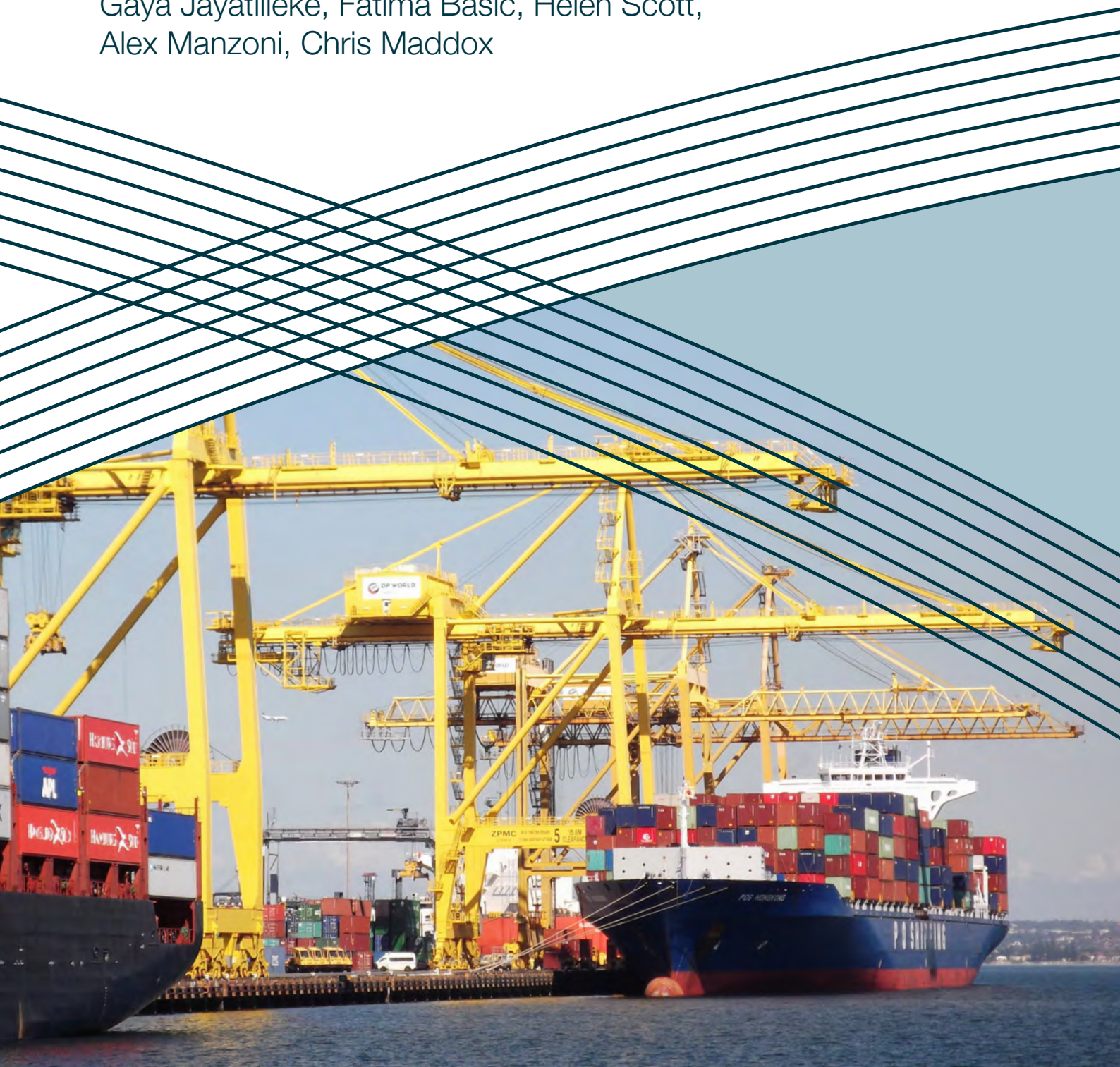


Functional resilience of port environs in a changing climate – assets and operations

Report series: Enhancing the resilience of seaports to a changing climate

Prem Chhetri, Jonathan Corcoran, Victor Gekara,
Brian Corbitt, Nilmini Wickramasinghe,
Gaya Jayatilleke, Fatima Basic, Helen Scott,
Alex Manzoni, Chris Maddox



Functional resilience of port environs in a changing climate – assets and operations

Enhancing the resilience of seaports to a changing climate report series

Work Package 2: Functional resilience of port environs in a changing climate – assets and operations

RMIT University

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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.

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EXECUTIVE SUMMARY

The growing importance of logistics in increasingly globalised production and consumption systems strengthens the case for explicit consideration of the climate risks that may impact on the operation of ports in the future, as well as the formulation of adaptation responses that act to enhance their resilience. Within a logistics chain, seaports are functional nodes of significant strategic importance, and are considered as critical gateways linking local and national supply chains to global markets. However, they are more likely to be exposed to vagaries of climate-related extreme events due to their coastal locations. As such, they need to be adaptive and respond to the projected impacts of climate change, in particular extreme weather events. These impacts are especially important in the logistics context as they could result in varying degrees of business interruption; including business closure in the worst case scenario. Since trans-shipment of freight for both the import and export of goods and raw materials has a significant impact on Australia's sustained economic growth it was considered important to undertake a study of port functional assets, to assess their vulnerability to climate change, to model the potential impacts of climate-related extreme events, and to highlight possible adaptation responses.

In order to understand the vulnerability of port logistics operations to climate-related extreme events, a first key step was to develop a comprehensive assets register. This can then be used as the platform to inform the spatial modelling of ports and their environs, as well as enabling the development of a decision support system to assist with evidence-based port infrastructure planning and operations management. The methodological framework developed in this project enables Australian ports to:

- map and assess the vulnerability of key functional assets to climatic hazards, informed by local knowledge and expertise;
- model intra-port container flows and develop a systematic assessment of different 'what if' scenarios associated with extreme weather events that are of most concern to port operations, perturbed by future climate scenarios;
- consider strategies that strengthen the adaptive capacity of the workforce; and
- access an integrated risk management framework that provides guidance for ports when developing tailored adaptation strategies. Adaptive capacity and the implementation of options are both considered, and are highlighted in a separate stand-alone project report on adaptation guidelines.

Three ports (Port Kembla Port Corporation, Sydney Port Corporation and Ports of Gladstone) were selected as case studies for the project. These were used to develop the methodological framework for assessing potential climate change impacts on port logistics. Port Kembla; with a diversified cargo portfolio including bulk resources, coal, iron ore and wheat, containerized and general cargo export and import freight, and involving multiple stakeholders, was used as an exemplar model for analysis and methodology development. Sydney is essentially a container port. One of its container terminals was used to develop a Container Terminal Operation Simulator (a simulation of the port logistics-related operation processes) with a view to identifying the productivity impact of disruptive weather events. Gladstone is a bulk commodity port, specialising in coal, and was used to examine the adaptive capacity of the workforce

and their work practices and to assess their preparedness to manage climatic shifts and extreme events.

Due to the limited availability and access to freight flow data from port authorities, the analysis was confined to the immediate port environs. The likely impact of climate change over a wider port environment was thus excluded but remains a research priority. Nonetheless, a generic yet robust methodology has been developed, which is inter-operable to any port setting. The Container Terminal Operation Simulator (CTOS) developed in this project should be considered 'proof of concept', which can be applied to any container port terminal (or to a bulk cargo terminal with some alteration in port configuration).

Research activity and the key findings and outcomes of the study are summarised for the purposes of this executive summary according to four domains as shown below:

Asset register and 3-D mapping

A major research activity involved the development of a comprehensive Geographic Information System (GIS) based assets database (Assets Register). This has the distinct advantage of providing a visual asset management tool, significant in spatially dependent businesses such as port logistics operations. The GIS assets database identified and mapped core operational assets for sea, land and sea-land interfaces as the basis for the analysis of core logistics operations. The database also collated information on ownership, quantity and types of assets; as well as asset maintenance and utilisation related records to assist in asset valuation, asset life-cycle and performance assessment.

In addition, an overlay of core operational assets, supported by the 3D mapping, was used to identify the perceived levels of vulnerability of port assets. This assessment was framed using a vulnerability matrix. Bottom-up analysis identified the climate variables of most concern as tropical cyclones (Gladstone), high wind speeds (Port Kembla), and storm surge and tides (Sydney). The assets of most concern were high impact technical equipment, shore and ship cranes, and some physical protection assets. Analysis indicated varying perceptions about the threat of sea-level rise to a range of functional assets.

Due to the timing of the 3-D modelling activity, the impact of sea-level rise was based on 'off the shelf' data (the CSIRO high emissions scenario) for Port Kembla. The model and simulation created for this study is transferable and can also be applied to other ports to determine the impacts of extreme events on port logistics operations.

Results from the 3-D modelling show that the impact of this scenario for Port Kembla would probably be low to moderate resulting in minor inundation and some impact on operational assets. However, further 'ground truthing' at the asset level is recommended.

Modelling the Impacts of Climate-Related Extreme Events

The development of a Container Terminal Operation Simulator (CTOS) used a combination of asset impact assessment and climate change data for the three case study ports. The model is underpinned by agent based modelling and simulation

(ABMS), which allows individual actors/nodes in a process to be independently encoded with operational rules in order to observe the collective behaviour. ABMS thus allows the logistics performance of operational assets to be individually and collectively modelled. By encoding the operational rules of individual operational assets (i.e. nodes in the process workflow), the likely impact of climate events on the business process flow when the performance of different operational asset nodes reduce to a sub-optimum level can be measured and compared. CTOS provides a generic inter-operable agent based simulation tool that can be applied across a wide range of ports.

The results of the simulations showed that while the impact due to these events were of relatively minor significance on container related operations, rain and high wind had the most impact, while flooding in the yard area impacted operations of the straddle carriers leading to backlog queues for trucks. Using annual hot days occurring at present and projected for 2030, the likely annual impact due to high temperature days was estimated to be a productivity loss of 183 containers per year and 241 containers per year respectively. This is less than 0.01% of the annual container volume of the port. However, it is important to note that the compounded impacts of weather events occurring across a year were not modelled.

The various modelling outputs however, are sensitive to ongoing operational changes and potential errors in existing data. Thus, realistic determination will have to be dynamic and reiterated as new data arise. Further ground testing at the asset level is also recommended.

Workforce adaptive capacity

Ports need to integrate climate change adaptation as part of their wider risk management strategies, as well as their sustainable development agenda. Whilst sustainability issues are increasingly important to businesses generally, it can be argued that the consideration of climate change impacts needs to be more central to the activity of many organisations. Climate risks have the potential to impact on economic profitability and as such need to be integrated into existing corporate risk management strategies and processes.

Findings from the analysis of adaptive capacity suggest that integration can be promoted through climate change champions within the ranks of CEO and senior executives. Awareness raising and training can lend impetus to the organisational cultural change that may be necessary. The strengthening of adaptive capacity will also be enhanced by mainstreaming climate considerations into existing risk evaluation and workforce management and operational systems. One such example relates to the ongoing reassessment of climate thresholds for enhancement of current OH&S procedures in order to update and guide the actions, behaviours, and practices of the port workforce. Here again, further awareness training for executives and staff would also be beneficial.

Climate change adaptation strategies

Climate change adaptation is highly context specific, so generic adaptation actions cannot be adopted without appropriate site-specific investigation. For this reason, this research recommends port authorities undertake a location-specific climate risk

assessment, building on the AS/NZS ISO 31000 Risk Management standard. All ports will generally operate a risk management system (which may or may not be aligned with the AS/NZS ISO 31000 Risk Management Standard). By modifying this approach to incorporate current day vulnerabilities to extreme weather events, as well as considering future climate impacts to create a “hybrid risk/ vulnerability” approach would appear to be suited to ports, in that it addresses two of the key barriers to effective climate change adaptation at ports, that of inconsistency in planning horizons and uncertainty of future localised climate projections. The methodology that was developed, covering both processes and outcomes, is detailed in the separate project document ‘Adaptation Guidelines’.

Research gaps

A future research agenda would attempt to extend this modelling framework to assess the vulnerability of a wider supply chain network, including cascading impacts, and the resultant simulated freight flow perturbation and logistics disruptions. Integration of historical data on the impact of extreme weather events on efficiency levels of terminal equipment and operations will further enhance the reliability of the results produced by CTOS. In addition, ‘extremes’ data with a lower spatial and temporal granularity will provide more reliable estimates of performance deterioration of port logistics operations. While CTOS is robust enough to work with available data, the accuracy of the outcome however depends heavily on the quality, resolution and reliability of input data. In sum, the report recommends more research in this area and that ports utilise a more systematic and detailed approach to data gathering, particularly as it relates to extreme climate conditions and related disruptions, asset registers, and GIS-ready data.

1. INTRODUCTION

The overarching aim of Work Package 2 (WP2) is to develop a research methodology that has the capacity to systematically assess the vulnerability of port assets, infrastructure and logistics operations within the port precinct. The focus of WP2 was to examine the potential implications of future changes in climatic conditions for ports and their catchment areas; the preparedness of ports and port authorities to changes that are perceived as detrimental to port operations; and the approaches that are necessary to be adopted in order to enhance the resilience of seaports to climate change. In achieving these aims WP2 investigated the changes in policy and practice that are necessary in order to enhance the resiliency of Australian ports to future climatic extremities.

1.1 Research questions

The purpose of this research was to develop a methodological framework for systematically identifying the vulnerability of port assets, infrastructure and logistics operations to weather-related impacts and future climate change in the context of Australian port. This was achieved by answering the following four research questions:

- *What are the key vulnerabilities of port functional assets and to each of the climatic variables?*
- *How can the impact of climate change on port operations and freight distribution be best modelled and simulated?*
- *What adaptation strategies and measures could be implemented by port authorities, particularly in the context of mainstreaming climate change considerations into existing risk management strategies?*
- *What policies can be formulated to increase industry preparedness and how can the labour force engaged in ports be best trained to manage potential climate-related risks?*

1.2 Study scope

WP2 comprised four interrelated domains through which the overarching research question and subsidiary questions were addressed (see Figure 1). These domains include:

- **Domain 1: Building an asset register and assessing the vulnerability of port assets**

Domain 1 involved the development of an asset register for the port precinct through the process of asset identification, characterisation and mapping. Using a Geographic Information System (GIS)-based spatial methodology this process was operationalised in the case study for Port Kembla. This exemplar port was used to demonstrate an innovative visualisation capability that permits an enhanced understanding of the vulnerability of port assets to particular climate change events, its variation across the port precinct and by various climate change events. An example of sea-level rise is given. The development

of a spatial register of Core Operational Assets provided the necessary foundational knowledge from which a Vulnerability Index is constructed that can be used to develop adaptation strategies.

- **Domain 2: Container terminal operations simulation (CTOS)**

Domain 2 investigated the possible impact of climate change related disruptions to container terminal operations through the development of an agent-based simulation tool. While the agent based simulation used in CTOS can be used to replicate any port process, this domain focused on a container terminal. Container trade is widely used and rapidly growing, thus playing a major role in the commodity supply chains which are connected through ports. The methodologies embedded with CTOS have the ability to be scaled to simulate container flows within a container terminal under different weather scenarios.

- **Domain 3: Adaptive capacity of the workshop and skills preparedness**

Domain 3 examined the adaptive capacity of the workforce and their work practices within the ports to assess their preparedness to manage climatic shifts and extreme events.

- **Domain 4: Climate Change Adaptation Strategies**

This domain integrated findings under a risk management framework to provide guidance for ports in developing their adaptation strategies. Adaptive capacity and the implementation of options were both considered, and are highlighted in a separate stand-alone project report.

The remainder of the report is organised into eight broad sections. First, the research methodologies are outlined in section two, followed by an overview of climate data including future projections for the regions in which the study ports are located in section three. Sections 4 and 5 evaluate the perception of asset vulnerability; undertake vulnerability mapping and modelling sea-level rises for the Port Kembla case study. The container terminal operational simulation (CTOS) and the results from the simulation runs are presented in section 6. Section 7 examines the workforce adaptive capacity, while section 8 addresses the recommendations for training on climate change adaptation to respond to extreme weather events. The conclusion section summarises the key findings.

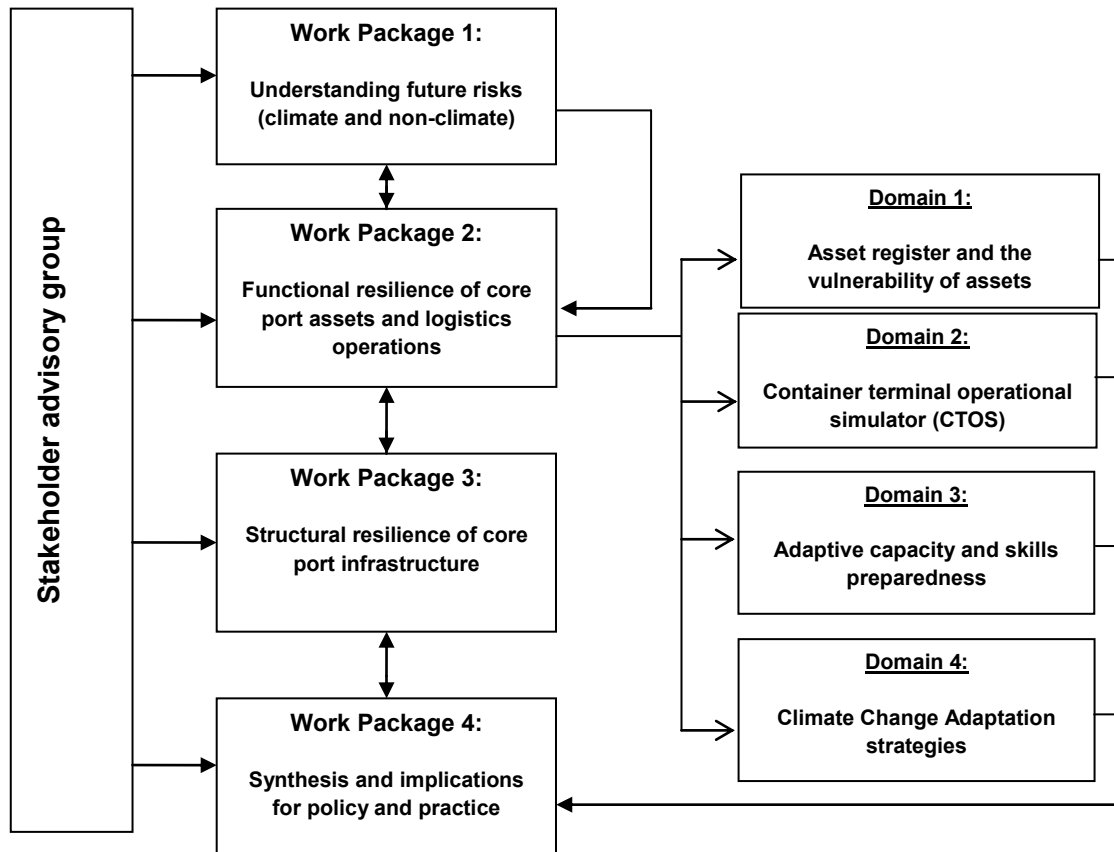


Figure 1: Research design

1.3 Study context

The functional response to climate change requires a better understanding of the characteristics of commodity trade and related port operations. This section discusses a functional perspective of ports, highlighting the characteristics of maritime trade in Australia.

1.3.1 A functional perspective

Traditionally, most ports are defined as “*simple trans-shipment hubs where freight is passed between ships and landside transport*” (Mangan and Lalwani, 2008). Stopford (1997) considered a port as “*a geographical area where ships are brought alongside land to load and discharge cargo*”. Modern ports however are regarded as the most critical gateways linking national supply chains to global markets. Mangan and Lalwani (2008) discuss the emergence of “port-centric logistics” hubs such as Dubai, Singapore and Rotterdam as a phenomenon of a large spatial accumulation of logistics-related value adding activities including storage and warehousing, packing and unpacking, freight consolidation, pre-processing activities, and assembly. Arguably, modern ports are functional nodes of value adding economic activities, which create economic growth *vis-à-vis* global connectedness through service innovation. Some of these ports are disproportionately large to empower control and regulation in domestic and international trade and thus in turn act as gateways to the entry or exit from a country, shaping the way commodity supply chains are formed.



Figure 2 Ports Australia members list with the study ports shown in yellow (Ports Australia, 2010)

The operational environments in ports vary with some ports being relatively simple, whilst others are diverse and complex in terms of handling various and differing types of freight. Some ports are equipped to handle liquid bulk (e.g. oil) or dry bulk (e.g. coal, iron ore and agricultural products); whilst others deal with unitised freight (e.g. lift-on/lift-off containers or Lo-Lo and roll-on/roll-off units or Ro-Ro) (Mangan and Lalwani, 2008). Furthermore, some ports are export oriented whilst others are largely focused on import.

Figure 2 depicts the location of some of the key commercial ports in Australia (Ports Australia, 2010) in which the locations for the case study ports for this study depicted as yellow dots. Selection of these case study ports was principally guided by differences both in the type and processes undertaken to the cargo they handle coupled with variations between each of the ports in respect to future climatic impacts. As such the three ports offer the capacity to account for a range of vulnerabilities across diverse port functions and infrastructure in relation to a range of climate risks.

1.3.2 Australian maritime trade

Ports are particularly critical to Australia's economic competitiveness given that Australia is resource-rich, geographically isolated and heavily dependent on international maritime transportation for both its imports and exports. The economic significance of ports is evident through the size of international and domestic cargo (1,052 million tonnes) handled by Australian ports between 2009 and 2010 (LMIU, 2010). Figure 3 shows the composition of cargo with respect to export, import and domestic.

In value terms, the exports accounted for \$178.9 billion and imports \$156.9 billion with a total value of \$335.8 billion of international freight handled by ports in Australia in 2009-10.

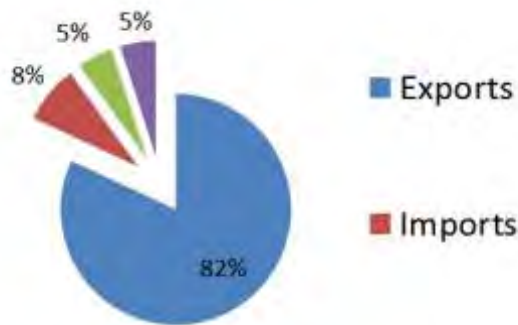


Figure 3 Cargo by type between 2009-11

Ship traffic of 4,199 ships was recorded in 2008-09 with a total of 26,709 port calls made by international and domestic ships (LMIU, 2010). The distribution of traffic across the different states since 1992-2009 highlights a general trend of growth in ports based in Queensland and Western Australia (see Figure 4). While the number of port calls declined in 2008-09, the fluctuations seem to follow a natural regular historical pattern in Figure 5.

The majority of the cargo handled by Australian seaports is in the bulk category (e.g. coal, iron ore and wheat). In 2007-08, 95 per cent of the international cargo was bulk, out of the 790 million tonnes handled via Australian ports. The following figures show the steady growth in bulk and containerised cargo handled by Australian ports. According to the BITRE (2010), port calls to Australian ports by both containerised and bulk cargo ships are to grow linearly (Figure 6) with trends in general cargo and other types of vessels to remain constant (Figure 7).

