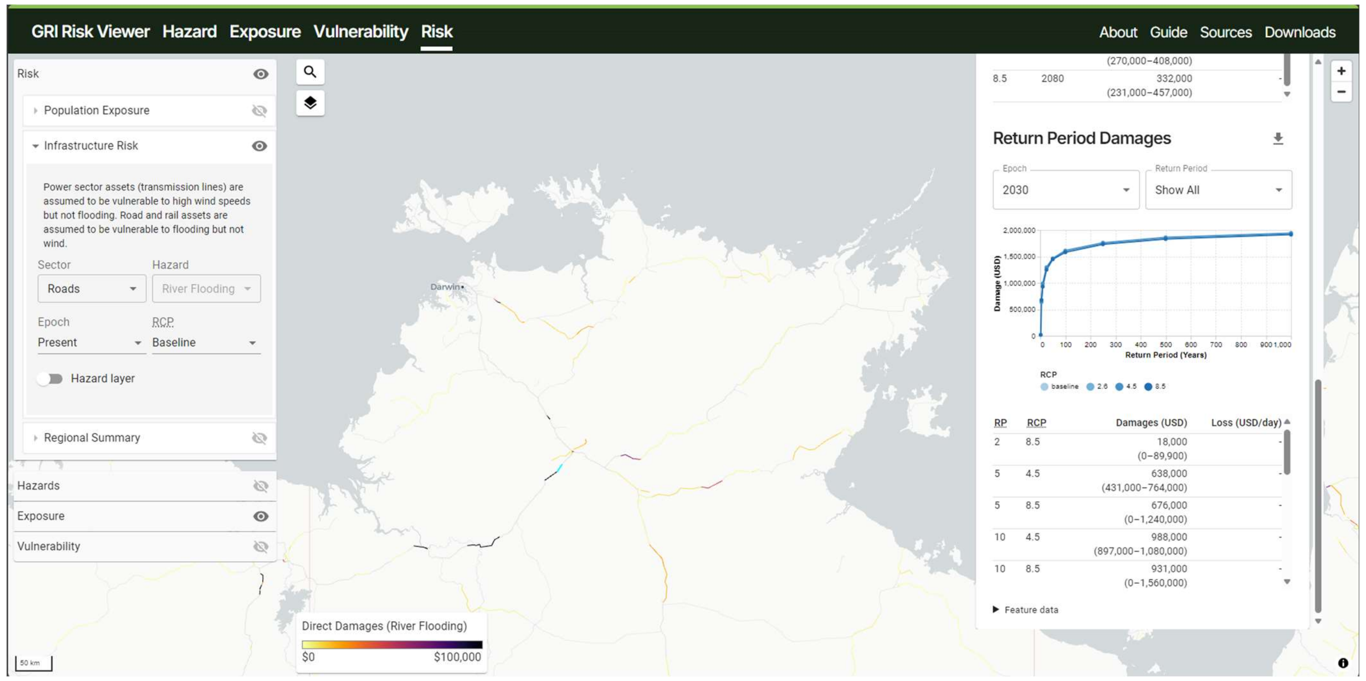


Fig: Forecast damages to roads from river flooding in the Northern Territory.

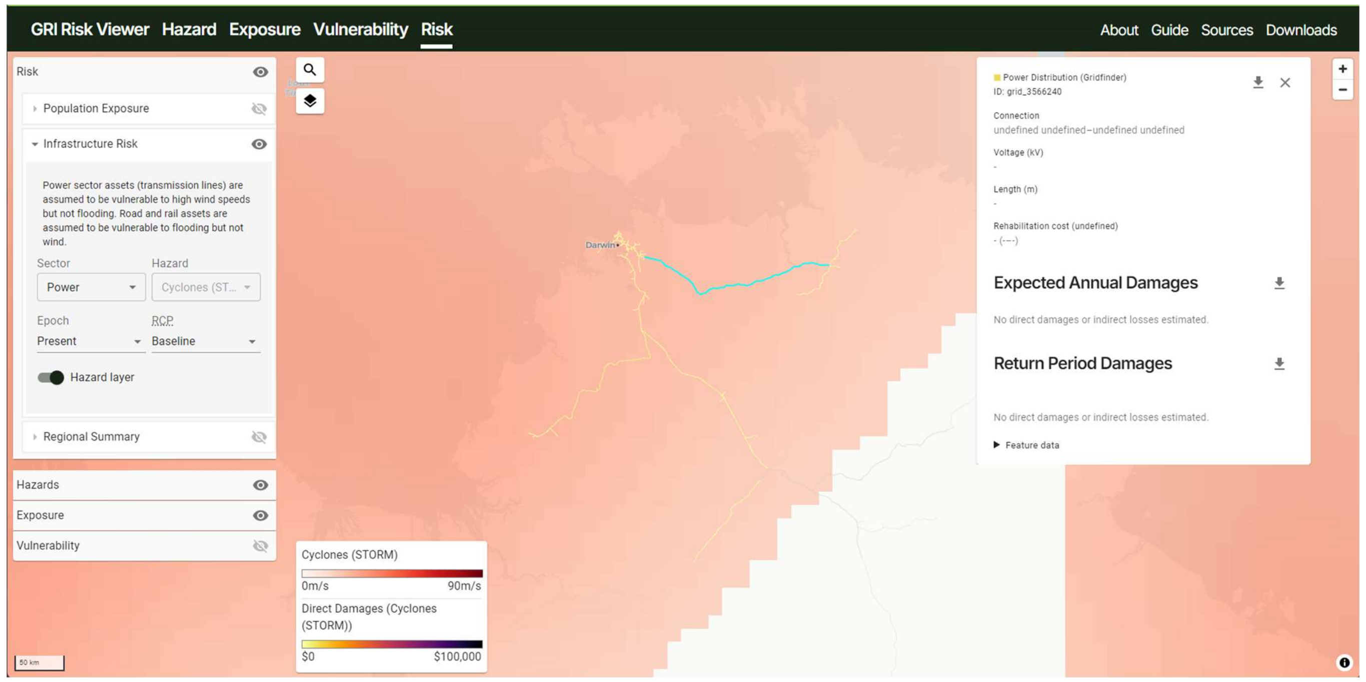


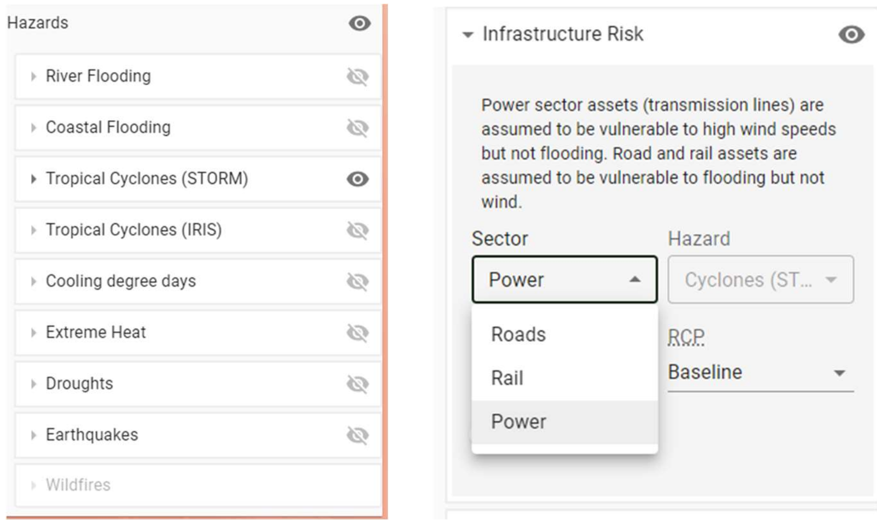
Fig: Forecast risk profiles for energy assets in the Northern Territory from cyclone risk. The map showing exposure to cyclones has been turned on in orange.

8.2 Areas of Augmentation

Broadly, there are three areas for augmentation of the Oxford platform for the GRI risk viewer to fully meet IA's needs:

8.2.1 Add Data Sources, Asset Types, and Asset Profiles

Add data sources for the model to draw information from. For example, the model only considers a small sample of infrastructure assets; Road, Rail and Power. There are additional Hazards that may be considered. It does not yet include opportunities to add modifier scores to specific assets.



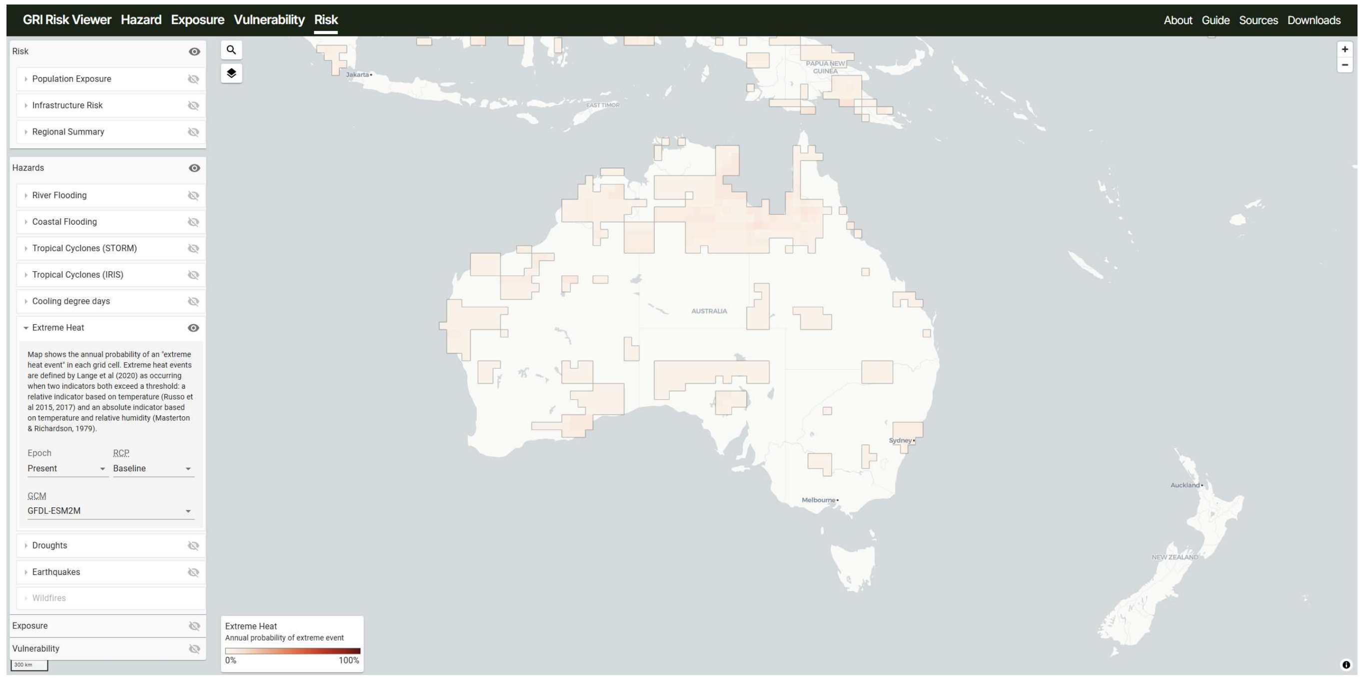


Fig: Examples of mapping of areas exposed to extreme heat in the GRI mapping tool.

