Climate risks and adaptation pathways for coastal transport infrastructure

Guidelines for planning and adaptive responses

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Executive Summary

Transport infrastructure across the spectrum of road, rail, airports and seaports includes assets that are long-lived and infrastructure that is designed today must consider expected increases in the intensity of extreme weather events. Much of Australia’s transport infrastructure is located close to the coast and so is vulnerable to sea-level rise and its associated processes (e.g. erosion, tidal inundation). Faced with the uncertainties of the timing and severity of climate change, decisions about what and how to build new coastal transport infrastructure, as well as maintaining existing ones, will become more and more challenging in the future.

High level vulnerability mapping assessments of future climate change, including sea-level rise, undertaken at the Australia-wide level (Department of Climate Change and Energy Efficiency 2011) and by the various state and territory governments demonstrate that transport infrastructure owners and operators have compelling reasons to begin planning and adapting now to climate risks.

These Guidelines were prepared to provide coastal transport infrastructure authorities and organisations with targeted information about climate risks for both assets and operations (including workforces).

Key risks examined include cyclones, storm surges, flooding, high wind events and increased lightning strikes as well as changes to rainfall patterns (leading to drought and water supply shortages), fog events, increased extreme hot days, temperature increases and long term sea-level rise implications.

The Guidelines also contain practical information pertaining to strategies and measures for building resilience of assets and operations to climate risks and undertaking adaptation planning. This includes information to guide timing and triggers for adaptation responses and information on an adaptive pathways approach.

The Guidelines draw on information, advice and guidance, contained within the National Climate Change Adaptation Research Facility (NCCARF) on-line portal CoastAdapt as well as other guidelines available across Australia.

This desktop review also showcases current strategies, plans and practices being undertaken by road, rail, airport and seaport authorities across Australia.
SECTION 1.0 Introduction: The need to consider climate risks to coastal transport infrastructure

1.1 Background

To address the growing risk of climate change, nearly 200 Governments agreed to pursue efforts to further reduce emissions and halt global temperature increases through the 2015 Paris Agreement (Taskforce on Climate-Related Financial Disclosures 2016). However, even if current carbon mitigation targets are achieved, this agreement will not avoid major global impacts, which means there is an urgent need for strong adaptation strategies (Parry et al. 2008). In 2013, the World Economic Forum ranked the failure to adapt to the impacts of climate change as one of the five highest impact global risks (World Economic Forum 2013).

While there is no consensus on the rate and speed with which our climate is changing, the growing realisation that some degree of climate change is inevitable is reflected in a shift of the debate from how to mitigate to how to adapt. Advocating for greater attention to be paid to adaptation is controversial in some quarters as it is interpreted as a tacit admission that mitigation efforts are no longer worth pursuing. However, the less effective mitigation efforts are, the more pronounced adaptation challenges will become; therefore, mitigation and adaptation need to be addressed in concert while taking advantage of all possible synergies.

Transport infrastructure in Australia across the spectrum of road, rail, airports and seaports already face a range of challenges in the future related to population growth and demand, reduced government investment, operating costs, and increased regulation in relation to safety, security and environmental issues (Department of Infrastructure and Regional Development 2014).
Future climate change will also affect transport infrastructure as assets are long-lived and what is designed today must consider expected increases in the intensity of extreme weather events. Much of Australia’s transport infrastructure is located close to the coast and is vulnerable to sea-level rise and its associated processes (e.g. erosion, tidal inundation). Faced with the uncertainties of the timing and severity of climate change, decisions about what new coastal infrastructure and how it should be built—as well as maintaining existing infrastructure—will become more and more challenging in the future.

Coastal transport infrastructure, in terms of its relative vulnerability to climate change and extreme weather events, can be both exposed (due to its location at or near the coast) and sensitive to climate risks (due to high usage and long design life that in many cases was designed prior to consideration of future climate impacts). Transport infrastructure can also have limited adaptive capacity (refer Department of Industry, Innovation, Climate Change, Science, Research and Tertiary Education 2013, Ng et al. 2016, Becker et al. 2012) because of:

- the numerous roles it plays in the economy and community (and cascading effects if there is damage to the asset and/or unacceptable levels of service)
- the necessity of uninterrupted operation to support vehicle, passenger movement and imports and exports
- their permanent and often historical location in coastal, estuarine or riverine areas
- their long lifespan.

Therefore it is imperative for transport authorities to consider measures that will increase the resilience of their assets to climate risks in the short to medium term. But it is also important to have a clear pathway for future adaptation in the long term, when anticipated impacts from climate change are more evident.

Much of the current advice and guidance in the literature has been targeted toward local authorities and other urban land use managers. This Guideline document has been prepared to:

- develop a transport infrastructure-centred typology of potential impacts and risks
- provide guidance on planning processes, resilience building actions and adaptive approaches that transport infrastructure owners and operators can use to address climate risks over time
- link these to guidance, maps and other information that can be found in the on-line decision support tool CoastAdapt (https://coastadapt.com.au/) developed by the National Climate Change Adaptation Research Facility (NCCARF).

### 1.2 What is at risk and what are the drivers for taking action?

High level vulnerability mapping assessments of future climate change including sea-level rise undertaken at the Australia-wide level (Department of Climate Change and Energy Efficiency 2011) and by the various state and territory governments have demonstrated that transport infrastructure owners and operators have compelling reasons to begin planning and adapting now to climate risks.
This research undertaken in preparing these guidelines included a desktop review as well as interviews with transport industry representatives across road, port, airport and rail authorities. From this it was confirmed that many of these organisations have either started, or will shortly commence, risk assessment processes to better understand their risks to future climate change both for existing assets and in the context of proposed expansion.

In a general sense, and as outlined in Department of Industry, Innovation, Climate Change, Science, Research and Tertiary Education (2013), transport infrastructure can be exposed to significant climate risks through the following:

- **Risks to assets**
  A changing climate may damage major assets including roads, rail, airport facilities and port facilities. Support structures and buildings, drainage infrastructure, energy infrastructure and communications facilities will also be potentially affected. Damage to assets can force owners to retire assets early, make major upgrades or increase maintenance frequency.

- **Risks to operations**
  More frequent or intense extreme weather events may disrupt business operations or else the useability or reliability of services. Examples include the effect of floods on transport and electricity supply, disruption of transport by cyclones and major storms, and reduced productivity of outdoor workers due to high temperatures.

- **Critical dependencies**
  Extreme weather events may interrupt supply chains or services such as transport, cargo, electricity, gas or water supply on which businesses depend. A changing climate may also affect global trading patterns, for example, by changing the supply of agricultural products or mining products.

- **The national economy**
  Climate change impacts are a potential drag on the national economy, with a flow-on effect to individual businesses.

- **Insurance and capital markets**
  Climate change shocks may affect the availability of insurance and access to capital, either locally or worldwide.

From a business perspective, future climate change has the potential to affect the valuation of infrastructure assets by impacting cash flows, operational cost and capital expenditure. The risk posed by climate change may not necessarily be to the asset itself but to the goals and objectives that may be compromised if the asset is impacted or damaged.

Thus the primary risks that need to be considered are those that will affect the reliability and performance of the assets as well as whether relevant targets and performance metrics can continue to be met.

Other drivers of climate risks that need to be considered by transport authorities come from sources that are external to organisations. These can include:

- climate risk regulations imposed by governments including, for example, requirements to consider climate risk as part of expansion and/or new development proposals
• responding to broader government strategies on climate change adaptation and resilience
• taking advantage of grant funding, disaster recovery funding and other incentives programmes to understand vulnerability and/or build resilience of infrastructure to climate risk
• responding to public and stakeholder concern about preparedness of assets or operations to climate risks
• seeking to manage escalating insurance premiums and reduce claims
• responding to investors and financial disclosure.

In particular, recent recommendations made by the Taskforce on Climate-Related Financial Disclosures (TCFD) in December 2016 reported on the need for organisations to include climate-related risks in their mainstream financial filings. The advice and recommendations applies to large asset owners and operators in particular, as they sit on the top of the investment chain. While still in its early stages, the recommendations of the Taskforce place an increasing importance on understanding climate risk and disclosing mitigation and adaptation actions to minimise this risk (Taskforce on Climate-Related Financial Disclosures 2016).

1.3 Barriers to adaptation

There is a very wide range of potential barriers to adaptation. Some of the specific barriers for transport infrastructure authorities and organisations can include those listed below.

• The lack of sufficient evidence and confidence in climate change impacts to compel these organisations to take adaptation actions. Without greater certainty, it is difficult to make a commercial argument for investing in climate change adaptation.

• Climate change adaptation means taking long-term decision that may be incompatible with the investment timeframes of the business.

• Guidance around appropriate engineering design standards for future climate conditions may be absent or unclear.

• Facilities such as airports and seaports are only part of a much larger global supply chain: even if a port is resilient to extreme weather events, other parts of the supply chain (road, rail) may not be.

• Normal (short term) business risks are often regarded as being more urgent that those posed by climate change, so there is limited pressure to invest resources in adaptation at the current time.

