# Climate resilience framework for rail

March 2026

Australasian Railway Association

# Contents

# Executive summary

Australia's rail infrastructure is vulnerable to increasing climate change impacts, including extreme weather events such as floods, bushfires and heatwaves. These disruptions result in significant operational, economic and community costs. The ***climate resilience framework for rail*** has been developed to support rail organisations in strengthening their resilience against these growing risks and to promote long-term stability and reliability across the network.

The framework provides a structured approach to help rail industry organisations:

- Assess and understand climate-related risks and vulnerabilities
- Implement practical, proactive resilience-building measures
- Maintain safe and reliable operations during and after climate events
- Embed resilience thinking into all aspects of business operations

The framework is intended primarily for operators of critical infrastructure under the ***security of critical infrastructure act 2018***, but its guidance is broadly applicable across the rail industry.

The framework is comprised of three key components:

1. **Resilience implementation cycle**
   A continuous five-step process (assess, implement and prepare, action, recovery, review and embed) that guides organisations through planning, response and improvement activities.
2. **The four Rs of resilience**
   - ***Resistance***: strengthening physical infrastructure to withstand hazards
   - ***Redundancy***: providing alternatives and backups to ensure service continuity
   - ***Reliability***: ensuring systems perform under a range of conditions
   - ***Response***: reacting quickly to minimise disruption and restore services
3. **The five pillars of the framework**
   - ***People***: building skills, capability, leadership and culture
   - ***Processes and practices***: embedding resilience into systems and governance
   - ***Assets and operations***: designing, maintaining and managing infrastructure for resilience
   - ***Interactions and interdependencies***: collaborating across industry and supply chains
   - ***Metrics and data***: quantifiable measurements which could be adopted to track progress and success of resilience-building initiatives

The framework aims to:

- Facilitate alignment and consistent national approaches
- Encourage proactive action to reduce risk and disruption
- Support targeted investment in high-impact areas
- Promote collaboration across the rail sector and related industries

While not all climate-related risks can be fully predicted or avoided, organisations can reduce their exposure and improve recovery through planned, strategic action. This framework offers a practical, scalable foundation for embedding resilience as part of business-as-usual operations, contributing to a more robust and future-ready rail network for australia.

# 1. Introduction

Extreme weather and changing climatic conditions have the potential for significant, tangible impact on the rail industry today. Damage and disruptions result in economic and social losses both to the impacted owners and operators, and the wider Australian economy and community which relies on the rail network for the transport and movement of freight and passengers. It is expected that weather events will continue to increase in unpredictability and severity in the coming decades[1], making it essential that the resilience of rail systems be improved.

This framework intends to address this issue by offering a tool to guide rail organisations' strategic thinking and decision making on the topic of climate resilience and identify the fundamental focus areas where consistency across the rail industry will add value for all participants.

Embedding resilience as "business as usual" across operations can lessen the impact of hazards and reduce recovery time. In turn this may prevent or minimise downtime, reducing costs spent on repair and rebuilding, and providing broader social and economic benefits by delivering a stable and reliable transport network to the wider community. This will also lend itself to the promotion of rail as reliable, viable transport alternative to other modes in changing climactic conditions.

The framework is comprised of three key sections:

1. **The resilience implementation cycle** – outlines the continuous cycle of assessment and initiatives for building resilience
2. **The four Rs** – resistance, redundancy, reliability and response, which represent the positive outcomes achievable through resilience-building initiatives
3. **The five pillars of the framework** – resources and suggested approaches for resilience-building in the rail industry

## 1.1 Intent and scope

The framework provides a structured approach to help rail organisations plan and implement actions to prepare for and respond to the impacts of climate change on rail infrastructure and operations. This includes identifying climate-related risks to rail infrastructure and assets, identifying organisational vulnerabilities, developing mitigation strategies to reduce those vulnerabilities, and strengthening capacity to cope with and adapt to challenging situations. It provides a blueprint for rail organisations to protect their assets, maintain operations during periods of disruption and achieve their resilience objectives.

This framework is intended to:

1. **Facilitate alignment** – provide a consistent national approach for the rail industry to streamline resilience planning and minimise duplication of effort across the value chain
2. **Promote action** – encourage proactive action and provide immediate solutions to support rail resilience
3. **Optimise response** – help prioritise investment and resource allocation to the areas where they will have the greatest impact
4. **Foster collaboration** – encourage communication and joint action between stakeholders to improve collective rail resilience

The audience of this framework is intended primarily to be asset owners and operators responsible for critical infrastructure under SOCI 2018[2]. However, it is expected that the advice for people, processes and practices will be highly relevant to most rail organisations.

It is noted that it is not possible to foresee, mitigate or prevent the impacts of all climate hazards or weather events, and it is generally not cost effective to do so, but it is prudent to be prepared for these events as far as is practicable.

1 CSIRO and The Bureau of Meteorology, 2024. State of the Climate 2024. https://www.csiro.au/en/research/environmental-impacts/climate-change/state-of-the-climate

2 The Security of Critical Infrastructure Act 2018 (SOCI Act) outlines legal obligations for those that own, operate, or have direct interests in critical infrastructure assets. https://www.cisc.gov.au/legislation-regulation-and-compliance/soci-act-2018

*Note about document evolution*

Resilience is a multifaceted concept with many overlapping parts. The climate resilience framework in its current form focuses specifically on building resilience to physical, climate-related hazards, and the impact of those hazards on physical infrastructure.

This aims to address the immediate needs of organisations to adapt their resilience strategies to meet rapidly evolving climate conditions. This framework is intended to be expanded upon in the future to capture transition risks more broadly, and the evolving nature of climate risks anticipated long-term. Improving resilience against climate-related risks will inherently improve organisational resilience more broadly.

| Inclusions | Exclusions |
|---|---|
| Extreme weather events | Cybersecurity |
| Heatwaves and temperature change | Personal/individual resilience |
| Rapid-onset disaster – bushfire, flood, tsunami, earthquake, landslide, cyclone | Disease and pandemic |
| Slow-onset disaster – heatwaves, sea-level change, increased rainfall intensity | Broader community and/or city resilience |

# 2. Definitions

The definition of "resilience" in this framework is:

*"The ability of a system, community or society exposed to hazards to resist, absorb, accommodate, adapt to, transform and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions through risk management."*[3]

Within the rail context, this translates to:

*The ability of rail infrastructure systems to withstand, adapt to, and recover from disruptions caused by climate-related shocks and stresses (acute and chronic), by improving resistance, reliability, redundancy and response capability.*

For the purpose of this framework, 'critical infrastructure' is intended to refer to the physical attributes of infrastructure, at risk from impacts of increasing temperatures and extreme weather events.

