Infrastructure Australia

Climate Risk & Resilience Assessment for Nationally Significant Infrastructure – Technical Report

Risky Business Submission

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Climate Risk & Resilience Assessment for Nationally Significant Infrastructure – Technical Report
Infrastructure Australia

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Executive Summary

This report presents a framework for assessing the resilience risks from climate hazards to nationally significant infrastructure assets. Designed to provide a structured and scalable approach, the framework evaluates asset vulnerability by quantifying exposure and sensitivity to climate hazards. The framework has been developed to be operated by advanced technologies, including digital twins for real-world simulations and AI systems to bridge and harmonise data sets.

The framework's applicability is demonstrated through a pilot study on nationally significant road infrastructure in Victoria. Scaling this framework for use on a national scale would enable consistent and systematic evaluations across geographies and asset classes, enabling Infrastructure Australia to provide informed advice and quantifiable recommendations to government bodies and stakeholders.

A key challenge identified in implementing this framework is the inconsistency of available data across different asset classes, geographic locations, and climate hazards. Variations in data quality and availability, along with discrepancies in climate hazard projections highlight the need for national collaboration to address these gaps and establish standardised methodologies.

To develop this framework for use on a national scale, the report makes the following recommendations:

- Develop a unified National Digital Twin to assess climate risks and simulate stressors and interventions.
- Expanding existing state-level digital twins into a unified National Digital Twin to provide consistent standardised assessments nationwide.
- Establish/assign a central authority to coordinate data collection, standardise climate projections and maintain a national database.
- Utilize AI-driven systems to address data gaps, improve prediction accuracy, and support adaptive learning.

By adopting this framework and implementing these recommendations, Infrastructure Australia will be positioned to provide informed, strategic guidance to government bodies. This will ensure that infrastructure investments are not only targeted and effective but also aligned with the pressing need to address the growing risks of climate change.

1. Project understanding

Infrastructure Australia is seeking an approach to assess and quantify the relative risks to nationally significant infrastructure from climate related hazards. Climate change is leading to increased frequency and severity of natural hazards, which is increasing the risk and exposure of vulnerable infrastructure, impacting national productivity and the physical, social and economic wellbeing of communities. Infrastructure resilience is a government priority, however there is currently no tool or systematic framework for identifying and quantifying the relative risks to infrastructure across different sectors, which would enable the government to make decisions to prioritise investment.

It is understood that in order to develop a robust, evidence-based understanding of the relative compound risks to national infrastructure – now and into the future – from a national perspective, the following is required:

- A risk taxonomy and assessment framework for infrastructure assets / networks.
- Identification and assessment of relevant existing data sources, and critical gaps.
- A methodology to quantify risk to infrastructure for different areas based on multiple factors.
- Development of an early "proof of concept" to demonstrate your approach int an area.

The framework is intended to be used by Infrastructure Australia staff to assess risks and enable informed decisions and recommendations to allocate funding for infrastructure investment to improve resilience outcomes, and to inform Ministerial advice. The framework will also help to inform IA's audit work on infrastructure risk and resilience.

By addressing climate risks and enhancing resilience, the Federal Government can protect infrastructure, support economic stability, ensure public safety, and strengthen national security. Investing in resilience of infrastructure to climate hazards into infrastructure planning ensures that investments are sustainable and effective over their intended lifespan. This approach helps avoid the need for costly retrofits and repairs in the future and help maintain economic stability by preventing disruptions in essential services and reducing repair and replacement costs.

The approach detailed in this Technical Report presents a desired future-state for Infrastructure Australia, that will enable it to effectively and efficiently understand at a national scale the key resilience risks and inform future planning and investment to be effective, valuable and impactful.

1.1. Project objective

Develop a framework for assessing resilience risks to nationally significant infrastructure from climate-related hazards, to enable Infrastructure Australia to provide strategic advice to the government on investment priorities.

2. Ultimate Vision

In anticipating an ultimate solution for Infrastructure Australia to be able to achieve the above project outcome, the vision of a national digital twin was developed. This is described below.

It is recognised that this is a longer-term solution that will require significant effort to achieve. However, the process and methodology that can be utilised immediately, in the interim, and once the digital twin is established, is described within this report.

2.2. Digital Twin

Digital twins are increasingly being leveraged globally to assess and mitigate climate change risks to infrastructure assets by providing a virtual model that replicates real-world systems and conditions. By integrating geospatial information, climate predictions, historical records and real-time data recorded from sensors, digital twins can enable scenario modelling of climate-related stressors such as flooding or temperature fluctuations.

For Infrastructure Australia, a digital twin could present a powerful tool to evaluate the relative risk of climate change to a range of infrastructure assets. A detailed model would allow users to simulate climate change stressors to reveal which infrastructure assets and geographical locations are most vulnerable. This would enable Infrastructure Australia to make informed recommendations to government bodies that relate to infrastructure investment.

There are several international examples where digital twins have been developed and utilised to mitigate flooding risks for road networks. In the United Kingdom, the Environment Agency and Centre for Digital Built Britain, have simulated flood impacts on roads and nearby infrastructure in flooding vulnerable areas. The models incorporated geospatial data, real-time weather information and historical flood records to assess which parts of the road network are most likely to experience flooding under different conditions. In some cases, this insight has led to preventative measures being introduced such as installing flood defences and modifying stormwater drainage systems.

In Australia, investment has already been made with state-level digital twins, notably in New South Wales and Victoria. To fully harness the potential of these tools, Infrastructure Australia could advocate for the expansion and integration of the NSW and Victorian digital twins into a unified National Digital Twin. This national platform could pool data across all states and territories, standardising datasets and methodologies to ensure consistency and scalability. A centralised model would enable Infrastructure Australia to assess infrastructure resilience at a national scale, providing insights into potential vulnerabilities and opportunities for investment.

Creating a national digital twin would require significant collaboration among state governments, federal agencies, and private sector partners. The breadth of input would increase with the number of asset types that would require assessment and consideration would also need to be given to the availability of data across various sectors and geographic locations. Taking the example of road networks and their risk of flooding, the following information would be required in developing an effective digital twin:

Geospatial and Topographical Data

- **Data**: terrain, elevation, and floodplain maps.
- **Potential Sources**: national geospatial agencies, state planning departments, local councils.

Meteorological and Hydrological Data

- **Data**: rainfall patterns, river flows, storm surge, and sea-level projections.
- **Potential Sources**: national meteorological services, regional hydrology departments, climate research organisations.

Infrastructure-Specific Data

- **Data**: road network layout, drainage infrastructure details, traffic patterns.
- **Potential Sources**: national and state road authorities, transport departments, local councils.

Environmental Data

- **Data**: climate projections, vegetation cover, soil saturation levels.
- **Potential Sources**: environmental agencies, climate research institutions, land management bodies.

Sensor and Monitoring Data

- **Data**: real-time water levels, rainfall, traffic conditions.
- **Potential Sources**: national meteorological services, local water authorities, IoT and sensor technology providers.

Historical and Scenario Data

- **Data**: historical flood records, extreme weather scenario modelling.
- **Potential Sources**: national meteorological services, flood management agencies, research institutions.

Policy and Regulatory Data

- **Data**: emergency response protocols, maintenance records, economic impact data.
- **Potential Sources**: emergency services, national and state infrastructure authorities, insurance organisations.

2.3. AI-driven system

Artificial Intelligence (AI) is increasingly playing a pivotal role in addressing data gaps and enhancing our understanding of climate resilience risks in the infrastructure sector. One of the primary ways AI contributes is through the analysis of vast datasets to identify patterns and predict potential climate impacts, or fill data gaps. This technology is particularly valuable in scenarios where data may be incomplete, inconsistent, or inaccessible, providing the tool to bridge these gaps effectively.

In the proposed framework, AI can be utilised to predict and fill data gaps in vulnerability indicators, such as assessing community reliance on infrastructure assets. Through the collation of existing datasets, an AI system could be developed and trained to generate reliable predictions for missing values, thus creating a more comprehensive and accurate foundation for resilience assessment. This would be of particular benefit to address incompatibility of data between states or infrastructure classes.

Examples where similar systems are being developed or utilised include:

- **CSIRO Critical Infrastructure Protection and Resilience (CIPR) initiative**: coordinating national efforts and collaborating with government, industry and research partners to enhance Australia’s capability through understanding risks and vulnerabilities to critical infrastructure, modelling impacts and identifying effective mitigation and resiliency.
- **ClimateIQ:** focused on providing hyper-local climate data to enable communities and decision-makers to identify the neighbourhoods facing the greatest climate risks. Through a freely accessible digital

dashboard, ClimateIQ provides high-resolution data for flooding from extreme rainfall and extreme heat conditions, leveraging continuously evolving climate models. It uses 'machine learning', utilising existing/traditional climate modelling data to train machine learning models. These models learn correlations between simulation inputs and outputs to predict climate hazard outcomes.

  - ClimateIQ uses a machine learning (ML) approach. For example, an ML model for flood predictions uses spatial features representing city morphology (e.g. elevation) and temporal features describing rainfall patterns to predict flood height at two meter resolution given a pattern of rainfall (aggregated up to 10m on the ClimateIQ dashboard). This approach allows the ML model to learn from both spatial and temporal features.

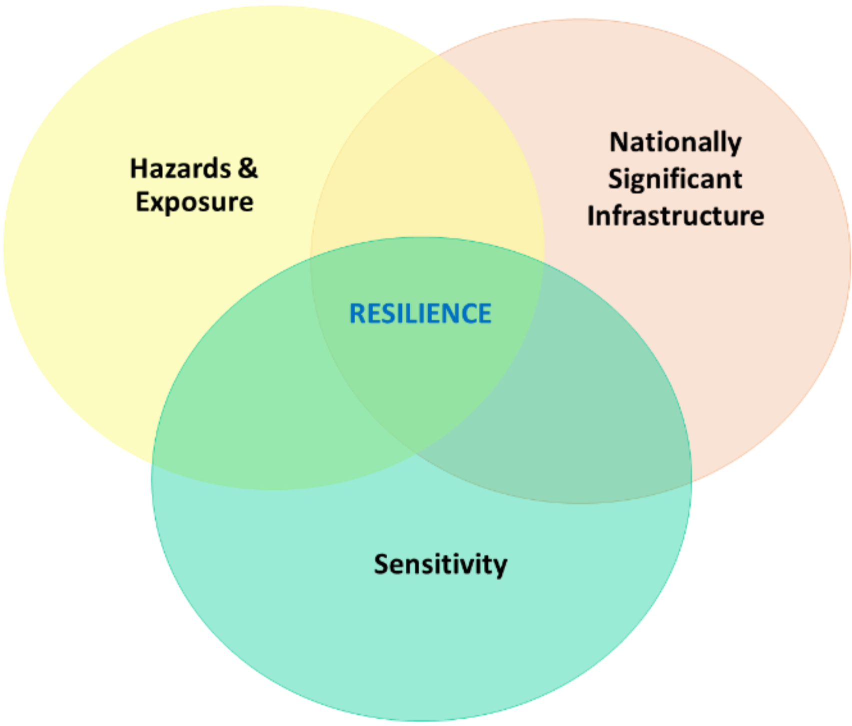
- **The Allan Turing Institute:** The institute's research integrates AI with digital twins to simulate climate impacts on infrastructure. These AI-enhanced digital twins incorporate real-time and historical data, enabling scenario analysis for assets under various climate stressors. Such systems demonstrate how AI can enhance predictive capabilities and inform resilience planning.

Incorporating AI into a national framework for infrastructure resilience offers significant potential. An AI-assisted system could unify data from a variety of sources, normalise inconsistencies and provide standardised inputs for analysis. To enhance its effectiveness and AI-assisted system could also incorporate feedback loops where outcomes from resilience measures are reintroduced into the model which would lead to an improvement of accuracy over time. Collaboration with existing initiatives such as CIPR and ClimateIQ would help avoid duplication of effort, while leveraging their expertise could accelerate development.

3. Proposed Framework

The framework and methodology described are proposed to be the consistent approach for Infrastructure Australia, even as additional data and developments are progressed toward the digital twin.

Our approach is based on a 'Threat and Vulnerability Analysis' (TVA). TVA involves identifying and evaluating potential threats and vulnerabilities to infrastructure. It focuses on understanding how threats can exploit vulnerabilities and what impacts this might have. The diagram below shows the key considerations of our framework, adopted to show the threat (hazards and exposure), vulnerability (sensitivity), and our subject of nationally significant infrastructure. The intersection of the these will inform the relative resilience.



The key steps in the proposed framework are:

This framework has been designed to be:

- Practical: able to be applied and adapted to different infrastructure sectors.
- Scalable: can be used across various geographical scales (State/Territory, National, local government authorities), and across current and future climate scenarios.
- Robust: aligned to leading risk and resilience assessment approaches.

Key existing frameworks and documents that were considered to inform our framework and assessment include:

- NZ Rautaki ā-Motu Manawaroa Aituā | National Disaster Resilience Strategy.
- Australian National Climate Risk Assessment – Methodology and First ass Assessment Findings (DCCEEW, 2023).
- A Universal Taxonomy for Natural Hazard and Climate Risk and Resilience Assessments (Arup, 2024).
- Incorporating Climate Change Resilience in Asset Management (Austroads, 2024).

3.4. Taxonomy and Definitions

The following definitions have been used in the proposed framework.

Resilience: resilience is the ability to withstand or rapidly recover from the effects of a hazard. A simpler way of thinking about resilience is the tolerance for disruption (Rautaki ā-Motu Manawaroa Aituā | National Disaster Resilience Strategy). Resilient systems anticipate and prepare for disruptive trends or events. When these events occur, they resist then absorb them and subsequently recover, learn and adapt. Below is an illustration to assist in describing the definition of resilience.

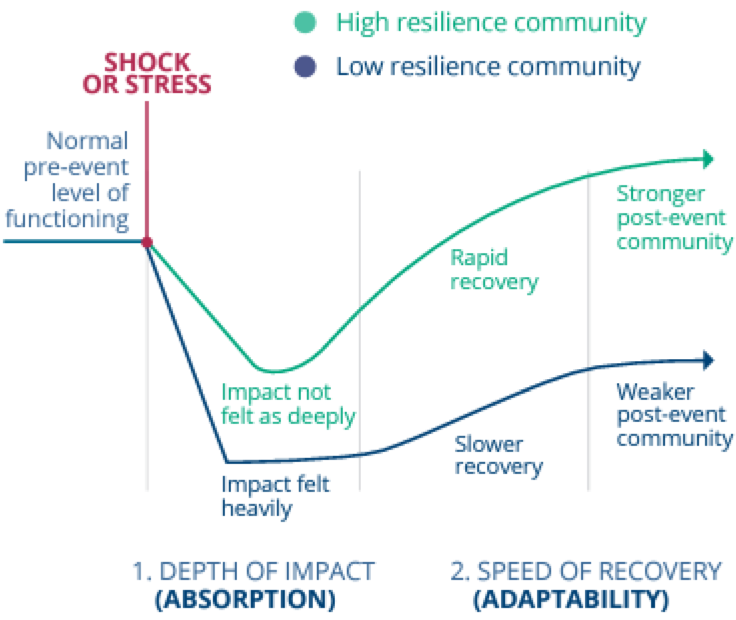


Figure 3 Two dimensions of resilience: absorption and adaptability

Source: https://www.civildefence.govt.nz/assets/Uploads/documents/publications/ndrs/National-Disaster-Resilience-Strategy-10-April-2019.pdf

Downtime: downtime is perhaps the best indicator of "resilience." This can be measured in terms of functional recovery, which is the time it takes for the infrastructure to regain its functions, or usage levels, which is the time it takes to allow (e.g. road) users to safely use/access (traverse) the infrastructure. In this assessment we use the term **'historical performance'** to represent 'downtime'.

