

Climate change adaptation guidelines for ports

Enhancing the resilience of seaports to a changing climate report series

Helen Scott, Darryn McEvoy, Prem Chhetri,
Fatima Basic and Jane Mullett



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Published by the National Climate Change Adaptation Research Facility 2013

ISBN: 978-1-921609-83-1 NCCARF Publication 12/13

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Please cite this report as:

Scott, H, McEvoy, D, Chhetri, P, Basic, F & Mullett, J 2013, *Climate change adaptation guidelines for ports. Enhancing the resilience of seaports to a changing climate report series*, National Climate Change Adaptation Research Facility, Gold Coast, 28 pp.

Acknowledgement

This work was carried out with financial support from the Australian Government (Department of Climate Change and Energy Efficiency) and the National Climate Change Adaptation Research Facility.

The role of NCCARF is to lead the research community in a national interdisciplinary effort to generate the information needed by decision-makers in government, business and in vulnerable sectors and communities to manage the risk of climate change impacts.

The authors would like to acknowledge the time and commitment of all the information providers and stakeholders that were involved in the project and actively contributed to the co-generation of knowledge. Particular thanks go to the CSIRO and the BoM, the case study ports, and key stakeholders; comprising Ports Australia, Transport & Logistics Industry Skills Council, Shipping Australia Limited, and the Maritime Union of Australia. Additional matching funds provided by RMIT University, the University of Queensland, and the Transport & Logistics Industry Skills Council also contributed to the program of research. Finally, we would also like to thank the anonymous referees for their valued comments and insights.

Disclaimer

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INTRODUCTION

Climate change adaptation is highly context specific, so generic adaptation actions cannot be adopted without appropriate site-specific investigation. For this reason, this research recommends port authorities undertake a location-specific climate risk assessment, building on the AS/NZS ISO 31000 Risk Management standard. There is not one 'correct' way to deal with climate change assessments, rather there are many approaches that could be taken (Dovers 2009; Fünfgeld and McEvoy 2011). However, risk management, as described below, is emerging as the most applicable method for assessing climate change and identifying adaptation options.

As ports are operational hubs for the logistics supply chain, it is appropriate for ports to undertake an assessment in partnership with key logistics providers and /or local governments. While climate change may impact ports locally, it is often disruptions to the supply chain and local infrastructure that compound disruptions at the actual port, emphasising the need to work collaboratively on a broader climate risk and adaptation strategy.

However, several barriers to climate adaptation have been recognised (Becker 2011, IAPH 2011, UKCIP 2007), including inconsistency between organisational planning timeframes (5 – 15 years) compared with climate projections of 30 – 90 years; as well as the uncertainty of local climate projections leading to decision-makers delaying action until there is perceived to be more certainty. To help address these concerns, this report proposes a hybrid “risk / vulnerability” approach to understanding and adapting to climate change. That is, consideration of current day vulnerabilities to extreme weather events, integrated with an assessment of future climate risks.

This guidance document distils some of the key research findings in support of decision-making. These insights can inform and strengthen individual port assessments, and be used to test assumptions held by ports. The following sections outline how this research can contribute to site-specific port risk assessments.

Climate adaptation can be generically divided into two categories (UKCIP, 2011):

1. building capacity for future change through awareness raising, skill development, data collecting and monitoring and research, and
2. the implementation of adaptation initiatives such as technological, engineering change, planning, design, legal/regulatory, insurance/financial measures and management system change.

Stage 4 of this report outlines some adaptation opportunities for Australian ports within these two overarching categories, which have evolved through this research project, and which may provoke thought and provide guidance.

WHAT IS ADAPTATION TO CLIMATE CHANGE?

Adaptation is defined by the Australian Government (Australian Greenhouse Office, 2006) as “actions in response to actual or projected climate change and impacts that lead to a reduction in risks or realisation of benefits”. While adaptation to climate hazards and risks can be reactive or anticipatory, it is important to note it is not an end point in itself, rather, it is an ongoing process. Several studies (UKCIP 2011b, AGIC 2010, HM Government 2011) have elaborated on the core principles that underpin effective adaptation, these include:

- Ensure executive understanding and commitment to adaptation
- Build or secure appropriate technical capability – to undertake climate risk assessments, and to assist with implementing adaptation options, and ongoing monitoring
- Work in partnership – climate impacts do not respect borders, working with relevant partners contributes to more effective outcomes
- Understand risks and thresholds – ideally identified and analysed through some form of risk assessment process
- Manage highest priority risks first, in a balanced way with non-climate risks
- Employ adaptive management principles to cope with uncertainty – that is, iterative decision-making, incorporating feedback, and testing / updating of assumptions
- Look for “no/low regrets” and “win-win” adaptation options - those that as well as reducing the risks of climate change impacts, help produce other benefits
- Avoid “maladaptation” – or actions that limit future adaptation options
- Ensure adaptation is effective, and is reviewed regularly – reducing risks without introducing unintended effects
- Ensure adaptation is efficient – long-term benefits outweigh the costs
- Adaptation measures are equitable – the effects of different adaptation efforts, and the costs should be considered across different groups/sectors

These principles look to strengthen both the process side of climate risk management, for example, ensuring executive understanding and commitment and working in partnership; and also look to the outputs and outcomes of the risk management process, such as avoiding maladaptation, and ensuring adaptation measures undertaken are effective and efficient. All principles are applicable to seaports in Australia.

MANAGING CLIMATE RISKS USING A HYBRID VULNERABILITY / RISK MANAGEMENT APPROACH

A climate risk assessment should form part of a port's broader risk management process. It identifies the risks to a port of existing and future climate hazards with the aim of providing data that enable decisions to be made about how and when to deal with hazards. Identifying risk is not a purely quantitative operation; it also involves qualitative decisions about the importance of the identified risks and which risks should be taken into account.

All ports will generally operate a risk management system, which may or may not be aligned with the AS/NZS ISO 31000 Risk Management Standard. This standard provides a structured approach to enterprise risk management. Modifying this approach to incorporate current day vulnerabilities to extreme weather events, as well as considering future climate impacts to create a “hybrid risk/ vulnerability” approach would appear to be suited to ports, in that it addresses two of the key barriers to effective climate change adaptation at ports, that of inconsistency in planning horizons and uncertainty of future localised climate projections. It has been noted (Becker et al 2011, IAPH 2011, UKCIP 2007) that the short organisational planning time-frame of between 5 – 15 years, does not facilitate consideration of impacts that may not materialise for 30 – 90 years. However, port infrastructure generally lasts beyond these short planning timeframes. Additionally, the uncertainty inherent in future climate projections, particularly at the downscaled local level, can lead to decision-makers deferring action on climate change until there is perceived to be more certainty in projections. Addressing current vulnerabilities, identified through a hybrid assessment framework can be one way to overcome this inertia.

Our recommended approach is underpinned by the risk management process outlined in the international standard, AS/NZS ISO 31000:2009 (Figure 1). The ISO standard includes the key steps of:

- Establishing the context
- Identifying risks
- Analysing risks
- Evaluating risks
- Treating the risks

These steps are buttressed by ongoing communication and consultation throughout the process, and monitoring and review. This process is traditionally referred to as a “top-down” risk assessment process (Jones and Preston, 2011).