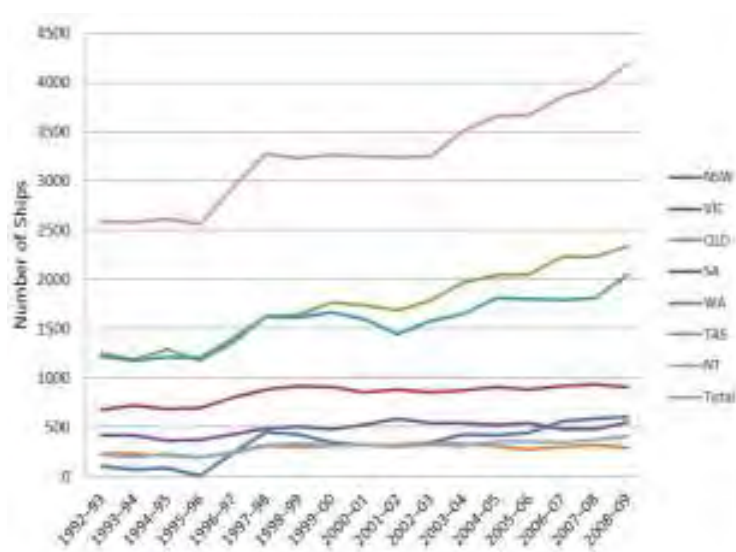


Figure 4 Number of ships (data source: LMIU 2010)

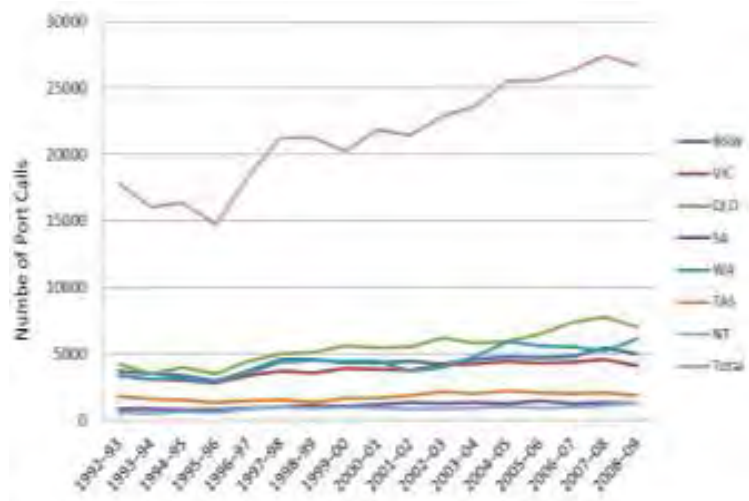


Figure 5 Number of port calls (data source: LMIU 2010)

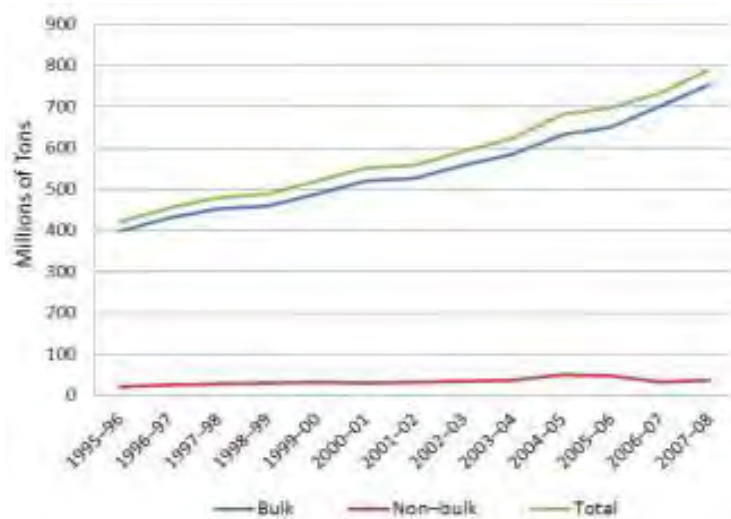


Figure 6 Bulk and non-bulk cargo (data source: LMIU 2010)

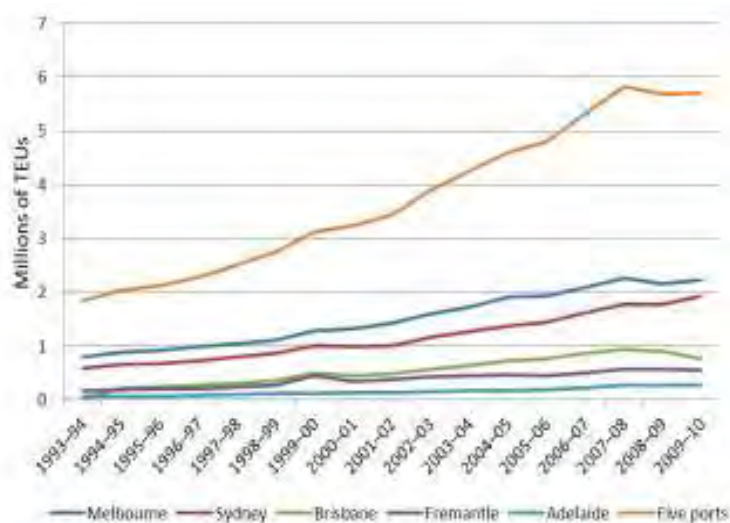


Figure 7 Containerised cargo (data source: BITRE 2010)

1.3.3 The case study ports

Three ports were selected for the study, namely Gladstone Ports Corporation, Sydney Ports Corporation, and Port Kembla Port Corporation. The three ports are all located on the east coast of Australia (Figure 8) and vary in the type of cargo they handle and the handling processes (Table 1). The study ports' locations spread over two states – New South Wales and Queensland – bringing diversity in geography and climatic conditions.



Figure 8 Location of case study ports

Gladstone Ports Corporation in the town of Gladstone is the single port located in the state of Queensland of the three study area ports. Gladstone predominantly deals with coal, alumina, aluminium and cement and is in the world's top five ports for handling coal. In the 2011/12 financial year, an excess of 50 million tonnes of coal was handled at the ports two export terminals: RG Tanna and Barney Point.

Sydney Ports Corporation in New South Wales is the biggest of the three ports and is spread over six locations throughout Sydney. Containerised goods are the main commodity handled at Sydney Ports. It is Australia's second largest container port with over 2 million containers handled within the port during the 2011/12 financial year. Our focus was limited to a single terminal operator. Due to sensitivities around information collected, the name of the terminal operator for Port of Sydney used as a case study cannot be revealed.

Also located in New South Wales, around 100 km south-west of Sydney is the Port Kembla Port Corporation in the town of Port Kembla. Major products handled at Port Kembla include coal and coke, steel, motor vehicles and machinery, and grain. Around three quarters of cargo handled at Port Kembla is bulk. The rest is general cargo.

All three ports are capable of handling containerised goods.

Port Corporation	Trade overview
Gladstone	<ul style="list-style-type: none"> Major products include coal, alumina, aluminium and cement Largest export commodity is coal which represents 70% of the total cargo exported through the port (75% coking; 25% thermal) In the world's top five coal export ports, handling in excess of 50 million tonnes of coal per annum Internationally recognised as a major bulk port but also caters to all forms of containerised and general cargoes On average, over 50 million tonnes of coal is handled per annum at the ports two export terminals: RG Tanna and Barney Point
Sydney	<ul style="list-style-type: none"> Australia's second largest container port Imported commodities such as manufactures, household consumables, machinery and equipment, chemicals, paper and paper related products, prepared food goods, and fruit and vegetables to Sydney and NSW For the 2011/12 financial year, total number of containers handled at Sydney was over 2 million TEUs
Port Kembla	<ul style="list-style-type: none"> Major products include coal and coke, steel, motor vehicles and machinery, and grain Largest export commodity is coal and coke (72%) followed by steel at 16% Largest import commodity is steel (62%) and motor vehicles and machinery (28%) 75% bulk cargo, 24% general cargo Over 32 million tonnes of commodities were traded in the 2011/12 financial year

Table 1 Trade overview of case study ports

2. METHODOLOGY

Section 2 presents the research methodology that was adopted to evaluate various research domains described in Section 1. Enhancing the resilience of a port to climatic changes and its vulnerability to extreme events requires, *ab initio*, an understanding of the facilities, assets and infrastructure that make up its logistics operations. At a high level, the methodology we developed follows the five broad stages as listed below in Figure 9 while the relationships and data flow between the different domains are shown in section 2.3, Figure 10:

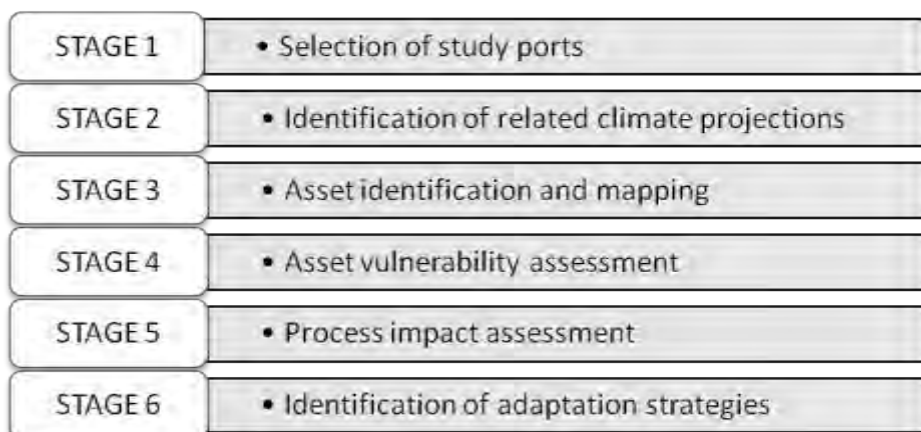


Figure 9 Main steps of the methodology

2.1 Selection of case study ports

Three case study ports were selected for this research to account for the vulnerability of different types of ports, 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 five criteria:

- Ports to be representative of at least two different climatic regimes
- Representative of a range of port operations, informed through the application of a functional typology screening process
- Immediate port environs to be comprised of different types of physical infrastructure (linked to 2 above)
- Geographic setting (although not an initial consideration it became evident that this additional influence may have a bearing on research findings and needs to be explicitly considered as part of the forward program)
- Ports' willingness to participate in the study

Meeting the criteria, and following positive discussions and clarification of the project's aims and objectives, the port authorities selected for the project were:

- Gladstone Ports Corporation
- Port Kembla Port Corporation
- Sydney Port Corporation

2.2 Identification of climate data

The data related to climate change specific to the regions and relevant for the case study ports were obtained through CSIRO and the Bureau of Meteorology in close consultation with Work Package 1(WP1).

2.3 Asset identification and mapping

The objective of this stage was to identify all assets and create a register, which enumerates them, describes their functions, and determines their operational ownership and location. Typically assets are clustered by location of use in a sequence of logistics operations, hence the need to delineate the port environs into three key areas; namely, (1) sea-side, (2) sea-land interface; and, (3) land-side. This geographic distinction also allows the recognition of how climatic vulnerability differs across these three zones according to where the assets are operating within the port precinct. The methodology adopted here was applied to Port Kembla as a case study for the generic modelling. This first required a comprehensive register of all core operational port assets to be assembled that included their locations to be mapped such that their vulnerability to climatic events could then be assessed.

2.3.1 Identifying study parameters and adopting a case-based approach

- Formal meetings and a workshop with stakeholders from all ports in the study. These elicited stakeholder views on existing hazards, vulnerabilities and individual concerns as well as ascertaining their needs.
- Normal port operations were studied to provide background information and to determine if Port Kembla would provide a suitable case for model building.
- Port Kembla was decided upon as the case study template for the project because of its suitability as displayed through the variety of facilities and diversity of freight handled.

2.3.2 Data gathering and stakeholder consultation

- Stakeholder meetings were held with key port personnel during a site visit and subsequently maintained through frequent electronic and telephone communication.
- Maps, engineering schematics and an engineering-based register of port assets were provided by the Port Authority and information in the public domain was vetted for inclusion.
- The engineering asset register was filtered for assets that fit the category of core operational assets (COAs).
- The engineering asset register was also converted to a database that would enable mapping.
- Data collected on each COA included operations location in the logistics sequence of sea-side, sea-land interface and land-side, and the number and ownership of assets noted.

GIS encoding and visualization

- Georeferencing of the assets was completed using data supplied by the Port Authority and local council (Wollongong Council). This provided 2D and 3D visualisations of port assets.

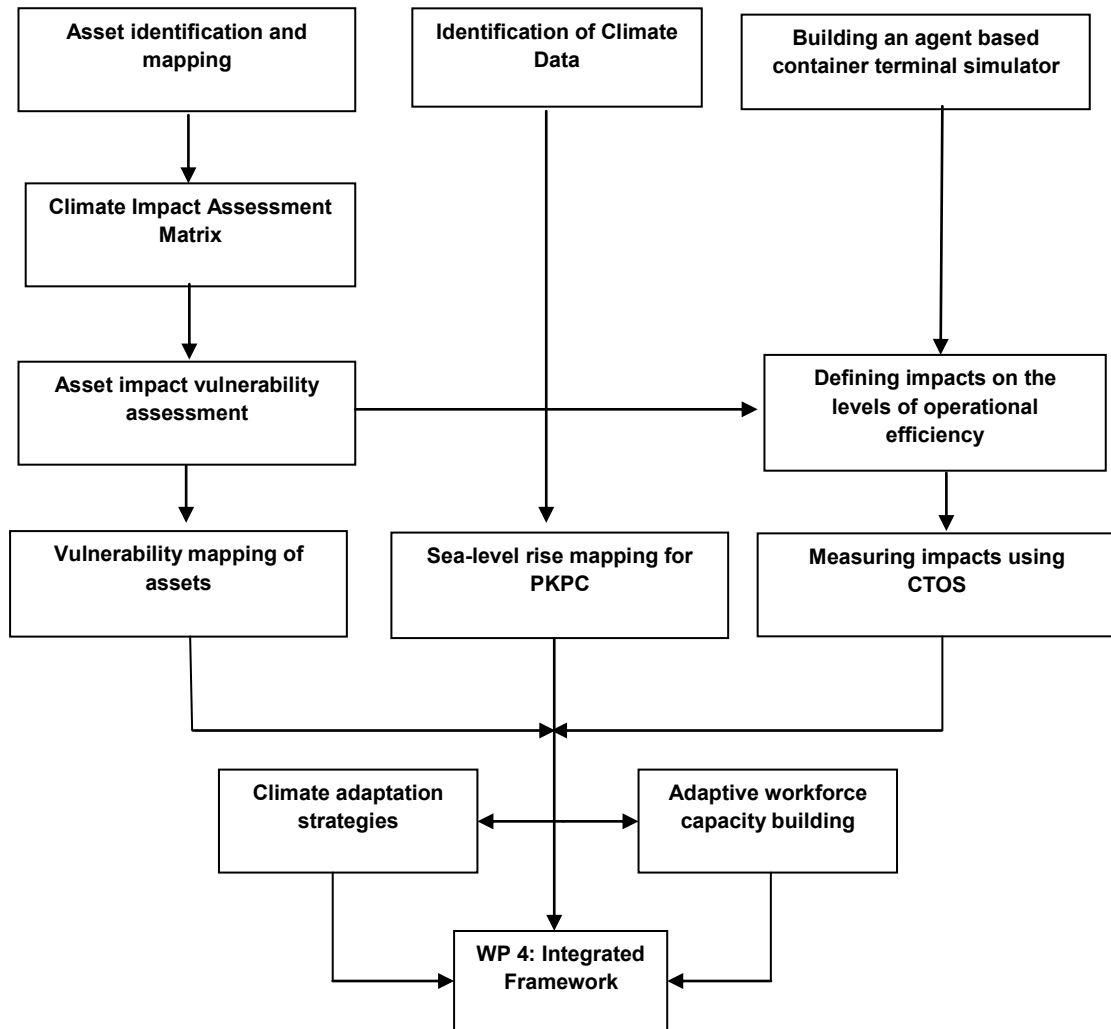


Figure 10 Framework for climate impact assessment on port operations

2.4 Asset vulnerability assessment

This stage of the methodology involved an assessment of the perception of vulnerability and threats to port assets and logistics operations across key areas of sea-side, sea-land interface and land-side. It involved a cross-case evaluation of the three case study ports. Data for this stage was collected and collated through a number of sources that employed a variety of methods. These included:

- Formal meetings and a workshop with stakeholders from all ports in the study. These elicited stakeholder views on existing hazards, vulnerabilities and individual concerns as well as ascertaining their needs.
- Stakeholder meetings were held with key port personnel during a site visit and subsequently maintained through frequent electronic and telephone communication.

- A subjective assessment of different climatic events impacting on port operations and assets ascertained through vulnerability ratings using a climate impact assessment matrix across different climate regimes and port types (i.e. resource port versus container port).
- Integration of likely impacts of key climatic events on port efficiency levels.
- Construction of climate change scenarios based on CSIRO and BoM climate projections for simulating the likely impacts on logistics operations.

2.5 Operations impact assessment (Container Terminal Operational Simulation)

The objective of this component was to design an intra-port workflow system to simulate the vulnerability of port operations to extreme weather events and future climate change scenarios. A single terminal within the Port of Sydney was used as context to develop this model; however care was taken in its design to ensure that its application had the capacity to be broadened to include other terminals at the Port of Sydney in addition to other ports. However, due to commercial confidentiality regarding data, the terminal operator is not named.

Building the simulation involved six steps:

- Gaining an understanding of container terminal operations, operational parameters and key performance indicators through discussions with stakeholders from the selected container terminal
- Identifying the core operational assets, resources and operations to be simulated
- Building an agent based design of the system
- Implementing the design using the Jack Agent Language and Java programming language
- Identifying climate scenarios to be simulated with input from stakeholders on the climate events that have the most impact
- Running the simulation (under the various identified scenarios ascertained in step five) and analyzing the results

The simulation outcome is a set of Key Performance Indicators that allows a comparison of operational performances (e.g. average waiting time for trucks and ships, loading time for cranes, space utilisation) under various climate change scenarios. The simulation model enables a systematic assessment of different 'what if' scenarios associated with extreme weather events that are of most concern to port operations.

2.6 Identification of adaptation strategies

This step identified strategies to build a more adaptive workforce with greater capacity to respond to a changing climate.

The adaptive capacity of the workforce was assessed using semi-structured interviews with staff, conducted between July and September 2012 across the three case study ports. Through open-ended questions, respondents were invited to explain and discuss climate impacts on port operations. In addition, a series of workshops held during September 2012 were organised to ascertain workforce adaptive capacity options with the objective of identifying possible training needs.

3. CLIMATE DATA

This section outlines the projected climate change information, used in building scenarios for the CTOS simulation model and the sea-level rise modelling for Port Kembla. It also provides a review of the literature the likely impact of extreme events on ports and factors that influence a port's vulnerability to climate change. It thus offers an overview of the expected impacts on ports due to expected increases in frequency and intensity of climate variables.

3.1 Likely impact of extreme climate events on ports

The key climate related factors that can affect port performances have been outlined by the International Finance Corporation (2011), presented in Figure 11. Future climate related events along the coast such as storm surge, winds and wave conditions may increase in intensity or frequency. Within a port, the expected physical impacts of changing climate conditions includes: increased runoff and siltation requiring increased dredging; disturbance and distribution of currently entrained heavy metals and other pollutants; increased high wind stoppages under Occupational Health and Safety (OHS) requirements; delays to berthing and cargo handling; coastal flooding; and required engineering upgrades to wharfs, piers, gantries and other cargo handling equipment (Australian Government, 2009).

Ports are likely to be particularly at risk from extreme climate events for a number of reasons. The International Finance Corporation (2011:12) lists these as:

- Due to their long lifetimes, ports will face considerable climate change
- By virtue of their locations on coasts, rivers or lakes, they are often exposed to a range of climate hazards, including sea-level rise, storm surges, extreme wind and waves, and river flooding
- Shipping movements into and out of ports could be affected by adverse climatic conditions, causing delays to port operations
- They are vulnerable to the economic impacts of climate change on global trade
- They can transport goods for which demand or supply is climate-sensitive, e.g. agricultural products, fuel
- Inland movement of goods to and from ports relies on transport infrastructure which is likely to be managed by others yet still vulnerable to climate change
- Ports, similarly to other industrial facilities, are vulnerable to disruptions to utilities such as water and electricity which are both vulnerable to climate change. The decreased reliability of these utilities due to climate change is likely to be a material risk to some ports (Acclimatise, 2009)

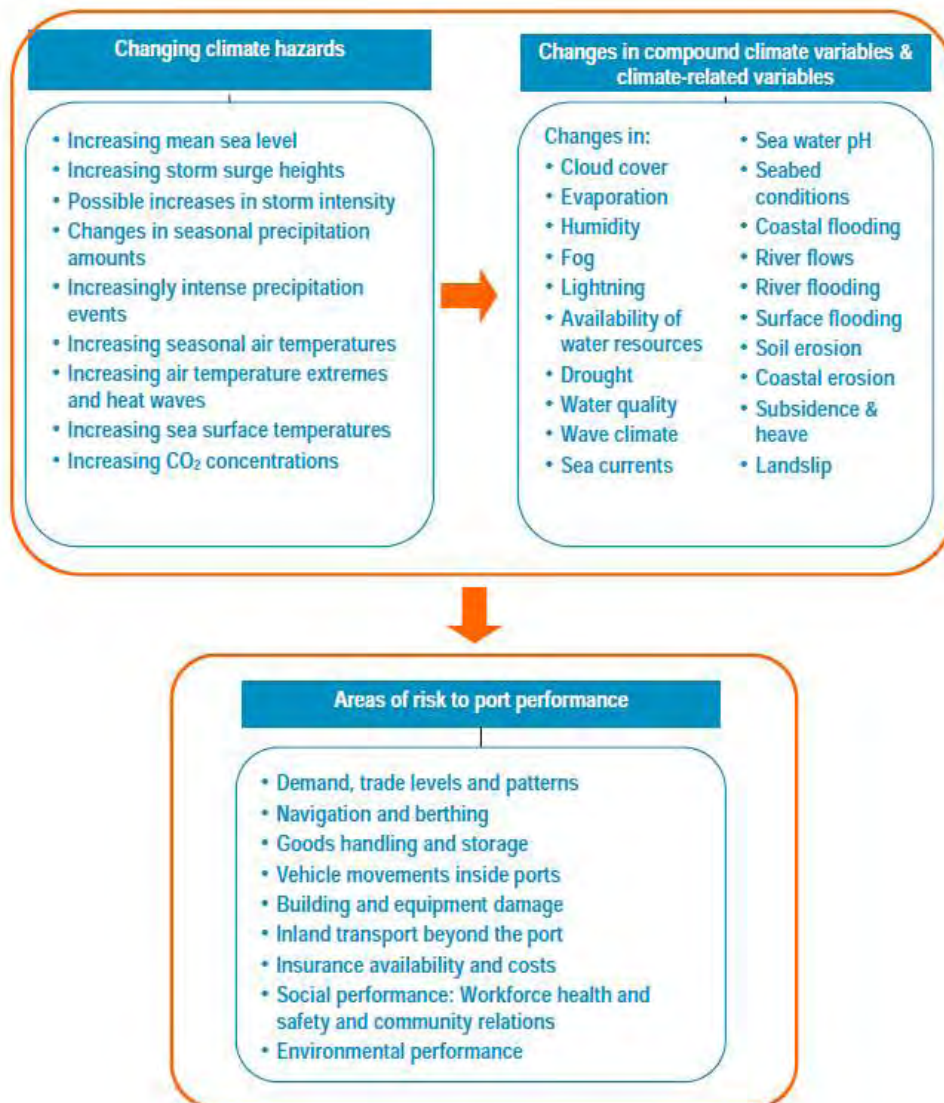


Figure 11 Key climate change factors affecting port performances (International Finance Corporation, 2011)

The level to which ports are affected by extreme climate conditions is strongly correlated with port type and location, as well as intensity and frequency of extreme events. Container ports tend to be located in sheltered harbour locations, close to population centres. Bulk ports are more likely to be located on open-ocean, in locations with good proximity to the production and transportation of the bulk commodities (Maunsell Australia Pty Ltd and CSIRO, 2008: 56)

The impacts of extreme climate conditions are evident around the world. In 2007, Port Hedland was hit by four tropical cyclones (ranging between Category 3 and 5), which caused a significant impact on infrastructure and disruption to port operations. The port was closed to all vessels for a total of 146 hours due to the tropical cyclones (Port Hedland Port Authority, 2007). The insurance cost of tropical cyclone George (Cat 5) was \$8 million (EMA, 2007). In 2008, high-speed winds damaged two cranes at the

Port of Felixstow in the UK after a ship broke free from its moorings. Extensive damage was caused when the cranes on board the vessel collided with land-side containers.

In 2010, a survey study by Becker *et al.* (2011), disseminated to ports around the world ascertained how administrators felt climate change might impact their operations and how they planned to address adaptation issues. There were 93 responses. Fifty three per cent felt that climate change would have negative consequences on their operations and 86 per cent agreed that the port community needed to better understand how to address issues of climate change adaptation. The climate variable of greatest concern (52 per cent) was sea-level rise. Twelve per cent of ports feel they would have a problem at a sea-level rise of 50 cm; 39% feel they would have a problem at 100 cm; and 58% of ports feel they would have a problem at 200 cm.

3.2 Projected climate information for 2030

Future climate data was sourced from the CSIRO Mk 3.5 model, representing a 'most-likely future for Gladstone and a 'hot/dry' future for Sydney/Port Kembla. Projections are based on a mid-emission climate scenario (A1B) for 2030 which was developed by the Intergovernmental Panel on Climate Change (IPCC). The emission scenarios developed by the IPCC depict different levels of future economic development and carbon emissions related to fuel use. An extensive description of the scenarios can be found in (IPCC, 2000). The "A1" storyline from the IPCC (2000) used for the emission scenario in this study is shown in Table 2 below.

A1 emission storyline
The A1 storyline and scenario family describes a future world of very rapid economic growth, global population that peaks in mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies. Major underlying themes are convergence among regions, capacity building, and increased cultural and social interactions, with a substantial reduction in regional differences in per capita income. The A1 scenario family develops into three groups that describe alternative directions of technological change in the energy system. The three A1 groups are distinguished by their technological emphasis: fossil intensive (A1FI), non-fossil energy sources (A1T), or a balance across all sources (A1B).

Table 2 A1 emission storyline (IPCC 2000)

The projection data has been used to look at contrasts between the ports' perception of current climate threats and the future outlook. Future climate data beyond 2030 is not used because ports plan to time horizons of 5 to 10 years (Becker et al., 2012). Tables 3 and 4 below provide a summary of the projected climate changes for 2030 in New South Wales and Queensland under the A1B climate scenario from a range of sources.