8.2.2 Expand on Calculation; i.e. the FortiFactor

Perhaps due to the focus on human and population impact, the back-end calculation is quite reductive in its approach to infrastructure risk. E.g. Roads and rail are only assumed to be impacted by coastal and riverine flooding. power assets are only assumed to be impacted by high winds (i.e. cyclones).

Given the variety and diversity of asset types even in an asset class, this is an area that will need to be expanded with the FortiFactor to allow for more exposure combinations to be considered. E.g. a substation in a power asset network may be affected by flooding.

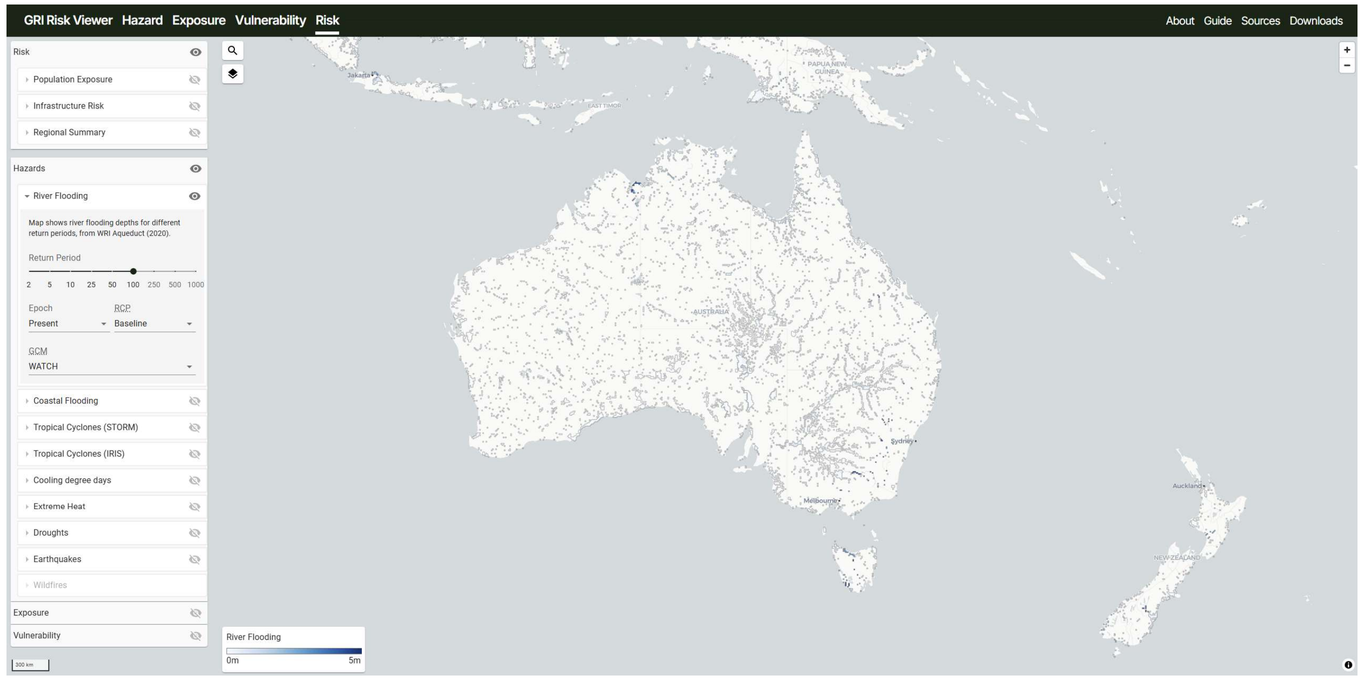
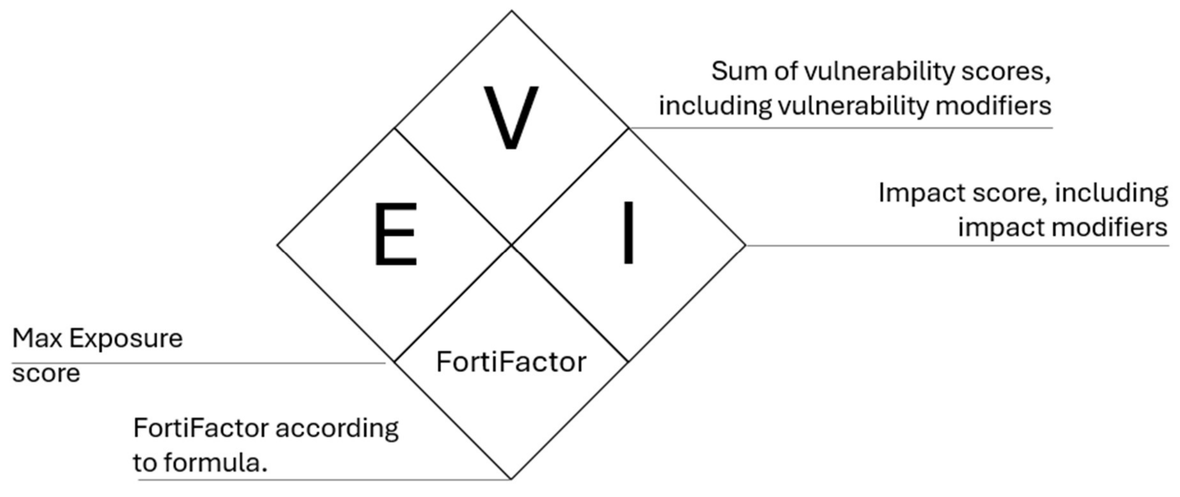


Fig: Examples of mapping of areas exposed to river flooding in the GRI mapping tool.

8.3 Mock Up: Visually Representing the FortiFactor

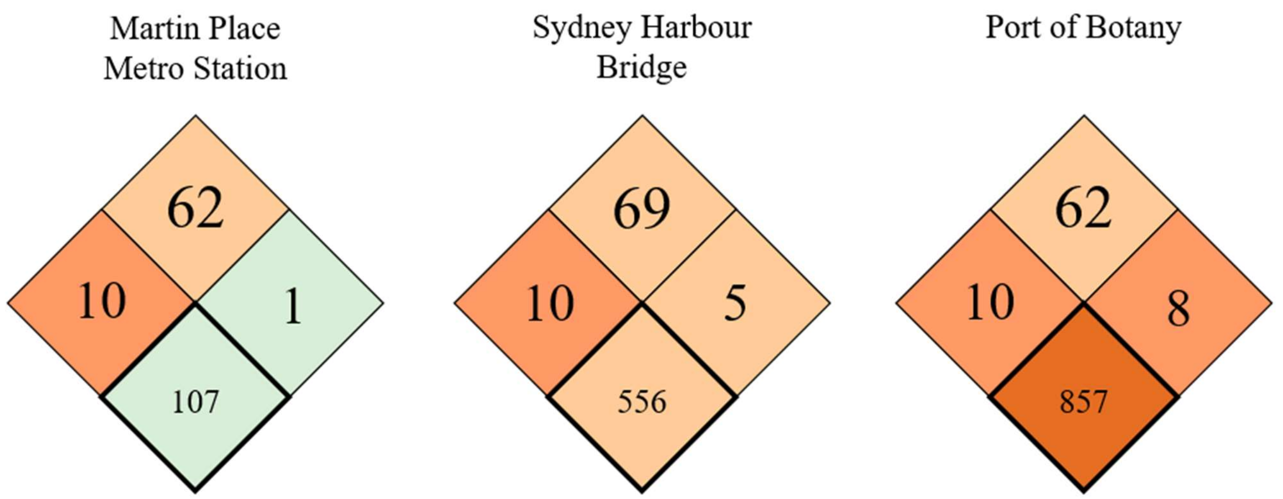
The calculated FortiFactor is an aggregate value of the asset risk profile. Whilst necessary for determining a relative comparison against multiple assets, there is equally a risk of losing the nuance of the risk profile when the number is presented alone.

The following visual format is proposed to demonstrate the component parts of the risk profile at high level and at a glance. It is has been inspired by the UN Globally Harmonized System of Classification and Labelling of Chemicals (GHS)



In the following examples, based on the FortiFactor alone, the Port of Bontany is a far more important asset for bolstering resilience than the Sydney Harbour Bridge or Martin Place Station.

However, when the other components are also presented, it is evidence that this distinction primarily stems from the Impact Score. The Exposure profile is quite similar; which makes intuitive sense as all three assets are located in a close geographic radius. The aggregate vulnerability scores are also quite similar. It is the scale of impact, including for any impact modifiers, which distinguishes the assets.