Resilience risks: risk of operating outside safe operating space and not meeting business as usual (BAU) service or performance requirements. This could be failure of a single component from anticipated disruptions (e.g. intense rainfall event) or cascading failure of multiple interconnected components.

BAU Operating Requirements: is providing the services for which the infrastructure is intended to provide and that are expected by customers, operators, regulators, and/or government. It also refers to the standards that the infrastructure has been designed to operate within (e.g. wind speed, flood immunity).

Hazard: a hazard is the potential intensity of a particular natural physical event that can cause physical impacts to nationally significant infrastructure. For the purposes of this assessment, we have adopted the priority hazards (climate threats) detailed in the 'Australian Climate Services'.

Exposure: relationship between infrastructure assets/networks and the level of exposure to hazards.

Sensitivity: sensitivity are conditions which increase susceptibility to impact from the hazard, and hence the assets resilience.

Vulnerability: factors which affect the susceptibility of assets to hazard impacts (such as asset age, condition, value and utilisation) and factors related to wider economic, social or other community impacts of disruption to infrastructure (such as impacts on people movements and supply chains).

3.4.1. Impact Assessment categories

This scoring system will provide Infrastructure Australia with the system to prioritise investment recommendations, and insights into the key factors affecting the Vulnerability score which will support targeting the resilience investment into the most relevant activities/intervention:

Vulnerability Score	Description
Very high	Immediate need for resilience investment due to [x, y, z] factors (factors defined during implementation of methodology).
High	Priority need for resilience investment due to [x, y, z] factors.
Medium	Track changes to exposure and sensitivity over the short term for changes in Vulnerability score.
Low	Track changes to exposure and sensitivity over the medium term for changes in Vulnerability score.
Very Low	Lowest priority for investment in resilience measures. Track changes to exposure and sensitivity over the long term for changes in Vulnerability score.
Negligible	No need for resilience investment in the short/medium term.

4. Methodology

The proposed methodology for assessing the vulnerability of nationally significant infrastructure from climate hazards is outlined in the five key steps shown and described below.

4.1. Identify nationally significant infrastructure

Step one of the framework is to identify the nationally significant types of infrastructure to be assessed.

This initial step of Infrastructure Australia's framework to quantify the relative risks to nationally significant infrastructure from climate related hazards, is the categorisation of assets and their spatial location. The type of asset infrastructure categories has been defined nationally by the Australian Government's Department of Home Affairs and the Critical Infrastructure Centre as a result of the Security Legislation Amendment (Critical Infrastructure Bill) 2020. The identified asset categories are the following (Protecting Critical Infrastructure and Systems of National Significance,2021):

- Communication sector.
- Energy and water sector.
- Food and grocery sector.
- Social infrastructure sector.
- Transport sector.

This is where the scope of the assessment would be defined by selecting the type of infrastructure the assessment focuses on. The assessment could focus on one, multiple, or all types of infrastructure, and gives Infrastructure Australia the flexibility to decide on the breadth of the infrastructure to be included in the assessment.

In this step you would also define the spatial scale that is to be assessed. For example, infrastructure could be assessed on a state basis, or nationally.

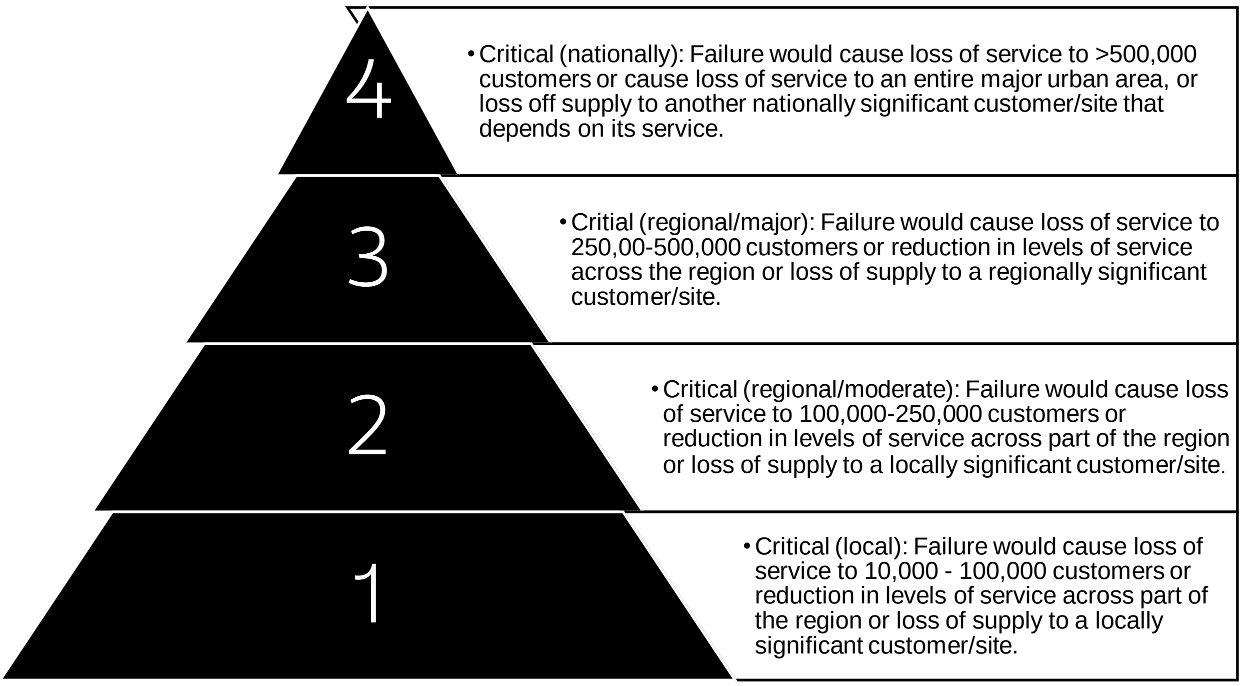
Data inputs

The data inputs required for this step is a large database that includes information on all infrastructure, including the following information:

- Type of infrastructure (e.g. national land transport, telecommunications, etc.).
- Location (spatially mapped).

4.2. Identify critical infrastructure

Once the infrastructure type is selected, the criticality of the infrastructure must then be determined. This framework adopts the approach to infrastructure criticality that is used by the New Zealand Lifelines Council (NZLC 2023) which assessed infrastructure criticality based on the service impact of the asset failing (relative to number of customers served). In this step of our framework, the nationally significant infrastructure would be assigned a weighting factor (1-4) based on criticality. A proposed criticality weighting for Nationally Significant Infrastructure (adapted from New Zealand Lifelines Council (NZLC 2023) National Infrastructure Vulnerability Assessment) is depicted in the figure below.



Data inputs

To assess the criticality of infrastructure and determine criticality weighting, the following data categories have been identified by the Australian Government's department of home affairs and the Australian Infrastructure Policy Statement of 2023. This data may assist in determining the criticality weighting of the nationally significant infrastructure.

Asset Purpose and Usage:

- This data category focuses on the main functionality of the asset and its usage. For example, if several transport assets such as a major freeway are being determined nationally critical, the following data would be required:
    - Asset purpose: access / commercial / emergency services.
    - Number of vehicles / freight utilising the asset.
    - Key towns / cities being serviced by the asset (LGA's).

Safety and Social Impacts:

- Whether it provides safety for human life (e.g. a power station providing electricity to a hospital).

Economic Productivity and Impact

- Infrastructure impact on the economy.

Asset Redundancies and Alternatives:

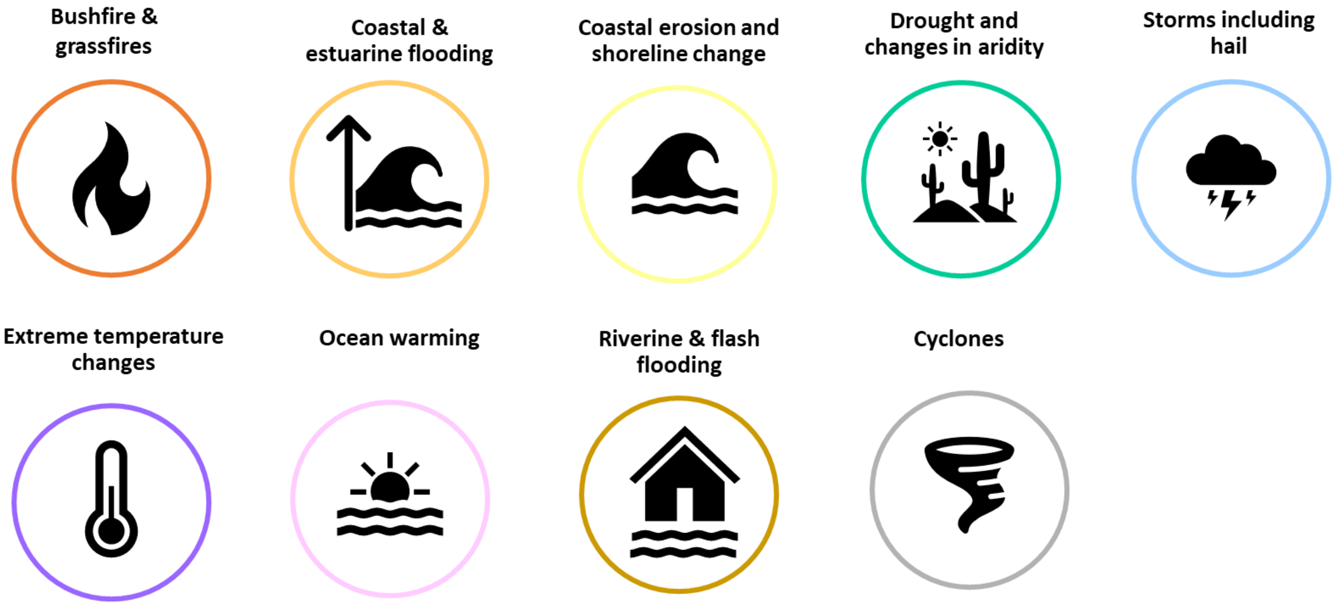
- Potential alternatives that exist (proximity of infrastructure assets that provide similar service/function).

4.3. Identify climate threats

This step looks at identifying potential climate threats.

The Australian Climate Services (ACS) is an Australian government entity encompassing a partnership between the Bureau of Meteorology, CSIRO, Geosience Australia, and the Australian Bureau of Statistics. ACS was established to provide improved data, intelligence and expert advice on climate risks and impacts to support and inform decision-making.

Australian Climate Services has identified nine priority climate hazards; it is recommended that Infrastructure Australia aligns this assessment approach with these nine hazards. The nine hazards are shown below. These nine hazards will apply to the framework proposed in this report and form an input to the next methodology step.



Data inputs

Data should include historical information about these nine climate hazards, including frequency, severity and location.

In addition to historical hazard information, climate change projections should also be considered and applied to enable assessment of potential threat in the future.

4.4. Evaluate Vulnerability

4.4.1. Determine exposure and sensitivity

In this step the exposure and sensitivity of the identified infrastructure asset is assessed. In some cases, an infrastructure asset may not have any sensitivities that may influence its resilience, or in some cases it may be able to recover quickly without causing a significant disruption. The asset may not be exposed to climate threats (current and/or future) and hence has no identified resilience risk/vulnerability.

There are several factors which influence the sensitivity of infrastructure and therefore may impact its resilience to climate hazards.

To support the assessment and scoring of exposure and sensitivity the following categories have been defined:

Exposure of asset to climate hazards.

This is based on a simplified version of the PIARC International Climate Change Adaptation Framework (2023). A scoring system is used to assign an exposure level to the asset.

Level of Exposure		Description
0	**Negligible**	Infrastructure Asset has no likelihood of exposure to climate hazards (now and/or in future)
1	**Low**	Infrastructure Asset has high likelihood of exposure to 1-3 climate hazards (now and/or in future)
2	**Medium**	Infrastructure Asset has high likelihood of exposure to 4-6 climate hazards (now and/or in future)
3	**High**	Infrastructure Asset has high likelihood of exposure to 7-9 climate hazards (now and/or in future)

As identified in the recent Austroads guidance on Incorporating Climate Change Resilience in Asset Management, GIS data such as planning overlays (e.g. flood or bushfire management overlays) or projected future hazard extents may support the assessment of asset exposure. Through overlaying infrastructure asset location/network with climate hazard data sets and identifying where the two intersect, the number of hazards which the asset is exposed to can be determined.

Sensitivity of asset

Sensitivity are conditions which increase susceptibility to impact from the hazard, and hence the assets resilience.

A similar scoring mechanism to the exposure has been defined for each sensitivity category. Building on the recently published Austroads Guidance on Incorporating Climate Change Resilience in Asset Management (2024), we have identified several sensitivity categories to be assessed:

- Infrastructure asset condition and age.
- BAU operating requirements.
- Historical performance.

Sensitivity Score		Category Description		
		Infrastructure asset condition and age	**BAU Operating Requirements**	**Historical Performance**
0	**Negligible**	New asset constructed with modern materials and standards. Well-defined maintenance regime.	BAU operating requirements are within expected current and/or future climate hazard conditions that are likely be experienced.	Past climate hazard events have not resulted in any loss of performance of the asset.
1	**Low**	Relatively new (Recently constructed with modern materials and standards / Still within expected lifespan, minor wear, well maintained)	Most BAU operating requirements are within expected current and/or future climate hazard conditions that are likely be experienced.	Past climate hazard events have led to small loss of performance of the asset (asset damage less than $50M or loss of service less than 1 day).
2	**Medium**	Middle aged (Approaching mid-life, moderate wear and tear. May require minor upgrades or replacement of some components, moderate maintenance)	Only some BAU operating requirements are within expected current and/or future climate hazard conditions that are likely be experienced.	Past climate hazard events have led to moderate loss of performance of the asset (asset damage between $50M - $100M or loss of service for multiple days (less than 1 week)).
3	**High**	Old/very old (Significant wear, nearing or beyond expected lifespan, limited maintenance undertaken)	Only 1-2 BAU operating requirements are within expected current and/or future climate hazard conditions that are likely be experienced.	Past climate hazard events have led to severe loss of performance of the asset (asset damage greater than $100M or loss of service for more than 1 week)).