The seaward-side of operations (ship movement and mooring, loading and unloading) and the supply chain hinterland (road and rail movement, intermodal hubs) were found to be most affected by current climate variability. Continued research is needed into the modelling of seaward variables of concern, future extreme events and possible consequences, and the impact on wider supply chains.

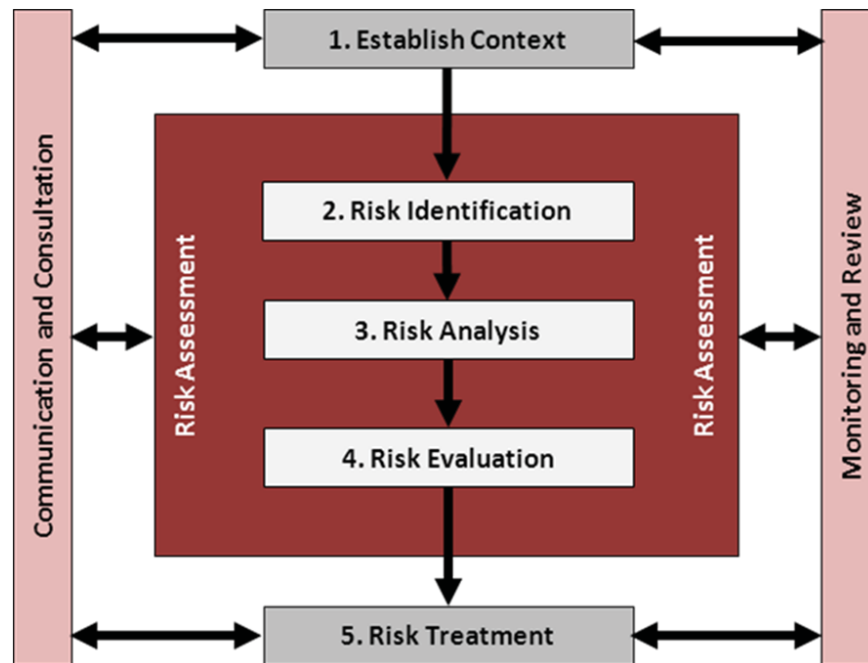


Figure 1: International standard for risk management: ISO 31000: 2009 (Standards Australia, 2009)

The key modification to this standard process is the integration of primary data from port personnel to determine current “vulnerability” (Figure 2). Jones and Preston (2011) refer to this as a “bottom-up” approach. For this project the following understanding of “vulnerability” was used:

‘The degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity.’ (McCarthy et al. 2001)

This definition is usefully elaborated on by the Intergovernmental Panel on Climate Change (IPCC, 2007), which noted that vulnerability consists of three main elements:

- **Exposure** to a hazard (for this project, the extent to which a port may be subjected to heatwaves, intense rain events, sea level rise and so forth);
- **Sensitivity** (the degree of negative impact on the port’s human resources, infrastructure, and assets); and
- **Adaptive capacity** (of the port’s human resources, assets and infrastructure to manage that impact).

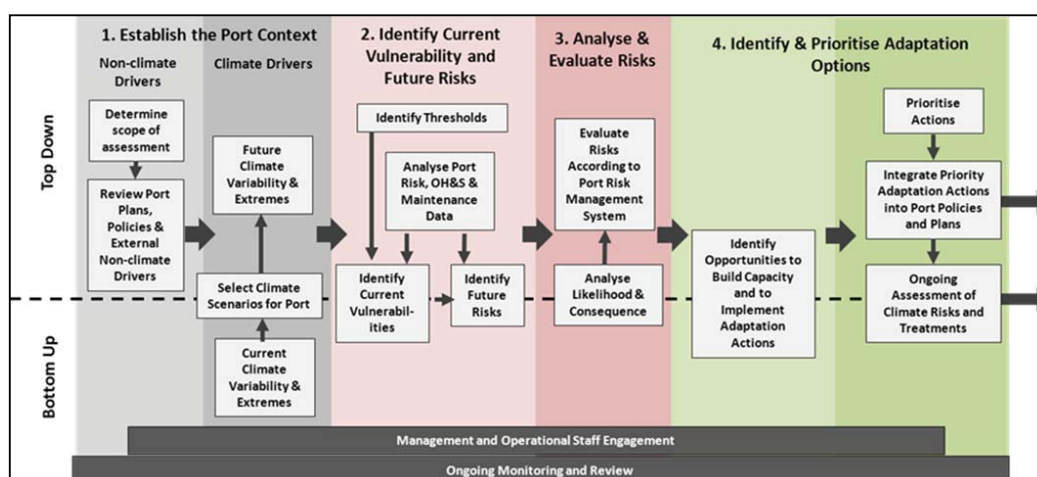


Figure 2: Hybrid Vulnerability / Risk Assessment Process for Ports

The following sections of this report outline the key steps involved as part of a hybrid climate risk / vulnerability assessment. There are numerous tools and guidelines available to assist ports with this process. This report does not try to replicate those guidelines, rather it aims to outline the overarching process and contextualise each step by using examples drawn from the case study ports for this project, and from existing climate change assessment studies from the international sea ports sector. Examples of adaptation plans have been sourced from the United Kingdom, including 9 Harbour Authorities in England and Wales, the port of New York and New Jersey in the USA and Cartagena in Colombia. These public reports provide a substantial repository of applied information.

STAGE 0: GETTING STARTED – EXECUTIVE SUPPORT

One of the core principles of effective adaptation is ensuring executive understanding and commitment to adaptation. While the process of undertaking a risk assessment may help build greater understanding and commitment, ideally executive support needs to be there at the outset of the assessment and adaptation process. Project proponents may need to do some initial research and project scoping to develop a sound business case for action. The importance of ‘champions’ should not be underestimated as the involvement of all three case study ports in this study highlighted.

STAGE 1: ESTABLISH THE PORT CONTEXT

The impacts of climate change are 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. 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. The impacts may have either a negative or positive bearing on the port's business, and there is also a possibility that there will be little significant direct impact.

Initial scoping of the project will determine the key stakeholders to involve through the process, and identify whether the port should work in partnership with its local government authority, or other members in its supply chain, such as road and rail logistics providers, or commercial operators at the port. Working in partnership with others is a core principle of effective adaptation. Involving others in the initial risk assessment process helps to engage them as part of identified adaptation options later. Figure 3 lists the key stakeholders involved as part of the Port of Dover climate change adaptation assessment.

Whether direct or indirect, climate risks are context specific, and a hybrid assessment approach requires an understanding of both the current context, as well as understanding of the future context for the assessment. This includes defining the internal and external parameters to be taken into account when identifying and managing risk (Standards Australia, 2009). Internal parameters take into account such things as the objectives and scope of activities of the port currently, and for a defined period of time in the future, for example, 2050 or 2100. Port of Dover, for example, included the organisational structure and function, main shipping activities, statutory functions, missions, aims and objectives within its scope (Figure 3).

At this stage of the assessment, ports need to define the criteria that will be used to evaluate the significance of the risk, reflecting the port's objectives and resources, and their tolerance for risk. Evaluation criteria for Port of Dover included financial, reputational, service and safety categories (Figure 3). The risk assessment for Terminal Marítimo Muelles el Bosque in Cartagena, Colombia, included legal, financial, environmental, local community, operational, health and safety, reputational and external stakeholder criteria (Stenek et al, 2011).