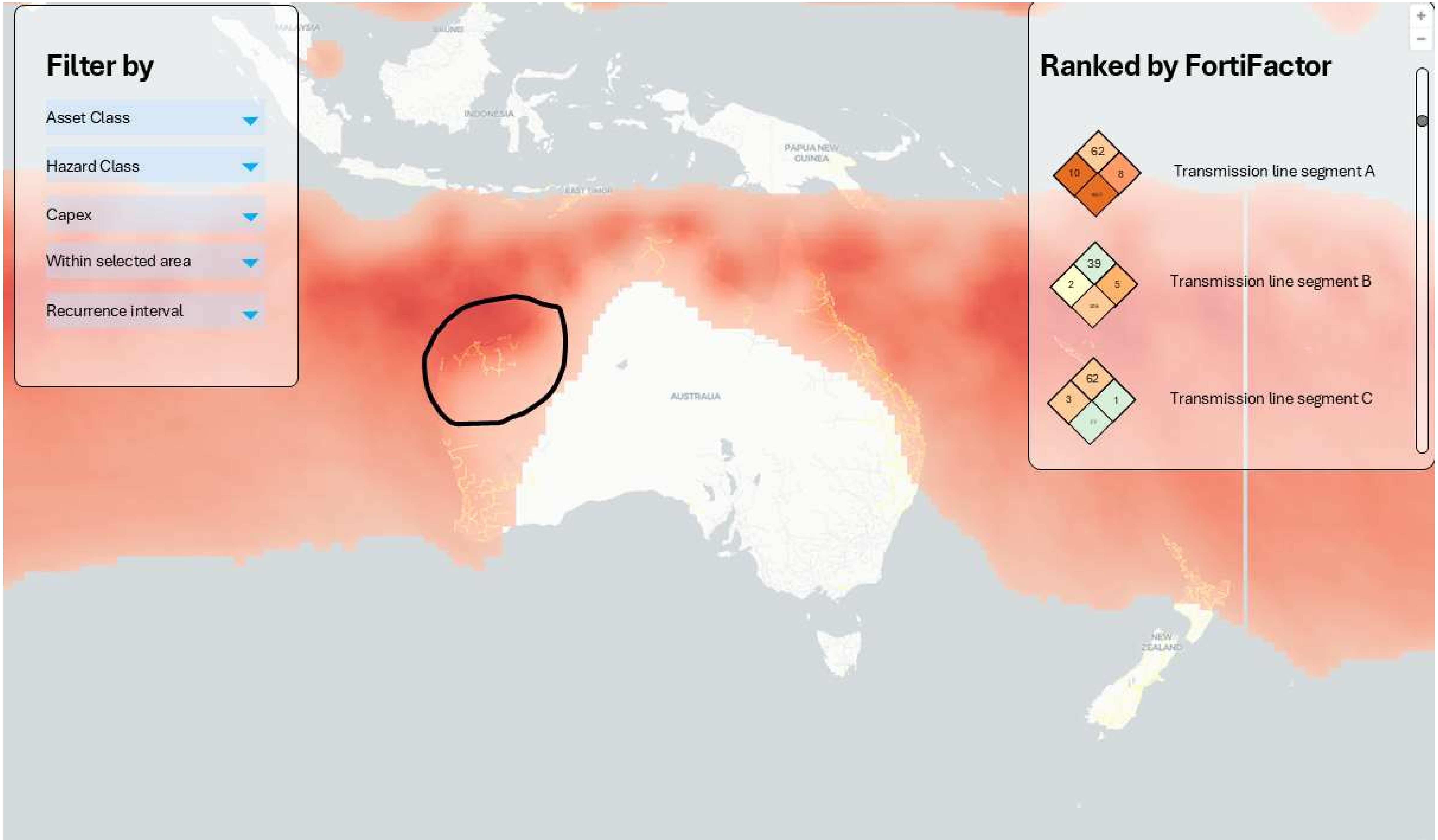


Should the reader which to better understand why, they may drill down into the component parts of the Impact score.

As presented below, the raw impact scores for each asset class is actually quite similar. However, the Port of Botany has a higher cascade potential, less redundancy than the station, and is expected to take longer to repair, hence the higher score.

	Martin Place Metro Station	**Sydney Harbour Bridge**	**Port of Botany**
Asset Class	Railways	Bridges	Ports/ Harbours
Impact Score for Asset Class	8	10	8
I1, Cascade Potential (modifier)	2	4	4
I2, Redundancy (modifier)	0.25	0.5	0.5
I3, Mean Time to Repair (modifier)	0.25	0.25	0.5
Impact Score (including modifiers	**1**	**5**	**8**

8.4 Mock Up View: Rankings in a Selected Region



8.5 Mock Up: Exposure, Vulnerability, Impact in a 3D Plot

We also propose to add a 3D plot view of each asset against:

X-asix: Exposure

Y-axis: Vulnerability

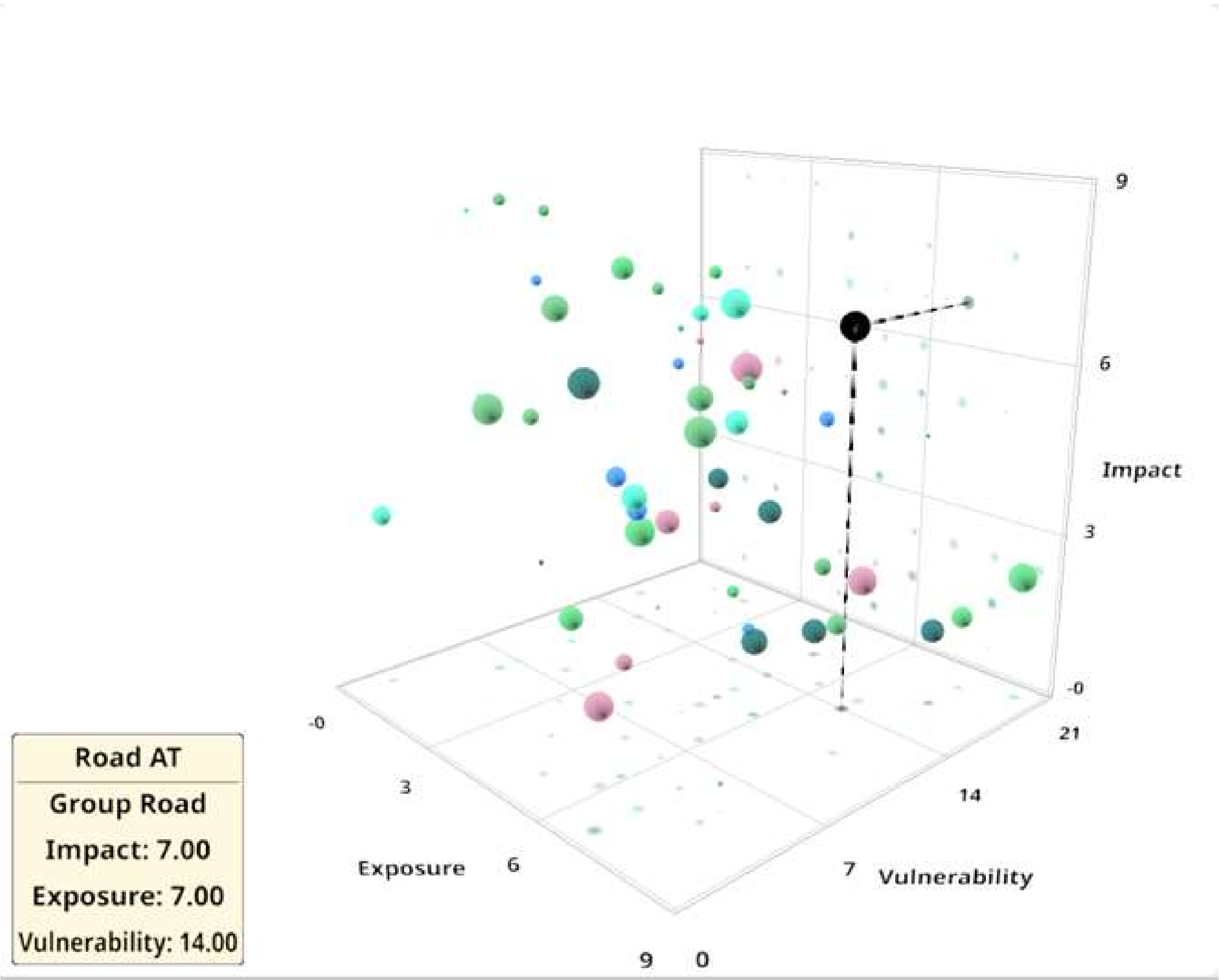
Z-axis: impact

Size: Asset capex

Colour: Asset type

Assets clustered in the high-E, high-V, high-I portion of the cube should be analysed for further detail.

Plotted using dummy data and https://miabellaai.net/



9 CONNECTING INTO COMMUNITY KNOWLEDGE

This section focuses on strengthening the engineering community's approach to climate resilience by embedding climate risk management into education, professional certifications, and industry practices. Key initiatives include collaboration with universities to introduce climate hazard courses, establishing professional certifications centered on resilient infrastructure, and creating forums for knowledge exchange among engineers.

The integration of Indigenous knowledge and fostering active stakeholder engagement are highlighted as critical components, offering valuable insights and promoting inclusivity in hazard management. Historical databases and case studies provide a foundation for informed decision-making, while community-focused outreach initiatives help prepare vulnerable populations through education, scenario planning, and resource distribution.

By building a culture of shared knowledge and proactive engagement, these strategies aim to enhance the engineering community's capacity to address climate hazards effectively and sustainably.

9.1 Embed into Engineering Community

Integrating climate hazard awareness and resilience practices into the engineering community is crucial for fostering proactive infrastructure development. This involves embedding climate risk management into engineering education, professional certifications, and industry practices.

Strategies:

- Educational Integration: Partner with universities and professional bodies to include courses on climate hazard management in engineering curricula. Topics could include climate risk assessment, sustainable design principles, and resilience planning.
- Professional Development: Create certification programs for engineers focusing on climate-resilient infrastructure design and risk mitigation strategies.
- Knowledge Sharing: Establish forums, conferences, and online platforms for engineers to share best practices and innovations related to climate resilience.

Benefits:

- Enhanced Expertise: Ensures that engineers are well-equipped with the knowledge needed to integrate hazard mitigation into project planning.
- Standardized Practices: Promotes consistent application of climate risk principles across all projects.
- Long-term Resilience: Embedding these practices contributes to building long-lasting, climate-resilient infrastructure.

Action Steps:

- Collaborate with engineering accreditation bodies to develop training modules.
- Fund research grants focused on engineering solutions for climate resilience.
- Promote partnerships between engineering firms and climate science institutions.

9.2 Data Sharing Platforms

To improve access to climate hazard data and promote collaboration, Infrastructure Australia (IA) should prioritize the development of advanced data-sharing platforms. These platforms would serve as a centralized hub for exchanging critical climate-related information among engineers, urban planners, policymakers, researchers, and community stakeholders. By providing seamless access to up-to-date hazard assessments, climate risk data, and real-time information, such platforms enable more effective, informed decision-making and facilitate proactive climate risk management.

In addition to fostering collaboration, these platforms could leverage technology, including Artificial Intelligence (AI), to enhance their functionality. AI could assist in processing large datasets quickly, uncovering patterns and trends that might otherwise take longer to identify. It could also contribute to providing tailored alerts and personalized notifications based on user needs. However, the key focus remains on creating an accessible and reliable space where all stakeholders can contribute to and benefit from shared climate knowledge. Ultimately, these platforms will enable smarter, more adaptive infrastructure planning and climate resilience strategies.

Key Features of the Platform

- Centralized Data Repository: A secure hub that compiles reports, hazard assessments, maps, and real-time data relevant to climate risks. AI-powered tools can help aggregate and organize this data more efficiently, ensuring it is easily accessible and up-to-date.
- Collaborative Tools: AI-driven visualization and analytics tools that enable stakeholders to jointly analyze data, identify patterns, and plan responses to climate challenges. These tools can automatically suggest insights based on the data and facilitate more effective collaboration among diverse groups.
- Open Access Protocols: AI-powered access management systems ensure that relevant data is shared with engineers, urban planners, and community organizations, while also personalizing the data access based on users' roles, needs, and areas of interest. This promotes widespread contribution and use while maintaining data security and integrity.
- Alerts and Notifications: AI-based monitoring systems that automatically analyze real-time data to send early warnings about climate events, such as extreme weather, and provide updates on hazard management. These systems can offer personalized alerts based on the user's location or area of interest, improving the relevance of notifications.