To determine the overall sensitivity score for an asset, an index-based method is proposed: combining multiple indicators into a single score. The sum of the sensitivity score for each category results in an overall sensitivity score.

Data inputs

- Infrastructure asset condition and age - can impact how it may respond to certain hazards and how quickly it may degrade. Current condition data (e.g. fair/poor/good) may be represented by maintenance or asset management records.
- BAU operating requirements (e.g. designed for a 1 in 50 year flood, wind loading of 100km/hr etc.) - Design thresholds may identify limits at which an asset may be more sensitive to degradation or failure.
- Historical performance : The historical performance of an infrastructure asset during climate hazard events can provide insights into its sensitivity.

Where no historical information is available, an informed hypothesis or AI could be used to assess potential impacts.

4.4.2. Evaluate the potential impacts

To assess potential vulnerability, the selected nationally significant infrastructure asset type(s) are assessed against the Exposure (to climate threats) and Sensitivity (factors that may affect resilience of asset to climate threats).

			Sensitivity Score		
Exposure Score		0-2	3-4	5-6	7-9
	3	MEDIUM	HIGH	VERY HIGH	VERY HIGH
	2	LOW	MEDIUM	HIGH	VERY HIGH
	1	VERY LOW	LOW	MEDIUM	HIGH
	0	NEGLIGIBLE	VERY LOW	LOW	MEDIUM

4.5. Outputs

This scoring system will provide Infrastructure Australia with the system to prioritise investment, and insights into the key factors affecting the Vulnerability score which will support targeting the resilience investment into the most relevant activities/intervention:

Vulnerability Score	**Description**
Very high	Immediate need for resilience investment due to [x, y, z] factors.
High	Priority need for resilience investment due to [x, y, z] factors.
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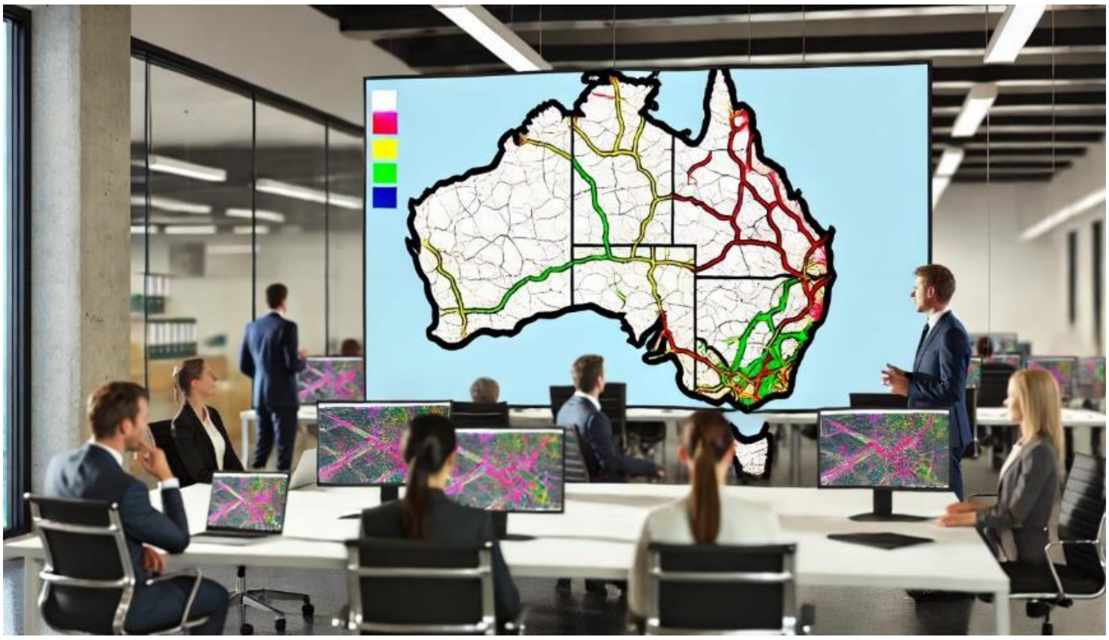
Very Low	Lowest priority for investment in resilience measures. Track changes to exposure and sensitivity over the long term for changes in Vulnerability score.
Negligible	No need for resilience investment in the short/medium term.

Highest scores are areas of priority (“Very High” score) for investment. Outputs will detail the key factors feeding into the score (e.g. is it due to multi hazard exposure or is it due to the asset being very old plus being a key route for community to access essential services). Based on this data insight Infrastructure Australia can target not only where the investment needs to be, but they type of investment needed (to address the critical factors impacting the resilience of the infrastructure asset).

The GIS system and digital twin will map and analyse the spatial data and apply the indices. It will show a spatial map of the infrastructure and visualise the scores in a heat-map. An example output is shown in the image below.



5. Data sources

Conducting a data analysis on an array of data sources at both statewide and national levels is essential for gaining insight into trends, patterns and disparities which influence decision making across sectors. By examining a diverse set of categories mentioned below, Infrastructure Australia will be able to aid policy makers and stakeholders to make informed decisions.

A data analysis has been undertaken for the following data categories:

- Asset classification.
- Critical infrastructure.
- Climate hazards.
- Asset sensitivity.
- Impacts and costs.

5.1. Nationally Significant Asset Classification

This qualitative data step has been well defined by various government and private authorities in a national scale and has identical asset categories across various publications and sources.

The data input required for this step is a large database that includes information on all infrastructure, including the following information:

- Type of infrastructure (e.g. national land transport, telecommunications, etc.).
- Location (spatially mapped).

Infrastructure types and the spatial locations of national assets are well defined within the Digital Atlas of Australia. The interactive digital atlas, which is an initiative of the Australian government's geoscience department, enables the user to build a custom map of Australia with a varying array of data layers. The digital atlas is data-rich within transport, social infrastructure and energy sectors.

For example, the Public Hospitals dataset available on the Digital Atlas of Australia. This feature layer describes the location of Australia's public hospitals, operational at some point during the 2021-22 Financial Year. A public hospital is defined as a hospital included in the Australian Institute of Health and Welfare's (AIHW) National Public Hospital Establishment (NPHE) database, for the relevant financial year. The NPHE database holds data for each public hospital in Australia, including public acute hospitals, psychiatric hospitals, drug and alcohol hospitals and dental hospitals in all states and territories. Hence, public hospitals not administered by the state and territory health authorities (hospitals operated by correctional authorities for example, and hospitals in offshore territories) are not included. This can be supplemented by the Commonwealth '**Error! Hyperlink reference not valid.**'.

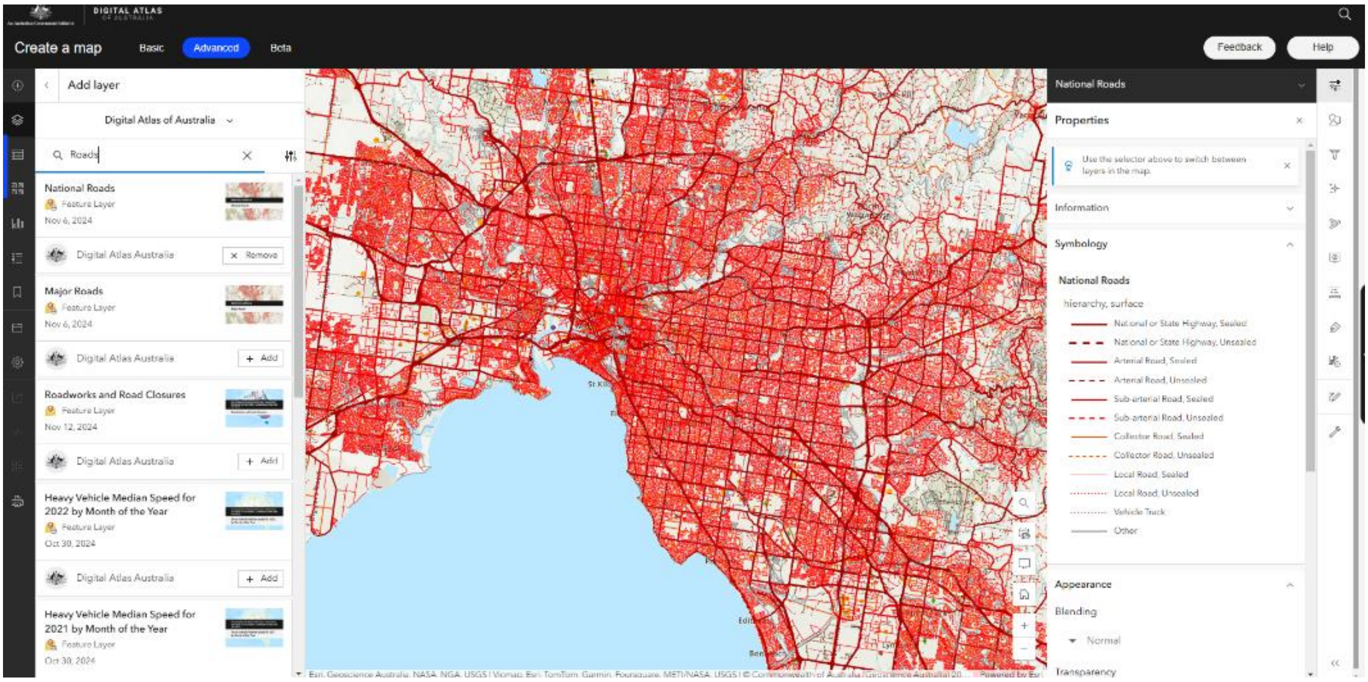


Figure 1 A map of national roads within Victoria

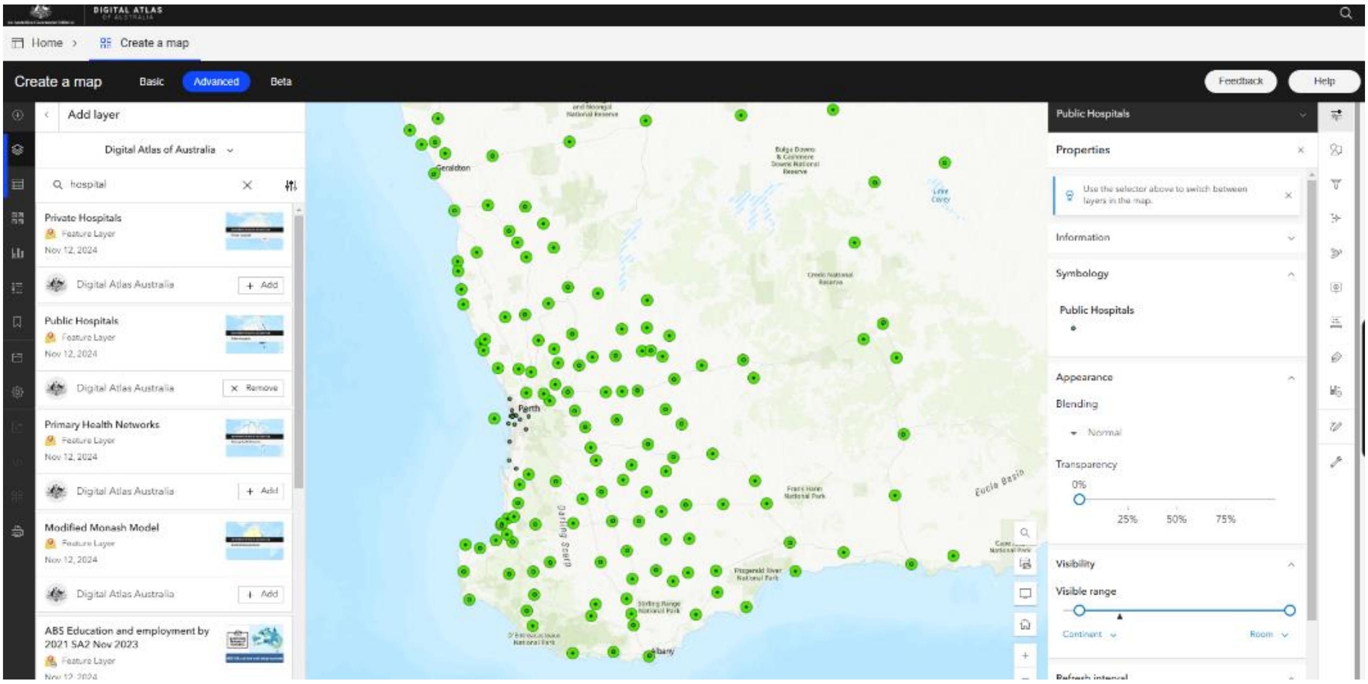


Figure 2 A map of public hospitals and ambulance stations in Western Australia

The digital atlas of Australia is a great tool to gather information on the main asset types and spatially position them to carry out the proposed Infrastructure Australia framework. However, the digital atlas presents with major data gaps in the sectors of communication, water and food and grocery. Wider research and publications are available on these assets with good spatial coverage. For the communication sector, several GIS/ESRI data maps are available by both public and private web publications. The ‘National Map’ developed by the Geoscience Department of the Australian government is a similar map based online tool to the digital atlas and is data rich within the communications sector with multiple overlays available of telecom towers, NBN types and radio broadcast stations.

Figure 3 A map of NBN fibre to distribution point map of New South Wales

The water sector has several key authorities with online map-based data tools. However, most tools that were identified were state specific and isolated in nature. A complete map of an Australian wide tool was not identified. As an example, for the state of Victoria along with water service providers such as Southeast Water, Melbourne Water, Yarra Valley water, etc, the Victorian governments ‘VicMap’ online tool provides good data on the water sector.