Table 3 Climate data summary for New South Wales

NEW SOUTH WALES	
Temperature	<p>Most likely temperature change relative to a baseline period 1980 – 1999:</p> <p>An increase of annual mean temperature of 1.1 °C by 2030</p> <p>An increase of annual mean temperature of between 1.7 °C –3.4 °C by 2070</p> <p>Consistently spring is the season that shows the greatest temperature increase</p>
Extremely hot days	<p>Days over 35°C relative to the AWAP baseline (1974-2005) indicate a wide range;</p> <p>An annual increase between 4.5– 8.7 days by 2050</p> <p>An annual increase between 5.9 –13.9 days by 2070</p>
Extremely hot days (for Sydney only)	<p>The ports temperature policy states that at 36 degrees, breaks become longer and at 38 degrees, operations related work ceases.</p> <p>Current day conditions – temperatures exceed 38 degrees Celsius once annually</p> <p>*By 2030, it is expected that the number of days to exceed 38 degrees annually will increase to 1.9</p> <p><i>*This projection is based on a mid-emissions scenario (A1B) for 2030 from a 'hot/dry model – CSIRO Mk 3.5 (CSIRO and BoM, 2007a)</i></p>
Rainfall	<p>Most likely precipitation change relative to a baseline period 1980 – 1999:</p> <p>An annual decrease of between 9.6% and 15.4% by 2030</p> <p>An annual decrease between 12.7% - 24.9% by 2070</p> <p>Winter and spring show the greatest decreases</p>
Wind, storm	<p>There is no definitive information on changes to wind speed although current work points to the likelihood of more extreme weather events, with an increase in rain intensity in spite of an overall reduction in the days it rains, and the possibility of more intense storms.</p>
Sea-level rise	<p>**The best national and international projections of sea-level rise along the NSW coast are for a rise relative to 1990 mean sea levels of 40 cm by 2050 and 90 cm by 2100. These projections were released by the NSW Government in the NSW Sea Level Rise Policy Statement (New South Wales Government, 2009).</p> <p><i>**Projections were derived from projections by the IPCC, 2007 and the CSIRO (McInnes et al., 2007) and are periodically reviewed.</i></p>

Table 4 Climate data summary for Queensland

QUEENSLAND (CENTRAL REGION)	
Temperature	<p>Most likely temperature change relative to a baseline period 1980 – 1999:</p> <p>An increase of annual mean temperature of 1°C by 2030</p> <p>An increase of annual mean temperature of between 1.7°C –3.2°C by 2070</p> <p>There is little variation in projections across the seasons.</p> <p>(Queensland Department of Environment and Heritage Protection, 2009)</p>
Extremely hot days	<p>Days over 35°C relative to the AWAP baseline (1971-2000) indicate a wide range;</p> <p>An average annual increase of 29 days by 2030</p> <p>In the current climate, the average number of days above 35°C is 16 per year.</p> <p>(Queensland Department of Environment and Heritage Protection, 2009)</p>
Extremely hot days (for Brisbane only)	<p>Currently, day temperatures exceed 38 °C 0.2 times annually. By 2030, it is expected that the number of days to exceed 38°C annually will increase to 0.4</p> <p>This projection is based on a mid-emissions scenario (A1B) for 2030 from a 'most likely' model – CSIRO Mk 3.5 (CSIRO and BoM, 2007b)</p>
Rainfall	<p>Most likely precipitation change relative to a baseline period 1980 – 1999:</p> <p>An annual decrease of 3.0% by 2030</p> <p>An annual decrease between 6.0% - 10.0% by 2070</p> <p>Spring shows the greatest decreases</p> <p>(Queensland Department of Environment and Heritage Protection, 2009)</p>
Wind speed	<p>Most likely wind speed change to a baseline period 1980 – 1999:</p> <p>An annual increase of 2.0% by both 2030 and 2070 (CSIRO and BoM, 2007c)</p>
Sea-level rise	<p>Projections of sea-level rise along the Queensland coast are for a rise relative to 1990 mean sea levels of 30 cm by 2050 and 50 cm by 2070. Released by the Queensland Government in the Queensland Coastal Plan (Queensland Department of Environment and Resource Management, 2012).</p>

Cyclone intensity	10 per cent increase in cyclone intensity and frequency, as well as a 130 km shift southwards in cyclone tracks (Hardy et al., 2004).
Storm surge (wave)	The 1-in-100-year storm tide event is projected to increase by 51 cm in Gladstone if certain conditions (30 cm sea-level rise, 10 per cent increase in cyclone intensity and a 130 km shift southwards in cyclone tracks) eventuate (Queensland Department of Environment and Heritage Protection, 2009)

3.3 Summary

This section has presented the projected climate change information, identifying the likely impact of climate change on port operations and assets with particular reference to extreme weather events. The extent to which ports are affected by extreme climate conditions was highlighted as being strongly associated with port type and its geographical location. The intensity and frequency of extreme weather events was shown to vary across our three case study ports.

Extreme weather events are considered to have greater impact on port operations, drawing on historic events that include the 2009 heatwave in Melbourne and cyclone Yasi in Gladstone both of which highlighted major disruptions to port operations that included complete shutdown in some instances. In the light of these impacts this section utilised CSIRO future projections for temperature, hot days, rainfall, sea-level rise and wind for 2030 to assess the likely implications for operations at each of the three case study ports.

In the subsequent chapters the same CSIRO climate data will be drawn upon in order to analyse operational asset vulnerability (section four) and container terminal operations simulation (section five).

4. OPERATIONAL ASSET MAPPING AND SEA-LEVEL RISE MODELING

This section develops a better understanding of different operational asset vulnerabilities to climate events and captures climate events perceived to be of most threat to the continuation of cargo handling between the ship and truck/train. Figure 12 shows the steps in building an operational asset register through to creating a 3D model of the port environment and sea-level rise mapping.



Figure 12 Steps for defining and mapping operational assets

4.1 Defining operational assets

An asset is considered a resource from which economic benefits can be derived. It can be owned by an individual or an organisation. In this research, the definition of an asset is restricted to tangible resources in the context of their role in performing logistics operations in ports. Other assets such as buildings are not included in the operational asset register. The building of an asset register for the port requires a listing of the tangible assets that are owned and operated by the port authority or leased by it to other operators to carry out logistics activities necessary for the trans-shipment of freight. Assets are therefore considered to be those plant, equipment and physical infrastructure facilities that are used for the purpose of generating revenue. However, not all assets are used in purely logistics activities. Some are used to augment logistics activities, provide services or enhance customer convenience.

Port operations may be separated into two categories; those activities that are directly related to the trans-shipment logistics functions and those operations that are not, i.e. those that are ancillary. Furthermore, some port activities are under the ownership, control or oversight of other parties e.g. leased, while some functions are outsourced entirely. These assets do not come under the jurisdiction of the port authority and thus

are not eligible for inclusion in the register of port assets. Operational assets can therefore be defined as core operational assets (COAs) and non-core ancillary assets. Here we are only concerned with core operational assets.

4.2 Identification of core operational assets

COAs are normally identified according to their role in the logistics cycle - whether the activities take place at sea, on land or at the sea-land interface. It is necessary to identify the assets with this distinction, i.e., Sea-side COAs, Land-side COAs or Sea-Land COAs.

In early September 2011, two members of the project team visited Port Kembla and embarked on a two day site tour of the port precinct. During this time a series of field photographs were taken and meetings were held with leaseholders to gain a fuller understanding of the nature and distribution of assets across the port precinct. In addition, a series of schematics, spreadsheets, engineering drawings and oblique aerial photographs were supplied from the Port Kembla authority for reference use within the project. The spreadsheet describing all assets in the Port Kembla precinct was used as the basis for the development of the spatial asset register (described in Section 4.4). The Sydney and Gladstone operational assets were identified in conjunction with the respective projects contact persons in each port.

Assets of most concern to our assessment are those owned by Port Kembla and regarded as core to logistics operations. They are listed below (Table 5) together with their geographic locations and number of units to provide locale specific vulnerabilities to climatic events.

Table 5 Summary of assets

Operational Asset	Logistics Function	Number	Location
Buoys	Navigation/pilotage	5	Sea-side
Pilot boats	Navigation/pilotage	2	Sea-side
Pilot station	Navigation/pilotage	1	Sea-side
Stackers	Cargo transfer	3	Land-side
Rail tracks	Cargo transport	30km	Land-side
Roadways	Cargo transport	5km	Land-side
Leading lights	Navigation/pilotage	5	Sea-Land interface
Communication equipment	Navigation/pilotage	Numerous	Sea-Land interface

Operational Asset	Logistics Function	Number	Location
Breakwater	Navigation/pilotage	2	Sea-Land interface
Berths/terminals	Docking	17	Sea-Land interface
Dolphins	Docking	5	Sea-Land interface
Fenders	Docking	Numerous	Sea-Land interface
Water mains	Services	3km	Sea-Land interface

4.3 Characterisation of core operational assets

The COAs are characterised by their activities at sea, sea-land interface and on the land side. Table 6 shows the different functions used to categorise the COAs.

Operational Area	Functions
Sea	<ul style="list-style-type: none"> • Navigation and pilotage • Docking
Sea-Land	<ul style="list-style-type: none"> • Navigation and pilotage • Docking • Cargo transfer • Cargo transport • Services
Land	<ul style="list-style-type: none"> • Cargo transfer • Cargo transport • Storage • Services

Table 6 Key functions used for categorising the core operational assets

Consequently, sea-side COAs are those used in navigation and pilotage, cargo transport and transfer, and docking. Landside COAs are those used exclusively on land for cargo transport, transfer and storage. Sea-land COAs are those activities that occur when the vessel is berthed and cargo is transported or transferred. Appendix 1 provides a list of the COAs found in each of the three ports categorised using these functions.

4.4 Compilation of an asset register

The asset register is a list of all COAs in use by each port. It was necessary to compile a different asset register for each port given the type of commodity handled by each differs and as such the processes between each asset then also differ.

Compiling the asset register required liaison with representatives within the port environment who, on a day-to-day basis, deal with cargo port operations. Port representatives were asked to place each asset into categories reflecting where the asset is used in the logistics cycle i.e. at the sea, sea-land or land interface; and what each assets core function is i.e. navigation and pilotage, docking, cargo transfer etc. This information was compiled by port representatives using forms prepared by WP2.

Assets in the register are attributed to three sets of characteristics. These include:

- Asset-related attributes (ARA),
- Environment-related attributes (ERA); and,
- Maintenance related attributes (MRA).

Using the asset ID as the unique identifier, these attribute tables were created as a single access database and then transformed into Geographic Information System (GIS) data for the purpose of mapping. As shown in Figure 13, the ARA database has been populated through the direct input from the port authority; whilst values across the fields in the ERA database were assigned to assets by 'intersecting' asset layer with GIS datasets. The MRA database has been designed for the Port Kembla to record maintenance data.

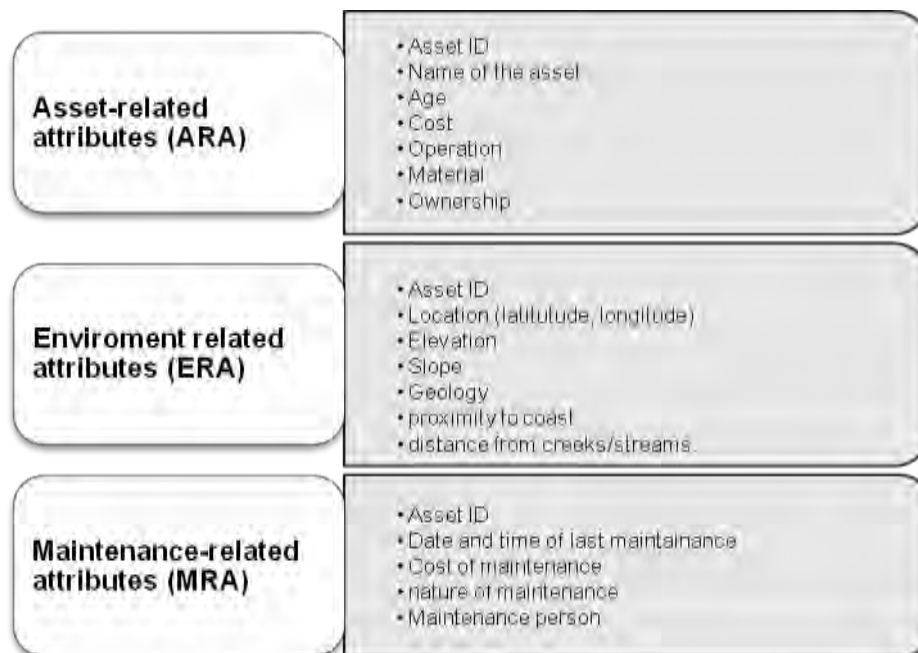


Figure 13 Asset register – relational database structure

4.5 Geo-referencing and asset mapping

A variety of spatial data types were used to prepare the base layers for the mapping. Much of these data required substantial amounts of pre-processing before they could be integrated into the project. The data sources and specifications are summarised below.

4.5.1 LiDAR

Wollongong City Council acquired Light Detection and Ranging (LiDAR) data sets on previous occasions and supplied the existing data for use in this project. Wollongong City Council commissioned AAMHatch to capture airborne laser surveys from a fixed wing aircraft over the Port Kembla project area on the following dates;

- 23rd May 2005
- December 15th and 16th 2005
- 10th January 2007

These data sets were supplied in twenty-nine 2 km² tiles (.las file format) in both classified (ground and non-ground points) and unclassified (full data set points) that formed part of flight swaths. The LiDAR data was supplied in a Transverse Mercator projection with a 1994 Geocentric Datum of Australia 1994 Map Grid of Australia (Zone 56) projected coordinate system. The height datum of these data sets was that of the Australian Height Datum using the Ausgeoid 98 Geoid Model. AAMHatch documented an expected accuracy within the LiDAR data sets of <0.40m in the horizontal and 0.15m in the vertical.

To transform the supplied classified LiDAR data into a GIS-ready format, the initial LiDAR points were first converted from a .las file format to a .txt file format. The .txt files were then split into smaller record numbers (to enable easy transfer of data between software types) and saved as separate .txt files. The reduced .txt files were then imported into separate Microsoft Excel spreadsheets and saved as .xlsx files that were subsequently imported into ArcGIS and displayed via the x and y coordinates function and exported into ESRI shapefile (.shp) format. Once all of the shapefiles had been created, each was then merged to form a single geodatabase (.gdb) and clipped to a buffered Port Precinct layer to reduce the overall file size. The same process was repeated to transform the unclassified LiDAR data into a GIS-ready format.

The classified LiDAR geodatabase was then used to generate a Digital Elevation Model (DEM) dataset (.gdb format) using the points to raster conversion function. The resolution of the DEM was set at 0.5m with a 'most frequent' cell assignment type used to output the average height value for each 0.5m cell. The unclassified LiDAR geodatabase file was used to generate a Digital Surface Model (DSM) dataset in ArcGIS .gdb format using the points to raster conversion function. The resolution of the DSM was set at 0.5m with a 'most frequent' cell assignment type used to output the average height value for each 0.5m cell. The DEM was then subtracted from the DSM using the raster calculator function to create a feature heights dataset in ArcGIS geodatabase format. Using the DEM dataset, algorithms within ESRI's ArcGIS Spatial

Analyst toolbox were implemented to create a slope dataset in ArcGIS .gdb format. All derived datasets were generated in a Transverse Mercator projection with a 1994 Geocentric Datum of Australia 1994 Map Grid of Australia (Zone 56) projected coordinate system. The height datum of these data sets was that of the Australian Height Datum using the Ausgeoid 98 Geoid Model.

4.5.2 Aerial imagery

Orthophotography sourced from Wollongong City Council was originally acquired by AAMHatch from aerial photography surveys captured from a fixed wing aircraft over the Port Kembla project area between May and December of 2009. These data sets were supplied in fifty-seven 8-bit colour 1km x 1km tiles in .tiff and .ecw formats with a pixel resolution of 0.1m (10cm). All of the Aerial imagery data was supplied in a Transverse Mercator projection with a 1994 Geocentric Datum of Australia 1994 Map Grid of Australia (Zone 56) projected coordinate system. The height datum of these data sets was that of the Australian Height Datum using the Ausgeoid 98 Geoid Model. AAMHatch documented an expected accuracy within the Aerial imagery data sets of 0.25m in the horizontal and 0.25m in the vertical.

All of the supplied aerial imagery .ecw tiles were merged into a single geodatabase (.gdb) (at maximum 10cm resolution) and then clipped the output to a buffered Port Precinct layer to reduce the file size and coincide with the clipped LiDAR products. The 10cm resolution product was also re-sampled to create a 50cm resolution dataset for efficient viewing and computation in a 3D environment. The 50cm re-sampled product was also clipped to the buffered Port Precinct extent for consistency and to keep project file sizes to a minimum.

A coastline was generated using the 1st July 2011 New South Wales State boundary, which was sourced from the Australian Bureau of Statistics as a reference. The original state boundary data set was set in a Geocentric Datum of Australia 1994 datum and with a geographical latitudes and longitudes projection. Small modifications to the base data set were needed in some areas within the port precinct (such as jetties and new land developments) as they had not been captured. These updates were digitized and merged manually into the base data set using the 10cm aerial imagery as a reference point. The mapping of COAs reflects the location of their use and once again follows their logistics function.

Using the 10cm aerial imagery, asset footprints were manually digitized into a GIS layer using features visible from the imagery. This digitised layer was used as a spatial base layer from which to develop a spatial association with the asset register (Figure 14).

4.5.3 3D visualisation of port assets

In addition to the map in Figure 14, a 3D model was developed showing various port precinct features (Figure 15). The model provides an additional perspective on the port's assets in terms of height and shape. In addition to this, the model can be a useful means of communicating outcomes of our vulnerability assessment to stakeholders as they are able to view the outcomes in relation to assets that are closely representative of how the asset looks on the ground.

The model was developed using a combination of Google SketchUp Pro, field photographs, drawings and oblique aerial photographs supplied by Port Kembla. Google SketchUp Pro was implemented to create a 3D environment in combination with Google Earth as a base imagery layer. Within Google SketchUp Pro, 3D features using building tools within the software package were manually drawn. The integration of freely available models from Google's 3D Warehouse allowed for the 3D environment to be populated with common features such as trees, cars, boats and containers. The ad-hoc design of many of the cranes and buildings within the port precinct area necessitated the manual generation for more complex features.

The Google SketchUp 3D models were exported as .dae Collada files, and then imported into ArcGIS as geodatabase files, allowing for other datasets to be used in conjunction with the 3D models e.g. the high resolution DEM and 10cm aerial imagery. The height of the individual 3D model features were modified to relate to schematic heights (if available) from drawings supplied by Port Kembla. In absence of any schematic drawings the feature heights dataset was implemented. By using the feature heights data set, the 3D models in Google SketchUp Pro were scaled up to the approximate height of the tallest features for the corresponding feature. The placement of the 3D features on the high resolution aerial imagery improved the horizontal accuracy whilst the use of the LiDAR derived DEM improved the vertical accuracy. ArcScene was used to generate the final fly-throughs as a 3D visualization by using the LiDAR derived DEM, the high resolution aerial imagery and the 3D models draped over the top.



Legend

Asset Register - This is displayed by random colours as there are too many attributes to symbolise



Figure 14 Map of assets at Port Kembla



Figure 15 3D rendered visualisation of port assets

4.6 Sea-level rise modelling

For the modelling of potential climate change impacts, the choice to mainly focus on sea-level rise was decided by the availability of data for climate impact modelling. IPCC high-carbon emission sea-level rise scenario (A1F1) has been used to model the levels of sea rise in Port Kembla. The A1F1 is a higher-emission scenario that gives a greater emphasis on the intensive use of fossil-fuels and represents a future with fossil fuel-intensive economic growth and a global population that peaks mid-century and then declines. For the purpose of a comparison, adjusted projections of sea-level rise are provided in Table 7 to show the difference between two different scenarios – A1F1 and B1.

Figure 16 shows the location of the berths at Port Kembla and the areas of greater risk of inundation under three time projections, using the A1F1 scenario. The red colour on the map depicts areas that are at a greater risk of inundation. The provisional modelling outputs for a sea-level rise scenario were reviewed, adjusted and revised based on field work and through consultation with experts in the Port Kembla.

As spatial data relating to high-speed winds and storm surge was not available to WP2 during the time of this analysis and sea-level rise data was, this information was used in the primary analysis of inundation. This research activity, even with only one climate event scenario, therefore demonstrates the application of a geovisualisation methodology for assessing asset vulnerability, using sea-level rise as the climate impact of concern.

A series of screenshots were captured from the three-dimensional movies which track across the port precinct. These screenshots were generated at 2010 (normal conditions) and at 2100 (High Tide + Sea-level Rise) scenarios visualising vulnerability to sea-level rise as shown in Figure 17. Within the three-dimensional movies the inundated areas are visualised using a transparent red/maroon colour.

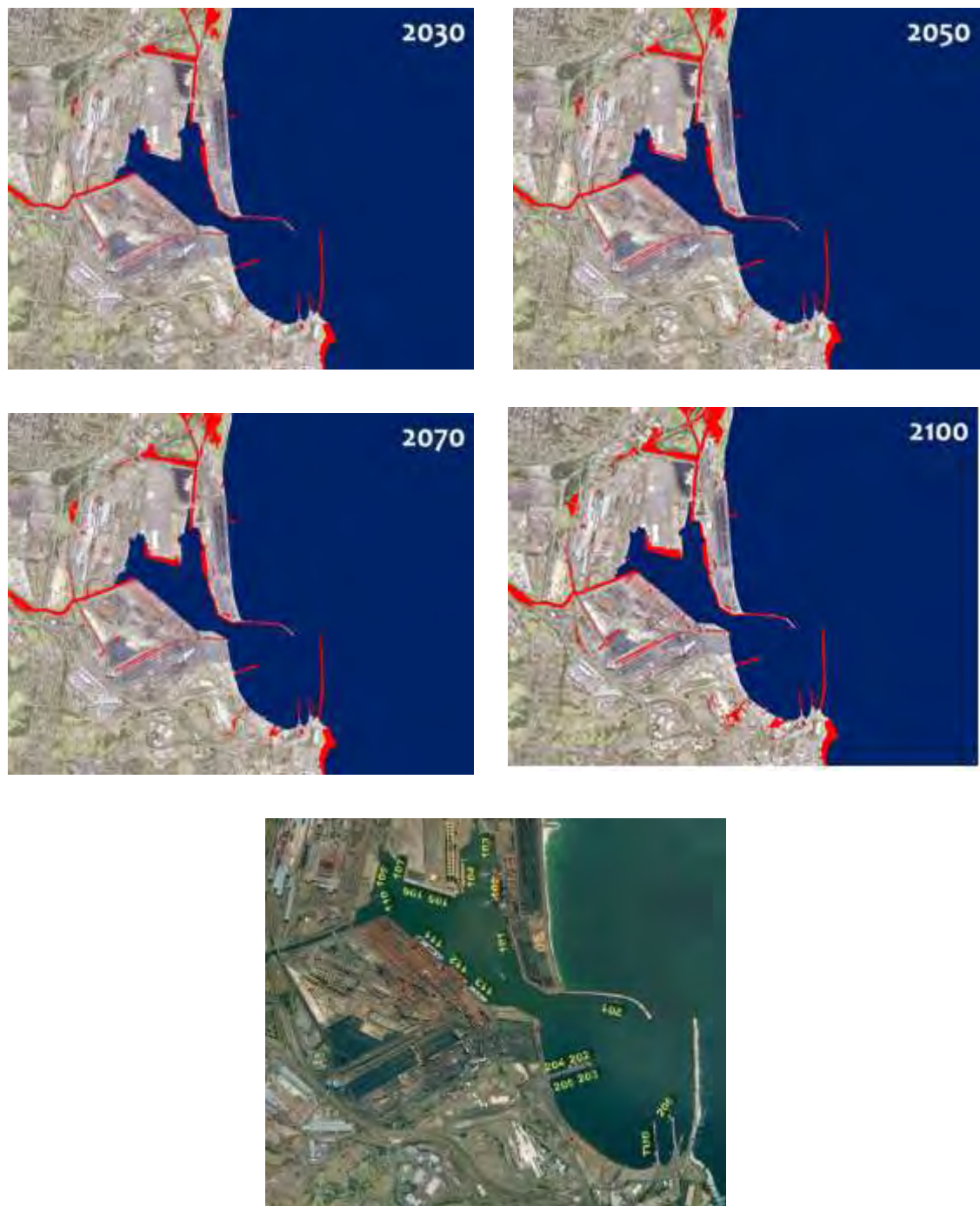
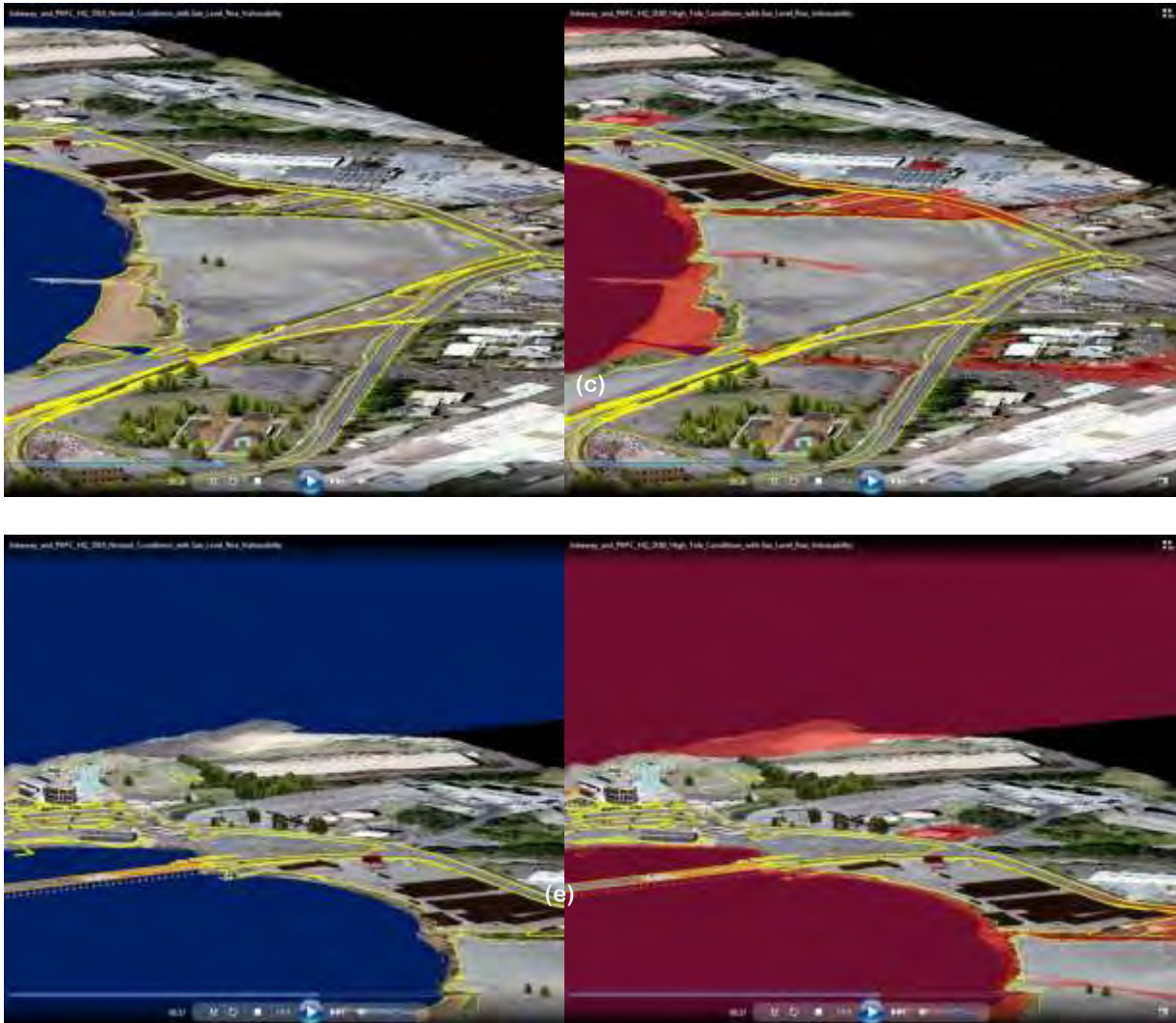


Figure 16 The likely impact of sea-level rise on the Port Kembla Port precinct. The red colour on the map depicts areas that are at a greater risk of inundation under the IPCC high carbon emission sea-level rise scenario (A1F1). These are provisional modelling outputs for a sea-level rise scenario that will be reviewed and revised based on field work and through consultation with experts in the Port Kembla.

