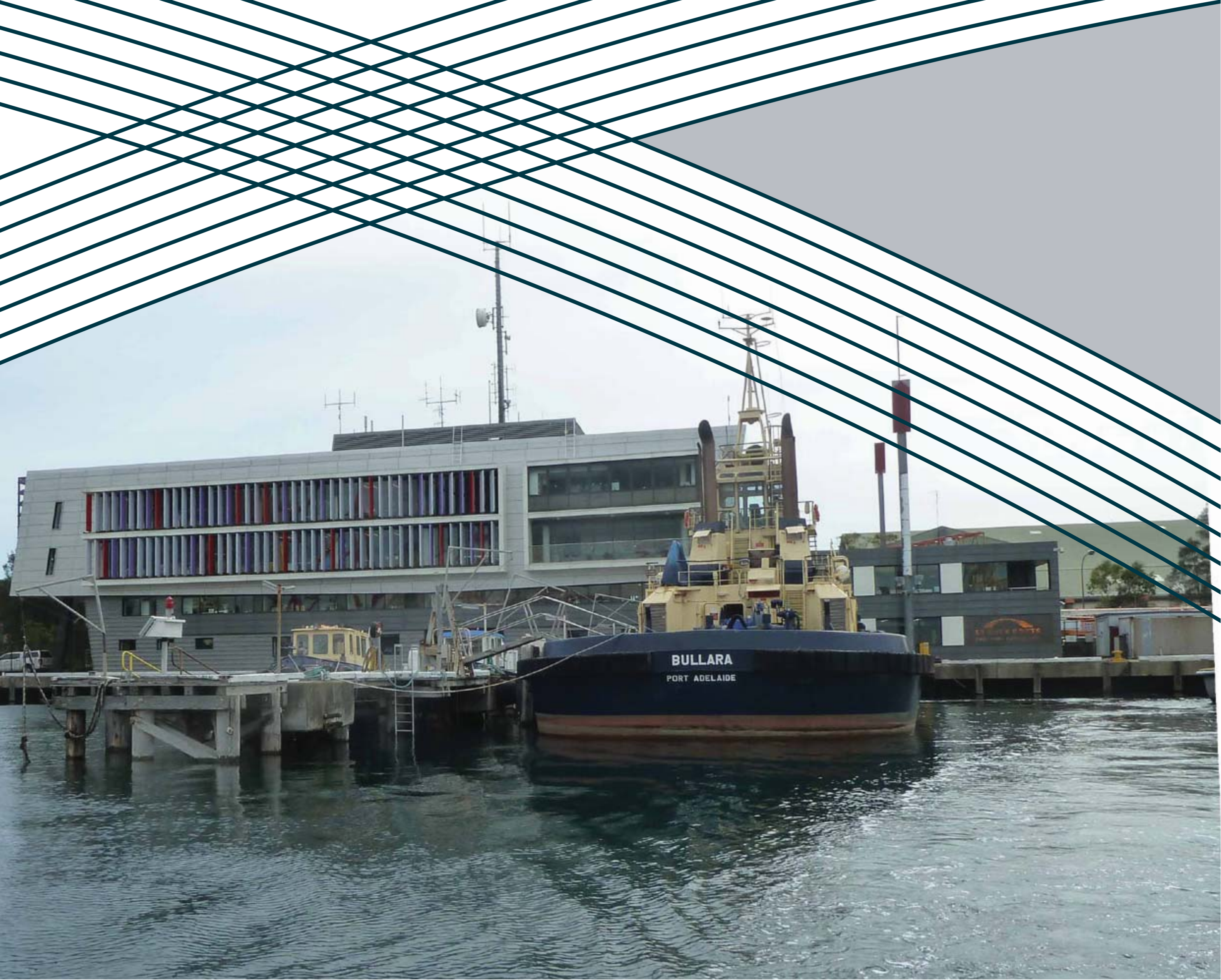
Understanding future risks to ports in Australia

Work Package 1 of Enhancing the resilience of seaports to a changing climate report series

Darryn McEvoy, Jane Mullett, Sophie Millin,
Helen Scott and Alexei Trundle



Understanding future risks to ports in Australia

Work Package 1 of Enhancing the resilience of seaports to a changing climate report series

RMIT University

AUTHORS

Darryn McEvoy

Jane Mullett

Sophie Millin

Helen Scott

Alexei Trundle

Published by the National Climate Change Adaptation Research Facility 2013

ISBN: 978-1-921609-84-8   NCCARF Publication: 13/13

Please cite this report as:

McEvoy, D, Mullett, J, Millin, S, Scott, H & Trundle, A 2013, *Understanding future risks to ports in Australia. Work Package 1 of Enhancing the resilience of seaports to a changing climate report series*, National Climate Change Adaptation Research Facility, Gold Coast, 77 pp.

Acknowledgements

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.

Table of contents

List of figures

List of tables

ABSTRACT

This document reports on research carried out for work package 1 – to better understand the complexity (and uncertainty) of the future climate and non-climate risks that are likely to affect future port operations in Australia. The activity involved close liaison with both information providers and the case study ports, with the quantitative and qualitative data then used to inform the assessments of functional and infrastructural resilience (project work packages 2 and 3). The report highlights some of the many challenges involved when assessing the risks that Australian ports need to contend with; not only contributing to the knowledge-base but also providing detail of an integrated assessment methodology that can be replicated for other cases.

EXECUTIVE SUMMARY

There has been increasing emphasis placed on ensuring the resilience of Australia's critical infrastructure in the face of multiple stressors over the coming years and decades. This includes concern that climate change will pose increasing challenges to the continuing successful operation of Australia's seaports. In response, this report documents the activity and findings of research that was carried out to better understand the future risks that ports need to plan for.

In the first instance, a comprehensive literature review was carried out to establish the necessary context for climate change impacts in Australia and then to explore the implications for infrastructure generally before giving specific consideration to seaports. It is clear from this review that climate change considerations are increasingly being taken on board by policy and sectoral documentation, notably in the last couple of years. Indeed, new ports and freight strategies endorsed in 2012 provide significant opportunities for mainstreaming climate change considerations.

An integrated assessment methodology – comprising quantitative, qualitative and participatory approaches – was used to underpin the research activity. There was particular recognition that the expert input and knowledge of the port authorities, and other stakeholders, would form an important contribution to the assessment process. Adopting a participatory approach was considered important in three main ways: firstly, to ensure that the project was cognisant of, and built upon, already existing knowledge (acknowledging the various research initiatives taking place both nationally and internationally); secondly, to promote access to - and interpretation of - the scientific data and information necessary for effective risk assessment and adaptation planning; and thirdly, to allow for iterative feedback during the lifetime of the project from the port authorities (as well as other stakeholders) to ensure that the deliverables were fit for purpose and practical application.

Six main components acted to frame the integrated assessment of risks. These were: 1) analysing ports as systems, 2) considering observed climate / weather data, 3) interpreting future climate projections, 4) reconciling climate information with research needs (risk assessment and adaptation planning for infrastructure and functions), 5) compilation of climate information packs for each of the case study ports, and 6) contextualising with non-climate drivers.

The task of matching available future climate information to end user requirements, and understanding and interpreting the processed data whilst dealing with the inherent uncertainties involved, formed a key part of the learning process. These learnings, and knowledge gained about translating climate data for engineering and logistics applications, represent an important outcome from the project. Dealing with the uncertainty of the climate data proved to be a significant challenge. Uncertainty manifested itself in different ways. As one example; there are a multitude of global climate models that are potentially applicable to the Australian context. For the purposes of this project, the selection was guided by the CSIRO Climate Futures framework. This enabled a suite of models to be run that were representative of a range of possible futures (most likely, hot/dry and cool/wet), and also ensured that there was consistency across the case study analyses. Further elaboration of the challenges that were faced when dealing with uncertainties is discussed in the main text.

Each of the climate models was run to account for the time periods of 2030, 2050, and 2070; with comprehensive ‘climate information packs’ produced for each of the port case studies as part of the project activity. The data packs included observed climate; a considered explanation of the global climate models, emissions scenarios and time periods used; and descriptions of atmospheric and ocean projections as well as information on extreme weather events. These detailed climate data constitutes a major deliverable for the work package.

Recognising that climate change is only one of the many drivers affecting the functioning of ports, the project also drew on key national and sectoral documentation to frame and explore the non-climate drivers that are likely to have most impact on seaports in the near to medium term. The variables considered were: demography, economy, technology, institutions, and supply chains. The description of the challenges that ports and their wider supply chains face from salient non-climate drivers put the risks from climate change within the context of the current thinking about reform to Australia's freight system. Given recent developments, now is the time to build appropriate adaptive strategies into this reform process.

1. OBJECTIVES OF THE RESEARCH

As highlighted by the National Adaptation Research Plan for Settlements and Infrastructure, seaports are vital to Australia's current and future prosperity and there is recognition that climate change impacts will pose challenges to the operation of ports and their associated infrastructure over coming decades. However, whilst there has been considerable emphasis placed on the importance of ports and the need for anticipatory planning to ensure a sustainable ports system in the future, the integration of climate change impacts into decision-making processes remains at an embryonic stage and in many cases the required technical detail remains lacking. This multi-disciplinary project, in close collaboration with interested stakeholder communities, aimed to address this knowledge gap.

Research activity was scheduled over 21 months, starting in February 2011 and completing in September 2012. The project employed a range of different methodologies to address four discrete research objectives, which were matched to the expertise of research teams from RMIT University and the University of Queensland. The synthesis and integration of the research was facilitated by the Climate Change Adaptation Program at RMIT University.

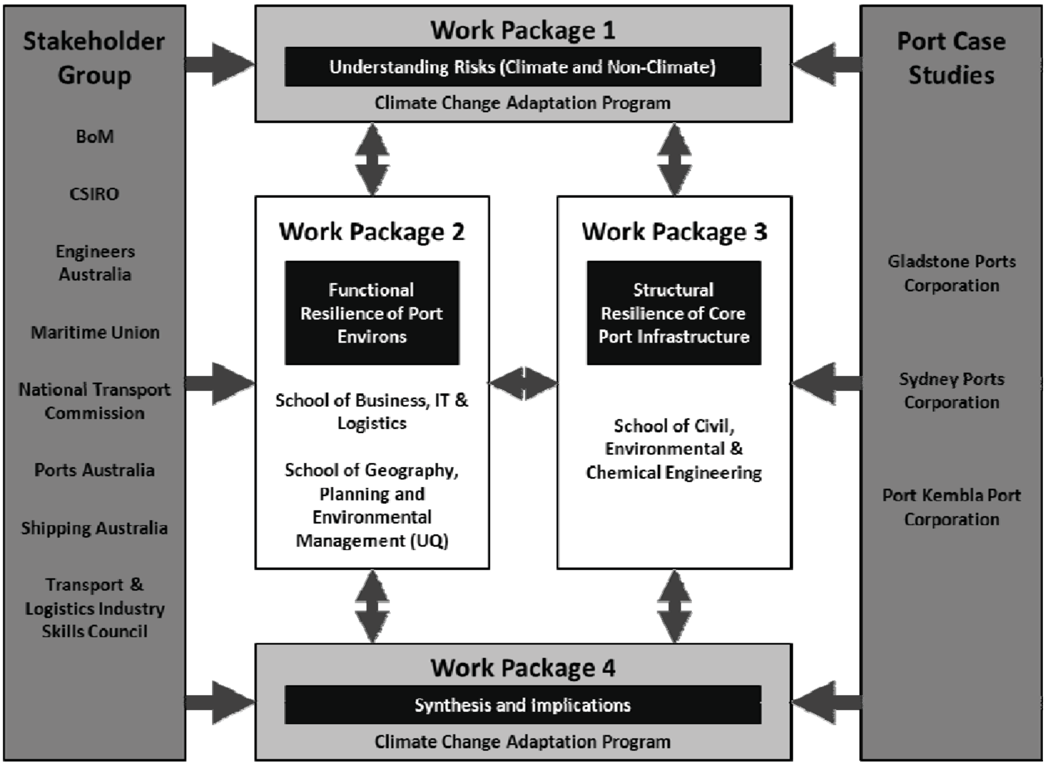


Figure 1: Project design

The research objectives were:

1. To gain a better understanding of the complex mix of climate and non-climate drivers that are likely to affect future port operations;
2. To assess the vulnerability of elements at risk in the wider port environs, including workforce, and identify appropriate adaptation measures;
3. To assess the vulnerability of core port infrastructure and identify appropriate adaptation measures for enhancing resilience; and,
4. To produce a synthesis report exploring the implications for policy and practice and integrated decision support guidance.

This document reports on the research activity and findings for Work Package 1 (WP1) – to gain a better understanding of the complex mix of climate and non-climate drivers that are likely to affect future port operations. The purpose of this 'foundation' work package, conducted by the Climate Change Adaptation Program at RMIT University, was to make sense of the complexity (and uncertainty) of the future risks that ports need to be planning for. The work involved close liaison with climate information providers [the Commonwealth Scientific and Industrial Research Organisation (CSIRO), the Bureau of Meteorology (BoM) and the Centre for Australian Weather and Climate Research (CAWCR)]; as well as the case study ports to ensure that the data and modelling efforts were informed by user needs. This was an iterative process with the translation of complex climate data into useable information proving to be a much more challenging endeavour than was anticipated at the outset. In addition, recognising that climate change will only be one of a set of stressors affecting future port operations, analysis also considered other socio-economic and institutional drivers with the potential to influence change.

2. CLIMATE CHANGE IMPACTS: THE AUSTRALIAN CONTEXT

Australia has a long history of coping with climate variability; impacts which have become all the more pronounced in the public consciousness in recent times. Drought, bushfires, cyclones and floods over the past decade have had significant social and economic impacts on communities, highlighting the exposure and sensitivity of different parts of the country to current day climate variability. Scenarios project that climate change will not only force longer term change to average trends but will also lead to an increase in the intensity and frequency of these extreme events.

Whilst considered fortunate to have a great deal of climate data from past observations to draw upon in order to identify past trends in climate patterns, this does not lessen the uncertainty when projecting future climate change; with modelling uncertainties increasing once beyond a twenty year future time horizon (all global climate models show similar results for 2030, though divergence between models occurs after this date). Addressing uncertainty remains a major challenge.

The CSIRO is acknowledged as a reliable and trusted resource to draw on for the forward projections of climate impacts on Australia. Indeed, it was partly through the CSIRO's ground breaking work in the early 1980s in Antarctica that the link was made between climate change and greenhouse gas emissions. CSIRO scientists have since led Australia's scientific input to the IPCC Assessment reports as well as producing country-specific scenarios (which have been published in tandem). Their analysis focuses on the time periods of 2030, 2050 and 2070, using the current best available climate modelling resolution. The following brief overview is informed by this work.

2.1 Overview of future climate projections

This initial appraisal of climate change impacts for Australia was based on the most recent research output from Working Group 1 in the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC, 2007) supported by research carried out by the CSIRO and the BoM, as published in the Climate Change Technical Report 2007 (CSIRO and BoM, 2007). Up front, it needs to be recognised that the physical size of Australia means that that climate regimes range from tropical monsoon in the northern reaches to a temperate climate in the south (see Figure 2). Along the eastern coast there are three climate zones – the hot humid zone, the warm humid zone and the temperate zone. The project deliberately selected case studies that were representative of two of these zones - the warm humid zone and the temperate zone – to ensure that analysis addressed observed and future variability across different climate regimes.

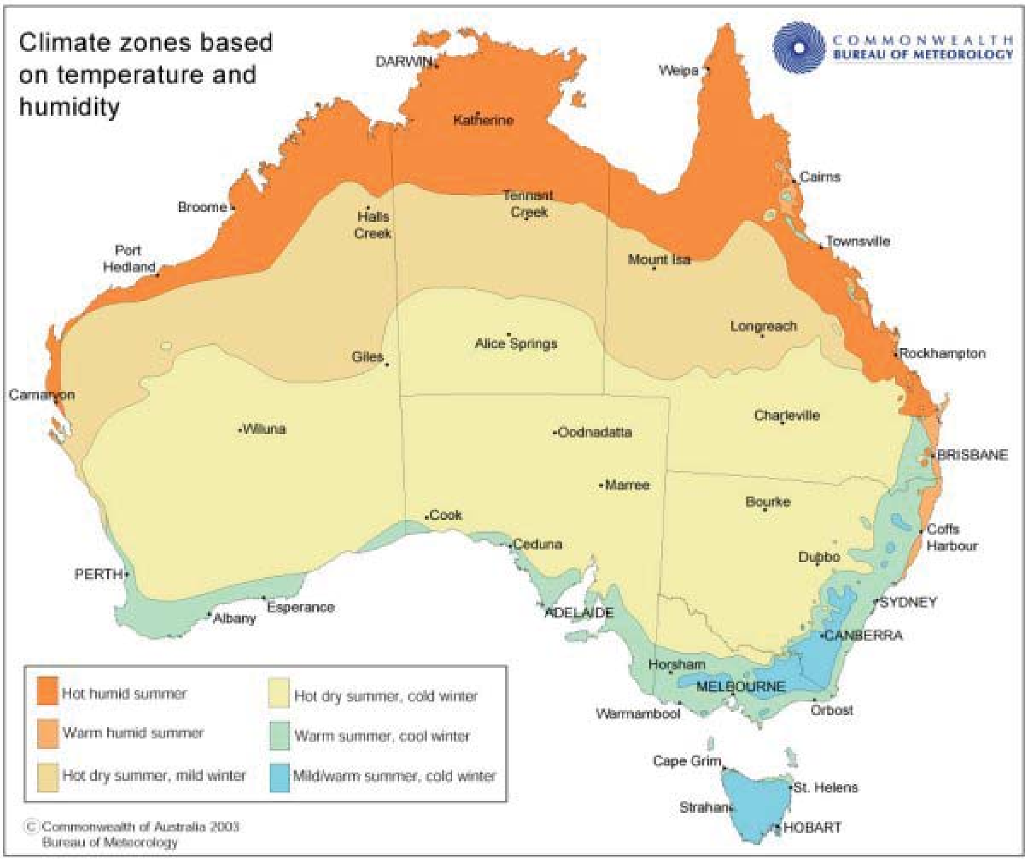


Figure 2: Australian climate zones (BoM, 2003)

Temperature: Australia is considered very likely to warm this century, with an increased frequency of extreme high daily temperatures. Australian average temperatures have increased by 0.9ºC since 1950, though with significant regional variations. The frequency of hot nights has increased and the frequency of cold nights has declined.

Precipitation: Rainfall is likely to decrease in southern Australia in winter and spring, very likely to decrease in south-western Australia in winter; however trends in most extreme rainfall events are rising faster than trends in the mean. Thus, there is likely to be an increase in both the extreme daily precipitation and an increase in the likelihood of drought in southern areas. In contrast, north-west Australia has experienced a rainfall increase.

Cyclones and storms: There is less clarity with respect to regional changes in the frequency and movement of tropical cyclones, partly due to less accurate recording in the past. However, there are indications that the cyclone track is moving southward and that although the number of cyclones may not increase, a greater number of them will be at the intense end of the scale. There are also indications of a modest strengthening of the mean wind speed over inland and northern areas and a weakening of the mean westerlies along the southern coast.

Sea level rise: Projections of mean sea level rise have been calculated globally for 2100 by the IPCC, and the CSIRO models indicate that mean sea level rise for the southern section of Australia's east coast may be greater than the global mean by around 100mm. There is also a strong indication that the East Australian current is likely to strengthen leading to warmer waters extending further south. Sea level rise in the Australian region has been projected to 2070 only, and the number of specific sites that have been analysed in detail are gradually increasing. Past information from the Australian Baseline Sea Level Monitoring Project, through the Australian Climate Change Science Program, shows that the net relative sea level trend in mm/year (after adjustments) from 1990s - 2008 is strikingly different in different parts of Australia (Figure 3).

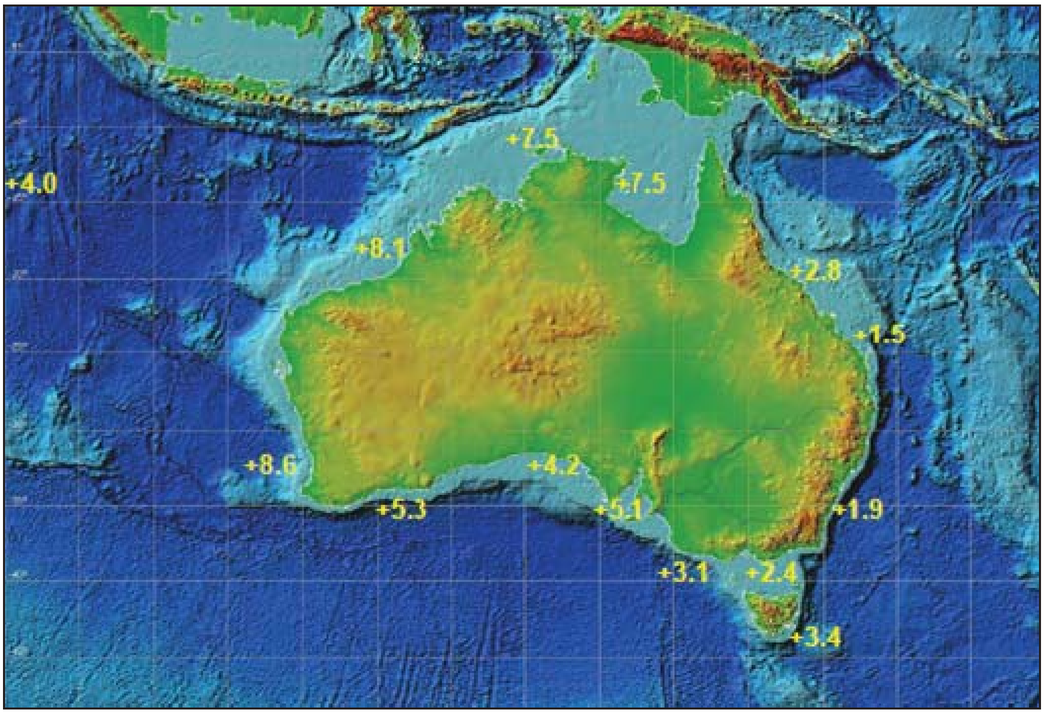


Figure 3: Average rate of sea-level rise 1993-2011 (mm/year) (BoM, n.d.)

To show the changes over different time scales tabulated data has been assembled from the regional projections section of the CSIRO Technical Report (CSIRO and BOM, 2007), supported by additional scientific evidence where relevant. This information is shown in Appendix A.

Significantly more information exists for projections of land temperatures, precipitation, humidity and frequency of drought; than for other climate impacts such as changes in the frequency or intensity of wind (at this point in time there are no large scale analyses of wind directional changes). Even so, there may be further geographical differences with projected warming having significant variance nearer the coast (Watterson et al, 2007: 59). It is also worth noting that the Engineers Australia's National Committee on Coastal and Ocean Engineering (NCCOE) determined the following to be its priorities for climate research (Engineers Australia, 2004: 9): Priority 1 (wind climate, wave climate, rainfall); Priority 2 (sea level rise, ocean currents, ocean temperatures); and Priority 3 (air temperatures).

Research for the resilient seaports project employed a range of different data sources and methodologies for sourcing and collating more detailed climate data for each of the case studies. Full details are included in the integrated assessment section of this report.

3. CLIMATE CHANGE AND INFRASTRUCTURE

Although there has been longstanding recognition of the historical importance of infrastructure in underpinning socio-economic prosperity in Australia; in recent years (most notably since 2008) there has been a heightened focus on ensuring the continued resilience of different types of infrastructure in the face of diverse social, economic, and environmental challenges. However, whilst there is evidence of increased interest in this topic area, a review of grey literature found that the majority of documentation either:

1. Pays scant regard to the issue of climate change;
2. Highlights climate change as an important issue, though addresses it in terms of mitigation rather than from an adaptation or vulnerability perspective; or
3. Recognises the importance of enhancing resilience of infrastructure to climate change, though analysis remains relatively broad-brush (usually at the macro-scale) with little technical or real world detail.