The Foundation Electricity Infrastructure product (available in the Digital Atlas of Australia) contains three databases, Electricity Transmission Lines, Major Power Stations and Transmission Substations. The Electricity Transmission Lines Database presents the spatial location, in line format, of all known high voltage electricity transmission lines that make up the electricity transmission network within Australia. The Major Power Stations Database presents the spatial locations, in point format, of known major power stations within Australia. The Transmission Substations Database presents the spatial locations, in point format, of all known electricity transmission substations within Australia

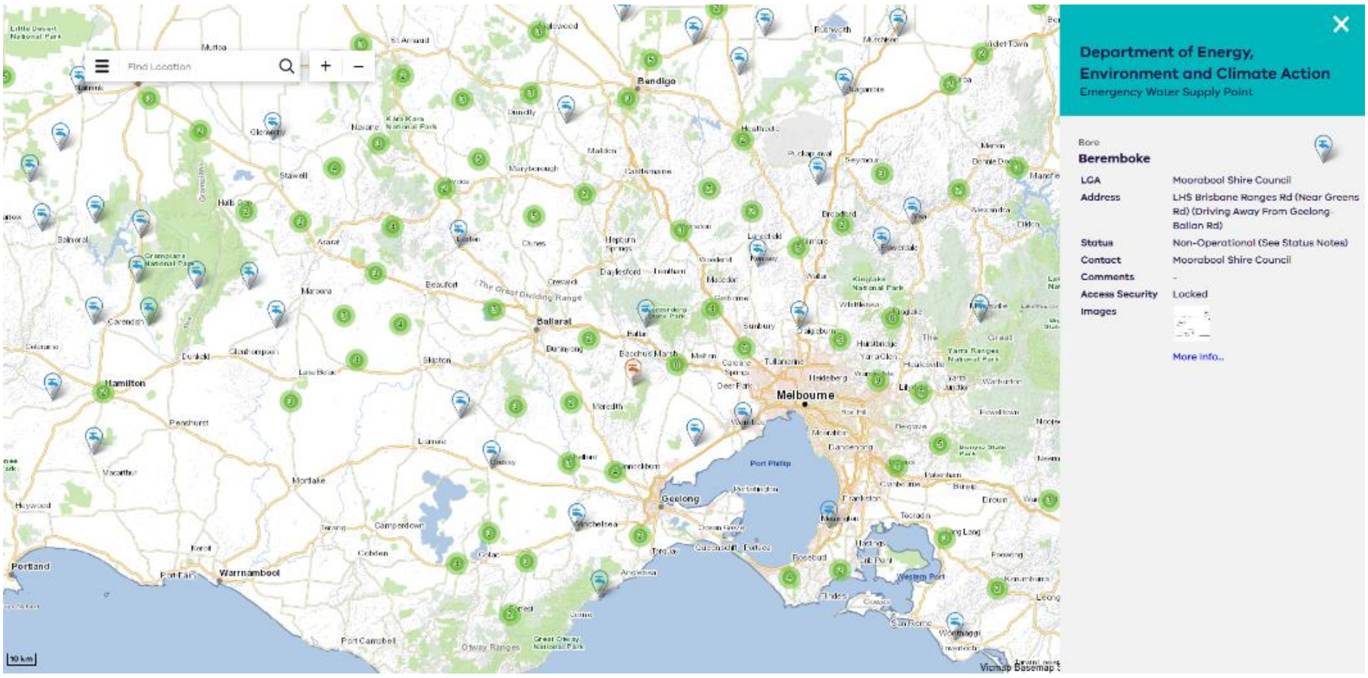


Figure 4 A map of emergency water supply points in Victoria

The food and grocery sector is not as data-rich as the others. A deep dive on the availability of data within this sector yielded little to no results. The only available online data map by the 'Farm Transparency Project' provides data on different farm types within Australia. The map has a sole focus on farms and lacks data of warehouses, distribution centres, supermarkets, etc.

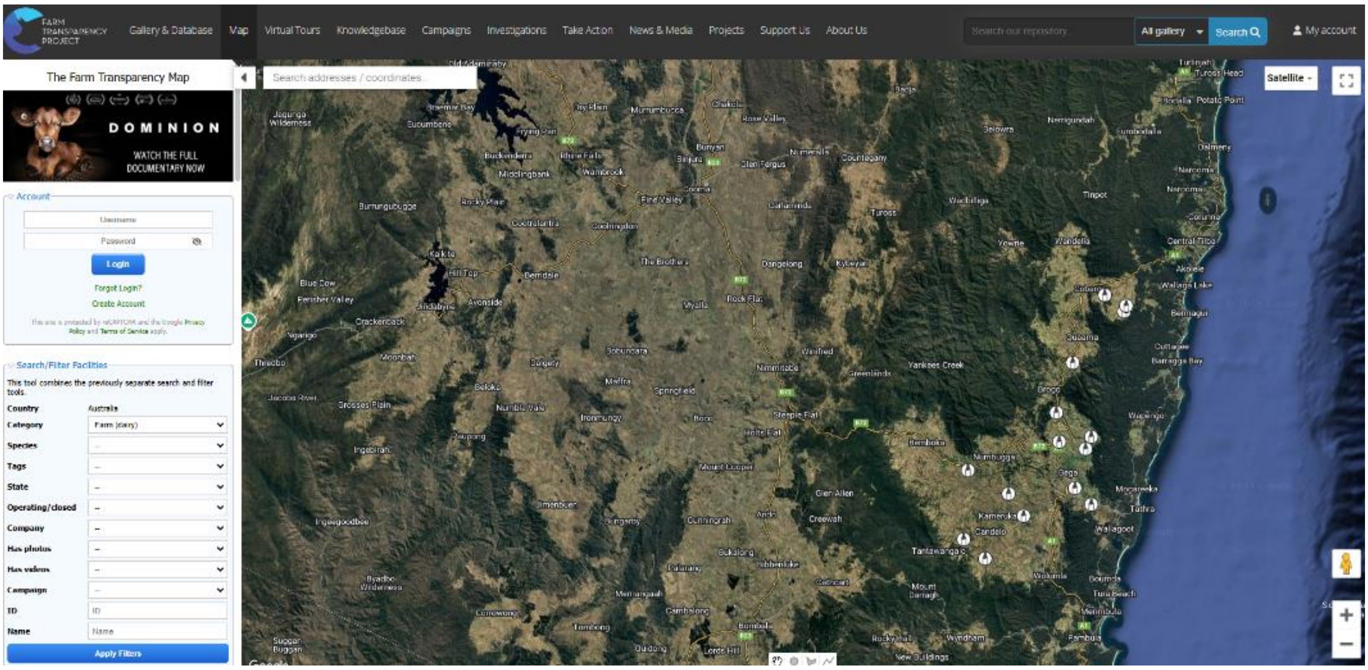


Figure 5 A Map of dairy farms within Canberra

Data gaps and challenges

A detailed analysis of the data identified the following data gaps:

- A single data source / tool is not available to assess all major asset categories within Australia.
- Limited availability of data within communications sector.

- Poor availability of data within the food and grocery sector in relation to supermarkets, warehouses and distribution centres.
- The various web tools and publications have data recorded up to varying time periods, which lead to inconsistencies.
- Varying data sources and publications have different data control and online system maintenance approaches which makes the availability / reliability of these tools an issue to the development of the Infrastructure Australia framework.

Data opportunities

The major data challenges within the asset classification step is the lack of a centralised 'one stop shop' for all asset sectors and the lack of data within the food and grocery and communications sector. The following opportunities have been identified as an approach to counter it.

- Integration of data within government departments: Both 'National Map' & 'Digital Atlas of Australia' are online tools created by the Geoscience department of the Australian government. The integration of these maps results in efficiencies of having a single data source and enables to eliminate the risks of varying data quality and control measures you find by having multiples web tools.
- The opportunity for these web maps to collect data from major private organisations that are key players within these sectors: Data could be collected from companies such as Telstra / Vodafone who may already possess large amounts of data on communication towers, satellite stations, etc. Similarly, companies like Coles and Woolworths may already include data in relation warehouses, distribution centres, etc.
- The use of regulatory bodies such as the ACCC (Australian Competition and Consumer Commission) & AFGC (Australian Food and Grocery Council) to bring in requirements for key private organisations to provide such data as a part of their market regulation processes.

5.2. Critical Infrastructure

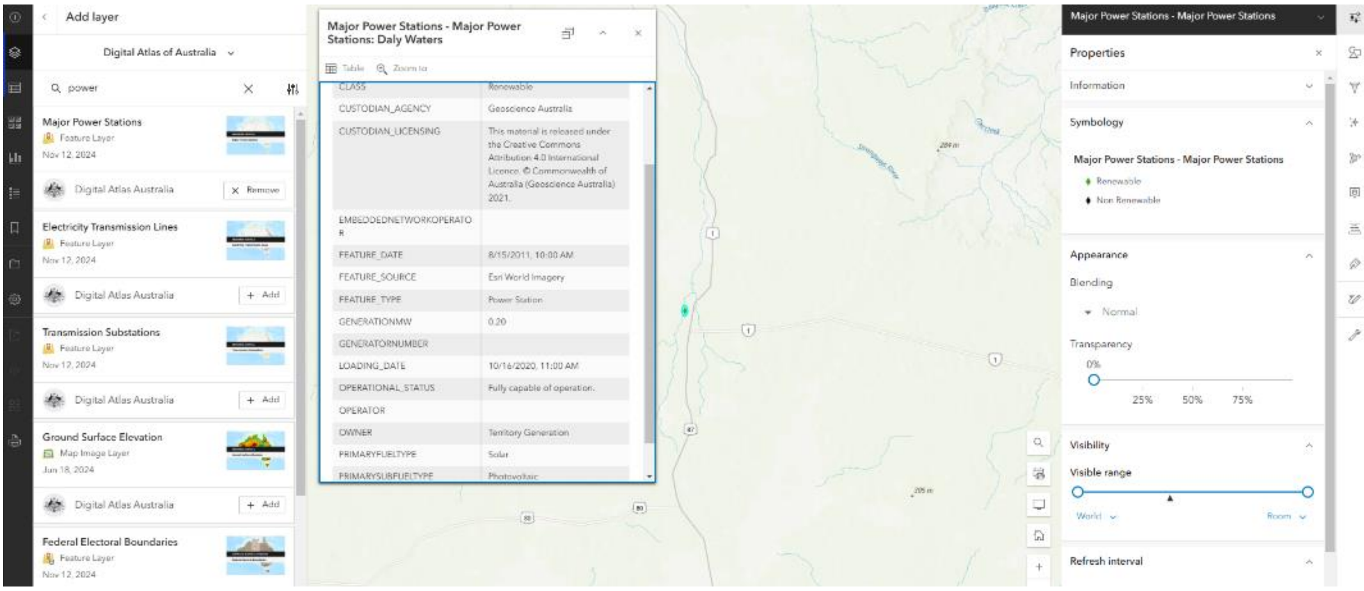
The critical infrastructure classification is based on the data inputs related to service impact (customer service loss and/or level of service). Data sources that may provide insights for this categorisation include:

Primary asset purpose/s: access / commercial / emergency services route

This information can be implied from the infrastructure type.

- Communication sector: telecommunications (tower/lines), satellite stations, radio broadcast stations, NBN hubs.
- Energy and water sector datasets: Electricity Transmission Lines, Major Power Stations and Transmission Substations, major water and wastewater transmission pipelines, water treatment facility, water storage (dam, reservoir).
- Food and grocery sector: commercial food warehouse, major supermarket.
- Social infrastructure sector: health facility.
- Transport sector: passenger and freight movement.

The use of the online map-based tools is also a great way of collecting this information. The web publications mentioned within section 5.1 such as the digital atlas of Australia, National Map, VicPlan, etc provide data tags and descriptors as well as spatially locate them. The data descriptions and tags provide general information of the assets and their purpose. As an example, the following data points of major power stations within the digital map of Australia provide information on a power station in the Northern Territory.



Asset usage (people/vehicles / freight) utilising the infrastructure asset (per day)

- Communication sector datasets: are datasets available that provide insights into the telecommunications infrastructure and usage in Australia. The Australian Communications and Media Authority (ACMA) publishes detailed reports on telecommunications trends and developments, which include data on the number of customers serviced by various telecommunications infrastructures, including towers. Additionally, the Australian Competition and Consumer Commission (ACCC) releases communications market reports that provide comprehensive data on the telecommunications sector, including customer numbers and service coverage.
- Energy and water sector datasets:
  - Water: BoM provides reporting on water assets, including number of main bursts, breaks and leaks, that could be useful in determining asset condition: National performance report 2022–23: urban water utilities
  - Water: data on water supply, connection and consumption is collected by Water Authorities.
  - For specific data on electricity infrastructure, such as the number of people serviced by major power stations or transmission lines, there may be relevant information in the detailed tables and reports provided by the Australian Energy Statistics. Additionally, the Australian Energy Update report offers an overview and analysis of the latest trends in energy usage.
- Food and grocery sector datasets: Limited datasets found to be available.
- Social infrastructure sector datasets: the health department in each state and territory in Australia would publish annual reports and statistics on hospital performance and capacity. Additionally, Australian Institute of Health and Welfare (AIHW) provide comprehensive data on hospital activity, including patient capacity and usage rates.
- Transport Sector datasets:
  - Road: This data shows traffic volumes for freeways (excluding toll roads) and arterial roads in Victoria: https://discover.data.vic.gov.au/dataset/traffic-volume. The annual average daily traffic volume is provided, including the number of commercial vehicles. The data provided is for the current year, with values derived from traffic surveys or estimates.
    - Similar datasets are likely to be available for other States and Territories (e.g. the annual average daily traffic volume (AADT) New South Wales can be found using the Traffic Volume Viewer provided by Transport for NSW). This tool shows traffic volumes for various locations across the state: https://www.transport.nsw.gov.au/operations/roads-and-waterways/corporate-publications/statistics/traffic-statistics/traffic-volume

- Rail: The National Freight Data Hub provides interactive maps and datasets related to rail freight movements, including volume and average speed along various routes. The Bureau of Infrastructure and Transport Research Economics (BITRE) publish comprehensive reports and datasets on rail infrastructure and freight/passenger movements in Australia. There are also datasets available on the Data.gov.au site.

Key towns / cities being serviced by the asset (LGA's): this dataset would be created through overlay of dataset on infrastructure asset location (as identified in Section 4.1) and LGA boundaries. LGA boundaries are readily available on many online databases, including the Digital Atlas of Australia, which contains the 2021 Local Government Areas (LGA) from the Australian Statistical Geography Standard (ASGS) Edition 3.

Data gaps and challenges

No evidence has been found to suggest databases exist that record potential redundancies and alternatives for infrastructure. This data may be available through Emergency Services providers, or SES branches for some infrastructure types: It is recommended that Infrastructure Australia conduct further research as to whether other companies or agencies already have a database or framework for assessing and filing this information.

5.3. Climate Hazards

A review of major climate data sources was conducted to identify the availability of identified climate data. The 9 key climate threats identified were reviewed at both national and state level. The review resulted in the following data summary table.

Data Source	Bushfires & Grassfire	Coastal and esturine flooding	Coastal erosion and shoreline change	Storms and hail	Droughts	Extreme temperature changes	Riverine and Flash flooding	Tropical Cyclones	Ocean warming and acidification
Bushfire Boundaries Data (Digital Atlas of Australia)	Y	Y	Y	N	N	N	Y	N	Y
AFIRP Flood Study	N	N	N	N	N	N	Y	N	N
Australian Flood Risk Information Portal	Y	Y	Y	Y	Y	Y	Y	Y	N
Australian Institute of Disaster Resilience	Y	Y	Y	Y	N	N	Y	Y	N
Geoscience Australia Hazards Portal	Y	N	N	N	N	N	Y	Y	N
Australian Disaster Resilience Information (ADRI)									
Climate Risk Map	Y	Y	N	N	N	N	Y	Y	N
National Exposure Information System (NEXIS)	Y	Y	Y	Y	N	N	N	Y	N
VicPlan Mapshare	Y	Y	Y	N	N	N	Y	N	N

Australia wide
State specific

The results of the data review indicate an abundance of data within flooding, cyclones, bushfire data whilst a major data gap within extreme temperature change, hails and ocean warming.