Benefits

- Enhanced Preparedness: AI ensures stakeholders receive timely, accurate, and actionable insights, helping them take proactive measures before hazards occur. By predicting climate risks based on historical and real-time data, AI helps enhance early warning systems.
- Efficient Decision-Making: By streamlining data processing and analysis, AI significantly reduces the time required to develop actionable plans. Its predictive analytics capabilities allow stakeholders to make informed decisions swiftly, improving their response time to emerging risks.
- Integrated Learning: AI continuously archives and analyzes lessons learned from past projects and hazard events. This knowledge base is used to improve future planning and decision-making, ensuring that stakeholders can learn from past successes and failures to create more resilient infrastructure.
- Data Quality Assurance: AI enhances the quality control of shared data by identifying inconsistencies, gaps, or errors in datasets, ensuring that all stakeholders work with accurate and reliable information.
- Scenario Simulation: AI can run simulations to visualize the impact of various climate scenarios and test mitigation strategies before implementation. This helps engineers and planners refine their strategies and better understand potential risks.

> *"AI and machine learning are opening new avenues for managing climate-related risks, especially when it comes to assessing and predicting severe weather events. The ability of AI to analyze vast amounts of data enables better decision-making for insurers and businesses, allowing them to adapt proactively to climate change impacts"*
>
> *- Risk & Insurance, 2024*

Action Steps

- Partner with Technology Firms and AI Experts: Collaborate with AI and technology companies to design and implement the platform, ensuring it leverages the latest advancements in AI, such as predictive analytics and machine learning.
- Conduct Pilot Programs: Launch pilot programs with key stakeholders to test and refine AI functionalities in collaboration with engineers, policymakers, and data scientists. These programs should focus on improving the accuracy of predictive models and fine-tuning AI-driven tools for real-world applications.
- Integrate Real-Time Monitoring Systems: Integrate the platform with real-time data monitoring systems, enabling continuous updates and insights. This ensures that the platform remains dynamic, with ongoing input from various data sources to maintain its accuracy and relevance.
- Training and Adoption: Develop training materials and workshops for users, ensuring they understand how to leverage AI-powered tools effectively within the platform. This will help foster broader adoption and ensure stakeholders can fully utilize the platform's capabilities.

9.3 Mandate Registration of New Projects With IA.

Mandating the registration of new infrastructure projects with Infrastructure Australia (IA) will facilitate comprehensive oversight and enhance tracking of climate hazard risks. This requirement ensures that climate risk management and resilience strategies are incorporated into projects from the outset, driving a proactive approach to managing future climate-related challenges.

How will this be achieved?

- Essential Fields: The form should collect key project details, such as location, scope, budget, and timelines, alongside a thorough climate hazard risk assessment. This should include the identification of potential climate impacts, such as extreme weather, flooding, or sea-level rise, and proposed mitigation strategies tailored to address these risks.
- Digital Submission: Implement an online portal for the submission of project data, ensuring ease of use for project teams and quick data processing and analysis by IA.
- Compliance Checklist: Incorporate a checklist based on IA's climate resilience standards, which projects must adhere to during the registration process. This checklist should align with recognized frameworks like the Infrastructure Sustainability Council of Australia (ISCA) ratings, ensuring projects are not only evaluated for sustainability but also for their ability to manage climate change risks.

Benefits:

- Comprehensive Database: This system would create a central repository of all new infrastructure projects, providing IA with valuable data to support future climate risk analysis and resource allocation.
- Improved Compliance: By requiring projects to adhere to climate resilience criteria, this approach fosters greater alignment with best practices for managing climate risks and ensuring long-term resilience.
- Proactive Oversight: IA would be able to identify potential vulnerabilities early in the planning stages, facilitating proactive risk management before projects are approved for development.

Action Steps for Implementation

- Design the Registration Form: Work with key stakeholders, including engineers, urban planners, and environmental experts, to develop a comprehensive registration form that captures all necessary data.
- Integrate with IA's Data-Sharing Platform: Ensure that project submissions are linked to IA's centralized data-sharing platform for seamless access, collaboration, and ongoing monitoring.
- Establish Review Protocols: Develop a robust review process to evaluate submissions and ensure projects meet climate resilience standards, with particular attention to alignment with ISCA ratings and other recognized frameworks for managing climate change risks.

9.4 Natural Disaster War-Rooms

The establishment of Natural Disaster War-Rooms provides an effective approach to brainstorming and strategising how governments and other stakeholders can improve responses to climate-related disasters. These war-rooms are events where specialists come together to "wargame" natural disaster scenarios, analysing potential challenges and collectively developing recommendations to enhance disaster preparedness and resilience. By fostering interagency collaboration, leveraging expert knowledge, and using data-driven approaches, these war-rooms can help produce actionable insights for safeguarding communities and critical infrastructure.

Functions

- Scenario Analysis and Simulation: Specialists utilise tools like Geographic Information Systems (GIS) and AI-powered analytics to simulate natural disaster scenarios. This allows for the identification of vulnerabilities and the testing of potential response strategies in a controlled environment.
- Interdisciplinary Collaboration: Bring together experts from government agencies, emergency services, private sectors, and community organisations to collaboratively brainstorm response strategies, share knowledge, and foster a unified approach to disaster preparedness.
- Strategic Recommendations: Analyse lessons learned from simulations and discussions to refine existing disaster protocols. Use insights gathered during these sessions to create reports and develop strategies for mitigating the impact of future hazards.

Benefits

- Collective Decision-Making: Facilitates a comprehensive approach to decision-making by incorporating diverse perspectives, leading to more robust disaster management strategies.
- Enhanced Interagency Collaboration: Strengthens partnerships between government bodies, private sectors, and experts for unified disaster management, ensuring cohesive action plans.
- Data-Driven Solutions: Encourages the use of analytics, scenario modelling, and predictive tools to improve disaster preparedness, response outcomes, and resource allocation.
- Community and Infrastructure Resilience: Increases public trust through visible, proactive disaster planning and preparedness efforts. Protects critical infrastructure and supports faster recovery by identifying and addressing vulnerabilities in advance.

Action Steps for Implementation

- Organise Regular War-Room Events: Schedule regular war-room sessions involving experts from relevant sectors. Ensure that each session has a clear agenda focused on specific disaster scenarios or risks.
- **Engage** Multidisciplinary Experts: Assemble and involve a wide range of specialists, including engineers, emergency response personnel, climate scientists, and community leaders, to ensure diverse expertise is leveraged.
- Develop and Utilise Advanced Simulation Tools: Equip war-room participants with cutting-edge tools such as AI-driven models, GIS systems, and dynamic visualisation platforms to facilitate informed discussions and scenario analysis.
- Document and Disseminate Findings: Produce comprehensive reports with actionable recommendations after each war-room event. Share these findings with relevant stakeholders, including policymakers and community organisations, to drive improvements in disaster management.
- Promote Community Involvement: Engage local communities by sharing insights from war-room sessions, building public awareness of disaster response strategies, and involving community leaders in discussions to ensure alignment with local needs.

9.5 Community Outreach and Education

Infrastructure Australia (IA) is committed to empowering communities to effectively face climate hazards through targeted education and outreach efforts. These initiatives focus on fostering preparedness and resilience by equipping communities, particularly those in high-risk areas, with knowledge, practical skills, and critical resources to reduce the impacts of climate disasters.

Goals and Approaches

- Raise awareness about region-specific climate hazards, such as flooding, bushfires, and extreme weather, and their potential impacts on communities.
- Conduct workshops and training sessions that simulate disaster scenarios, helping participants develop personalized response plans and gain practical skills.
- Provide multilingual, accessible materials, including guides, checklists, and emergency kits, tailored to meet the diverse needs of communities.
- Collaborate with local governments, schools, and community groups to ensure the programs are relevant, widely accessible, and culturally sensitive.

Benefits

- Empower communities by equipping them with the tools and knowledge to respond effectively during emergencies.
- Reduce panic and fear by fostering a culture of preparedness and confidence in disaster response.
- Strengthen community networks that support collective resilience and recovery after climate events.
- Continuously improve outreach efforts by gathering insights and feedback from participants to refine the programs.