One of the first sets of documentation to explicitly address climate change was an Engineers Australia set of guidelines on coastal engineering (Engineers Australia, 1991). These guidelines were updated in 1993, 1995 and 2004 (Engineers Australia, 2004). In this year, the Austroads report also heralded the beginning of a wider focus on infrastructure. This study included climate modelling by the CSIRO and concluded that there will be effects on road infrastructure from changes in rainfall patterns, flooding, salinity increase, sea level rise, and changes in road use from alterations in the number and size of freight trucks on the roads; primarily related to changes in population (Austroads, 2004). The projections for this study were made for 100 years in the future (2104) with the IPCC A2 SRES scenario (representing regionally oriented economic development) providing a "business as usual" trajectory. Both reports highlighted the need for further research, indeed the Engineers Australia guide concludes with the following statement: "action is needed … to provide the essential scientific parameters for the planning authorities such as safe setbacks, sea level limits, bunded zones, infrastructure replacement and aquifer management plans etc." (ibid: 37). Engineers Australia has recently updated its guidelines (Engineers Australia, 2012) and continues to highlight the need for further research.

Documentation which places the greatest explicit emphasis on the risks associated with a changing climate includes: Impacts of Climate Change on Infrastructure in Australia and CGE Model Inputs for the Garnaut Climate Change Review (CSIRO and Maunsell, 2008), Assessment of Impacts of Climate Change on Australia's Physical Infrastructure (ATSE, 2008), and Infrastructure and Climate Change Risk Assessment for Victoria (CSIRO, 2007). The report, State of Australian Cities 2011 (DIT, 2011), produced by the Commonwealth provides good up-to-date data on the current state of urban infrastructure assets. There are also two good contextual reports from the Australian government on climate change and the coast; with specific work on infrastructure (DCCEE, 2009; 2011).

The national 'report card' system created by Engineers Australia was augmented by an agreement made by the Council of Australian Governments (COAG) in 2005 that each State and Territory jurisdiction prepares a five yearly report on their infrastructure. The COAG reports are a detailed record of assets. The Engineers Australia reports comment on the state of the assets, with ports addressed in the transport chapters. Engineers Australia's latest set of 'report cards' focus on 2010 and include reports for each of the states and territories Australia-wide. While the majority of these reports acknowledged that there would be challenges to infrastructure from climate change, none explored the implications of the projected impacts on ports nor their related infrastructure or supply chains.

Table 1: Infrastructure report card (Engineers Australia, 2010)

Infrastructure Type	Australia 2010	Australia 2005	Australia 2001	Australia 1999	ACT 2010	NSW 2010	NT 2010	QLD 2010	SA 2010	TAS 2010	VIC 2010	WA 2010
Roads overall	C	C	-	C-	B	C-	C	C-	C-	C-	C+	C+
National Roads	C+	C+	C	C	-	B-	B	C-	C	C+	C+	B-
State/Territory Roads	C	C	C-	C-	-	D+	C-	C-	C	C	C+	B-
Local Roads	D+	C-	D	D	-	D+	D+	C-	D	D	C-	C-
Rail	D+	C-	D-	D-	F	D-	C+	C-	C	F	D	C+
Ports	**B-**	**C+**	**B**	**-**	**-**	**C**	**C+**	**B**	**B-**	**B-**	**C+**	**B-**
Airports	B-	B	B	-	B-	B	B-	B-	B-	B	B	C+
Water Overall	C+	C	-		C+	C+	C	C+	C+	C+	C	C+
Potable Water	B-	B-	C	C-	B-	B-	C-	B-	B	B-	C	B-
Wastewater	B-	C+	C-	D-	C+	C+	C-	B-	B-	C	B-	B
Stormwater	C	C-	D	-	C+	C	B-	C	D	C-	C-	C
Irrigation	C	C-	D-	-	-	C		C+	C+	B-	C-	C+
Electricity	C+	C+	B-	-	B+	C-	C-	C	B-	B-	C-	B-
Gas	B-	C+	C	-	A-	C	A-	C+	B+	C	C	C+
Telecommunication	C		B	-	B-	C-	C-	B	C	C+	C	C-
Overall	**C+**	**C+**	**C**	**D**	**B-**	**C**	**C+**	**C+**	**C+**	**C**	**C**	**C+**
Approx. % of GDP					*2.1%*	*32.2%*	*1.3%*	*18.8%*	*6.6%*	*1.9%*	*24.3%*	*12.8%*

The Engineers Australia infrastructure report, which gave the ports sector a 'B-' rating overall, described Australia's port infrastructure as "good condition, requiring relatively minor changes to be fit for current and medium-term purposes" (Engineers Australia, 2010: 25), though made no mention of adaptation planning. This may prove to be more problematic given that Australia is in the midst of a significant population increase, placing growing demands on existing aging infrastructure, a pressure which is likely to be amplified by the impacts of future climate change.

Infrastructure Australia was established in 2008 with the aim of bringing a greater degree of national coherence to infrastructure planning. Their first report in 2008 noted that climate change is a major economic, environmental and social issue (Infrastructure Australia, 2008), though the focus was predominantly on mitigation, sustainability and trade measures. The report recommended no specific adaptation measures, however it did recommend improved coordination of planning beyond the dockside area and noted that while trade is expanding, the ports sector must manage the necessary expansion of capacity in order to secure future growth. A significant outcome of this report was the recommendation that a national ports strategy be developed to adequately cope with the demands that will be placed on Australia's major ports and their freight networks in the coming decades. This call, along with the outcomes of the Parliamentary Inquiry into Coastal Shipping in 2008, resulted in a document outlining a national ports strategy being produced at the end of 2010. The strategy emphasised the importance of the ports sector to Australia by stating that, "ports and associated infrastructure are of the utmost economic and social importance to Australia" (Infrastructure Australia, 2011a: 6) and the aim of the strategy is to "drive the development of efficient, sustainable ports and related freight logistics that together balance the needs of a growing Australian community and economy with the quality of life aspirations of the Australian people" (ibid: 7). The resilient seaports project contributes directly to the strategy's remit to "improve the evidence and forecasting basis for exports and growth in services, and develop scenarios for the impact of changes such as demography, climate, and energy for planning consideration" (ibid: 20).

If the definition of a port includes the functionality of the port as well as physical infrastructure assets, then consideration of the impacts of a changing climate on Australian ports needs to extend beyond the more obvious impacts such as sea level rise. Not only do a range of climate-related hazards need to be assessed, risks need to be framed by an understanding of ports as complex systems. For instance when thinking about functionality, it is also important to include the linkages with major infrastructure sectors, particularly the transport sector (road and rail) which is part of the port's logistics and supply chain; as well as the utility services that support business operations: energy, water, and telecommunications. For example, the impacts from the 2009 heatwave in Melbourne on the Port of Melbourne revealed immediate impacts on physical port infrastructure in the form of melting bitumen at one of the stevedore company's yards, as well as a loss of machines functioning due to the overheating of hydraulics and secondary impacts from cascading failures of the electricity system which affected all electrical equipment and contributed to the loss of operational hours by the workforce (QUT, 2010). The same heatwave event resulted in rail lines buckling and the electricity blackouts, which forced sections of the rail system to stop operating, and at one point more than one third of Melbourne’s commuter rail system was out of action (ibid).

Discrepancies in research results are also evident. Work carried out by Australian Academy of Technological Sciences and Engineering (ATSE, 2008) suggested that no significant consequences were anticipated for major seaports in Victoria, New South Wales, Tasmania, SW Western Australia, and South Australia. Interaction between sea level rise, storms and flooding were identified for SE Queensland, NE Queensland, NW Western Australia, and the Northern Territory. This contrasts with Victorian Government commissioned research carried out by the CSIRO and Maunsell during the same period, which identified high winds and flooding combined with sea level rise as having the potential to damage port infrastructure after 2030 using a high emissions SRES scenario (CSIRO, 2007; Jones et al., 2008). These discrepancies point to a need for a greater understanding of potential climate risks to ports.

Infrastructure Australia reflect that "[a]t present there is little coordination or visibility in forecasting and capacity analysis for Australia’s ports and related supply chains. Shared forecasting and capacity analysis is essential for supply chains that have economic or physical influence on each other … National level expertise in matters such as impacts on trade of changing patterns of world economic growth, industrial specialisation or demography, energy prices and climate change could assist in improving robustness of forecasts and capacity analyses” (Infrastructure Australia and the National Transport Commission, 2010: 21).

This literature review was carried out at the start of the project; however it is important to note that even during the course of the past 21 months there have been significant sectoral developments, as illustrated by the endorsement of two new national strategies for ports and land freight in 2012.

4. CLIMATE CHANGE AND PORTS

> *"By the nature of their business, seaports are located in one of the most vulnerable areas to climate change impacts: in coastal areas susceptible to sea level rise and increased storm intensity and/or at mouths of rivers susceptible to flooding. Ninety per cent of the world's freight moves by shi.p" (Becker et al, 2011)*

Ports worldwide are now engaging with sustainability and greenhouse gas mitigation agendas to a much greater extent than previously (e.g. the Green Guide produced by the European Sea Ports Organisation, June 2012). In the Australian context, the peak industry body 'Ports Australia' has set up an Environment and Sustainability Group as part of its program of working groups to attempt to bring coherence to the raft of mitigation efforts, conservation and biodiversity initiatives, and broader 'green' port issues, now being implemented by Australian seaports. However, it is evident that much less attention has been paid to considering climate-related impacts, the future risks that a changing climate may bring (with the exception of sea level rise), and possible adaptation responses. This is an important knowledge gap that this project sought to address.

From the academic and grey literature review that was carried out it was found that although the topic is relatively new, with limited international studies on 'climate change and seaports' to date, a knowledge base is slowly beginning to develop. Worthy of academic note is the international analysis of exposure to sea level rise that was released by the World Bank and the OECD in 2008. This benchmark study - consisting of 136 ports, of which 5 ports were Australian - mapped the port cities considered most vulnerable to climate change in 2070 (Nicholls et al, 2008). Analysis was based on a one in one hundred (1:100) year storm surge as the definitive water level from which to base calculations; with exposure of population and assets then estimated as a function of elevation against this water level (Hanson et al, 2011). Another international example, which adopted an alternative 'actor-based' approach, was the worldwide survey of Port Authorities that was undertaken by Becker et al (2011) to elicit information on the sector's risk perceptions, the likely impacts of climate change on future international port operations, and potential adaptation strategies.

Other exemplar studies that have focused on the future impacts of climate change on international ports (and coastal zones more generally) include a study by Nicholls et al (2010) that furthers the earlier analysis on sea level rise and storm surge by undertaking a preliminary economic costing of adaptation to sea level rise in coastal zones. Another key study by Stenek et al (2011) carried out a comprehensive analysis of the Cartagena port facility, Colombia. This piece of work was the only study uncovered by the literature review that takes a system-based and integrated approach; explicitly considering both the functional and infrastructure assets of the case-study port in its analysis. As such, it can be considered a pioneering system-wide effort to assess climate risks and adaptation options of international seaports in a comprehensive way.

Analysis of the grey literature indicated an increasing awareness of the need for port authorities to consider climate impacts as part of the broader spectrum of risks that need to be managed. For example, the World Association for Waterborne Transport Infrastructure (PIANC) responded to the findings of the IPCC 4th Assessment Report in 2007 by releasing a detailed paper that examined climate drivers and the potential impacts on maritime and inland navigation. It specifically explored potential responses to "infrastructure, vessels, and transport management in an effort to create a continuing dialogue for consideration of adaptation or mitigation strategies to climate change by the navigation community" (PIANC, 2008: 50). Other recent documents of importance include a review of climate change adaptation measures that are available to seaports (International Association of Ports and Harbors, 2011), and a growing number of climate risk assessments that have recently been carried out by ports in the UK (see for example Peel Ports Group, 2011). Importantly, this assessment activity was driven by national legislation, in this case the UK Climate Change Act 2008, which now requires all major seaports – as well as other infrastructure owners - to report to national Government on their climate risk assessments and identified adaptation measures.

Whilst Australian seaports are not legally required to assess climate risks in such a way, there has been a marked shift in emphasis even during the lifetime of this project. For instance, climate change adaptation is explicitly addressed in Infrastructure Australia's fourth annual report to the Council of Australian Governments. Here, adaptation is defined as "assessing risks to infrastructure from extreme events, and understanding how asset management and the design and location of assets can be adapted in consideration of these risks" (Infrastructure Australia, 2012: 21). Though less explicit about climate change, the now endorsed National Ports Strategy recommends that ports' planning documentation, with a suggested minimum time horizon of 15-30 years, should consider external factors (both risks and opportunities) that may impact on port functions (Infrastructure Australia, 2011a).

In relative terms, as highlighted by Nicholls et al (2008), Australian ports are not considered to be at the same level of risk when compared to counterparts in the Asian and American regions. However, a salutary reflection is provided by a study of the city of Copenhagen (Hallegatte, 2008). Although not considered particularly vulnerable to coastal flooding, in the absence of protection the author estimated that "the total losses (direct and indirect) caused by the current 120-yr storm surge event, at 150 cm above normal sea level, would reach EUR 3 billion" (ibid: 3).

Whilst adaptation to future climate change is not high on the agendas of many Australian ports as yet, the research team's experience of engaging with the case study ports and other key stakeholders over the period of the project has shown that there was an openness to better understanding future climate risks, to engage in dialogue about the implications for the structural and functional resilience of ports, and to collaborate with research efforts that can help to inform how best to respond.

5. CASE STUDY SELECTION

The case study focus of the research project was deliberately designed to account for the vulnerability of different port functions and infrastructure to a range of different climate risks. To this end, a systematic approach to port selection was adopted to ensure that a range of port operations across the Australian ports and a diversity of geographic and climatic conditions were represented. The selection of ports was driven by the following criteria:

- Representative of at least two different climatic regimes in Australia;
- Account for a range of port operations, informed through the application of a functional typology screening process;
- Linked to (2), immediate port environs to be comprised of different types of physical infrastructure;
- Geographical setting; and
- Ports' willingness to participate in the study.

Based on the above criteria, the port authorities that were selected as the case studies (listed from north to south) were: Gladstone Ports Corporation, Sydney Port Corporation, and Port Kembla Corporation (Figure 4, details in Appendix B). The ports are all found on the Eastern seaboard of Australia and are representative of two different climate zones: warm humid (Gladstone Port) and temperate (Sydney Port and Port Kembla).

Figure 4: Location of case study ports (Ports Australia, n.d.)

5.1 Functional Typology

Traditionally, most ports were seen as hubs where freight passes between ships and landside transport. Modern ports however are also the interface that connects a regional economy to a global economy and are increasingly regarded as critical gateways that link national and regional supply chains to global markets. This wider focus for defining ports, one where they play a strategic role in the development of international trade and logistics, is captured through the emergence of the concept “port-centric logistics”. The role of ports is particularly important in the Australian context as it is dependent on ports to bring in a majority of goods from overseas, as well as exporting raw materials to international markets.

Operational environments in ports vary. Some are relatively simple whilst others can be both diverse and complex in terms of handling various types of freight. Many ports are equipped to handle liquid bulk (the most significant sub-category being oil), dry bulk (such as coal, iron ore and agricultural products); whilst others deal with unitised freight - which comprises both lift-on/lift-off containers, i.e. load-on/load-off (Lo-Lo) and roll-on/roll-off units (Ro-Ro) (Mangan, 2008).

The types of cargoes typically shipped through Australian ports fall into six broad categories:

- Iron ore (bulk)
- Coal (bulk)
- High-value mineral and agricultural exports (including live animal exports);
- Containers
- Liquid goods: such as crude oil, petroleum products and LNG (all bulk cargoes); and
- High-value specialised goods & services (including rolling cargoes, vehicles, cruising etc.).

Useful differentiation between the case study ports is possible through a listing of different cargo types and contents. These are shown in Table 2, and can be seen to be representative of most of the categories of cargo that is moved in and out of Australia.

Table 2: Cargo types & contents, adapted from Background Paper 5, National Ports Strategy (GHD Meyrick, 2010a)

Cargo Type	Cargo Content	Gladstone	Kembla	Sydney
Bulk	Iron ore		X	
	Coal	X	X	
	Mineral & Agricultural	X	X	
	Liquid	X		X
Containers	Containers			X
Specialised goods & services	Rolling (vehicles)		X	
	Project & Cruising			X

A functional typology of ports was further developed to guide the selection of case studies so that a range of business functions (and associated support infrastructure) would be subject to investigation. As a first stage, the functional characteristics of Australian ports were described using the trade statistics data (accessed through the Ports Australia website).

Characteristics were analysed using:

- The total throughput;
- Freight composition;
- Export/import ratios; and
- The degree of specialisation or diversification.

Results from the analysis show that ports such as Newcastle, Gladstone, Dampier, Mackay and Esperance predominantly handle bulk freight. Port Kembla, although smaller by value, is Australia's leading port for steel exports and the second largest for grain, whereas ports with the largest throughput by value (typically linked to the major coastal cities) such as Sydney, Melbourne and Brisbane are associated with containerised cargo. Fremantle, Rockhampton, and Devonport ports handle more general cargo and Gladstone is Queensland's largest multi-commodity port. It is also worth noting that the capital city based ports are more diversified than the resource dependent ports. For example, the Port of Sydney handles almost equal proportions of bulk (31%), general cargo (31.34%) and containers (34.35%). This is in contrast to Gladstone which is predominately bulk freight (75%). Furthermore, ports also differ in terms of the ratio between their export or import activities. Predictably, the capital city ports, Ports of Melbourne (59.6% import), Sydney (73% import) and Brisbane (51.5% import) all have a greater concentration in imports in comparison to resource-based ports.

5.2 Categorisation of Physical Infrastructure

The physical infrastructure of a port is, to a large extent, determined by the functions it performs. For the purposes of this project and to enable a systematic assessment of climate change impacts, categorisation was made according to the primary material used in the construction of the physical infrastructure assets. The division of materials is:

- Concrete – docks, jetties, buildings, railway sleepers, marshalling yard, piers, sewage pipes, water reservoirs, bridges, breakwater, culverts, piles;
- Steel – retaining walls, gantry cranes, warehouse, rails, silos, culverts;
- Timber – buildings, jetties, piers, railway sleepers, piles; and
- Pavement – roads, marshalling yard.

Port structures are subjected to various deteriorating agents throughout their service lives. The degree of deterioration typically depends on the properties of ambient water, its seasonal fluctuation, tidal range, climatic conditions, and chemical composition of the construction materials. However, it is also important to note that the performance of material depends not only on physical and mechanical properties when the facility is put into service but also on their response to the environment in the immediate vicinity of the structural member (micro-climatic conditions) and on both the use of the structure and the preventive and remedial maintenance techniques used. Each of these variables needs to be considered when addressing the vulnerability of port infrastructure assets.

For the case studies, the following physical assets were initially identified:

- Gladstone & Kembla – bulk cargo (conveyor belts, stackers, reclaimers, bucket elevators, railcar dumpers, hoppers, storage silos, stockpile area); and
- Sydney – containerised cargo (roads and rails, marshalling yard, container freight station, gantry cranes).

6. STAKEHOLDER ENGAGEMENT

From the earliest stages of the project it was recognised that effective engagement with a range of different actors (scientific experts from multiple disciplinary backgrounds, information providers, seaport authorities, practitioners, and policymakers) would be a critical element affecting the success of the program of research. Adopting a participatory approach was considered important in three main ways: firstly, to ensure that the project was cognisant of, and built upon, already existing knowledge (acknowledging the various research initiatives taking place both nationally and internationally); secondly, to promote access to - and interpretation of - the scientific data and information necessary for effective risk assessment and adaptation planning; and thirdly, to allow for iterative feedback during the lifetime of the project from the port authorities (as well as other stakeholders) to ensure that the deliverables were fit for purpose and practical application. The forms of interaction included: interactive workshops presenting interim findings, visits to ports to access data, more specific exchanges between researchers and port experts, submission of all progress reports to stakeholders for comment, and dissemination workshops.

Academically, the project benefited from the guidance received from national and international experts; with their input particularly valued in the early stages when exploring some of the key methodological issues and data challenges that the project faced. In addition, the regular NCCARF thematic meetings convened by the ‘Settlements and Infrastructure’ network proved to be a valuable platform for benchmarking the progress of the project and providing informal scientific peer review. In terms of climate information provision, the CSIRO and BoM made substantial contributions to the project; and without their time and effort, advice, and provision of data, this project would not have been possible. Finally, the involvement of the three case study ports, and the support of the peak body ‘Ports Australia’, ensured that the analysis carried out was subjected to consistent scrutiny through a practitioner lens. Over the course of the research project, engagement with the ports included numerous meetings, interviews, and site visits in order to ground truth data. Here again, their active engagement with the research being carried out was vital to the project.
A broad mix of stakeholders was engaged from the early stages. These included Shipping Australia, the Maritime Union of Australia, Engineers Australia, National Transport Commission, Transport and Logistics Industry Skills Council. In Victoria, a range of other groups were also kept informed - Port of Hastings Corporation, South East Councils Climate Change Alliance (SECCCA), Mornington Peninsula Shire, and the Victorian Department of Transport. Key stakeholders that engaged with the project are listed in Appendix C.

A series of six stakeholder workshops formed an integral part of the ‘co-generation’ of knowledge. Three of these were held in 2011 and were designed to inform the proposed research activity at an early stage. The first of these (Melbourne, July 2011) was convened to discuss the methodological and data challenges associated with assessing future climate risks (in the context of Australian seaports). Attendees included members of the CSIRO, BoM, CAWCR; with the conversations also benefiting from additional input from national and international climate risk experts who were present. This initial ‘scientific’ workshop established a valuable early framing for the research parameters, particularly with regards to the scenario selection process. Two further workshops were then held in Sydney (November 2011) and Melbourne (December 2011) in order to engage with a broader range of stakeholders; not only the case study port authorities but also other sector organisations associated with ports, transport, and supply chain logistics.

The Sydney workshop, which involved representatives from each of the case study ports as well as other key experts, proved to be a useful forum for interactive discussions and for the project team to receive feedback on appropriate analytical frameworks. Sessions were designed to introduce climate information – past and current data from the BoM and future scenario data from the CSIRO and State Governments - as well as allowing the attendees the opportunity to identify and discuss the vulnerability of key infrastructural and functional assets (and the perceived effectiveness of existing risk management strategies). An unexpected, though important, outcome of this early meeting derived from a debate on the selection of climate models that were to inform the scenarios for each case study (the climate information introduced at the workshop had been based on a hotter and drier future and differed from scenarios advised by State Government in New South Wales). On the basis of these important differences (in relation to future rainfall) the project subsequently refined the suite of climate models that were included in the project to enable the consideration of a wider range of climate 'futures' (discussed further in this report in the section on 'integrated assessment of risks').

The stakeholder meeting in Melbourne, held one month later, enabled the project team to engage with interested groups in Victoria, to further test the assessment framework that was being developed, and to get additional feedback from a different group of stakeholders. This workshop also included a presentation by an international visitor (Hans de Moel, Vrije Universiteit, Amsterdam) on the adaptation activity currently being carried out by the Port of Rotterdam in the Netherlands.

Three project dissemination workshops were then held at each of the case study ports during September 2012 (Sydney, Port Kembla, and Gladstone). These presented the draft findings and deliverables from each of the work packages to the port authorities and provided a platform for final feedback. More details on each of these workshops can be found in Appendix D.

7. INTEGRATED ASSESSMENT OF RISKS

Integrated assessment methodologies (IAMs) have become increasingly commonplace since the 1990s, chiefly as a result of advances in computing technology. Put simply, integrated assessments are attempts to bring together, and analyse, different sources and types of (multi-disciplinary) knowledge in order to address complex real world problems; with the ultimate aim of both informing decision-making processes and acting as guidance to the formulation of relevant policy responses. Since their emergence, they have been extensively applied to a wide range of global environmental change issues, including climate change.

In response to the limitations of a purely top-down IA methodology, this project applied a ‘hybrid’ approach which explicitly involved a bottom-up perspective to problem framing / solving. As such, the research methodology involved a combination of quantitative, qualitative, and participatory processes and inputs. A useful example of a similar approach recently used in the context of Australian settlements is documented by Li (2010). There was particular recognition that the expert input and knowledge of the port authorities, and other stakeholders, would form an important contribution to the assessment process. A framing of integrated assessment as the bringing together of different knowledge – quantitative, qualitative and participatory – therefore underpinned the analysis for this project.