• A range of internal organisational barriers including a lack of awareness by senior executives. These executives may often confuse carbon management (that is managing greenhouse gas emissions) with climate change adaptation or a lack of authority, corporate priority and resources for effective action across the organisation.

• Considering climate risks as a sustainability or environmental issue rather than a corporate or financial risk.
• A lack of practical guidance, specific to the transport sector for adaptation, for commencing and implementing climate change adaptation plans.

Despite these barriers, there is a strong indication from transport authorities and organisations that there is growing interest and activity around future climate risk, particularly as it relates to resilience planning and future adaptation.

1.4 **Focus of these guidelines**

Recognising the drivers for taking action discussed in Section 1.2, the focus of these guidelines is on the assets (both existing and proposed) and operations (including workforces) of transport infrastructure authorities and organisations. Management systems and institutional arrangements within transport organisations are also relevant and important for developing an effective response to climate risks, however these are outside the scope of the current study.

These guidelines are specifically designed for use by staff within transport infrastructure organisations and/or departments or large organisations that are responsible for understanding vulnerability and associated adaptation responses for assets and operations. These may include transport planners, asset managers, risk managers, engineering staff, and environment, health and safety staff.

The guidance may also be useful for practitioners from consulting firms and academia who are engaged to prepare vulnerability assessments and adaptation plans on behalf of these organisations. It may also be of use for government agencies charged with the review, assessment and approval of resilience/adaptation plans or ensuring such plans are prepared and implemented.
SECTION 2.0 Understanding the risks to transport infrastructure from coastal climate change and extreme weather events

2.1 Key parameters of concern for coastal transport infrastructure

There are now numerous studies, considerable research and other information available concerning the possible impacts of future climate change on built, social and natural environmental assets, services and functions.

In synthesising this information for the purposes of these Guidelines, the key climate risk parameters that are considered most relevant to transport infrastructure assets and operations (including workforces) in coastal areas are outlined in Table 2.1.
Table 2.1: Key climate change parameters of concern for coastal transport infrastructure assets and operations.

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Parameter</th>
<th>Potential effects</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>An increase in the severity of cyclones, storms and extreme weather events</td>
<td>• increased erosion, storm surge and flooding events</td>
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<tr>
<td></td>
<td></td>
<td>• increased high wind events</td>
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<td></td>
<td></td>
<td>• increased lightning events</td>
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<td></td>
<td>Changes to rainfall patterns</td>
<td>• increased periods of drought and changes to the seasonality of rainfall</td>
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<tr>
<td></td>
<td></td>
<td>• changes to water supply and availability</td>
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<tr>
<td></td>
<td></td>
<td>• fog events (causing impacts to visibility and safety)</td>
</tr>
<tr>
<td></td>
<td>Increasing temperatures</td>
<td>• increased incidents of very hot days and heatwaves</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• increased bushfire risk and intensity</td>
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<tr>
<td></td>
<td></td>
<td>• increased average air and water temperature</td>
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<tr>
<td></td>
<td>Sea-level rise</td>
<td>• more frequent erosion events</td>
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<tr>
<td></td>
<td></td>
<td>• more frequent and far reaching tidal inundation associated with storm surge and</td>
</tr>
<tr>
<td></td>
<td></td>
<td>storm tide events</td>
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<tr>
<td></td>
<td></td>
<td>• permanent inundation of coastal areas</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• exacerbate the effect of cyclones and extreme storm events listed above</td>
</tr>
</tbody>
</table>

These key risks may lead to a range of impacts to assets, workforces and operations. In this context, the parameters may act in isolation or in combination (for example, the impacts from storm surge combined with a higher sea state causing increased frequency of overtopping wharves and quays at a seaport).

2.2 Climate risks and potential impacts


In reviewing Table 2.2, it is important to know that the dynamics between climate change and transport infrastructure can significantly differ between regions and localities. This is a significant source of uncertainty that should be addressed by site-based studies.

In addition to these direct impacts on assets and operations, climate change may also have indirect impacts in the form of cascading risks on interdependent infrastructure and communities. For example, flooding and storm tide impacts on connecting road and rail networks may have significant impacts on the use and operation of coastal airports and seaports in terms of passenger movements and freight transport. This in turn can affect the supply chain in the context of scheduling, delays and availability of ships and aircraft at their
Another example of cascading effects is documented in the Climate Institute (2013) report concerning the effect of the heatwave that occurred in Melbourne in January 2009. During the heatwave, electricity demand—primarily driven by air conditioning use—led to rolling electricity blackouts through western and central Melbourne. This cut overhead power lines and signals for the train system and associated stranding of passengers and assets.

Indirect impacts from climate risks may also affect long-term usage patterns of transport infrastructure. For example, broad scale changes to agriculture production may change the quantity and types of products exported from a seaport. For rail and road, indirect impacts may come from reduced grain crop leading to reductions in rural services and revenue. Likewise, changes to global tourism linked to climate change and weather events may affect airport usage, passenger movement and surface transport networks. These externalities are difficult to influence at the individual asset level but are important to consider in the context of future investment, expansion and other long term planning across networks.
<table>
<thead>
<tr>
<th>Climate Change Parameter</th>
<th>Sub-risk</th>
<th>Potential impacts to road assets and operations</th>
<th>Potential impacts to rail assets and operations</th>
<th>Potential impacts to airport assets and operations</th>
<th>Potential impacts to seaport assets and operations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cyclones, storms, and extreme weather events</td>
<td>Increased erosion, storm surge and flash flooding events</td>
<td>Increased risk of erosion, storm tide and flood damage to road infrastructure</td>
<td>Increased risk of erosion, storm tide and flood damage to rail infrastructure</td>
<td>Increased risk of erosion, storm tide and flood damage to runways, taxiways, aprons and aviation facilities including carparks</td>
<td>Increased risk of erosion and wave damage to wharves and other portside facilities including container yards and bulk storage facilities</td>
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<tr>
<td></td>
<td></td>
<td>Degradation and failure of tunnel/bridge structures close to coast</td>
<td>Degradation and failure of tunnel/bridge structures close to coast</td>
<td>Suspend operations - flow on impacts on passengers and supply chains</td>
<td>Suspend operations/stoppage of work - flow on impacts on supply chain</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Delays and closure of roads and impacts on supply chains</td>
<td>Delays, cancellations and reliability implications due to inundation of drainage structures, track and infrastructure</td>
<td>Increased likelihood of power outages due to flooding of electrical facilities</td>
<td>Increased maintenance/repair costs including need for emergency maintenance dredging following events</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Increased maintenance and repair of damaged roadways</td>
<td>Increased likelihood of power outages</td>
<td>Increased impacts on airport drainage systems</td>
<td>Increased likelihood of power outages due to flooding of electrical facilities</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Increased impacts on road drainage systems including siltation and debris in culverts</td>
<td>Increased maintenance and repair of damaged railways</td>
<td></td>
<td>Increased impacts on port drainage systems</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Landslides, slope failures and embankment instability causing safety risks, delays and damage</td>
<td>Landslides, slope failures and embankment instability causing safety risks, delays and damage</td>
<td></td>
<td>Inundation/release of stockpiled cargos and/or hazardous material leading to environmental impacts</td>
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<tr>
<td></td>
<td></td>
<td>Reduced driver safety and slow movement during extreme weather causing delays</td>
<td>Reduced traction and slow movement during extreme weather causing delays</td>
<td></td>
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</tr>
<tr>
<td>Increased high wind events</td>
<td>Unsafe driving conditions particularly in exposed areas</td>
<td>Wind damage to overhead power lines for rail</td>
<td>Suspension of operations or restrictions on runway operating modes resulting in reduction in runway capacity (movements)</td>
<td>Damage to cargo loading infrastructure and equipment such as cranes</td>
<td>Suspend/stoppage of work – gantry cranes and other port infrastructure are not able to be used above specific wind speeds</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Increased likelihood of power outages affecting services</td>
<td>Suspension of ground handling operations due to safety concerns</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>Debris blown onto overhead wires, track or rolling stock causing safety risks, delays and damage</td>
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<td></td>
<td></td>
</tr>
</tbody>
</table>