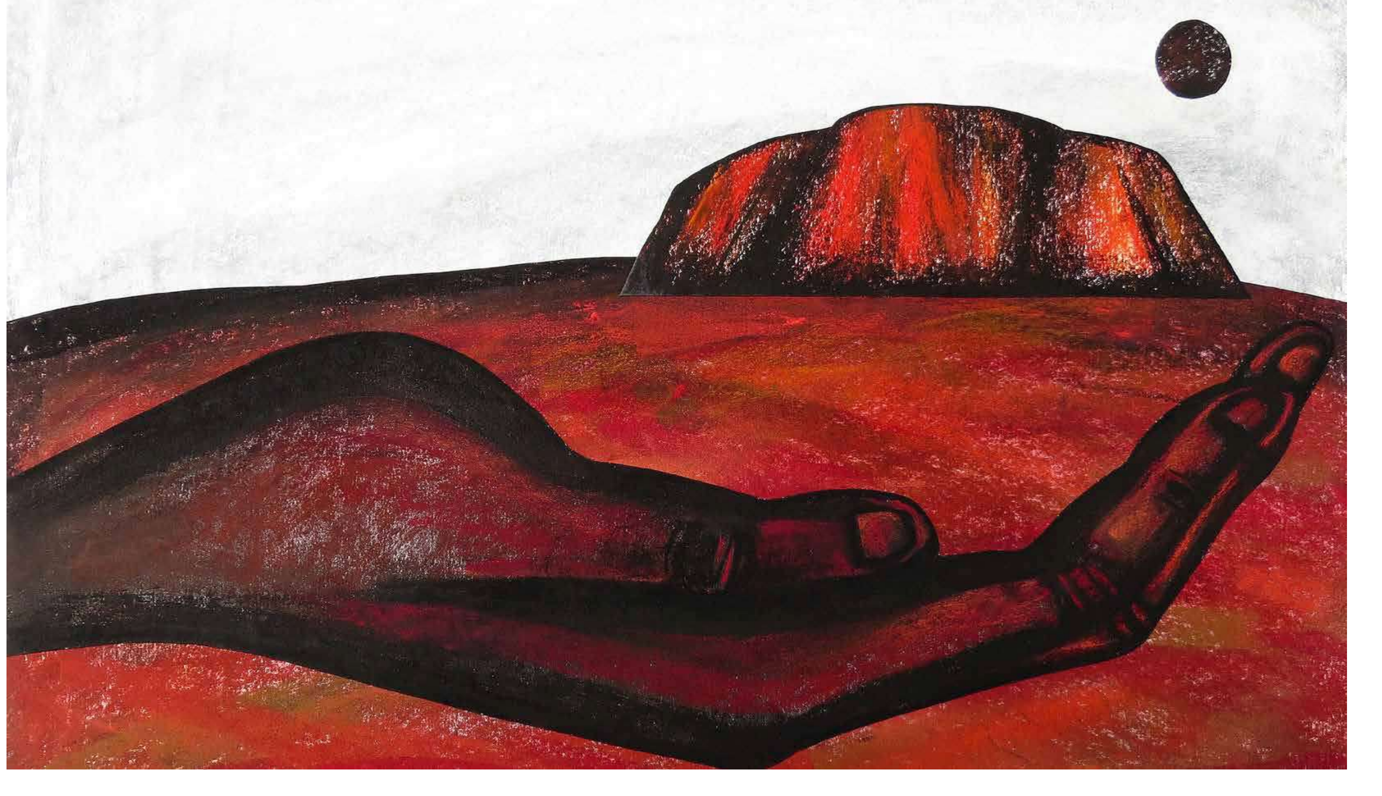
Action Steps for Implementation

- Develop and distribute educational resources such as digital content, printed guides, and emergency preparedness kits through schools, community centers, and online platforms.
- Organize interactive workshops in high-risk areas to teach emergency response techniques, evacuation planning, and practical preparedness strategies.
- Partner with local organizations to expand outreach efforts and ensure they reach all segments of the community.
- Measure the effectiveness of these programs through surveys, preparedness assessments, and participant feedback to guide ongoing improvements.

9.6 Indigenous Knowledge

Indigenous communities often possess deep-rooted knowledge about the land and its natural patterns. Leveraging this knowledge can provide invaluable insights into climate hazard management.

Incorporating Indigenous knowledge offers unique insights into sustainable land management and resilience practices. This traditional understanding of the environment can complement scientific approaches to hazard management.



Implementation

- Work closely with Indigenous leaders and knowledge holders to understand their perspectives and historical experiences with natural hazards.
- Create a comprehensive repository to document effective traditional practices for mitigating environmental risks.
- Collaborate with Indigenous communities to co-design programs that integrate traditional ecological knowledge into education and hazard management strategies.

Benefits

- By blending traditional knowledge with scientific methods, a more holistic approach to risk management is achieved.
- Indigenous practices often prioritize sustainability and long-term environmental balance, enriching hazard management efforts.
- Recognizing and incorporating Indigenous contributions fosters inclusivity and strengthens relationships with these communities.

> *"We absolutely need to protect, preserve, and promote the traditional knowledge, customary sustainable use, and expertise of Indigenous communities if we want to halt the damage we're doing – and ultimately save ourselves."*
>
> *- Siham Drissi, UNEP Biodiversity and Land Management Officer*

Action Steps

- Establish formal partnerships with Indigenous councils and organizations to ensure meaningful collaboration.
- Organize workshops that merge traditional knowledge with scientific expertise, creating a platform for shared learning.
- Document case studies highlighting successful applications of Indigenous practices in managing climate hazards.

9.7 Stakeholder Engagement

To ensure an inclusive approach to hazard management, engaging all relevant stakeholders is vital. This includes institutional stakeholders, such as government agencies and organizations, as well as those directly affected by infrastructure projects.

Engaging all relevant stakeholders ensures that climate hazard management strategies are comprehensive and supported by diverse perspectives.

Institutional Engagement:

- Collaborations: Work with government bodies, environmental agencies, and other key institutions to align efforts and resources.
- Joint Policy Development: Involve stakeholders in developing policies that guide climate hazard responses and infrastructure standards.
- Public-Private Partnerships (PPPs): Encourage partnerships between public sector entities and private companies to share expertise and funding.

Engaging Affected Communities **(Refer to Section9.5 for further information)**

- Community Meetings: Hold public forums where residents can voice concerns, share personal experiences, and contribute to planning processes.
- Feedback Mechanisms: Implement surveys and feedback forms to gather input from people affected by past or potential hazards.
- Advisory Panels: Create community advisory panels that work alongside IA in shaping and monitoring hazard management initiatives.

Benefits:

- Broader Perspective: Engaging various stakeholders ensures diverse inputs that lead to more robust solutions.
- Increased Buy-In: People are more likely to support and comply with initiatives they helped shape.
- Enhanced Resilience: When stakeholders are involved, solutions are better tailored to on-the-ground realities.

Action Steps:

- Schedule regular stakeholder roundtables and workshops.
- Establish a digital platform for ongoing communication and updates.
- Collaborate with NGOs to enhance outreach to affected populations.

9.8 Historical Database

Maintaining an extensive database that records the impacts of past climate hazards can provide critical insights for future risk mitigation. As discussed in previous sections, a central database that consolidates both quantitative data and qualitative insights will support improved risk mitigation strategies, particularly when linked with data from community engagement and institutional inputs. This approach allows for informed planning and targeted responses, drawing from historical experiences to shape future actions.

Case Reports After Natural Hazards:

- Detailed Reports: Archive comprehensive reports detailing the impact of past hazards, infrastructure performance, and response actions taken.
- Lessons Learned: Highlight what strategies were effective and which areas require improvement.
- Accessibility: Ensure these reports are easily accessible to engineers, planners, and policymakers for use in future project development.

Interviewing People for Historical Knowledge:

- Oral Histories: Conduct interviews with community members who have firsthand experience with past climate hazards.
- Documenting Insights: Record and catalog interviews to capture the nuances of human experience and response during these events.
- Supplementing Data: Use these qualitative insights to provide context to quantitative data, enriching risk assessment and response planning.

Benefits:

- Informed Planning: Using past data helps predict potential future risks and improves preparedness.
- Comprehensive Insights: Interviews add a human dimension to data, revealing community responses and resource needs.
- Enhanced Strategies: Historical case studies provide a foundation for developing effective hazard management practices.

Action Steps:

- Partner with research institutions to conduct and record interviews.
- Create a publicly available archive of reports and interviews.
- Regularly update the database to include new case reports and insights.

> *"Through multiple lines of data and evidence, we have tracked what it is doing to make Australia hotter, more prone to floods and fires, and cutting river flows in the south where most of us live."*
>
> *- State of the Climate 2024 Report, Australian Government*

9.9 HAZOPS

HAZOPS (Hazard and Operability Studies) is a structured method used to identify and assess potential risks in infrastructure projects, particularly related to climate hazards. Integrating HAZOPS into IA's planning helps identify issues early and build more resilient infrastructure.

Purpose and Components:

- Risk Identification: Identify potential climate-related hazards, such as flooding or extreme weather, early in the project lifecycle.
- Multidisciplinary Teams: Involve experts from various fields, including engineering, environmental science, and risk management, to ensure diverse perspectives.
- Systematic Review: Use structured approaches like "what if" scenarios to explore possible risks at each stage of the project.
- Documentation: Record all identified risks and the corresponding mitigation strategies to ensure comprehensive coverage.

Benefits:

- Early Risk Detection: Identify potential issues during the planning phase, preventing costly design changes later.
- Enhanced Resilience: Projects built with HAZOPS are better equipped to withstand climate hazards, improving long-term safety and reliability.
- Adaptability: Continuously update risk management strategies based on emerging data and evolving climate risks.

Implementation:

- Develop Protocols: Create specific HAZOPS protocols focused on climate-related hazards for IA projects.
- Training: Provide training for staff and stakeholders to understand and conduct HAZOPS effectively.
- Integration: Make HAZOPS a standard part of the project review and registration process.
- Regular Reviews: Continue to assess projects at key milestones and after completion, incorporating new climate data as necessary.

> *"HAZOP studies help organizations uncover potential hazards and inefficiencies within their processes, thereby enhancing safety and operational performance.:*
>
> *- IChemE, 2001*

9.10 Monitoring and Evaluation

Ongoing monitoring and evaluation (M&E) are essential to assess the effectiveness of climate hazard management strategies and make necessary adjustments over time. By integrating M&E practices, IA can ensure continuous improvement and adaptation of its approaches to managing climate risks and impacts.

Components of M&E:

- **Performance Metrics**: Define clear, measurable metrics to evaluate the success of hazard mitigation initiatives. Examples include response time during a hazard event, the number of community members trained in disaster preparedness, and the effectiveness of implemented mitigation structures.
- **Regular Reporting**: Develop a framework for periodic progress reports that capture the achievements, challenges, and lessons learned from projects.
- **Feedback Mechanisms**: Create channels for stakeholders to provide feedback on hazard management practices and suggest improvements. This feedback loop can involve community workshops, surveys, and collaborative forums.
- **Impact Assessments**: Conduct post-event evaluations to study the actual impact of climate hazards on infrastructure and assess the adequacy of risk mitigation measures taken.

Continuous Improvement Process:

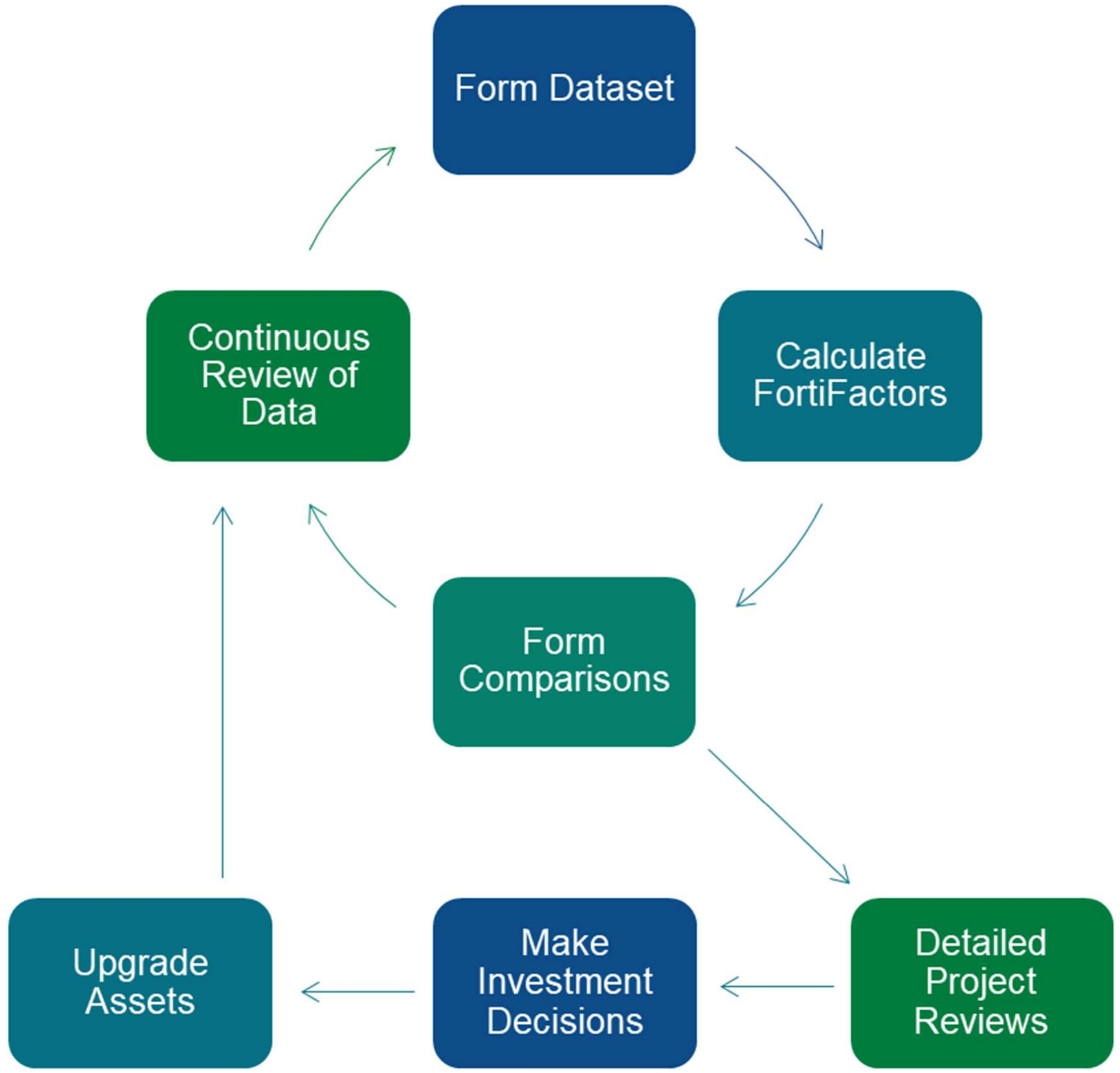
- **Adaptive Planning**: Use insights from M&E to modify existing strategies and adopt new technologies or methodologies that enhance resilience.
- **Training Updates**: Update training programs for engineers, planners, and stakeholders based on M&E findings to keep skills and knowledge current.
- **Policy Adjustments**: Work with policymakers to refine regulations and guidelines based on evaluation results, ensuring that hazard management remains aligned with current needs and future projections.

Benefits:

- **Sustained Resilience**: Continuous M&E allows IA to stay ahead of potential hazards by refining risk management processes.
- **Informed Decision-Making**: Decision-makers benefit from a data-driven approach that highlights what works and what doesn't.
- **Community Trust**: Demonstrating accountability through transparent M&E practices fosters trust and collaboration with communities and stakeholders.

Action Steps:

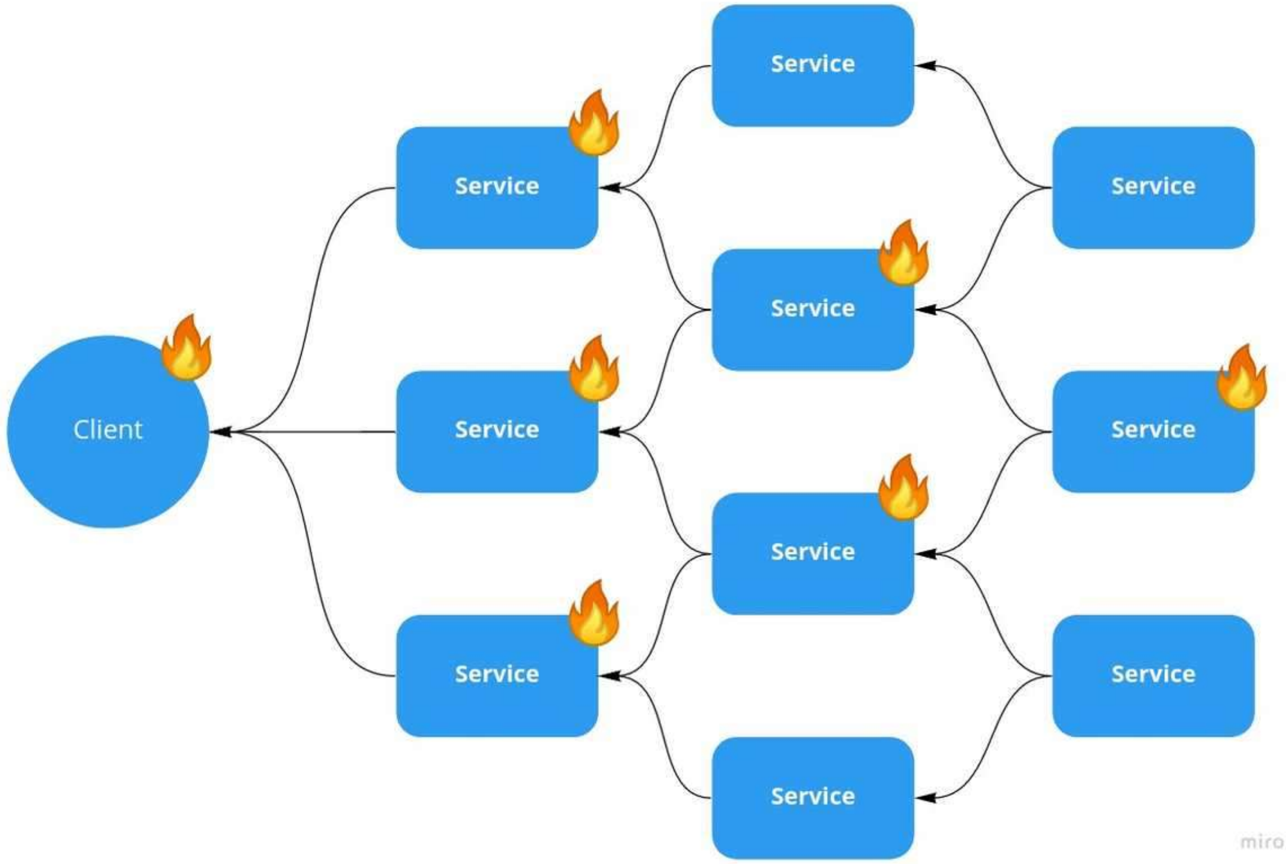
- Develop an M&E framework in collaboration with environmental and risk management experts.
- Establish teams dedicated to tracking and reporting the performance of infrastructure projects in relation to climate hazards.
- Regularly update M&E tools to incorporate new technologies and techniques.



10 POTENTIAL FURTHER WORK

10.1 Cascade Failure

Cascade failure is a phenomenon whereby the failure of an asset causes the failure of another asset and so on. For example, if power lines supplying a train line go down it may prevent operation of the line. This may have several steps of dependency of individual assets and relationships may not be single-source; for example if there are two power sources for an asset, it may function if one power source is inoperable, but not both. Assessing the network of interconnected assets to determine these relationships is non-trivial and may require considerable investment of time to be made accurate, particularly as the number of assets in a network becomes large. We have recommended that this phenomenon be captured within the Impact value, with a variable called "Cascade Potential" but there are other potential solutions to capture the cascade phenomenon.



10.1.1 Parent-Child relationships Using Artificial Intelligence

To remove some of the labour from the task of determining parent-child relationships, that is to say to find which assets may cause knock on failures to other assets in the event that they become inoperable, would take considerable effort. It may be possible to train AI to recognise these interdependencies based on available data of asset locations, asset types and a knowledge of how various assets operate.

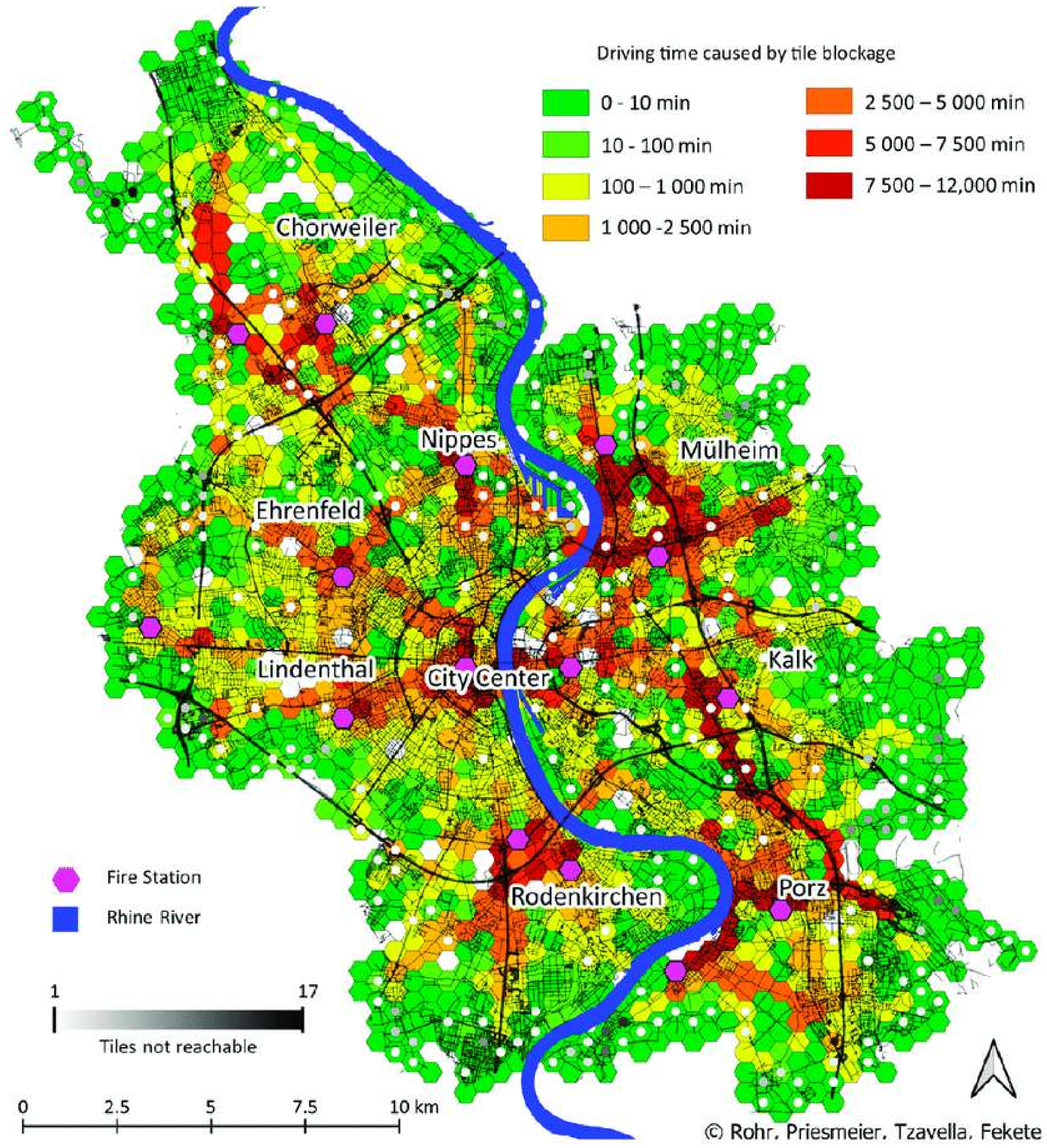
10.1.2 Network Reliability Analysis

Network criticality analysis is a method used to determine the importance of different components within an infrastructure network. By identifying which nodes or connections are most critical to the overall functionality of the network, decision-makers can prioritize resources for maintenance, upgrades, or protection. This type of analysis involves assessing how the failure of individual components affects the overall network performance and resilience. In large-scale infrastructure systems, understanding criticality helps in pinpointing vulnerabilities, optimizing redundancy, and ensuring that key parts of the network are safeguarded against potential disruptions.