2010 Normal Conditions

2100 High Tide Conditions



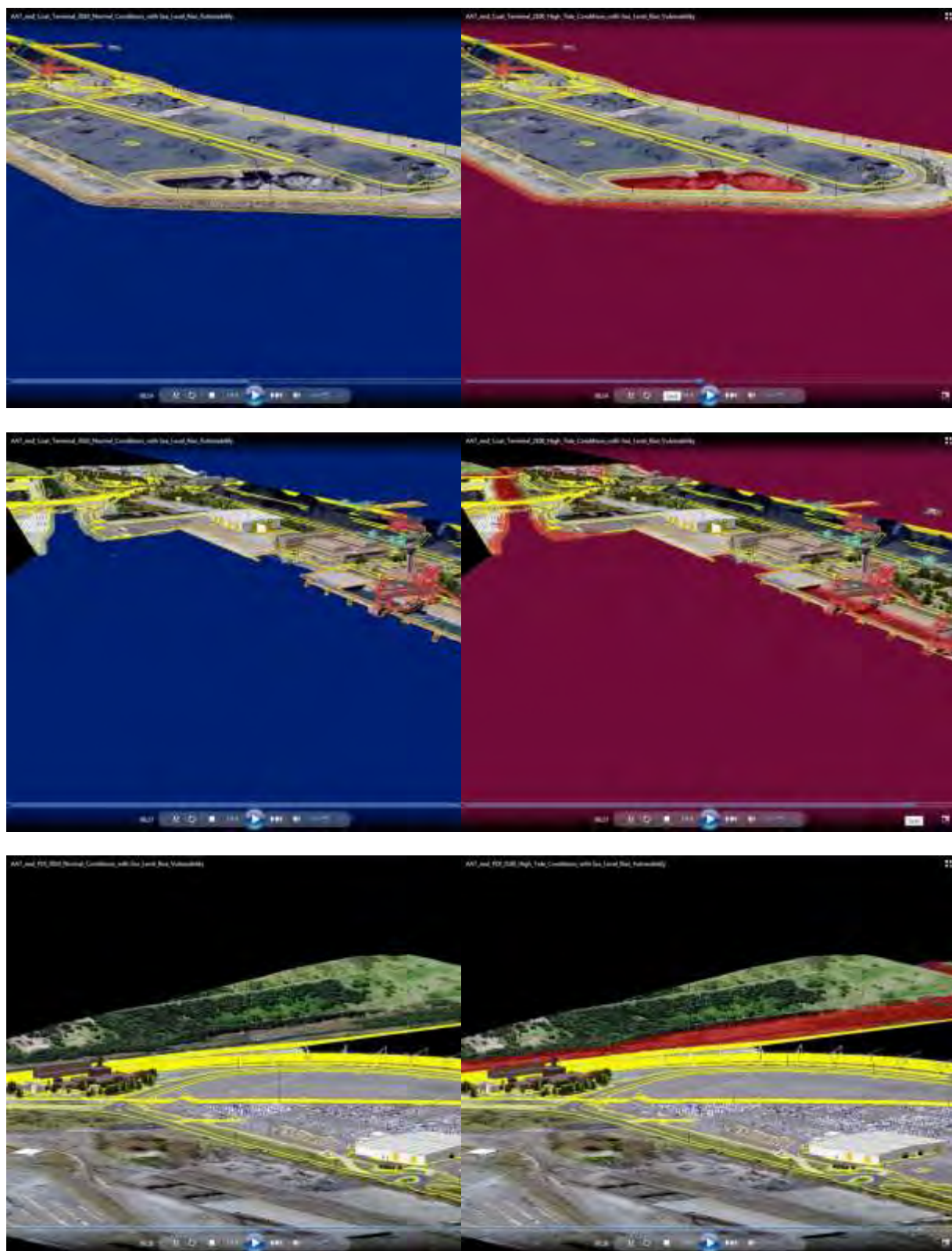


Figure 17 Modelled sea-level rise over 3D visualisation of Port Kembla (for the A1FI Scenario)

As the analysis explored and visualised the likely impact of sea-level rise on the port precinct as well as on operational assets using the estimates of the maximum sea-level rise projections (mm) from CSIRO, only the A1FI for high emission scenario was used. The time horizon appropriate for assessing the likely impacts on port assets and operations is 20 years of business cycle, which included time-intervals of 2030, 2050, 2070 and 2100. However, the maximum sea-level rise estimated for A1F1 and B1 by CSIRO for 2050 is 278 mm and 227mm respectively (Table 7). A maximum rise of 400mm relative to 1990 sea levels by 2050 is projected for NSW coast by the Natural Hazards Profile, Sydney/Central Coast Region, NSW Govt (p.12). The local configuration of coastal geomorphology however has not been considered in the CSIRO sea-level rise projections so a uniform rise in projected sea-level was applied without any attempt to capture the local variability of coast. Table 7 shows the adjusted projections of sea-level (mm) for 95-percentile maxima, derived by adjusting the TAR projections to correspond to the AR4 projections at 2095.

Year	A1FI	B1 (low emission scenario)
	(high emission scenario)	
2030	146	132
2050	278	227
2070	471	333
2100	819	496

Table 7 Adjusted projections of sea-level (mm) for 95-percentile maxima

4.6.1 Adjustments to determine the base sea level

It was necessary to adjust the LiDAR digital elevation model (DEM) captured at the Australian Height Datum (AHD) to conform to the Port Kembla Height datum (PKHD), which is categorised as the lowest astronomical tide mark (LAT). Adjustment in the DEM required undertaking the following two computational tasks. The first was to identify a set of control points between the LiDAR data (using the 10cm aerial imagery overlay for reference) and schematic drawings sourced from the Port Kembla. These control points represent known locations that exist in both data sources where the height above sea level has been surveyed. This was necessary because the aerial imagery and the LiDAR data were captured at different points in time and as such the state of tide cannot be accurately determined.

Using a Neil Charters Pty Ltd Survey and Design Services/Waterway Constructions Pty Ltd survey drawing of Port Kembla's Inner Harbour Berth 105 East (as of 29th October 2008), a small area of 10.64m² that had not been modified since the LiDAR capture and that had Port Kembla Height datum measurements on the drawing over the same area was identified. From the schematic drawing five measurements in PKHD over the control point area were identified. The mean height of this area was +2.9624m PKHD, (minimum height +2.939m PKHD, maximum height +2.981m PKHD with a standard deviation of 0.018m).

The second task, using the location of the control points and overlaying the DEM, was to select a total of fifty cells. The mean height of these cells was +2.229096m AHD, the minimum height value was +2.14164m AHD, the maximum height value was +2.29096m AHD with a standard deviation of 0.03m. Next, by subtracting the PKHD mean height value from the AHD mean height value, the height of LiDAR DEM was ascertained to be +0.1387 higher than the PKHD mean value. Therefore the LiDAR DEM was adjusted by -0.1387 to align with the PKHD at a 2010 level. In order to identify the indicative sea level climate change prediction at year 2100 for example, a further addition of 0.759m (for the A1F1 scenario) was added to the adjusted LiDAR value along with an additional highest astronomical tide value of +2.1m to equate to the maximum sea level height of 2.859m above current conditions. [PK1] However, it must be noted that the level of inaccuracy of the LiDAR dataset could be at +/- 0.075m due to LiDAR capture accuracies.

4.7 Summary

This section reported the development of a comprehensive methodology to produce an asset register and to create 2D and 3D models of port assets. An asset register was created to store the repository of data that identifies and physically describes the assets. Port assets were classified into sea, land and sea-land interface and critical asset related data was gathered from relevant port authorities. The register was also structured to store maintenance and utilisation related records to assist in asset valuation, asset life cycle and performance assessment.

The mapping of core operational assets used both LiDAR data and aerial imagery. In addition, 3D visualisation of port assets was developed using a combination of Google SketchUp 3D models, field photographs, drawings and oblique aerial photographs. The development of comprehensive strategic asset management plans is recommended to Port Kembla port authority. The GIS-based spatial methodology developed for the Port Kembla case study provides innovative visualisation capability for better understanding the vulnerability of port assets to particular climate change events, in this case, sea-level rise.

The outputs of sea-level rise modelling show that the impact of the 'A1FI high carbon emission scenario' for Port Kembla Port Corporation would probably be low to moderate, resulting in minor inundation and some impacts on some assets.

However it is important to note that the visualization adopted here can be an effective tool in identifying and communicating the possible impact on port assets and related business processes. For instance, comparing the projections for 2050 with the current

allocation of berths (Figure 16) indicates an inundation risk on berths 105 – 107 operated by Australian Amalgamated Terminals (AAT), used mainly for vehicle imports, and berths 101 -102 operated by the Port Kembla Coal Terminal (PKCT) for handling coal and bulk cargo. With coal and coke making up 72% of the exports and vehicles making up 28% of the imports in 2010/11 (see Table 1), any risk of inundation for the above berths could have a major impact on the port's operations. While the inundation demarcations are not precise, any impact on the berth front will render fixed assets such as cranes and coal loaders unusable.

The results presented here for sea-level rise projections are largely data-driven and are therefore subject to error. For example, errors could be associated with data capturing process (airborne laser surveys), data spatial resolution, re-classification, and data conversion (i.e. from the classified LiDAR geodatabase to a DEM dataset using the points to raster conversion function). Therefore, further verification at the asset level will be required. For instance, some jetties and berths (e.g. berths 201 - 205) are incorrectly shown to be inundated. Reasons for this could be that the infrastructure was not built or could not be detected at the time the LiDAR imagery was captured.

This section has provided a preliminary modelling output of the impact of sea-level rise based on the IPCC high emissions scenario. The model and simulation created for this study can also be applied to other Australian ports.

5. MAPPING PERCEIVED ASSET VULNERABILITY AND A CROSS CASE COMPARISON

This section evaluates the perception of vulnerability of port's assets as reflected upon by port experts using Port Kembla Port Corporation as a case study. This section specifically aims to answer: 'What are the key vulnerabilities of port functional assets and to which climatic variables?'

There are numerous methods documented for how to assess the vulnerability of coastal assets to climate change and weather impacts. Ramieri *et al.* (2011) and Abuodha and Woodroffe (2006) describe several of these methods including index-based methods, indicator-based approaches, GIS-based decision support systems, and methods based on dynamic computer models. In this study each port rated how vulnerable each core operational asset, crucial to their cargo handling processes, was to the climate variables of most concern, i.e. data collected was on the "perceived vulnerability" by the port experts related. This involved the key port operational representatives compiling an asset register for each of the seaport logistic interfaces – sea, sea-land, and land – and then rating each asset on a vulnerability rating scale developed in consultation with port operation managers.

Many ports around the world are taking the initiative in commissioning risk assessment and adaptation studies to help ascertain localised risks and adaptation capacity. Terminal Marítimo Muelles El Bosque in Columbia (Stanek *et al.*, 2011), PD Teesport in the United Kingdom (Haskoning UK Ltd, 2011), and Port Kembla in Australia (AECOM Australia, 2010) are examples of this. Generally, assessment methods use data collected directly from key stakeholder groups and future climate information. The International Association of Ports and Harbors (IAPH, 2011) have released guidelines for planning adaptation measures against future climate changes for the ports community. These guidelines provide aspects that need to be considered when conducting sensitivity and adaptive capacity analyses as part of a vulnerability assessment (IAPH, 2011:16). The aspects of the IAPH guidelines used in this study were listed earlier in figure 11.

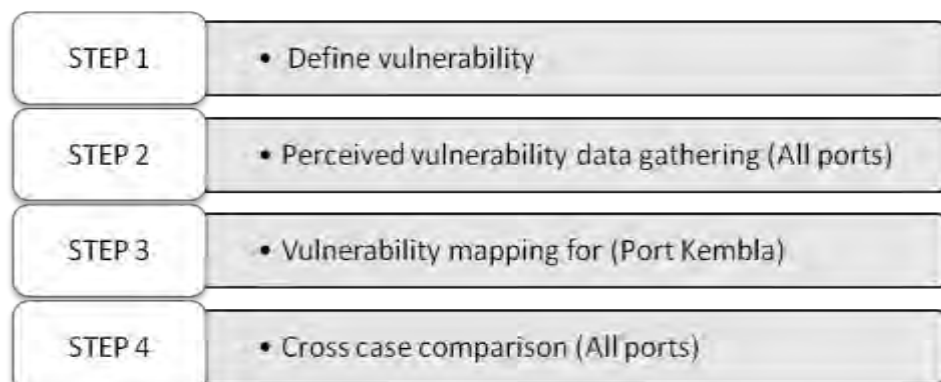


Figure 18 Vulnerability mapping and cross-case comparison

The December 2011 interim report for this work package, as part of the *Enhancing the resilience of seaports to a changing climate* project, proposed a framework for assessing vulnerability. It involved the use of GIS spatial analysis in assessing vulnerability but because of the unavailability of GIS data for the Port of Gladstone and the commercially confidential identity of the terminal operator at the Port of Sydney, the framework was revised to focus on vulnerability assessments that come from the working knowledge and perceptions of port authority experts. The method for assessing vulnerability presented in Figure 18, is outlined below.

5.1 Defining vulnerability

The Intergovernmental Panel on Climate Change (IPCC) have defined vulnerability as:

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

This may be expressed by the following formula:

$$\text{Vulnerability} = \text{Exposure} \times \text{Sensitivity} / \text{Adaptive Capacity}$$

Exposure refers to a system being subject to the experience of climate stressors such as changes in patterns, increase or decrease in averages and changes in frequency of extreme events. Sensitivity is the responsiveness of a system to climate stressors where it is often assumed that the higher the sensitivity the larger the rate or magnitude of an adverse response to a stressor, and adaptive capacity refers to a systems ability to change in a way that makes it better equipped to manage its exposure and sensitivity was well as the ability to respond to existing impacts.

For the purposes of this study the IPCC definition is interpreted as:

The degree to which operational processes during berthing, loading and unloading at the sea, sea-land and land logistical interfaces are susceptible to climatic extremes. Vulnerability is a function of the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity

5.2 Vulnerability ratings

Since vulnerability is the combination of exposure, sensitivity and adaptive capacity, climate impact assessment matrices were designed to gauge the exposure and sensitivity of operational assets to climate variables at the sea, sea-land and land interface (see Appendix 1). Operational assets that were rated as having a high level of sensitivity were investigated further to assess the capacity of operational processes to adapt during and after impact caused by a climate variable/s. The assessment concluded that once assets are inoperable due to climate impacts, the adaptive capacity of the cargo handling system (unloading/loading between ship and truck/train) to continue operations is zero. Since vulnerability is now seen as primarily an expression of exposure and sensitivity the matrices are referred to as “vulnerability ratings”.

Vulnerability ratings rank the perceived magnitude of impact port assets are likely to experience, given exposure to the most threatening climate variables. The performance of each asset was rated according to productivity changes that may occur during a climate event. Ratings were allocated by port representatives who were able to derive the basis of each rating from various sources including logged records, reports, personal experience or the experience of others. In the ratings, illustrated in Table 8, scaled from 1 to 5, 1 means 'not at all vulnerable' while 5 means 'operation ceased (operation down for weeks or more)'. The data collected on climate impact assessment matrix across all case study ports are provided as appendices (see Appendix 1 through to 4).

Vulnerability surveys, customised for port asset registers, were emailed to each port and ratings collected. The left column of the vulnerability matrix consisted of a list of all assets identified by the port and categorised according to which logistic interface the asset was used (i.e. sea, sea-land or land) and the asset's core function. The climate events of most concern, as identified by port authorities in discussion, were listed along the top of the matrix. The matrix was sent to port representatives in an editable file so that additional assets or climate variables could be added to the matrix axes if need.

Vulnerability rating	Rating description
1	Not at all vulnerable
2	Somewhat vulnerable
3	Moderately vulnerable (Operation down for hours)
4	Significantly vulnerable (Operation down for days)
5	Operation ceased (Operational down for weeks or more)

Table 8 Rating scale for asset vulnerability to climate variables

5.3 Data collection

The assessment of which assets are at risk to climate variables and the degree of their vulnerability required the identification of core operational assets and the key climate variables which were of most concern to each port. It also required an assessment of how these variables impacted upon the productivity rate of normally functioning assets. Furthermore, in order to understand the potential impacts of climate change on operational processes, we also needed to gather projected climate information of most concern to each port and relevant to each ports geographic location. In response to this, the following steps were used in collecting the data required:

- Compilation of an asset register for each port
- Obtain vulnerability ratings for each asset against climate variables considered a threat to the area
- Collect climate information for all three regions on future projected climate changes.

5.4 Mapping the vulnerability of assets

The asset vulnerability maps (Figure 19, Figure 20, Figure 21) were created using GIS-based data collected and processed as a component of chapter four. Data used to create the maps includes the asset register compiled as part of this research and the vulnerability ratings allocated by port authorities in Table 8. Note that all the following figures depict ratings of vulnerability based on assessments obtained from port authorities. Figure 19 maps the assets in the port precinct perceived to be “moderately vulnerable” (rating of 3) and “significantly vulnerable” (rating of 4) to high speed winds, as listed in Table 8. Figure 20 depicts the assets perceived to be “moderately vulnerable” and “significantly vulnerable” (rated 4) to Storm Surge (SS) and similarly Figure 21 depicts these vulnerabilities for High Speed Winds (HSW), which out of the seven climatic events considered in Table 9 has yielded a rating of 4 out of 6 in Figure 21. In other words, Figure 19, Figure 20, Figure 21 show the most vulnerable assets as perceived by PK to the climatic events under consideration.

The most vulnerable assets to storm surge are the breakwaters, specifically Northern and Eastern breakwaters marked as “significantly vulnerable” (rated 4). Figure 22 shows berth 201, used by Port Kembla for bulk liquid handling, where the berth itself is rated as “significantly vulnerable” (rated 4) to high speed winds, located off the Northern breakwater. As can be seen in Figure 23, any vulnerability due to a storm surge on the Northern breakwater makes the Port Kembla Coal Terminal vulnerable, which is positioned less than 100m from the breakwater. Figure 21 summarises the maximum vulnerability rating allocated to assets by Port Authorities for each climate variable. Only ratings of 3 and above are shown. No asset was allocated a rating of 5 (high vulnerability where operations would cease). In general the vulnerability of breakwaters on the outer harbour poses a risk to the port operations in the inner harbour berths. For example, Berths 101 – 110 in the inner harbour operated by BlueScope steel, Australian Amalgamated Terminals, Port Kembla Coal Terminal and The Port Kembla Grain Terminal are marked as “significantly vulnerable” to high speed winds. The yard cranes operating on the BlueScope steel terminal where berths 109 and 110 are located are also perceived to be “significantly vulnerable” to high-speed winds. The aforementioned terminals handle the majority of the cargo handled through Port Kembla (i.e. coal/coke, steel, motor vehicles and grain) leading to significant risk to port operations due to high-speed wind.



Figure 19 Port Kembla operational asset vulnerability to high speed winds



Legend

Vulnerability to Storm Surge Index	
 1 - Not at all vulnerable	 3 - Moderately vulnerable (Operation down for hours)
 2 - Somewhat vulnerable	 4 - Significantly vulnerable (Operation down for days)
	 5 - Operation ceased (Operation down for weeks or more)



Figure 20 Port Kembla operational asset vulnerability to storm surge

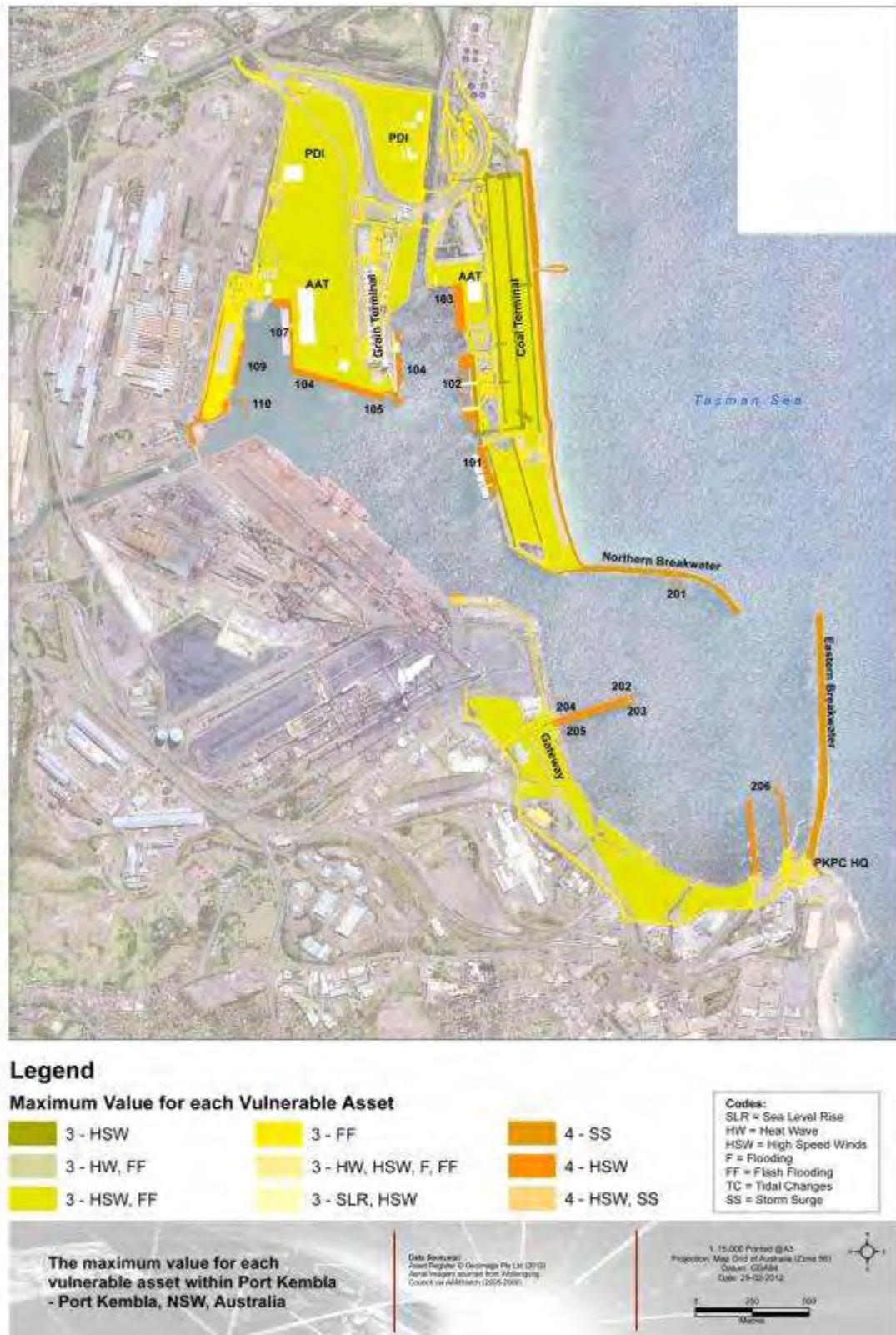


Figure 21 Maximum vulnerability rating of assets for each climate variable.



Figure 22 Berth 201 and the Northern Breakwater (significantly vulnerable to high-speed winds)



Figure 23 Port Kembla Coal Terminal (significantly vulnerable to storm surge by proximity to Northern Breakwater)

5.5 Cross case analysis

The analysis was undertaken to investigate which climate variables were perceived as most concern to each port and which assets were under greatest threat. Comparisons were made between the ports and commonalities and differences identified. The analysis also set the basis for discussion on climate impacts at the sea, sea-land and land interfaces using a visualisation method as a tool for comparing patterns, similarities and differences between the ports, climate variables and levels of vulnerability.

To assess climate variables that are of greatest concern to each port, climate variables were ranked from most to least concern. A score was allocated to each climate variable for each port where a higher score meant greater concern. Overall scores were calculated by summing ratings 2 to 5 because a rating of 1 represented assets that are not at all vulnerable to climate impacts. Since the analysis is concerned only with assets that are sensitive to climate variables scores of 1 were excluded.

The most commonly occurring level of vulnerability (mode) for each climate variable was also provided to clarify that although a climate variable has been identified as a high concern for a port, it does not mean that this climate variable is a high threat to every asset. In some cases, a high rating was given to only a few assets whereas all other assets were rated as 'not at all' vulnerable. This is the case at Gladstone where boats, helicopters and GPS navigation aids were all rated as being significantly vulnerable however all other assets are 'not at all' vulnerable. The analysis for the sea, sea-land, and land) interfaces at each port was completed with graphs used to visualise the highest allocated vulnerability rating for each climate variable and the mode. Discussion included similarities and differences between the ports, their three interfaces and between climate variables. Each of the three case study ports was studied individually to reach a conclusion, having cross comparisons discussing the implications of future climate projections on the ports.