For the case study ports of Gladstone Ports Corporation (at the Gladstone site), Sydney Ports Corporation (at the Port Botany site) and Port Kembla Port Corporation, the scope of the study focused on infrastructure, functional vulnerability, and the adaptive capacity of the people working at ports. Therefore, the internal parameters considered by this project were:

- Core operational assets of ports (as part of logistics vulnerability assessment, **work package 2 – functional resilience of the port environs**)
- Port workforce (investigating adaptive capacity, **work package 2 – functional resilience of the port environs, section 7**).

- Built infrastructure (as part of materials deterioration analysis, **work package 3 – structural resilience of core port infrastructure**)

The research focused on the immediate port environment, rather than assessing upstream impacts to the supply chain. To that end, the onsite built infrastructure assets that were considered as part of the engineering analysis for WP3 included transport infrastructure (road and rail) and landside infrastructure (berthing structure, protection barriers, buildings) in terms of the vulnerability of component materials – concrete, steel and timber.

The functional vulnerability of the ports was investigated through the core operational assets, which varied between the different ports. The first stage of the functional vulnerability assessment involved compiling an asset register for each of the ports, mapping core operational assets (COAs). These were defined as assets directly related to the trans-shipment logistics function. These were grouped according to their physical location in the port; land-side COAs, sea-land COAs, or sea-side COAs.

Finally, the people who work at the ports were brought into the assessment through consideration of their adaptive capacity to climate risks. Through interviews and workshops, enablers of and barriers to adaptive capacity such as skills, organisational culture and management systems, were considered.

External parameters include both climate and non-climate drivers. Analysis for the seaports project considered the following non-climate variables (**work package 1 – understanding future risks, section 7.5.**):

- Demographic change, that is, anticipated population growth and the impacts of an aging population;
- Settlement patterns, reflecting largely continuing urbanisation along the Eastern seaboard of Australia;
- Economic change including expected growth in both container imports, and bulk materials exports, but volatility in some of the growth exports such as agriculture
- Technological change including the trend to larger and more efficient ships, reduction in noxious emissions and automated logistics handling at ports; and finally
- Institutional and policy change.

Where a climate risk assessment breaks from the traditional ISO Risk management approach, is that it specifically considers current weather drivers and impacts, as well as building in future climate scenarios. Scenario analysis is one of the tools often employed as part of climate adaptation assessment and planning. This is a process of identifying possible futures (given a set of parameters), and analysing selected events given those possible futures. The IPCC climate scenarios, for example, focus on the likely level of global greenhouse gas emissions, given a certain set of parameters, such as global population change, economic growth and the effectiveness of global policies to mitigate greenhouse emissions. This then leads to an assumed level of greenhouse gas emissions, and a range of modelled climate impacts. To undertake a climate risk / vulnerability assessment, considering climate risks at a point in the future, ports need to select particular future climate scenarios, and associated modelled climate variables.

Determining the climate information that will be used in the assessment can be as simple as choosing 'off the shelf' parameters (such as Port of Dover) given by the relevant government authority, or as complex as working directly with climate scientists on specific 'downscaled' information. However, because of the potential complexity and uncertainty of the information, it is always necessary to declare the origin of the climate data and the underlying assumptions.

Figure 3 summarises the context elements considered by Port of Dover. It is taken from the Port of Dover Climate Change Adaptation Report (Port of Dover, 2011), which responds to a set of UK government directives, and has a clear scope for its assessment. It uses "off the shelf" climate information, for a high emissions scenario, for the years 2020, 2050 and 2080.

Climate Change Adaptation Report March 2011, Port of Dover
<p>In accordance with the direction from the Secretary of State this report will contain:</p> <ul style="list-style-type: none"> a) an assessment of the current and predicted impact of climate change in relation to the reporting authority's functions; b) a statement of the reporting authority's proposals and policies for adapting to climate change in the exercise of its functions and the time-scales for introducing those proposals and policies <p>The context included:</p> <p>The organisational structure and function, including main shipping activities, statutory functions, mission, aims and objectives.</p> <p>Weather is a key consideration of Port of Dover operations, therefore "present day" weather impacts were identified, "future" impacts and known thresholds.</p> <p>The assessment was carried out using the probabilistic output data of the United Kingdom Climate Projections (UKCP09), using a high emissions scenario for the years 2020, 2050 and 2080 (Port of Dover, 11)</p> <p>Stakeholders of the Port of Dover can be categorised as:</p> <p>Transport operators and infrastructure providers (the key stakeholders), statutory bodies, customers, tenants, interested others (Port of Dover, 9-10)</p> <p>The same methodology to assess all risks affecting the Port was used, with the key evaluation criteria categories of financial, reputation, service and safety.</p>

Figure 3: Contextualising the scope of the assessment

The 'Climate Resilient Seaports' project sourced observed and past climate information and its localised impacts from the Bureau of Meteorology for long term trends and detailed weather information; the Disaster Database at Emergency Management Australia for examples of historically relevant climate 'disasters', and first-hand knowledge from the ports. To determine the particular climate variables of most importance to the case study ports, an initial workshop was held with a cross-section of stakeholders. Phenomena of particular interest to ports in this study related predominantly to their experiences of extreme weather events; intense rainfall events, storms (including cyclones) and related storm surges, strong wind gusts, and to some extent, fog and heatwaves (Figure 4). Incorporating this ground-up knowledge is fundamental to understanding local impacts of extreme weather events.

Future climate projections were guided by the IPCC scenarios, CSIRO modelling (OzClim), state government climate advice, and existing climate change studies undertaken by the ports. The IPCC A1FI and A1B climate scenarios for the years 2030, 2050 and 2070 were used. The CSIRO "climate futures program" identified a range of possible climate futures. They included:

- “most likely future” using the MRI 2.3.2 model;
- “hot/dry future”, using the CSIRO MK 3.5 model
- “cool/wet future”, using the MIROC MedRes model, and finally,
- “wetter future”, using the MIROC HiRes model. Note, this last model was chosen for its inclusion of the “sea-salinity” parameter, which was required by WP2, and not present in other models. **(work package 1 – understanding future risks)**

WP2 used the “hot/dry” future, CSIRO MK 3.5 model outputs for the year 2030. Within this “future” WP3 were able to access ‘days over 35°C and days over 40°C’.

The ports were particularly interested to know how current extreme weather events would change in the future, that is, what was the likelihood of increased intensity of rainfall, increased intensity of storm events and related storm surges, velocity and directional changes of wind, changes in sea level rise and wave behaviour. There was additional interest in changes to sea surface temperature, and the engineering research team (WP3) were particularly interested in changes in humidity, and salinity of local waters. Figure 4 summarises the most important climate impacts identified by port stakeholders at a workshop in Sydney, 2011.

Identification of the most important climate impacts – feedback from stakeholder meeting – held in Sydney, 18 November 2011

On the sea side:

In general there were more concerns for the sea side of the operations than the land side.

Severe storms and/or cyclones leading to storm surge creating difficulties at the berths, leading to lost work time or port closure (winds greater than 35 knots is a critical threshold for some ports). NB: Cost of closure can be estimated using loss of income from port cargo charges

Intense rain could affect bulk shipping for short periods of time

Most ports have factored in sea level rise to the respective state governments specifications at the time of the workshop (0.5m by 2050 and 0.8m or 0.9m by 2100) and all new infrastructure is built to accommodate this possibility. It will be an issue with preserving the operational life of older infrastructure.