There were six main components that acted to frame the integrated assessment of risks. These were:

1. Analysing ports as systems;
2. Considering observed (and past) climate / weather data;
3. Interpreting future climate projections;
4. Reconciling climate information with research needs (risk assessment and adaptation planning for infrastructure and functions);
5. Compilation of climate information packs for each of the case study ports (details in Appendix E); and
6. Contextualising with non-climate drivers.

7.1 Analysing ports as systems

As noted previously, modern-day seaports are complex systems; represented by multiple functions and assets. The schematic diagram shown in Figure 5 is not only useful for highlighting the different sub-components of the system under investigation - and the primary focus of the different work packages - but also reinforces the importance of considering a range of different climate-related variables beyond just sea-level rise.

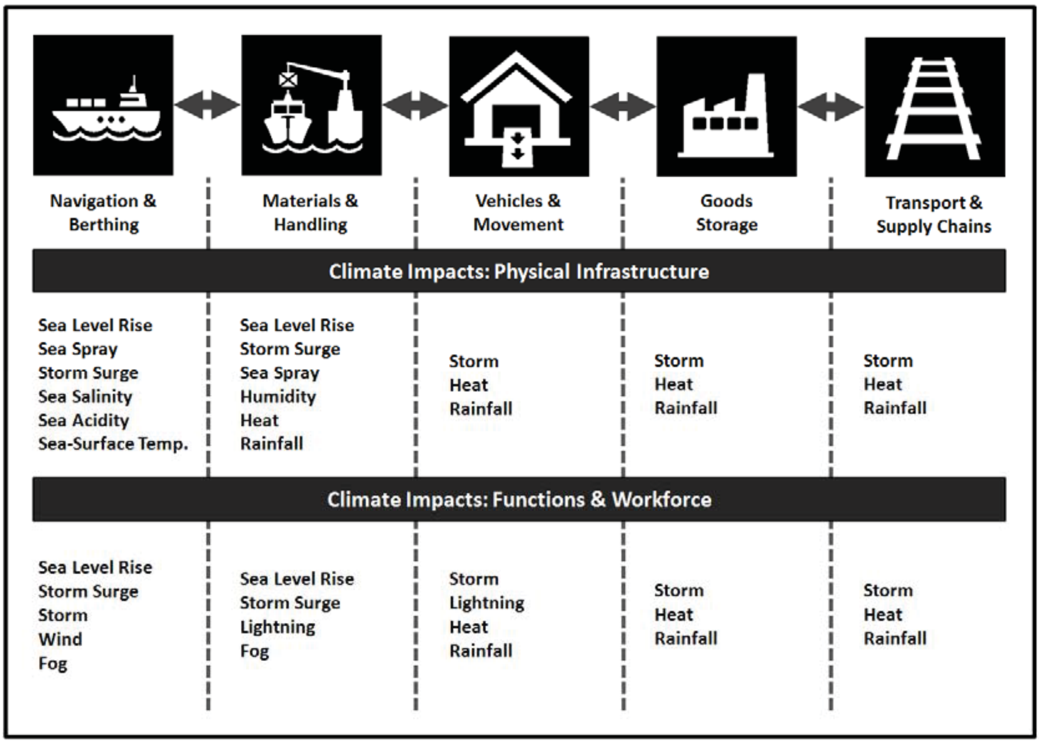


Figure 5: Potential climate impacts on different sub-components of the port system

All the case study ports are on the eastern seaboard of Australia and face impacts from some of the same synoptic-scale meteorological systems, though they are also confronted by different climate impacts at the local level. Thus, the east coast lows (between latitudes 25 - 40^{0}S), also known as winter cyclones or easterly trough lows, are one of the weather systems that the three ports experience (Dowdy, 2011); whilst heat, humidity, wind and flood are experienced locally. Gladstone is the only case study port affected by tropical cyclones (Hardy, 2004). All of the ports will be exposed to sea level rise and storm surge to varying degrees.

The program of research that was carried out sourced and collated different climate-related data (at differing temporal scales), and reconciled this information with the needs of the infrastructural and functional vulnerability assessment work. Analysis also considered possible indirect or cascading effects that may further impact on port operations (electricity black-outs being an obvious example). This system-wide analysis has been used to develop and refine transferable knowledge, methodologies, and decision-support toolkits, to enhance the resilience of seaports to climate change.

7.2 Observed (and past) climate / weather data

Information concerning observed climate provided an initial base from which to explore the climate-related impacts that affect the infrastructure and functioning of seaports. A focus on existing hazards was used in workshop settings to stimulate discussion around current day vulnerabilities (particularly the impacts associated with extreme events) and any adaptation measures the ports had put in place in response to climatic stressors.

It is important to note that the ports sector uses the BoM information regularly. Information on tides is used daily by ports that are dependent on high tide to move ships in and out of berths. Ports also access the daily and three-day weather forecast by the BoM to plan for immediate logistics operations. Ports are responsive to changes in current climate variability; however it is consideration of longer-term climatic change that remains a challenge.

Analysis of past and current events was also extended to cover supply chain impacts. Table 3 highlights some of the impacts that ports have experienced from recent extreme events.

Table 3: Narratives on weather-related impacts on ports and their supply chains

Port Botany, New South Wales
• Flash flooding: March 2011 - 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 • Wind gust: October 2010 - southerly winds blew 45 full containers over causing operations to cease for three days
Port of Gladstone, Queensland
• Flooding: December 2010-January 2011 - coal stopped being transported to the port due to damage to the Blackwater rail line and flooding at coal mines. International coal transport vessels were anchored off the port for the duration. Coal stockpiles were reduced as the port tried to meet the coal export requirements
Port of Brisbane, Queensland
• Flooding: January 2011 - closure of Port of Brisbane to commercial shipping 11 - 16 Jan 2011 (reopened for all shipping on 18 Jan 2011) backlog of ships caused scheduling disruption. The port's main dredger removed an extra 1 million m^3 of deposited sediment from the port limits, which then had to be stored safely (Port of Brisbane 2011) The navy assisted in surveying and taking soundings of the Brisbane River. The Australian Defence Force supplied a minesweeper to help locate submerged objects in the Brisbane River. A significant number of aids to navigation such as buoys were damaged. The Pinkenba (AMSA) team undertook the task of restoring the navigational aids (AMSA, 2011)
Port of Melbourne, Victoria
• Heatwave: January-February 2009 - tarmac melted at DP World – 5% of the terminal out of action. Cranes stopped work. Slowdowns due to overheating of machinery (QuT, 2010)

Australia is fortunate to have a great deal of weather data from past observations to draw upon in order to identify past trends in climate patterns. Not only do records go back over 100 years in some places, there is also substantial coverage by numerous data collection points around the most populated areas. The online portal of the Bureau of Meteorology contains a significant amount of information in this regard. Even so, the data that are available is patchy in places and the database does not provide an unbroken record for all variables that could have been used by this project [for example, the closest weather station to Port Kembla - the Port Kembla Signal Station - only operated between 1950 and 1977. This does not provide the required record for a 30 year time period (a climatology), thus it was necessary to find a weather station further from Port Kembla to provide the required data]. This highlights the ongoing requirement to keep the data consistent. For example, there are inconsistencies in the baselines (climatologies) used by the main CSIRO, the IPCC and the BoM. Similarly, the spatial exactitude of the observed weather data related to specific weather stations does not match the wider spatial coverage of the modelled data, thus care has to be taken when making comparisons, with the source of data always acknowledged.

Synoptic-scale weather systems, such as the east coast lows and cyclones have been dealt with by using the BoM online information and guidance, including the cyclone tracking tool. However, it is important to note that the larger-scale influence of the El Nino Southern Oscillation (ENSO) represents part of the natural variability of the climate that can have huge effects on extreme weather and is an amplifier of both drought and flood.

The BoM also provided access to a number of new, and currently under development, products that aim to quantify extreme events. The BoM in New South Wales, for instance, provided access to their MATCHES (Maps and Tables of Climate Hazards on the Eastern Seaboard) website via a registered users' site. It includes the visualisation of East Coast Lows (ECL) tracks recorded in the Eastern Seaboard of Australia (ESA) region since 1950 as well as associated rainfall, wind, wave and water level data. This website provides access to wide-ranging data-sets, combining BoM weather observations with wave data from Manly Hydraulics Laboratory (MHL), Queensland Department of Environment and Resource Management (DERM) and Sydney Ports Corporation (SPC) within an interactive framework (Coutts-Smith et al, 2011). Other BoM tools that were used during the project included the Rainfall Design IFD Data System (a computerised system allowing automatic determination of a full set of Intensity-Frequency-Duration curves for rainfall for any location in Australia), the record of tropical cyclone tracks, and data on climate extremes.

The historical data related to extremes in Australia is also extensive, but as yet it is not possible to model future extreme events with any accuracy. This is currently a major focus of scientific attention, though remains a challenging endeavour (see for example: IPCC, 2012). Work that is beginning to be published on average recurrence intervals (ARI) [also referred to as return period (R)] is of great benefit as it enables direct communication of possible changes to existing conditions.

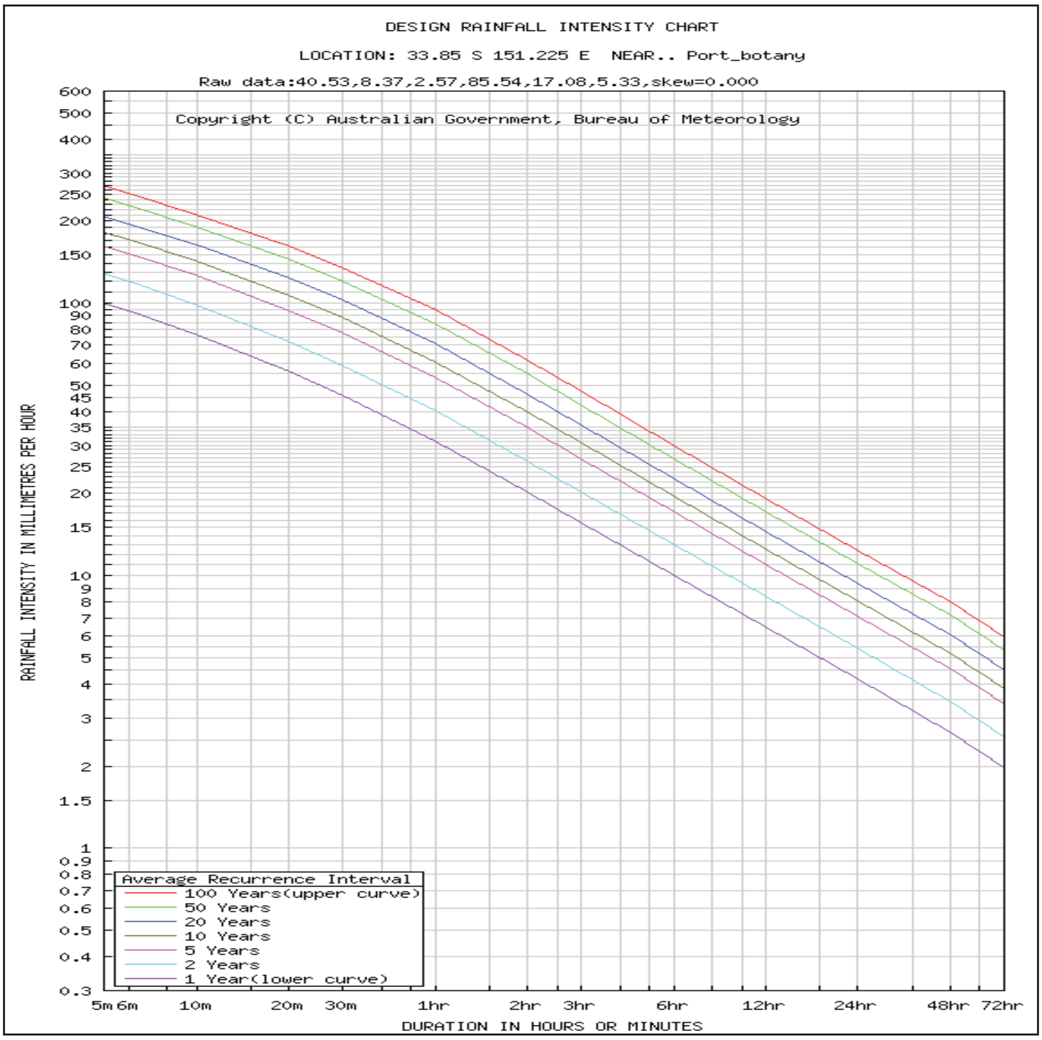


Figure 6: Design IFD Rainfall chart for Port Botany

A useful domestic source for information on past natural disasters was the Disaster Database (Emergency Management Australia). It contains records of all natural and non-natural disasters within Australia (and outside Australia where a number of Australians have been affected), dating from 1622 to the present day. The site's definition of a disaster is, "a serious disruption to community life which threatens or causes death or injury in that community and/or damage to property which is beyond the day-to-day capacity of the prescribed statutory authorities and which requires special mobilisation and organisation of resources other than those normally available to those authorities". Although an ‘uneven’ source of information, it was useful in providing a broad overview of the sorts of natural disasters that the area around the three case study ports had suffered going back over the last century.

The Disaster Database was mined for information to create spread-sheets that listed the recorded weather-related disasters for the vicinity of the ports, or nearest designated region. This can only act as a guide but was a useful starting point for engaging with port operators in order to identify threshold figures (intensity, duration etc.) for some of the climate impacts that can't easily be projected into the future (alternatively addressing current impacts and adaptation deficits). Table 4 covers the time period post-2000 and gives some indication of the economic costs associated with extreme events (recognising that these are insured costs only).

Table 4: Recent disasters in the vicinity of the case study ports (source: EMA database)

Disaster	Region	Start Date	End Date	Insured Cost ($ millions)
Bushfire				
NSW	Dubbo, Sydney, Wollongong	21/12/2001	15/01/2002	69
Cyclone				
Cyclone Yasi	QLD - Ayr, Cairns, Townsville	02/02/2011	03/02/2011	967
Cyclone Larry	QLD - Cairns	20/03/2006	20/03/2006	540
Cyclone Tessi	QLD - Townsville	02/04/2000	04/04/2000	15
Cyclone Steve	QLD - Cairns	27/02/2000	09/03/2000	11
Flood				
NSW	Bourke , Broken Hill , Canberra, Cooma, Dubbo, Narrabi, Swan Hill, Sydney, Tamworth, Tibooburra, Wollongong	24/01/2012	13/03/2012	108
South East QLD	Blackall , Bundaberg, Cairns, Cape York, Charters Towers, Clermont, Cooktown, Croydon, Longreach, Mackay, Mitchell River, Normanton, Rockhampton, Taroom, Tibooburra, Townsville , Weipa	10/02/2008	18/02/2008	Not Available
QLD	Ayr, Birdsville, Blackall, Boulia, Cairns, Cape York, Charleville , Charters Towers, Clermont, Cooktown , Coringa Islets, Croydon, Cunnamulla, Eromanga , Longreach, Mackay, Mitchell River, Moree, Mount Isa, Normanton, Osprey Reef, Richmond, Rockhampton, Roma, Taroom, Tibooburra, Townsville , Weipa, Windorah, Winton	01/01/2008	31/01/2008	70
Hail				
Sydney	Sydney	09/12/2007	09/12/2007	415
Severe storm				
NSW	Sydney	08/06/2007	10/06/2007	1,480
NSW, VIC, TAS, and SA	Sydney , Wollongong, Canberra, Cooma, Adelaide, Hobart, Launceston, Melbourne	01/02/2005	03/02/2005	216
South East Australia	Sydney , Wollongong, Canberra, Cooma, Warrnambool, Wilsons Promontory, Hobart, Melbourne	24/08/2003	24/08/2003	25
Sydney	Sydney	16/02/2002	16/02/2002	10
Eastern NSW	Sydney	18/11/2001	21/11/2001	30
Sydney, Hunter Valley, North Regions	Sydney, Tamworth, Wollongong	03/12/2001	03/12/2001	30
Sydney and Region	Sydney, Wollongong	15/01/2001	15/01/2001	12

7.3 Future climate projections

At the outset of the project, it was thought that access to appropriate climate data to inform the engineering and logistical analysis would be a relatively straightforward process. However, this did not turn out to be the case. The project's 'journey' of matching available future climate information to end user requirements, and understanding and interpreting the processed data whilst dealing with the inherent uncertainties involved, formed a key part of the learning process for all those involved. These learnings, and knowledge gained about translating climate data for infrastructure and logistics applications, represent an important outcome from the project.

In the initial stages of the project, 'off- the- shelf' scenarios, produced by the CSIRO for Australia, were used to inform discussions regarding asset and operational vulnerability to climate-related variables for each of the ports (projections of changes to land air temperature, precipitation, humidity, wind, and extreme severe weather events, for the periods 2030, 2050 and 2070). These projections are based on the latest published modelling work as showcased by from the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC, 2007); informed by the scenarios generated by the CSIRO and BoM (CSIRO, 2007). This coarse-level data provided an early framework for internal discussions amongst the different work package teams. Based on this scoping activity, and feedback from the port authorities, the work package teams were then able to begin the process of identifying the climate-related variables that were needed for a more detailed assessment to take place.

7.3.1 Work package data needs

WP2 required data on weather-related extreme events as this was identified to have the largest impact on the operation of the seaports. Due to the difficulties of predicting actual port operations beyond a relatively short time frame, WP2 looked at the occurrence of extreme weather events up to 2030 [this time period is consistent with the best available trade projections]. Climate variables of greatest importance for this work package included extreme rainfall, fog, hail, storms and wind (it is important to note that these variables are influenced by the intensity of the event in relation to the length of duration. For example, gusts of wind may only occur for a short period, a hail event may last for less than an hour, and fog can appear in the morning and burn off by lunchtime, but steady rain over many consecutive days can have the same effect on flooding as more intense rain over a shorter period).

Given the focus on deterioration of port infrastructure assets, the engineering component (WP3) required data that related to longer term changes, usually expressed as means (i.e. annual or seasonal). The key climate variables identified were: temperature, rainfall, humidity, wind speed (and direction); as well as patterns related to these variables such as the number of consecutive days with no rainfall, or the number of wet days in one year. The group also requested information related to changes in sea surface temperature, salinity, acidity and sea level rise to 2100.

7.3.2 Consistent selection of climate models

Twenty-three GCMs were used in the IPCC's Fourth Assessment Report. Producing results for each of these models was deemed both timely and unnecessary so the project team worked with the CSIRO to identify the most appropriate GCMs for the research. Part of the selection process involved identifying the models that included the variables required by each of the work packages. The engineering group required information on the projected change in climate and ocean variables (temperature, rainfall, relative humidity, sea surface temperature and sea surface salinity) for three ports up to the 2070's. The logistics and business group required information on extreme weather events (projected change in the number of days over 35^{0}C and 40^{0}C, annual extreme rainfall and annual extreme wind speed) for the three ports up to the 2030's.

To assist with the selection of the GCMs, CSIRO and the project team used the Climate Futures framework (Clarke, Whetton and Hennessy, 2011) to enable an assessment of the likelihood of combined changes in two climate variables (temperature and precipitation), and provide the team with a sub-set of models to work with. The development of the 'Climate Futures' framework is a valuable initiative to tailor scenarios to the specific needs of end-user applications. The software produces a matrix for the user which shows the number of models (the likelihood) in each category. These groups of models and their associated likelihood are then labelled as 'most likely', 'worst case' or 'best case', or, in the case of this project, 'most likely', 'hot/dry' and 'cool/wet'.

Table 5: Climate Futures template applied by the project

Rainfall – Annual (% change)	Surface Temperature – Annual (C)			
	Slightly Warmer <0.5	Warmer 0.5 to 1.50	Hotter 1.5 to 3.00	Much Hotter >3.00
Much drier < -15			1 of 24 models	
Drier -15 to -5		12 of 24 models	3 of 24 models	
Little change -5 to 5		6 of 24 models	2 of 24 models	
Wetter +5 to 15				
Much wetter >15				

The project team adopted the commonly used axes of annual mean surface temperature and annual average rainfall to frame its selection of representative models. Using this approach, a set of models was chosen that focused on a 'hotter, drier future', a 'cooler, wetter future' and a 'most likely' future. The rationale for the choice of models was to allow an investigation of not only the 'most likely' future i.e. the future climate that most of the models project, but also some of the alternative futures that may occur. This gives the results as much robustness as possible when considering uncertain future changes (representing a more comprehensive framing of climate risks). This approach enabled the WP1 team, supported by the CSIRO staff, to identify where the GCMs fell across a range of changes to temperature (Celsius) and rainfall (expressed as a percentage loss or gain). On this basis a sub-set of models was then chosen to generate internally consistent datasets for the needed variables. This approach was crucial to providing the specific information needed by the two work packages. It also needed to be iterative as once researchers became more immersed in the project they began to understand more fully the variables needed as inputs, e.g. to the material deterioration models, and what data was actually available from the climate models.

> *"For a given region, timeframe and emission scenario, there might be 5-10 climate futures. A subset of climate futures can be chosen to suit a particular impact assessment … An optimisation function identifies which model has the projections that are most representative of the mean of each climate future. This small set of representative models can then be used in impact assessments". (Hennessy et al, 2012: 10)*

The final suite of models that were used for the case study ports is shown in Table 6. As well, a 'wetter' future was added when the engineering group requested data related to sea salinity (as this was the only model available that provided salinity data). Each of the climate models was run to account for the time-slices of 2030, 2050, and 2070; with comprehensive 'climate information packs' produced for each of the port case studies as part of the project activity (Appendix E). The data packs include observed climate; a considered explanation of the global climate models, emissions scenarios and time periods used; and descriptions of atmospheric and ocean projections as well as information on extreme weather events. This detailed climate data constitutes the major deliverable for WP1.

Table 6: Climate models used to represent different climate futures

Climate Future	Sydney / Kembla	Gladstone
Most likely	Model MRI2.3.2	Model CSIRO Mk 3.5
Hotter drier	Model CSIRO Mk 3.5	Model MRI2.3.2
Cooler wetter	MIROC3.2-Medres	MIROC3.2-Medres
Warmer wetter	MIROC3.2-Hires	MIROC3.2-Hires

The complexities involved with interpreting the climate models is clearly evident in the way that these models express different climate futures for the different case study seaports. Although the same 3 models were used for all seaports, the model that was in the 'most likely future' category for Sydney was a different model from that in the 'most likely future' category for Gladstone. This not only highlights the challenges of bridging the gap between the climate modelling and adaptation communities (and how best to make sense of the complexities and contemporary limitations of climate science by non-modelling experts), but also brings home in more basic terms the sheer size and climatic complexity of the Australian continent. It should also be stressed that the use of different models for the ports of Sydney and Gladstone does not prevent comparisons; rather the different models ensure that a full range of results is provided and thus comparisons can be made in the context of understanding the range of possible futures.

7.3.3 Generating the climate data

The actual generation of different climate scenarios based on each of the representative models was done through the on-line OzClim tool (CSIRO n.d.); a publicly accessible tool designed to allow end users to generate and explore scenarios up to 2100. However, even with the support of such tools scenario generation can be a complex and challenging process - interpretation of outputs using the current interface requires advanced GIS capabilities and can be time-consuming even for those with a reasonable level of expertise.

OzClim allows for the data to be downloaded for different areas of Australia, but it difficult to use. With the support and guidance of the CSIRO, the team chose to download the data in GIS format to enable a selection by location. The Climate Futures data was captured within a 1° buffer (0.5° radius) around the sites of interest (Figure 8, Figure 9 and Figure 10), which allowed for a number of OzClim grid cells to be captured. This created a better and more robust representation of the OzClim output than just using one grid cell. The data extracted from OzClim was averaged (area weighted) over the one degree circle to produce one figure. In other words, taking the data from just one cell could allow site specific climate anomalies to skew the data. Taking the data from a larger set of cells smooths out any such anomalies.

The process of converting the file into a useable format, intersecting the data with the buffer and averaging the data over the 1 degree circle can be seen in the model diagram below (Figure 7). This was created in model builder in ArcGIS and was used to run the data for sea surface salinity and sea surface temperature for all the selected emissions scenarios, time periods and models.