5.5.1 Gladstone Port Corporation

5.5.1.1 Climate variables of most concern

The most highly rated climate threat to Gladstone was severe tropical cyclone which affects operational assets at all three logistic interfaces (sea, sea-land and land) with a significantly high vulnerability level. Following on from cyclones, climate variables of most to least concern were fog, storm surge, high speed winds, flash floods, floods / heat wave, tidal changes and sea-level rise (Figure 24). Storm surge, high speed winds and flash floods were the only other climate variables perceived to be of significant threat and to only a few assets. Sea-level rise was not perceived as being a threat to any asset listed.

MOST CONCERN		MOST COMMON OCCURRING LEVEL OF VULNERABILITY (MODE)	
SEVERE TROPICAL CYCLONE	⇒	Significant	
FOG	⇒	Moderate	
STORM SURGE (WAVE)	⇒	Moderate	
HIGH WIND SPEEDS	⇒	Somewhat	
FLASH FLOODS	⇒	Somewhat	
FLOODS (streams and creeks) / HEAT WAVE	⇒	Somewhat	
TIDAL CHANGES	⇒	Somewhat	
SEA-LEVEL RISE	⇒	Not at all	
LESSER CONCERN			

Figure 24 Gladstone Ports; Climate variables of most concern

5.5.1.2 Assets of most concern

At sea, all assets were ranked as being significantly vulnerable to severe tropical cyclones. Boats, helicopters and GPS base station pilot navigation aids were ranked as being significantly vulnerable to high speed winds and automatic gauges were perceived as being significantly vulnerable to storm surge.

Similarly, at the sea-land interface, severe tropical cyclones have a high impact on operational assets used within the Navigation and Pilotage function which includes mainly leading lights. Fog was also a problem for these assets. All other climate variables were not a concern. At the Docking function within the sea-land interface, severe tropical cyclones were seen as a problem for swing mooring buoys at the marina as well as mooring piles at Auckland Creek. Storm surge was a moderate threat at the Auckland Point docking terminal at all berths.

On land, severe tropical cyclones were also perceived as being of most threat to assets, particularly at Auckland Point where the gantry loader was allocated a rating of “5” meaning operation would cease for weeks or more after impact. The gantry loader at Auckland Point was also rated as being moderately vulnerable to both high speed winds and storm surge. We explored whether alternative machinery or processes can be used while a gantry loader is inoperable to minimise productivity loss and the response was “No”. Auckland Point’s No. 4 wharf and the adjacent Gladstone Container Terminal are used to handle all containerised and general cargoes (Gladstone Ports Corporation, 2011).

The gantry loader at the RG Tanna coal terminal was also ranked highly as “significantly vulnerable” to severe tropical cyclones and moderately vulnerable to high speed winds.

Cargo transport and storage were rated as moderately vulnerable to storm surge and floods.

5.5.2 Port Kembla Port Corporation

5.5.2.1 Climate variables of most concern

Figure 25 shows that high-speed winds were identified as the climate variable of most concern at Port Kembla scoring around 40 per cent higher than flash floods which rated second. Storm surge, tidal changes and heat wave were rated closely. Stream flooding was not perceived as being a large threat to operations with flooding the only variable not to be rated above 2. For the majority of variables, the highest rating allocated which occurred most often was 2 (somewhat vulnerable). This was the case for high speed winds however the frequency of a “2” rating exceeded that of a 3 or 4 by only one count – almost half of the assets were identified as being either moderately (rate of 3) or significantly vulnerable (rate of 4) to high speed winds. A rating of 4 (significantly vulnerable) was the most common occurring rating for storm surge.

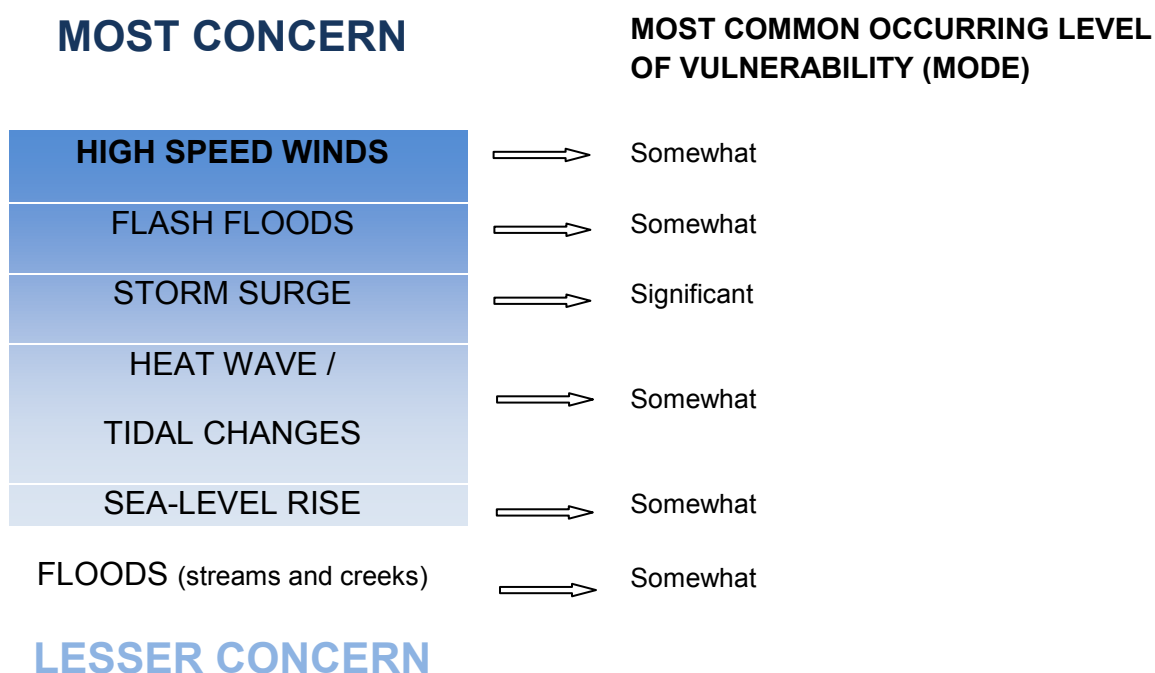


Figure 25 Port Kembla; Climate variables of most concern

5.5.2.2 Assets of most concern

Assets of most concern at sea were cargo vessels/ships which were significantly vulnerable to high speed winds and storm surge. At the sea-land interface, there were a greater number of assets used to carry out processes thus the high speed winds and storm surge were perceived as having the greatest impact at the sea-land interface with ships' cranes rated as being significantly vulnerable from both variables. Leading lights, communication equipment and the breakwater were deemed as significantly vulnerable to storm surge and berths, shore cranes and grab unloaders to high speed winds. Sea-level rise was seen as a moderate threat to shore cranes, grab unloaders, grain loaders and coal loaders.

On land, the most vulnerable assets are yard cranes and hoppers which were rated as being significantly vulnerable to high speed winds. Rail tracks, trucks, roadways and storage areas are rated as being moderately vulnerable to flash floods.

5.5.3 Sydney Ports Corporation

5.5.3.1 Climate variables of most concern

As shown in Figure 26, climate variables of concern for Sydney were closely rated. Flash floods were perceived as being of most concern followed by heat wave, storm surge and high speed winds. Floods and sea-level rise were perceived as being equally threatening but of lesser concern. The most commonly occurring rating for all climate variables is somewhat vulnerable. Very few assets were allocated a rating of 1 – not at all vulnerable.

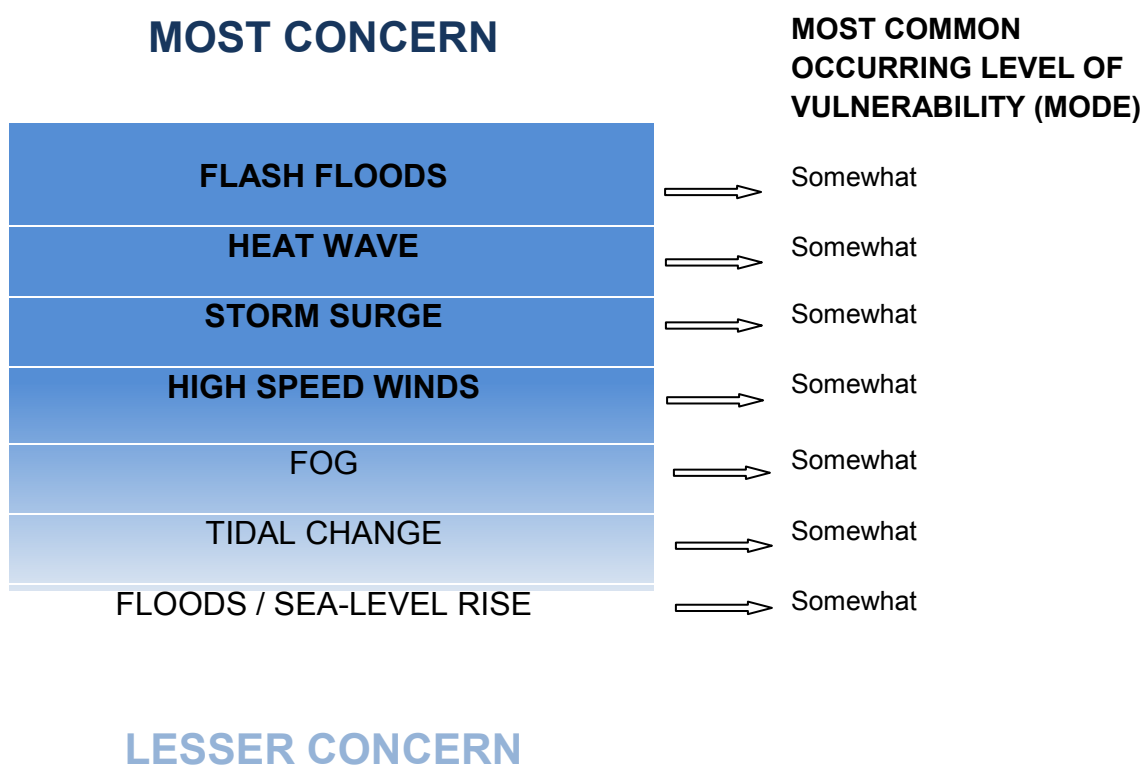


Figure 26 Sydney Ports; Climate variables of most concern

At the sea interface, each of the core functions (navigation and pilotage, docking, and channel transit) were perceived to be of equal threat to every climatic variable listed with the level of vulnerability being 'somewhat'. All assets were impacted by each climate variable with the same level of threat.

At the sea-land interface (and comparable to the sea interface), climatic events were perceived as being somewhat of a threat to almost all assets; particularly those used during navigation and pilotage, and docking. Storm surge, tidal changes, flash floods and floods were perceived as having an impact on all assets at the sea-land interface in the same way with varying levels of vulnerability. For example, multi-trailers (roll trailers) were moderately vulnerable to all four climate variables, however mooring bitts were perceived as at lesser threat (somewhat vulnerable) to the same four climate variables. Similarly, high speed winds and heat wave are perceived as having an impact on all assets in a similar way, with shore cranes being the exception (high speed winds are perceived as having a greater effect on shore cranes than a heat wave). Sea-level rise and fog were also perceived as having impact on all assets used at the sea-land interface in a similar way, with multi-trailers, shore cranes and power supply being the exception. The most commonly perceived level of vulnerability at the sea-land interface is somewhat vulnerable (a rating of 2) followed by moderately vulnerable (rating of 3). High speed winds were of most concern at the sea-land interface.

The highest concentration of significantly vulnerable assets to the climate occurred at the land interface. Storm surge, tidal changes, flash floods and heat wave all impact on assets significantly (assets vary). Three of the eight assets used at the land interface can be inoperable for days when effected by storm surge and flash flood climate events. Fog impacts on all assets at the land interface with the same level of threat – moderately vulnerable. Somewhat vulnerable is the most commonly occurring vulnerability rating on land.

5.5.3.2 Assets of most concern

At sea, all assets were perceived to be at equal threat to all climate variables listed with every asset being allocated a rating of somewhat vulnerable.

The asset of most concern at the sea-land interface was shore cranes which is the primary asset used for cargo transfer. Shore cranes were perceived as being vulnerable to storm surge, tidal change and flash floods – significantly. Shore cranes were also perceived as being moderately vulnerable to fog and heat wave, and somewhat vulnerable to sea-level rise. Multi-trailers (roll trailers), which are used to transport cargo, were perceived as being moderately vulnerable to all climate variables but sea-level rise. Most of the assets used for navigation and pilotage as well as docking have been allocated a vulnerability rating of somewhat.

On land, assets of most concern include yard cranes (significantly vulnerable to storm surge, tidal changes and flash floods), rail tracks (significantly vulnerable to storm surge, flash floods and heatwave) and roadways (significantly vulnerable to storm surge). All assets used at the land interface were moderate to significantly vulnerable to flash floods and high speed winds, moderately vulnerable to fog, and significantly vulnerable to tidal changes.

5.5.4 Overall comparison

Table 9 shows the climate variables of concern to the study ports. This is followed by an assessment of the vulnerabilities at each of the three interfaces. Figure 27 shows the highest vulnerability rating allocated by the respective port for each climate event; graphically depicting how the impact of climate events compares across each of the three ports, at each of the three logistic interfaces. Given that each of the study ports are functionally different to one another in regards to utilising different assets for cargo handling processes, comparisons are focussed on the three logistic interfaces i.e. sea, sea-land and land.

For container movement between the ship and on-land freight transport, high speed winds and flash floods are common concerns. All other climate variables, excluding sea-level rise and fog, are perceived as threats at one of the logistic interfaces but are not a concern throughout the entire process. Future climate projections by the CSIRO using a mid-emission scenario (A1B) relative to a 1980-1999 baseline period indicate an annual rainfall decrease in both New South Wales and Queensland by 2030. Despite this, there is a likelihood of more extreme weather events with an increase in rain intensity and the possibility of more intense storms. Under current conditions flash flooding can cause the entire port to close. This happened in Sydney 2011 in February and March where three days of rain caused the port to close. Several truck-loads of sand were brought into the terminal area to prevent straddle slippage as oil had risen above the water (Port of Sydney terminal operator, personal communication, April 23, 2012). A possible implication for port operators facing more episodes of intense rainfall and potentially greater risks of flash flooding in a future climate is dealing with the challenge of managing potentially larger quantities of flood water due to heavier rainfall and possibly longer work stoppage.

Sea-level rise is seen as a consequence of global warming. Sydney is the only study case where sea-level rise was perceived as a threat to assets at all logistic interfaces. Port Kembla also indicated sea-level rise as a concern to asset operability but only at the sea-land interface. Sea-level rise by 2050 relative to a 1990 mean sea level for New South Wales is 40 cm (NSW Government, 2009) and 30 cm for Queensland (Queensland Department of Environment and Resource Management, 2012). The impression port representatives gave during discussion (Port of Sydney terminal operator, personal communication, 20 April 2012) was that ports are not overly concerned with sea-level rise at this point in time, mainly due to sea-level rise being projected well beyond the shorter business planning horizons of a typical port, say 5 to 10 years) (Becker *et al.*, 2012).

Table 9 Climate variables of concern to study ports by most common rating

Vulnerability Rating	<i>Port Kembla Port Corporation</i>	<i>Sydney Ports Corporation</i>	<i>Gladstone Ports Corporation</i>
5 - Operation ceased			
4 - Significantly vulnerable	Storm surge		Severe tropical cyclone
3 - Moderately vulnerable			Fog Storm surge
2 - Somewhat vulnerable	High speed winds Tidal changes Sea-level rise Heat wave Flash floods Floods (streams/creeks)	Flash floods Heat wave Storm surge High speed winds Fog Tidal Changes Floods (streams/creeks) Sea-level rise	High speed winds Flash floods Floods (streams/creeks) Tidal changes
1 - Not at all vulnerable			Sea-level rise

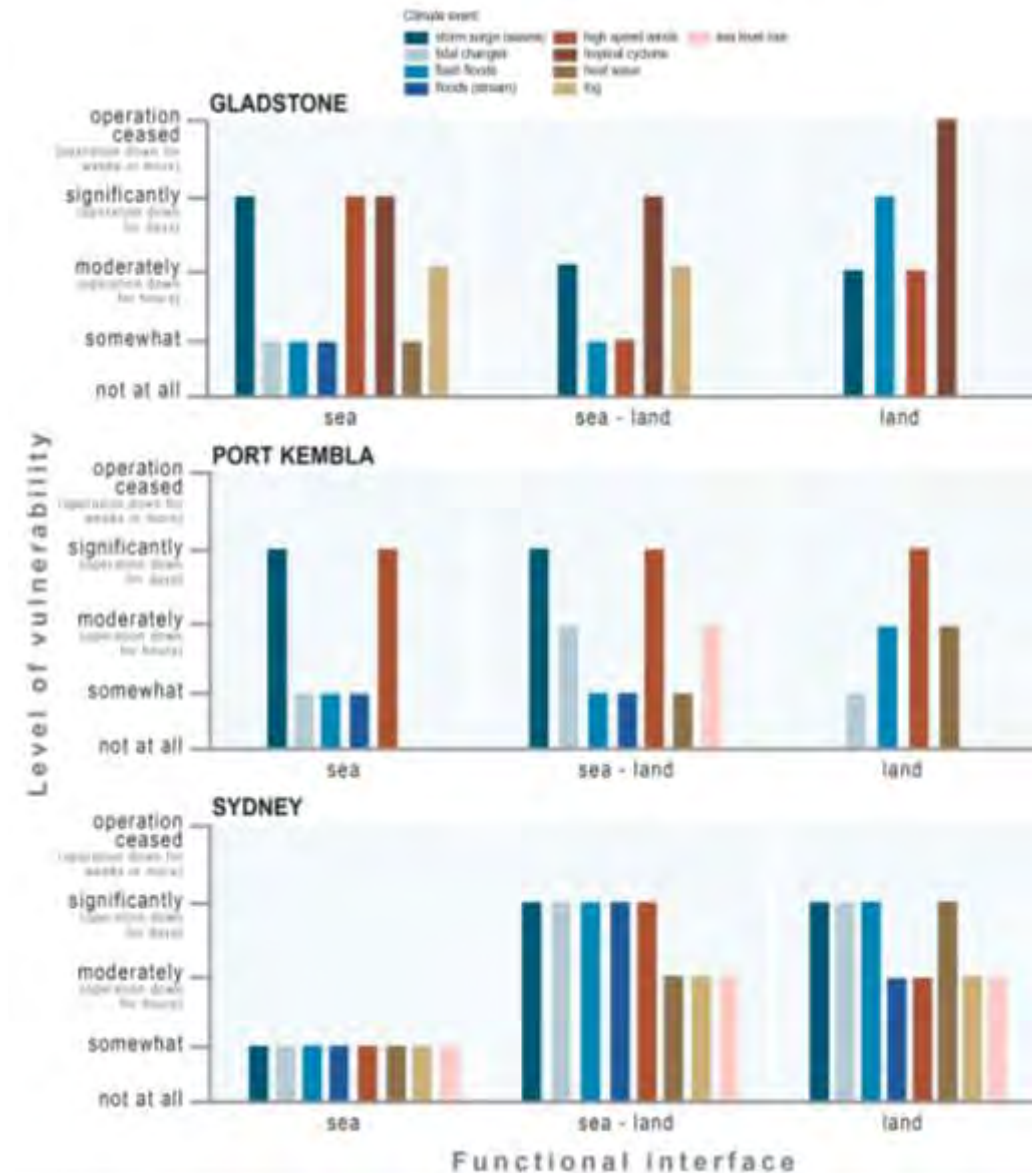


Figure 27 Highest vulnerabilities by port for each weather event

Temperature in both Queensland and New South Wales is expected to increase by 2030. Using a mid-emissions scenario (A1B), CSIRO have projected temperature to change in Central Queensland by 1 degree Celsius and in New South Wales by 1.1 degree Celsius, by 2030. In the current climate, both New South Wales ports express concern towards impacts on operational processes due to heat wave. The ports temperature policy states that at 36 degrees Celsius, breaks become longer and at 38 degrees Celsius, operations related work ceases. For current day conditions, temperatures exceed 38 degrees Celsius once a year. Future projections for 2030, expect this number to increase to 1.9 days per year.

5.5.5 Discussion of weather impact thresholds

In addition to collecting data on climate using vulnerability ratings, data on the perception of weather event thresholds of most concern was also collated through discussions with port experts. Typical of discussions with the study ports was that some climate variables triggered work slow-down or stoppage. Table 10 summarises the qualitative data that were gathered in the interview regarding the possible impact due to different thresholds being met for different climate variables. While this data is specific to a container terminal operation, it provides an additional insight into the ratings discussed earlier.

Climate variable	Impact on workflow
Rain	<ul style="list-style-type: none">• There is no formal quantity of rainfall that the port operators go by to determine whether employees should stop work.• When work stoppage occurs due to rain, all components of the workflow stop
Wind	<ul style="list-style-type: none">• Cranes and straddle carriers are equipped with wind alarms. Once a wind alarm goes off, operators must cease work. Once the alarm stops, operations resume.• Cranes stop work at 70km/hr• Straddles stop work at 90 km/hr
Heat	<ul style="list-style-type: none">• Heat policy – 36 degrees, break becomes longer. 38 degrees, cease work.• Work continues as soon as the temperature drops.
Fog	<ul style="list-style-type: none">• Informal policy – if the cranes on the ship can't be seen from the manager's office block building then it's too foggy to work
Floods	<ul style="list-style-type: none">• No flooding as such at the terminal because of effective drainage systems. However there was isolated flooding at the terminal where drainage cannot cope. Source of flooding was rain.

Table 10 Summary of weather variables impacts on workflow

5.6 Summary

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

Assets that were most susceptible to climate impacts at Gladstone are ships, helicopters, GPS base station pilot navigation aid and gantry loaders. At Port Kembla, assets deemed most susceptible to impacts were ships, ship and yard cranes, hoppers, leading lights, communication equipment and the breakwater. For the terminal operator at Sydney, assets identified as being most susceptible to climate impacts were shore and yard cranes. Of all three study ports, gantry loaders at Gladstone were the only asset allocated a rating of 5 meaning operation would cease for weeks or more after impact.

A number of assets were identified by port representatives as ceasing for some period of time during and after the impact of a climate event, particularly in Port Kembla and

Gladstone. Port representatives were asked whether the cargo handling system can continue even after assets of most concern were inoperable. Responses indicated that the system cannot function to its maximum capability without all assets operating. Part of the system is capable of continuing, for example, if a shore crane is inoperable but other assets are able to operate, containers in the holding yard can still be transferred to trucks/trains. However, the function of the shore crane cannot be replaced by another operational asset.

Future climate information provided by CSIRO points to a dryer climate with a likelihood of more extreme weather events with an increase in rain intensity and the possibility of more intense storms. As mentioned, flash floods and high speed winds were identified by all ports as climate concerns at all logistic interfaces. A 2030 climate may exacerbate the intensity of flash flooding and elevate high speed wind impacts (assuming current operational processes remain). Future climate data for fog from the CSIRO was unobtainable.

Vulnerability ratings were obtained from port personnel based on their knowledge and experience of port operations, particularly from those who are employed in the area of logistic operations.

6. CONTAINER TERMINAL OPERATIONS SIMULATOR (CTOS)

The Container Terminal Operation Simulator (CTOS) is an agent based simulation of container flow at sea-land and land operations at a sea port. It simulates the various operational assets such as cranes and their movements in the unloading, loading, and transshipment/intermodal operations. The outcome of this simulation was a set of Key Performance Indicators (KPIs) that allowed a comparison of the level of operational performance of each operational asset (e.g. crane rates, straddle productivity, truck queue length, yard utilisation) under various climate change scenarios. The simulation enables a systematic assessment of different 'what if' scenarios associated with extreme weather events that are of most concern to port operations, under future climate scenarios. The CTOS emulates the impact on the capacity of different operational assets, and measures the variation in performance levels and the overall throughput within the container handling process.

An Agent based simulation modeling approach was adopted for two main reasons. Firstly, the complexity of the operational environment of a port which includes a multitude of variables related to climate data (e.g. temperature, wind speed, rainfall) and port configuration (e.g. containers loaded/unloaded, number of straddles used, truck arrivals). Hence an ABM is used to model possible scenarios that can occur in the operational environment by varying the values of the multitude of variables to gain an understanding of possible outcomes. This allows decision makers to better understand the possible impact on the port's container operations due to weather related events of varying severity.

Secondly, ABM provides a disaggregated level simulation at an asset level. Climate change or extreme weather events have variegated impacts on different parts of port operation. ABM allows interdependencies of different parts of the logistics systems to be measured. For example, the likely impact of a reduction in crane capacity on space utilisation at the yard. ABM provides a simulation capability to mimic the impact of different scenarios on an hourly basis at an equipment level where individuals or agents are described as unique and autonomous entities that usually interact with each other and their environment locally. This in turn allows emergent patterns of behaviour to be observed.

The main objectives of CTOS are therefore to design an intra-port workflow system to simulate the vulnerability of port operations to extreme weather events and future climate change scenarios. A single terminal within the Port of Sydney was used as the context to develop the simulation; however its application can be broadened to include other container terminals and ports.

The simulation outcome allows the analysis of the container handling process within the port, addressing the following three questions:

- What is the likely impact of a range of extreme weather events on the total number of containers handled at a container terminal over a 24 hour period (and how will this be affected by changes in intensity and/or duration of events)?
- What is the average productivity loss – *defined in terms of average time required to handle a container* – of different operational assets under different climate change scenarios (represented by the three different 'futures' – most likely, worst, wetter)?

- What is the likely impact on the performance of key operations such as crane rate and truck queue lengths given projected growth in container numbers and the likely future climatic events?