Data gaps and challenges

The current data around climate hazards varies temporally, which will need to be considered for the assessment. Considering the numerous and inter-related factors that affect climate change, one of the main challenges is being able to adapt the model as climate projections (and associated climate hazards) change over time. This will need to be regularly updated as data is collected over time and climate projections change.

- Spatial resolution and detail: some websites may offer broad or aggregated data with varying levels of spatial resolution, which might lack the granularity needed for detailed local assessments.
- Temporal coverage: historical data and projections may vary in terms of the time periods covered. Some datasets might focus on recent data, while others might include historical data but lack updated projections. Incomplete temporal coverage can affect the accuracy of risk assessments and resilience planning, particularly for long-term climate change projections.
- Data consistency and quality: **v**ariability in data quality and consistency across different sources can occur. Inconsistent data quality can affect the reliability of risk assessments and resilience evaluations.
- Infrastructure data specificity**: n**ot all datasets may include detailed information on the specific types and conditions of infrastructure assets. Without detailed infrastructure data, it's difficult to accurately assess the vulnerability of different asset types to climate change impacts.

Climate Projections

DCCEEW is currently working with state and territory governments, CSIRO, Bureau of Meteorology, universities, and other Australian Government funded initiatives such as the National Environmental Science Program (NESP) Climate Systems Hub and the Australian Climate Service (ACS) to develop an updated set of national downscaled climate projections. This partnership is known as the National Partnership for Climate Projections.

There are some currently available climate projections that can be used. Previous national projections were released in 2015 and are available from Climate Change in Australia website. They were produced by CSIRO and the Bureau of Meteorology. The projections are based on 40 global climate models driven by four greenhouse gas and aerosol emission scenarios and are presented for eight regions of Australia. They include 21 climate variables (both on the land and in the ocean) across four 20-year time periods (centred on 2030, 2050, 2070 and 2090).

More localised projections have been produced for some areas of Australia by state and territory agencies. These are available from:

- Queensland Future Climate Dashboard.
- NSW and Australian Regional Climate Modelling.
- SA Climate Ready.
- Climate Futures for Tasmania.
- Victorian Climate Projections 2019 (and Victoria Future climate tool: https://vicfutureclimatetool.indraweb.io/project).

It is recommended that Infrastructure Australia support this Partnership and utilise the outputs for application of the framework proposed in this report.

The following key climate variables are presented for NSW and ACT (utilising the NARCliM2.0 datasets):

- Temperature (average, maximum, minimum).
- Hot days (above 35°C).
- Cold nights (below 2°C).
- Average rainfall (annual and seasonal).
- Severe fire weather (Forest Fire Danger Index above 50).

https://www.climatechange.environment.nsw.gov.au/projections-map

5.4. Asset sensitivity

Infrastructure asset condition and age - can impact how it may respond to certain hazards and how quickly it may degrade:

- Datasets from the relevant authority Asset Management System (e.g. VicRoads, Main Roads WA, Victorian Health Building Authority), for example VicRoads spatial datasets on Digital Twin Victoria contains some data on asset conditions.

Challenge: Different sections have different ages – either average or the spatial system can assign a value for each segment.

BAU operating requirements (e.g. designed for a 1 in 50 year flood, wind loading of 100km/hr etc.) - Design thresholds may identify limits at which an asset may be more sensitive to degradation or failure:

- Datasets from the relevant authority Asset Management System (e.g. VicRoads, Main Roads WA, Victorian Health Building Authority).
- Austroads Standards, relevant Australian Standards for asset design.

- For newly built assets BAU operating requirements may be located in as-built data and reporting that is handed over upon completion of asset construction.

Historical performance - The historical performance of an infrastructure asset during climate hazard events can provide insights into its sensitivity:

- Datasets might include previous reports and Government budget/spend data on assets (e.g. https://transport.vic.gov.au/news-and-resources/projects/flood-capital-works-program---hume).
- Datasets may also include economic impact data from previous climate hazard events. Refer to Section 4.5.1 below for further information.

Data gaps and challenges

A challenge at this stage is that there may not be reliable information on how exactly a climate hazard will impact an infrastructure asset. Datasets are generally disjointed across geographic regions and asset types.

Further, to be able to determine the ability of the infrastructure asset to recover/be recovered, detailed information about the asset may be required, such as the age of the infrastructure, maintenance history, etc., which can vary within an infrastructure asset type.

5.5. Critical gaps

Each state and territory collects and manages its data independently, often using different standards, formats, and methodologies. This lack of uniformity makes it difficult to integrate data into a cohesive national dataset. Additionally, the volume of data required is immense, encompassing various infrastructure types such as roads, bridges, railways, and public buildings, each with its own set of attributes and conditions.

Another challenge is sourcing the data from multiple locations. Data might be held by various state and territory government departments, local councils, and private sector entities. Coordinating with these diverse stakeholders to obtain accurate and up-to-date information can be complex and time-consuming. Furthermore, ensuring the data's accuracy and completeness is crucial for reliable climate risk assessments and infrastructure condition evaluations. Overcoming these challenges requires significant collaboration, standardisation efforts, and investment in data management systems to create a robust and consistent national dataset.

There is currently no single standardised format that data is collected and stored. Critical data gaps identified in the development of the framework include:

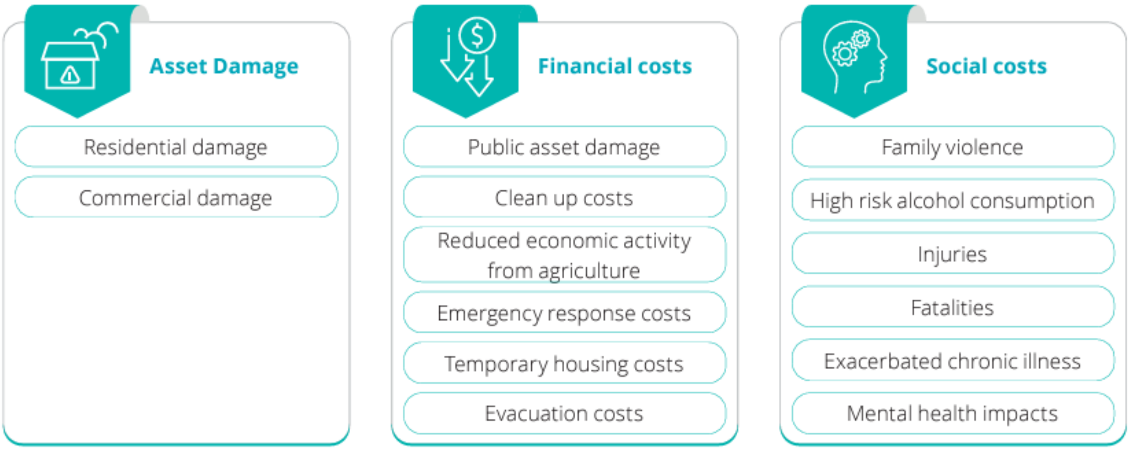
- Comprehensive asset maintenance records for all applicable infrastructure types.
- Community reliance data: datasets that identify the criticality of an infrastructure asset to a community (e.g. critical access routes or facilities with no back-up/alternative). It is possible that Emergency Services departments may have this information which could be collated into a dataset, however security of the dataset would need to be considered (e.g. national security considerations for specifying critical assets).

5.5.1. National dataset on losses from climate-related hazard in Australia

There is a large gap in nationally consistent and available datasets on losses from climate-related hazards. Many agencies hold time-series data on losses from bushfires, among other hazards, but these are usually neither continuous in time or space, nor available outside the agency concerned.

Quantification of costs associated from these hazards can be complex and difficult to calculate. Possible factors to be accounted for include those outlined in the image below:

Figure 2.1: Quantified economic and social costs of natural disasters in Australia



Source: Deloitte Access Economics 2021

Source:
https://australianbusinessroundtable.com.au/assets/documents/Special%20report:%20Update%20to%20the%20economic%20costs%20of%20natural%20disasters%20in%20Australia/Special%20report%20_Update%20to%20the%20economic%20costs%20of%20natural%20disasters%20in%20Australia.pdf

Available Australian data identified by Australian Institute for Disaster Resilience (2018), identified three main sets:

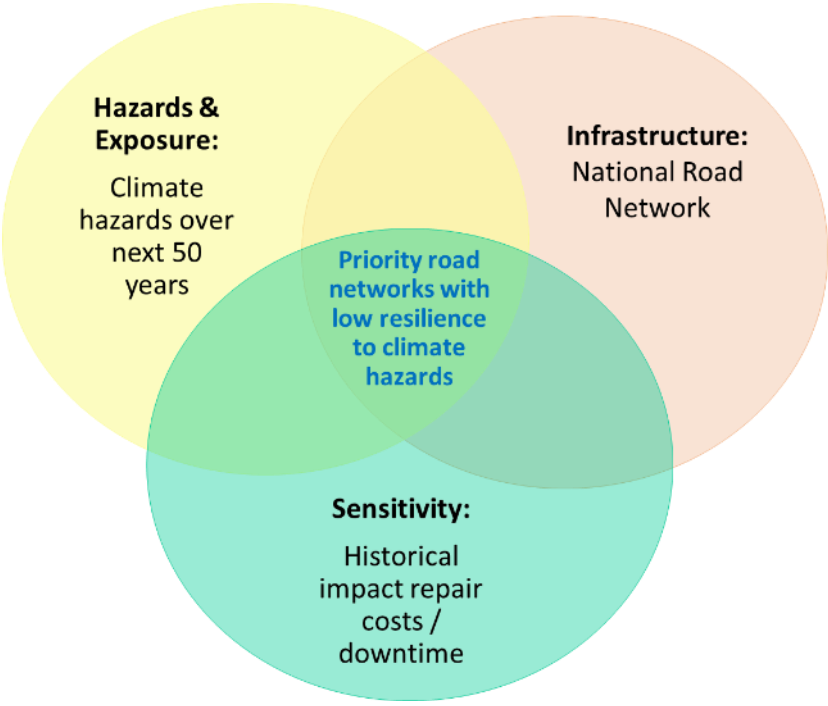
- A proprietary dataset held by Risk Frontiers, which is mainly concerned with insurance-related issues.
- A dataset from the Insurance Council of Australia (ICA 2015) on insurance losses from 1967 to the present, which is publicly available as the ICA's Catastrophe Database.
- The Emergency Management Australia (EMA) Knowledge Hub (formerly EMATrack, and now the Australian Disaster Resilience Knowledge Hub), which is a long-running Australian Government dataset on disaster loss in Australia.

The insurance sector likely holds comprehensive datasets on economic losses or recovery costs associated with climate-related hazard events. This data is generally not available or accessible, but would provide key insights into the costs associated with these events. An example of publicly available data is the paper developed for the e Actuaries Institute 2016 General Insurance Seminar (https://www.actuaries.asn.au/Library/Events/GIS/2016/NaturalDisastersWorkingGroup2016.pdf).

The Insurance Council of Australia (ICA) collects data provided by ICA members to the ICA on insured catastrophe events, however the data provided online does not appear to be in a format suitable for this framework: https://insurancecouncil.com.au/industry-members/data-hub/.

6. Pilot Application

This section details the pilot application of the framework, it is intended to display the intended functionality and outputs of the proposed framework. The scope of the pilot application is looking at road infrastructure in Victoria. For the purposes of this assessment, some indicative or assumed values have been selected for some steps to demonstrate the methodology. Some of the data presented below has not been cross-checked with the datasets and data sources for accuracy.



6.1. Identify nationally significant infrastructure

According to the Department of Infrastructure, Transport, Regional Development, Communication and the Arts, the image below identifies the national land transport network in Victoria.

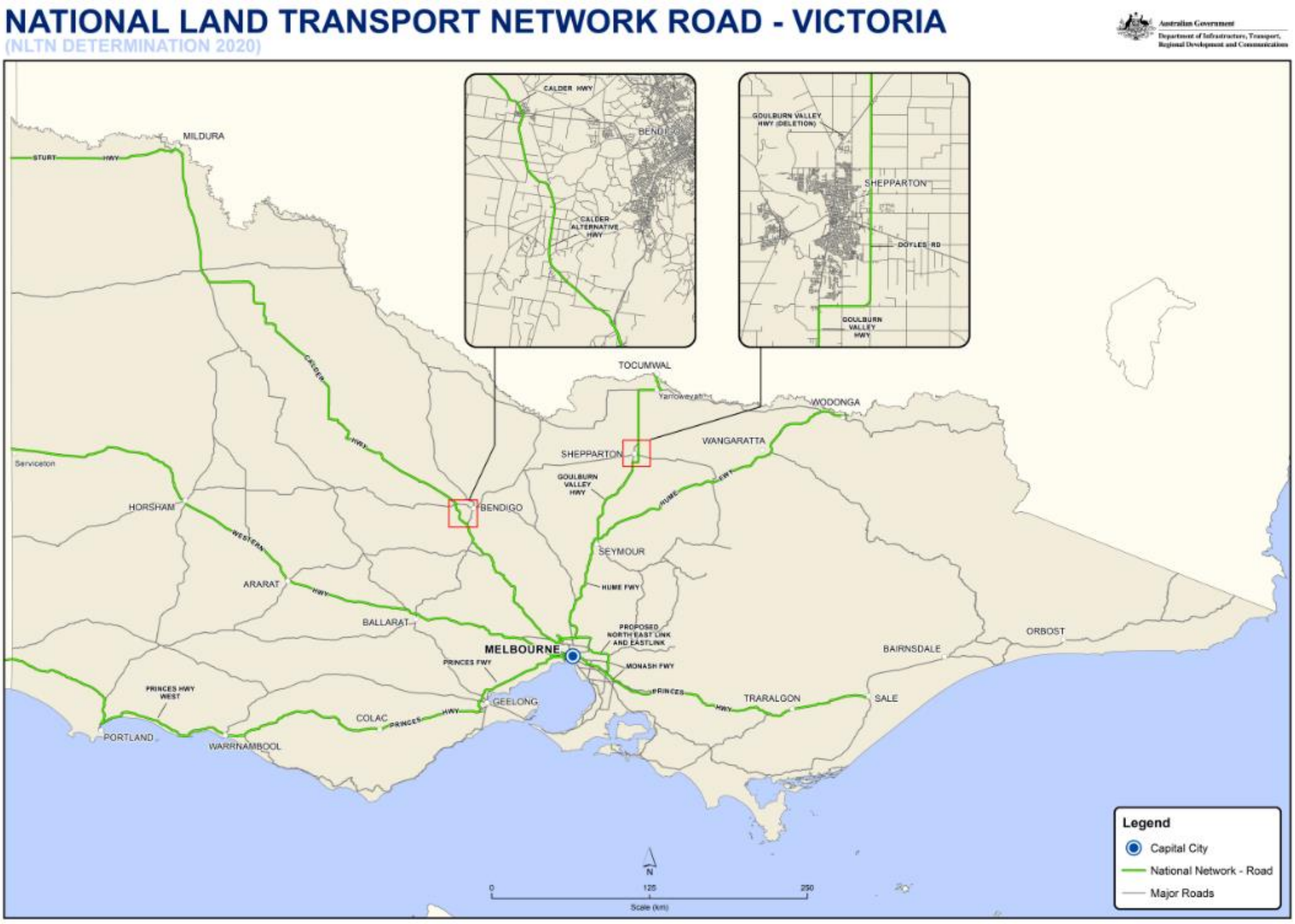


Image source: https://investment.infrastructure.gov.au/resources-funding-recipients/national-land-transport-network#anc_road

The identified assets are:

- Princes Highway.
- Western Highway.
- Calder Highway.
- Goulburn Valley Highway.
- Hume Freeway.
- Monash Freeway.
- Proposed Northeast Link.