**Table 2.2:** Climate change risks and potential impacts for specific coastal transport infrastructure.
<table>
<thead>
<tr>
<th>Climate Change Parameter</th>
<th>Sub-risk</th>
<th>Potential impacts to road assets and operations</th>
<th>Potential impacts to rail assets and operations</th>
<th>Potential impacts to airport assets and operations</th>
<th>Potential impacts to seaport assets and operations</th>
</tr>
</thead>
</table>
|                          | Increased lightning strikes | Unsafe driving conditions  
Damage to roadways, bridges and other infrastructure from direct lightning strikes | Delays, cancellations & reliability implications due to direct and indirect lightning strikes on electrical and communications equipment | Temporary suspension of operations  
Damage to electrical and communications equipment from direct and indirect lightning strikes including airport lighting systems  
Damage to runways, taxiways, aprons from direct lightning strikes | Temporary suspension of operations  
Damage to electrical and communications equipment from lightning strikes |
|                          | Changes to rainfall patterns | Decrease in annual rainfall leading to greater drought periods and changes to seasonality of rainfall  
Potential increases in dust and sand/sediment drift affecting road services  
Potential impacts to vegetation alongside roadways and associated maintenance regimes (including higher incidence of weeds)  
Increased fire risk on roadside vegetation  
Potential changes/increased frequency of nuisance fauna species on roads | Potential increases in dust and sand/sediment drift affecting rail services  
Potential impacts to vegetation alongside railways and maintenance regimes (including higher incidence of weeds)  
Potential changes/increased frequency of nuisance fauna species on rail tracks | Potential for greater dust storms and impacts on aviation operations  
Prolonged drought conditions affecting embedded airport lighting systems and increased maintenance  
Potential changes/increased frequency of nuisance fauna species on airport such as birds and bats near waterways and grassed infield areas | Potential increases in dust and sand/sediment drift from stockpiles and cargos  
Potential impacts to vegetation and maintenance regimes |
|                          | Changes to water supply and availability | Water supply cost increase for workforces particularly in remote areas  
Water supply cost increase for workforces particularly in remote areas | Water supply cost increase for facilities, landscaping and workforces | Water supply cost increase for facilities, stockpile management (dust suppression) and workforces | Water supply cost increase for facilities, stockpile management (dust suppression) and workforces |
<p>|                          | Fog events | Temporary impacts to visibility - safety impacts on drivers | Temporary impacts to visibility - safety impacts for operators | Potential for greater fog events and associated delays and impacts on aviation operations | Potential for greater fog events and associated delays and impacts on maritime navigation and operations |</p>
<table>
<thead>
<tr>
<th>Climate Change Parameter</th>
<th>Sub-risk</th>
<th>Potential impacts to road assets and operations</th>
<th>Potential impacts to rail assets and operations</th>
<th>Potential impacts to airport assets and operations</th>
<th>Potential impacts to seaport assets and operations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Increasing temperatures</td>
<td>Increased incidents of very hot days and heatwaves</td>
<td>Increased fatigue rates of pavement due to increasing temperature and moisture fluctuations, Tarmac and road surfaces melting/degradation of roads, Pavement oxidation from increased UV radiation leading to increased maintenance frequency and cost, Increased stress on expansion joints on bridges, Higher risk of heat related illness and worker health and safety incidents, Reduced/changed working hours by workforces</td>
<td>Track failures (buckling, mechanical, electrical failure) due to more extreme temperature days, Delays and cancellations due to speed restrictions, Higher energy costs of air conditioning in stations and on passenger services and possible power overloads and failures on operational systems, Higher risk of loss of electricity due to higher peak electricity demand impacting rail and tram systems, Higher risk of heat related illness and worker health and safety incidents, Reduced/changed working hours by workforces</td>
<td>Higher energy costs of air conditioning (terminals and export cargo areas), Higher risk of heat related illness and worker health and safety incidents, Reduced/changed working hours by workforces</td>
<td>Higher energy costs of air conditioning (cruise terminals and workplace area), Challenges to maintain temperatures in refrigerated storage areas and health and safety of perishable cargoes and possible power overloads and failures on operational systems, Risk of combustion and fire of stockpiled cargos, Higher risk of heat related illness and worker health and safety incidents, Reduced/changed working hours by workforces</td>
</tr>
<tr>
<td></td>
<td>Increased bushfire risk</td>
<td>Bushfire close to road melts/destroys assets in the event of a fire (e.g. signals, street furniture), Smoke and fire making driving conditions unsafe, Inadequate access/escape routes from fire at adjacent developments/existing highway endangers lives of residents, Inadequate emergency vehicle access on highway (adequate shoulder widths)</td>
<td>Suspend/stoppage of work – fire and/or smoke hazards, Increased bushfire damage risk to rail assets, Delays and cancellations due to bushfire or bushfire warnings, Direct heat damage to overhead wires and electrical infrastructure causing increased costs</td>
<td>Potential for greater smoke events and associated delays and impacts on aviation operations</td>
<td>Risk of fire damage to infrastructure and equipment (for example pipeline leaks and explosions)</td>
</tr>
<tr>
<td>Climate Change Parameter</td>
<td>Sub-risk</td>
<td>Potential impacts to road assets and operations</td>
<td>Potential impacts to rail assets and operations</td>
<td>Potential impacts to airport assets and operations</td>
<td>Potential impacts to seaport assets and operations</td>
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<td>-------------------------------------------------</td>
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<td>-------------------------------------------------</td>
</tr>
<tr>
<td><strong>Increases to average air and water temperatures</strong></td>
<td>In areas subject to ice – increased temperatures may be beneficial</td>
<td>In areas subject to ice – increased temperatures may be beneficial</td>
<td>Marginal changes predicted to wind speed, direction and air temperatures unlikely to have major impacts on airport or aviation operations</td>
<td>Warming of waters means possible changes to the types and incidence of marine pests at ports with the introduction of more exotic tropical species</td>
<td></td>
</tr>
<tr>
<td><strong>Sea-level rise</strong></td>
<td>Sea-level rise impacts leading to increased areas exposed to erosion, storm tide and flooding and more severe impacts</td>
<td>Inundation of low-lying roadways causing increased costs, delays and damage Saltwater intrusion onto roads and facilities Costs to protect and restore coastal roads from future erosion events</td>
<td>Inundation of low-lying rail track and infrastructure (yards, workshops) causing increased costs, delays and damage Saltwater intrusion onto railways and facilities Costs to protect and restore coastal rail from future erosion events</td>
<td>Inundation of low lying facilities including more permanent inundation of runways, taxiways and aprons Saltwater intrusion onto runways, taxiways and other aviation facilities Costs to protect airport infrastructure from future erosion events</td>
<td>Exposure of structures to increased wave action and corrosive effects of saltwater Reduction in clearance between ships and booms affecting loading and unloading Changes to vessel clearance below overhead obstacles such as bridges and power lines Impacts on rail and road supply chains affecting port operations</td>
</tr>
</tbody>
</table>
2.3 Risk assessment processes

Infrastructure owners and operators face uncertainty about the likely consequence of future climate as well as the effectiveness and risk of unintended consequences of a proposed intervention. Often, this can result in infrastructure owners and operators becoming paralysed by a desire to wait for more detailed analyses and data regarding the precise timing, manifestation or impact of future climatic changes in their local environments.

To address this uncertainty, the *CoastAdapt* advocates a risk assessment methodology and provides guidance on three potential risk processes that can be undertaken by an asset manager: (i) a first pass risk screening, (ii) a second pass risk assessment and (iii) a third pass (detailed) assessment. These processes are shown diagrammatically in Figure 2.1.

![Figure 2.1: Risk assessment processes in CoastAdapt.](https://coastadapt.com.au/sites/default/files/infographics/Three_tier_risk_assessment.pdf)
2.3.1 Key information needs

Key information and data inputs for a risk assessment process generally needs to include the following contextual information:

- Picking a timeframe for the assessment (for example: current day, 2050 and 2100), the climate change emissions scenario to be used (most likely, best case, worst case), the spatial study area of the assessment and scope of the assessment.

- Knowledge of climate risks and trends for the local and regional area including expected changes to sea-level rise, storminess, rainfall patterns, temperature and sea-state conditions.

- Knowledge of asset registers and the condition of assets at the study area, the relative value and significance of assets and where available, more detailed vulnerability or hazard mapping.

As illustrated in Figure 2.1 much greater and more detailed information (and investment) will be needed for a third pass assessment compared to a first pass screening and the cost of obtaining this information should always be considered commensurate with current and future risk levels.

2.3.2 Determining likelihood

Determining the likelihood of a hazard occurring will generally be guided by the outputs of previous hazard or vulnerability assessments including hazard lines and mapping which are now widely available at various scales and accuracies from local, state and the Australian governments.

*CoastAdapt* has developed a range of mapping tools that can assist understanding of the likelihood of impact in a risk assessment processes. These tools have been developed to apply across Australia. These include:

- **Shoreline Explorer** used to access past and present day risk information including coastal sediment compartment information, coastal landform information (Smartline) and Water Observations from Space (WOFS) satellite data; accessible via https://coastadapt.com.au/tools/coastadapt-datasets#present-day

- **SLR and you** tool used to assess future inundation risk; access via https://coastadapt.com.au/tools/coastadapt-datasets#future-datasets

Hazard mapping may also have relevant temporal scales (e.g. 2050, 2100) to take into account and care should always be taken to determine the degree to which future conditions shown in maps take into account climate change and which climate change emission projection has been adopted (if at all).

Choosing an appropriate spatial scale for coastal hazard mapping is important to the level of detail sought from the risk assessment process. For further guidance on this issue, see BMT WBM (2017) within *CoastAdapt*, and as summarised in Figure 2.2 below.
2.3.3 Assessing consequence

The other half of the risk equation is consequence – that is assessing the consequence of hazards on asset condition, life and function or on the operations and useability of the transport infrastructure.