6.1 Agent based modelling and simulation – An overview

An agent based model was used to build CTOS. This is a type of computational model where individuals or agents are described as unique and autonomous entities that usually interact with each other and their environment locally, leading to emergent patterns of behaviour that can be observed (Railsback and Grimm, 2011). Hence agent based modelling allows individual actors/nodes within a process to be independently encoded with operational rules while observing the collective behaviour. While agent based models are useful in building various applications in the broader field of multi agent systems and agent oriented software engineering), in this work its application is to simulate a system (i.e. Agent Based Simulation). In CTOS the agent based model was used to simulate the operations of port operational assets such as cranes, straddle carriers and trucks to observe the individual and collective performance under various climatic conditions. By encoding the operational rules of individual operational assets (i.e. nodes in the process workflow), the likely impact of climate events on the business process flow (when the performance of different operational asset nodes reduce to their sub-optimum level) can be measured and compared.

CTOS was developed using the JACK Agent Oriented Programming (AOP) language, a Belief- Desire-Intention (BDI) based agent platform developed by Agent Oriented Software (AOS) Pty Ltd, Melbourne. JACK is a commercial programming platform developed as an extension to the mainstream Java programming language, readily available as a free 60-day evaluation version (<http://www.aosgrp.com>).

The Belief-Desire-Intention (BDI) model is a popular reasoning model for rational agents where ‘beliefs’ represent the information about the internal and external ‘environmental’ state of the agent, ‘desires’ represent the world states that the agent wants to reach and ‘intentions’ represent those desires that the agent has committed to pursuing (Rao and Georgeff, 1992; Winikoff and Padgham et al, 2001). As pursuing a desire requires a course of action, intentions are also seen as partial or complete plans used to achieve the adopted desires. Therefore a BDI model based agent is defined as having: a set of events or goals it can handle; a set of plans to achieve the goals; and beliefs or data about the real world/environment.

The typical reasoning cycle used by a BDI agent is shown in Figure 28 where in response to an event or goal “e” received from the environment or internally generated (e.g. the goal “move container” given to a crane agent), the agent selects from its plan base a set of plans ($P_1 - P_n$) relevant for handling e. Based on the *context conditions* of the selected plans, the agent determines an applicable set of plans ($P_j - P_r$) that could be used to handle the event e. A *context condition* defines the state of the external environment or agent’s internal state for the given plan to be applicable. For example in the case of the crane, there can be multiple plans to handle a container move based on the prevailing weather, type of container etc. From the applicable set, the agent selects a single plan (P_i) based on a predefined algorithm, which is normally specific to the given BDI implementation. For example, in JACK the default mechanism simply selects the first plan in the applicable set. The agent then executes the actions contained within the selected plan P_i (shown in the Figure 28 as a, e, b). Actions typically found in agent systems results in interactions with the environment, raising new goals/events or reading/changing agent’s own beliefs.

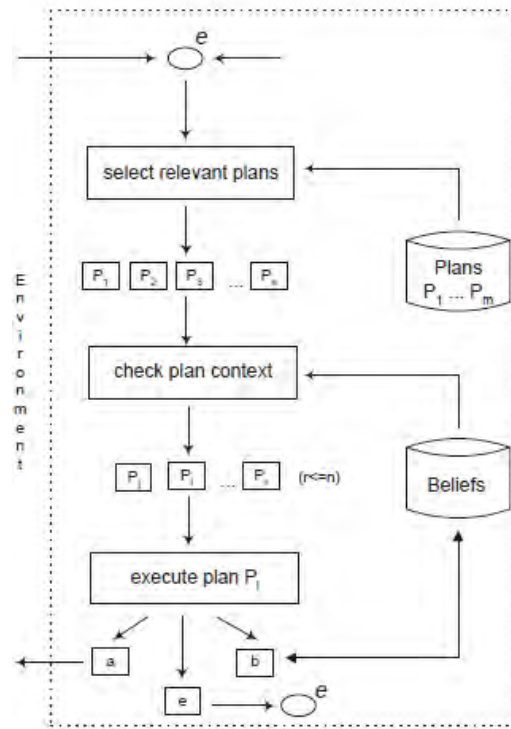


Figure 28 Reasoning cycle of a BDI agent

The advantage of using an agent model for CTOS is in its ability to localise the operational rules of different agents in the system, which makes it simpler to build complex models with many operational assets compared to modelling the system as a whole. This also makes the system extensible as new agents can be added or existing ones removed to reflect the characteristics of realistic scenarios (e.g. adding new type of equipment such as an automated guided vehicle (AGV)). Furthermore, the BDI model also allows agent behaviours to be altered by adding new plans or goals that provide the modellers a way to incorporate new behaviours (e.g. working under new weather or other operational conditions) as the system requirements evolve. Hence agent based models can be made as complex as required by extending agents and their behavioural rules to suit new operational situations. With the agent approach CTOS also allows asset level simulation, which is at a much finer granularity than considering the port environment as a monolithic system, allowing modellers to look at “what-if” scenarios by making much finer changes such as reducing the efficiency of certain asset type (e.g. straddles) or even specific assets (e.g. few identified straddles).

6.2 CTOS system concepts

CTOS was developed on the container operations at Sydney Port and simulates the sea-land and land side container movement operations of a single terminal. A single terminal was used for the purpose of the simulation, as opposed to the entire Sydney Port, so that a finer scale of detail can be captured and modelled hence producing a closer to real-life outcome of possible climate impacts. A high level design of the various agents in the system and their interactions are shown in Figure 29.

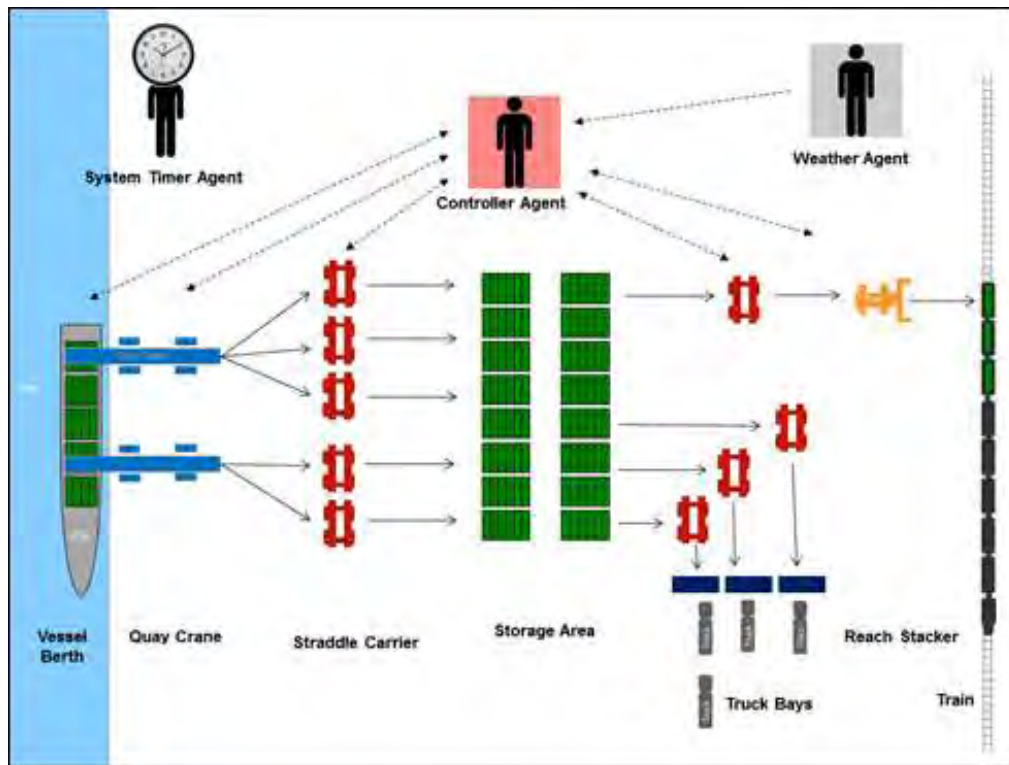


Figure 29 System agents and their interactions

Building an agent based simulation requires identifying the agent types (e.g. vessel, crane, and truck), number of agent instances (e.g. number of cranes, and trucks), capturing the operational rules and developing the events, plans and data model of the agent using a programming language such as JACK. In CTOS the agents can be broadly categorised as “operational agents” (Table 11), which are part of the actual terminal operations and “system agents” (Table 12), which are part of the simulated environment.

Table 11 Operational agents

Operational Agent Type	Description
Vessel	Represents the vessels that are served at the terminal. Simulation assumes the vessel to be at the berth
Quay Crane (QC)	Quay Cranes are used to load and unload containers to/from the vessels.
Straddle Carrier (SC)	In the selected terminal straddle carriers are the main means for moving containers within the terminal area. This includes QC to yard and yard to trucks and train.
Reach Stacker (RS)	Reach Stackers are used to load/unload containers from the train
Truck	Trucks used in transporting containers
Train	Trains used in transporting containers

Table 12 System agents

System Agent Type	Description
Controller Agent	Acts as the central control node of the different operational agents. Responsible for initialization and communication of weather and scheduling data
Weather Agent	Generates simulated weather events such as wind, rain, fog etc of different intensities
System Timer Agent	Regulates the ticking of the system time. Each tick is representative of an hour in real time.

6.2.1 Port configuration

The Port Configuration defines the standard operating parameters required by CTOS to run a simulation and includes the number of different operational assets (agents) in use, their operational times and assignments. This allows the simulation system to initialise the simulation to depict a given port set up.

In the current version of the simulation the port configuration includes the following eight items of data:

- Performance indicators for each operational asset under simulation. These include:
 - a. Crane rate (numbers of containers handled per hour)
 - b. Containers handled by a straddle carriers per hour
 - c. Trucks served per hour
- Number of vessels at berth
- Number of craned assigned to each vessel
- Number of straddle carriers assigned to each crane
- Number of containers to be loaded and unloaded to or from each vessel
- Container yard capacity and current utilization
- Number of containers loaded/unloaded from trains
- Number of containers loaded/unloaded from trucks

6.2.2 Simulation window and process

The model is able to simulate a 24 hour window. The 24 hour window was selected as a repeatable window of time because it allowed modellers to aggregate and compute the impact for days, weeks or months. Furthermore, the port operations are run 24/7 and a unit of one hour represents a reasonable granularity for the purpose of modelling climatic event occurrences and their impact. This allows users to assign different climatic conditions to hour blocks in a given 24 hour window, representing a chosen weather “profile” for that period. Table 13 provides an example of such a profile.

Table 13 Example of a 24hr window weather profile

8am	9am	10am	11am		3am	4am	5am	6am	7am
Clear	Clear	High_Wind	High_Wind		Clear	Clear	Clear	Fog	Thick_Fog

The climatic events such as *High_Wind*, *Fog* and *Thick_Fog* shown in the example in Table 14 are user defined weather events where the user is able to link each event to an impact on the various operational assets. Users are able to define any number of such events that they want to simulate.

Table 14 User defined events including the impact on productivity of assets

Event Label	Climate Parameter	Definition	Impact
High_Wind	Wind	> 70km/h < 90km/h	QC = 0% productivity SC = 100% productivity Truck Rate = 100%
Fog	Fog	Low impact on visibility	QC = 100% productivity SC = 50% productivity Truck Rate = 100%
Thick_Fog	Fog	High impact on visibility	QC = 100% productivity SC = 0% productivity. Truck Rate = 50%

In the current version of CTOS, the impact was defined as a productivity loss between 0 and 100% of the operational assets. However given the agents are based on the BDI model which allows more complicated impact rules to be included as plans for any future developments of the simulation. The input required for the simulation is data about the climate event and the hourly weather profiles.

6.2.3 Simulation Output

CTOS is able to calculate the following indicators to compare the performance of the terminal and the various operational agents under different weather conditions and different agent configurations such as having different number of cranes and straddle carries assigned to move containers (see Table 15).

Table 15 Simulation output KPIs

KPI	Description
Port Crane Throughput (PCT)	Total number of containers loaded/unloaded by all cranes in the 24hr period
Crane Rate (CR)	Number of containers handled by a crane per hour
Crane-side Straddle Hourly Rate (crane-Straddle Rate)	Number of containers handled by a straddle on the crane side
Truck Rate	Number of trucks served per hour
Total number of trucks served	Total number of trucks served within the 24hr period
Truck Queue	Number of trucks in queue after the 24hr period

Containers moved in to yard	Total number of containers moved into the yard in the 24hr period via vessels, trucks and train
Containers moved out from yard	Total number of containers moved out of the yard in the 24hr period via vessels, trucks and train

A user is able to vary the port configuration, hourly weather profiles and climate impact on each operational asset to compare the performance under each case.

6.3 6CTOS design overview

The simulation system consists of three main components (Figure 30):

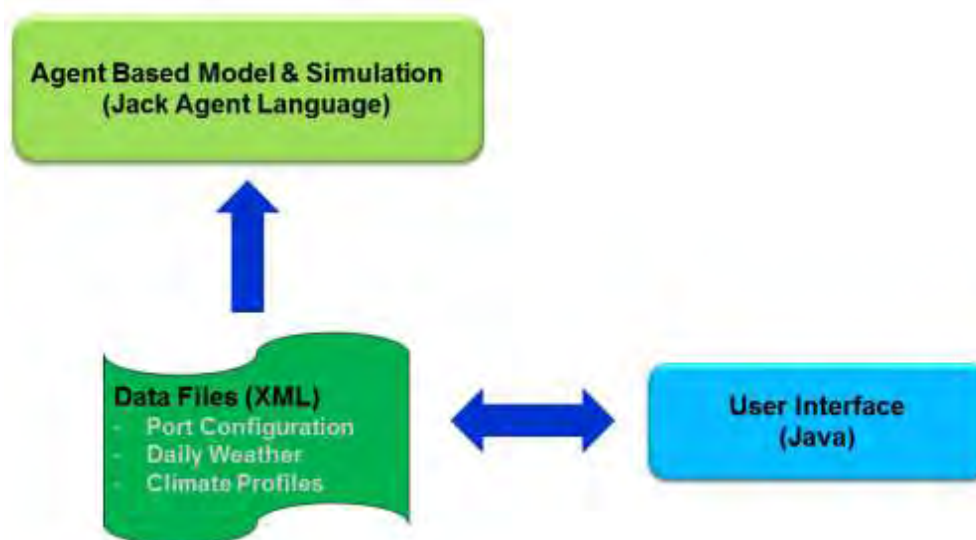


Figure 30 Simulation system components

1. **JACK agent system:** Implements the agent types and interactions shown in Figure 29 using the JACK agent language. JACK is a commercial agent oriented programming language developed by Agent Oriented Software (AOS) Pty Ltd, Melbourne. WP2 used a free evaluation version of JACK (<http://www.aosgrp.com>).
2. **Input data files:** The agent system requires three input XML files in order for the simulation to run. These include:
 - **Port configuration:** Defines the port set up with number of operational assets in use (such as cranes, straddle carriers), their assignments (such as how many cranes are assigned to a vessel) and their performance data (such as number of containers handled per hour). See Figure 31.
 - **Climate profile:** Defines the climatic events and their impact on the performance of the different operational assets.
 - **Daily weather:** The weather based on the climate profiles (Table 13 and Figure 32) defined for each hour of the 24 hour period is being simulated.

- User Interface:** The Java based user interface allows the user to update the input files and also run the simulation. While the current version is a standalone Java application, given the component based nature of the system, the user interface can be developed as an online module without changing the rest of the system. Following are screenshots (Figures 31 to 34) from the system.

Agent Based Port Container Process Simulation

Open Port Config File F:\MyOwn\Projects\JACK_Projects\Scenarios\Normal_3_SHIP\PortConfig....

Port Configuration Climate Scenarios Daily Weather Run Simulation

Port Configuration Parameters View Layout

Container Yard

Current Utilization	Yard Capacity	Assigned to Load
1000.0	3000.0	800.0

Train Yard

Train Bay	TEU to Load	TEU to Unload	Straddle 1	Straddle 2	Straddle 3	Straddle 4
train_1	100.0	300.0	sc_61	sc_62		

Truck Loading Bays

Truck Bay	TEUs per Hour	Assigned Straddle
truck_1	5.0	sc_71
truck_2	5.0	sc_72
truck_3	5.0	sc_73
truck_4	5.0	sc_74

Berth Details

Ship Name	TEU Unload	Quay Crane 1	Quay Crane 2	Quay Crane 3
SHIP_1	800.0	qc_1	qc_2	qc_3
SHIP_2	600.0	qc_4	qc_6	
SHIP_3	800.0	qc_7	qc_5	qc_8

Quay Cranes

Crane Name	TEUs per Hour	Assigned Ship	Operation	Straddle 1	Straddle 2	Straddle 3	Straddle 4
qc_1	26.0	SHIP_1	unload	sc_1	sc_2		
qc_2	26.0	SHIP_1	unload	sc_4	sc_5		
qc_3	26.0	SHIP_1	load	sc_7	sc_8		

Cancel

Figure 31 Set up screen for the port configuration

Agent Based Port Container Process Simulation

Open Port Config File F:\MyOwn\Projects\JACK_Projects\Scenarios\Normal_3_SHIP\PortConfig...

Port Configuration Climate Scenarios Daily Weather Run Simulation

Climate Scenarios

Profile Name	Description	Crane Efficiency	Straddle Efficiency	Truck Rate Impact
normal	No weather impact	100	100	100
high_temp	High temperature	75	100	75
high_wind	Wind between 70-90...	25	50	75
heat_wave	Heat wave condition	50	50	80
no_work	No work hours	0	0	0
extreme_wind	Wind above 90km/h	0	0	100

Save Add Profile Remove Profile

Cancel

Figure 32 Definition screen for the climate scenarios

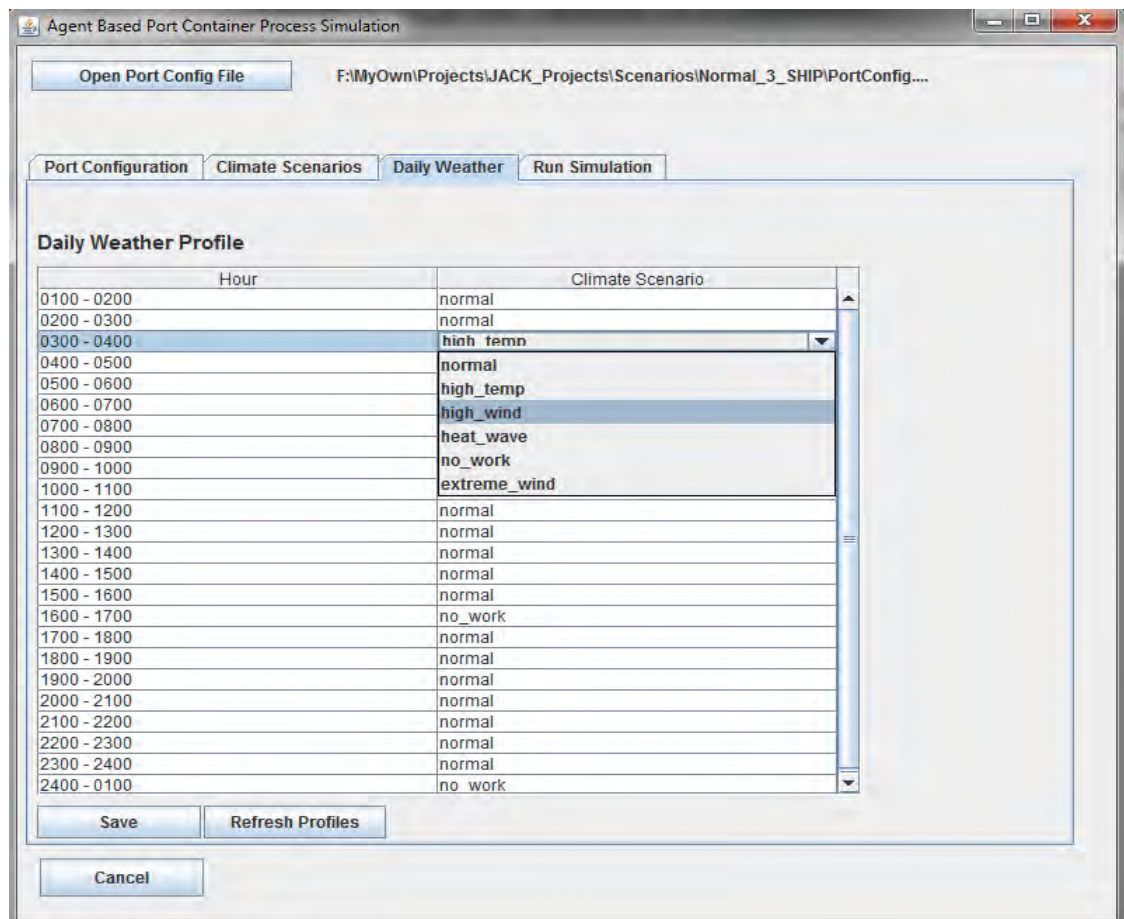


Figure 33 Set up screen for hourly weather outlook

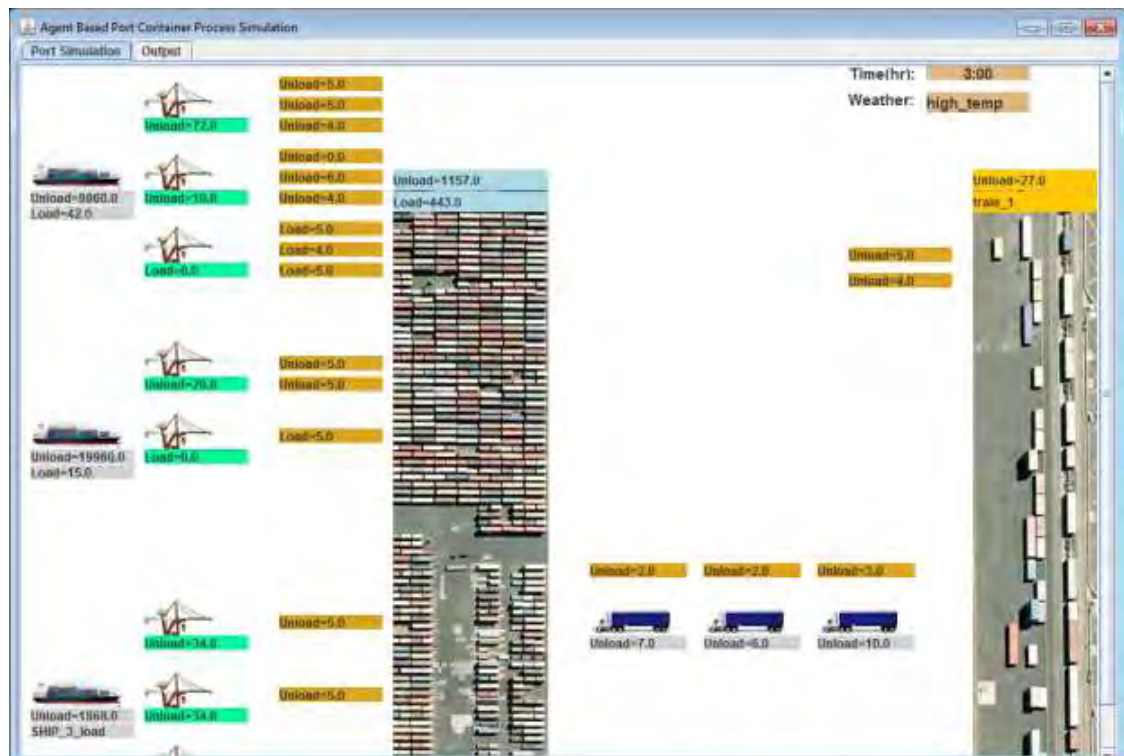


Figure 34 Simulation screen

6.4 Climate impact assessment

Based on the climate data type presented in table 10 and, for the purpose of the simulation the output for impact under three climate scenarios is presented, The scenarios are; high temperature, high rainfall and high winds with a baseline scenario of no impact and a scenario where climate events have an impact on the wider port environment affecting the truck rate (for example a flooding of roads affecting the arrival of trucks). In summary, the scenarios are shown in table 16 below:

Table 16 Climate scenarios for the simulation

Scenario name	Description
<i>Scenario 1</i>	Baseline (no impact)
<i>Scenario 2</i>	High temperature / heatwave for six hours per day
<i>Scenario 3</i>	High rainfall / flash flooding for six hours per day
<i>Scenario 4</i>	High wind / cyclone for six hours per day
<i>Scenario 5</i>	Flooding of port area affecting straddle operations for five hours

Asset vulnerability ratings allocated by Port of Sydney terminal operators for shore crane, straddle carrier and truck are shown in Table 17 for the three climate events producing an output under rainfall, high speed winds and heat wave conditions (for more details see Appendix 3). Rating descriptions are shown in Table 18 and are the same as those described in section 5 on asset vulnerability assessment. The ratings are based on the terminal operator's perception of impacts and fed into CTOS to determine changes in productivity efficiency due to current climate impacts on assets (see Section 5.2 for more details on data collection). For example, shore cranes have been allocated a vulnerability rating of 4 to high speed winds meaning port operators perceive shore cranes to be 'significantly vulnerable' to high speed winds.

Table 17 Impact on selected operational assets at the container terminal

OPERATIONAL ASSET	Vulnerability Rating				Impact on Efficiency (%)		
	Flash floods (rainfall)	High speed winds	Heat wave		Flash floods (rainfall)	High speed winds	Heat wave
Shore cranes	4	4	2	➔	25	25	75
Straddle carrier	1	3	1		100	50	100
Trucks	2	2	2				

The input data format for CTOS is a percentage representing productivity loss. Therefore we have converted these ratings to a percentage using the key in Table 18. Using the input in Table 17, the current climate variables of rainfall, high speed winds and heat wave can have an impact on productivity efficiency. For example, the high speed wind vulnerability for a shore crane (rated 4) will impact on efficiency by 25%.