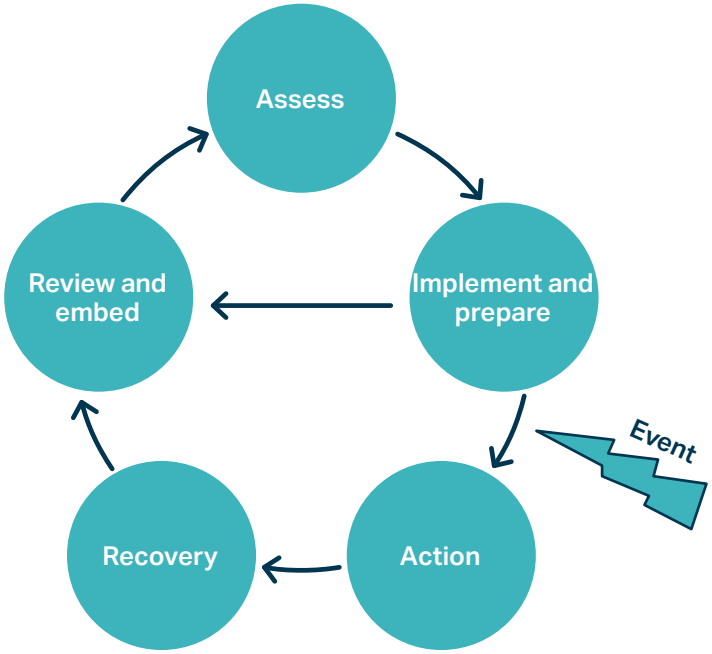
The 2023 critical infrastructure resilience strategy defines critical infrastructure as:

*Those physical facilities, supply chains, information technologies and communication networks, which if destroyed, degraded or rendered unavailable for an extended period, would significantly impact the social or economic wellbeing of the nation, or affect australia's ability to conduct national defence and ensure national security.*


3 This definition was selected in alignment with the NSW State Disaster Risk Mitigation Plan, the National Emergency Management Agency (NEMA), and the United Nations Office for Disaster Risk Reduction (UNDRR).

# 3. Resilience implementation cycle

The figure below outlines a basic cycle for implementing and assessing resilience-building measures in an organisation while encouraging and supporting continuous improvement. The process is intended to be continuous, but the assessment phase should be triggered on a scheduled basis in the absence of an event until the process becomes embedded into business as usual. This could be conducted annually as a starting point, but is adjustable based on individual organisations' needs and capacity.




## 3.1 Assess

- Conduct a baseline assessment of resilience, preparedness and vulnerabilities
- Use the five pillars of the framework to review all aspects of operations
- Prioritise high-risk areas or those where intervention has the greatest impact
- Consider:
    - Timeframes of potential impacts
    - Geographic variability in exposure and vulnerability across operations
- Refer to section 6.1.1 for more information on risk identification

## 3.2 Implement and prepare

- Identify and implement initiatives addressing priority vulnerabilities based on risk assessment outcomes
- Select actions aligned with:
    - Organisational capacity and resources
    - Risk profile
- Train staff on any new resilience systems and processes implemented
- Assign a team to track implementation progress
- For events with forewarning (e.g. cyclones, bushfires, seasonal extremes):
    - Check readiness of people, systems and processes for immediate action
    - Inspect and prepare assets in areas likely to be impacted
- When no events are forecast:
    - Conduct regular check-ins and simulations to maintain preparedness
    - Conduct maintenance and testing of equipment and operability to perform as required during response

## 3.3 Action

- Activate emergency response protocols, or other response procedures relevant to the event severity, immediately when alerted to an event
- Monitor for changing conditions and adapt as needed
- Collaborate with relevant agencies where appropriate
- When safe to do so:
    - Communicate actions and recovery plans with stakeholders
    - Commence preliminary recovery planning to reduce downtime

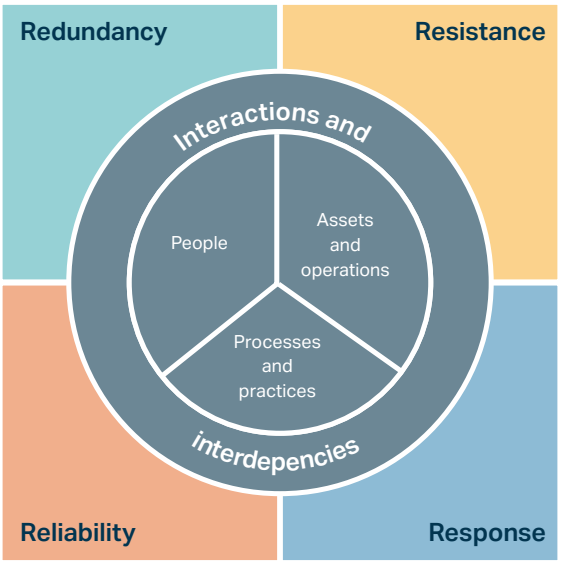
## 3.4 Recovery

- Begin recovery once immediate risks subside
- Assess damage and prioritise recovery of:
    - Critical assets
    - Key network locations
- Use prepared redundancies (such as stockpiled resources or spare assets) where available to resume operations.
- Where rebuilding is needed:
    - Redesign for improved robustness against future events, where feasible
    - Consider upstream and downstream impacts of new designs

## 3.5 Review and embed

- Gather stakeholder feedback on what worked and what didn't, as soon as practicable
- Identify gaps, to enable lessons learned and opportunities for improvement, and communicate learnings with relevant stakeholders, including community members and indigenous partners
- Conduct after action reviews to identify themes and opportunities for improvement, and create action plans for implementation where relevant
- Update:
    - Training
    - Plans and processes
    - Operational practices
- Embed the cycle into:
    - Risk management systems
    - Asset management processes
- Promote a resilience culture through ongoing integration, record-keeping and monitoring

# 4. The climate resilience framework




The framework offers a visual representation of the interconnectedness between the four Rs of embedding resilience. "Interactions and interdependencies" represents the opportunity for collaboration and information sharing between rail organisations and other external stakeholders and agencies, for collective resilience benefiting all.

# 5. The four Rs

The four Rs of resilience[4], below, refers to four complementary facets of resilience that, when taken together, offer a complete picture for attributes of a resilient rail organisation.

**Resistance**

Refers to the physical robustness of an asset and its capacity to withstand the physical impacts of climate-related events

**Redundancy**

Refers to additional network capacity, availability of alternate or diversion routes, access to alternate supply chains, and spare infrastructure, assets or materials which can be utilised when original sources are disrupted

**Reliability**

Refers to the ability of an asset or service to remain operational under a variety of conditions

**Response**

Refers to the ability of assets or systems to respond quickly to identified disruption, and recover to "business as usual" operations as rapidly as possible

4 UK Government, 2011, 'Components of infrastructure resilience', from the Natural Hazards and Infrastructure report. https://www.gov.uk/government/publications/keeping-the-country-running-natural-hazards-and-infrastructure

Resilience in managing and operating critical infrastructure refers to[5]:

- Understanding and minimising risks
- Maintaining service in the face of hazards
- Responding rapidly to a crisis
- Recovering quickly if service is disrupted

| Examples of actions supporting the four Rs | |
|---|---|
| **Resistance** | • Use climate-considerate robust materials and infrastructure designed to resist environmental stresses (e.g. extreme weather, corrosion)<br>• Implement vegetation management along tracks to reduce fire and storm damage risks<br>• Strengthen bridges, tunnels and embankments to endure natural hazards such as floods and earthquakes<br>• Conduct regular maintenance and inspections to identify vulnerabilities early |
| **Redundancy** | • Develop multiple parallel tracks or alternate routing options to maintain service if one route is blocked<br>• Maintain spare locomotives, carriages and critical components to replace failed equipment quickly<br>• Implement duplicate signalling and communication systems to ensure continuous operation<br>• Train staff across multiple roles to allow operational flexibility during disruptions<br>• Consider outsourced roles and services and critical supply chain partners<br>• Establish alternative power sources for critical infrastructure (e.g. backup generators) |
| **Reliability** | • Implement predictive maintenance using IoT sensors and data analytics to prevent unexpected breakdowns<br>• Use advanced scheduling and asset management software to optimise usage and reduce wear<br>• Standardise equipment and procedures to minimise variability and errors<br>• Conduct thorough testing and quality assurance for new technologies and infrastructure<br>• Regularly train operational staff on safety and operational best practices |
| **Response** | • Develop and regularly update comprehensive emergency response plans. Consider external and outsourced services as well as the supply chain<br>• Conduct frequent drills and simulations for various incident scenarios (accidents, extreme weather)<br>• Establish coordination protocols with local emergency services and authorities<br>• Maintain rapid repair teams and pre-position materials near critical points<br>• Use real-time monitoring systems to quickly detect disruptions and mobilise resources efficiently |

5 Department of Home Affairs Cyber and Infrastructure Security Centre. https://www.cisc.gov.au/how-we-support-industry/organisational-resilience/resilience-and-critical-infrastructure

## Case study: Pacific National, the four Rs in response to a flood event

In early July 2022, St Mary's rail line in NSW experienced severe flooding caused by a prolonged heavy rainfall event, exceeding the design assumptions of a 1 in 50 year flood to an unprecedented 1 in 75 year level. This led to the railway culvert and low-lying track being submerged under water.

**Resistance:** The site was constructed with physical robustness in mind, including the design of a culvert and stabilised embankments intended to manage flooding. After the waters receded, inspections found no visible damage, confirming the track and supporting structures withstood the extreme conditions without compromise.

**Redundancy:** The rail layout incorporated low-lying sections designed to serve as deliberate overflow zones. This prevented water from creating a dam effect on embankments, thus preserving overall infrastructure integrity and allowing alternate drainage paths during high water events.

**Reliability:** Despite the flooding, operational safety was quickly assessed and restored. Certified inspectors confirmed the track was safe for service within hours, and prudent speed restrictions were implemented based on water levels to maintain operational continuity and prevent equipment damage.

**Response:** Pacific National's rapid inspection and adaptive operational protocols ensured minimal disruption. Clear guidelines on speed limits and when to halt operations provided safety assurance while allowing the swift return to normal service as conditions improved.

This event underscores how careful engineering design combined with systematic operational controls enables rail infrastructure to resist, adapt to and quickly recover from extreme natural events, ensuring ongoing service resilience for the community.

# 6. The five pillars

The five pillars supporting the framework offer a checklist of potential mechanisms for improving capacity for resilience, organised by relevant business aspects. Each pillar is intended to address a different facet of organisational resilience, although it is noted there is inherent overlap.

1. **Processes and practices** – the systems and policies that underpin daily activities
2. **People** – employee capabilities and organisational culture
3. **Assets and operations** – physical infrastructure and day-to-day business activities
4. **Interactions and interdependencies** — all other organisational aspects which influence or are influenced by entities or actions beyond an individual organisation's operational boundaries
5. **Metrics and data –** quantifiable measurements which could be adopted to track progress and success of resilience-building initiatives

## 6.1 Processes and practices

Processes and practices are the foundation of how an organisation operates day to day. By embedding resilience into these systems, organisations can maintain stability and continuity even during disruption. Clear processes provide consistency, reduce uncertainty, and support quick, coordinated responses when challenges arise.

Resilient practices also help identify risks and vulnerabilities early, allowing for targeted action where it will have the greatest impact. They ensure that lessons from past events are captured and built into future operations, strengthening overall preparedness. Importantly, having resilience built into business-as-usual systems means that resilience is not just an emergency response, but a normal way of working.

Strong processes and practices turn resilience from a one-off effort into an ongoing capability.

The section outlines how to embed resilience into processes and practices.

### 6.1.1 Risk identification

The risk assessment process is one of the most critical steps to adequately assessing operational resilience for an organisation. The risk assessment enables the prioritisation of focus and resources on the most high-risk or high-impact aspects of operations, providing the best value for investment. This can also enable narrowing the scope of assets or operations to be included in adaptation activities, further directing resources to those areas where the value will be highest.

The key metrics for consideration in the risk identification process are:

- Hazards (which unique climate and weather hazards may impact different areas or aspects of operations)
- Criticality (how essential are specific assets and areas to operations)
- Exposure (how vulnerable are specific assets or regions)
- Impact (how significant would experience of a hazard be to a specific asset or region)

**Figure 1** outlines a process by which the most critical and at-risk assets can be identified and filtered for more detailed risk assessment[6]. **Figure 2** provides an example of a risk matrix for determining the level of risk for each identified asset, based on the specific hazard being considered.

6 Figure source: Austroads, 2024. Incorporating Climate Change Resilience in Asset Management. Austroads research report AP-R716-24