Inundation of some older terminal areas is a concern for some ports

Older breakwaters could be vulnerable to overtopping in storms and with sea level rise

Water temperature, indirect effects on the barrier reef, could affect tourism

Water temperature, affects the type of organisms that can live on a ship's hull – invasive pests, hull cleaning and quarantine procedures

On the land side:

Duration of rain leading to flooding and port closures is more of a problem than sudden intense rain, impacts on commodities held at the port

Flooding in relation to land/sea front issues such as erosion

Heavy rains give rise to storm surges and drainage issues

Temperature- case study ports are not directly susceptible to high temperature (some consideration for the impact of heat on pavement, melting asphalt). However, rail transportation could slow down due to heat, power failure possible.

Temperature affects machines as well. It should be noted that actual ground temperature will be different to BOM data that includes the influence of air cooled by the sea.

Heat - prolonged drought leads to rationing the water used in operations

Heat – workforce - all crane operators etc. stay in air conditioned environs.

Dust storms – have affected ports in the past

Figure 4: Outcomes from the Sydney stakeholder meeting

STAGE 2: IDENTIFY CURRENT VULNERABILITIES AND FUTURE RISKS

The Risk Management standard asks organisations to identify the sources of risk, the areas of impact, and their potential consequences (Standards Australia, 2009). The Australian Government's Guide to Climate Change Impacts and Risk Management suggest businesses "describe and list how climate changes impact on each of the key elements of the organisation" (AGO, 2006: 19). A hybrid approach is essentially capturing the "bottom-up" or vulnerability led approach, which directs ports to start with the identification of known climate impacts using past and current meteorological data and local knowledge, as well as the "top-down" or scenario-led approach which takes the information from the Global Climate Models and refines it to create information at a regional scale.

Some indicative risks, compiled from the climate risk assessments of nine UK port authorities, accessible on the DEFRA website include:

Table 1: Indicative climate risks for UK ports (DEFRA, 2012)

Climate Variable	Indicative Risks
Increased intensity of rainfall	<ul style="list-style-type: none"> - Extreme flooding could lead to loss of radar and radio equipment - Capacity overload of the drainage system may lead to flooding and consequently erosion of road, railway foundations, cause pollution, flooding of stacking and stockpiling yards and lack of road access - Damage to storage buildings due to flooding
Heatwave	<ul style="list-style-type: none"> - Higher risk of rail track buckling - Higher deterioration rates of pavements and roadways - Higher energy consumption of refrigerated containers
Increased intensity of storms	<ul style="list-style-type: none"> - Closure of linked modes of transport, affecting supply and distribution of goods to and from the ports - Toppling of containers in stacking yards
Increased intensity of storm surge	<ul style="list-style-type: none"> - Increased wave action at waterfront structures and consequently an increase in overtopping rates, hence flooding of berth facilities - Beach erosion
High speed winds	<ul style="list-style-type: none"> - Damage to navigation and communication equipment - Delays/stoppages to unloading/loading vessels - Damage to older buildings and warehouses
Other	<ul style="list-style-type: none"> - Reputation of port operator damaged by impacts of a severe weather incident - Insurance premiums rising due to growing global losses from weather-related incidents

The approach taken by this project was to identify the current vulnerability of core operational assets (COAs); specifically their exposure and sensitivity to identified extreme weather impacts using a qualitative assessment approach. For each of the three ports, the most pertinent “extreme weather events” were identified collaboratively with the ports (a group stakeholder workshop, and individual port stakeholder conversations). Representatives were then asked to rate the level of impact on the asset, using a score of 1 – 5, where 1 represented not at all vulnerable, and 5 represented operations ceased for several weeks (**work package 2 – functional resilience of the port environs**). The following Table 2 summarises some of the vulnerabilities of the COAs identified for one of the ports. It presents just those assets perceived to be significantly or moderately vulnerable (as defined in the table).

Using an agent-based model developed by WP2 for the project, disruptions to or sub-optimal performance of workflow caused by extreme weather events can be modelled and potential future risks identified under different extreme weather event scenarios. (**work package 2 – functional resilience of the port environs, Section 6**).

Particular weather variable thresholds were identified at each port. There were both quantitative and qualitative variables. Quantifiable variables included specific temperature thresholds which triggered extra work breaks for the workforce, or stop-work, and wind speeds that triggered stop-work and machine lock-down procedures. Qualitative variables included fog and intense rainfall, that is, there was no recorded volume of rain or density of fog that triggered particular work procedures, a qualitative assessment was undertaken by personnel during the event.

In exploring the adaptive capacity of the workforce, WP2 discussed the exposure to extreme events, and the sensitivity of the workforce, addressing what systems and controls were in place to reduce vulnerability and improve adaptive capacity. This was undertaken very much as a “bottom-up” exercise, involving interviews with port staff. (**work package 2 – functional resilience of the port environs, section 7**).

As WP3 was addressing long-term, gradual change (through materials deterioration rates of such things as concrete, timber and steel), rather than catastrophic failure potential of infrastructure elements, it did not explore the current vulnerability, but focused on future risks. These risks were identified by processing a variety of future climate scenario parameters through climate linked deterioration models developed by the engineering research team (**work package 3 – structural resilience of core port infrastructure**).

Table 2: Operational assets vulnerable to climate variables at a case study port

Climate variable	Asset Vulnerability			Current effects of climate variable
	Interface	Significant (operation down for days)	Moderate (operation down for hours)	
FLASH FLOODS	SEA-LAND	<ul style="list-style-type: none"> • shore cranes 	<ul style="list-style-type: none"> • multi-trailers (roll trailers) 	Flash flooding can cause the entire port to close. This was the case in 2011 during February and March where three days of rain caused the port to close while several truck-loads of sand were brought into the terminal area to prevent straddle slippage as oil had risen above the water
	LAND	<ul style="list-style-type: none"> • yard cranes • rail trucks 	<ul style="list-style-type: none"> • trucks • straddle carriers 	
HEAT WAVE	SEA-LAND		<ul style="list-style-type: none"> • pilot / port control room / vts • communication equipment • shore cranes • multi-trailers (roll trailers) • power supply 	The ports temperature policy states that at 36 degrees, breaks become longer and at 38 degrees, operations related work ceases.
HEAT WAVE cont.	LAND	<ul style="list-style-type: none"> • rail tracks 	<ul style="list-style-type: none"> • trains • trucks • roadways • storage areas • warehouses 	Current day conditions – temperatures exceed 38 degrees Celsius once annually
STORM SURGE	SEA-LAND	<ul style="list-style-type: none"> • shore cranes 	<ul style="list-style-type: none"> • multi-trailers (roll trailers) 	
	LAND	<ul style="list-style-type: none"> • yard cranes • rail tracks • roadways 	<ul style="list-style-type: none"> • straddle carriers • trucks 	
HIGH SPEED WINDS	SEA-LAND	<ul style="list-style-type: none"> • shore cranes 	<ul style="list-style-type: none"> • pilot / port control room / vts • breakwater • multi-trailers (roll trailers) • power supply 	In October 2010, southerly winds blew 45 full containers over in one day causing operations to cease for 3 days at the Port. This event was considered a 1 in a 100 year event
	LAND		<ul style="list-style-type: none"> • yard crane • straddle carrier • storage areas • warehouses 	
FOG	SEA-LAND		<ul style="list-style-type: none"> • pilot / port control room / vts • shore cranes • multi-trailers (roll trailers) 	No event could be recalled from port representatives. Work ceases due to fog around 2 to 3 days per year.
	LAND		<ul style="list-style-type: none"> • yard cranes • straddle carriers • trains • rail tracks • trucks • roadways • storage areas 	

STAGE 3: ANALYSE AND EVALUATE RISKS

This research did not undertake a specific risk analysis and evaluation at the case study ports, however, it is an important component of the process, and helps to embed climate considerations within the broader risk framework of the port. Essentially, risk analysis involves developing a deep understanding of the risk, in particular how it is likely to affect achievement of the port's goals, whereas risk evaluation determines whether the risk is tolerable by the organisation; that is, is the risk significant enough to require action?