Assessing consequence can be far more difficult and subjective without detailed understanding of the asset and/or operation being impacted and should generally involve content specialists such as asset managers and maintenance staff. Consequence can be assessed on a range of scales; with some relevant examples for transport infrastructure related assets and operations shown in Table 2.3, particularly Criteria 1 and 4.
Table 2.3: Example of consequence scales relevant to transport infrastructure (NCCARF 2016a).

<table>
<thead>
<tr>
<th>Consequence</th>
<th>Criteria-1</th>
<th>Criteria-2</th>
<th>Criteria-3</th>
<th>Criteria-4</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Assets that are owned by the organisation</td>
<td>Community Asset (infrastructure and services)</td>
<td>Environmental assets</td>
<td>Business continuity (capacity of the organisation to manage a disruption)</td>
</tr>
<tr>
<td></td>
<td>assessing risk</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Catastrophic</td>
<td>Asset(s) completely damaged and/or large scale</td>
<td>Community assets and private properties completely damaged with irreversible loss</td>
<td>Irreversible loss of environmental assets</td>
<td>Significant disruption in business operation (virtually dysfunctional)</td>
</tr>
<tr>
<td></td>
<td>engineering works required for reinstating</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Major</td>
<td>Extensive structural damage to the asset(s)</td>
<td>Extensive damage to community assets with wide spread impacts.</td>
<td>Extensive damage to environmental assets with long-term effects and that can have impact in local economy and life style.</td>
<td>Major disruption in business operation with significant loss of revenue and market reputation</td>
</tr>
<tr>
<td></td>
<td>requiring significant engineering stabilisation work</td>
<td>Major disruption in the asset’s service</td>
<td>Long-term loss of private property</td>
<td></td>
</tr>
<tr>
<td>Moderate</td>
<td>Moderate damage to some part of the structure of</td>
<td>Considerable impact upon access to community assets. Major long-term impact upon private property</td>
<td>Considerable impact on environment but with no long-term effects and can be recovered with moderate management efforts</td>
<td>Considerable impact in business operation with loss of revenue</td>
</tr>
<tr>
<td></td>
<td>the asset(s) and require large engineering</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>stabilisation work</td>
<td>Considerable impact upon access to community</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Moderate disruption in the asset’s service</td>
<td>assets. Major long-term impact upon private</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Minor</td>
<td>Limited damage to some part of the asset(s)</td>
<td>Minor short-term impacts (mainly reversible) on community assets and services</td>
<td>Limited impact on the environment but can be recovered using minimum management efforts</td>
<td>Minor impact in business operation as disruption mostly can be managed through standby or alternate options. However, some loss of revenue or cost involved</td>
</tr>
<tr>
<td></td>
<td>and require some small scale stabilisation work</td>
<td>Minor long-term impacts to private property</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>resulting in minor service disruption</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Insignificant</td>
<td>Little disruption in service but no structural</td>
<td>Little disruption of non-critical community assets</td>
<td>Little impact on environment and recovery occurs without management efforts</td>
<td>Little impact in business operation.</td>
</tr>
<tr>
<td></td>
<td>damage to the asset(s)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No risk</td>
<td>No assets are at risk</td>
<td>No community assets and/or private property are at risk</td>
<td>No environmental assets are at risk</td>
<td>No impact on business operation</td>
</tr>
</tbody>
</table>

18
2.3.4 Generating a risk rating

Risk ratings can be generated based on the combination of the likelihood of the hazard occurring and the consequence of the hazard on the asset, using the standard risk matrix shown in Table 2.4 or an existing risk framework already adopted by the organisation.

When considering future condition, the risk levels for assets are best assessed at different time scales (current, 2050 and 2100). Note that adopting such timeframes can link well with climate change projections, with the practical design life of the asset, and with required maintenance schedules and associated triggers for management intervention.

Table 2.4: Example risk rating matrix (NCCARF 2016a).

<table>
<thead>
<tr>
<th>Likelihood</th>
<th>Insignificant</th>
<th>Minor</th>
<th>Moderate</th>
<th>Major</th>
<th>Catastrophic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Almost</td>
<td>Medium</td>
<td>Medium</td>
<td>High</td>
<td>Extreme</td>
<td>Extreme</td>
</tr>
<tr>
<td>Likely</td>
<td>Low</td>
<td>Medium</td>
<td>High</td>
<td>High</td>
<td>Extreme</td>
</tr>
<tr>
<td>Possible</td>
<td>Low</td>
<td>Medium</td>
<td>Medium</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>Unlikely</td>
<td>Low</td>
<td>Low</td>
<td>Medium</td>
<td>Medium</td>
<td>Medium</td>
</tr>
<tr>
<td>Rare</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Medium</td>
</tr>
</tbody>
</table>

2.3.5 Existing controls and adaptive capacity

For any risk assessment it is important to remember that risk levels can be tempered by two things:

(1) existing management controls such as the planning, design and management measures already being implemented by the transport authority

(2) the adaptive capacity of assets and operations to future change.

For example, it could be that existing management controls for extreme weather events are adequate and/or only need to be modified slightly to accommodate the additional impacts of climate change. However, these safeguards may not be well understood or able to be validated until a broader risk assessment process has been undertaken across the organisation. Some key criteria to consider in the context of adaptive capacity of assets and operations include

- the design life and resilience of the asset to impacts (particularly if it is not a permanent asset or structure)
- planning controls and design standards for new infrastructure and facilities to take into account extreme weather
- the degree to which the asset can be reconfigured or redesigned to accommodate changes in climate or extreme weather events
- existing policies and procedures related to workplace health and safety including for example operations in storm, wind, wave and visibility conditions
- technological changes including the ability to work longer/function during periods of more challenging conditions.
SECTION 3.0  Taking action to build resilience and adapt

3.1  Adaptation planning cycle - C-CADS

While risk and vulnerability assessments are a critical first step, they are only one component of the broader resilience and adaptation planning cycle for a transport infrastructure authority or organisation.

As shown in Figure 3.1, CoastAdapt includes C-CADS, the Coastal Climate Adaptation Decision Support tool for developing resilience and adaptation pathways. While principally aimed at local authorities, this process is suitable for use by transport authorities given its close links to ISO 31000 risk management standard.

For a transport authority/organisation to undertake building resilience and adaptation planning, the following sections set out additional guidance for these steps in the C-CADS process.

3.2  Goals and success criteria

Establishing goals is one of the most crucial but poorly developed areas of the adaptation practice (Webb et al. 2013, Messner et al. 2016). Appropriate goals for climate change adaptation should reflect integration across functions, department and work units at the transport authority and consider short, medium and long term planning horizons for assets and operations.
Examples of goals, objectives and success criteria could include, for example:

- there is adequate underpinning science, evidence and understanding that will be used in decision making
- there is a clear articulation of vulnerability of transport assets to climate change and the values provided by the asset that need to be protected (e.g. reliability, public safety, efficiency, etc.)
- development (including its design, siting, location and building materials) takes into account and incorporated where practical, climate variability and future climate change
- capacity and awareness about future climate risk is built within the organisation and with associated stakeholders over time
- the organisation implements measures that reduce the risk and duration of climate related downtime of infrastructure and maintains the safety of the workforce and community
- climate change impacts are monitored over time and mainstreamed across the relevant departments of the organisation.

In particular, goals and success criteria for adaptation need to consider and articulate broader policy perspectives (rather than policies in isolation) including how they link to carbon mitigation strategies, sustainability strategies and economic growth and expansion plans.

Establishing these linkages will serve to help avoid mal-adaptation and to ensure climate change considerations are more ‘mainstreamed’ into organisational planning and decision-making.

### 3.3 Identifying options for building resilience and adaptation

In responding to risks identified in risk and vulnerability studies and assessments, it is important to identify the range of planning and management options available. This can involve the need for not only feasibility assessments but also cost benefit analysis of different alternatives before making a decision.

Hallegatte (2009) notes the importance of developing climate change adaptation strategies that understand and cope with the inherent uncertainties of climate change, favouring strategy options that:

- have no or minimal regrets
- are reversible/flexible
- have ‘safety margin’ strategies that reduce vulnerability at null or low costs
- consider soft strategies such as institutional and financial tools
- reduce decision-making time horizons (if possible)
- take into account conflicts and synergies between strategies.
Looking across the literature, there are a range of generic measures emerging for building resilience and adaptation for transport infrastructure. These typically include:

- undertaking more detailed analysis of prospective risks including the likely timing and severity of future impacts on assets and operations including cost analysis
- reviewing incident and disaster management procedures to include new or increased climate related risks such as flooding, storm surge, bushfire, dust and fog
- reviewing current design standards against existing and future impacts of climate change
- adding climate change considerations to existing planning, asset management, capital works, development codes and delivery process reviews
- progressive upgrade and replacement of assets using more resilient designs and materials
- reviewing and altering workplace health and safety standards (including PPE) and procedures to address current and future climate risks
- improvements to monitoring of key indicators including hazard frequency and intensity, asset failure, maintenance frequency, and incidents
- building awareness and educating employees and contractors on the impacts of climate change and ways to adapt the assets over time ahead of climate change
- collaborating with stakeholders and agencies to address shared climate change risks.