Performing a cascade failure analysis or network criticality analysis on a large infrastructure network comprising roads, power grids, telecoms, pipelines, airports, and similar systems is a challenging and multifaceted task. One of the primary difficulties lies in the fragmented nature of the datasets available for such analyses. Data for different infrastructure sectors are often stored in disparate formats and managed by separate organizations, resulting in significant inconsistencies. For example, while road networks may have well-mapped GIS datasets, telecom infrastructure might lack comprehensive spatial or operational data. Furthermore, the interoperability of these datasets is limited due to varying standards, incomplete records, or outdated information, making it difficult to establish meaningful connections across infrastructure types. The absence of a unified data framework impedes efforts to model interactions between systems accurately, a critical aspect when analysing cascading failures.

Another significant challenge is the sheer size and complexity of the datasets involved. Large-scale networks inherently involve millions of nodes and connections, making computational analysis resource-intensive. The difficulty is exacerbated by the need to account for dynamic factors, such as temporal variations in infrastructure usage, external stressors like natural disasters, and interdependencies between networks. For instance, a power outage may affect telecom services, which, in turn, could hinder transportation systems reliant on communication networks. Simulating such complex interactions requires sophisticated algorithms and immense processing power. Additionally, uncertainty in the data—stemming from missing records, estimations, or assumptions—further complicates the analysis. These challenges make it hard to produce reliable results, necessitating a significant investment in data integration, modelling tools, and expert interpretation to ensure the analyses are actionable.

This could be integrated into out proposed system by forming a separate program to conduct a criticality analysis of all assets on the network of available data, to determine an Impact modification variable, as the level of criticality of the asset would affect how much it impacts the community.



10.2 Integration of Continuous-Collection Data

The Internet of Things (IoT) and the growing interconnectedness of devices have transformed the way data is collected and analysed. This provides deep insights into both population behaviour and infrastructure health. Real-time data connectivity allows organisations and governments to make more informed, timely decisions about public infrastructure, safety, and resource allocation.

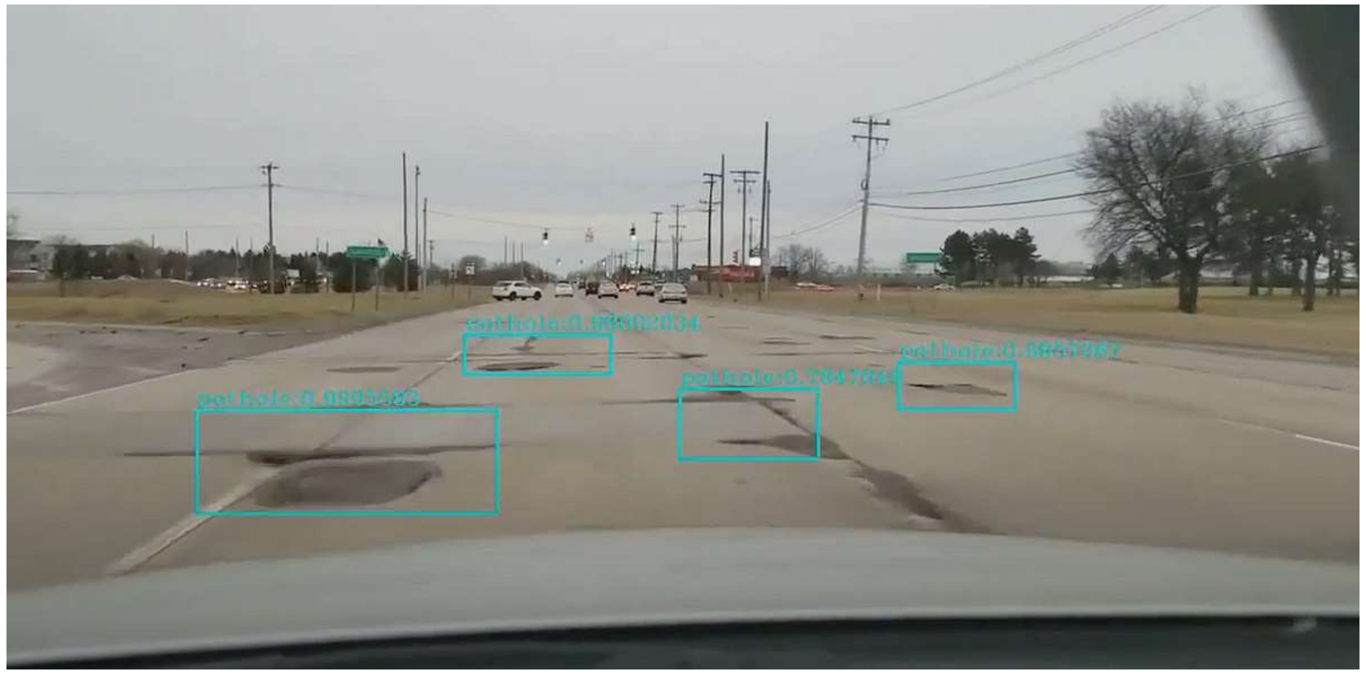
One notable example is the use of accelerometer data from vehicles (or even mobile phones within vehicles[1]) and road sweepers equipped with cameras[2]. By collecting near-real-time data from these accelerometers and cameras, engineers can continuously monitor road conditions and detect gradual deterioration. With sufficient historical data, it becomes possible to predict when and where roads are likely to degrade. This may help authorities prioritise maintenance and allocate budgets effectively. Predictive maintenance is not only cost-effective but also crucial for public safety, especially in areas prone to natural disasters like flooding or earthquakes.

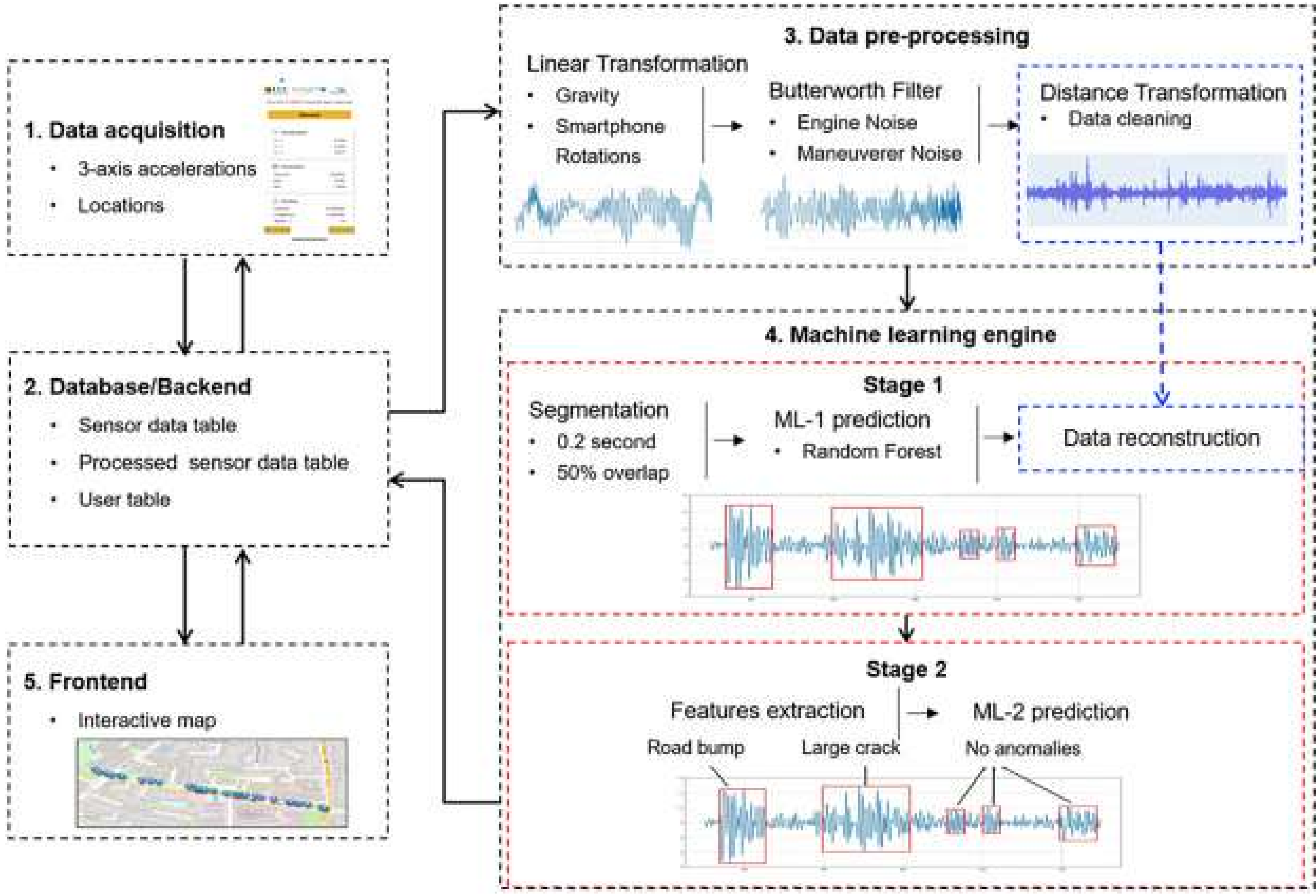
Similarly, GPS data from smartphones can reveal traffic patterns and detect unusual behaviour in real time. If people suddenly begin avoiding certain stretches of road or rail networks, this could serve as an early indicator of issues such as flooding, accidents, or other incidents affecting route usability. Such real-time behavioural data facilitates a proactive approach to managing infrastructure and can be invaluable during natural disasters, allowing emergency services to quickly assess affected areas.