The analysis of risks needs to be determined against the ports' stated goals; which might include profit, efficiency, safety and environmental goals (amongst others). It is a process that determines the negative (and positive) consequences of the risks, and the likelihood that those consequences will occur. The AS/NZS ISO 31000 standard describes the consequence of a risk, as the "outcome of an event affecting objectives", (Standards Australia, 2009) while the likelihood is the chance of something happening. To embed climate risks within the broader port risk frameworks, the consequence and likelihood scales should be aligned with the port risk framework. Depending on the data available, this analysis may be undertaken in a qualitative or quantitative manner. It is a process that is strengthened by bringing different people from across the organisation together, so that different viewpoints can be incorporated.

Once climate risks have been analysed to determine their consequence and likelihood, they then need to be considered within the suite of organisational risks. Tolerance levels may be lower for some types of risk than others, for example, risks to health and safety generally are rated highly, as there is a low tolerance for them. This process is risk evaluation, and is defined by the AGO as "the process of comparing the level of risk against risk criteria (AGO:72)." Risk criteria should have been determined as part of the initial context setting process, (see stage 1).

At the end of stages 1 – 3, ports should have a good understanding of the vulnerabilities and risks posed by current and future climate change, and a consideration of the relative importance of the different risks, within their organisational risk portfolio. Figure 5 provides a sample of a risk register for the Port of Sheerness in the UK. It shows the risk, provides a rating of the likelihood that the risk will occur, and the severity rating of the consequence of that risk. The "priority" column indicates how important this risk is within the collection of risks facing the port. The priority scales are broadly narrative, defined as low (L), medium (M) and high (H), and point towards areas of risk for which more detailed analysis is needed. A further refinement might define the threshold at which these vulnerabilities become a serious problem.

Detailed climate change risk matrix [<i>selected examples</i>] Peel Adaptation Assessment (Port of Sheerness)					
No.	Risk	Quantification			Confidence
		Likelihood	Consequence	Priority	
18	Increased rainfall leads to port being cut off from highway network as primary access flooded	3	4		M
21	Increased risk of flooding to warehouses and covered storage areas from heavy rain	3	4		M
30	Damage to hard standings and other surfaces from extended high temperatures	4	3		H
35	Corrosion of structures from increased contact with (especially salt) water	4	2		H

**Figure 5: A range of analysed and evaluated risks
(Peel Ports Group 2011: 43-49)**

STAGE 4: IDENTIFY AND PRIORITISE ADAPTATION OPTIONS

This step includes answering the questions: what options do we have to adapt; what adaptation options will be the most effective; are they cost effective; what timelines are involved; and, what is the capacity of the organisation to undertake the identified adaptive processes / works? Adaptation options can include large-scale infrastructure projects, such as raising the height of berths to accommodate sea-change, it may relate to behavioural change options as part of an emergency management plan, or it could mean diversifying product lines to focus on less climate sensitive products.

Once a port has identified the current and future context, identified vulnerabilities and risks, analysed and evaluated them, it is time to identify and assess adaptation options to mitigate the highest rated risks, and capitalise on the opportunities. Experience has shown that an effective approach to identifying options is to convene a cross-organisational group to creatively identify a broad range of options, and then go through a process of evaluating the options. For ports, engaging management and administrative staff, as well as front-line workers will be important, due to the very different perspectives they will bring to the process. The initial process may involve a simple brainstorming session, as well as research into options identified and implemented by other ports around the world. Ports may then wish to classify their options.

The AS/NZS ISO 31000 standard lists seven generic risk treatment classifications (which do not need to be mutually exclusive). These are (Standards Australia, 2009):

- Avoiding the risk (by deciding to halt, or not start the activity that is at risk)
- Accepting the risk (perhaps in order to pursue an opportunity)
- Removing the source of the risk
- Changing the likelihood
- Changing the consequence
- Sharing the risk (particularly through insurance opportunities)
- Retaining the risk.

Adaptation guidelines and tools provide numerous ways to classify adaptation options, but one rather compact approach suggested by the UK Climate Impacts Program (UKCIP) is to consider two overarching classifications:

- Opportunities to build adaptive capacity, and
- Implementation of adaptation actions

Building adaptive capacity to future climate change involves developing the organisational ability to respond effectively to climate change challenges. It covers such things as awareness raising, skill development, data collection and monitoring and research. Implementation of adaptation actions is concerned with taking practical steps to reduce vulnerability to climate risks (or develop opportunities). It includes technological, engineering change, design and maintenance, planning, insurance measures and management system change.

Within these overarching categories, the core principles can be applied, so that options can be categorised according to whether they are:

- No regrets – options that will deliver significant benefits that exceed expected cost, irrespective of the extent of climate change
- Low regrets – similar to no regrets options, these options deliver benefits at relatively low cost
- Win-win – options that contribute to enhancing adaptive capacity, while also delivering social, economic or environmental co-benefits
- One-off adaptation – this involves investing in a single, up-front adaptation measure that aims to protect against the impacts of climate change over a defined period of time
- Flexible/adaptive management – concerned with applying adaptation measures incrementally, allowing the most appropriate decisions to be made based on evidence available at the time.

Figure 6 outlines a range of “no regrets” and “low regrets” strategies at the Terminal Maritimo Muelles el Bosque Cartenga in Colombia.

Climate Risks and Ports: Terminal Maritimo Muelles el Bosque Cartenga, Colombia Adaptation options	
Action	Further information
Raise the height of the causeway road	It is a gravel road, so quick and easy to raise (a cheap safety margin)
Pave the port's unpaved areas	Expensive, but has other benefits in terms of reduced dust etc.
Improve drainage	Uncertainty in projected extreme rainfall makes replacement of drainage financially unviable. However ongoing maintenance, fitting valves to drainage outlets would be no regret strategies
Understand/trade in climate resilient commodities	Climate change may impact current trade crops. The business can focus development of different crops that will not be affected (soft strategy)
Manage energy costs for refrigeration	The cost of refrigeration will rise with rising temperatures. There are 3 strategies – reduce energy consumption (no regret); Pass cost onto customers (reversible strategy); purchase more efficient refrigeration over time as appropriate (reduced decision horizon)
Protect goods from sea water flooding	There are a range of options including: reorganise storage and place the most vulnerable cargo in the most protected area (reversible strategy); provide emergency flood protection (cheap safety margin); increase sea wall height; increase height of the base of the warehouses and the area they occupy
Contract additional insurance	A renegotiation of the insurance policy in tandem with applying some adaptation measures may be of benefit (soft strategy)

Figure 6: A list of adaptation strategies (adapted from Stenek et al 2011:177-179)

The case study ports have already modified behaviour and processes to adapt to an altered climate. The actions often emerged through the incremental change of management systems such as OHS, environmental or emergency management systems. Table 3 outlines some of these actions, classified according to no regrets, low regrets, win-win, one-off adaptation or flexible/adaptive management.