For significant assets, as outlined in Deloitte Access Economic (2016), embedding resilience into the planning process for critical infrastructure can prevent unnecessary disruption and generate significant reductions in disaster costs. Mitigating disaster risk therefore should be a priority for both existing and future assets.

To illustrate this, Figure 3.2 shows an example decision tree of various resilience and adaptation options for transport infrastructure assets, separated between existing assets and new/proposed assets. For this example, options are shown for addressing impacts from sea-level rise and associated erosion and storm tide impacts. Of note is the different approaches and measures that need to be considered for existing (e.g. protect, accommodate or retreat) versus proposed and new assets (e.g. avoid, accommodate or accept).

A more detailed summary of adaptation actions for different types of transport infrastructure across the key impacting processes of climate change identified in Section 2 (e.g. increased storminess, changes to rainfall patterns, increased temperature and sea-level rise) is listed in Table 3.1. This table has been compiled based on current practices being undertaken by transport authorities and organisations in Australia (see Appendix A) as well as examples in the literature and practices from other jurisdictions cited in Table 2.2. Within CoastAdapt, specific guidance is also provided around adaptation in CoastAdapt Information Manual 7, Engineering solutions for coastal infrastructure (Webb 2016) which includes key links and references to Engineers Australia guidance on coastal engineering and climate change adaptation.
In considering the summary of actions in Table 3.1, it is vital to consider that adaptation actions are locally specific and relevant to the type of infrastructure and context in which they are developed; they also need to build on existing measures and approaches to planning and management of the organisation.
Resilience and Adaptation Options for Existing versus New Assets (in response to sea level rise, erosion and storm tide impacts)

**Existing Assets**
- **Protect**
  - Coastal engineering works
  - Sand bypassing
  - Levee banks
  - Culvert and drains
  - Bank stabilisation/re-profiling
- **Accommodate**
  - Beach nourishment
  - Enhance natural barriers
  - Retrofit
  - Redesign following extreme events
  - Evacuation Planning
  - Insurance
- **Retreat**
  - Relocate Item
  - Abandon
  - Acquire and re-lease
  - Compulsory Acquisition
  - Termed Approval

**New Assets**
- **Avoid**
  - Prohibit/refuse/setback
  - Fill to raise land
- **Accommodate**
  - Siting requirements
  - Design standards
  - Evacuation planning
  - Termed approvals
- **Accept**
  - Accept risk and monitor change over time
  - Build as sacrificial or willing to abandon

**Greenfield Sites (Avoid or Accommodate)**
- In-Fill Sites (Accommodate or Accept)

**Figure 3.2:** Decision tree for resilience and adaptation options for transport infrastructure assets in response to sea-level rise, erosion and storm tide impacts.
Table 3.1: Sample resilience and adaptation actions for specific transport infrastructure types (various sources)

<table>
<thead>
<tr>
<th>Climate Risk Category</th>
<th>Road</th>
<th>Rail</th>
<th>Airports</th>
<th>Ports</th>
</tr>
</thead>
<tbody>
<tr>
<td>Increased Storminess</td>
<td>Review and revise design engineering and operational standards for roadways, bridges and tunnels</td>
<td>Review and revise design engineering and operational standards for railroads, bridges and tunnels</td>
<td>Review and revise design engineering and operational standards as they relate to:</td>
<td>Review and revise design engineering and operational standards as they relate to:</td>
</tr>
<tr>
<td>(including erosion and storm tide, flooding, wind, and lightning effects)</td>
<td>Upgrade drainage systems to meet rainfall and flooding predictions</td>
<td>Upgrade drainage systems to meet rainfall and flooding predictions.</td>
<td>• port drainage infrastructure including in cargo stockpiles and container yards</td>
<td>• port drainage infrastructure including in cargo stockpiles and container yards</td>
</tr>
<tr>
<td></td>
<td>Review land stability and erosion control requirements given greater flood impacts</td>
<td>Assess implications of increased wind and lightning events on operational efficiencies including lightning protection systems</td>
<td>• higher wind gusts and storminess for crane operation, moorings and container stacks</td>
<td>• higher wind gusts and storminess for crane operation, moorings and container stacks</td>
</tr>
<tr>
<td></td>
<td>Increase maintenance regimes including inspection of potential hazards from debris on roadways</td>
<td>Increase maintenance regimes including inspection of potential hazards from debris on railways</td>
<td>• rainfall and flooding impacts on electricity generators, fuel supply and power lines</td>
<td>• rainfall and flooding impacts on electricity generators, fuel supply and power lines</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• access and safety for maintenance and operation in stormy conditions</td>
<td>• access and safety for maintenance and operation in stormy conditions</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Assess changes to emergency management procedures including safe harbours</td>
<td>Assess changes to emergency management procedures including safe harbours</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Increase storage capacity of existing facilities to account for delays caused by weather</td>
<td>Increase storage capacity of existing facilities to account for delays caused by weather</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Protect hazardous materials and stockpiles from potential release as a result of storm or flooding impacts</td>
<td>Protect hazardous materials and stockpiles from potential release as a result of storm or flooding impacts</td>
</tr>
<tr>
<td>Climate Risk Category</td>
<td>Road</td>
<td>Rail</td>
<td>Airports</td>
<td>Ports</td>
</tr>
<tr>
<td>--------------------------------------------------------------------------------------</td>
<td>-----------------------------------------------------------------------</td>
<td>----------------------------------------------------------------------</td>
<td>---------------------------------------------------------------------------------------------------</td>
<td>--------------------------------------------------------------------------------------------------</td>
</tr>
</tbody>
</table>
| Changes to rainfall patterns (including droughts, seasonality of rainfall, water supply and fog events) | Consider changes to vegetation management practices to account for drought conditions  
Explore and develop alternative water supplies including, where appropriate, harvesting stormwater and flood waters, more efficient use of water, water treatment and recycling | Consider changes to vegetation management practices to account for drought conditions  
Explore and develop alternative water supplies including, where appropriate, harvesting stormwater and flood waters, more efficient use of water, water treatment and recycling | Consider changes to pest fauna controls to limit bird strike impacts, including reduction of permanent water holes or features that could act as refugia during drought conditions  
Explore and develop alternative water supplies including, where appropriate, harvesting stormwater and flood waters, more efficient use of water, water treatment and recycling  
Assess incidence and implications of fog on airport operations | Explore and develop alternative water supplies including, where appropriate, harvesting stormwater and flood waters, more efficient use of water, water treatment and recycling  
Investigate more robust dust suppression systems (e.g. covering stockpiles rather than dampening)  
Assess incidence and implications of fog on maritime operations |
<table>
<thead>
<tr>
<th>Climate Risk Category</th>
<th>Road</th>
<th>Rail</th>
<th>Airports</th>
<th>Ports</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature-related impacts (including hot days, bushfire risk and increased air and water temperature)</td>
<td>Consider use of asphalt surfaces made of polymer modified binders which raises the softening point of the asphalt</td>
<td>Painting train tracks with white reflective paint to reduce rail temperatures</td>
<td>Improve energy efficiency to reduce air conditioning cost and supply during extreme hot days in passenger terminals and transfer areas</td>
<td>Alter refrigerated storage specifications to meet demands of temperature changes and seek less energy intensive alternatives</td>
</tr>
<tr>
<td></td>
<td>Review operational procedures related to workforces operating in hot conditions</td>
<td>Check the stability of the track and replenish the ballast that surrounds the sleepers, and re-tensing continuously welded rail</td>
<td>Alter refrigerated storage specifications to meet demands of temperature changes and seek less energy intensive alternatives</td>
<td>Improve energy efficiency to reduce air conditioning cost and supply during extreme hot days in passenger terminals and transfer areas</td>
</tr>
<tr>
<td></td>
<td>Review or augment firebreaks adjacent to road way and undertake increased fuel reduction strategies</td>
<td>Improve energy efficiency to reduce air conditioning cost and supply during extreme hot days in passenger terminals and transfer areas</td>
<td>Review operational procedures related to workforces operating in hot conditions</td>
<td>Review operational procedures related to workforces operating in hot conditions</td>
</tr>
<tr>
<td>Climate Risk Category</td>
<td>Road</td>
<td>Rail</td>
<td>Airports</td>
<td>Ports</td>
</tr>
<tr>
<td>-----------------------</td>
<td>------</td>
<td>------</td>
<td>----------</td>
<td>-------</td>
</tr>
<tr>
<td>Sea-level rise impacts</td>
<td>Explicitly consider climate risks when planning for new infrastructure or upgrades to existing infrastructure. Consider phased relocation of supporting assets outside of areas vulnerable to climate change impacts. Review and upgrade evacuation routes and procedures. Where possible, diversify spread of assets across geographical regions to distribute climate change risks.</td>
<td>Explicitly consider climate risks when planning for new infrastructure or upgrades to existing infrastructure. Consider phased relocation of supporting assets outside of areas vulnerable to climate change impacts. Where possible, diversify spread of assets across geographical regions to distribute climate change risks.</td>
<td>Explicitly consider climate risks when planning for new infrastructure or upgrades to existing infrastructure. Consider phased relocation of supporting assets outside of areas vulnerable to climate change impacts.</td>
<td>Explicitly consider climate risks when planning for new infrastructure or upgrades to existing infrastructure. Assess impacts of sea-level rise on unloading activities (e.g. space between top of vessel and crane arm during unloading, wharf height, etc.) Incrementally increase structure heights and/or reconfigure structure design to meet sea-level rise and storm surge predictions. Consider how climate impacts to supply chains may affect seaport operations. Assess implications of ship clearance under bridges and other obstructions with a higher mean sea state. Raise floor levels in storage areas designated for dry cargo that could be spoiled by flood (e.g. animal feed, biomass).</td>
</tr>
</tbody>
</table>
3.4 Evaluation of options