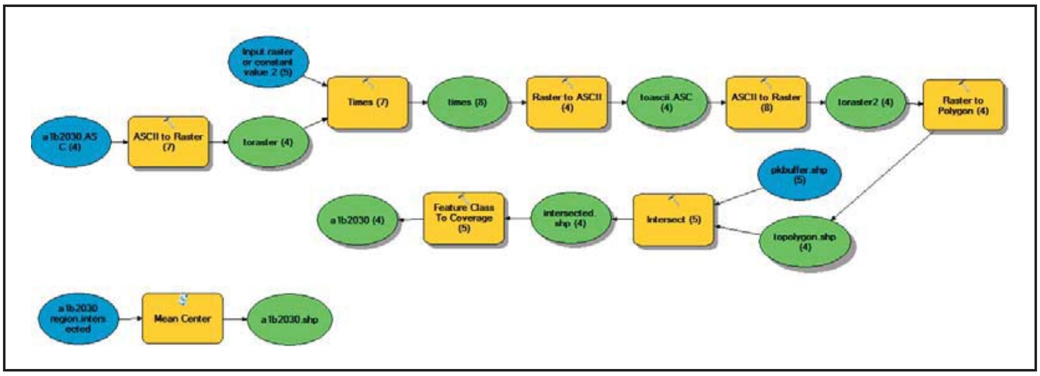


Figure 7. Model created in model builder (ArcGIS) to convert and select files from OzClim

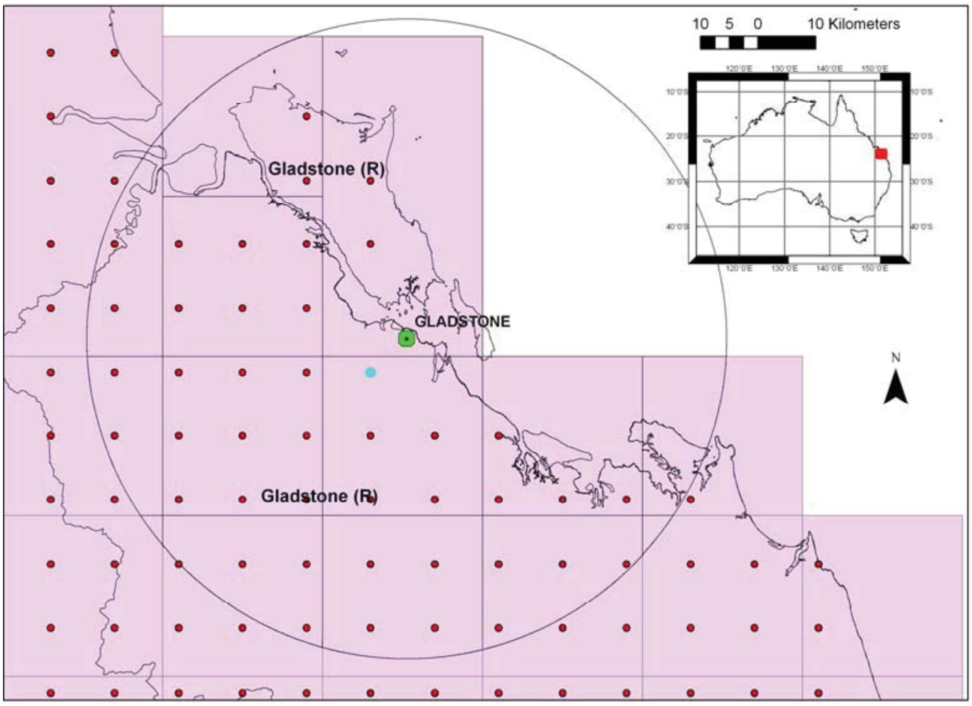


Figure 8: Gladstone. Ozclim grid cells: 1° Buffer (0.5° radius) around site of interest. Blue highlight indicates the points from which climate threshold information was obtained for Gladstone port

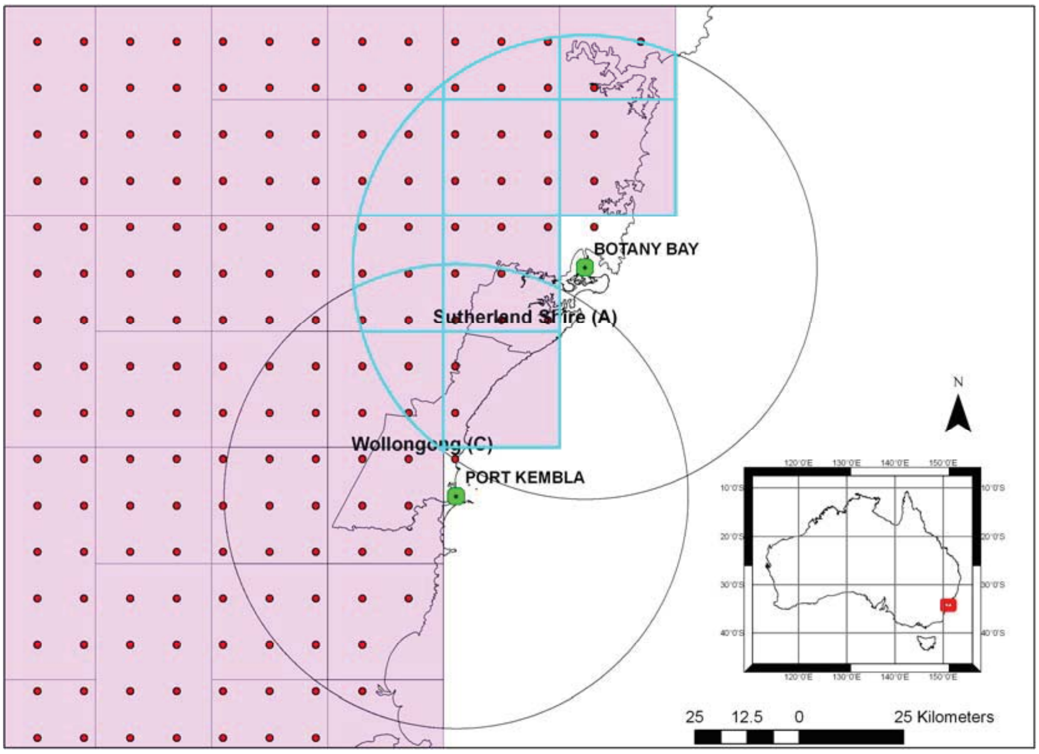


Figure 9: Sydney and Port Kembla. Ozclim grid cells: 1° Buffer (0.5° radius)

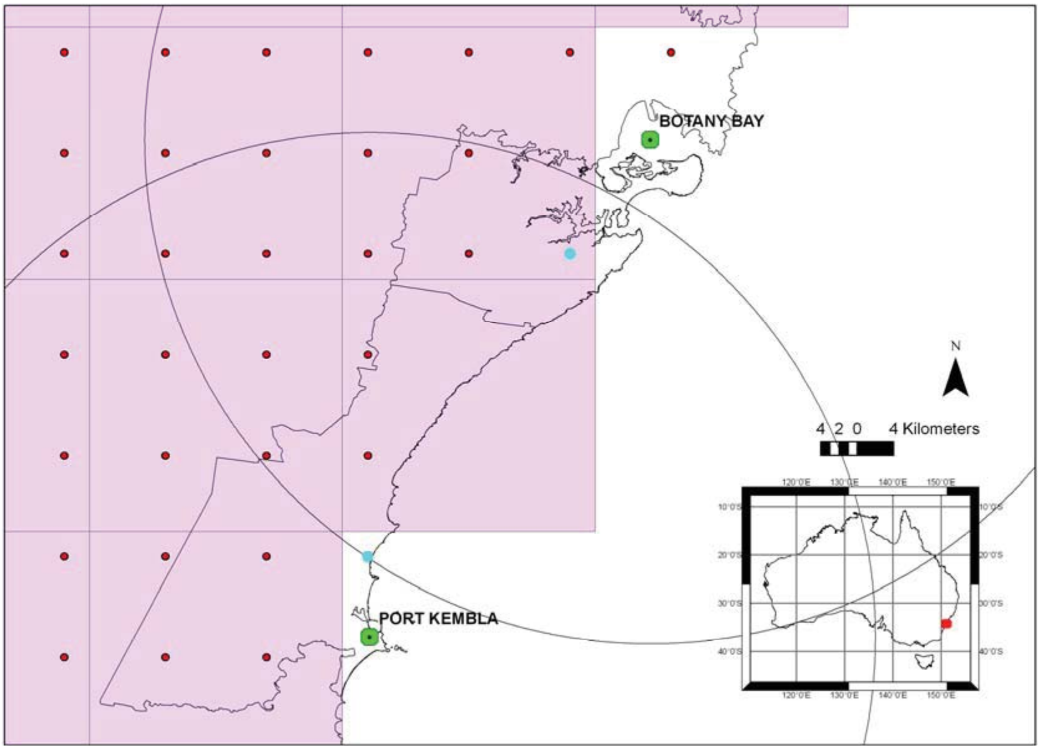


Figure 10: Climate threshold information points for Sydney and Port Kembla ports (see blue points)

Table 7 and Table 8 illustrate the broad climate futures that have been used to inform the analysis for the case study ports. The variables modelled, expressed annually, included: rainfall, surface temperature, relative humidity, sea surface temperature, and sea surface salinity. As noted, the only model that produces data for salinity is MIROC3.2-Hires. Ideally the same models should be used for all variables, keeping an internal consistency across the results. However, in this case this was not possible and MIROC3.2-Hires was substituted in place of MIROC3.2-Medres for sea surface salinity results. The engineering group also requested sea acidity data but this was unavailable in a form that could be integrated into their deterioration model.

Table 7: Climate future categories for models for Gladstone

Model:	2030 A1B	2030 A1FI	2050 A1B	2050 A1FI	2070 A1B	2070 A1FI
CSIRO Mk 3.5	Warmer Little change	Warmer Little change	Hotter Little change	Hotter Little change	Hotter Little change	Hotter Drier
MRI2.3.2	Warmer Drier	Warmer Drier	Warmer Much drier	Hotter Much drier	Hotter Much drier	Hotter Much drier
MIROC3.2-Medres	Warmer Little change	Warmer Little change	Hotter Little change	Hotter Wetter	Hotter Wetter	Hotter Wetter
MIROC3.2-Hires	Warmer Little change	Warmer Little change	Hotter Little change	Hotter Little change	Hotter Little change	Much hotter Little change

Table 8: Climate future categories for models for Sydney / Port Kembla

Model:	2030 A1B	2030 A1FI	2050 A1B	2050 A1FI	2070 A1B	2070 A1FI
MRI2.3.2	Warmer Little change	Warmer Little change	Warmer Little change	Hotter Little change	Hotter Little change	Hotter Little change
CSIRO Mk 3.5	Warmer Little change	Warmer Little change	Hotter Drier	Hotter Drier	Hotter Drier	Much hotter Drier
MIROC3.2-Medres	Warmer Little change	Warmer Little change	Warmer Wetter	Hotter Wetter	Hotter Wetter	Hotter Wetter
MIROC3.2-Hires	Warmer Little change	Warmer Little change	Hotter Wetter	Hotter Wetter	Hotter Wetter	Much hotter Wetter

7.3.4 Data from other sources

Some of the required variables needed to be collated from other sources. This included information on sea level rise. The project used a combination of research findings to inform the assessments, including research on projected sea level rise (Hunter, 2010) and the information made available through Geoscience Australia's 'Oz Coasts Australia' online coastal portal; as well as the regionally distributed sea level rise projections which are available through the CSIRO Marine and Atmospheric Research (CMAR) website. This latter data source was used to populate the case study climate packs.

The modelling of climate extremes is fraught with difficulties and scientific understanding of how extreme events will manifest themselves in the future remains limited. As noted by the IPCC report on climate extremes (IPCC, 2012: 11):

> *"Projected changes in climate extremes under different emissions scenarios generally do not strongly diverge in the coming two to three decades, but these signals are relatively small compared to natural climate variability over this time frame. Even the sign of projected changes in some climate extremes over this time frame is uncertain. For projected changes by the end of the 21st century, either model uncertainty or uncertainties associated with emissions scenarios used becomes dominant, depending on the extreme".*

As such, given the uncertainties involved with contemporary scientific modelling efforts (as well as those inherent in any futures thinking), the project adopted a focus on current day variability as the foundation for the assessment of climate extremes, which was then extended to consider what may happen in the future in terms of natural variability when combined with possible, but uncertain, amplification effects of global warming e.g. the recent La Niña event affecting Australia was a naturally occurring system, though the BoM notes that this particular La Niña event was the strongest on record (BoM, 2012).

Return periods are a useful way of investigating potential changes to extremes. They provide a reliable scientific description of the extreme (rated in terms of a 30 year climatology) as well as incorporating the extreme within a time sequence. There are published return periods that this project used for heat (Nguyen, 2011) and for rainfall (IPCC, 2012); however this data generally relates to a large spatial scale. The NSW Government has published a set of annual returns for events that affect the State, e.g. the following information relating to hail (Table 9), which illustrates the current state of knowledge.

Table 9: Table of hazard indicators for NSW (OEH, 2011)

Sydney/Central Coast hail hazard indicators to 2050		
Indicator	**Current Conditions**	**Status of research**
Frequency	Average 10 hailstorms per year, with approx. 2 per year with hail at least 5cm diameter.	Research is currently limited to only a couple of studies for NSW (Schuster, 2005; Leslie, 2007; Niall, 2005).
Intensity	Severe thunderstorms can produce hail over 2cm in diam. The largest hail recorded between 1990 and 2007 was 11 cm in diameter (Cherrybrook, 2007).	There is currently no published work on observed trends in intensity
Seasonality	August through to March. Peak frequency October through February.	

7.4 Reconciliation of climate information with research needs

The climate information needed by WP2 - the logistics research team - was markedly different from that required by WP3 - the engineering team - as previously discussed. However, both teams were unfamiliar with all the meteorological concepts involved in this project and thus had to work through the choice of climate variables and their expression (as annual, seasonal or one off-extremes) that were needed for their research and then reconcile them with the data that the models could produce. This required iterative adjustment by both teams. As the major user of future climate data, the engineering requirements are discussed first.

7.4.1 Structural resilience to climate impacts (WP3)

The overarching aim of WP3 was to investigate life cycle assessment given the possibility of accelerated degradation of materials driven by climate change. The engineering group modified existing deterioration models to analyse how climate change may alter the deterioration rates for concrete, steel, and timber (there are many different models that calculate deterioration). Provided that port marine structures are properly maintained, the design life of assets is usually considered to be 35 to 50 years (although they often last significantly longer than that). As such, research activity for WP3 focused on change over relatively long time periods. This contrasts with the temporal focus of the functional element of ports which concentrated on the short and medium term.

Some of the likely issues that were identified by the early scoping activity included:

Five distinct zones that affect structures in water: These zones are atmospheric zone, splash zone, tidal zone, zone of continuous immersion and seabed zone. The atmospheric zone tends to contain some amount of salt, which can increase the rate of atmospheric corrosion of metal structures and the deterioration of concrete over that of materials not exposed to salt. In timber structural components above the splash zone, fresh water may collect and stagnate, initiating rot. The splash zone constitutes an area from the high water level to the upper levels attained by spray. This zone is subjected to intermittent wetting and drying as waves run up or break on the structure. The tidal zone is the usual range between high and low levels, which is periodically immersed. Below low tide level to the seabed the structure is continuously immersed and this is typically a zone of moderate to light attack on steel and concrete but not timber. Below the seabed, the structure's elements are buried and are relatively well protected as the lack of oxygen prohibits oxidation and the existence of most organisms. A summary of material deterioration is shown in Table 10.

Sea-level rise: Will have a major impact on design as it will change the zones described above.

Waves: In order to analyse the strength of maritime structural members, two pieces of information about external load induced by ocean waves are needed. The first is the extreme value of wave-induced load under long-term distribution, which is necessary for a large deflection and a limit state strength analysis of these structures. The second is the long-term distribution and a time history model of wave-induced load for a fatigue strength analysis.

Air and ocean temperature: Increased temperature and solar radiation could potentially reduce the life of a structure. Higher temperatures increase expansion and accelerate material degradation of concrete joints, steel, asphalt, coatings, sealant, and timber. Since port structures lie within the coastal zone, they are subject to increases in humidity which affects corrosion and material degradation. This accelerated degradation of material has the potential to reduce the service life of the structure and facility; increasing maintenance costs and the probability of structural failure due to extreme weather events.

Wind climate: Changing conditions will affect determination of design criteria. Future extreme events may lead to marginal probability of failure.

Rainfall/runoff: The effect that rainfall has on the lifetime of physical structures is related to the wetting and drying cycle, increases in that cycle will result in increased deterioration. However, extreme events which lead to lengthy inundation are a concern and may affect design criteria.

Table 10: Summary of material degradation

Material	Deterioration mechanism	sea level rise	water table	temperature	rainfall/runoff	wave	wind	salinity	humidity
		(Climate variables)							
Steel	corrosion	tidal range, decade	n/a	air & ocean temp, avg & ext	n/a	mean, decade	mean, decade	mean, decade	mean & ext
	fatigue	n/a	n/a	n/a	n/a	mean, decade	mean, return period	n/a	n/a
	fracture	n/a	n/a	n/a	n/a	n/a	ext	n/a	n/a
Concrete	efflorescence	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	erosion (salt scaling)	mean, decade	mean, decade	mean air temp	no of dry days/yr, distribution	mean, decade	mean, decade	mean, decade	mean, decade
	acid attack	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	sulphate attack	mean, decade	mean, decade	n/a	n/a	n/a	n/a	n/a	n/a
	alkali-silica attack	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	corrosion of steel reinforcing bar (chloride)	mean, decade tidal range	n/a	mean	3-day wet/dry period	mean, decade	mean, decade	mean, decade	n/a
	corrosion of steel reinforcing bar (CO_2)	n/a	n/a	n/a	no of wet days in 1 year	n/a	n/a	n/a	n/a
Timber	weather deterioration (erosion)	mean, decade	mean, decade	mean air temp	no of dry days/yr, distribution	mean, decade	mean, decade	n/a	mean, decade
	separation of cracks	mean, decade	mean, decade	mean air temp	no of dry days/yr, distribution	mean, decade	mean, decade	n/a	mean, decade
	decay fungi	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a

Over the course of the project, the engineering researchers refined their understanding of what data the GCM models could provide and what additional data was necessary to model the three materials under investigation – concrete, steel, and timber. In the initial stages, the engineering team requested a range of values; some of which were unavailable from the climate models. Timed variables that are commonly used in deterioration models - that could not be provided by the climate models – were the number of wet hours in a year and the number of wet/dry cycles in a year. The engineering group, by necessity, had to simplify the climate data input to the deterioration models they used and manage the inputs that were not available by inserting estimations and assumptions. Some of these assumptions had to be derived from data that were produced and calibrated for the UK climate, which led to a less precise output for Australian conditions. The group also wanted to model sea level rise beyond 2100, but these calculations were not available. Data on changes to the acidity of the ocean was also requested, however the available information was not expressed in a form that could be used in the models (the group unable to make the necessary conversion). Another set of information that they were unable to access was detailed information on possible changes to wave climate. Nonetheless, the work ascertained that that main climate driver for changes to deterioration of materials in the sites under consideration is temperature change.

In order to reconcile modelling needs with availability of data, the engineers iteratively reduced the scope of climate variables used as input to the material deterioration models. The final variables used were surface temperature, rainfall and relative humidity expressed as annual figures. The group also requested sea salinity, which entailed introducing a fourth model as this data was not available in the three chosen climate models.

7.4.2 Functional resilience to climate impacts (WP2)

The aims of WP2 were manifold and revolved around the expertise of the business and logistic researchers within the Business, IT and Logistics School at RMIT University as well as the GIS skills of researchers within the University of Queensland's School of Geography, Planning and Environmental Management. The research addressed functional resilience by focussing on two elements at risk: functional assets and the workforce. Analysis then considered adaptation options and the building of adaptive capacity. Ports use, as do other businesses, a timeframe of between fifteen and twenty five years for the planning of infrastructure that relates to trade. As such, research activity for the logistics team focused on the short to medium term. The management of trade passing through a port, either import or export, involves the activities of many organisations in a complex set of relationships that are manifest within and beyond the port's boundaries. Therefore the work package focused on extreme events that could impact the port's operational and logistic divisions in the short to medium term.

The main measure of changes to functionality will be time lost to productivity. The loss of work time is not directly linked to the duration of the extreme event and the extreme event does not have to occur at the port, as impacts on the supply chain of a port will also have consequences at the port itself. The types of extreme events that impact ports include:

Short term events: Lightning, hail and wind gusts can inflict damage in a matter of minutes.

Medium term events: Intense rainfall leading to flooding, fog, severe storms or cyclones may last a number of hours or several days.

Long term events: Extreme events can also have a longer duration such less intense rainfall that continues over a longer period of time or heatwaves that by definition last at least three days.

Information related to extremes, and their possible average return period is difficult to source from both the future and past climate data. This work is just beginning to be undertaken by the international climate science community (IPCC, 2012). A further impediment to analysing risks from climate extremes is that the port operators that the logistics team worked with did not have a precise definition for many of the thresholds that were important. The operators had a working knowledge that enabled them to operate on the basis of stopping work once identified thresholds had been reached, but this did not necessarily translate into data that could be used by the research team. For example, due to OH&S and engineering requirements cranes have a clearly defined wind speed threshold beyond which they are legally required to stop work, but for fog the accepted wisdom is that work will stop once an identified landmark can no longer be see clearly (interview with operator – WP2 data). Thus, there was both formal and informal data available on thresholds at the operations level. However, the global climate models did not provide data on wind gusts and there is no modelled data for Australian conditions related to fog. Nonetheless, the work of the logistics team married logistical modelling at port level with the impact of climate extremes as well as providing information on the adaptive capacity of the port workforce to extreme events.

The researchers refined their understanding of the climate impacts on port functions over the course of the project. The nature of the research meant that it was not possible to use the sorts of data that WP3 could use, for example numerical data related to percentage change to projected annual climate statistics. The data required by WP2 was: (i) definitions of extreme events, (ii) definitions of the thresholds at which port operations were affected, and (iii) data related to average return intervals for events that were greater than the thresholds.

Some definitions of extreme events were available through the BoM. For example, cyclones have clear definitions (see Table 11), whereas fog is defined as "a concentrated suspension of very small water droplets causing horizontal visibility to be less than 1000 metres" (BoM, 2011).

Table 11: BoM definition of a cyclone

	Mean wind speed (km/h)	Strongest gust (km/h)	Pressure (hPa)	Description
Category 1 Cyclone	63-88	<125	>985	Negligible house damage. Damage to some crops, trees and caravans. Craft may drag moorings
Category 5 Cyclone	>200	>279	<930	Extremely dangerous with widespread destruction

Practical definitions of thresholds were also sourced from the ports, for example, operation of cranes cease once wind gusts reach a certain level or wind comes from a direction that leads to unsafe handling conditions. Most modern cranes are fitted with alarms that sense gust speed or wind load that exceeds the safe working load for the crane. The structural design of cranes is based on industry standards expressed as (50) year return intervals of wind speeds. The definition of the threshold for fog however is anecdotally related to whether certain land marks can be seen or not. Thus, at this point in time there is not a great deal of detailed knowledge of the quantitative definitions of the all the climate thresholds as they affect ports. Further, even if this information had been available, the production of data related to average return intervals for those threshold events is just beginning (IPCC, 2012) and the specific data needed were not available to this project.

The extreme event data that was available to the researchers was in the form of days over 35^0C or 40^0C and this data was used by WP2 in its simulations as was the data related to design rainfall created by the BoM (see earlier discussion on projected climate data). The CSIRO also produced sets of data related to extremes in the form of percentage increase in annual extreme wind and rain; however the conversion of this information into time sequences for detailed modelling was not possible for this project.

A final component of WP2 was the use of GIS to spatially map vulnerable port assets – this was done for Port Kembla and used the online CSIRO Marine and Atmospheric Research data related to sea level rise. The following table (Table 12) informs the above discussion, showing an early example of the thinking for both the research teams in terms of the types of climate impacts that would affect the material infrastructure or the operational functions of a port. The engineering group dealt with a variety of impacts, including corrosion, fatigue and borer attack, while the logistics group dealt mainly with delays in productive output.