Table 3: Sample of actions taken by case study ports

Adaptation undertaken	Further information	No regrets	Low Regrets	Win-Win	One-Off	Flexible
Alteration of coal stacking regimes	Recent extreme heavy rains had led to coal slumping, so new coal stacking regimes were introduced					
Dampening coal stacks	The long, hot, dry windy conditions of the last decade have led to advancements in coal wetting techniques to reduce dust being blown over neighbouring community; this process has evolved over time so that water is not wasted, using water-saving nozzles on misting sprays.					
Weather and camera monitoring on site	For early detection of dust					
Altered work regimes during extreme heat, fog, very intense rain and wind events	OHS management system requirements to keep workers safe					
Storm lock position for equipment	This occurs when certain pre-determined thresholds are met					
Wind monitors on ship loaders	Automatically switch off when the wind speed reaches a certain threshold					
Sea level rise projections incorporated into future port infrastructure design	To ensure infrastructure was built higher than expected rises over the next 90 years.					
Reinforced rock walls	Built to withstand stronger, higher wave surges					
Partnerships with local weather stations	To receive forward warning of approaching winds					
Reduced stacking height of containers	Especially empty containers, so as they will not tumble during heavy winds					
Assessing drainage system	To determine if the system has the capacity to handle heavy and prolonged rain events					
Use of recycled water	Particularly during drought conditions when water restrictions are applied					
Use of active mooring systems	Where sea and swell conditions can be difficult					
Automation of logistics tasks	Removes the requirement for "cease work" during extreme heat, wind, rain and fog events					
Schedule of maintenance tasks	Having a list of tasks that can be undertaken if other operations cease due to extreme weather event					
Working with insurance agencies	To collaborate on "what if" scenarios, leading to alterations in the risk register, and emergency management systems					

Opportunities to build adaptive capacity

Several further opportunities to build adaptive capacity were identified through the project, covering training for awareness raising and skill development; data collection and monitoring, and research.

In the area of training, six key training opportunities were identified (**work package 2 – functional resilience of the port environs, section 8**).

These covered:

- Executive risk and climate awareness training specifically targeting executive level management at ports, delivered through a recognised and respected industry organisation such as Ports Australia. For climate change adaptation to be considered in ports, support is needed from executive level management. Therefore, management need to have a good understanding not only of climate change per se, but a grounded understanding of climate change as it relates to their industry, and particularly their organisations. This training would be a first step to garnering commitment to climate adaptation action, and thus building capacity for future climate change.
- Strategic futures training, which includes climate considerations, targeting executive, senior and middle managers involved in port planning. Scenario analysis is one of the tools often employed as part of climate adaptation planning. This program would provide managers with the skills to employ scenarios in their future planning – for climate and other competitive considerations.
- Training on how to adapt organisational management systems to incorporate climate considerations. As most responses to extreme weather events occur within the framework of a management system, such as risk or emergency management, then developing the skills and knowledge to update and improve these systems to take climate considerations into account is a key training opportunity for ports.
- Climate risk management training would help ports build specific skills and knowledge in this area, greatly improving their adaptive capacity to climate change. There are emerging processes and techniques for undertaking climate risk assessments at ports, requiring specific knowledge and further training for existing risk professionals.
- General climate risk awareness training would provide a more generic climate awareness training for management, administrative and frontline staff. This training would assist staff ground the concept of climate change in their own reality, thus helping ports progress adaptive capacity initiatives.
- Locating and interpreting relevant climate information was identified as a gap through the project. This would involve working with specialist port personnel to help them identify and find appropriate climate information, interpret and analyse the data.

Before planning for the future, ports need to understand their current vulnerability to climate impacts, such as extreme weather events. While the case study ports generally collected data on localised extreme weather events, they acknowledged that there was little analysis done of these events. They did not cross check OHS incidents with the occurrence of extreme weather events for instance, nor did they formally record weather related disruptions to ports. Therefore, to help build their adaptive capacity to future climate change, gaining a greater understanding of their current vulnerability, through data collection and monitoring is a recommended “no regrets” strategy to build adaptive capacity.

Research, particularly collaborative research with partners in the logistics chain and city infrastructure managers, would be a further strategy to help bolster adaptive capacity at ports. Gladstone port mentioned that as a result of the recent floods, collaborative research was being undertaken with the City of Gladstone to better

understand the catchment area, water flows and thresholds. This work is intended to feed directly into the stormwater drainage system review and upgrade work at the port. Port Kembla also participated in their local council's flood planning risk management process, and completed a flood study for the port and surrounding environs. Encouraging this form of activity, with support from senior executives, is a tangible way of understanding current vulnerability to climate, and building adaptive capacity for future climate change. It also helps the port understand the broader adaptive capacity of the region and their supply chain.

Implementing adaptation actions

Implementing adaptation actions, as already noted, is highly context specific. However, through the project, several innovative adaptation actions were identified, with further opportunities to improve logistics flow, manage infrastructure lifecycles and reduce potential OHS hazards, as additional co-benefits to building climate resilience.

Opportunities identified during the course of the project covering technological, engineering, design and maintenance, planning, insurance and management system change as shown in Table 4.

Table 4: Adaptation opportunities

Action area	Adaptation Action
Technological	As extreme weather events become more frequent, more targeted investment in technology that expands the operating boundaries of equipment, for example, cranes that safely operate under stronger wind gusts.
	To address increased temperatures, alter refrigerated storage specifications to meet demands of temperature changes and seek less energy intensive alternatives.
	Onsite renewable and low emission energy for a range of functions, to avoid risks associated with power disruption, the increased cost of energy and environmental legislative requirements. Some of this is already happening, for example, fuel cells to power mobile logistics elements and to cool refrigerated cargo, and photovoltaic cells to generate administrative building power requirements.
	Automation of logistics procedures is already being undertaken at some ports, and this process is expected to continue.
Engineering	Future procurement of assets such as gantry loaders, conveyor belts, shore cranes etc. needs to be assessed against future operating environment requirements. That is, the expected life of the equipment, and anticipated future climate it needs to operate in, needs to be considered.
	Storage facilities may need to be upgraded to accommodate more extreme events.
	Assess and upgrade drainage systems to cope with projected intense rain events (potentially work in partnership with city governments for this option).
	Ongoing hydrographical monitoring, to identify if dredging requirements need to be modified.
	More robust dust suppression systems may be required (such as covering coal stockpiles, rather than just dampening)
	Incremental growth of breakwaters as sea conditions require; alternatively, assessing whether breakwaters need to be reconfigured to deal with unpredictable swells conditions.
Design and Maintenance	Roadways in, and through the ports may need to be raised to respond to flooding issues.
	Encouraging modal shift to improve resilience by introducing elements of redundancy into the supply system; that is, removing the reliance on EITHER rail OR road, but looking at better incorporation of the two.
	Ensure climate changes are included in future design specifications, including accommodating future rainfall requirements into new building designs, incorporating sea level rise and storm surge into all port infrastructure elements.
Planning	Ensure ports have a proactive infrastructure and asset management plan that considers asset lifecycle elements, including altered materials deterioration regimes.
	Working in partnerships with city 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.
Insurance	Investigate diversification of trade into climate resilient commodities.
	Some risks cannot be mitigated, and instead, the risk may need to be outsourced to a third party, through purchasing insurance. Working collaboratively with insurance providers to determine the quantitative elements of climate risk will assist ports to appropriately insure against risks they are unable to reduce.
Management systems	The range of systems that could incrementally introduce climate considerations includes environmental, OHS, emergency and risk management systems. <ul style="list-style-type: none"> - Updating policy elements across the management systems to include consideration of climate change impacts - Incorporate training on climate change, as part of ongoing system training elements - Consider appropriate strategies and metrics for the different management systems, and relevant to individual ports. - Update legal compliance elements regularly.
	Develop pandemic plans as part of the emergency preparedness and response system. This was discussed as an opportunity particularly for the more northern ports, as vector and water-borne diseases become a more likely threat.