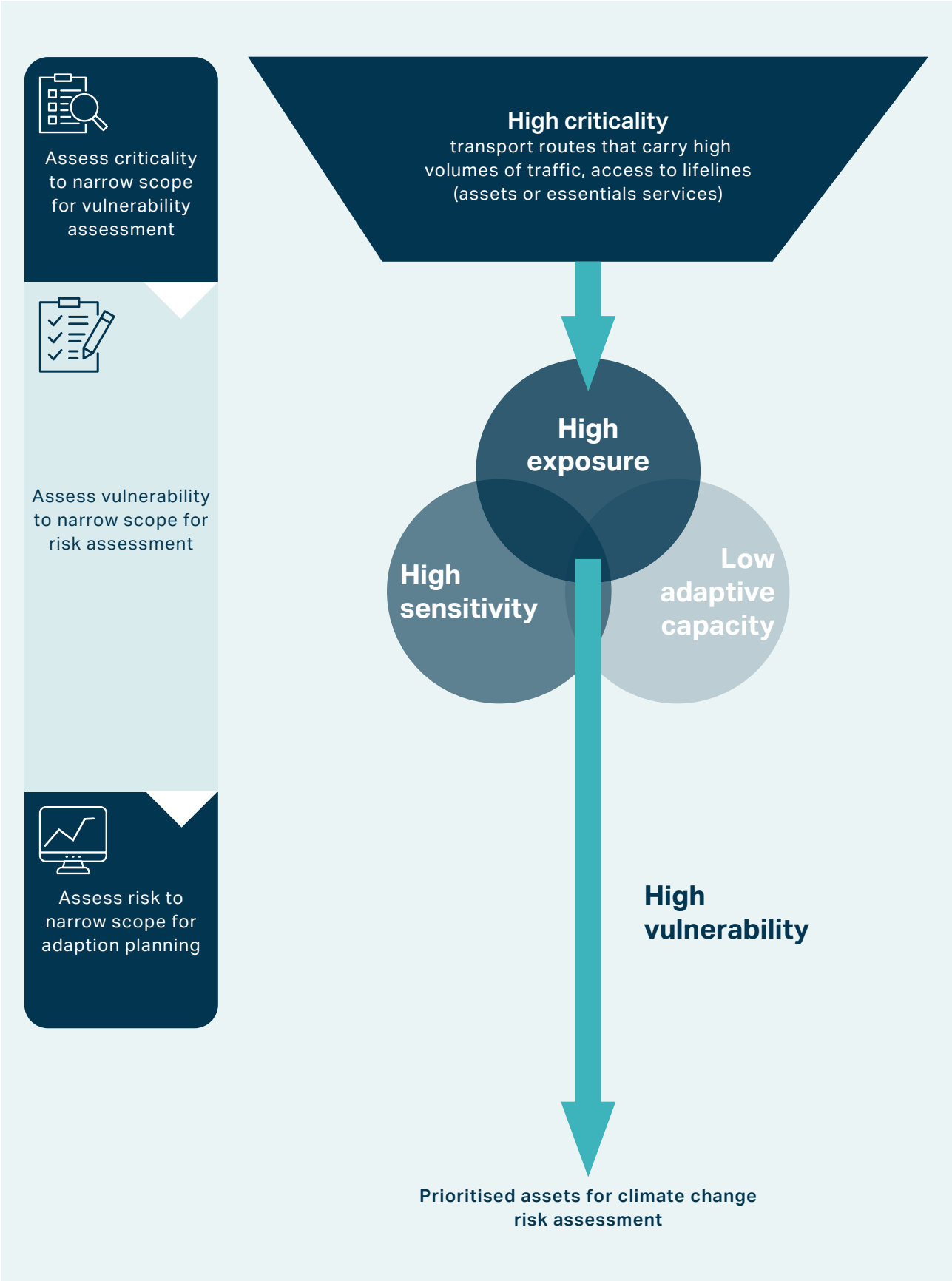



*Figure 1: process to narrow the scope of a risk assessment*

| Risk matrix | | | | |
|---|---|---|---|---|
| **HAZARD**<br>**Probablity of occurance** | **consequence of impact** | | | |
| | Low (1) | Medium (2) | High (3) | Very high (4) |
| **Very low (1)** | Low (1) | Low (2) | Low (3) | Low (4) |
| **Low (2)** | Low (2) | Low (4) | Medium (6) | Medium (8) |
| **Medium (3)** | Low (3) | Medium (6) | Medium (9) | High (12) |
| **High (4)** | Low (4) | Medium (8) | High (12) | Very high (16) |
| **Very high (5)** | Medium (5) | High (10) | Very high (15) | Very high (20) |

*Figure 2: Example of a basic risk matrix*

| Risk identification | |
|---|---|
| **Resistance** | Conduct a risk assessment for specific hazards and vulnerabilities relevant to the organisation or operations. Include mandatory consideration of climate-related risk as part of the assessment process. |
| | Identify critical infrastructure, such as key bridges, culverts, tunnels, signalling hubs and track sections where a failure during an extreme event could cause widespread network disruption. |
| | Conduct modelling to predict relevant risks, such as flooding, stormwater, coastal erosion, coastal inundation, extreme heat and landslide. |
| | Utilise scenario planning to map long-term projections of climate impact. |
| | Engage widely across the organisation when conducting the risk assessment, to capture the breadth of exposure at different parts of the business. |
| | Regularly review and adapt the risk assessment and risk management frameworks as necessary. |
| | Where the network or extent of operations is large, utilise the hazard/vulnerability assessment to narrow the scope of focus to those areas and assets deemed most at risk. |
| **Reliability** | Develop risk registers of various types (e.g. hazard location register). |
| | Review historical maintenance records, incident reports and operational data to identify patterns of resilience-related failure for assets or equipment. |
| | Assess the risks associated with current maintenance practices, including the potential for the lack of qualified personnel at critical recovery times. |
| | Develop a structured assurance program to ensure that risks are being effectively addressed and the compliance obligations being met. |
| **Redundancy** | Evaluate the capacity, operational readiness and constraints of alternative rail lines, and other alternate transport modes. |
| | Identify dependencies on single suppliers for critical spare parts, materials, recovery equipment and human resources. Assess the risks of disruption to these supply chains and plan for alternative procurement sources. |
| **Response** | Conduct a critical review of existing emergency response plans to identify potential gaps or weaknesses. |

## Case study: Climate change risk assessment at Inland Rail

Consideration of climate change now and into the future is increasingly important in the development of safe, resilient, financially sustainable and reliable infrastructure.

This climate change risk assessment was conducted to evaluate the potential impacts of climate change on a section of inland rail. It aligned with the Infrastructure Sustainability Council (ISC) v1.2 Requirements for cli-1 and cli-2 credits and supported national and state climate adaptation strategies.

The approach included the following steps:

| | |
|---|---|
| **Asset description** | Provide details on scope and key components of the Project being assessed. |
| **Climate context and climate projections analysis** | Based on the identified historical and ongoing climate variable, consider relevant hazards to the project. |
| **Project screening** | Based on the identified historical and ongoing climate variable, consider relevant hazards to the project. |
| **Risk** | Detail the risk to the project based upon the identified hazard, this includes determining the direct and indirect risks to the project. |
| **Existing risk controls** | Identify relevant existing controls to minimise the climate risk to the project. |
| **Risk rating** | Identify the relevant risk rating based on the Consequences and Likelihood on a minimum of two time horizons. |
| **Adaption identification** | Identify adaptions that are beyond current BAU or legislative practices to minimise risks. |
| **Residual risk rating** | Reassess the risk ratings on the minimum two time horizons (2030 and 2090) based on the additional adaptions, controls and measures to minimise, mitigate or adapt to the identified risks. |
| **Report, monitor, review** | Share findings with different stakeholders, including integrating adaptions into relevant documentation for execution and monitoring. This report does not detail the monitoring or review process however, it is advised that this is adopted to continued consideration of climate risk on the project as well as effective adoption of relevant adaptions especially during operation and maintenance phases. |

The climate projections were based on CSIRO, Bureau of Meteorology and NARCliM models, using the rcp 8.5 Scenario (high emissions trajectory), with two time horizons assessed:

- Near-term (2030): 2020–2039
- Long-term (2090): 2080–2100

A total of 38 climate-related risks were assessed:

- 21 direct, 13 indirect, and four combined risks, including:
- Extreme rainfall and flooding
- Increased bushfire likelihood
- Higher temperatures affecting track integrity
- All high risks and 70 per cent of medium risks were treated effectively

### Adaptation measures

The key adaptation measures identified through the ccra were designed to address both direct and indirect climate risks across the project lifecycle. While the full list of adaptations is detailed in an appendix (risk register), the overarching strategies are:

1. **Design modifications**
    - Elevating infrastructure to reduce flood risk
    - Using heat-resistant materials to prevent track buckling
    - Designing drainage systems to handle increased rainfall intensity
2. **Construction phase adaptations**
    - Scheduling works to avoid peak fire and flood seasons
    - Implementing erosion and sediment control measures during extreme weather
3. **Operational strategies**
    - Monitoring systems for early detection of heat stress on tracks
    - Monitoring systems for real time flooding conditions
    - Emergency response protocols for bushfire and flood events
4. **Maintenance planning**
    - Increased inspection frequency during high-risk periods (e.g. summer for bushfires)
    - Proactive vegetation management to reduce fire fuel loads
5. **Stakeholder engagement**
    - Collaboration with emergency services and local councils to align response plans
    - Ongoing consultation with indigenous communities to integrate traditional knowledge
6. **Policy and governance**
    - Embedding climate risk into asset management and procurement processes
    - Aligning with isc cli-1 and cli-2 level 3 requirements to ensure no high or extreme residual risks remain
7. **Monitoring and review**
    - Regular updates to the risk register based on new climate data
    - Adaptive management approach to refine measures over time

These adaptations were developed through two stakeholder workshops and additional expert consultations. They successfully reduced all high risks and 70 per cent of medium risks across both 2030 and 2090 time horizons.

### 6.1.2 Tools

Tools offer an avenue for preparedness by establishing plans and processes for how to assess the value of resilience, or how to act in the event of exposure to a climate hazard. Following the steps set out in these tools can reduce stress and empower employees to feel confident in their actions. Tools can also include physical assets or software systems which contribute to resilience efforts.

| | Tools |
|---|---|
| **Resistance** | Establish or update a Business Continuity Plan based on the outcomes of risk assessments and hazard modelling. |
| **Redundancy** | Establish or update a Business Impact Analysis to adequately assign value to resilience activities and the cost of not preparing or responding. |
| | Invest in and utilise technology and innovations to support resilience initiatives. For example: drones for monitoring land changes and water accumulation; GIS systems for mapping risk areas and impacts; Internet of Things sensors to monitor stress, vibration, temperature, moisture, etc; digital twins for scenario planning and predictive maintenance; early warning systems for monitoring and alerts. |
| | Invest in modelling tools for risk identification and hazard prediction. For example, climate modelling, hydrology and flood modelling, bushfire modelling, etc. |
| | Consider network modelling software that allows planners to map out the network and simulate disruptions. These tools identify potential vulnerable locations and help in planning and optimising alternative routes, enabling the pre-positioning of materials and resources, e.g. ballast and quarry material. |
| | Identify single point of failure items and have spares or alternative options available such as uninterrupted power supplies or generators to ensure operations can continue. |
| **Reliability** | Establish or update an Emergency Response Management Plan, including what to do in the event that safety inputs fail. |
| **Response** | Establish or update a communications tree, to spread awareness of a hazard or an event rapidly, enabling targeted and immediate action by relevant personnel and accounting for safety and whereabouts of employees. Consider extending communications to include customers, community stakeholders and indigenous partners, or other external stakeholders as necessary. |
| | Establish an Incident Management Team with dedicated roles and responsibilities to be enacted in the event of an incident. For example, Incident Controller, Logistics Officer, Operations Chief, Safety Officer, Media and Communications Lead, etc. |
| | Investigate asset management software (AMS) that provides a holistic view of all assets, their condition and maintenance history. An AMS helps optimise maintenance schedules for high risk locations and manage material, parts and equipment inventories used for rapid recovery situations. |
| | Where relevant, consider real-time monitoring and alarm management systems that aggregate data from various sources (weather forecasts, train movements, in-field weather stations readings) to provide a single, real-time view of the network's status. This allows operators to quickly detect a disruption, assess its impact, manage train movements and mobilise resources. |

### 6.1.3 Governance, systems and policies

An organisation's policies and governance structure provide the backbone which supports day-to-day operations, and thus provides a key opportunity to embed resilience as an accepted part of corporate culture. This includes budgeting adequate financial resources for long-term resilience, both for adaptations and upgrades, as well as anticipating recovery and rebuild costs for physical infrastructure impacted. It is important that the benefits of investment in resilience are appropriately quantified to capture the cost savings from avoided climate-related disruptions.

It is noted that some organisations will be impacted by external governance, such as those covered by regulatory protections for cost recovery from climate-related events.

| Governance, systems and policies | |
|---|---|
| **Resistance** | Financial allocation to resilience: embed dedicated financing for resilience activities into long-term budgets, including allocations to "build back better" into repair budgets. |
| | Review Asset Management Plans to check for resilience, including embedding climate-related risk considerations in procurement and end-of-lifecycle disposal. Consider building resilience into the Asset Management Framework, so the effect cascades through asset planning, funding, design, construction, operation, maintenance, renewal and replacement. |
| | Enshrine resilience and climate-related risk management, hazard assessments and resilience-based design standards into corporate policies. |
| | Include consideration of climate-related risk as a requirement to inform major capital investment decisions. |
| | Use sustainability and climate KPIs to drive general performance uplift and/or incentivise resilience actions for executives. |
| | Establish dedicated timeframes to regularly review and amend strategies and policies so they remain fit-for-purpose and flexible to include newly identified risks. |
| | Establish resilience-informed design standards. This should require all new infrastructure and asset upgrades to include mandatory resilience requirements, ensuring they are built to resist specific climate hazards like extreme heat, flooding or high winds. |
| | Establish asset management policies that require regular risk-based and/or pre-seasonal inspections and condition assessments of all infrastructure. |
| **Redundancy** | Consider implementing a formal policy that requires the development and maintenance of alternative routes and operational plans for critical corridors. This policy ensures that the network is not solely reliant on a single path and that alternative routes are regularly assessed to be operationally ready. |
| | Develop policies for maintaining strategic stockpiles of critical equipment, spare parts and materials. |
| | Create systems to track and analyse resilience based performance data against key performance indicators (KPIs). |
| **Response** | Develop an emergency management framework that defines clear roles, responsibilities and communication protocols for various incident scenarios. Regularly review and test the appropriateness of the framework, including the use of drills and simulations. |
| | Establish financial policies that pre-authorise spending and allocate emergency funds for rapid recovery operations to remove hurdles and allows for the immediate mobilisation of resources to repair damage and restore service as quickly as possible. |
| | Develop formal policies for communicating with external stakeholders, including customers, indigenous partners, community members, government agencies, emergency services during a crisis. |

There are a range of policy documents that can directly address resilience, for example, a climate risk assessment, but the opportunity to embed resilience within adjacent policies or standard business-as-usual documents should not be overlooked. For example, some common policies with the potential to strengthen an organisation's resilience include:

| | |
|---|---|
| • Safety Management Plan | • Corporate Resilience Policy |
| • Risk Management Procedure | • Adverse Weather Working Conditions Procedure |
| • Risk Register | • Extreme Weather Training guidelines and manuals |
| • Business Continuity Procedure | • Weather Monitoring Strategy |
| • Emergency Management Procedure | • Rail Safety Acts and Regulations |
| • Climate Risk Assessments | • Risk Appetite Statement |
| • Asset Resilience Strategy | • Climate Adaptation Plan |

## 6.2 People

People are at the core of an organisation's resilience. Business continuity relies on employees' ability to adapt and respond effectively when circumstances change. Frontline workers, who often experience disruptions most directly, bring critical insights into risks, vulnerabilities and practical solutions that may be overlooked elsewhere.