Table 12: Climate parameters initially considered by the work package teams

Material	Mechanism	Climate parameters
WP2		
Pavement	Loss of seal	Temperature (maximum seasonal) Rainfall (extreme)
Navigation and berthing	Delays	Extreme: temperature, rain, humidity, wind
Bulk un/loading	Delays	Extreme – temperature , rain, humidity, wind
Container un/loading	Delays	Extreme – temperature, rain, humidity, wind
Rolling cargo un/loading	Delays	Extreme – temperature, rain, humidity, wind
Yard movement and stacking	Delays	Extreme – temperature, rain, humidity, wind
Road transfer	Delays	Extreme – temperature, rain, humidity, wind
Rail transfer	Delays	Extreme – temperature, rain, humidity, wind
Workforce	Loss of work hours, other	Extreme – temperature, rain, humidity, wind
WP3		
Steel	Corrosion	Rainfall (no of wet days in 1 year) Humidity (mean decade + extreme) Temperature (mean annual) Salinity (mean decade) Wind (mean decade)
	Fatigue	Wind (mean decade)
	Fracture	Wind (extreme)
Concrete	Erosion (salt-scaling)	Salinity (mean decade) Rainfall (no of dry days in 1 year) Temperature (mean annual) Humidity (mean decade) Wind (mean decade)
	Corrosion of steel rebars (chloride ingress)	Temperature (mean annual) Rainfall (3-day wet/dry period) Wind (mean decade) Salinity (mean decade)
	Corrosion of steel rebars (carbonation)	Temperature (mean annual) Rainfall (no of wet days in 1 year)
Timber	Weather Deterioration	Temperature (mean annual) Humidity (mean decade) Rainfall (no of dry days in 1 year + distribution) Wind (mean decade) Salinity (mean decade)
	Separation of cracks	Temperature (mean annual) Humidity (mean decade) Rainfall (no of dry days in 1 year + distribution) Wind (mean decade) Salinity (mean decade)
	Marine borer attack	Temperature (mean annual) Humidity (mean decade) Rainfall (no of wet days in 1 year) Wind (mean decade)

7.5 Non-Climate Drivers

Climate change is only one factor amongst many that seaports need to consider when planning for the future. Therefore, to contextualise the information on future climate risks the research also carried out a review of policy, grey, and academic literature to determine some of the key socio-economic trends, and possible ‘sideswipes’, that may influence future risks. Five main categories were researched:

1. Demography;
2. Economy;
3. Technology;
4. Institutions; and
5. Supply chains.

In terms of thinking about port ‘futures’, preparatory work that laid the groundwork for the National Ports Strategy and National Land Freight strategy has provided a valuable legacy of information. Of particular note are a series of consultancy reports on the Australian ports system (GHD Meyrick, 2010a, b, c, d, e).

7.5.1 Demography

Australia's population now totals more than 21.5 million (ABS, 2012). Of these, approximately three quarters are clustered along the Eastern seaboard in the States of Queensland, New South Wales, and Victoria; with close to two-thirds of Australia's population residing in a capital city (see Table 13).

Table 13: 2011 Population Figures (ABS, 2012)

States and Territories	2011 Total Population	Capital City	2011 Capital City Total Population
NSW	6,917,658	Greater Sydney	4,391,674
VIC	5,354,039	Greater Melbourne	3,999,982
QLD	4,332,739	Greater Brisbane	2,065,996
SA	1,596,568	Greater Adelaide	1,225,235
WA	2,239,169	Greater Perth	1,728,867
TAS	495,352	Greater Hobart	211,656
NT	211,945	Greater Darwin	120,585
ACT	357,220	*	*
Australia (incl. Other Territories)	21,507,719	-	-

* Total pop is equated to capital city population for ACT ABS figures

This settlement pattern has been reinforced by recent population growth - between 2001 and 2011 increases in population were most prominent in capital cities and along the coast (Figure 11). This trend is superimposed on areas where economic development is strong; with the growth areas also consistent with the location of the major ports of Australia. The cities of Melbourne, Sydney, Brisbane, Freemantle and Adelaide (which house the main container ports) all show population increases of around 20 per cent over the same ten year period. Similarly, areas around the bulk ports of Western Australia (WA) and Queensland also indicate similar rates of growth. Australia-wide, Dampier (WA) handled the largest volume of exports by value, and Port Hedland (WA) handled the largest volume of exports by weight in 2009–10 (BITRE, 2011: 6).

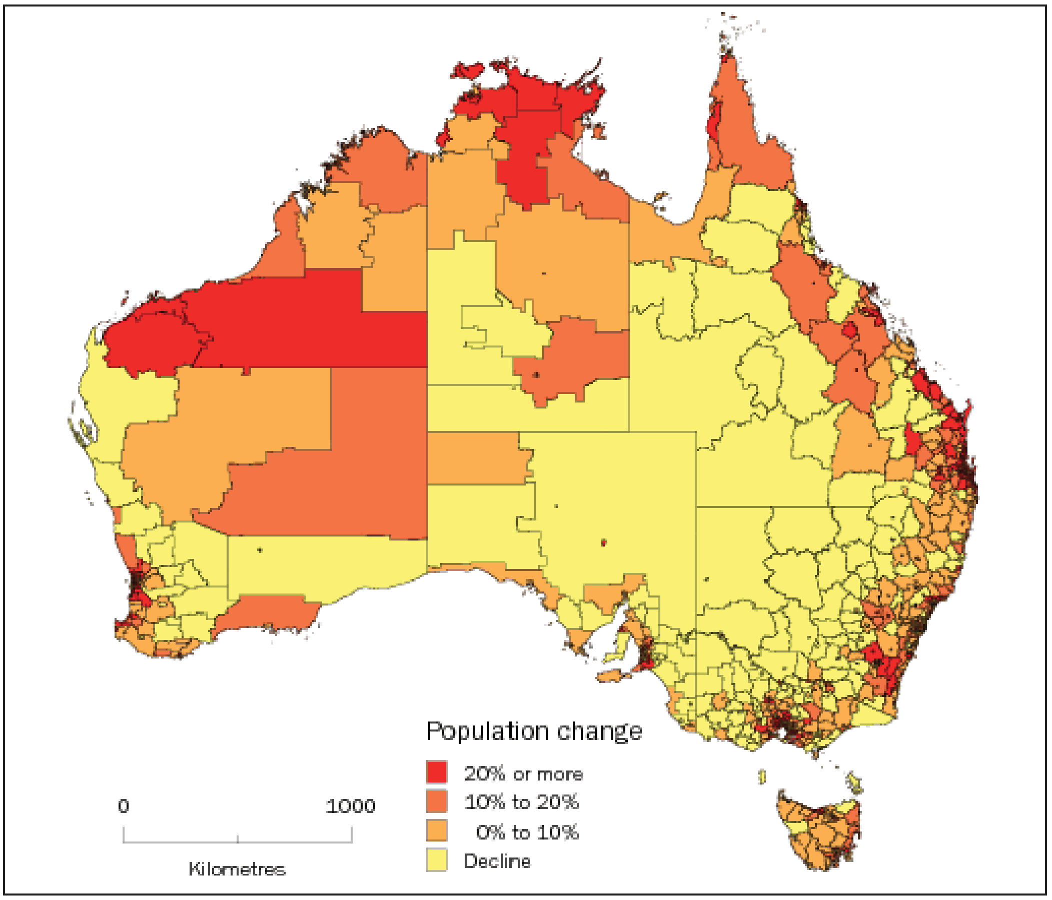


Figure 11: SA2 Population Change, 2001-11 (ABS, 2011)

Three population projections to 2100 are provided by the Australian Bureau of Statistics, with estimates for the resident population ranging between 30.9 - 42.5 million people by 2056, and between 33.7 - 62.2 million people by 2101 (Figure 12). The central projection (Series B) reflects current trends in fertility, life expectancy at birth, net overseas migration, and net interstate migration. Series A and Series C are based on higher and lower assumptions for each of these variables respectively. In summary, Series B is based on the following trends:

- A total fertility rate of 1.8 babies per woman from 2021 onwards;
- Life expectancy at birth increasing to 85.0 years for males and 88.0 years for females by 2056 and remaining constant thereafter;
- Net overseas migration of 180,000 per year from 2008 onwards; and
- Medium levels of interstate migration.

Population growth will affect the ports in direct and indirect ways. The most obvious of the direct impacts will be an increased throughput of goods through the container ports to meet the demands of a growing population. However, conversely, as urban populations increase the major ports in capital cities will find opportunities for expansion limited. Capacity constraints will also be tested through increasing pressure on transport infrastructure. Population growth may also create pressure on other forms of critical infrastructure such as energy generation and distribution and water resources, which may then have cascading impacts on port operations. In the major cities there is already pressure on ports as populations, and the need for inner city housing, encroaches on land and road / rail links that have been traditionally used for industry. Port congestion and container traffic are seen as an increasing challenge for the sector, and it has been recommended that that long term reservation of maritime and land access and connecting rail corridors is necessary (GHD Meyrick, 2010e).

Given their export focus, the major bulk ports are less likely to be directly affected by increases in domestic population. However, they may benefit from a larger workforce as long as aging does not constrain labour force participation rates. The ABS table (Table 14) shows that if current trends continue to 2056, the population will double in the two States with major mining activities, Western Australia and Queensland.

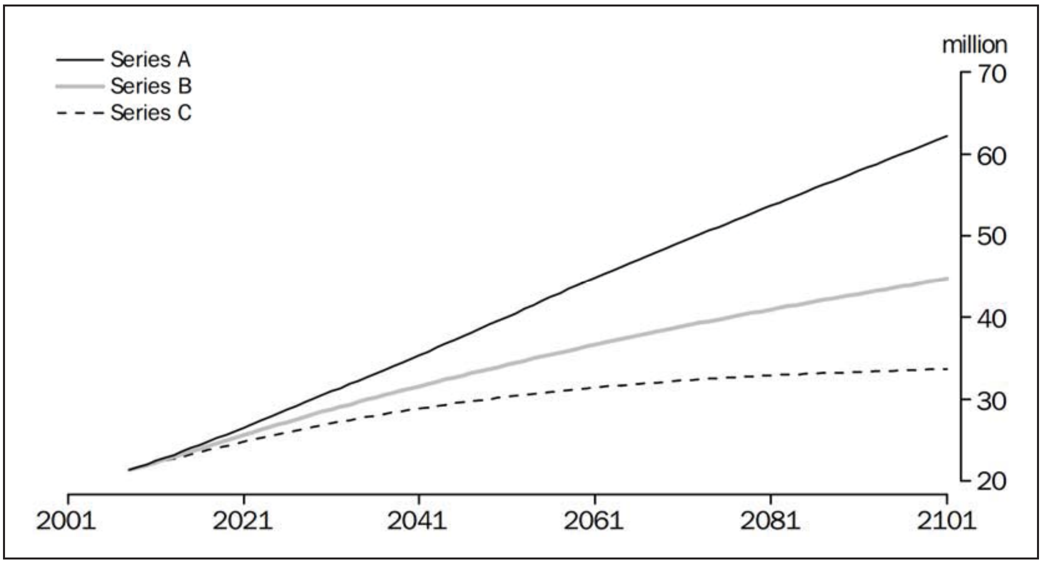


Figure 12: Projected population (ABS, 2008)

Table 14: Population Projections by Australian State, 2006 to 2101 (ABS, 2008)

States and Territories	State & Territory Total Population in 2011	State & Territory Projected 2056 Populations*
NSW	6,917,658	10,200,000
VIC	5,354,039	8,500,000
QLD	4,332,739	8,700,000
SA	1,596,568	2,200,000
WA	2,239,169	4,300,000
TAS	495,352	571,000
NT	211,945	401,600
ACT	357,220	509,300
Australia (total including other territories)	**21,507,719**	**35,381,900**

7.5.2 Economy

> *"Barring a nuclear or climate cataclysm, the central message [is that] economic power will continue to shift to the South and East [and] is likely to prove robust even in the event of major unexpected shocks, such as wars and global depression. The troubled history of the twentieth century suggests that the advance of globalization and the spread of technology are extremely powerful forces that may be temporarily interrupted and even reversed, but not permanently stopped". (Dadush & Stancil, 2010: 17)*

The recently released white paper 'Australia in the Asian Century' (Department of the Prime Minister and Cabinet, 2012) outlines the growth of Asia and some of the likely implications for Australia. It notes that the Asian region will be the world's largest producer of goods and services - and the world's largest consumer of them - within a few years. Over the decade from 2000 to 2010 Asia's largest economies have grown considerably, while over the same period the relative global significance of the US and Japan, in terms of share of total global GDP, has reduced (Figure 13).

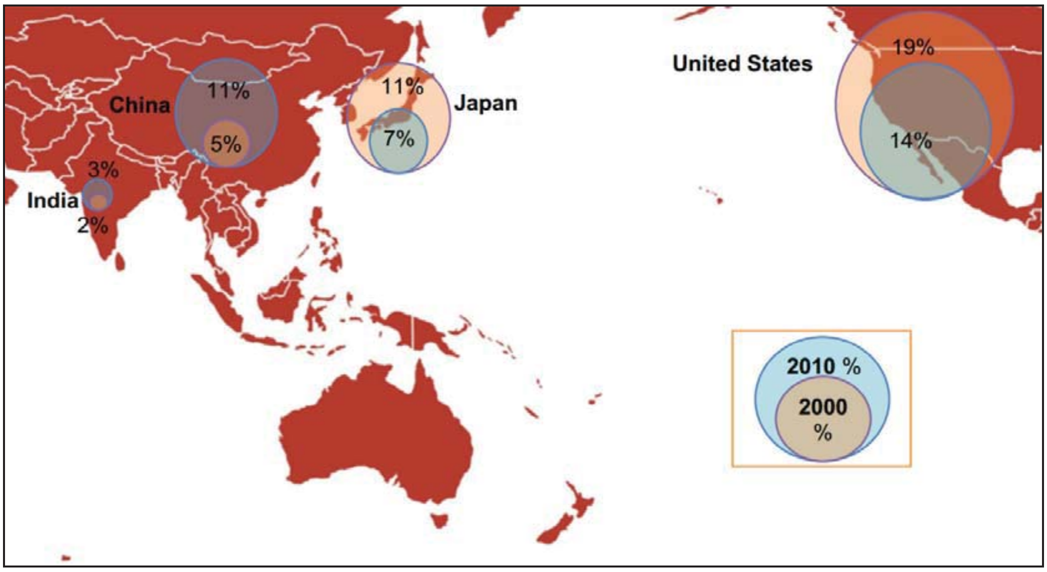


Figure 13: Index of global economic power showing the weighted average of the share of a nation in terms of the world GDP and how it has changed from 2000 to 2010 (DPMC, 2012)

Forecasting accuracy declines significantly as the planning horizon increases beyond five or ten years. Most economic projections are little more than extrapolations of past trends (GHD Meyrick, 2010e). However, the need for a range of more robust forward-looking economic (and other planning) scenarios is recognised and is a major plank in the National Land Freight Strategy (Infrastructure Australia, 2012). Traditionally, forecasts of trade for Australia come from either the Bureau of Infrastructure Transport and Regional Economics (BITRE) or the Australian Bureau of Agricultural and Resource Economics (ABARE). In 2011 the Australian Government also set up the Bureau of Resources and Energy Economics (BREE) in order to understand the drivers behind the mineral boom, which is one of the most important current economic drivers for Australia. This directly affects seaports as the export of all minerals and ores goes through the seaport system. BREE is also charged with understanding the increasing uncertainties in global economic outlook – from climate change and other global forces – that might affect trade. It delivers forecasts, data research, analysis and strategic advice to the Australian government and to stakeholders in the resources and energy sectors. This work is in its early stages but will eventually feed into strategic thinking at the bulk ports. Indeed, what has been labelled as a 'boom' was, in fact, a "terms-of-trade shock providing Australia with windfall gains from the sudden but sustained increase in prices for our minerals due to rapidly increasing demand, particularly from China" (Parkinson, 2012).

Embedding the impacts of climate change into economic forecasts is an activity that is still in the early phase of development, and there is still limited knowledge on the linkages between climate impacts and economic damages [see: Lenton & Ciscar (2012) for a current review of integrating tipping points into integrated assessment models]. A number of international models, such as FUND, DICE, PAGE (which are referred to by the IPCC), do attempt to create economic scenarios that reflect the impacts of future change by combining climate change impacts, economic growth, and feedbacks including tipping points; however results are only applicable at a broad global or regional scale. The Garnaut Climate Change Review, commissioned by COAG in 2007 to provide an independent study of the impacts of climate change on the Australian economy, contains a literature review of the main models used internationally (Frontier Economics, 2008). This paper also discusses the Australian model, Global Integrated Assessment Model (GIAM), which was created by the ABARE and the CSIRO in 2008 (Frontier Economics, 2008).

GIAM released results in a discussion paper (Gunasekera et al, 2008). Using a high global emissions scenario that is similar to the IPCC SRES Scenario A2, the key findings were:

- A clear divergence in economic potential is projected to occur from about 2050 as climate change impacts are expected to have a material effect on regional economies;
- Globally, climate change impacts are expected to reduce economic output by about 1.4 per cent in 2050 and 11.4 per cent in 2100 (relative to the reference case without impacts);
- Australia will be less affected than many other countries and the estimate is that Australia's economic output will be reduced by about 0.6 per cent by 2050, and about 5 per cent by 2100 relative to the reference case.

Elsewhere, the UK Stern Review estimated that if global emissions are not reduced, the overall cost of climate change will be equivalent to losing at least 5 per cent of global GDP each year (Stern, 2006). If a wider range of risks and impacts is taken into account, the estimates of damage could rise to 20 per cent of GDP. However, if strong action is taken to reduce emissions the cost of action could be limited to around 1 per cent of global GDP each year. There is clearly a wide divergence of opinion as to what the real costs of future climate-related impacts will be. It is worthy of note that the Garnaut Review estimated the high consequence for economic loss to Australian trade by 2100 as a 0.5–1.5% per cent loss of annual GDP for the economic activities of international trade, agriculture and mining. These constitute major activities of Australian seaports.

Table 15: Estimation of impacts by 2100 with high economic consequence (Garnaut, 2008: 254-257)

Sector	Description of Impact with a High Economic Consequence*
International trade	Changes to import prices Changes to demand for some commodities
Agriculture	Changes in dryland crop production Reduction of carrying capacity of pasture for sheep, cattle, dairy Reduction in water availability for irrigated agriculture
Mining	Slower growth due to multiple factors

* Equivalent to 0.5–1.5% per cent loss of annual GDP by 2100

Australia is currently the 13th largest economy in the world with the 5th highest GDP per capita. Seaports handle the majority of trade for Australia. In 2010-2011 the top 6 commodities by weight were iron ore, coal, general cargo, oil and petroleum, aluminium, and grain (Table 16).

Table 16: Bulk commodities and general cargo 2010/2011 (BITRE, 2012)

Bulk Commodities and General Cargo through Australian Ports 2010/2011	Mass Tonnes (millions)
Iron ore	345.3
Coal	286.2
General cargo: container and break bulk (import & export)	165.8
Oil and petroleum (import and export)	77.8
Aluminium	40.1
Grain	25

Bulk cargo: Australia is currently experiencing a historic resources boom due to its high-grade resources (particularly iron ore and coal) and its relative geographical proximity to China. Between 2005 and 2010, China accounted for over 80 per cent of the increase in global demand for nearly all energy and metal products (Drysdale & Hurst, 2012). This demand is expected to continue until 2025 at least (BREE, 2012); however there is continuing discussion amongst experts as to the rate of growth. In a recent speech, Martin Parkinson, Secretary to the Treasury said:

> *"Labelling this […] wave of change washing over Australia's economy as a 'mining boom' fails to capture the more complex progression of what is, in fact, an evolution in our mining sector and the reshaping of our economy." (Parkinson, 2012)*

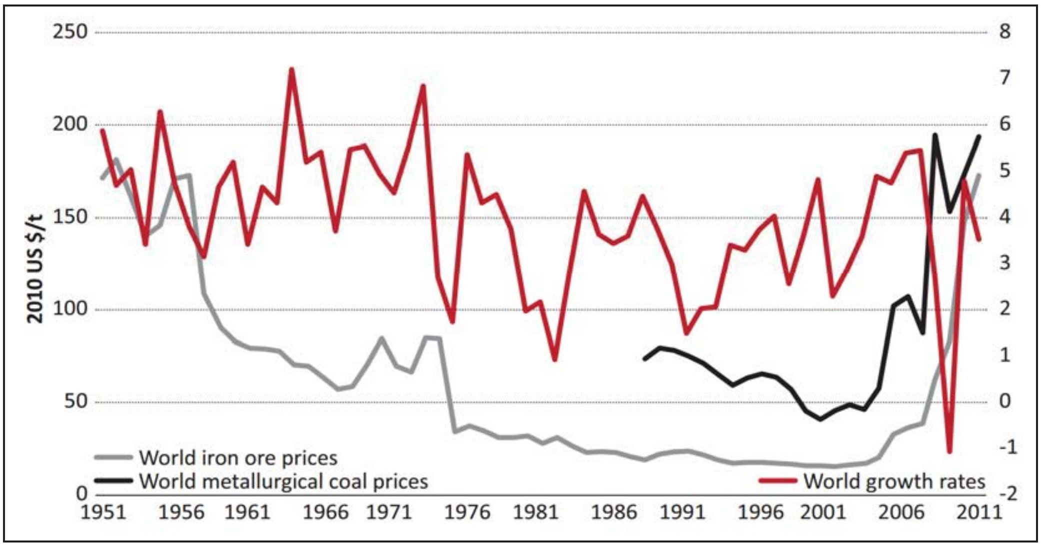


Figure 14: Global coal and iron ore prices alongside global growth rates (from Garnaut in Drysdale and Hurst, 2012: 13)

According to BREE, over the period 2012 to 2025 global and regional demand for resources and energy commodities is likely to be determined by four key variables (BREE, 2012: 13):

1. Population growth,
2. Economic growth,
3. The commodity intensity of economic growth, and
4. Climate change policies

The modelling done by BREE shows all bulk commodities increasing in growth significantly for the next 5 years, and then displays 3 possible trajectories of high, medium and low growth (for example, projections for thermal coal: Figure 15).

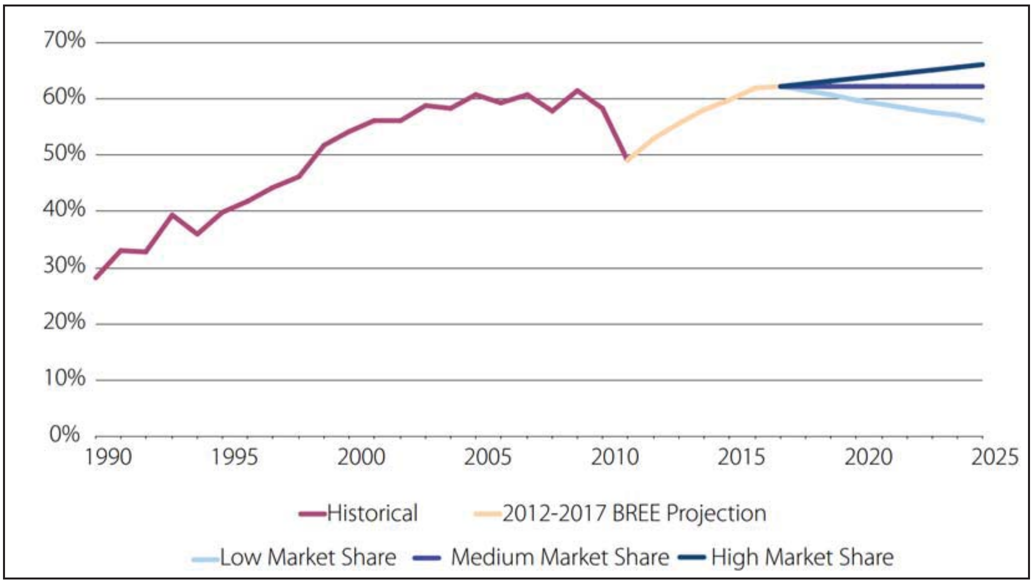


Figure 15: Modelling of thermal coal (BREE, 2012)

As the impacts of climate change become more pronounced (as well as more uncertain) after 2050 this presents challenges for long term planning.