Prioritising adaptation options

Resource constraints and conflicts will mean adaptation options need to be assessed and prioritised. There are numerous financial and non-financial criteria against which adaptation options can be assessed. Stemming from the core principles for effective adaptation, some of these criteria include:

- Effectiveness – will the adaptation option achieve the stated objective?
- Efficiency – will the benefits of the option be greater than the costs?
- Equitable – the adaptation option should not adversely affect other areas or people
- Priority – how high a risk is the adaptation option addressing? High or extreme risks should be addressed urgently
- Costs – this not only refers to the immediate economic costs of the option, but also likely ongoing costs, as well as associated social and environmental costs
- Co-Benefits – adaptation options may be able to take advantage of opportunities, which lead to environmental, social or economic benefits.
- Maladaptation – does the option lock in outcomes, and limit future adaptation options, or adversely impact on other areas or people?

Some of the tools that may assist in helping to prioritise adaptation options are:

- Cost benefit analysis: This is predominantly an economic decision support tool. It helps determine if the total monetary benefits of a selected adaptation option exceed the monetary costs. It is best used where actions have focused objectives and where monetary costs and benefits can be generated.
- Multi-criteria analysis: Decision support tools that can assist assess benefits, where the monetary values are harder to define. They can generally accommodate quantitative and qualitative variables.
- Cost efficiency analysis: A tool to help compare the relative costs and outcomes from two or more alternatives. This is also appropriate to use when monetary values are hard to determine.

STAGE 5: MONITORING AND EVALUATION

Monitoring and evaluation essentially looks at three elements:

Ensuring the analysis and evaluation material is kept current

- Updated climate information, risks and vulnerabilities may emerge, or assumptions challenged. Throughout the risk assessment process, the monitoring and review function needs to be aware of, and address these changes.
- As climate adaptation is an emerging field, this function is even more crucial, for example, in 2013 the IPCC will be releasing “Representative Concentration Pathways” to replace the 2001 Emission Scenarios. This updated information will impact the global climate models on which most climate risk assessments depend. As time progresses, new models will be developed with parameters of particular interest to ports, such as wave climate information. New government reports relating to non-climate drivers will also be frequently updated, shifting the context for the assessment.
- A new online tool that is to be released next year, the Australian National Data Service “Climate Smart Seaports: Decision Support Tool” will provide a portal to much of the relevant information to assist Australian ports undertake a high level climate risk assessment for themselves.

Evaluating progress on activities to build adaptive capacity and adaptation actions implemented.

- Most ports will have a system in place to monitor and evaluate projects, programs, and ongoing operations; however, the evaluation of adaptation actions is a complex field. Particular challenges for evaluating adaptation actions include:
 - Working with uncertainty: Uncertainty is an inherent element of future climate risk assessments. As so many factors outside a port’s control may change in the future, it can be difficult to assess the effectiveness and appropriateness of individual adaptation actions.
 - Long timescales: As mentioned earlier in this report, one of the challenges of climate adaptation for ports is that many of the future climate change impacts may fall outside the planning horizon of the port, but need to be considered now (particularly in the case of infrastructure investments). The same challenge exists for monitoring and evaluation; what framework do ports need to establish to sufficiently capture and analyse appropriate data for future impacts? Additionally, some actions may have an immediate, obvious outcome, such as new coal stockpiling techniques tested at Gladstone when intense rains fell. However, the outcomes of some initiatives designed to adapt ports to future climate change, may only be able to be evaluated at a point in the future. For example, building new berths to higher levels to accommodate projected sea-level rise.
 - Problem of attribution: A direct consequence of long timescales for implementing adaptation actions can be the issue of correctly assigning costs and benefits to a particular adaptation action over time. For ports,

where budgets are driven by a business case, this is particularly problematic.

- Defining appropriate measures of success: This challenge encompasses both the selection of appropriate metrics for monitoring performance, as well as the definition of “success”. A successful adaptation initiative needs to encompass the principles outlined earlier, including being equitable, efficient and effective. How will unintended impacts be measured to determine if the initiative was a “success” for the port, and other stakeholders? More research is needed in the area of appropriate adaptation indicators for ports.
 - As part of a good monitoring and evaluation process, ports need to determine the purpose of the evaluation at the outset. Ongoing learning is an important aspect of adaptation, and should be considered at this planning stage.
- Defining what is being evaluated; either adaptive capacity or adaptation outcomes should be clearly defined, and integrated into the monitoring and evaluation process at the ports.

Monitoring the process, ensuring it is kept on-track, and implemented on budget.

- Applying some of the principles for good adaptation, ports can monitor how well their adaptation process is progressing, by identifying key process milestones.