When employees are trained, equipped and empowered, disruptions have less impact and recovery is faster. Encouraging staff to actively engage in resilience practices fosters shared responsibility, sparks innovative ideas, and strengthens resilience strategies. Ultimately, engaged people don't just follow resilience processes — they help create and sustain a culture of resilience across the organisation.

This section outlines how to embed resilience into *people*.

### 6.2.1 Capability building

Building employee capability improves both confidence and competence to react effectively and appropriately to climate hazards. By empowering team members to feel confident in the systems and processes that underpin their roles, they will be able to respond and communicate effectively, offer advice and lessons learnt to improve processes and risk identification post-event, and propagate the culture of resilience across the business to both internal and external stakeholders.

| Capability building | |
|---|---|
| **Resistance** | Integrate resilience training relevant to specific roles: technical, operational and strategic. |
| **Reliability** | Collaborate and share resources across the industry. |
| **Redundancy** | Implement a program to cross-train employees across different roles, teams and locations to minimise the risk of a key person being unavailable during a disruption. |
| | Establish and train dedicated crisis leadership teams composed of staff from various functions who will be responsible for activating and managing all rail operations, including use of alternative routes, coordinating the use of spare materials, critical spare parts and communicating effectively during a disruption. |
| **Response** | Provide specialised training for staff on how to prepare for and mitigate the effects of specific hazards. |
| | Conduct training and simulation exercises to validate response processes for suitability and develop staff awareness and confidence. |

### 6.2.2 Leadership

Investment in resilience inherently competes with other business priorities for resources and attention. Resilience leadership sets the stage for the rest of the team to follow. Visible leadership commitments can empower employees to engage with the resilience process and inspire innovative thinking. By assigning appropriate value to resilience, it can be positioned correctly as a key aspect of decision making.

| Leadership | |
|---|---|
| **Resistance** | Understand the business case for rail resilience, and promote it at the executive level. |
| **Response** | Take a top-down approach to resilience so that the prioritisation of resilience comes from the top. |
| | Nominate designated resilience "champions" within the organisation. Leaders can be seen demonstrating a culture of innovation and collaboration. |
| | Engage the Board and Executive leadership teams with resilience plans and policies. |
| | Share practices and policies to demonstrate the organisation's position and provide information to others. This can take a public forum, such as a corporate webpage, or via communication and collaboration with industry peers in a closed forum, such as the ARA's Resilience Working Group. |

### 6.2.3 Culture

Once resilience is truly enmeshed as an aspect of organisational culture, capacity to respond and recover from hazards or climate events will improve.

| | Culture |
|---|---|
| **Resistance** | Embed resilience as an organisational priority, and communicate it internally as such. |
| **Response** | Incentivise innovation, creative thinking and taking a proactive approach to risk – empower employees to share their ideas and suggestions, and showcase case studies to promote best practice. |
| **Resistance** | Empower all employees, particularly field-based maintenance staff, to proactively identify and report network vulnerabilities that are not part of routine asset defect reporting. This includes identifying broader risks such as high-risk flood locations, material degradation or vegetation overgrowth that could contribute to fire or storm risks. |
| **All** | Build a culture that encourages employees to think and act flexibly during a crisis. Empower staff to make on-the-ground decisions to overcome immediate challenges and keep the network operational. |
| | Create an environment where learning from failures is encouraged, not punished. By fostering a blame-free culture around incidents, employees feel empowered to share insights and improve systems, which leads to greater long-term resilience improvements. |

## Case study: Kiwirail keeping people safe through the use of severe weather event management frameworks

Kiwirail uses severe weather event management frameworks to keep their staff and customers safe. Operational and infrastructure teams actively monitor weather forecasts and receive specialised advice from forecasters. If risky conditions are forecast, senior leaders will decide in advance whether services should be cancelled.

Kiwirail has remote sensors in place at high-risk locations such as the buller gorge and arthurs pass to monitor hazards such as rainfall, snow fall or rock movements. If hazards exceed acceptable risk thresholds, train services are delayed or cancelled.

Kiwirail's interislander ferry team use a wide range of weather modelling data and forecasts to make sailing decisions. If swells are forecast to be unsafe for vessels, services will be cancelled and passengers and freight rebooked on the next possible ferry.

*Figure 3: A freight train impacted by a landslide in bullers gorge*

## 6.3 Assets and operations

Physical assets are the backbone of operations, and strengthening them, or designing for rapid repair, serves to directly reduce the impact of shocks and disruptions. Well-designed and maintained infrastructure can withstand extreme conditions, keeping services running and limiting costly downtime, repairs or rebuilding.

Because improvements to physical infrastructure are visible and tangible, they also make the benefits of resilience easier to demonstrate. This visibility can help secure organisational and community support for resilience initiatives, while ensuring that critical operations remain robust in the face of future challenges.

The section outlines how to embed resilience into *assets and operations*.

### 6.3.1 Asset management

Asset management involves the system of planning, design, maintenance and operation across the entire lifecycle of an asset. Effective asset management planning offers a key opportunity to embed resilience within the physical infrastructure of an operation, with long-term benefits. It is critical that the outcomes of the risk assessment process and scenario planning be carefully considered and data-informed so that the asset management systems can proactively consider future risk profiles.

| | **Asset management** |
|---|---|
| **Resistance** | Conduct regular resilience focused reviews of the network and assets to identify vulnerabilities in existing infrastructure and corridors. Utilise outcomes from these risk assessments to inform the asset management lifecycle and to prioritise and fund the retrofitting of critical assets and tracks to resist natural hazards. |
| | Measure and evaluate the impacts of climate change across an asset's lifecycle to inform future design considerations. |
| | Utilise high-level risk assessment to identify which assets and areas to prioritise, then analyse local conditions to identify how climate changes might impact specific assets. |
| **Reliability** | Assess against a range of scenarios and models such as:<br>- climate models to predict how networks and assets will perform under different future climate scenarios<br>- rail simulation software to test how the network will perform under various operational loads and disruptive events and analyse the potential consequences |
| | Use a predictive risk-based maintenance model in lieu of a time-based or reactive model. Use Internet of Things sensors and data analytics to monitor the condition of assets in real-time and predict when maintenance is needed, preventing unexpected breakdowns. |
| **Redundancy** | Identify and manage alternate routing options for critical sections of the network allowing for service continuation if one route is blocked due to a disruption. |
| | Keep an inventory of spare critical assets, components and materials to allow for rapid replacement of failed equipment. |
| | Install duplicate signalling, power and communication systems at key network nodes. This redundancy ensures that critical operational functions remain available even if a primary system is compromised. |
| **Response** | Pre-position critical assets, and materials such as sleepers and ballast, at strategic locations allowing for improved recovery times. |
| | Deploy real-time monitoring systems that can quickly detect network risks and disruptions and provide real-time situational awareness. |
| | Invest in specialised equipment and train teams in efficient repair and recovery methodologies to minimise service restoration following a disruptive event. |