Adaptation options will vary widely in the cost, time and effort they take to develop and implement. As such, evaluation of adaptation options should be based on a number of factors or criteria such as extent and tolerance of the risk (including acceptable service levels for infrastructure), available resources, time and leadership, practicality of implementation, community acceptance, and other factors.

Information typically needed to support an option evaluation can include:

- the time required to implement the action
- the lead up time required to plan, seek planning approvals, and obtain approvals
- a cost estimate of the action (which helps to develop an indication of the time that may be required to obtain the funding)
- the form and length of engagement with the community and other stakeholders about some of the actions (this is important because some actions may be highly controversial, and may require lengthy periods of consultation in order to get a social licence to act)
- an indication of other benefits that may result from implementing the option
- the implementation and other risks that may accompany the selection of the option.

Further guidance on selecting and evaluating options is provided in CoastAdapt, C-CADS Steps 3 and 4.

In this regard, there are many different options and tools available to assess the relative cost and benefits of options. As outlined in CoastAdapt these methods include cost-benefit analysis, cost-effectiveness analysis, cost-minimisation and multi-criteria analysis, just to name a few. For more information about assessing costs and benefits refer CoastAdapt Information Manual 4, *Assessing costs and benefits of adaptation* (Wise and Capon 2016).

3.5 Adaptive pathways

As outlined in CoastAdapt, a pathways approach to adaptation planning is about keeping options open and so avoiding path dependency and lock-in. It provides structure and guidance to help incorporate flexibility into adaptation planning and can reduce unnecessary expenditure that may not be the best solutions for what is a long-term and on-going problem.

Under the pathways approach, rather than determining a final outcome or decision at an early stage, decision makers are able to build a strategy that will follow changing circumstances over time. The approach acknowledges that while not all decisions can be made now, they can be planned, prioritised and prepared for. As such, it is a useful approach for dealing with uncertainty, especially in cases where the uncertainty may reduce over time, for example with improvements in estimates of future local sea-level rise.

There are a number of different ways to undertake an adaptation pathways approach, but in general the approach covers the following:
• Defining and scoping the areas of decision-making including determining the objectives or a vision of what success might look like. The results of this scoping exercise can be used to identify stakeholders and elicit their values.

• Determining thresholds and trigger points. Achieving this step is likely to involve stakeholder consultation and/or interrogation of future climate change scenarios and projections.

• Determining the range of adaptation options and their lead-times and then making an evaluation of each option in terms of a set of criteria involving cost, community acceptability, time to implement, technical complexity etc.

The timing of adaptation activities can be very important. For example, it makes sense to delay expensive engineering retrofits until threats are more immediate. Alternatively, the implications of sea-level rise need to start to be considered as part of land use planning decisions on ports and in the context of new port infrastructure that will be expected to have a design life into the latter part of the 21st century and beyond.

Complementary to the pathways approach, these Guidelines set out a simple framework for setting triggers for when adaptation actions should be considered based on a continuum model shown in Figure 3.3. This model was originally developed in Fisk and Kay (2010) and reproduced more recently in LGAQ (2016).
Figure 3.3: Framework for setting adaptation action triggers.
SECTION 4.0 Developing a strategy, current practices and evaluating success

4.1 Documenting a plan or strategy

Following an evaluation of management options and consideration of the adaptive pathways approach, C-CADS identifies the need for preparation of an adaptation plan or strategy.

In general terms, an adaptation plan or strategy will include the following contents or headings:

- A local context and introduction.
- A methodology (where the plan or strategy is underpinned by a technical assessment or a risk assessment process).
- An understanding of the vulnerability of assets and operations to various aspects of climate change.
- Adaptation vision or goals and underlying principles.
- An action plan or similar set of policies and measures to build resilience and adapt.
- How the plan will be implemented, monitored and evaluated including roles and responsibilities.

However, it should be noted that stand-alone plans or strategies are not the only way to effectively address the issue of climate risk. Transport infrastructure authorities and organisations can consider these issues as part of suite of existing documentation such as master plans, land-use plans, design guidelines, asset management registers and operational plans, policies and procedures. The key here is to make sure all relevant departments and functions are aware of the risk issues and that decision-making is cognisant of the risks and identifies appropriate responses.

4.2 Communicating risk and stakeholder engagement

One of the most challenging engagement aspects of climate change adaptation is communicating the risk of future impacts – particularly where an adaptation solution is not yet able to be clearly articulated. This may be the case both for internal stakeholders of a transport organisation (such as boards and shareholders) as well as external stakeholders, users, customers and the broader community.

Climate risk communication can occur along a broad spectrum of involvement and engagement processes but generally is useful when the following key messages can be set out:

- Clear statements of the key climate change risks and how they could impact assets and operations (even where the timing of such impacts are uncertain).
- Reference to or release of a vulnerability or risk assessment process (including for instance maps of current and future hazard areas) if relevant.
- The rationale for why some sort of adaptation response is required.
• Current activities being undertaken by the infrastructure authority or organisation to address the future risk (in the form of an adaptation strategy or similar).

• Plans by the infrastructure authority or organisation to address the future risk (in the form of an adaptation strategy or similar).

• The roles and responsibilities of the infrastructure authority or organisation versus other managers and stakeholders in tackling the problem.

As outlined in CoastAdapt, stakeholders, whether they are internal or external, have a variety of experiences, skills, knowledge and values, that are often developed with direct experience of the locality of the plan being developed. These attributes and local knowledge—through awareness of local risks combined with experience of options that have been tried elsewhere—enable stakeholders to identify and suggest potential adaptation options and strategies.

There is a range of different approaches to engage stakeholders in identifying options. Many of these are listed in CoastAdapt Information Manual 9: Community Engagement (Smith, Leitch & Thomsen 2016). In selecting the approach or approaches to use, the transport organisation should consider the objectives of the exercise, the time and budget available and the expertise available to assist with the engagement exercise.

Transport infrastructure authorities and departments can have a particularly important influencing role with other stakeholders, particularly in regional and rural areas where they are a major driver of economic prosperity and job creation. This can include working in partnership with city and council governments and supply chain logistics infrastructure providers to appropriately plan and design connected logistics hubs resilient to the impacts of climate change relevant for the area. Authorities can also investigate opportunities to diversify suppliers across geographic regions to decrease impact from weather-based events for a particular region.

4.3 Evaluating (and re-evaluating) success

The final steps of the C-CADS process are implementation, and monitoring and evaluation.

In considering the effectiveness of a transport infrastructure authority or organisation’s response to climate risk and associated strategy, any evaluation should be linked to the goals and success criteria set earlier in the C-CADS adaptation planning cycle. The triggers set for future adaptation action (as illustrated in Figure 3.3) can also form the basis for monitoring indicators of climate impact trajectory and the need for additional or new responses.

Key indicators in the context of organisational readiness may include the following.

• **Information Capacity** – addressing issues such as availability and access to relevant information; credibility and accuracy of the information, communication about the information, translation of information and levels of knowledge and awareness.

• **Institutional Capacity** – leadership and commitment on the issue at board and senior management levels; cooperation and institutional governance structures, stakeholder awareness and expectation; regulatory compliance; incentives; reporting and monitoring.

• **Resource Capacity** – availability of funds; access to external and internal funding sources; availability of staff resources; availability of expertise.
At an asset or operational level indicators and triggers could include those listed in Table 4.1.