Table 18 Percentage efficiency impact of vulnerability rating

Vulnerability rating	Rating description	Efficiency Level after Impact
1	Not at all vulnerable (No impact)	100%
2	Somewhat vulnerable	75%
3	Moderately vulnerable (Operation down for hours)	50%
4	Significantly vulnerable (Operation down for days)	25%
5	Operation ceased (Operational down for weeks or more)	0%

6.5 Output of the simulation

A hypothetical port configuration is shown in Figure 35 below. In this configuration a total of 3,000 containers are marked to be loaded/unloaded from three berths in a period of 24 hours, which is within the operating capabilities of the terminal as we simulated.

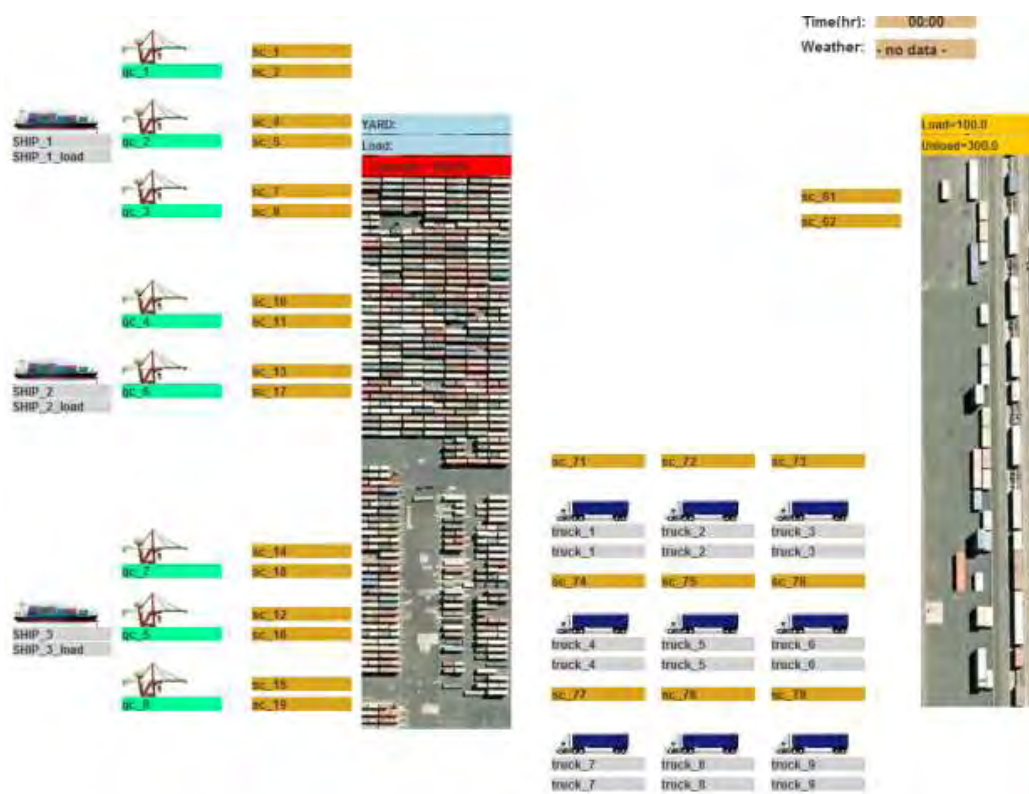


Figure 35 Hypothetical port configuration with three vessels

6.5.1 Climate scenario based impact

The following three tables (tables 19-21) present the different KPI's generated by CTOS for the five simulated scenarios.

Table 19 shows the crane rate, crane-side straddle carrier rate and loading/unloading of trucks as performances per hour. Compared to the baseline scenario, the most impact on crane and straddle carrier performance is due to high wind and rain. This aligns with the comments made by the port operator discussed earlier in section 1.24. Rain and wind were listed as having the most impact on container terminal operations.

Table 19 Impact on hourly KPIs

Scenario	Crane Rate	Crane-Straddle Rate	Truck Rate (load/unload)
Scenario 1 (baseline)	19.91	9.96	45.00
Scenario 2 (high temperature)	19.70	9.85	42.43
Scenario 3 (rain)	17.62	8.81	42.43
Scenario 4 (high wind)	17.62	8.81	39.86
Scenario 5 (flooding)	19.91	9.73	36.42

Table 20 shows the total number of containers (Port Crane Throughput), total number of trucks served, truck queues (backlogs) created and total number of containers moved in/out of the yard. Table 21 shows the percentage drop in port crane throughput under each climate scenario against the baseline case.

Table 20 Impact on daily KPIs

Scenario	Port Crane Throughput (PCT)	Total trucks served	Truck Queue	Total Containers moved in	Total Containers moved out
Scenario 1 (baseline)	3346	945	0	3056	1635
Scenario 2 (high temperature)	3310	891	0	3008	1593
Scenario 3 (rain)	2960	891	0	2658	1593
Scenario 4 (high wind)	2960	837	54	2646	1551
Scenario 5 (flooding)	3346	765	180	2940	1491

The data displayed in Table 21 shows that while high wind and rain have the highest impact on the crane throughput, high wind and flooding in the port area leads to a backlog in servicing trucks. This is mainly due to the impact of flooding and high wind on the operation of the straddle carries. The CTOS outcome for the port configuration shows that the crane throughput loss within a 24 hour period due to six hours of rain and six hours of high wind (separately) is 13.04%. While this is a considerable loss within a 24 hour period, it is important to note that port operators do take corrective measures such as increasing their productivity in the work shifts after such an incident. However this is only possible when such extreme events occur in a sporadic manner giving sufficient 'good weather' windows to make up for the time lost. The future projections for wind and rain show that there is more likelihood of these events occurring within a year in the future. This may give rise to noticeable productivity losses due to high wind and rain. Without quantitative data on the occurrence of high wind and rain related days per year it is not possible to calculate the annual impact due to rain and high wind for the given simulation scenarios. However, the next section presents the likely annual impact due to hot days based on the simulation outcome.

Table 21 Impact on port crane throughput

Scenario	Drop in PCT as a %	Drop in PCT in container numbers
Scenario 1 (baseline)	0	0
Scenario 2 (high temperature)	1.08	36
Scenario 3 (rain)	13.04	386
Scenario 4 (high wind)	13.04	386
Scenario 5 (flooding)	0	0

6.5.2 Future climate projections based impact

The future impact is based on the currently available CSIRO climate projections for high temperature in 2030 for the number of hot days in NSW, as shown in table 22. The ports temperature policy states that at 36 degrees Celsius, breaks become longer and at 38 degrees Celsius, operations related work ceases. Annually, days above 35 degrees Celsius in Sydney, according to the model CSIRO Mk 3.5, are currently 5.1 days. In 2030 there may be 6.7 days and in 2050 there may be up to 14.4 days above 35 degrees Celsius.

Table 22 Temperature forecast based on CSIRO Mk3.5

CSIRO Mk3.5	Days above 35°C						Days above 40°C					
	Current*	2030	2050		2070		Current*	2030	2050		2070	
SEASON		A1B	B1	A1FI	B1	A1FI		A1B	B1	A1FI	B1	A1FI
Annual	(5.1)	6.7	7.2	14.4	9.0	22.1	0.23(0.8)	0.7	0.8	1.8	0.9	4.1
Summer	(3.7)	5.0	5.4	9.7	6.5	14.6	0.2(0.7)	0.6	0.6	1.4	0.7	3.3
Autumn	(0.4)	0.4	0.4	1.3	0.7	2.1	0.0(0.0)	0.03	0.03	0.1	0.03	0.2
Winter	(0.0)	0.0	0.0	0.0	0.0	0.1	0.0(0.0)	0.0	0.0	0.0	0.0	0.0
Spring	(1.1)	1.2	1.4	3.1	1.7	4.9	0.03(0.1)	0.1	0.13	0.3	0.17	0.6

With regard to heatwaves the CSIRO and BoM (2007c) definitions are used. They define a heatwave as a run of 3 to 5 consecutive days above/below a threshold temperature. Projections for Sydney 2030 demonstrate a run of temperature which exceeds 38 degrees Celsius to be unchanging from present day conditions, i.e. zero days. This projection is based on a mid-emissions scenario (A1B) for 2030 from the CSIRO Mk 3.5 model. According to Sydney Port terminal operators, the most recent heatwave in Sydney did not directly impact on productivity efficiency (Port of Sydney terminal operator, personal communication, 20 April 2012), despite the heatwave having broken several records for number of warm nights (BoM, 2011). The most recent heatwave in Sydney to date occurred in February 2011 where the city experienced seven days of temperatures higher than 30 degrees Celsius. The highest temperature recorded during this period was 36 degrees Celsius (BoM, 2011).

Based on the above projected heatwave data, the hypothetical scenario two produces an impact forecast for 2030 hot days as shown in table 23. These efficiency impacts can be assessed against a current annual container trade of 2.02 million containers for Sydney in 2010/2011.

Table 23 Impact port efficiency and loss in dollars forecast for 2030

Scenario	Current annual occurrence of hot days	2030 annual occurrence of hot days (based on A1B and Mk3.5)	Current annual impact on container handling (in no of containers)	As a percentage of total annual container trade*	2030 annual impact on container handling (in no of containers)	Percentage increase from now to 2030
Scenario 2 (Temp above 35 C)	5.1	6.7	183.6	0.0091%	241.2	31.4%

6.6 Limitations

There are some limitations of the model which include technical aspects pertaining to scalability. The model has been designed to simulate the likely impacts or disruption to the daily container handling processes but while the process can be repeated to simulate weeks, months and years, the current implementation does not support these iterations. This means that such iterations would need to be built on top of the current tool

Following discussion with port operators, it was ascertained that it is not possible to obtain data on likely process and asset changes for the period of 2030 or beyond because port operators do not plan the business that far ahead with regard to equipment and technology. Hence when simulating future scenarios the simulation assumes currently used resources and work practices. However users can experiment with increasing the number of deployed agents and their productivity (e.g. increased crane rate to depict enhanced cranes in the future), so as to mimic increased capacity in handling containers in the future. In addition, the exclusion of container movements outside the port is another limitation, which is partly due to the lack of information on freight flow patterns based on origin-destination data.

The current simulation uses a generalised impact over three categories of assets namely cranes, straddle carriers and trucks. These assets form the core operations on the sea-land and land operations of the case study terminal, providing a better estimate of impact on the port operations. However the simulation can be extended to model the impact on individual assets or asset groups (e.g. based on the area of the port they are deployed) rather than high level categories, resulting in finer grained analysis. A similar drill down can be performed on the scheduling of assets, which is currently static as defined at the start of the simulation by the 'port configuration'. This can be extended to dynamic scheduling where assets are re-assigned at run time, allowing users to create more detailed what-if scenarios.

The current model is transferable as long as the handling process remains the same with regard to the number of processing stages and associated parameter constraints.

If the workflow changes (a workflow will most likely change for a port where materials other than containers are dealt with or where machinery used differs) the simulation can be altered to accommodate for such workflow by changing the input parameters. However, these changes will need to be made in computer programming using JACK Agent Language and Java. For simplicity, the current tool was developed as a stand-alone application based on Java, which limits its use to a single user per installation. A more scalable approach would be to implement the software as a web deployable application that would permit multiple users to use the tool concurrently mitigating the need for local installations.

One way to overcome the above challenge of customising the simulation is to extend it with a “component based” approach with generic agents that can be customised by the users themselves to simulate different operational assets including links between other interacting agents. This will allow “drag-n-drop” style building of port operations simulation for any given port. Such a model will require significantly more time to design and develop which will also include extensive requirements capturing with respect to different types of processes used in different ports. Further the climate information was specifically collected for the study terminal. Applying CTOS to different port environments will require additional research into how the climate impacts on operational processes and on assets for that terminal. The current simulation provides an effective proof of concept (POC) prototype where the system architecture can be reused in developing an open generic port operations model.

6.7 Summary

CTOS is an agent based simulation of a typical container terminal operation, implemented at the granularity of the individual operational assets in use. CTOS was designed to simulate a 24 hour window with hourly weather profiles. Drawing on data from a container terminal operator from Sydney Port multiple simulated scenarios were computed including high temperature, heavy rain, high wind and extensive flooding impacting the port precinct over 5-6 hour duration in a single day. CTOS has an agile design structure, which is adaptive to fit to user’s requirements in creating realistic ‘what-if’ scenarios to mimic the impact of extreme weather events on port logistics operations.

In this study the results of the simulation showed that while the impact due to these events were non-significant on the container-related operations, rain and high wind made the most impact while flooding in the yard area hindering the operations of the straddle carriers led to backlog queues being created for trucks. Using annual hot days occurring at present and projected for 2030 it was possible to calculate the likely annual impact due to high temperature days. According to the simulation outcome, the current impact is a loss of 184 containers per year at present and 241 containers per year based on the projected hot days in 2030, which is less than 0.01% of the annual container trade of the port.

7. WORKFORCE ADAPTIVE CAPACITY

7.1 Introduction

In the last thirty years ports have been under great pressure to adapt to a rapidly changing business environment under globalisation. Not only has inter and intra-port competition increased (Haezendonck et al., 2000; Huybrechts et al., 2002), new technologies have been adopted with the aim of enhancing operational efficiencies and overall port productivity (Gekara and Fairbrother, forthcoming 2013). A changing global political economy has also created a shift in port management from predominantly (pre-1980s) state-owned to largely private-owned. More recently the ports industry, just like many others, has come under pressure to respond to the threats of climate change. Such response requires a consideration of the port's environmental externalities and ways to mitigate their impact on the climate as well as the ports' preparedness for the implications of more intense and more frequent extreme events as a result of climate change.

This section of the report specifically focuses on the "adaptive capacity" of the workforce at the ports to climate change. Adaptive capacity to climate change can be described as the capability to modify behaviour to cope with current or predicted climate variability and change. A review of the literature reveals that, although research has been conducted on the port industry's adaptive capacity to climate change, little specific attention has been paid to the workforce (Pelling, 2008; Adger et al., 2004), yet even in the most technology determined operations the human element still remains the key to safe and sustainable productivity (Nurse-Bray and Miller, 2012; Nurse-Bray and Ferrier, 2009). Thus, the study is premised on the understanding that effective avoidance and/or mitigation of negative impacts of extreme weather scenarios at the port depend on the level of awareness, skills and preparedness for both managers and front-line workers at the port.

This research investigated the adaptive capacity elements of workforce knowledge/skill/education, organisational customs/norms, and the organisational management systems and structures. This component of the project sought to understand these elements in relation to ports' capacity to adapt to future extreme weather events.

This section of the report is based on interviews with staff. Interviewees will be attributed to the particular port, then a number, i.e., Gladstone 01, Gladstone 02, Sydney Port 01, Port Kembla 01 and so forth.

7.2 The context

The concept of adaptive capacity has its roots in both the "vulnerability" literature, and "resilience" literature (Engle, 2011). It is a central determinant in helping a system to adapt to an external stressor, that is, in assisting a system to "modify or change its characteristics of behaviour so as to cope better with existing, or anticipated external stresses" (Adger et al., 2004). This concept can be applied to both ecological and human social systems – from country or community level, down to the organisational and individual level. For human social systems, adaptive capacity relates to the institutions and networks that allow the system to learn, and store knowledge and experience, and that create flexibility in problem solving (Resilience Alliance, 2002). The vulnerability literature views the lack of adaptive capacity as a key component of vulnerability, where vulnerability of a system is perceived as a function of exposure of

the system to a stressor, sensitivity of the system exposed, and the adaptive capacity of the system, (see section 5.1, Defining Vulnerability).

The concept of adaptive capacity has been applied to the subject of climate change, and research has looked at the determinants of adaptive capacity to climate change. The IPCC Third Assessment Report Working Group II (Ch 18) (2001) summarised the determinants of adaptive capacity at the national and community levels as economic resources, technology, information and skills, infrastructure, institutions and equity. Further research has led to a deeper understanding of the complexity of adaptive capacity at different scales, and in different contexts, which was elaborated on by Working Group II in the Fourth Assessment Report, Ch 17. For example, it considers such factors as the range of technological options available for adaptation, availability and distribution of resources, structure of critical institutions, the stock of human capital (including education), the stock of social capital (including the definition of property rights), risk spreading processes, ability of decision-makers to manage and process information, and the public's perception of climate change.

Early research into adaptive capacity at the organisational level focused more on adaptive capacity to general external change stimuli and competitive environments. According to Staber and Sydow (2002), adaptation is often viewed as a dynamic process of continuous learning and adjustments, rather than a static end point. This process takes into consideration such factors as the number and diversity of relations between actors in an organisation, the level of redundancy within the organisational structure, learning capability of the organisation, its operational flexibility, strategic ability to recognise and respond to change and the level of proactive behaviour (Korbangyang and Ussahawanitchakit, 2010; Staber and Sydow, 2002). Research that has looked at organisational adaptive capacity to climate change in particular, tends to focus on proactive change to deal with climate change impacts. It has included some of these determinants, particularly the focus on the learning capability of the organisation, and the strategic ability to recognise the risks posed by climate change, and to respond proactively (Lonsdale, 2010). Additional characteristics of organisational adaptive capacity to climate change include:

- access to resources (including financial and human resources – embodying skills and knowledge),
- engaged leadership creating a clear vision on adaptation,
- working with others both across the organisation and outside organisational boundaries,
- access to information to inform adaptation decisions,
- awareness of what climate change means for the organisation,
- effective internal communications,
- change agents who can achieve action on climate adaptation,
- motivation to act, particularly for those in decision-making positions,
- management processes that encourage transparency and avoid duplication and assist in embedding climate adaptation across the organisation (Lonsdale, 2010).

The workforce is of course a major part of an organisation; in fact some researchers do not distinguish between the adaptive capacity of the workforce and the adaptive capacity of the organisation. With this in mind, the body of research that is concerned specifically with the adaptive capacity of the workforce, looks more to the behavioural aspects of an organisation, and its capacity to learn; the importance of formal and informal structures, and processes of information sharing and learning (Pelling, 2008). It can therefore be distilled that the adaptive capacity of a workforce consists of both

structural organisational elements within which the workforce work, as well as behavioural elements.

For this research, the efforts focused on the adaptive capacity of the port workforce to climate change impacts (particularly extreme weather events), the analysis was framed by three key elements, that is, the knowledge/skill of the members of the workforce to cope with extreme events, the implied organisational customs/norms towards climate change, and the organisational management systems which address the impacts of extreme weather events. These three overarching elements encompass many of the structural and behavioural elements outlined earlier. Each element influences the other within an organisation, as represented in Figure 36.



Figure 36 Adaptive capacity elements

The element of “systems and processes” provides the framework within which port employees work. That is, they work within a certain organisational structure, which may be hierarchical and quite siloed, or it may be a flatter, more flexible structure. Additionally, they work within organisational operating systems such as environmental management, safety and emergency management, each with particular processes and operating rules that guide the work undertaken by individuals. The integration of climate change within these systems can help provide the motivation for action. If climate change is not implicitly or explicitly incorporated into these systems and processes, then it may prove a barrier for the workforce to adapt to future climate impacts.

The second “skills and knowledge” element of the research relates to the individual’s broad understanding of climate change, and the diversity of potential impacts over time. It encompasses knowledge of climate change and its impacts, particularly as they relate to their roles, or area of work at ports. A key component of being able to frame climate impacts, is access to relevant information in a comprehensible form. The port workforce includes workers that are predominantly office-based, as well as those that work outside (on land and water). This implies a variance in the type of knowledge of climate change that will be required across the ports, and different skill sets to consider climate impacts relevant to particular roles.

Finally, the “organisational culture and norms” element underpins and influences both the other elements to some degree. It is generally accepted to be strongly influenced by the organisational leadership. Thus if the CEO and other management team members accept that climate change is happening (awareness), that it may impact the operations of the port, and that they need to proactively act to address any impacts

(willingness to act), then this will influence the workforce towards considering the implementation of climate adaptation measures.

7.3 Methodology

The adaptive capacity of the workforce was assessed through semi-structured interviews with staff, conducted between July and September 2012 across three different ports in Australia – Gladstone, Sydney Port (Botany) and Port Kembla. These three ports featured different management structures, locations and operational characteristics, thus offering the opportunity for generalising the findings to a broader range of Australian ports. The interviews were conducted mainly with respondents from the operations, human resources and environment departments or equivalent departments of the ports. Through open-ended questions, respondents were invited to explain and discuss climate change and port operations with reference to: 1) specific experiences of extreme weather events at their respective ports and how they were addressed, 2) their view of future changes to the climate and possible implications for port operations, 3) existing procedures to deal with extreme weather conditions resulting from climate change and 4) their views on the vulnerability of their ports to weather disruptions presently and in the future. With respect to existing procedure, interviews explored whether they were documented, or based more on organisational and individual knowledge. The interviews lasted one hour on average and were digitally recorded.

To complement the interview discussions, the respondents were also asked to complete a table, tailored to their particular port and region, rating the vulnerability of port operations to different climatic events, including extreme heat, cyclone, rainfall and fog (see Appendix 5 for sample table). The interviews were formally transcribed and coded and then thematically analysed alongside data from the tables and workshop feedback to inform the report.

Finally, to help inform the development of workforce adaptive capacity options and to identify possible training needs, feedback was sought from participants at a series of research dissemination workshops held at each of the ports during September 2012.

7.4 Case studies

The following section outlines the structure and management systems in place at the case study ports, as well as their experience of extreme weather events.

7.4.1 Workforce structure

Port workforces in Australia are tightly regulated, and are generally highly unionised (Griffin and Svensen, 1998; Hyman, 2007). The size and type of port, in terms of the cargoes it handles, and recently the extent of automation of its operations, are the main determinants of the size and structure of the workforce at any one port. With the increasing use of technology and automation of the port labour process the size of the workforce has been significantly reduced in many ports, including container and bulk ports (Gekara and Fairbrother, forthcoming 2013). Generally, however, the port workforce is divided into four components. Firstly, there is a distinct division between marine operations staff, comprising of harbourmasters and the vessel traffic services (VTS) staff, port pilots, pilot boat crews, tug operators and linesmen, and cargo operations staff, who do the actual loading and unloading work. These are commonly known as stevedores. Another broad categorisation, though less distinctive, is between the management and front-line workforce. Whereas the administration and management, and marine components of the workforce remains invariably similar (with

variances determined by port sizes), container terminals in Australia retain a larger number of frontline workers compared with bulk ports. This is because most bulk operations are often simple, less fragmented and highly automated.

A typical frontline container terminal workforce is made up of teams (also known as gangs). A team is normally organised around a ship-to-shore crane with three straddles. It typically comprises seven members, including 2 crane operators, who work rotationally; four straddle drivers (also working rotationally) and a team leader. The significance of the nature and organisation of the workforce at container terminals relates to the fact that the teams are normally located in the open yard and thus more exposed to the weather elements. Similarly, bulk-port yard workers, for example, tractor drivers and operators of other mobile equipment are normally exposed to the elements.

At Gladstone, the investigation focused on the adaptive capacity of the Port Corporation, at Sydney Port, the focus shifted to the adaptive capacity of one of the stevedoring companies at a single terminal (therefore not the broader port environment); for Port Kembla the terminal operators (stevedores) were excluded, and the focus was more on the Port Corporation itself.

All organisations have a majority of employed staff, rather than externally contracted staff, and all prefer to use permanent employed personnel in an overtime situation when workload capacity requires, as opposed to bringing in contract or casual labour. The Sydney Port terminal operator investigated as part of this research does have external labour contracts for its site maintenance; however, the other two ports keep this function in-house.

Gladstone has quite a diverse workforce, as their responsibilities include managing and operating the Port, as well as a local marina and its parklands, and a second port further along the coast. Port land and facilities are located at various sites within the port precinct. Because Gladstone is a predominantly public port whereby the port authority organises most of the operations, including stevedoring, the roles are highly diverse. The respondents, drawn from the port authority were therefore able to cover the broad spectrum of issues – including management, regulatory and operational. The roles include office-based roles such as administration, marketing and business development, finance and port planning, as well as field-based maintenance and operations roles, engineering, environmental and labouring roles, customer relations and engagement roles.

For the Sydney Port terminal operator, the workforce roles include office-based roles such as administration, finance, planning, logistics, sales and marketing. This component represents a smaller percentage of the workforce. The larger proportion of the workforce is employed in frontline cargo operations. This comprises mobile equipment operators (cranes, saddle carriers, trucks, forklifts etc.), supervisors, lashers and riggers. As pointed out earlier this larger proportion of the workforce is not office-based, and is therefore exposed to the weather, and its potential impacts. Although the workforce is predominantly permanently employed, there is a significant proportion of casual and semi-permanent workers [known as permanent guaranteed employees (PGE)] who supplement the workforce and provide the needed flexibility in situations of fluctuating work intensity. Furthermore, the PGE cohort forms the normal training and recruitment channel for the permanent workforce.

Port Kembla has a relatively compact workforce with a tight management group. Roles include marine and port operations roles [including marine operations, pilotage and vessel traffic services (VTS)], engineering and environmental management roles

(including infrastructure construction and maintenance, technical engineering and environmental management, and dredging), and corporate services (such as finance, administration, planning and business development).

For many of the roles across the ports, high levels of specialised skills are required – whether that be engineering, crane driving or vessel piloting. Because of the safety-critical nature of the work, training and certification is highly regulated and would normally be provided through an external accredited training program. However, the interviews revealed that the ports engage in extensive and continuous training of their staff, both new and existing with the aim of improving and/or maintaining high productivity as well as ensuring high safety standards.

“The pilots They go through an extensive training program when they get here...to become familiar with local conditions... that is fully accredited by the Harbourmaster. It's maritime safety requirements” (Port Kembla 01).

7.4.2 Management systems

A port's ability to adapt to climate change, particularly extreme events, is strongly influenced by the management systems in place, and how staff work within those systems. Thus, all kinds of climate change related disruption might be considered workforce related. However, there are some weather situations, which, in their extreme, would affect the workers directly e.g. extreme heat, intense rain or strong wind. Mostly, these weather conditions would impact directly on the health and safety of individual employees.