### 6.3.2 Design

Given the inherently long lifecycle of assets such as infrastructure or rollingstock, climate resilience measures considered during the design phase can provide long-term flow on effects throughout the asset's life. However, this requires considering the specific risks and hazards identified as relevant today may not be the same hazards impacting assets in 10-20 years' time. Adequate scenario planning can help address this risk by identifying predictions for future weather conditions assets will need to be resilient against.

| Design | |
|---|---|
| **Resistance** | Regularly update design standards to align with company resilience policy. This will ensure all new assets and upgrades are built to withstand specific climate hazards like extreme heat, flooding and high winds. |
| | Harden assets to improve their ability to withstand extreme weather events such as reinforcing embankments, upgrading culverts to handle higher water flow, or ensuring that ballast can freely drain. |
| **Redundancy** | Design redundancies and resistances into all new assets and critical sections, taking into account specifics identified during risk assessment or scenario modelling. |
| **Reliability** | Use standardised or pre-prepared designs for assets, using modular designs and easily sourced components to enable rapid recovery and promote redundancy. |
| **Response** | Consider climate resilience inclusions when completing design safety checks. |
| | Integrate sensors and other smart technologies into asset design to enable real-time monitoring and data collection from the start, allowing for a proactive, data-driven approach to maintenance and increased long-term reliability. |
| | Design assets that facilitate rapid repair and restoration after an incident. This could include using pre-fabricated/modular components or ensuring easy maintenance and inspection access and access for heavy equipment. |

### 6.3.3 Maintenance

Proactive inspection and maintenance of physical assets can help identify and resolve potential issues before they become critical or disruptive to operations. Well-maintained infrastructure is more resilient to sudden shocks to the system and more capable of adapting to stressors. Additional preventative maintenance, in addition to routine checks and fixes, can reduce operating costs in the long-term by decreasing the risk of unexpected shutdown or more substantial repairs, and improve operating efficiency.

| Maintenance | |
|---|---|
| **Resistance** | Embed preventative maintenance above and beyond minimum requirements for asset operation. |
| | Ensure maintenance schedule is adequate to meet the needs and risk level identified in the climate risk assessment. |
| | Prioritise inspections and maintenance on assets most vulnerable to climate hazards, such as bridges in flood zones or tracks in areas prone to landslides. This targeted approach ensures that resources are allocated to where they are needed most. |
| **Redundancy** | Implement a maintenance-based system for managing critical spare parts and components, including procurement and conducting regular inventory checks to ensure they are in good condition and can be deployed quickly. |
| | Proactively maintain backup power generators, secondary communication lines, and other redundant systems to ensure they are operational when required. |
| **Reliability** | Shift maintenance standards from time-based to condition-based using data from in-field sensors and monitoring systems to predict when assets need maintenance. |
| | Utilise automated inspection systems such a drones, inspection vehicles with recording devices such as LIDAR, accelerometers etc and perform frequent, detailed checks of assets. |
| **Response** | Use preventative maintenance data to inform future design. |
| | After a disruptive event, include maintenance-focused analysis in the lessons learned processes. Document what worked and what didn't and use those lessons to refine maintenance protocols and improve future response and recovery efforts. |

### 6.3.4 Operations

When resilience is truly embedded within an organisation, it may not be obvious within day-to-day operations, as the systems, processes and teams which underpin the operations are running as they should. In the face of climate hazards or sudden shocks, however, the training, protocols and redundancies will show their value, keeping disruptions to the network as limited as possible.

| Operations | |
|---|---|
| **Resistance** | Regularly monitor operations for improvement opportunities. |
| **Reliability** | Utilise real-time and predictive weather monitoring systems at critical locations for risk identification and better decision-making during weather events. For example, flood gauges, temperature sensors, cameras, wind/weather stations, etc. |
| | Track and measure how assets and systems perform under stress conditions, to inform future design and process development. |
| | Improve network capacity to meet modelled future demand, including potential demand surges during extreme weather events. |
| **Redundancy** | Target asset redundancies at key locations where the risk identification process has indicated the highest risk of disruption. |
| **Response** | Stockpile critical materials and resources and position response teams at a range of strategic locations across the network, both trackside and depots, to ensure access in the event of a disruption to the transport network. |

### Case study: Kiwirail Midland River protection works

Between 2022 and 2024, Kiwirail delivered a major project to enhance the resilience of the midland line against river erosion. The project, with an approximate budget of $15 million, involved risk assessment, implementation of river protection works and the strategic stockpiling of materials to support future rapid-response efforts.

The assessment involved categorising sections of the midland line adjacent to major rivers on both sides of the southern alps into risk profiles. For each section identified as having erosion potential, tailored mitigation strategies were proposed. These ranged from increased monitoring to the design of physical river protection measures such as riprap-armoured embankments and groynes. All solutions incorporated projections of future climate change impacts.

By 2024, river protection works at high-risk locations were successfully implemented. In addition, surplus riprap material was stockpiled to ensure Kiwirail can quickly respond to evolving risk profiles, particularly following major flood events. As of mid-2025, there have been no significant incidents related to river erosion along the midland line.

## 6.4 Interactions and interdependencies

Interactions and interdependencies sit between and across all other resilience pillars. No organisation operates in isolation, and resilience efforts can create a positive flow-on effect across supply chains and communities. At the same time, external resilience (or lack of it) can significantly impact internal operations.

Interdependencies also include opportunities for collaboration and knowledge sharing. Many organisations face similar risks, from regional weather patterns to shared infrastructure or business models. By working together, organisations can share solutions, reduce duplicated effort and achieve stronger resilience outcomes.

Aligning resilience strategies where risks overlap promotes consistency, reduces confusion and builds collective capacity. Looking across value chains and supply chains can reveal opportunities for redundancies and mutual support, identifying vulnerabilities and ensuring these don't place the whole system at risk. Strengthening resilience through collaboration not only lowers the burden on individual organisations but also improves the resilience of the entire network.