For the purposes of this pilot to demonstrate the framework, the scope has been refined to explore three of these seven assets; Princes Highway, Calder Highway and the Hume Freeway.

Data inputs:

Data required for this step	Pilot Application Inputs
Type of Infrastructure	Land Infrastructure; Roads
Location	Victoria

6.2. Identify critical infrastructure

Data inputs:

Data required for this step	**Pilot Application Inputs**
Primary Asset purpose	**Princes Highway**: primary route for connection between Melbourne and Geelong, tourist connection to Great Ocean Road, regional industry connection to domestic markets and major ports. Provides local connectivity for communities. **Calder Highway**: primary route for connection between Melbourne and Bendigo, crucial for the movement of freight, providing access to domestic and export markets through key intermodal transport terminals like Tullamarine Airport and the Port of Melbourne. Provides local connectivity for communities. **Hume Freeway**: primary route for movement of freight between Melbourne and Sydney. Main service route for Albury-Wodonga Region.
Number of customers (people/vehicles / freight) utilising the infrastructure asset (per day)	The current annual average daily traffic volume (AADT) for the **Princes Highway** in Victoria is approximately 60,000 vehicles per day. The current annual average daily traffic volume (AADT) for the **Calder Highway** in Victoria is approximately 40,000 vehicles per day. The current annual average daily traffic volume (AADT) for the **Hume Freeway** in Victoria is approximately 50,000 vehicles per day. Source: https://discover.data.vic.gov.au/dataset/traffic-volume (available on Digital Twin Victoria)
Key towns / cities being serviced by the asset (LGA's)	A simple spatial calculation of intersects of the highways/freeways with an LGA dataset would create the required data (along with population dataset for the LGAs). Princes Highway: Based on geographical length it is assumed to be high. Calder Highway: Based on geographical length it is assumed to be high. Hume Freeway: Based on geographical length it is assumed to be very high.
Criticality weighting	**Princes Highway: 3 Critical (regional/major).** **Calder Highway: 3 Critical (regional/major).** **Hume Freeway: 4 Critical (nationally).**

6.3. Identify climate threats

To assess the potential climate threats to the Princes Highway, Calder Highway and Hume Freeway, overlays on the digital twin (or earlier databases) of climate hazards would be used to assess whether the location of the infrastructure asset is within potential impact areas for the climate hazards.

Below a map of each climate hazard's potential threat is shown. It is noted that these maps are sourced from several different data sources, and have varying degree of reliability, timescales and level of detail. Further, it is noted that most of these overlays are focused on historical climate hazard data, however it is anticipated that the digital twin would allow for different future climate scenarios to be assessed. However, without the compiled database / digital twin, the below images are included to illustrate an example of how the data is anticipated to be depicted.

The below images are compared against the asset location identified in **Section 6.1** to identify whether the asset is exposed to that climate hazard. It is anticipated that in the digital twin a "layer" for each climate hazard can be overlain on the base map that would show the selected infrastructure assets for ease of comparison/assessment.

Bushfires and Grass fires

Bushfire Prone Area (BPA) are shaded grey, and Bushfire Management Overlay (BMO) shaded red in the below image.

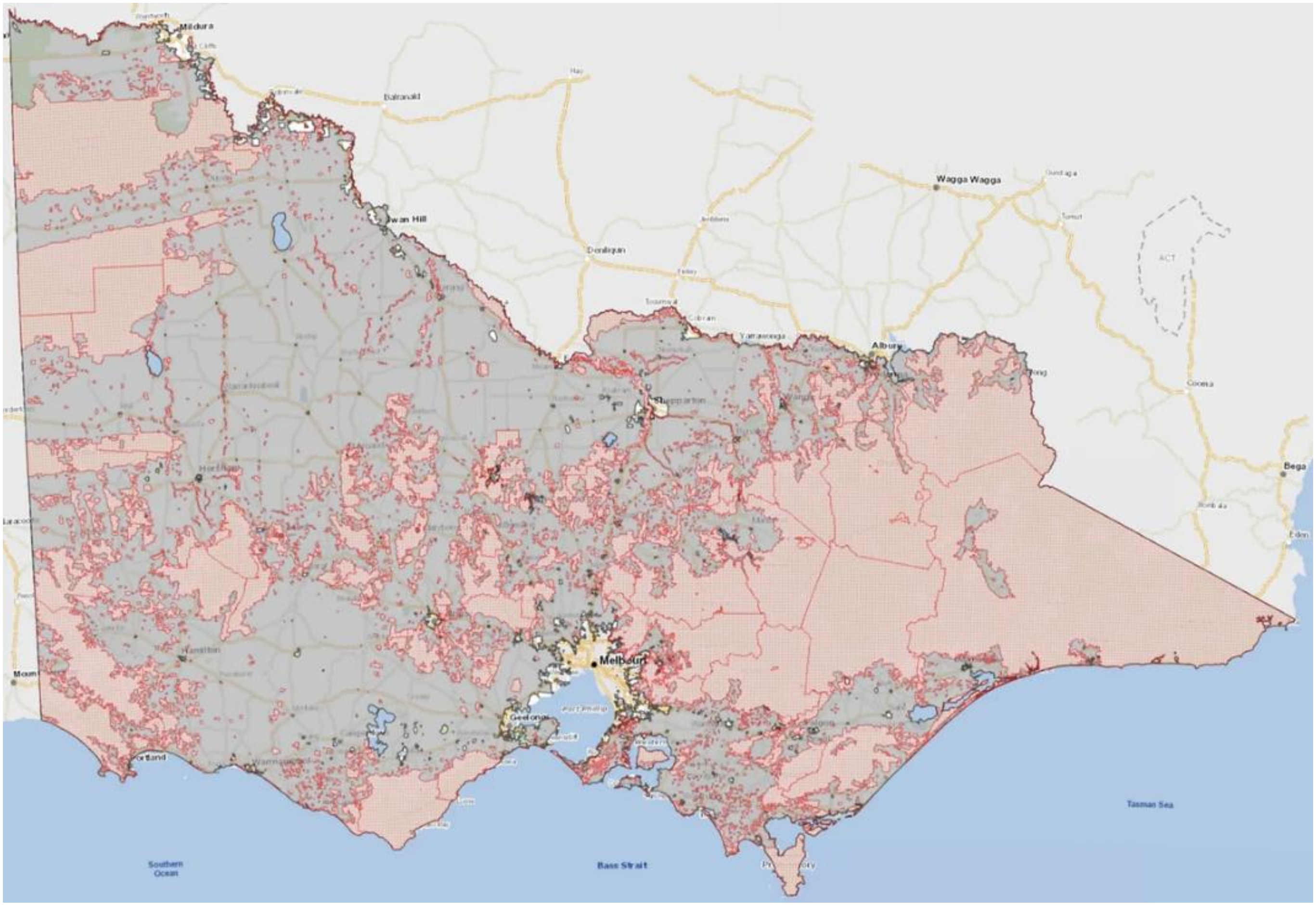
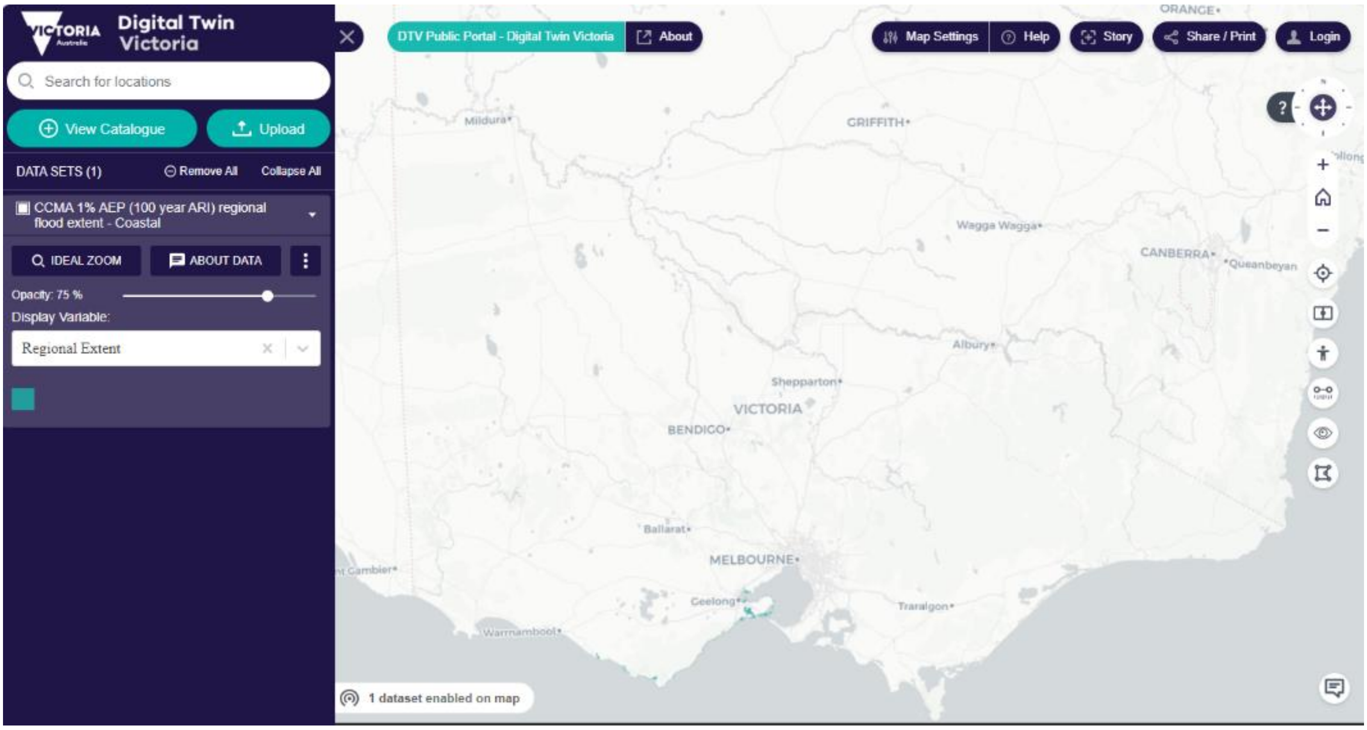


Image source: [Bushfire Prone Area Map | BPA & BMO | Victoria]

It is noted that Bushfire Management Overlay mapped information is available from VicPlan for a specific land parcel/property, but could not be extracted for a road network for this pilot application.

Coastal & Estuarine flooding

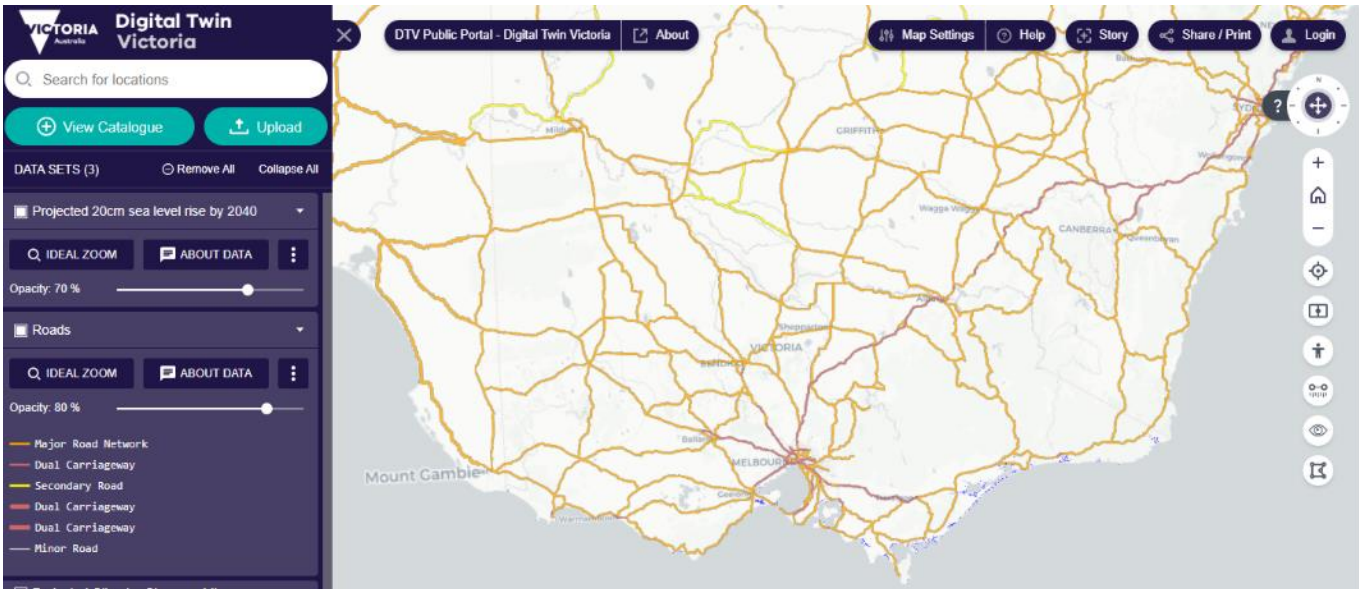
The current available digital twin for Victoria shows 1% AEP (100 year ARI) regional flood extent data for the Corangamite Catchment Management, which is relevant for the Princes Highway. It is noted that this appears to be the only catchment authority with data in the digital twin, however for the purposes of this pilot, considering the distance from the Calder Highway and Hume Freeway to the coast, this data gap is not expected to impact the conclusions drawn for this pilot study.