**Table 4.1: Example adaptation action indicators/triggers**

<table>
<thead>
<tr>
<th>Financial/built environment indicators</th>
<th>Physico-environmental indicators</th>
<th>Workforce health and safety indicators</th>
</tr>
</thead>
<tbody>
<tr>
<td>• replacement costs for assets (set as annual budget or similar)</td>
<td>• when erosion scarp reaches within defined distance from of existing asset (e.g. 50 m)</td>
<td>• deaths or injuries attributable to hazards</td>
</tr>
<tr>
<td>• damage costs to assets</td>
<td>• when estimated or modelled hazard line occurs within defined distance of existing asset (e.g. 50 m)</td>
<td>• loss of work productivity or time due to hazards</td>
</tr>
<tr>
<td>• increased maintenance frequency or costs for assets</td>
<td>• measured extent of sea-level rise (with different depths for different development types) as an indicator of increased storm tide risk</td>
<td>• frequency of stop workages due to hazards</td>
</tr>
<tr>
<td>• acceptable days or hours of shutdown/closure</td>
<td>• measures extent of storm tide and/or flooding impact</td>
<td>• number and extent of evacuations</td>
</tr>
<tr>
<td>• acceptable days or hours of suspended or reduced work practices</td>
<td>• depth of inundation events (depth in m) across property</td>
<td></td>
</tr>
<tr>
<td>• acceptable days of loss of use of a particular asset or group of assets</td>
<td>• frequency of coastal or flood inundation events (times per year or season)</td>
<td></td>
</tr>
<tr>
<td>• cost/availability of insurance for one or more assets</td>
<td>• frequency of very hot days (over 35 °C)</td>
<td></td>
</tr>
<tr>
<td>• full or partial engineering failure of an asset</td>
<td>• frequency of extreme hot days (over 40 °C)</td>
<td></td>
</tr>
<tr>
<td>• approaching the end of the life of an asset</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Where vulnerability or risk assessments have been developed, the resultant risk registers provide a useful basis for monitoring and re-evaluation of risks or vulnerabilities over time. Recommended timing for this should be between –three to ten years from the original risk assessment.

Ultimately though, the transport authority or organisation will need to continually evaluate and re-evaluate its risk tolerance as it moves down an adaptation pathway.

### 4.4 Current practices

Desktop research as well as targeted interviews with industry professionals identified a range of documents, guidelines, strategies, projects, plans and practices being undertaken by coastal transport infrastructure organisations in the climate change adaptation space. A summary of these
documents and practices are provided in Appendix A for all classes of transport infrastructure as well as specific examples for road, rail, airports and seaports and harbours from across Australia.

4.5 Conclusions

As demonstrated by the risks and vulnerability identified in these Guidelines, transport infrastructure owners and operators have compelling reasons to begin planning, building resilience and adapting now to climate risks.

To this end, the desktop research undertaken as part of preparing these Guidelines as well as comments from many of the transport industry representatives interviewed as part of the research (across road, port, airport and rail authorities) have indicated their organisations have either started or will shortly commence risk assessment processes to better understand their risks to future climate change both for existing assets and in the context of proposed expansion.

Drawing on the information, guidance and advice contained within CoastAdapt, these Guidelines provide a practical approach to addressing current and future climate risk on coastal transport infrastructure assets and operations as well as providing an overview of current practices being implemented across Australia.

While a broad range of potential resilience and adaptation measures have been identified, it should be noted that climate risk management is a ‘long game’ issue and there is no single approach or tool that will effectively address the issue of climate risk in the short term. Instead, those transport infrastructure authorities and organisations that have a sound awareness of their risks and vulnerabilities and can implement an adaptive approach over time will be most prepared.
References


Department of Climate Change and Energy Efficiency (2011). *Climate change risks to coastal buildings and infrastructure a supplement to the first pass national assessment*. Australian Government: Canberra.


Department of Planning, Transport and Infrastructure (2015). *Climate change adaptation guideline for asset management*. Department of Planning, Transport and Infrastructure: Adelaide.


APPENDIX A – Current practices

A.1 General guidance for transport infrastructure

ALL TRANSPORT INFRASTRUCTURE

Climate Change Adaptation Guideline for Asset Management (Department of Planning, Transport and Infrastructure 2015)

As a manager of significant State infrastructure with a long asset life, the South Australia Department of Planning, Transport and Infrastructure (the Department) has a responsibility to protect its assets against the potential risks of climate change, and ensure that new infrastructure is designed to withstand future climate conditions.

In 2015 the Department adopted a Climate Change Adaptation Strategy, which commits the Department to assessing and responding to future climate risks. The Climate Change Adaptation Guideline has been developed to assist Departmental staff in the implementation of the Strategy by providing a process for considering future climatic risk and treatment options in the management of the Department’s projects, assets and operations. It describes when climate change risk should be considered and how treatment (adaptation) options can be identified for the short and long term.

The Guideline outlines that climate change risks should be considered whenever planning work or risk assessments are undertaken for an asset or program. This includes:

- regular, ongoing risk assessments for existing assets and programs
- risk assessments undertaken during concept development and project initiation/planning phases.

ALL TRANSPORT INFRASTRUCTURE

Australian Green Infrastructure Council for Climate Change Adaptation (AGIC 2011)

Accessible via the New South Wales Government home page AdaptNSW, this guideline has been developed by the Australian Green Infrastructure Council (AGIC) to inform industry on climate change risks and opportunities presented for new infrastructure projects and existing assets.

It provides a roadmap for developing appropriate adaptation measures, noting the benefits of addressing climate change risks and opportunities include satisfying approval requirements, reducing risk and incorporating ‘win-win’ features.

The guidelines note that adaptation measures to address climate change vulnerability can include both ‘structural’ and ‘non-structural’ measures. Structural measures are physical changes to the infrastructure to achieve or facilitate adaptation and non-structural are other measures such as changes to contracts or implementing an emergency management plan.

This guideline also provides an explanation about climate change adaptation assessment to align with the AGIC Rating Scheme and a range of adaptation measures using industry examples.
ALL TRANSPORT INFRASTRUCTURE

CoastAdapt Information Manual 7: Engineering Solutions for Coastal Infrastructure (Webb 2016)

This CoastAdapt information manual summarises engineering functions and organisations and the roles they have played and continue to play in the coastal environment. It should be read in conjunction with the other information manuals in CoastAdapt, as sound engineering decisions cannot be made without solid understanding of climate change processes and other hazards; interaction with the environment, policy, planning and legal frameworks; and the need to engage the community.

A particular focus of this information manual is a series of three coastal engineering guidelines issued by Engineers Australia’s National Committee on Coastal and Ocean Engineering (NCCOE). These guidelines provide – not only for coastal specialists, but also for related professionals – methodologies, recommendations and sources of information especially relevant to CoastAdapt.

This manual provides information about the following topics:

• The role engineers play in adapting coastal infrastructure and developments (existing or planned) to the possible impacts associated with climate change.

• The three coastal engineering guidelines issued by NCCOE on climate change and the broader topic of sustainability.

• Other standards, codes and guidelines of relevance.

• What coastal planners and managers can do to ensure sound engineering practice is adopted, taking into account the effects of projected changes in climate.

• Some of the traps associated with inappropriate action.

• How to decide whether coastal engineering expertise is required.

• Where to find such expertise.
A.2 Guidance for roads

Western Australia, Department of Main Roads (Main Roads, Western Australia 2017). 
https://www.mainroads.wa.gov.au/AboutMainRoads/AboutUs/Sustainability/Pages/ClimateChange.aspx

The Western Australia Department of Main Roads completed a report in 2011, ‘Major Roads at Potential Risk due to Climate Change’, identifying highways and main roads that may be at risk due to a rise in sea level. As part of this report, analysis was also undertaken on coastal communities to assist local authorities in identifying local roads at risk.

It is reported that two projects have specifically addressed risks identified in the report ‘Major Roads at Potential Risk Due to Climate Change’:

• Great Eastern Highway Upgrade – Kooyong Road to Tonkin Highway
• Great Northern Highway Port Hedland Realignment.

Other projects that have their climate change risks assessed to inform project planning and design during 2015/16 have been Gateway WA, Muchea-Wubin Program of works and NorthLink WA.

Initiatives that are planned or underway include:

• climate change risk assessments undertaken in project planning
• reviewing incident management procedures
• continuing review of current standards against impacts of climate change
• exploring options to offer benefits that counter climate change impacts
• adding climate change considerations to existing planning, development and delivery process reviews
• collaborating with stakeholders agencies to address shared climate change risks
• educating specific employees and contractors on the impacts of climate change and ways to adapt the assets over time ahead of climate change
• climate change considerations are being integrated into design standards and major roads are being incrementally adapted as upgrades or infrastructure investments occur.
The VicRoads Sustainability and Climate Change Strategy 2015-2020 sets out a framework that will guide the delivery of activities which will contribute to the environmental sustainability, and health and wellbeing objectives of the Transport Integration Act (Vic) 2010.

A supporting climate change risk assessment has been undertaken to summarise the work undertaken to assess the risks to VicRoads infrastructure associated with climate change parameters, as well as some appreciation of the timeframe and potential directions for climate change adaptation.