This section outlines how to embed resilience into *interactions and interdependencies.*

### 6.4.1 Value chain

The value and supply chains encompass the breadth of organisations, as well as activities which fall outside of a business' direct control. However, these organisations still provide significant opportunity to enhance resilience within individual operations. Where the value chain can be reinforced to withstand disruptions, or redundancies introduced to offer alternatives in the event of disruption to primary supply, operations will be more capable of maintaining business-as-usual during an extreme weather event.

| Value chain | |
|---|---|
| **Redundancy** | Conduct detailed mapping of the supply chain to identify vulnerabilities and note where adding redundancy could reduce risk. |
| | Expand the above mapping to include connections between external entities. This can include other rail industry members, as well as utility providers (for example, telecoms or electricity supply) to identify shared exposures and vulnerabilities where resilience would benefit all entities. |
| | Use a diverse range of suppliers for critical equipment, spare parts, materials and resources to mitigates the risk of a single supplier failure causing a network-wide shortage. |
| | Work with suppliers for them to maintain a strategic stockpile of critical parts and equipment. |
| **Resistance** | Collaborate across industry to identify where value chains overlap and resilience practices can be shared. |
| | Work with key supply chain providers to help them improve their own resilience. This might involve setting minimum resilience standards in contracts or collaborating on risk assessments to identify shared vulnerabilities. |
| **Reliability** | Create platforms or agreements to share real-time data on risks and performance with key partners in the value chain. |
| **Response** | Establish agreements with other RIMs or similarly aligned organisations to provide mutual support during a crisis. This could include sharing spare parts, maintenance crews or operational resources. |

### 6.4.2 Response processes

Response processes encompass the plans and practices which are to be enacted in the event of extreme weather. While exact process may be unique to an organisation, there is opportunity for collaboration with the wider industry and relevant stakeholders to align processes for better effect.

| Response processes | |
|---|---|
| **Reliability** | Identify areas where emergency management plans or systems overlap and could be shared in the event of a hazard occurring. |
| **Response** | Collaborate on emergency response practices and large-scale training and exercises (simulations). |
| | Implement plans to rapidly re-route assets in high-risk areas in event of disruption. |
| | Consider reviewing any existing governance arrangements between organisations, local governments and other transport asset owners and operators to facilitate coordination and planning for instances of evacuation or delivery of emergency supplies. Incorporate into Local Emergency Management Arrangements (LEMA) as a key tool for external collaboration and commitment, where relevant. |
| | Communicate resilience initiatives and responses outwards to community and customers. |
| | Work with key partners or adjoining RIMs to develop joint emergency response plans. These plans should clearly define roles, responsibilities, and communication protocols for a range of scenarios. |
| | Conduct a joint post incident review with your value chain partners. This collaborative analysis helps identify lessons learned and improve the resilience of the entire system for future events. |

### 6.4.3 Standards and regulations

Governments and regulators can incentivise rail infrastructure resilience by setting overall requirements, including legislation, planning requirements or restrictions, and by offering grants or financial incentives.

Industry-wide standards provide an opportunity to collaborate and align actions between entities. Harmonisation of standards reduces red tape around adopting new products or technologies, allowing organisations to more quickly adapt and adopt new technologies or resilience innovations. Consistency between organisations also improves interoperability, which can serve to build in redundancies and offer more opportunities for alternatives when faced with network disruptions.

| Standards and regulations | |
|---|---|
| **Resistance** | Government lobbying and engagement – identify opportunities to collaborate and align strategies to maximise impact and outcomes. |
| | Align activities with requirements under SOCI 2018. |
| | Ensure standards adequately cover the range of climate scenarios and risks identified in the risk assessment process, and update them where necessary. |
| **Response** | Ensure recovery activities are supported by necessary permits, permissions, and/or exemptions. For example, planning restrictions, environmental and cultural heritage permits, etc. |
| **Redundancy** | Engage with governments to establish financial grants for projects that upgrade alternate routes and bypasses. This encourages investment in network redundancy where it is most needed. |
| **Reliability** | Set common standards for new technologies, such as Internet of Things sensors to make it easier for RIMs to adopt new, more reliable technologies and ensures interoperability across the industry. |

### 6.4.4 Collaboration across industry

Resilience doesn't exist in a silo. By engaging and collaborating with industry peers, community members, indigenous partners and other key stakeholders throughout the value chain, opportunities for redundancies and partnerships can be identified. This eases the resource burden of trying to establish resilience activities alone.

| Collaboration across industry | |
|---|---|
| **Resistance** | Map and identify key stakeholders for communication and consultation on resilience, these are likely to be shared across entities with similar operating areas. |
| **Reliability** | Innovation and trials – collaborate and share findings and opportunities. |
| | Share modelling and scenario assessments where they overlap with industry peers and supporting industries. |
| | Partner with other rail operators and key stakeholders (e.g. freight companies, ports, energy suppliers) to conduct shared risk assessments. This identifies common vulnerabilities and external threats that could impact the entire value chain. |
| | Creating shared, strategically located stockpiles of critical materials and spare parts to reduce the individual cost for each company while ensuring a collective reserve is available for a major incident. |
| **Response** | Identify opportunity for partnerships with external agencies such as emergency services or local councils, for education, awareness and collaboration on response strategies. |
| **Redundancy** | Work together to build a shared understanding of network vulnerabilities, enabling you to strategically position and divert resources to the areas at greatest risk. |
| | Identify potential gaps in response processes or redundancies which could be addressed through partnership with other organisations or government entities. |
| | Partner and engage with industry to identify opportunities where network overlap offers opportunity to support mutual redundancy during an emergency response scenario. |

## 6.5 Metrics and data

The following section outlines a range of potential metrics which could be adopted to measure the success of resilience-building initiatives.

Optimum metrics will differ depending on organisation-specific requirements. These metrics are not intended to represent mandatory reporting requirements, but offer guidance and a starting position to those looking to assess the impacts of implemented resilience activities. Metrics can also be incorporated into the risk management process, by mapping the metrics against the organisation's risk appetite. This enables ongoing monitoring and evaluation of improvements in resilience.

Metrics have been categorised under the four Rs, however, it is often the case that metrics can be applicable to more than one aspect of resilience.

- Resistance (physical robustness)
    - Achievement of planned maintenance
    - Maintenance delays and/or backlog
    - Derailments, stoppages, cancellations, delays, track closures, restrictions
    - Asset condition, physical condition of critical systems, structural integrity of infrastructure and assets
    - Worker health and safety
    - Investment in resilience improvement (e.g. improvement spend and/or number of improvement projects)
    - Percentage/number of network assets that have/have not been risk assessed
- Redundancy (spare capacity or diversion routes)
    - Percentage/number of critical locations with/without redundancy, availability of alternate routes, communication system redundancy, power supply
    - Percentage/number of critical assets with diversified suppliers
    - Emergency equipment and material availability
    - Intermodal connectivity
- Reliability (ability to operate under a variety of conditions)
    - Additional traffic volume added during climate extremes
    - Employee training and preparedness
    - Network on-time running
    - Passenger health, passenger comfort, journey time
    - Capacity to absorb mode shift changes
    - Mean time to failure (MTTF) of critical components
    - Network availability
    - Lost traffic during disruptions such as train paths lost during floods
- Response (respond and recover from disruption)
    - Estimated time for emergency equipment and personnel to reach critical locations
    - Incident reviews, time taken to re-open
    - Time to return to acceptable performance level
    - Governance documents, emergency management plans and response plans, climate-related databases, early monitoring systems
    - Distribution of funds for climate-related preparedness and recovery
    - Hazards identified, hazards removed
    - Percent of workforce who have received resilience and/or response training
    - Number of or percentage of high-risk locations with remote sensing installed
    - Customer satisfaction surveys to measure satisfaction with the organisation's communication and recovery efforts following a disruption

# 7. Additional resources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