CONCLUSIONS

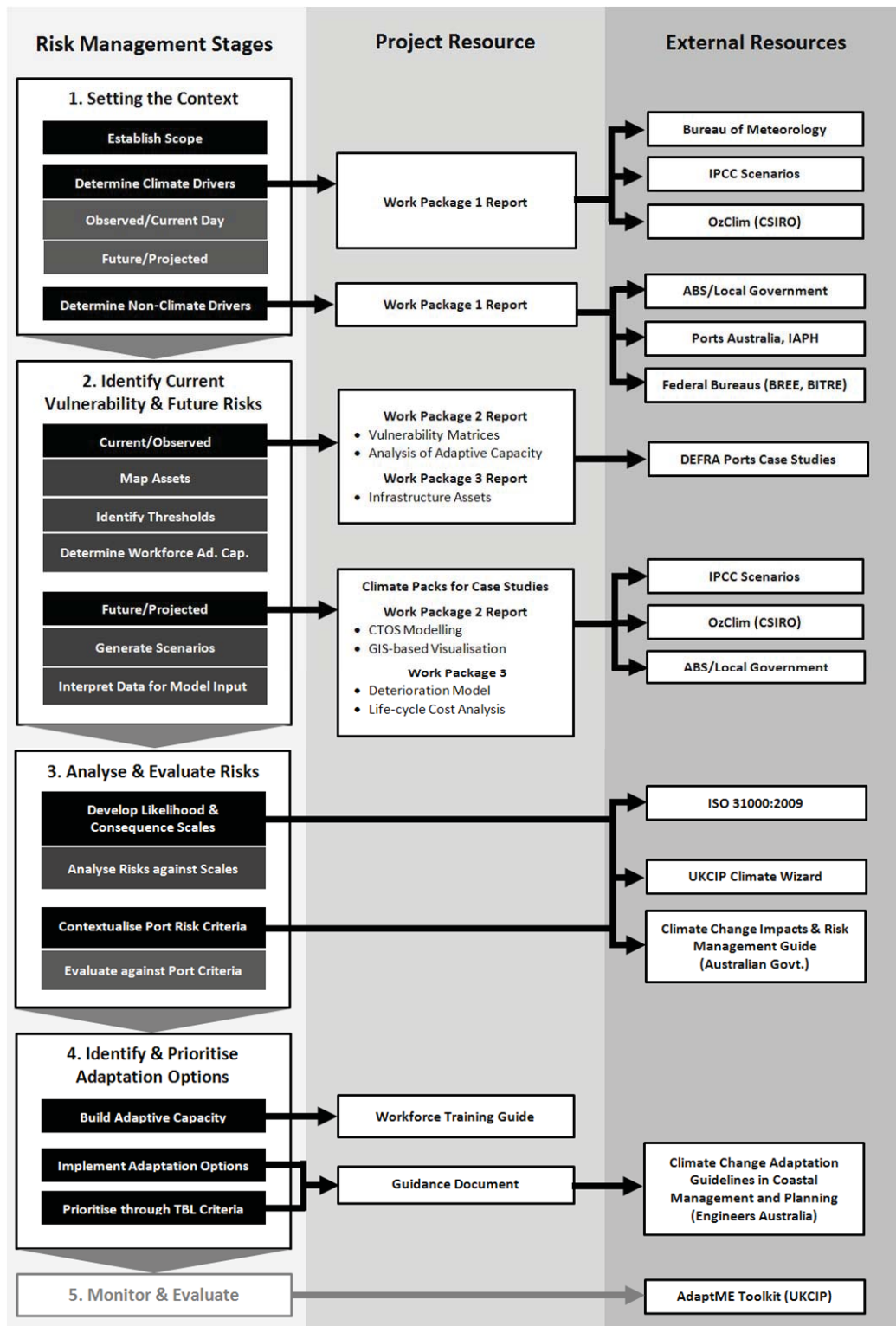
This report has documented a structured framework for seaports to carry out a hybrid climate change risk / vulnerability assessment. This enables port authorities (and others) to identify their vulnerability to current extreme weather events, and risks to projected future climate change impacts. A number of identified tools are available to guide ports through this process.

The key steps in a hybrid risk / vulnerability assessment have been contextualised, based on the research undertaken as part of this project, as well as introducing information from other climate risk assessments undertaken by ports in the UK, USA and Colombia. Figure 7 highlights the different stages of the risk management process, project resources which can be accessed in support of activity, as well as providing signposts to other external resources.

Adaptation options were identified for ports, including opportunities to build adaptive capacity through training, data monitoring and research; and a range of adaptation actions that would require site-specific investigation.

While climate risk processes are emerging, along with innovative adaptation priorities, there still needs to be further research conducted into appropriate metrics and indicators to adequately monitor and evaluate adaptation implementation outcomes over the long term.

Figure 7: Decision support framework



ACKNOWLEDGEMENTS

We would like to acknowledge the time and commitment of all the information providers and stakeholders that were involved in the project and actively contributed to the co-generation of knowledge. Particular thanks go to the CSIRO and the BoM, the case study ports, and key stakeholders; comprising Ports Australia, Transport & Logistics Industry Skills Council, Shipping Australia Limited, and the Maritime Union of Australia. Additional matching funds provided by RMIT University, the University of Queensland, and the Transport & Logistics Industry Skills Council also contributed to the program of research. Finally, we would also like to thank the anonymous referees for their valued comments and insights.

REFERENCES

- Australian Green Infrastructure Council (AGIC) (2010), AGIC Guidelines for Climate Change Adaptation.
- Australian Greenhouse Office (AGO) (2006), Climate Change Impacts and Risk Management: A Guide for Business and Government, Report, Broadleaf International & Marsden Jacobs Associates for the Australian Greenhouse Office, Canberra.
- Becker, A., M. Fischer, B. Schwegler, S. Inoue (2011), Considering Climate Change: A Survey of Global Seaport Administrators, Centre for Integrated Facility Engineering, Stanford.
- Department for Environment, Food and Rural Affairs (DEFRA) (2012), Adaptation Reporting Power: received reports. <http://www.defra.gov.uk/environment/climate/sectors/reporting-authorities/reporting-authorities-reports/>
- Dovers, S. (2009) Normalizing adaptation, *Global Environmental Change*, 19.1: 4-6.
- Fünfgeld, H. and D. McEvoy (2011) Framing Climate Change Adaptation in Policy and Practice. Melbourne: VCCCAR.
- HM Government (2010) Climate change: Taking action. Delivering the Low Carbon Transition Plan and preparing for a changing climate. Crown Copyright, UK.
- International Association of Ports and Harbours (IAPH)(2011) Seaports and climate change: An analysis of adaptation measures, IAPH, Hamburg.
- IPCC (2007) Contribution of Working Group II to the Fourth Assessment Report on the Intergovernmental Panel on Climate Change, Available at: <http://www.ipcc.ch/pdf/assessment-report/ar4/wg2/ar4-wg2-spm.pdf>
- Jones, R. and B. Preston (2011) Adaptation and Risk Management, *WIREs Climate Change* 2011, 2: 296-308. doi: 10.1002/wcc.97
- McCarthy, J.J., Canziani, O.F., Learty, N.A., Dokken, D.J. & White, K.S (eds) (2001) Climate change 2001: Impacts, adaptation and vulnerability, Cambridge: Cambridge University Press.
- Port of Dover (2011) Climate Change Adaptation Report, March 2011, <http://archive.defra.gov.uk/environment/climate/documents/adapt-reports/07ports/dover-harbour-board.pdf>
- Standards Australia (2009) AS/NZS ISO 31000: 2009 Australian/New Zealand Standard, Risk management – Principles and guidelines, Standards Australia /Standards New Zealand, Sydney/Wellington.

Stenek, V., Amado, J.C., Connell, R., Palin, O., Wright, S., Pope, B., Hunter, J., McGregor, J., Morgan, W., Stanley, B., Washington, R., Liverman, D., Sherwin, H., Kapelus, P., Andrade, C. and Pabon, J.D., (2011) *Climate Risks and Business Ports; Terminal Maritimo Muelles el Bosque*, Cartagena, Colombia, International Finance Corporation, Washington.

UKCIP (2007) *Identifying Adaptation Options*, http://www.ukcip.org.uk/wordpress/wp-content/PDFs/ID_Adapt_options.pdf, Accessed 14 Oct 2012

UKCIP (2011) *AdOpt: Types of Adaptation*, <http://www.ukcip.org.uk/adopt/types-of-adaptation/>

UKCIP (2011b) *AdOpt: Guiding Principles*, <http://www.ukcip.org.uk/adopt/guiding-principles/>