Source: [Digital Twin Victoria]

Coastal erosion and shoreline change

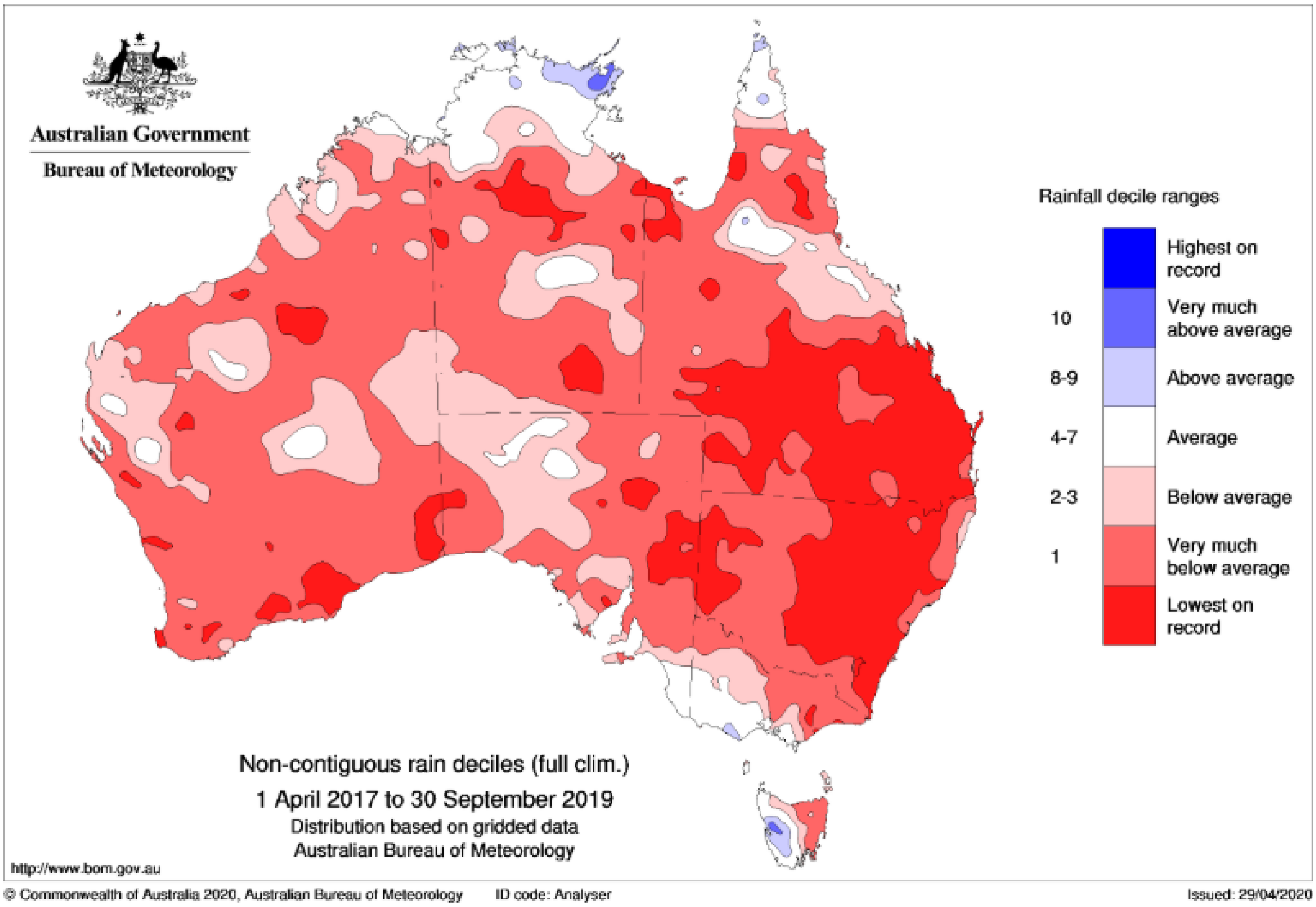
The currently available Digital Twin Victoria shows Seal Level Rise (2040 / 2100) / Storm Surge.



Source: [Digital Twin Victoria]

Drought and changes in aridity

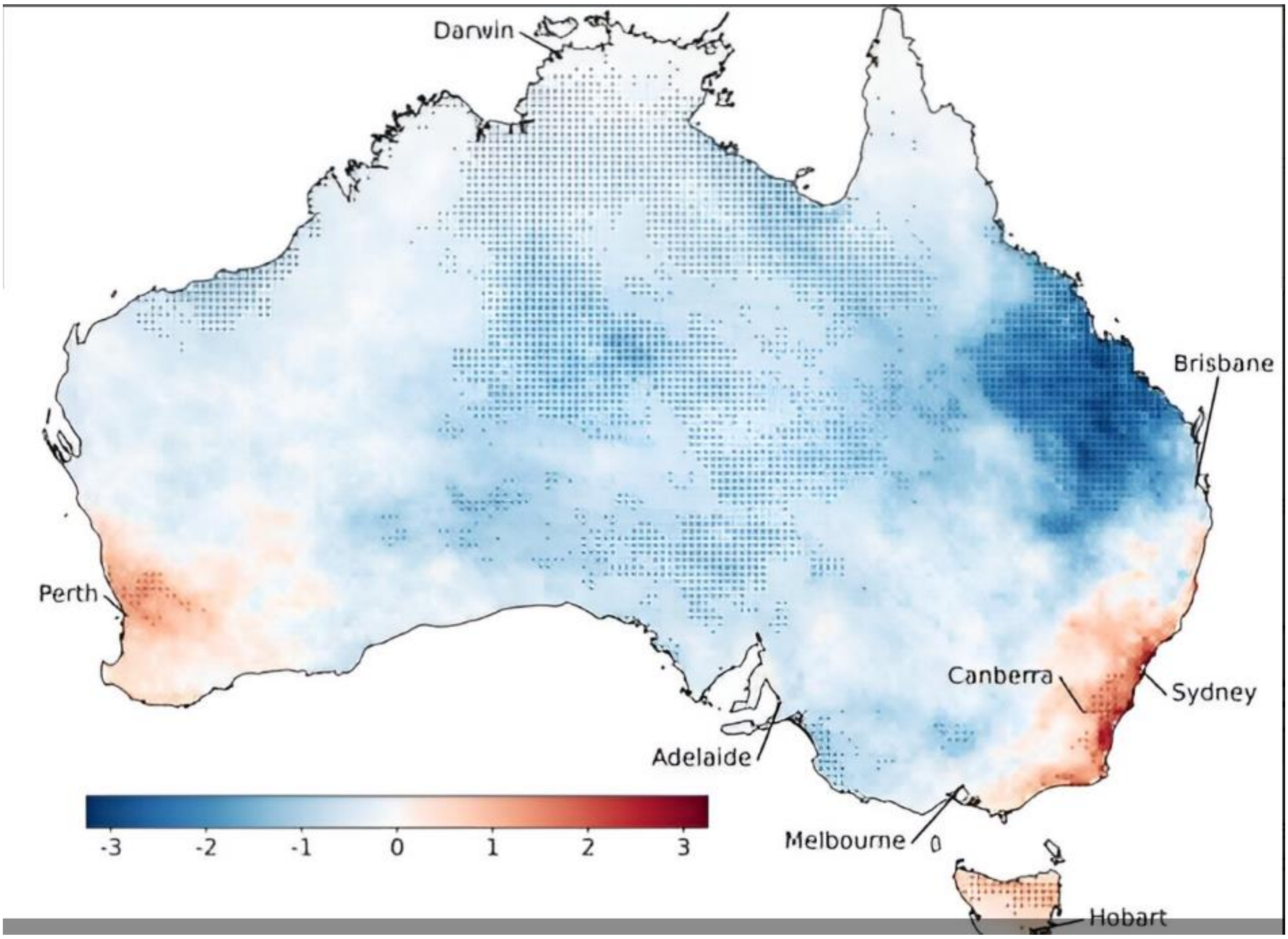
A visual representation of drought was not able to be obtained for this pilot study. The figure below maps the rainfall deciles from 1 April 2017 to 30 September 2019. The source website linked below the image includes similar maps dating back to 1901. The most recent map available (below) was selected for this pilot study.



Source: [Previous droughts]

Storms including hail

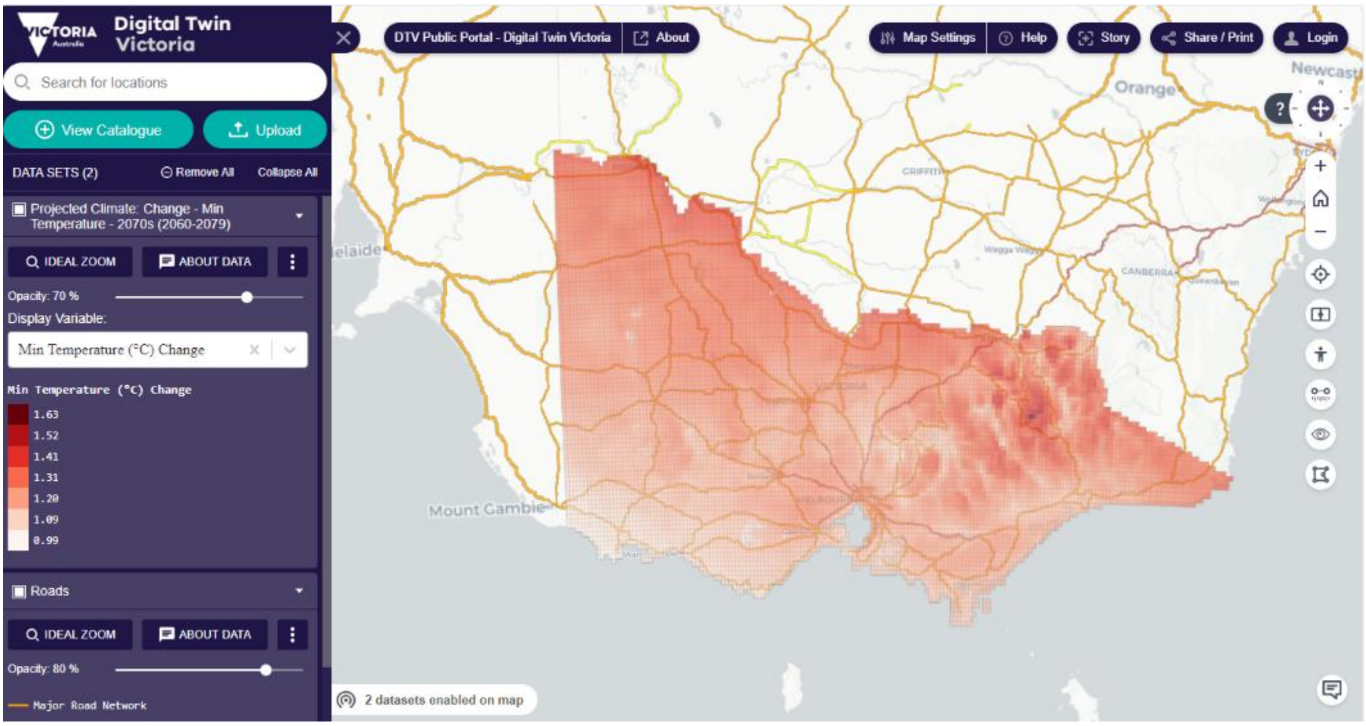
A valuable map showing storm and hail data was not able to be obtained for this pilot study. The image below shows the annual hail-prone days per decade, indicating where incidents of hail storms has increased. It is noted that the timescale for this map is not known.



Source: [Likelihood of hail in Australia has changed substantially over the last four decades]

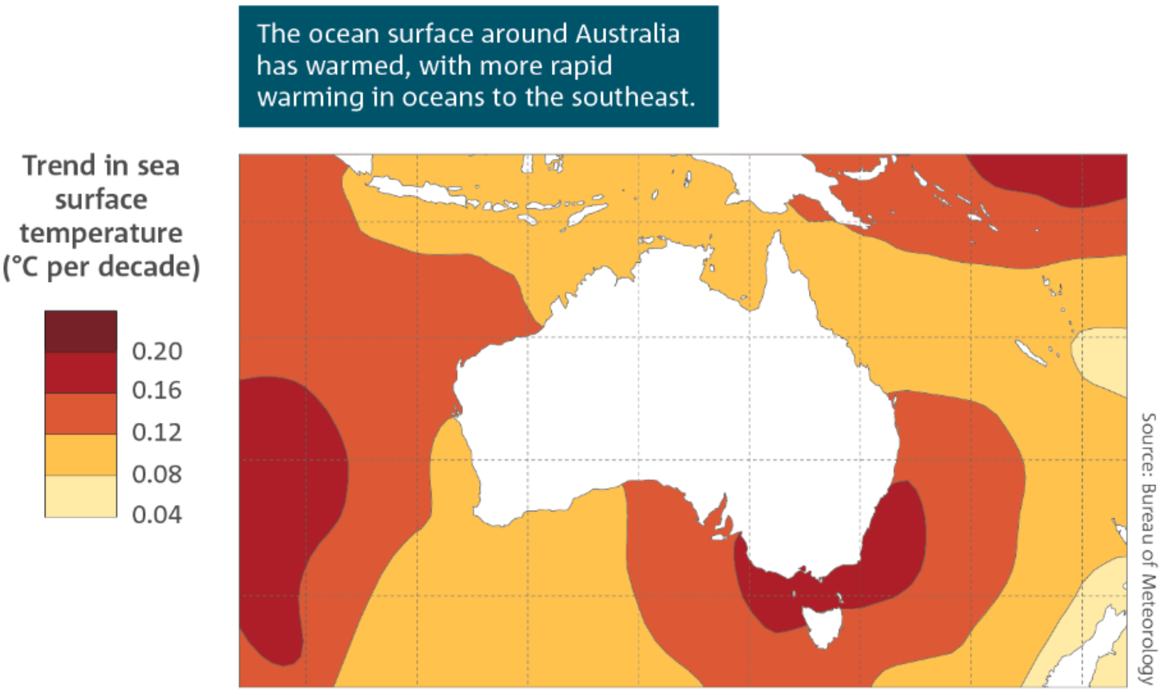
Extreme temperature changes

The current available digital twin includes minimum temperature changes (2030s / 2090s). Below shows the minimum temperature change predicted for the 2070s (2060-2079).