Grain and agriculture: The agricultural sector is significantly affected by climate variation and climate change (Stokes & Howden, 2010). It is also difficult to forecast as it can be very volatile, influenced both by changing markets and by climate variability. For example, the Australian wheat harvest dropped significantly during the drought period early in the 21st Century, though currently is at a premium because of recent drought conditions in the USA and good cropping in Australia. Hence, it is likely that the market (and by extension the ports sector) will need to cope with even greater swings and volatility in agricultural markets in the future (GHD Meyrick, 2010e). In the shorter term, the nature of agriculture exports may change as Australia's trade links with Asia increase to at least one-third of GDP by 2025, up from one-quarter in 2011 (Department of the Prime Minister and Cabinet, 2012). Over a longer period, agricultural activity may even shift geographical location due to changing climate patterns.

General Cargo: The general cargo load taken by seaports is over 100 million tonnes annually. This compares with around 0.5 million tonnes moved by air transport on a yearly basis. Analysis indicates that there will be growth in container imports and thus increased pressure on container ports to deal with greater levels of throughput (GHD Meyrick, 2010e). This growth is attributable to growing prosperity and population in Australia. Using a 'business as usual' scenario, findings show that the 'container task' will double by 2020, triple by 2035, and increase to more than 30 times by 2060. A medium growth rate will increase the 'task' eleven times by 2060, and a much lower growth rate will still see the 'container task' triple by 2060 (GHD Meyrick, 2010e).

Continuing globalisation of manufacturing production and distribution is also part of the reason for the prediction of continued growth in the container and break bulk port sector. Another driver is the growth of the middle class in Asia which is expected to become the major source of new opportunity, potentially increasing container exports as discussed by the Department of the Prime Minister and Cabinet (DPMC, 2012: Ch 2.3). As the graph below illustrates, BITRE is forecasting container trade to double by 2029/30, though others introduce a note of caution. For example, KPMG predicts that, "the global container industry is likely to face over supply in the next few years and affect profits" (KPMG, 2012: 3). There is obviously a great deal of uncertainty and more rigorous modelling is needed.

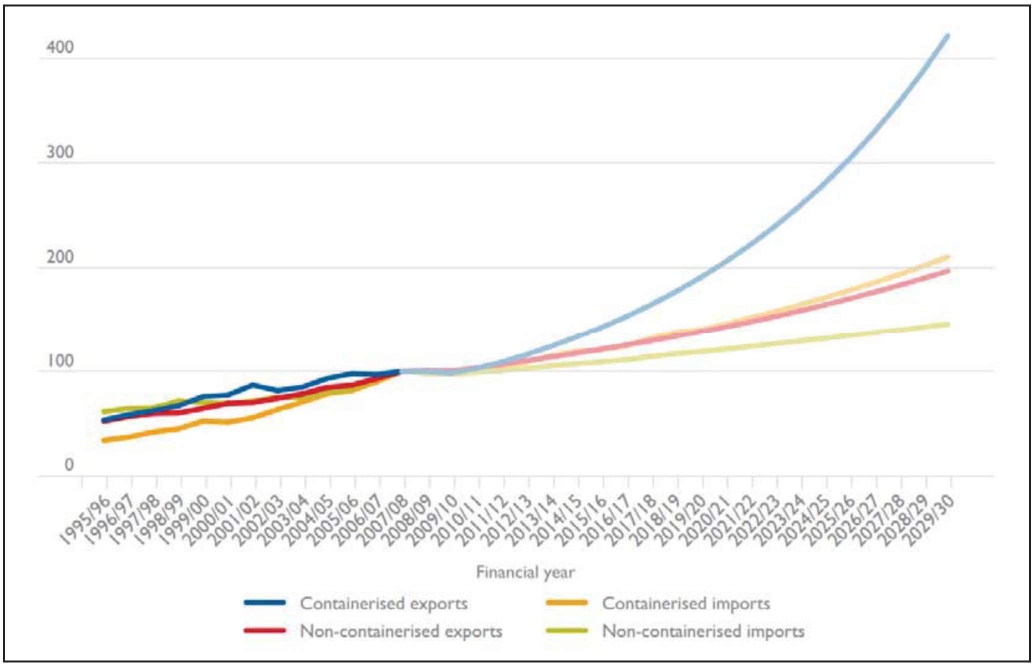


Figure 16: Comparison in projected growth of Australia's imports and exports (BITRE, 2010: 2)

7.5.3 Technology

Technological change cannot be underestimated as a driver of change for seaports. Containers were introduced to shipping in the 1950s, leading to significant changes in the way that shipping takes place. Ports now adopt a systems approach that crosses the sea-land divide and includes the development of intermodal hubs (and by implication 'just-in-time' principles of trade). Containerisation and the need for fuel economy is driving the development of larger ships (with deeper draughts), which in turn require deeper harbours. This leads to more dredging of channels and berthing pockets, with knock-on implications for local environmental sustainability.

The growing demand for better environmental performance is also driving innovation within the shipping industry. The industry as a whole is working on reducing greenhouse gas emissions and new ships are being developed that use combinations of solar and wind power to augment traditional energy sources. At the ports, regulations for cleaner air are influencing emissions including NOx (nitrogen oxides: NO and NO2) and SOx (sulphur dioxide: SO2). For example, the Port of Los Angeles has an ocean-going emissions reduction program that includes: vessel speed reduction, shore-power/Alternative Maritime Power (AMP); and fuel improvements for engines (Port of Los Angeles, 2012).

Container operations are also becoming increasingly automated, which may lead to less noxious emissions, depending on the power source. The container ports, both in Australia and overseas, are moving in this direction and the machinery and the technology is readily available. For example, Asciano, parent company of Patrick Stevedoring, has announced it has signed a contract with a global leader in cargo and load handling solutions to deliver 44 automated straddle carriers between end of 2013 and early 2014 to its Port Botany container terminal (Asciano, 2012). Asciano already operates an automated site at the Port of Brisbane.

7.5.4 Institutions

The recent endorsement of both the National Ports strategy and the National Land Freight strategy has provided a 'roadmap' for port reform, particularly in the areas of planning, governance and regulation. These new developments harbour a significant opportunity for the sector to adapt; by strengthening adaptive capacity and by implementing best practice to address the immediate, medium, and long term impacts of a changing climate.

The reform agenda provides encouragement for whole of system planning; emphasising the need for integration across jurisdictions and greater levels of transparency and openness in the development of port level plans. Current challenges are noted as "port congestion, container traffic, land access, carrying and storage capacity, through to supply chain and logistics impacts from inland ports, road and pipeline activities" (KPMG 2012: 3). At the port level the barriers to change (and to coordinated action) are related to the mix of commercial and non-commercial organisations that operate and the increasing pressure to increase throughput. At a Federal Government level, a lack of coordination of national, state and local regulations is seen as problematic (Infrastructure Australia, 2011b, Maddocks, 2012). At the infrastructure and transport level, bottlenecks in the supply chain (due to increased congestion on the road, increased freight task, lack of coordinated forward planning and funding) are keeping productivity below optimum (Infrastructure Australia, 2011a, 2011c). Tackling these major issues will strengthen the resilience of the whole system to future risks.

Australia's seaports have been criticised for operating with governance structures that hinder an integrated approach to planning for future risks. For example, there is consistent advice to the federal government that there is significant fragmentation of the governance and planning regimens as they apply to ports (GHD Meyrick, 2010b; Maddocks, 2012). Part of the complexity of decision-making is that port ownership is made up of different sorts of titleholders, from government through to commercial owners and operators. The reforms of the 1990's that led to the corporatisation of public ports in Australia remain influential, with drivers that impel ports to privatise still continuing. This will affect adaptation processes as it relates to cooperation across supply chains and ports' ability to better plan and coordinate activity in a transparent manner (GHD Meyrick, 2010a).

There needs to be a balance struck between the commercial imperative for short term profitability and the longer term imperatives for port resilience, environmental sustainability, and economic benefits for the local region (and wider afield). To this end, publicly accessible port plans would be helpful, and could be used to support the coordination of future port growth, as well as to plan integrated land use and transport and infrastructure developments. It has been noted that current land use plans "do not consider transport infrastructure requirements, planning for preservation of corridors or freight networks beyond the port estate" (GHD Meyrick, 2010b).

Whilst most States and Territories have adopted planning benchmarks for sea-level rise (guiding building heights and set-backs from erosion and high-tide lines) these are not nationally uniform (Gurran, 2011). A coordinated approach to land use planning across jurisdictions would help provide ports with a framework for future planning.
On a final note, the Trusted Information Sharing Network (TISN) for Critical Infrastructure (CIR) within the Federal Attorney General's Department is one of the primary mechanisms for building stronger partnerships (and dialogues) between business and government to deal with vulnerabilities either within sectors or on a national or cross-jurisdictional basis. However none of this information is publicly

available. The allied Critical Infrastructure Program for Modelling and Analysis (CIPMA) also provides a range of information that also cannot be accessed. While there are very good reasons for restricting access to some of this information, there are also equal imperatives for the sharing of information that can help build resilience into critical infrastructure systems. One example of controlled transparency is in the UK, where the 2008 Climate Change Act mandated required climate risk assessments for critical infrastructure. These are made public.

7.5.5 Supply chains

Supply chain issues in Australia are acute and the National Land Freight Strategy (Infrastructure Australia, 2012) has identified the need for significant improvement of the transport infrastructure that supports the nation's supply chains. There are lengthy transport routes that need to be managed across different political state boundaries and through different forms of transport (road-rail-sea). Figure 17 gives an indication of the size of the transport task – this relates to internal freight only. As trade increases globally, all major ports and their supply chains face the dual task of having to handle an increasing throughput as well as planning for the impacts from a changing climate.

Ports can be regarded as fixed nodes in a supply chain that is increasingly modally focused. While the sea ports sector has tended to focus on climate impacts to the marine facilities and to the sea side operations, the hinterland connections are also important considerations. The main transport links in Australia are either road or rail. There are fairly straight forward connections between the bulk freight of iron ore and coal moving directly between the mines and the ports on rail or using coastal shipping. The more complex distribution of goods from container ports in the capital cities is spread between road and rail, and increasingly includes the use of intermodal hubs.

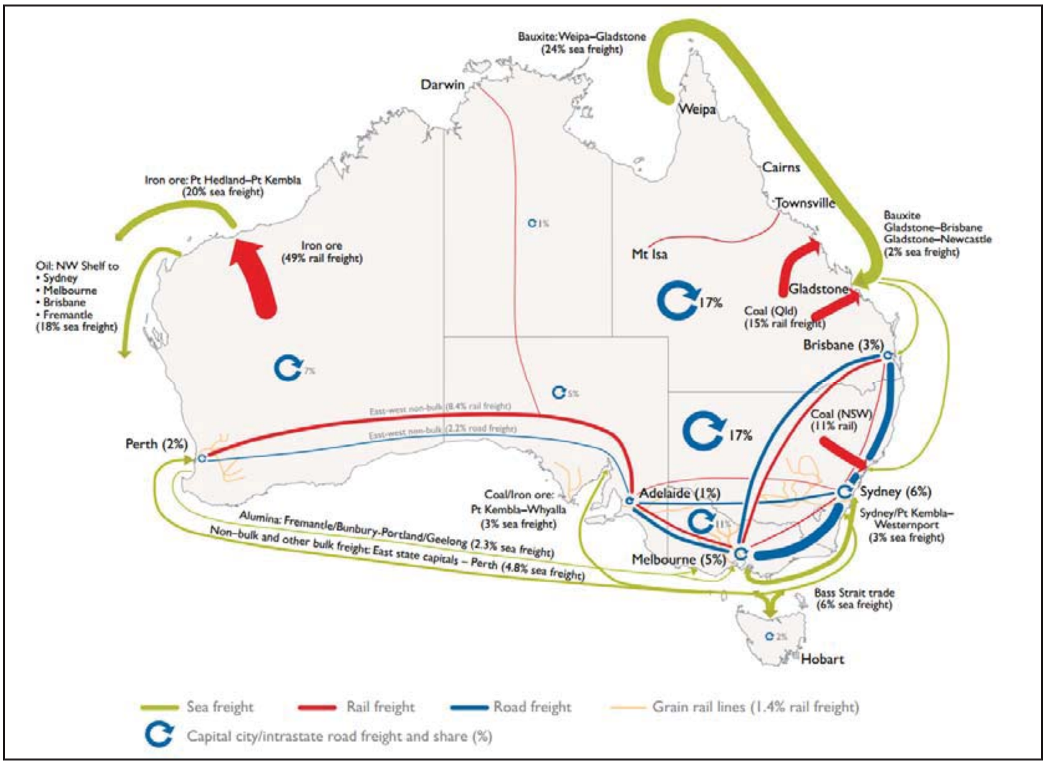


Figure 17: Principal freight movements in Australia (BITRE & ARA 2012: 3)

Table 17: Supply Chain Characteristics (Infrastructure Australia, 2012)

Task	Location	Mode
Bulk minerals	**Mining regions to ports**	**Rail, shipping, pipelines**
Agricultural produce and livestock	Regional Australia to urban areas and ports	Road and rail as complements, and as substitutes, shipping, and some aviation
General freight, interstate line haul	Between major urban areas and industrial centres	Road and rail as complements, and as substitutes
General freight, urban distribution	Urban centres	Road
Industrial freight	Between major industrial centres	Road and rail as complements and as substitutes, shipping

The current bottlenecks on supply chains are broadly caused by increasing traffic on road and rail, a fragmentation of governance along the supply routes, inadequate maintenance and a lack of coordinated long term planning which is itself hampered by a lack of robust strategic forecasts that would enable a national freight strategy to plan for a number of alternative futures and thus reduce the shock of unforseen and unplanned for changes (Infrastructure Australia, 2012).

The main climate risk to road and rail is the possibility of increased flooding due to more intense rainfall (International Association of Ports and Harbours, 2011:30-33). This can result in landslides, road collapse, and washout of roads and rail tracks. Single failure to a section of the road or rail from an event like a significant flood or bushfire can disrupt the entire transport link (see the previous climate section of this report on the impacts to ports from extreme events). There are also identifiable weak points in the chain; for example, bridges, or areas that are identified as flood prone. Heat also affects the rail lines and it is possible that rail buckling could be an issue. Thus, there will be impacts that will be unique to each transport mode, but many impacts such as flooding and erosion will be common. These weaknesses are exacerbated by a transport system that is itself in need of reform and upgrading. For example, Engineers Australia has identified deficiencies within the overall rail network servicing ports, such that it issued a 'D+' rating for rail:

> *"Improving the efficiency and productivity of existing rail networks is a challenge in many jurisdictions. For instance, increasing train length, load capacity, operating speed and turnaround time will require considerable improvements in rolling stock, below-rail infrastructure, and port-rail connections and intermodal hubs" (Engineers Australia, 2010: 21).*

The beginning of a larger discussion about where climate change and adaptation fits into Australia's infrastructure plans was highlighted when Infrastructure Australia's fourth annual report to COAG was produced in June 2011. In this report the Chairman, Sir Rod Eddington, put the case for major reform in the way that Australia finances, develops, operates and maintains critical infrastructure networks. The report lists climate change as one of its key challenges:

> *"The Climate Commission's recent report, 'The Critical Decade', articulates the great weight of scientific evidence pointing to the prospect of changes in our climate. That evidence reinforces the need to take steps to; mitigate future increases in greenhouse gas emissions, and; adapt to future climate change …There is broad agreement that doing nothing is not an option. On the other hand many in the infrastructure sector are frustrated that the architecture of an*

> *enduring national response to climate change remains a matter of debate" (Infrastructure Australia, 2011b: 26).*

The National Ports Strategy, adopted by COAG in 2012, is focused heavily on supporting integrated planning at all levels of government related to the entire freight network and on removing the barriers to freight movement. The later National Land Freight Strategy, also adopted by COAG in 2012, echoes these aims and includes the aim to plan strategically at a national level including the development of long-term planning, more robust forecasting and scenario development within a framework that acknowledges future uncertainty and the need for flexible solutions for the creation of both sustainability and growth. This is a significant step towards creating a national infrastructure plan that includes appropriate adaptation planning.

8. CONCLUSIONS

This report has set out some of the challenges involved when assessing the myriad of risks that Australian ports need to contend with, both now and into the future. The research findings not only contribute to the existing knowledge-base but also provide detail of assessment methodologies that can be replicated for other cases. As a consequence of the lessons learnt from this research, follow-up activity (funded by the Australian National Data Service) is now being undertaken to design a web-based decision-support toolkit for Australian seaports that will help inform their adaptation planning (Appendix F).

This concluding section summarises the main challenges faced by the project work package on ‘understanding future risks’, how they were dealt with, and importantly, how the research findings can enhance the resilience of seaports to a changing climate.

8.1 Methodology

Firstly, the integrated assessment methodology was extremely useful for framing the key issues and ‘making sense’ of the complex mix of quantitative and qualitative information that needed to be considered when conducting an analysis of ports as systems. Not only is every seaport different, with their range of assets and functions dependent on the cargo throughput, but each faces localised climate risks (a combination of the climate-related hazards in question and the vulnerability of different elements at risk). The sheer size of the Australian continent also means that it is affected by a number of different climate zones – this further complicates any consideration of future climate change in the Australian context.

The participatory approach adopted was considered central to the project. Close liaison with climate information providers such as the CSIRO, the BoM, and CAWCR, was vital to the assessments carried out. Equally valued by the project team was the commitment of the case study ports. This engagement provided valuable information on stakeholder perceptions of risk and the identification and analysis of vulnerabilities from a 'bottom-up' perspective. Their input also helped to shape the research agenda as the project, and thinking, evolved.

8.2 Climate data

The collation of observed and past climate data sourced from the BoM established an initial baseline for the assessment of future risks. These data provided the contextual background and acted as a stimulant for discussion in the stakeholder workshops; enabling attendees to contextualise their personal experience of recent weather events and, on the basis of this, to provide information on the current vulnerability of different elements at risk in their port. Given contemporary limitations of modelling future extreme events, information on the impacts of past weather events formed the basis for the evaluation of extremes and possible adaptation options. [It is also important to note that whilst ports regularly access weather and ocean data (tide tables, weather updates etc.), and in some cases take their own measurements of the climate variables of most concern to them, there is an opportunity to be more strategic and coordinate this activity in order to better understand trends at a local level].

A key task of the work package was to provide information on future climate change. The initial assumption was that accessing, collating, and then interpreting the climate data for the assessments would be relatively straightforward. Experience proved this not to be the case. However, by highlighting some of the challenges faced (and how

they were overcome) the experience of this project can provide valuable guidance to other similar studies and assessments.
Dealing with the uncertainty of the climate data proved to be a significant challenge (for literature on dealing with uncertainty within climate projections see: IPCC, 2007; Wilby & Dessai, 2010). Uncertainty manifested itself in different ways. For instance, there are a multitude of global climate models that are potentially applicable to the Australian context and the selection process was guided by the CSIRO Climate Futures initiative; from experience this is a resource that is highly recommended. The framework enabled a suite of models to be run that were representative of a range of possible futures (most likely, hot/dry, and cool/wet), and also ensured that there was consistency across the case study analyses. However, the complexities involved with then interpreting the climate data is clearly evident. These issues highlight the considerable challenge of bridging the gap between the climate modelling and adaptation communities (and how best to make sense of the complexities and contemporary limitations of climate science by non-modelling experts).

It is therefore not merely a matter of improving the robustness of climate models but also investing Federal resources into 'trusted' platforms for informing different stakeholders how to effectively use the models that are available, and then how to interpret the climate data outputs for their adaptation needs. With the necessary resources, this is either an extended role that CSIRO could perform or else it could be tasked to a 'boundary' organisation responsible for tailoring climate information and guidance as required by end users (similar to the role played by the UK Climate Impacts Programme). Making sense of the mass of information available (which leads to complaints of information 'overload'), and the provision of improved guidance on the interpretation of climate data, would be highly beneficial to the emerging adaptation agenda in Australia.

Other issues also arose from the uncertainties. These involved contradictions in how different organisations deal with the choice of models (e.g. the future climate projected for New South Wales - by the models chosen initially by the project - differed markedly to the future described by the models advised by the State Government), and also how the climate data is expressed (e.g. in New South Wales climate information is published as a narrative up to 2050, whereas in Queensland tables of figures provide climate information up to 2070). There is also inconsistency between the information providers, as evidenced by discrepancies in the time periods used by the CSIRO and the BoM to establish baselines. Efforts towards greater standardisation between organisations and jurisdictions (timelines, use of different scenarios etc.) would help to establish a more consistent framework for risk assessment and informed adaptation planning across the country. CAWCR (a joint CSIRO / BoM initiative) is arguably well placed to champion greater consistency.

Other modelling issues are also worthy of note. The first relates to the choice of the emissions scenario. Whilst the initial intention was to use the 'low' SRES B1 scenario this was replaced by SRES A1B (a 'medium' scenario); considered more representative given current trends in emissions (the world is currently tracking according to a high scenario). For the purposes of the project, SRES A1FI was used as the 'high' emissions scenario however it needs to be recognised that this particular scenario was introduced in the IPCC 4th Assessment Report to portray an 'exaggerated' case and as a consequence less data is available for it than, for example, SRES A2. Also, the IPCC will be unveiling the 5th Assessment Report in 2013 which will introduce new climate data in different formats than before (as such, funders of climate-related research should be cognisant of the timing of such initiatives to ensure synergy and that research is informed by the latest science).

Complexity is also associated with different climate variables. This relates to both the models (recognising that different GCMs can consider different variables e.g. salinity was important for this project, hence affecting the choice of models to be used) as well as the level of confidence placed on the modelling results of different climate variables. As noted, there is significantly more information (and certainty) for projections of land temperatures than other variables. Ironically, projections of the variables that are of greatest concern to marine operations – such as sea surge, storminess, wind, and other risk factors such as wave climate - are least understood at the current time. Engineers Australia's National Committee on Coastal and Ocean Engineering (NCCOE) has given top priority to research into wind climate, wave climate, and rainfall.

Future projections of extreme events are difficult to extract from GCMs with any confidence. Data that were possible to be sourced for this project included annual and seasonal figures for days over 35°C and 40°C, percentage changes to annual extreme rainfall, and percentage changes to annual extreme wind speed. However, lack of accurate climate information is not necessarily an impediment to action. One example is that of cyclones. Although there may no change to the number of cyclones overall, a greater number of them are projected to be at the intense end of the scale. This implies that ports in cyclone areas should ideally re-assess their preparedness and consider upgrading their protection for a higher category of impact (adopting a precautionary approach). Sea level rise provides another example. While it is difficult to obtain accurate hydrological modelling of the impact of rising sea levels for individual ports, this did not register as a major concern for the case study ports, as they have factored in a rise into current and future builds for their berths (note: by just building one or more metres higher there is the potential for unforeseen 'maladaptation' consequences, however this was not able to be investigated by this project). General details of sea level rise affecting the case study ports were sourced from CSIRO Marine and Atmospheric Research (CMAR).

8.3 Reconciliation with end-user needs

Reconciling climate data with end-user needs was an iterative process. Using the engineering application as an example, the research team first had to identify the set of climate variables that they, ideally, wanted to incorporate into their modelling efforts e.g. heat, humidity and the relationship between days of rain and dry days are important drivers for the deterioration of concrete. The next step was to define how these variables were expressed: as annual or seasonal data, as averages or maximum values, etc. It was found that some of the required data, e.g. the possible future number of consecutive days with rain, was beyond the current capability of the climate models. In other instances, although available, the data were not easily accessible in the formats needed (acidity data are modelled, though the conversion of pH to an engineering expression was overly problematic).

The engineering research group, by necessity, therefore had to simplify the deterioration models and manage the inputs that were not available by inserting 'best guess' estimations and assumptions. Some of these assumptions had to be derived from data that were produced and calibrated for the UK climate (leading to a less precise analysis for Australian conditions). Thus, over the life of the project, the engineers had to continually refine their modelling efforts to account for information that was readily available – annual temperature, rainfall, relative humidity, sea surface temperature, and salinity. The projected climate information that they were not able to access included: total number of hours it could be wet each year and possible wet/dry cycles. Data related to the marine side were also limited, for instance possible changes to wave climate. That said; findings indicate that the dominant variable for the deterioration of materials that were investigated was temperature change.