In the longer term, analysing this data can reveal trends that guide infrastructure planning. For example, vulnerable road sections that need reinforcement against recurring flood risks can be identified. Overall, IoT-driven data supports a dynamic and responsive approach to infrastructure management, helping to ensure community safety and resilience in the face of growing demands and environmental challenges.

The insights gained from IoT data can also be instrumental in determining where to allocate investments to fortify infrastructure against natural disasters. By identifying roads, bridges, and other critical infrastructure that show early signs of deterioration or increased vulnerability, authorities can target investments to reinforce these assets before a disaster strikes.

For instance, areas that exhibit frequent avoidance by the public due to poor conditions or flood risks can be prioritised for upgrades and flood-proofing measures. This data-driven approach ensures that funding is used efficiently, focusing on reinforcing the most at-risk infrastructure. Informed investment decisions based on real-time and historical data help minimise the risk of catastrophic failures and enhance the durability of critical infrastructure in the face of climate-related threats.





1 https://www.sciencedirect.com/science/article/pii/S092658052400400X

2 https://www.transport.nsw.gov.au/data-and-research/future-mobility/our-projects/asset-ai

11 SUMMARY

This report presents the FORTIFY Framework, a comprehensive tool developed for assessing the climate change resilience of nationally significant infrastructure assets in Australia. The framework introduces the "FortiFactor," a metric combining exposure, vulnerability, and impact to prioritize investments in resilience-enhancing measures. Key highlights include:

Purpose and Scope: The framework aims to assess risks across various hazard types, focusing on critical infrastructure like roads, power plants, and public buildings, with an emphasis on Aboriginal and Torres Strait Islander communities' unique needs.

Framework Design: The FortiFactor incorporates data on geographic exposure, asset vulnerability, and societal impact, enabling decision-makers to allocate resources effectively. Modifiers allow the model to refine assessments based on specific asset characteristics.

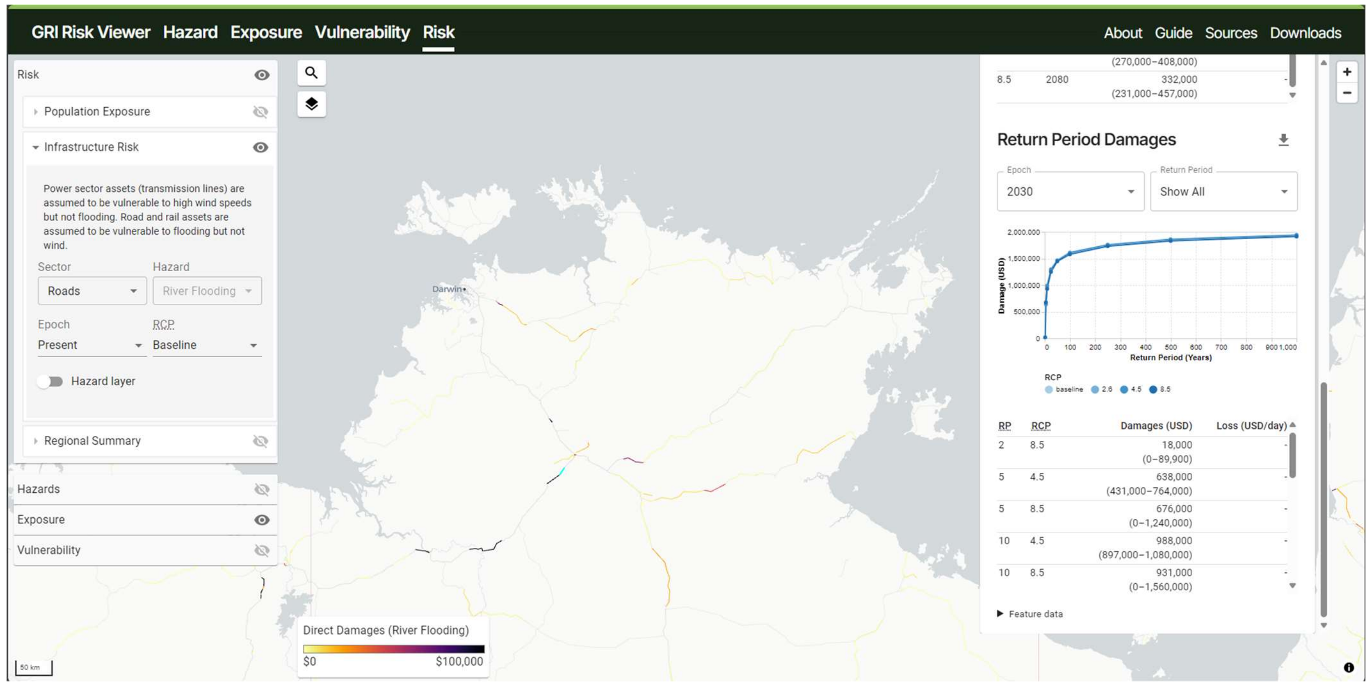
Implementation Strategy: The proposal suggests integrating FORTIFY into existing tools, such as the Oxford GRI Risk Viewer, with enhancements to data granularity, hazard inclusion, and visual presentation.

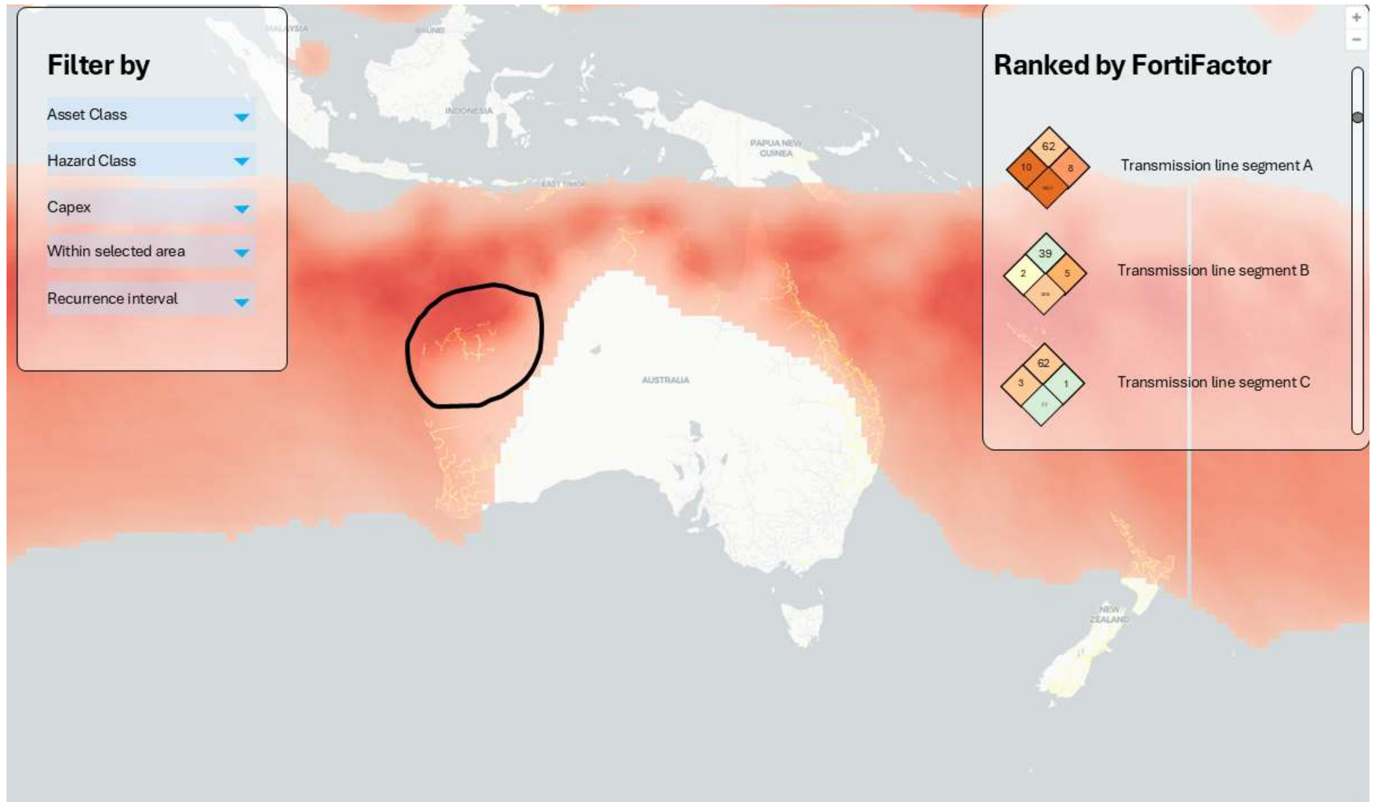
Data Gaps and Challenges: While leveraging extensive datasets, the report identifies gaps, including limited real-time data, insufficient remote and Indigenous community representation, and a lack of multi-hazard analysis. Addressing these will improve resilience planning.

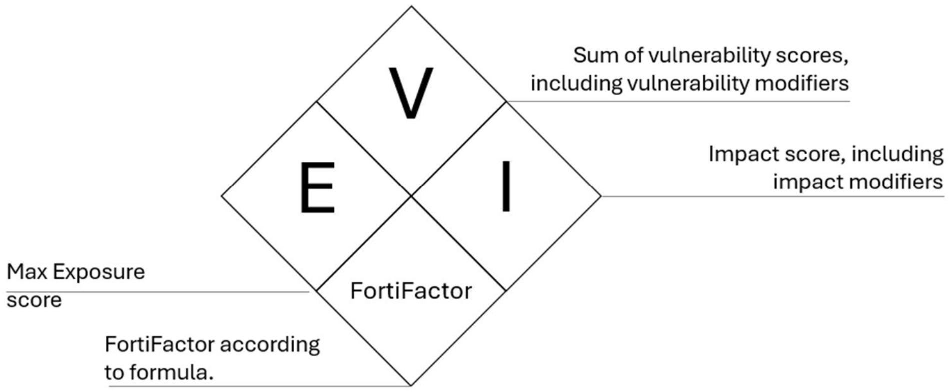
Worked Examples: A worked example using Martin Place Metro Station and the Sydney Harbour Bridge demonstrate the framework's functionality, highlighting its capability to generate nuanced insights for infrastructure resilience prioritization.

Future Recommendations: The report suggests expanding data sources, refining risk calculations, and incorporating Indigenous knowledge to enhance the framework's inclusivity and effectiveness.

This tool, with its focus on user-friendly outputs and adaptability, aims to support Infrastructure Australia in making informed, equitable decisions to Fortify the nation infrastructure against ever-worsening climate-induced risks.







FORTIFY

Framework for Optimized Resilience and Targeted Infrastructure Funding Yields.