Source: [Digital Twin Victoria]

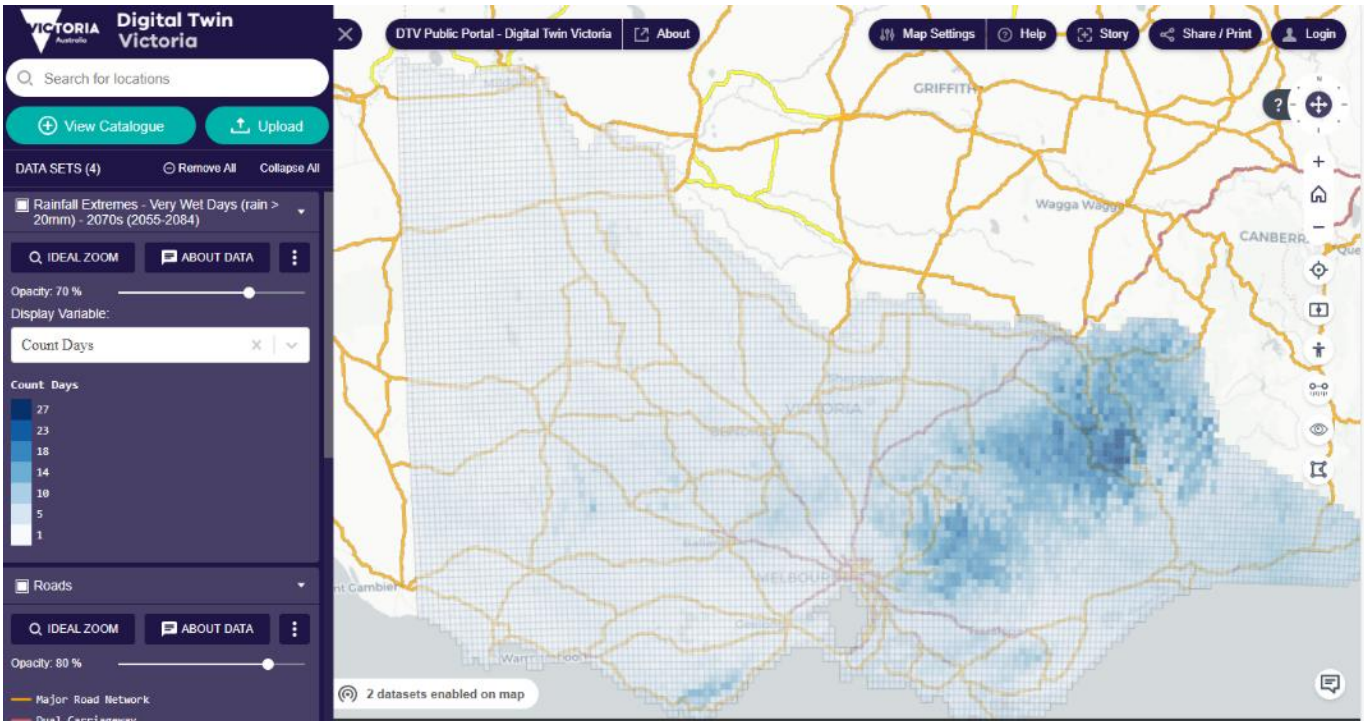
Ocean warming



Source: [State of the Climate 2020: Bureau of Meteorology]

Riverine & Flash flooding

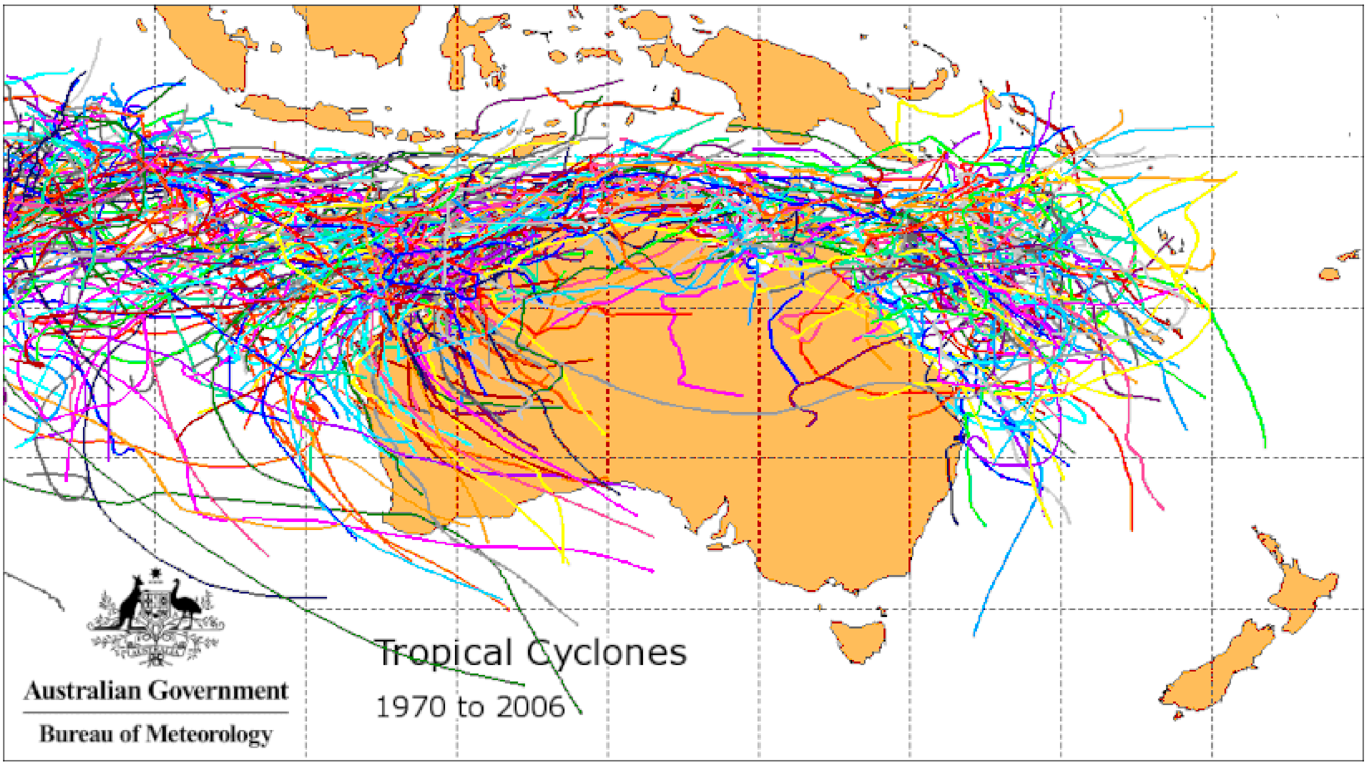
Although a visual representation of potential flood locations across was not able to be located in visual format, the current available digital twin includes rainfall extremes – very wet days (>20mm). Below shows the minimum temperature change predicted for the 2070s (2055-2084).



Source: [Digital Twin Victoria]

It is noted that Floodway, and Land Subject to Inundation overlay mapped information is available from VicPlan for a specific land parcel/property, but could not be extracted for a road network for this pilot application.

Cyclones



Source: Cyclones and East Coast Lows | CoastAdapt

6.4. Evaluate Vulnerability

This section looks at the exposure and sensitivity of the three major roads selected for this pilot study.

Exposure of asset to climate hazards

Climate Hazard	Bushfire	Coastal flooding	Coast erosion	Drought	Storms	Extreme temp.	Ocean warming	Riverine flooding	Cyclone
Princes Hwy	Yes	Yes	No	Yes	Yes	No	No	No	No
Calder Hwy	Yes	No	No	Yes	No	Yes	No	No	No
Hume Fwy	Yes	No	No	Yes	Yes	Yes	No	Yes	No

Overall exposure scale

Level of Exposure		Description
0	**Negligible**	Infrastructure Asset has no likelihood of exposure to climate hazards (now and/or in future)
1	**Low**	Infrastructure Asset has high likelihood of exposure to 1-3 climate hazards (now and/or in future)
2	**Medium**	Infrastructure Asset has high likelihood of exposure to 4-6 climate hazards (now and/or in future)
3	**High**	Infrastructure Asset has high likelihood of exposure to 7-9 climate hazards (now and/or in future)

Based on the above, the following exposure is determined for each of the three roads:

- **Princes Highway:** Medium (2) (exposed to 4 climate hazards now/future).
- **Calder Highway:** Low (1) (exposed to 3 climate hazards now/future).
- **Hume Freeway:** Medium (2) (exposed to 4 climate hazards now/future).

Sensitivity of asset

For the purposes of this assessment in some instances indicative values for the infrastructure assets have been selected to demonstrate the methodology. The data presented below has not been cross-checked with the datasets and data sources for accuracy.

Infrastructure Asset	**Sensitivity Category**			**Overall Sensitivity Score**
	Infrastructure asset condition and age	**BAU Operating Requirements**	**Historical Performance**	
Princes Hwy	Medium (2)	Medium (2)	High (3)	**7**
Calder Hwy	Medium (2)	Low (1)	Medium (2)	**5**
Hume Fwy	Medium (2)	High (3)	High (3)	**8**

Utilising the exposure and sensitivity score for each of the highways, the overall vulnerability can be determined.

Princes Highway

		Sensitivity Score			
Exposure Score		0-2	3-4	5-6	7-9
	3	MEDIUM	HIGH	VERY HIGH	VERY HIGH
	2	LOW	MEDIUM	HIGH	**VERY HIGH**
	1	VERY LOW	LOW	MEDIUM	HIGH
	0	NEGLIGIBLE	VERY LOW	LOW	MEDIUM

Calder Highway

		Sensitivity Score			
Exposure Score		0-2	3-4	5-6	7-9
	3	MEDIUM	HIGH	VERY HIGH	VERY HIGH
	2	LOW	MEDIUM	HIGH	VERY HIGH
	1	VERY LOW	LOW	**MEDIUM**	HIGH
	0	NEGLIGIBLE	VERY LOW	LOW	MEDIUM

Hume Freeway

		Sensitivity Score			
Exposure Score		0-2	3-4	5-6	7-9
	3	MEDIUM	HIGH	VERY HIGH	VERY HIGH
	2	LOW	MEDIUM	HIGH	**VERY HIGH**
	1	VERY LOW	LOW	MEDIUM	HIGH
	0	NEGLIGIBLE	VERY LOW	LOW	MEDIUM

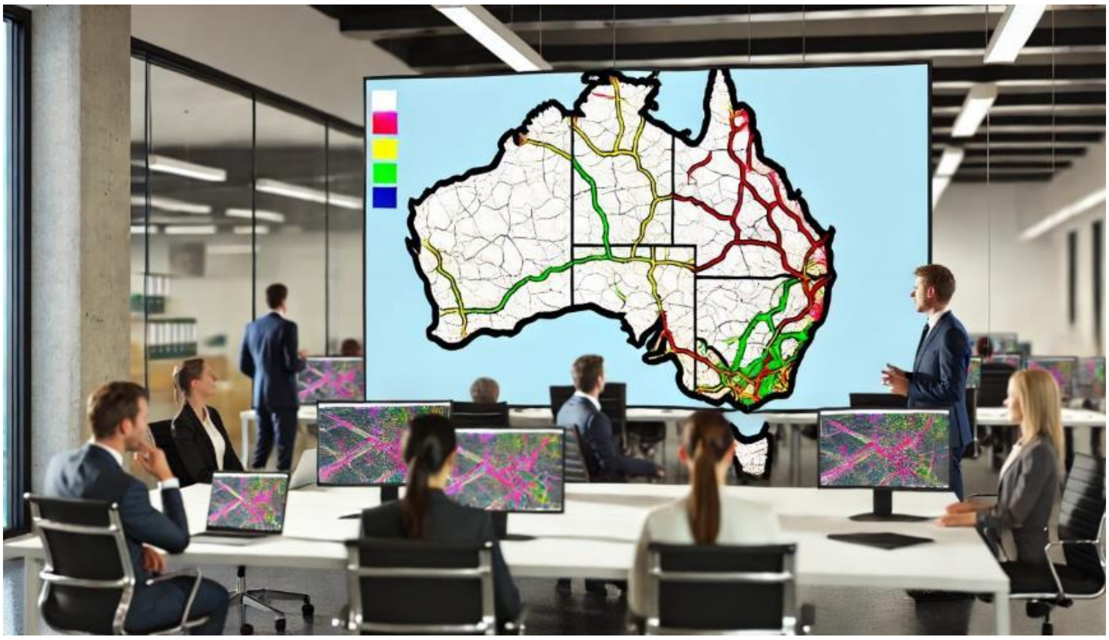
6.5. Outputs

Based on the vulnerability score and the table below, it can be concluded that the Princes Highway and Hume Freeway need immediate attention for resilience investment, whereas the Calder Highway can continue to be tracked to look for any changes in exposure or sensitivity over time.

Vulnerability scoring categories

Vulnerability Score	Description
Very high	Immediate need for resilience investment due to [x, y, z] factors.
High	Priority need for resilience investment due to [x, y, z] factors.
Medium	Track changes to exposure and sensitivity over the short term for changes in Vulnerability score.
Low	Track changes to exposure and sensitivity over the medium term for changes in Vulnerability score.
Very Low	Lowest priority for investment in resilience measures. Track changes to exposure and sensitivity over the long term for changes in Vulnerability score.
Negligible	No need for resilience investment in the short/medium term.

It is anticipated that the overall vulnerability scope would be displayed in the digital twin using a colour-coding / “traffic-light" system. This will further enable Infrastructure Australia to identify clusters of vulnerable assets. An example of what this might look like is shown in the image below.



7. Conclusions and Recommendations

This report presents a framework for assessing the relative risk of climate change to nationally significant infrastructure assets. The framework provides a structured basis to identify critical assets and quantify their vulnerability by considering their exposure and sensitivity to climate hazards.

The proposed framework is designed to utilise advanced tools such as digital twins to simulate real-world conditions and predict vulnerabilities while leveraging AI-driven systems to bridge data gaps and harmonize datasets. Implementing this approach will require significant collaboration among federal, state and local governments as well as private sector stakeholders to address challenges related to data availability and standardisation.

One of the primary challenges to implementing the framework is the inconsistency in available data across different infrastructure asset classes, geographic locations and climate hazards. Data availability varies significantly by region and some asset classes and climate hazards lack the detailed information necessary for comprehensive vulnerability assessments. Overcoming these inconsistencies is critical to developing a reliable framework suitable for assessments on a national scale.

The report's pilot study on Victorian road networks demonstrates the framework's capability to assess the relative vulnerability of infrastructure assets effectively. This methodology could be scaled for use on a national scale and expanded to consider a variety of infrastructure classes.

To facilitate the development of the framework at a national level, the report makes the following key recommendations:

- Developing a unified National Digital Twin to assess the relative risk of climate change to infrastructure assets. This platform should also enable the simulation of climate stressors and intervention measures.
- Expanding existing state-level digital twins into a unified National Digital Twin to provide consistent standardized assessments nationwide.
- Establishing a central climate hazards authority to oversee data collection, ensure uniform climate projections, and maintain a national database.
- Leveraging AI-driven systems to address data gaps, standardize inputs, improve prediction accuracy and enable adaptive learning for evolving climate risks.

By adopting this framework and implementing these recommendations, Infrastructure Australia will be positioned to provide informed, strategic guidance to government bodies. This will ensure that infrastructure investments are not only targeted and effective but also aligned with the pressing need to address the growing risks of climate change.

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