The logistics research team identified extreme events as of primary importance to the functioning of ports; however information on future extremes is extremely difficult to project. This analysis has recently been prioritised by the international climate science community (IPCC, 2012). A further impediment to analysing the risks from climate extremes was that the port operators (who were engaged with in this project) did not have a precise definition for many of the thresholds affecting operations; rather they used local working knowledge and experience to identify thresholds that would invoke interventions - such as stopping work. Clearly, this did not necessarily translate into data that could be readily used by the research team. As an example, cranes have a clearly defined wind speed threshold beyond which they are legally required to stop work (due to OH&S and engineering requirements), however when dealing with fog the accepted wisdom is that work will stop once an identified landmark can no longer be seen clearly. Thresholds for port operations are therefore subject to different formal and informal rules.

8.4 Non-climate drivers

Climate change is only one of the many drivers affecting the functioning of ports and any climate risk assessment therefore needs to contextualise potential climate impacts with other important non-climate drivers. However, integrating these two different sets of scenarios (climate and non-climate) can be difficult mainly as a result of their respective time horizons. For example, climate scenarios are typically modelled through to 2100 (with impacts increasingly evident in the second half of the century), though changes to socio-economic variables are difficult to forecast beyond a much shorter time period. The IPCC (2007) note that “over the course of 50-100 years, even the most basic scenario drivers, such as population and aggregate economic activity, are highly uncertain” and suggest that a timeline of “20 years may be more appropriate, reflecting the immediate needs of decision-makers”.

As such, the project drew on key national and sectoral documentation to frame and explore the non-climate drivers that are likely to have most impact on seaports in the near to medium term. The variables considered were: demography, economy, technology, institutions, and supply chains. Overall, the projections for significant domestic population growth and a continuation of large exports (particularly coal and iron ore) to China and other fast developing Asian countries would, without unforeseen sideswipes, signify a continued expansion of container and bulk port activity. However, this growth does not come without challenges. Those ports situated in major urban centres are likely to be increasingly in conflict with other demands for the use of land and will find it increasingly problematic to expand in order to deal with the increase in throughput. Greater levels of trade will also affect the efficient operation of the supply chain, supported by a transport system which is already considered sub-optimal with congestion on roads, pressure on the rail network, and an inadequate maintenance regime for existing infrastructure (Infrastructure Australia, 2012). Volatility in markets, for example increasing climate change impacts on agriculture, will also need to be factored into forward planning.

The governance arrangements of ports - an important ‘non-climate’ component with the capacity to either hinder or support adaptation processes - can be complex, with ports made up of a diversity of owners and operators (comprising both commercial and government actors). Even within the port precinct, climate impacts will differ according to the particular asset at risk, which will be owned or operated by different actors. This institutional fragmentation is further exaggerated when considering the supply-chain and the considerable hinterland that supports it. Indeed, though ports are used to dealing with the climate and the ocean, and have a relatively good understanding of their immediate climate risks, experience has shown that port operations can be significantly affected by impacts to the wider supply chain (the flooding of coal mines in Queensland being a prime example). This raises the important question of roles and responsibilities and what risks are 'theirs' and what risks belong to other entities along the supply chain e.g. the shipping companies, the stevedore companies etc. Improved institutional 'fit' will help to strengthen the sector's capacity to respond to future risks.

8.5 Findings summary

The overarching aim of the project was to develop new knowledge and tools for enhancing the resilience of seaports to climate change. The research activity carried out by the project and its different work packages, reinforced by engagement with the case study ports, indicates that resilience to observed climate variability is evident within the immediate port environment (at the level of individual organisations). This can be attributed to autonomous adaptation primarily as a result of a combination of regulatory and operational mechanisms such as OH&S requirements, risk management strategies, and incremental changes to practice brought about by the ports experience of previous weather-related events; rather than as part of a conscious adaptation strategy. However, important vulnerabilities were also identified; with the seaward-side of operations and the supply chain hinterland found to be most affected by climate variability (vulnerabilities which will intensify under a changing climate). Looking forward, although 'hard' infrastructure assets can be made more resilient by changing design and maintenance regimes, it is the functional resources (including the workforce) that are likely to become increasingly vulnerable.

Whilst the ports are already addressing some of their current vulnerabilities (e.g. working with local authorities on drainage issues, building in sea level rise headroom, extra training for marine operations staff to be able to perform in rougher seas etc.) the research has identified opportunities for better understanding future risks and reducing the ports' adaptation deficit. These measures have been identified in the project document 'adaptation guidelines' and can be related to either the building of adaptive capacity or the implementation of physical adaptation outcomes. Measures include 'soft' interventions such as the training of staff (see WP2 report), 'mainstreaming' climate change considerations into risk management and other port policies, greater collaboration with other stakeholders to consider future risks and adaptation options; and hard options such as changes to design standards and maintenance regimes (see WP3 report), consideration of more innovative (flexible) engineering options (an adaptive management approach), ensuring that climate change is explicitly addressed as part and parcel of normal port planning cycles (though it is necessary to recognise that smaller ports may have less capacity to respond) etc. Knowledge exchange between ports is a key component of enhancing resilience and having a web-based resource which showcases best practice for the sector is likely to be extremely helpful in this regard.

Finally, it is worth noting that legislation / regulation may also be an important driver for influencing change in the industry; for instance ensuring the Australian Standards fully account for the impacts of a changing climate. The requirement to conduct climate risk assessments and identify relevant adaptation options, as recently mandated in the UK, is also an interesting option that could be considered in the Australian context. The recent endorsement of national ports and freight strategies, introduced to improve the long term planning and management of national supply chains, presents a great opportunity to more fully embrace climate change adaptation principles and enhance the resilience of ports in the longer term.

REFERENCES

Academy of Technological Sciences and Engineering (ATSE) (2008). Assessment of Impacts of Climate Change on Australia's Physical Infrastructure. Australian Academy of Technological Sciences and Engineering Limited.

Australian Maritime Safety Authority (AMSA) (2011). On Scene - The Queensland Floods, National Plan Newsletter, 19th Edition, March 2011. Available Online: http://www.amsa.gov.au/marine_environment_protection/national_plan/Reports-Fact_Sheets-Brochures/Onscene/ONSCENE19.pdf

Asciano (2012). Asciano Signs contract for automated straddles for Port Botany. Media Release, 3 September 2012. Available Online: http://www.asciano.com.au/resources/newsres/040912104632_120903_mr_pb_autostrad_agreement_cargotec.pdf

Australian Bureau of Statistics (ABS) (2008). 3222.0 Population Projections for Australia 2006 to 2101. Commonwealth Government, Canberra. Available Online: http://www.ausstats.abs.gov.au/Ausstats/subscriber.nsf/0/0E09CCC14E4C94F6CA2574B9001626FE/$File/32220_2006%20to%202101.pdf

Australian Bureau of Statistics (ABS) (2011). 3218.0 - Regional Population Growth, Australia, 2011. Commonwealth Government, Canberra. Available Online: http://www.abs.gov.au/ausstats/abs@.nsf/Products/3218.0~2011~Main+Features~Main+Features?OpenDocument#PARALINK0

Australian Bureau of Statistics (ABS) (2012). 2011 Australian Census Data - Data and Analysis. Australian Bureau of Statistics, Commonwealth Government. Available Online: http://www.abs.gov.au/websitedbs/censushome.nsf/home/data?opendocument&navpos=200

Austroads (2004). Impact of Climate Change on Road Infrastructure. Publication No. AP-R243/04. Austroads Incorporated. Available Online: http://www.bitre.gov.au/publications/2004/files/cr_001_climate_change.pdf

Becker, A., Inoue, S., Fischer, M. and Schwegler, B. (2011). Climate Change Impacts on International Seaports: Knowledge, Perceptions, and Planning Efforts among Port Administrators. Climatic Change - Expert Paper. Available Online: http://archive.unctad.org/sections/wcmu/docs/AHM2011_2_18_Becker_en.pdf

Bureau of Infrastructure Transport and Regional Economics (BITRE) (2010). Australian maritime activity to 2029-30: Statistical report. Department of Infrastructure, Transport, Regional Development and Local Government, Commonwealth Government. Available Online: http://www.bitre.gov.au/publications/2010/files/stats_008.pdf

Bureau of Infrastructure Transport and Regional Economics (BITRE) (2011). Maritime sea freight 2009-10. Department of Infrastructure, Transport, Regional Development and Local Government, Commonwealth Government. Available Online: http://www.bitre.gov.au/publications/2011/files/asf_2009_10.pdf

Bureau of Infrastructure Transport and Regional Economics (BITRE) & the Australian Railway Association (ARA) (2012). Train line 1: Statistical Report. Department of Infrastructure, Transport, Regional Development and Local Government, Commonwealth Government. Available Online: http://www.bitre.gov.au/publications/2012/files/trainL_001.pdf

Bureau of Meteorology (BoM) (n.d.). Australian Baseline Sea Level Monitoring Project. Commonwealth Government, Canberra. Available Online: http://www.bom.gov.au/oceanography/projects/abslmp/abslmp_reports.shtml

Bureau of Meteorology (BoM) (2003). Map of Climate Zones Based on Temperature and Humidity. Commonwealth Government. Available Online: http://www.bom.gov.au/climate/environ/travel/map.shtml

Bureau of Meteorology (BoM) (2011). Hazardous Weather Phenomena - Fog. Bureau of Meteorology Weather Services, Aviation. Commonwealth Government. Available Online: http://www.bom.gov.au/aviation/data/education/hwp-fog.pdf

Bureau of Meteorology (BoM) (2012). Australia's wettest two-year period on record; 2010–2011. Special Climate Statement 38, National Climate Centre, Bureau of Meteorology. Available on line: http://www.bom.gov.au/climate/current/statements/scs38.pdf

Bureau of Resources and Energy Economics (BREE) (2012). Australian Bulk Commodity Exports and Infrastructure—Outlook to 2025. Department of Resources, Energy and Tourism, Commonwealth Government. Available Online: http://www.bree.gov.au/documents/publications/_other/Export-Infrastructure-Report.pdf

Clarke, J.M., Whetton, P.H. and Hennessy K.J. (2011). Providing application-specific climate projections datasets: CSIRO's Climate Futures Framework. 19th International Congress on Modelling and Simulation, Perth, Australia, 12–16 December 2011. Available Online: http://www.mssanz.org.au/modsim2011/F5/clarke.pdf

Commonwealth Scientific and Industrial Research Organisation (CSIRO) (2007). Infrastructure and climate change risk assessment for Victoria: Report to the Victorian Government. CSIRO Marine and Atmospheric Research, Aspendale. Available Online: http://www.climatechange.vic.gov.au/__data/assets/pdf_file/0019/73243/Infrastructureriskasses smentPart1.pdf

Commonwealth Scientific and Industrial Research Organisation (CSIRO) (n.d.). OzClim - Exploring Climate Change Scenarios for Australia. Available Online: http://www.csiro.au/ozclim/home.do

Commonwealth Scientific and Industrial Research Organisation (CSIRO) and Bureau of Meteorology (BoM) (2007). Climate Change in Australia: Technical Report 2007. CSIRO Publishing, Canberra. Available Online: http://www.climatechangeinaustralia.gov.au/technical_report.php

Commonwealth Scientific and Industrial Research Organisation (CSIRO) and Maunsell Australia (2008). Impact of climate change on infrastructure in Australia and CGE model inputs for the Garnaut Climate Change Review. CSIRO Sustainable Ecosystems, Melbourne. Available Online: http://www.garnautreview.org.au/ca25734e0016a131/WebObj/02-AInfrastructure/$File/02-A%20Infrastructure.pdf

Coutts-Smith, A., Gamble, F., Rakich, C. and Schweitzer, M. (2011). Eastern seaboard climate hazard tool – MATCHES. Coastal Conference, Coastal Conference.Available online: http://www.coastalconference.com/2011/papers2011/Aaron%20Coutts-Smith%20Full%20Paper.pdf

Dadush, U. and Stancil, B. (2010). The World Order in 2050, Policy Outlook. Carnegie Endowment. Available Online: http://carnegieendowment.org/files/World_Order_in_2050.pdf

Department of Climate Change and Energy Efficiency (DCCEE) (2009). Climate Change Risks to Australia's Coast: A First Pass National Assessment. Department of Climate Change, Commonwealth of Australia. Available Online: http://www.climatechange.gov.au/~/media/publications/coastline/cc-risks-full-report.pdf

Department of Climate Change and Energy Efficiency (DCCEE) (2011). Climate Change Risks to Coastal Buildings and Infrastructure: A Supplement to the First Pass National Assessment. Department of Climate Change, Commonwealth of Australia. Available Online: http://www.climatechange.gov.au/~/media/publications/coastline/riskscoastalbuildings.pdf

Department of Infrastructure and Transport (DIT) (2011). State of Australian Cities 2011. Major Cities Unit, Department of Infrastructure and Transport, Commonwealth Government, Canberra. Available Online:
http://www.infrastructure.gov.au/infrastructure/mcu/soac_files/00_INFRA1267_MCU_SOAC_2011_FA1.pdf

Department of Prime Minister and Cabinet (DPMC) (2012). Australia in the Asian Century White Paper. Department of Prime Minister and Cabinet, Commonwealth Government. Available Online: http://asiancentury.dpmc.gov.au/sites/default/files/white-paper/australia-in-the-asian-century-white-paper.pdf

Dowdy, A.J., Mills, G.A. and Timbal, B. (2011). Large-scale indicators of Australian East Coast Lows and associated extreme weather events. CAWCR Technical Report 37. Available online: http://www.cawcr.gov.au/publications/technicalreports/CTR_037.pdf

Drysdale, P. and Hurst, L. (2012). China's growth and its impact on resource demand and the iron ore trade in Fuelling the Dragon: Natural resources and China's development. Australian Strategic Policy Institute, The Brenthurst Foundation. Available Online:
http://www.thebrenthurstfoundation.org/Files/Brenthurst_Commisioned_Reports/Brenthurst-Special-Report-Fuelling-the-Dragon.pdf

Engineers Australia (1991). Guidelines for responding to the effects of climatic change in coastal engineering design. National Committee on Coastal and Ocean Engineering, Engineers Australia,The Institution of Engineers, Australia ISBN 85825 564 2.

Engineers Australia (2004). Guidelines for responding to the effects of climate change in coastal and ocean engineering – 2004 Update. National Committee on Coastal and Ocean Engineering, Engineers Australia, Barton. Available Online:
https://www.engineersaustralia.org.au/sites/default/files/shado/Learned%20Groups/National%20Committees%20and%20Panels/Coastal%20and%20Ocean%20Engineering/guidelines_coastal.pdf

Engineers Australia (2010). Infrastructure Report Card 2010: Australia. Engineers Australia, Barton. Available Online:
http://www.engineersaustralia.org.au/sites/default/files/shado/Infrastructure%20Report%20Cards/Australian/2010%20Australian%20IRC%20Report.pdf

Engineers Australia (2012). Guidelines for responding to the effects of climate change in coastal and ocean engineering: 3rd edition May 2012. National Committee on Coastal and Ocean Engineering, Engineers Australia, Barton. Available Online:
http://www.engineersaustralia.org.au/sites/default/files/shado/Learned%20Groups/National%20Committees%20and%20Panels/Coastal%20and%20Ocean%20Engineering/climate_change_adaptation_guidelines.pdf

Friedlingstein, P., Houghton, R.A., Marland, G., Hackler, J., Boden, T.A., Conway, T.J., Canadell, J.G., Raupach, M.R., Ciais, P. and Le Quéré, C. (2010) Update on CO2 Emissions. Nature Geoscience, 3, 811-812.

Frontier Economics (2008). Modelling Climate Change Impacts using CGE models: A Literature Review. Garnaut Climate Change Review, Commissioned by the Multi-Part Climate Change Committee, Commonwealth of Australia. Available Online:
http://www.garnautreview.org.au/ca25734e0016a131/WebObj/ModellingClimateChangeImpacts/$File/Modelling%20Climate%20Change%20Impacts%20-%20Frontier%20Economics.pdf

Garnaut, R. (2008) Costing climate change and its avoidance in The Garnaut Climate Change Review http://www.garnautreview.org.au/chp11.htm

GHD Meyrick (2010a). The Possible Future Market Challenges for Relevant Ports. Background Paper 5 for the National Ports Strategy, April 2010. Report for the National Transport

Commission and Infrastructure Australia. Available Online:
http://www.ntc.gov.au/filemedia/general/GHDMeyIANTCNPSBackgroundMay10.pdf

GHD Meyrick (2010b). Effective port governance and project evaluation: Background Paper 1 for the National Ports Strategy. Report for the National Transport Commission and Infrastructure Australia. Available Online:
http://www.ntc.gov.au/filemedia/general/GHDMeyIANTCNPSBackground1May10.pdf

GHD Meyrick (2010c). Current port planning practices in Australia: Background paper 2 for the National Ports Strategy. Report for the National Transport Commission and Infrastructure Australia. Available Online:
http://www.ntc.gov.au/filemedia/general/GHDMeyIANTCNPSBackground2May10.pdf

GHD Meyrick (2010d). Analysis of landside costs and the potential for container productivity gains: Background paper 3 for the National Ports Strategy. Report for the National Transport Commission and Infrastructure Australia. Available Online:
http://www.ntc.gov.au/filemedia/general/GHDMeyIANTCNPSBackground3May10.pdf

GHD Meyrick (2010e). Examples of best practice port planning overseas: Background paper 4 for the National Ports Strategy. Report for the National Transport Commission and Infrastructure Australia. Available Online:
http://www.ntc.gov.au/filemedia/general/GHDMeyIANTCNPSBackground4.pdf

Gunasekera, D., Ford, M., Heyhoe, E., Gurney, A., Ahammad, H., Phipps, S., Harman, I., Finnigan, J., and Brede, M. (2008). Global integrated assessment model: A new analytical tool for assessing climate change risks and policies. Australian Commodities, 15(1):195-216. Available Online:
http://adl.brs.gov.au/data/warehouse/pe_abare99001419/ac_08_climate_change_artice.pdf

Gurran, N,, Norman, B., Gilbert, C., Hamin E., (2011). Planning for climate change adaptation in Coastal Australia: State of practice. Report No. 4 for the National Sea Change Taskforce, Faculty of Architecture, Design and Planning, University of Sydney, Sydney.

Hallegatte, S., Patmore, N., Mestre, O., Dumas, P., Corfee-Morlot, J., Herweijer, C., Muir Wood, R. (2008). Assessing Climate Change Impacts, Sea Level Rise and Storm Surge Risk in Port Cities: A Case Study on Copenhagen. OECD Environment Working Paper 3.

Hanson, S., Nicholls, R., Ranger, N., Hallegatte, S., Corfee-Mortlot, J., Herweijer, C. and Chateau, J. (2011). A global ranking of port cities with high exposure to climate extremes. Climatic Change (104): 89-111.

Hardy, T., Mason, L. and Astorquia, A. (2004). The frequency of surge plus tide during tropical cyclones for selected open coast locations along the Queensland east coast. Queensland climate change and community vulnerability to tropical cyclones: oceans hazards assessment: stage 3, James Cook University.

Hennessy, K., Clarke, J., Whetton, P. and Kent, D. (2012). An introduction to internally consistent climate projections. Centre for Australian Weather and Climate Research, Aspendale. Available Online:
http://www.climatechangeinaustralia.gov.au/documents/resources/An%20introduction%20to%20internally%20consistent%20climate%20projections.pdf

Hunter, J. (2010). Estimating sea-level extremes under conditions of uncertain sea-level rise. Climatic Change, 99, 331-350.

Infrastructure Australia (2008) A report to the Council of Australian Governments, Canberra. Infrastructure Australia, Commonwealth Government, Canberra. Available Online:
http://www.infrastructureaustralia.gov.au/publications/files/A_Report_to_the_Council_of_Australian_Governments.pdf

Infrastructure Australia (2011a). National Ports Strategy: Infrastructure for an economically, socially, and environmentally sustainable future. Infrastructure Australia and the National Transport Commission, Commonwealth Government, Canberra. Available Online: http://www.infrastructureaustralia.gov.au/publications/files/COAG_National_Ports_Strategy.pdf

Infrastructure Australia (2011b). National Land Freight Strategy: Discussion Paper, February 2011. Infrastructure Australia, Commonwealth Government, Canberra. Available Online: http://www.infrastructureaustralia.gov.au/publications/files/NLFS_220211.pdf

Infrastructure Australia (2011c). Communicating the Imperative to Action: A report to the Council of Australian Governments. Infrastructure Australia, Commonwealth Government, Canberra. Available Online:
http://www.infrastructureaustralia.gov.au/2011_coag/files/2011_Report_to_COAG.pdf

Infrastructure Australia (2012). National Land Freight Strategy Update, Infrastructure Australia, Commonwealth Government. Available Online:
http://www.infrastructureaustralia.gov.au/publications/files/National_Land_Freight_Strategy_Update_2012.pdf

Infrastructure Australia and the National Transport Commission (2010). National ports strategy – Background Paper, December 2010. Infrastructure Australia and National Transport Commission, Commonwealth Government, Canberra. Available Online:
http://www.infrastructureaustralia.gov.au/gateways/files/ports_strategy_background_paper_20_December_2010.pdf

Intergovernmental Panel on Climate Change (IPCC) (2000). Emissions Scenarios: Summary for Policymakers. Special report of working group III, Intergovernmental Panel on Climate Change. Available Online: http://www.ipcc.ch/pdf/special-reports/spm/sres-en.pdf

Intergovernmental Panel on Climate Change (IPCC) (2007). Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, United Kingdom and New York, NY, USA, Cambridge University Press.

Intergovernmental Panel on Climate Change (IPCC) (2012). Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation - A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change. Field, C.B., V. Barros, T.F. Stocker, D. Qin, D.J. Dokken, K.L. Ebi, M.D. Mastrandrea, K.J. Mach, G.-K. Plattner, S.K. Allen, M. Tignor, and P.M. Midgley (eds.). Cambridge University Press, Cambridge, UK, and New York, NY, USA.

International Association of Ports and Harbors (IAPH) (2011). Seaports and Climate Change – An Analysis of Adaptation Measures. Port Planning and Development Committee, International Association of Ports and Harbours, Hamburg, Germany.

Jones, R.N., Webb, L. and Hatfield-Dodds, S. (2008). Sectoral and Regional Vulnerability to Climate Change in Victoria. Prepared for the Department of Primary Industries, Government of Victoria by the CSIRO Adaptation Flagship, Canberra.

KPMG (2012). Moving you forward in the shipping and ports industry. KPMG International, Sydney. Available Online:
http://www.kpmg.com/AU/en/IssuesAndInsights/ArticlesPublications/Documents/moving-you-forward-shipping-ports-industry.pdf

Lenton, T. M. and Ciscar, J-C. (2012). Integrating tipping points into climate impact assessments, Climatic Change, Special Issue on “Improving the Assessment and Valuation of Climate Change Impacts for Policy and Regulatory Analysis”, August 2012.

Li, G. (2010). A methodology for integrated assessment of climate change impacts on urban settlements (IACCIUS) in Australia. The Fenner School of Environment and Society, Australian National University, Canberra.

Maddocks (2012). The Role of Regulation in Facilitating or Constraining Adaptation to Climate Change for Australian Infrastructure. Report for the Department of Climate Change and Energy Efficiency, Commonwealth of Australia. Available Online: http://www.climatechange.gov.au/~/media/publications/adaptation/maddocks-report/DCCEE-Maddocks-Report-20120117-PDF.pdf

Mangan, J., Lalwani, C. and Fynes, B. (2008). Port-centric logistics. International Journal of Logistics Management, 19(1): 29-41.National Committee on Coastal and Ocean Engineering (NCCOE) (1991). Guidelines for responding to the effects of climatic change in coastal engineering design. Engineers Australia, Canberra.

National Committee on Coastal and Ocean Engineering (NCCOE) (1993). At what price data? Engineers Australia, Canberra. ISBN 85825-596-0

National Committee on Coastal and Ocean Engineering (NCCOE) (1995). Coastal zone management research needs. Outcomes arising from a priority setting workshop on coastal zone management research needs held in Sydney 11-12th October 1994. Engineers Australia, Canberra.