The greatest single climate change risk to VicRoads is reported as the impact on assets in coastal regions from sea-level rise. While these impacts are predicted in low lying areas across the entire Victorian coastline, the impact is likely to be greatest in the Eastern Region of the State, potentially through a combination of the overtopping of roads, impacts to pavement layers and the structure of bridges resulting in likely interruptions to network operations. Identified actions for responding to risks from sea-level rise include:

- confirming the projected sea-level rise and storm surge impacts through ongoing review and consultation
- confirming cost estimates for predicted impacts
- developing special bridge standards for flood prone areas
- identifying appropriate protective measures and situations and where they should be considered
- consulting with departments, catchment authorities and local government regarding options for rebuilding or realigning affected to routes to protect for sea-level rise and storm surges
- undertaking case studies to gain further insights into climate adaptation.
A.3 Guidance for rail

Sydney Trains, Climate Change Risk Assessment and Adaptation Management Plan (in preparation)
http://www.sydneytrains.info/about/environment/

Sydney Trains have developed and implemented a three-stage, systematic, evidence-based Climate Change Risk Assessment and Adaptation Masterplan, which quantifies and ranks the costs, impacts and risks of past extreme weather events to Sydney Trains’ rail infrastructure, safety, service performance, patronage and customers, and uses climate change projections, infrastructure standards, asset management planning, and cost-benefit analysis to identify the most effective adaptation strategies up to 2100. Current adaptation options being implemented include a cross-sectoral GIS adaptation planning tool, introduction of a new climate change objective into the Asset Management System Framework, development of an ambient environmental conditions and climate change standard for NSW Transport, a geographical and historical analysis of lightning activity affecting critical assets, development of extreme weather preparedness plans, introduction of an automated advanced weather warning system, and a program of tension regulation in overhead wiring.

Case Study on Adaptation of Melbourne’s Metropolitan Rail Network in Response to Climate Change (AECOM 2011)

The study focussed on the cost benefit analysis of commuter rail adaptation to climate change and particularly the delays from increased hot days impacting the Melbourne metropolitan rail network. Commuter delays are a strong indicator of network performance and reliability. The costs and benefits of reducing these delays through a range of climate adaptation options were assessed.

The cost benefit analysis revealed that the remainder of the adaptation options are prohibitively expensive ways to address risks of increased commuter delays. However, many of these options produce benefits other than reduced delays that have not been assessed. For example, concrete sleepers are expected to be more durable and long-living than the current timber sleepers which would significantly reduce the costs involved in maintenance of sleepers and increase the replacement intervals.

The take home message from the analysis was that adaptation measures that result in net benefits for the community also drive a range of other positive outcomes. This analysis is likely true across other rail network systems in Australia and worldwide.
Climate Change Adaptation Position Paper (Draft) – Assessing the Impact on Rail Infrastructure (Australasian Railway Association 2011)

This position paper includes recommendation on a structured framework and associated guidance to promote good decision-making. This should enable the rail industry to recognise and evaluate the risks posed by a changing climate, making the best use of available information about climate change, its impacts and appropriate adaptive responses. The paper reviews methods and techniques for climate risk assessment, and in particular gives guidance on the appropriate use of climate change projections/forecasting and modelling. Using these methods will be important in delivering adaptation responses that are successful in the face of an uncertain future.

Adapting large-scale infrastructure such as rail, to climate change, is a formidable challenge. Rail infrastructure is vast, has an extremely long useful life and decisions made now will have impact on whether or not future generations will be granted the same level of mobility and supply chain efficiencies we now experience. This initial analysis is the first step in adaptation planning for the rail industry. To succeed in future proofing critical infrastructure, the report notes that the industry will need to drive a long-term programme of activities aimed at mitigating a select group of important risks.

Tomorrow’s Railway and Climate Change Adaptation (Marteaux 2016)

This Executive Report, aimed at a non-specialist audience, presents the main findings and actionable insight that Rail Safety Standards Board (RSSB), working with a consortium led by Arup and with Network Rail, has derived from its research on Tomorrow’s Railway and Climate Change Adaptation.

Based on a gap analysis conducted on current preparations, and on identified good practice in the literature review (compendium) and among other national rail systems, the research project made a number of recommendations to improve the climate change resilience of the Great Britain rail network.

Many of these recommendations are equally relevant to an Australian context.
A.4 Guidance for airports

Brisbane Airport New Parallel Runway Project - as documented in a case study for CoastAdapt (NCCARF 2016b) -

This case study documents that process undertaken by Brisbane Airport to consider future climate risk as part of the development of the new parallel runway project. As the third busiest airport in Australia, continual increase in demand has resulted in the construction of a second parallel runway. Close to Moreton Bay, the airport is low lying. To ensure that the airport can operate continually over its projected lifespan, it was important to consider climate change implications in the design. Accordingly, a runway height of 1.5 m above the minimum regulatory requirements was adopted. Other climate change adaptation actions were also implemented including channels to reduce tidal flooding, and construction of a seawall. Stakeholder engagement around the design was considerable: conducted over a period of almost two years it implemented a range of engagement options.

North Queensland Airports Climate Risk Assessment - as documented in a case study for CoastAdapt (Fisk 2017) -

North Queensland Airports (NQA) operates the Cairns and Mackay Airports, which are situated on the tropical North Queensland coast. Cyclonic activity, flooding and storm surge can damage airport infrastructure as well as impact operations. Under future climate change and associated sea-level rise, these impacts are likely to intensify.

To better understand climate risks to the airports both now and in the future, NQA undertook an internal risk screening and risk assessment process using the mapping tools and guidelines published in CoastAdapt. The risk assessment looked comprehensively at current risks as well as future risks in 2030 and 2070, producing a risk register that will inform long term planning responses.
Chapter 10 of the Adelaide Airport’s Masterplan sets out the Environment Strategy for the Airport, which in turn includes a section on Energy and Climate Change (Section 10.11). The Strategy noted an adaptation study is underway to assess the impacts of future climate risk on aviation, infrastructure and habitat with the outcomes to be considered in future airport planning.

Additional information about AAL’s climate change initiative was reported in Australia’s National Climate Resilience and Adaptation Strategy (Australian Government 2015).

AAL sees climate change as both a business risk and an opportunity for sustainable development. It can affect airport infrastructure and operations in a variety of ways from physical and service impacts to financial implications. During an extreme weather event, for example, an airport may provide local shelter and support for aviation in disaster relief. When airports in one state or country deal with a climate risk, many other airports, both nationally and globally, are affected.

In its first climate change adaptation plan, due for release shortly, AAL has used the latest available climate science and projections from the Intergovernmental Panel on Climate Change (IPCC) and the Australian Government’s national science agency, the Commonwealth Scientific and Industrial Research Organisation (CSIRO). It has identified key climate risks and, where the existing comprehensive controls and operational plans required additional mitigation actions, these have been specified and will be integrated into key business documents and guidance.
A.5 Guidance for seaports


Developed as part of the NCCARF Report Series: Enhancing the resilience of seaports to a changing climate, these guidelines set out a structured framework for seaports to carry out a hybrid risk/vulnerability assessment process to understand and respond to climate change impacts. The guidelines note climate change impacts can be both direct (for example, a port operation experiencing more damaging storms or a higher mean sea level in future years compared to current conditions) and indirect (for example, a port operation experiencing water shortages as a result of drought affecting regional catchments, or electricity failure due to cascading effects on the power system due to extreme hot days and nights). The climate impacts may affect the economic profitability of operations, the environmental sustainability of the port, the types of trade goods going through the port and thus the functions of the port.

In terms of adaptation, the guidelines recognise that impacts can be dealt with on many levels of the port’s business, from forward planning and strategic governance, through the maintenance regimes of the physical infrastructure to human resources management. Adaptation options are identified for ports, including opportunities to build adaptive capacity through training, data monitoring, and research and a range of adaptation actions that require site-specific investigation.


The ‘Enhancing the resilience of seaports to a changing climate’ Report Series also undertook a study of port functional assets to assess their vulnerability to climate change, to model the potential impacts of climate-related extreme events, and to highlight possible adaptation responses. Assessments were undertaken in the above report based on participation of three case study port authorities at Port Kembla (NSW), Port of Gladstone (QLD) and Sydney (NSW).

Climate variables perceived as a concern to asset operability at all ports and at all logistic interfaces were flash floods and high speed winds, however, climate variables perceived as most concern at each of the study ports varied. At Gladstone Port Corporation, severe tropical cyclones were perceived as most threatening. At Port Kembla Port Corporation, high speed winds were most threatening; and at the Sydney Port terminal operator storm surge, tidal change and sea-level rise were perceived as most threatening.

The purpose of this guidance is to create awareness about the advantages of implementing a green port philosophy and about what this philosophy means at present for ports and port authorities around the world and community support for port growth. This is done by supplying tools and guidance that show how proactive environmental measures and strategies can contribute to obtaining consent for future operations and developments, how opportunities can be created through own initiatives (thereby remaining ahead of legislation) and how green growth can be realised.

Section 3.9 of the Guide briefly outlines information on climate adaptation with guidance on the challenges, issues, port authority perspectives, and various response options with references to various case studies and tools.