National Committee on Coastal and Ocean Engineering (NCCOE) (2004). Coastal engineering guidelines for working with the Australian coast in an ecologically sustainable way. Engineers Australia, Canberra.

Nguyen, M., W. Xiaoming, and C. Dong, C. (2011). An investigation of extreme heatwave events and their effects on building and infrastructure. Climate Adaptation Flagship Working Paper 9, Climate Adaptation Flagship, CSIRO.

Nicholls, R. J., Hanson, S., Herweijer, C., Patmore, N., Hallegatte, S., Corfee-Morlot, J., Chateau, J. and Wood, R.M. (2008). Ranking port cities with high exposure and vulnerability to climate extremes: exposure estimates. Environment Working Papers no.1, OECD.

Office of the Environment and Heritage (OEH) (2011). Climate Change - The Sydney / Central Coast Region. NSW Government. Available Online: http://www.environment.nsw.gov.au/resources/climatechange/10171Ch5RegionSydney.pdf

Parkinson, M. (2012). Challenges and opportunities for the Australian economy: Speech to the John Curtin Institute of Public Policy, Breakfast Forum, Perth. Available Online: http://www.treasury.gov.au/PublicationsAndMedia/Speeches/2012/Challenges-and-opportunities-for-the-Aust-economy

Peel Ports Group (2011). Mersey Docks and Harbour Company Ltd.Climate Change Adaptation Report: Report to DEFRA under the Adaptation Reporting Powers, Peel Ports Group. Available on line: http://archive.defra.gov.uk/environment/climate/documents/adapt-reports/07ports/mersey-docks-harbour.pdf

Permanent International Association of Navigation Congresses (PIANC) (2008). Waterborne transport, ports and waterways: A review of climate change drivers, impacts, responses and mitigation. EnviCom – Task Group 3 Climate Change and Navigation, PIANC, Brussels. Available Online: http://www.pianc.org/downloads/envicom/envicom-free-tg3.pdf

Ports Australia (n.d.). Map of the Ports of Australia. Available Online: http://www.portsaustralia.com.au/misc/Ports%20Australia%20map.pdf

Port of Brisbane (2011). Dredging Continues After Floods, Media Release 1 June 2011, Available Online: http://www.portbris.com.au/newsmedia/newsid537/147/dredging-continues-after-floods

Port of Los Angeles (2012). Ocean Going Vehicle Emission Reduction - Fact Sheet. Available Online: http://www.portoflosangeles.org/environment/ogv.asp

Queensland University of Technology (QUT) (2010). Impacts and adaptation response of infrastructure and communities to heatwaves: the southern Australian experience of 2009. Report for the National Climate Change Adaptation Research Facility, Gold Coast, Australia.

Raupach, M., Marland, R.,G., Ciais, P., Le Que´re, C., Canadell, J. G., Klepper, G., and Field, C. B. (2007). Global and regional drivers of accelerating CO2 emissions. Proceedings of the National Academy of Science,104(24): 10288-10293.

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 Martimo Muelle et Bosque Cartagena, Colombia, World Bank.

Stern, N. (2006). Stern Review: The Economics of Climate Change, Summary of Conclusions. HM Treasury, British Government. http://www.hm-treasury.gov.uk/d/CLOSED_SHORT_executive_summary.pdf

Stokes, C. and Howden, M. (2010). Adapting Agriculture to Climate Change: Preparing Australian Agriculture, Forestry and Fisheries for the Future. National Climate Change Strategy for Primary Industries and CSIRO's Climate Adaptation Flagship. CSIRO Publishing, Canberra.

Syed, A. and Penney, K. (2011). Australian energy projections to 2034–35. Bureau of Resources and Energy Economics, Department of Resources, Energy and Tourism, Commonwealth Government. Available Online: http://www.bree.gov.au/documents/publications/aep/Australian-Energy-Projections-report.pdf

Watterson, I, Whetton, P., Moise, A., Timbal, B., Power, S., Arblaster, J. and McInnes, K. (2007) 'Chapter 5' in Climate Change in Australia - Technical Report 2007. Available online: http://www.climatechangeinaustralia.gov.au/documents/resources/TR_Web_Ch5i.pdf

Wilby, R.L. and Dessai, S. (2010). Robust Adaptation to Climate Change. Weather, 65(7):180-185.

APPENDIX A: CLIMATE PROJECTIONS FOR AUSTRALIA

Climate change projections 2030 (adapted from Watterson et al, 2007)

2030	
Land Temperature	Best estimate is warming of around 1 ºC, with a range of between 0.4-1.8ºC when uncertainties are considered. Increased number of hot nights and decreased number of cold nights. An increase in the number of days above 35ºC.
Precipitation	Best estimate of annual change shows little change in the far north and decreases of -2% to -5% elsewhere. With uncertainties included the range of decrease can reach -15%. An increase in the intensity of rainfall events, although a decrease in the overall number of events i.e. longer dry spells but heavier falls.
Humidity	Best estimate is a -1% decline in relative humidity for most of Australia. The range of change is between -2% to +0.5%
Wind	Best estimate of +2% to +5% increase in mean wind speed in most coastal areas, except for the southern regions where there may be a best estimate decrease of -2% to -5%
Severe weather	Extreme wind speed projections are uncertain. There are indications that severe wind in the winter will follow the seasonal mean, but this relationship may not hold for the summer. Indications are that there may be less cyclonic activity but the cyclones that do occur may be at the severe end of the existing scale.
Seal Level Rise	Around Australia the rise has been calculated at 1.2mm per year during the 20thC. There is no information for all of Australia for 2030. However, sea level rise for SE Qld is conservatively projected to be 200mm by 2030 (Wang *et al*, 2010: 8).
Sea Surface Temperature	Trends of warming of the oceans surrounding Australia. The East Australian current is likely to strengthen leading to warmer waters extending further south.
Ocean Acidification	Increases in acidity are expected, with the largest increases in the oceans to the north of Australia.

Climate change projections 2050 (adapted from Watterson et al, 2007)

2050	
Land Temperature	Best estimate is warming of around 1.2 - 2.2ºC, with a range of between 0.8 - 2.8ºC when uncertainties are considered. Increased number of hot nights and decreased number of cold nights. An increase in the number of days above 35ºC
Precipitation	Best estimate of annual change shows little change in the far north and decreases of -5% elsewhere. With uncertainties included the range of decrease can reach -30% but may include increases of up to +10% in some areas in the north. An increase in the intensity of rainfall events, although a decrease in the overall number of rainfall events i.e. longer dry spells but heavier falls when they occur.
Humidity	There is a decline in relative humidity for most of Australia. The range of change is between -3% to +0.5%
Wind	Mean wind speeds may increase up to +2% for the north east coast, and decrease by -5% for the southern regions.
Severe weather	Extreme wind speed projections are uncertain. There are indications that severe wind in the winter will follow the seasonal mean, but this relationship may not hold for the summer. Indications are that there may be less cyclonic activity but the cyclones that do occur may be at the severe end of the existing scale.
Seal Level Rise	Around Australia the rise has been calculated at 1.2mm per year during the 20thC. There is no information for 2050 for all of Australia.
Sea Surface Temperature	Trends of warming of the oceans surrounding Australia. The East Australian current is likely to strengthen leading to warmer waters extending further south.
Ocean Acidification	Increases in acidity are expected, with the largest increases in the oceans to the north of Australia.

Climate change projections 2070 (adapted from Watterson et al, 2007)

2070	
Land Temperature	Best estimate is warming of around 1.8 - 3.4ºC, with a range of between 1.0 - 5.0ºC when uncertainties are considered. Increased number of hot nights and decreased number of cold nights. An increase in the number of days above 35ºC
Precipitation	Best estimate of annual change shows little change in the far north and decreases of -10% elsewhere. With uncertainties included the range of decrease can reach -40% but may include increases of up to +20% in some areas in the north. An increase in the intensity of rainfall events, although a decrease in the overall number of rainfall events i.e. longer dry spells but heavier falls when they occur.
Humidity	There is a decline in relative humidity for most of Australia. The range of change is between -5% to +2%
Wind	Mean wind speeds may increase up to +10% for the north east coast, and decrease by -5% for the southern regions
Severe weather	Extreme wind speed projections are uncertain. There are indications that severe wind in the winter will follow the seasonal mean, but this relationship may not hold for the summer. Indications are that there may be less cyclonic activity but the cyclones that do occur may be at the severe end of the existing scale. There is a dramatic increase in the likelihood of hail along the south-eastern coast by 2070.
Seal Level Rise	Around Australia the rise has been calculated at 1.2mm per year during the 20thC. There is no information for 2070 for all of Australia. However, sea level rise for SE Qld is conservatively projected to be 500mm by 2070 (Wang *et al*, 2010: 8).
Sea Surface Temperature	Trends of warming of the oceans surrounding Australia. The East Australian current is likely to strengthen leading to warmer waters extending further south.
Ocean Acidification	Increases in acidity are expected, with the largest increases in the oceans to the north of Australia.

APPENDIX B: CASE STUDY PORTS

Gladstone Ports Corporation Lat.23.87ºS Long.151.21ºE

Gladstone Ports Corporation manages and operates the Port of Gladstone, including the Gladstone Marina, and Port Alma Shipping Terminal. The Port of Gladstone is located 525 kilometres (km) north of Brisbane. Port Alma Shipping Terminal is located 62km east of Rockhampton on the southern tip of the Fitzroy River delta. It is Queensland's largest multi-commodity port, housing the world's fourth largest coal export terminal. It is one of the world's top five coal export ports, handling in excess of 50 million tonnes of coal per annum. GPC owns and operates two coal export terminals in the Port - RG Tanna Coal Terminal and Barney Point Terminal. Combined, these two terminals have the capacity to handle over 75 million tonnes per annum (Mtpa).

Port Alma Shipping Terminal facilitates the import and export of niche market products including ammonium nitrate; explosives; general cargo; salt; frozen beef; tallow and scrap metal. http://www.gpcl.com.au/

Sydney Ports Corporation Lat.33.86ºS Long.151.2ºE

Sydney Ports Corporation manages and operates Sydney Harbour, Port Botany, and the intermodal facilities at Glebe Island and White Bay, Enfield and Cooks River. Sydney Harbour Sydney forms approximately a quarter of the City of Sydney's boundaries, and handles a wide range of vessels through its 11 berths, including dry bulk, bulk liquids, general cargo and cruise. Facilities are located in Walsh Bay, Glebe Island/White Bay and Circular Quay. Sydney is the major cruise ship hub for Australia's east coast. There are two dedicated passenger cruise terminals located at Circular Quay and Darling Harbour with 24 ships visiting in 2005-06 carrying approximately 200,000 passengers.

Port Botany consist of two container terminals with six container vessel berths and a bulk liquids berth - complemented by container support businesses, bulk liquid berth storage facilities and private berths at Kurnell. Enfield is a 60 hectare site located 18km on a dedicated freight rail line from Port Botany, and Cooks River is a 17.3 hectare site approximately 7km from Port Botany.

Private stevedore companies operate terminals for the SPC.
http://www.sydneyports.com.au/

Port Kembla Port Corporation Lat. 34º28'S Long.150 º54'E

The Port Kembla Port Corporation (PKPC) is a state owned corporation and is responsible for managing the port of Port Kembla. Port Kembla is very close to the City of Wollongong. PKPC's main business is coal (export) and steel (import of raw materials and steel products). It has recently expanded to include general and break bulk cargoes, containers and motor vehicle imports.

Australian Amalgamated Terminals will be processing motor vehicles, containerised and break-bulk products.

BlueScope Steel operates berths adjacent to its steel making plant for importing bulk raw materials such as iron ore and exporting steel slabs and other steel products.

The Port Kembla Coal Terminal Ltd. in the Inner Harbour exports around 10 to 11 million tonnes of coal and coke per annum (with capacity up to 15 million tonnes).

The Port Kembla Gateway deals with bulk and break bulk cargo including copper concentrate, fertiliser, clinker, pulp/saw logs and steel products.

The Port Kembla Grain Terminal also located within the Inner Harbour exports a variety of grains from south and south-western NSW.
http://www.kemblaport.com.au/

APPENDIX C: LIST OF PROJECT STAKEHOLDERS

Jeroen Aerts	International 'Port Cities' network	Vrije Universiteit, The Netherlands
David Anderson	CEO	Ports Australia
Owen Barton	Port Infrastructure Asset Manager	Gladstone Ports Corporation
Alan Betts	Chairman	Engineers Australia NSW Maritime Panel
Mario Blasi	Port Operations Manager (PK)	BlueScope Steel
Trevor Brown	Environmental Sustainability Officer	Port Kembla Port Corporation
Jerome Carslake	Manager, Strategic Research & Planning	National Transport Commission
Gary Carter	Acting Port Planning and Development Manager	Gladstone Ports Corporation
Robert Cechet	Sen. Res. Scientist RISK Research Group, Geospatial & Earth Monitoring Div.	Geoscience Australia
Alex Chalk	Risk Manager	Port Kembla Coal Terminal
John Clarke	Project Manager - Climate Projections Liaison	CSIRO - Marine &Atmospheric Research
Doyle Cook	General Manager	Port Kembla Gateway Pty Ltd
Ron Cox	Convenor	Settlements & Infrastructure Network, NCCARF
Lori Dalton (and Mark Dossetor)	Freight, Logistics and Marine Division	Victorian Department of Transport
Hans de Moel	International 'Port Cities' network	Vrije Universiteit, The Netherlands
Andrew Dunne	General Manager, Engineering & Environment	Port Kembla Port Corporation
Dom Figliomeni	Chief Executive Officer	Port Kembla Port Corporation
Susan Fryda-Blackwell	EO	Ports Australia

Glenda Graham	Executive Director, Victoria Division	Engineers Australia
Lana Howell	Port Kembla Terminal Manager	AAT
Jason Humphreys	Director Rail & Ports Policy and GOC Governance	Rail, Ports and Freight Division, Qld govt.
Greg Hunt	Executive Officer	South East Councils Climate Change Alliance
Agata Imielska	Climatologist, Climate Monitoring	Bureau of Meteorology
Mark Ireland	Sustainability Manager	Sydney Ports Corporation
Belinda Irwin	Senior Policy Analyst	National Transport Commission
Mark Jelbart	Manager - Port Kembla Terminal	Graincorp Operations Limited
Rachel Johnson	Deputy Director General Freight and Regional Development	Transport NSW
Sandra Johnson	Project Officer	Port of Hastings Development Authority
Alison Karwaj	Environmental Coordinator	Sydney Ports Corporation
Rodney Keenan	Director	VCCCAR
Christopher Lee	Manager, Impacts & Adaptation	Office of Environment & Heritage, NSW Govt
Shoni Maguire	CAWR Support Manager	Bureau of Meteorology
Kathy McInnes	Research Scientist, sea level rise and coasts team	CSIRO - Marine &Atmospheric Research
Raphael Miller	Senior Commercial Analysis	Sydney Ports Corporation
Rod Pickette	National Policy Executive Officer	Maritime Union of Australia
Phill Piper	Director, Land Development and Infrastructure, Strategic Lands Planning	Dept. of Lands and Planning, NT
David Robinson	Snr Director	Queensland Climate Change Centre of Excellence

Llew Russell	CEO	Shipping Australia Ltd
John Sherriff	Environmental Manager	Gladstone Ports Corporation
Fotios Spiridonos	Director - Transport Modelling & Mapping	Department of Transport, Vic govt.
Anthony Sprigg	CEO	Australian Green Infrastructure Council
Amanda Thomas	Director, Research and Policy	Transport and Logistics Industry Skills Council
Bill Vrontas	Maintenance Engineer	Sydney Ports Corporation
David Walland	Manager climate Services, Climate & Water Division	Bureau of Meteorology
Rick Walters	Technical Director	Australian Green Infrastructure Council
Xiaoming Wang	Principal Research Scientist, Ecosystem Sciences	CSIRO
Chris White	Principal Scientist, Climate Systems Research	Queensland Climate Change Centre of Excellence (QCCCE)
Robert Wilby	Professor of HydroclimaticModelling	Loughborough University, UK

APPENDIX D: PROJECT WORKSHOPS

Climate Risks Experts Workshop, Melbourne (July 2011)

This workshop explored the key methodological and data challenges of finding appropriate observed and future climate data for informing the vulnerability assessments of the port infrastructure and operations. It proved to be a valuable workshop for WP1 providing feedback on parameters of the study, methodologies, the capabilities and limitations of the available global climate models (GCMs), and what information the CSIRO and the BoM could realistically provide. It also provided insights into methodologies for considering sea level rise and storm surge, and set out the limitations of the extreme events data.

John Clark	Project Manager – Climate Projections Liaison	CSIRO
Shoni Maguire	CAWR Support Manager	BoM
Harvey Stern	Meteorologist – Head of Climate Support Services	BoM
Chris White	Climate Scientist	QCCCE
Rod Keenan	Director	VCCCAR
Rob Wilby	Professor of Hydroclimatic Modelling	Loughborough University, UK (VCCCAR international fellow).

Stakeholder workshop, Sydney (November 2011)

This workshop allowed feedback from stakeholders on the research process. WP1 had met previously with all three ports – Gladstone, Sydney and Port Kembla - however, there had been no project interaction between the ports and one of the designed intentions of the day was to gain insights into how best to integrate the specific information from each case study into a coherent framework. There was immediate feedback re climate data that was provided, with discussion around the differences between the climate information supplied by the CSIRO for this project and the climate information supplied by the State Governments of New South Wales and Queensland (leading to a change in approach for the project). Discussion also included the ports' understanding of the most important climate impacts and the limitations of the climate risk management strategies employed at individual ports.

Susan Fryda-Blackwell	EO	Ports Australia
Xiaoming Wang	Principal Research Scientist	CSIRO
Llew Russell	CEO	Shipping Australia Ltd
Mark Ireland	Sustainability Manager	Sydney Ports Corporation
Christa Sams	Environmental Operations Manager	Sydney Ports Corporation

Alison Karwaj	Environmental Co-ordinator	Sydney Ports Corporation
Gary Carter	Acting Port Planning & Development Manager	Gladstone Ports Corporation
Andrew Dunne	General Manager - Engineering & Environment	Port Kembla Port Corporation
Trevor Brown	Sustainability Co-ordinator	Port Kembla Port Corporation
Ron Cox	Leader	ACCARNSI-NCCARF
Fiona Coombes	Department representative	Qld Dept of Transport

Stakeholder workshop, Melbourne (December 2011)

This workshop was used to inform interested parties that didn't attend the Sydney meeting. It functioned as an interim dissemination workshop; testing the assumptions and methodologies that had been refined after the Sydney workshop. It also provided a platform for the project's visiting scholar, Hans de Moel (Vrije Universiteit), to present the adaptation activity of the Port of Rotterdam. Dialogue centred on the use of climate information for adaptation planning. For example, there was agreement that drainage systems at Australian ports may need to be upgraded, but it was "not on the radar" and the information for making informed decisions was not easily available. This theme, of having to deal with the complexity of the climate data, coupled with the frustration at the lack of one definitive climate 'future' to be planned for, was a continuous thread that ran throughout the project.

Celeste Young	Climate change officer	WAGA
Rod Keenan	Director	VCCCAR
Lori Dalton	Policy Officer - Freight Network Legislation and Governance Freight Logistics and Marine Division	Victorian Department of Transport
Greg Hunt	Climate change officer	SECCCA
Ian Hunter	Project Director, Heavy Vehicle Access Arrangements & Supply Chain Strategy	National Transport Commission
Belinda Irwin	Ports Strategy	National Transport Commission
Anne Dansey	Climate Adaptation Sustainability Department, Environment & Planning	City of Port Phillip
Alex Atkins	Director Sustainable Infrastructure	Mornington Peninsula Shire
Sandra Johnson	Project Officer	Port of Hastings, Port of Melbourne Corporation
Jennifer Cane	Associate Director - Sustainability and Climate Change Technical Leader - Climate Adaptation	AECOM

Allie Levine	Policy Analyst, Strategy and Resource Efficiency Policy	Department of Transport
Andrew Potts	Consultant	AMOG
Jon Hinwood	Consultant	AMOG
Tim Woomersley	Consultant	AMOG
Ralph Roob	Senior Environmental Engineer, Environment & Natural Resources Department	City of Geelong
Burke Renouf	Coordinator Sustainability Environment & Natural Resource	City of Geelong

Dissemination workshops: Port Botany, Port Kembla, Gladstone (September 2012)

These workshops fed back the draft findings from the project to the case study port authorities and stakeholders who had been most directly involved, and to allow for final comment. At each meeting WP1 presented information about the development of the future climate data along with the methodology for choosing the climate models and an overview of the future climate projections for the individual ports.

APPENDIX E: CLIMATE PACKS

The following three documents are available as standalone climate risk information packs for each of the port locations:

- Climate Risk Information Climate Change Scenarios and Implications for Port Kembla
- Climate Risk Information Climate Change Scenarios and Implications for the Port of Gladstone
- Climate Risk Information Climate Change Scenarios and Implications for Port Botany

APPENDIX F: CLIMATE SMART SEAPORTS ONLINE TOOL

Climate Smart Seaports: Online Decision-Support Toolkit

Project Brief:

- Primary objective to provide Australian seaport managers, planners and engineers with **a 'one-stop-shop' for up-to-date current and future climate information, scoped to each port's local climatic, socio-economic and geographic characteristics** for ease of use.

- Toolkit aims to incorporate datasets from organisations such as the Bureau of Meteorology, the Australian Bureau of Statistics, the Bureau of Infrastructure, Transport & Regional Economics, the Bureau of Resources & Energy Economics and Geoscience Australia, **integrating both climate and non-climate data through a single, targeted and simple online workflow.**

- Outputs will be specifically **designed to feed into and comply with existing port processes**, such as risk management structures, strategic planning processes and material degradation models.

Key features:

- **Simplified selection and explanation of CSIRO climate data** and downscaling processes;

- **Tailored workflow and data outputs** to differing port types, throughputs and locations;

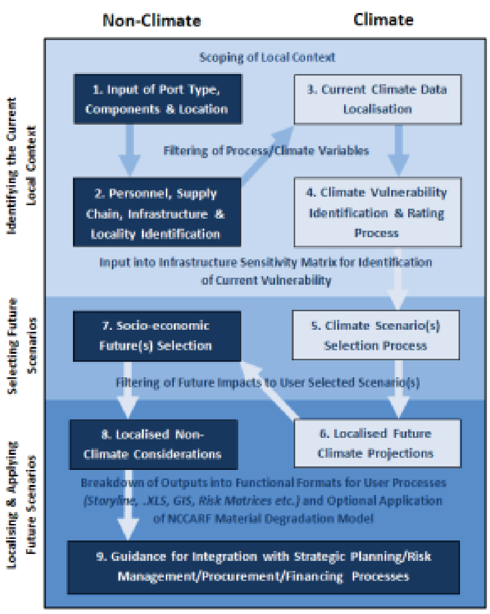
- **Localised socio-economic 'futures'**, allowing consideration of factors such as population pressure and commodity demand shifts;

- **Pre-populated Infrastructure Sensitivity Matrices** for vulnerability assessment;

- Integration of the soon to be released **National Climate Change Adaptation Research Facility Seaport Material Degradation Model**; and

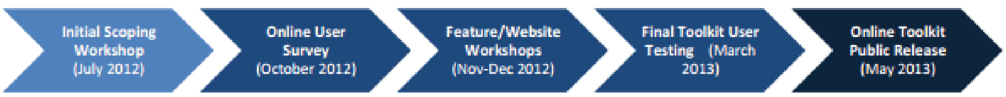
- **User-determined data access**, from private collaborative workspaces to public 'read-only' customisable report formats.

Draft User Workflow Process



Timeline:

- Interface features, content and outputs will be determined through an extensive participatory stakeholder consultation process, including an online survey, stakeholder workshops and one-on-one interviews. A draft timeline for this process is provided below:



ands

Climate Change Adaptation Program
Global Cities Research Institute
RMIT

NCCARF
National
Climate Change Adaptation
Research Facility

RMIT UNIVERSITY