All the ports involved in the study operate quality and environmental management systems (EMS), occupational health and safety (OHS) systems, as well as emergency management and recovery systems and risk management systems. Management systems consistent with international standards suggest a systematic approach to tackling the issue at hand, whether that be environmental impacts through an EMS, safety concerns through an OHS system, or emergency and risk issues. For example, complying with the EMS international standard ISO14001, suggests a strong internal system of identifying environmental impacts, monitoring them and controlling impacts. It also suggests broader organisational understanding of environmental impacts, as communication is one of the key elements of an EMS. Importantly, it implies a systematic approach to environmental considerations. An externally certified EMS is not mandatory (and certification can be quite costly), however, it enhances the rigour of the EMS process, and is perceived to boost the environmental credentials of organisations.

Port Kembla's EMS is broadly consistent with ISO14001 (although not accredited as such); Gladstone's EMS was externally certified in 2006 to ISO14001:2004; while the Sydney Port terminal operator does not advertise accreditation to a particular standard, they do note they have systems in place to ensure environmental compliance with the relevant state legislation and licensing requirements. The latter also operates within a broader organisation that does not have an accredited EMS. EMSs are, by their nature, more concerned with the impact the organisation has on the external environment, rather than the other way around. However, a well-functioning EMS, operated by appropriately trained staff, will normally create a heightened awareness of the internal risks posed by climate change – whether this be extreme events or gradual shifts. It is also an indication of the organisational culture towards environmental responsibility more generally, and the amount of weight it is accorded within the organisation. Gladstone and Port Kembla have staff who are actively aware of the risks posed by

climate change, and are keen to learn of updated information to keep the systems updated and relevant (Port Kembla 01, Gladstone 03).

A common approach to considering climate change impacts is to consider impacts posed by climate change within the broader risk profile of the organisation (Commonwealth of Australia, 2006). A well-functioning, proactive risk assessment and management system is therefore a contributor to the adaptive capacity of a port and its workforce. Understandably, the risk management systems of ports are commercially confidential, so details were not disclosed. However, their websites report that Port Kembla's risk management program complies with Australian standard AS4360, Gladstone maintains a business risk database, and is implementing a more proactive risk management regime. To illustrate, one of the workshop participants at Gladstone observed that *"making decisions on a decent risk basis is something that is being strengthened at [our port]"* (Gladstone workshop participant, 26 Sept 2012). The Sydney Port terminal operator, on the other hand, chooses not to publicise its risk management approach.

In relation to extreme weather events, one of the most influential management systems relating to workforce adaptive capacity is the OHS management system (often quite closely linked with enterprise agreements). Port Kembla has a publicly available OHS Policy, which commits the organisation to meet or exceed legislative requirements. However, it is not accredited to a particular standard, whereas Gladstone's OHS Policy and Procedures Manual for Contractors are both publicly available, with the OHS Management System accredited under AS4801. The Sydney Port terminal operator has a safety policy and associated documents that are publicly available. According to the website, a safety management system is being implemented, but does not mention accreditation of the system to any standard.

In addition to these systems all the ports maintain an emergency management and response system. For Gladstone, for example, it is this system that is automatically triggered when a cyclone is approaching, and certain protocols and procedures need to be followed (such as cyclone monitoring, tying down equipment and so forth). This procedure sits within a full corporate emergency response and recovery plan. Sydney Port terminal operator also has an emergency response plan, but acknowledges it is mainly concerned with chemical spills. The port official interviewed explained that their *"... type of emergencies are mainly hazardous chemicals leaks"* (Sydney Port 01) but continued to elaborate that their emergency drills are undertaken regularly. Port Kembla's crisis management strategy consists of four elements: an emergency/disaster response plan, protocols for response to security incidents, overall security preparedness and the Disaster Recovery Plan (DRP) and the Business Continuity Management Plan (BCMP). The emergency/disaster response plan aligns with the international Incident Control System (ICS) protocols.

7.4.3 Weather events and impacts

Through the interview and workshop process, we were able to gather employee recollections of experiences, observations or general records of severe weather events and their impacts on port operations. Based on these recollections, we discussed the existing systems for mitigating the impacts of extreme weather situations that have the potential to disrupt port operations. Table 24 illustrates the recalled weather events, and their associated impacts.

For Gladstone, the main concern was with the impacts of cyclones – not cyclones passing directly over the port, but more the residual impacts of cyclones. Interviewees highlighted the combined effects of strong winds and heavy rain on port operations.

Also, the threat of cyclone activity in the vicinity was presented as posing a threat to the port:

“...if the threat's here for a week, you got to shut down for a week. If it's here for six hours, shut down for six hours” (Gladstone 02).

Table 24 Recalled weather events and associated impacts

Gladstone	
Cyclones (combination of strong winds, heavy rain)	<p>Slumping of coal stockpiles, dozers bogged, therefore slowing the load rate.</p> <p>Several hundred thousand dollars in costs to repair roadways, and to push coal back into piles.</p> <p>Required to close/tie down ship loaders. In the past, the port has been closed for anything from 24 hours to several days due to a cyclone event.</p> <p>Restricts movement of helicopters, therefore restricting movement of vessels.</p>
Fog	Restricts movement of helicopters. They can't land on vessels, therefore restricts the movement of vessels in and out of the port.
Intense rainfall	As well as coal slumping, stormwater ponds can fill up, so can lead to an onsite flooding issue; and may have flow on environmental impacts.
Long-term drying and heatwave	<p>When this is combined with winds, there are significant dust issues.</p> <p>Also an issue with spontaneous combustion of coal.</p>
Sydney Port terminal operator	
Wind/combined with swell	<p>Large swells prevent the pilots from boarding the ships, therefore disrupting vessel movement.</p> <p>Swell and choppiness can come up over the wharf during high wind/swell events.</p> <p>The whole port has been closed in recent time (August 2012) (for about 48 hours) due to high wind/swell event.</p>
Wind	Wind over 75km per hour closes the terminal operations
Heatwave	<p>They are not common in Sydney Port terminal operator, however, if over 35 degrees, the workflow is reduced.</p> <p>Over 38 degrees and the workforce stop work, effectively ceasing the majority of outdoor port functions.</p>
Heavy rain	<p>Combined with drainage issues, makes movement around the port a risk.</p> <p>The port has been closed on one recent occasion when water, combined with surface oil, closed the port.</p>
Fog	Small delays during heavy fog – loading and unloading, as well as movement around the terminal.

Port Kembla	
Extreme wind conditions	<p>Pose a risk for navigation conditions, particularly for vessels moving to and from the outer harbour, leading to a delay in vessel movement, and therefore port operations.</p> <p>Dust impacts from stockpiles during wind events.</p> <p>Ship loaders at risk of tipping, so need to be tied down during strong wind conditions disrupting loading and unloading operations.</p>
Sea swell/storm conditions	<p>Vessels can break mooring lines – so may be directed to cease loading/unloading and sent back out to sea;</p> <p>Causing a delay in port operations;</p> <p>For those ships at anchor, there is a risk of them dragging their anchors and ending up on the coast, so they may be directed to pull up anchor and head out to sea;</p> <p>Causing a delay in vessel movement, and therefore port operations.</p> <p>This sort of delay may be only a matter of hours, but can lead to days of disruption.</p>

Contrary to expectation, heatwaves were not perceived by the interviewees as of major concern. Yet when questioned, it was acknowledged that hot, dry weather does “*cause [coal] stockpiles to combust*” (Gladstone 05), thus, posing danger to the port facilities and the workforce.

At the Sydney Port terminal, “*wind is probably the greatest danger to us because the wind can close the port, not just the terminal the whole port*” (Sydney Port 01). Wind was seen as the biggest concern in Sydney Port by the terminal operator, not only due to its direct impact on operations (having to cease work and tie down equipment above a defined threshold), but also because of its potential to create choppiness in the port approaches, making it difficult and dangerous for pilots to board ships. As one interviewee noted:

“in the case of the terminal at [Sydney Port], the wind will whip up huge swells in the ocean and that prevents the pilots being able to get on and off the ship. So if they can't get on and off the ship, the ship doesn't leave the port or it simply doesn't come into the port. So we've had occasions ... where the port's been closed for up to three days and that severely affects the business” Sydney Port 01).

When prompted, the interviewee also noted that there were issues at the terminal with heavy rain, due to inadequate stormwater drainage.

The discussion at Port Kembla focused predominantly on the impact of strong winds, and associated sea swells, as explained by one official:

“[There are] two or three occasions a year where you get one of those sort of scenarios [strong wind and swells], where basically port operations either have to cease altogether in terms of the movement of vessels or certain vessels have to be interrupted or sent off to sea and it

might take them a few days to get back in the queue to be handled by the port.” (Port Kembla 01) Heatwaves were not seen as a problem, “we probably don’t get the same sort of prolonged heat conditions that you get down in say Melbourne or Adelaide in the summer” (Port Kembla 01), and neither were floods “the last sort of significant flooding event to affect the port was in 1998” (Port Kembla 01)

When discussing the impact of extreme weather conditions on the port operations generally, all ports mentioned the impact of weather on the supply chain. There was almost a fatalistic ‘outside our control’ attitude expressed across the board. For Gladstone, the most dramatic impact was the heavy rains affecting coal supply from the mines (either because the mines themselves had ceased production or because the rail transport had been affected). This led to reduced product flow through the port that impacted them for more than six months. In relation to the heavy rains in 2011, one interviewee noted:

“the big event that we had [nearly] two years ago actually shut us down for some time because there was no coal coming in from the coal companies - shut down all the in-loading station and then reduced on the out-loading, at some stage.” (Gladstone 02), and “a year and a half later we still haven’t got back to the level that we were pre that event, and that’s primarily because supply chain” (Gladstone 01).

It was also noted, that Gladstone had to carry their staff costs during this time, that is, continue to pay staff salaries and related costs while they waited out the rains, which is a financial burden on the organisation. Not only do such off-site heavy rains and consequent flooding stop work at the port, it also apparently makes it harder for the workers to get to work. This was an issue raised particularly by the Sydney Port terminal operator, where flash floods would normally impede the workforce getting to work. For Port Kembla, their most dramatic impacts were caused by extreme weather events in overseas locations – the floods in Thailand and the tsunami in Japan (both directly affecting freight movements).

These impacts can affect the workforce at the different ports in a variety of ways. At Gladstone, for example, if loading or unloading is delayed, then the workforce may be moved to assist with general maintenance duties. For longer delays, then the organisation encourages staff to take up leave options. As one interviewee noted, *“there may not be enough work, so we tend to put people off on leave or encourage them to take leave,”* (Gladstone 03). However, it was also noted that some staff rely quite heavily on regular “overtime” bonuses in their pay, and that reducing overtime for any period of time can have a significant effect on individual income, *“some guys get so dependent on overtime that it does impact for months after”* (Gladstone 01).

At the Sydney Port terminal operator, staff will generally be kept onsite during an extreme weather event, in the hope it will pass quickly. They are rarely sent home, but rather, stay in a staff room. As one interviewee (Sydney Port 01) noted, *“we won’t send them home because there’s a chance the port might open. So they’ll just hit the mess room and play cards or whatever to entertain themselves.”* If catch up work needs to be done, then overtime may be offered. Various “stop work” thresholds exist pertaining to extreme weather events, including heat, rain, lightening, wind and fog.

7.5 Discussion

7.5.1 Systems and Processes

Management systems in place at the ports have led to a range of adaptation mechanisms being adopted over the years to deal with extreme weather impacts.

At Gladstone, the adaptation measures would appear to be driven predominantly by emergency management and response systems. Several Gladstone interviewees identified their emergency management and response procedures, and the role these procedures play in determining thresholds and actions during extreme weather. Interviewee Gladstone 03, for example, noted:

"[we] have a number of procedures for dealing with a range of possible emergency scenarios or incident scenarios. Included in that are things like cyclones, floods, heavy rainfall events" (Gladstone 03)

To illustrate further, closing down equipment during approaching strong winds/heavy rain and cyclone events was mentioned as being part of the emergency response procedure. That is, if winds are above 72 km/h the ship loaders are moved into storm lock position, and if lightening is detected within 12 km of the facility, it is also put into storm lock position. Several staff commented that the cyclone response procedure was tested and reviewed annually during October - being the beginning of "cyclone season":

"Every year - I can only speak for production - in November - October-November training days with our guys, we would run through cyclone procedures and those sorts of things," (Gladstone 04).

Additionally, several of Gladstone's procedures for the mitigation of extreme weather events are based on the EMS (and in line with that, externally driven regulatory requirements). For example, they are heavily monitored for dust and water discharge from the site, so during strong wind and heavy rain events, work procedures have been developed to reduce dust from the coal heaps, and to reduce polluted discharge from the site. One interviewee noted *"we are really trying to develop and enhance the systems we have for safety, environment and risk"* (Gladstone 03) and saw this as a key means to adapting to the future impacts of climate change.

At the Sydney Port terminal operator, extreme weather can cause work stoppages in a number of situations, including extreme heat, fog and strong winds. Discussions with the terminal operator focused on the role played by the OHS system (and associated enterprise bargaining) for developing particular processes and thresholds. For extreme heat, a negotiated position has been reached where there are increased work-breaks and relief teams over 35°C, and work ceases over 38°C. High wind speeds above a certain threshold will also cause work stoppage: at a recorded threshold of above 75 km/h cranes stop work, and above 90 km/h the whole terminal stops. There are also negotiated benchmarks for heavy rain and fog, which are less readily defined. That is, they are not recorded in a particular OHS document, as a pre-determined volume of rain, or heaviness of fog. However, there are pre-determined parameters which both the workforce and management are aware of and work to. Seemingly it is a combined decision of the Health and Safety Representative, and the ship manager. In all situations mentioned above, it is the OHS system that has been the operational system that supports and facilitates the adaptation action.

The safety, environment and risk management systems also drive adaptation actions at Port Kembla. Like Gladstone, the port has an issue with dust and water discharge, so many innovative adaptations are brought about to minimise these impacts. Safety procedures surrounding the locking down of equipment during strong winds are in place, and linking with weather stations south of the port provides advance notice of impending wind events.

The systems discussed above guide the actions and behaviour of the ports' workforce, thus they can either enhance, or constrain the workforce's adaptive capacity. Reviewing thresholds, and effective operation of port systems as the climate changes, is an important step in keeping the systems relevant as conditions change. Through this review process, however, there needs to be the allowance for creativity and innovation, otherwise adaptations can be limited.

7.5.2 Skills and knowledge

The environment staff at all three ports (or those staff with specific environment responsibilities, such as environment planning or monitoring and compliance), clearly had an understanding of climate change and its potential impacts on their respective port environs. However, they did not themselves have the technical knowledge and skill around the shipping constraints particular weather thresholds may impose, or how to assess the resilience of infrastructure materials etc. In some ways, this skill is currently outsourced to consulting firms, who undertake climate assessments as part of development planning proposals at ports. The information is then returned to the reports through a written report. It is up to individuals to take on board the climate-related knowledge within those reports.

Most port staff interviewed exhibited quite a confident understanding of sea-level rise implications for their region. This is a climate related parameter that has been given some level of "certainty" by state governments legislating for minimum sea rise levels in planning regulations. All ports commented that future infrastructure development plans had incorporated anticipated sea-level rise in their design stage, and that any developments at the port were subject to a review and risk assessment of future weather conditions, which contributed to the development procedure. It was explained thus:

"There's been a lot of work done around planning for sea-level rise" (Port Kembla 01), and "the way the walls are built, considered some variations in climatic events including floods and wave surges." (Gladstone 01)

Some staff exhibited knowledge of some of the broader impacts of changing climate conditions, for example, one Gladstone interviewee was gathering information and research to inform the development of a pandemic strategy, acknowledging that vector-borne diseases such as dengue fever may prove a threat to the port in the future. While at Port Kembla, one staff member was very keen to hear of advancements in wave modeling, and proactively sought out this information. However, for many staff, future climate change was strongly related to their perceptions of current extreme weather events. They felt that the port was coping well currently with extreme events and that it would probably continue to do so in the future, as systems and technology would evolve to handle the new conditions. Therefore, these individuals did not appear to

actively seek out further knowledge on climate change or to enhance their skills in relation to it.

During workshops at the ports, participants noted that individual skills and knowledge around climate change were generally gained through professional development opportunities; which might be training sessions through industry associations, or attending workshops and conferences relevant to their field of work.

An important aspect of individual knowledge and skill acquisition is the access to information. This project reiterates what other studies have found, that future climate data, relevant to local situations, is very difficult to access and interpret. This indicates broader issues of communicating climate risks. During the workshop, the information requirements around future climate parameters were highlighted including variation to wave heights, wind velocity and direction parameters, variations to extreme weather events such as rain and storms for their location and so forth. These are some of the hardest to model into the future, thus causing additional frustration in the acquisition of work-relevant knowledge around climate change (conflicting with the need for evidence-based decision-making).

7.5.3 Organisational Culture

The organisational culture, as it relates to climate change adaptation, is strongly related to the leadership team, their understanding of climate change and its potential impacts, and to their willingness to adapt. Port Kembla strongly exhibited a leadership team that was actively seeking out knowledge of climate change and its impacts, as well as engaging proactively on the issue. Members of the management group proactively looked at how their weather monitoring and reporting systems may be used to better predict their future weather situation, and to actively seek out climate science relevant to their area.

Overall, each of the ports had a somewhat different corporate culture in relation to climate change. This varied from a view that the weather was outside the control of the organisation, and they would just deal with situations when they arose, as explained by one official: *"I don't think the company really sees it [the weather] as something they can do much about."* (Sydney Port 01), to one that encouraged engagement of staff in understanding climate change. This corporate cultural view permeated the consideration of future climate risks, and how these were being regarded by the organisation.

7.5.4 Observations

The foregoing discussions lead to a number of points regarding the three ports' cultures and attitude towards workforce adaptation. Firstly, there is seemingly a view that the ports have adequate structures in place to ensure that their workers are able to cope with current manifestations of climate extremes. Such manifestations vary from port to port but broadly include extreme heat, extreme wind conditions, strong sea surge, fog and flash floods. Secondly and following from the above, a lot of the measures in place relate to Occupational Health and Safety systems, Environmental Management systems and Emergency Response procedures. Seemingly, a focus on current situations as they arise is informed by the view that future changes to climate change are scientifically vague and therefore hard to prepare for. As one port official observed, *"It won't be until we really think about it that we'll realise that climate change actually was one of the drivers towards us changing the way we do things."* (Port Kembla 01). In other words ports will continue to do what they have always done in terms of making sure that their operations are safe, efficient and productive. Thus, reflecting on the culture at the different ports, apart from some very specific examples,

there was generally a view that climate change had not really been considered too deeply in future planning, except where legislatively mandated. Comments such as “*I don't think anyone's really paid much attention,*” (Sydney Port 01) reflect this view.

Having said that, however, the ports are beginning to think about ways by which they may better manage the impacts of extreme weather conditions. Note that these are not necessarily thought of as ‘climate change’ but as isolated and irregular weather cases. One of the ways highlighted is increased automation technology. Automation of operations, both at bulk and container terminals is seen as the surest way of guarding operations from weather related disruptions. The adoption of automated and remotely operated cranes, straddles and other mobile cargo equipment will, as explained by one port representative, ‘*take away people*’ (B01) from the operations and thus reduce work stoppages caused by workers prevented from working or accessing work because of extreme weather. The view here is therefore not one of adapting the existing workforce to a changing climate but rather reducing the human intervention, which is viewed as highly vulnerable.

Some of the measures highlighted, however, deal directly with making the workforce ready to work with and manage extreme weather conditions. Port Kembla explained their move to enhance the training of their pilots and pilot-boat crews, to be able to navigate in rough approach conditions. At this port there was recognition of the possibility that such conditions will increase with time and that their marine operations staff needed to be aware of this and be equipped with the skills to manage them. More generally the ports viewed the need for training as relating to the general safety awareness and emergency preparedness of the workforce. Enhanced and more targeted workforce training has been recognised in recent research as key to climate change adaptation. Nursey-Bray and Miller (2012:280) observe that in order to prepare for and adapt to a changing climate ports must ‘train ports and shipping professionals in risk and vulnerability assessment techniques’. They observe that:

It is important that maritime industry planners and professionals are able to rate the probability of climate change impacts in order to assess the social, ecological, political, economic and legal consequences of that particular impact (p. 280)

7.6 Recommendations for building adaptive capacity of the workforce

During workshops held in September 2012 at each of the ports, it emerged that one of the most important measures to facilitate the development of a workforce adaptive to climate change, was the development, or reinforcement of an organisational culture that accepted the need to act on sustainability and climate change. It was also recognised, that this stemmed from the CEO and the executive;

“We need support from the executive” (Sydney Port Wkshp, 19 Sept 2012) and “there needs to be a cultural re-orientation [to think about climate change]. [Here] it is very much in the organisation.” (Port Kembla Wkshp, 20 Sept 2012).

Suggestions for building a “climate change culture” emerged including developing a business case that outlined what would be the cost of action, versus inaction to adapt to climate change. This could potentially be supported by a port CEO/executive awareness program that presented the outcomes of this (and other) research in a visual way. One participant at the Gladstone workshop noted, “*awareness is the starting point*”.

The workshops also discussed how the management systems at ports might be altered to provide greater adaptive capacity. One port felt it was worth re-visiting the thresholds determined in enterprise bargaining and OHS systems, such as wind speeds and heat thresholds. Did they take account of changing equipment standards, as well as changing climatic needs? *“Why did we pick the thresholds we are working to? What was the evidence base?”* (Sydney Port Wkshp, 19 Sept 2012). Another thought a regular review of systems and alteration in an incremental way would be the best approach, ensuring climate change is considered in an ongoing basis.

It was felt that climate considerations should be incorporated into the regular risk review process of the ports. For some ports, this involves the development of a risk profile every two years, and may include sitting down with insurers as part of that process. However, there was not a lot of awareness of what additional skills and knowledge might be needed to adequately consider climate risks within the broader risk profile of the port.

Additionally, all three ports acknowledged that a “better/best” practice approach to management systems would help address the emerging adaptive capacity needs. Gladstone was rolling out a more standardised approach across the organisation to emergency management procedures. *“[We] are looking at a more standardised approach, assessing, testing systems etc.”* (Gladstone Wkshp, 26 Sept 2012)

The discussion around individual knowledge and skills focused primarily on professional development opportunities, and how these differed across different professions and trades. Professional development could be accredited training, conferences and workshops, or even opportunities to present publicly. The range of skills and knowledge the ports were interested in varied from more information on specific climate impacts (such as wave climate) and scientific modelling, through to sharing of innovations and ideas. *“General awareness of the variability of models would be useful”* (Gladstone Wkshp, 26 Sept 2012) and *“Proactive sharing of innovation between ports - perhaps through Ports Australia”* (Port Kembla Wkshp, 20 Sept 2012). One of the ports noted the value of having a management team that could creatively plan for future scenarios, recognising that this skill needed to be developed, perhaps through an external facilitator.

There was also some discussion about the flexibility of the workforce to move within roles within teams. At all ports, discussion about this was a little circumspect, as it is generally a subject of enterprise bargaining negotiations, and can therefore be perceived as an Industrial Relations issue that people did not wish to comment on. One port was working on a skills level matrix to facilitate some flexibility for the workforce.

Section 8 outlines particular training directions that could be undertaken to help facilitate a corporate culture conducive to climate change adaptation, and to develop the skills and knowledge to improve management systems, including risk management systems, that explicitly account for climate change.

8. RECOMMENDATIONS FOR TRAINING ON CLIMATE CHANGE ADAPTATION

8.1 Introduction

A 'human-focused' component of WP2 was to investigate potential training needs in response to extreme weather events. The research determined that the case study ports' processes and procedures adequately addressed many of the extreme events they currently face, even though they may have been developed in response to external regulatory stimuli (environmental or safety), or market imperatives (logistics interruptions), rather than as a direct response to climate change. However, there were opportunities to improve the integration of climate considerations into management systems to cope with future impacts. The research also discovered that executive level support was crucial for explicitly considering climate adaptation as part and parcel of normal planning and practice, and that this support varied across ports.

As such, a key finding arising from the evaluation was that the greatest opportunities for training around climate change issues in ports were likely to be through executive level awareness programs, and training to integrate climate considerations into management systems (a process of 'mainstreaming'), delivered through industry and professional associations.

As in section 7, interviewees cited in this section are identified according to their port and allocated a number Gladstone 01, Gladstone 02, Sydney Port 01, Port Kembla 01 etc.

8.2 Discussion

Through the course of the interviews with port representatives, it emerged that the ports already have a variety of systems and processes in place to cope with and manage the impacts of extreme weather. Although acknowledging there is always room for system improvement, management staff interviewed were confident these systems and processes adequately addressed current day extreme weather events, and that specific training for mitigating the impacts from extreme weather was not required. However, the research concluded that while specific training on extreme events may not be warranted, training opportunities are available that would strengthen ports' adaptive capacity and improve adaptation planning.

As Berkhout (2012) notes, climatic stimuli are just one of many drivers for change that an organisation faces. The processes and procedures developed by the participating ports to deal with the impacts of extreme weather were generally developed in response to external regulatory stimuli (environmental or safety), or market driven stimuli (logistics interruptions). Repetition of these system procedures over time allows them to become habit, and in essence, part of organisational culture.

The particular systems and processes that provide an operational framework for dealing with extreme weather events (as identified by the ports) include: enterprise bargaining and occupational health and safety systems (e.g. facilitating the development of guidelines that establish thresholds to activate 'cease work' procedures

during extreme heat) or environmental management and monitoring frameworks that cover environmental legislative requirements (contributing to such things as coal dust suppression measures during wind events). Emergency response and recovery procedures focus on the port's response to some extreme weather events; such as storms, cyclones, heavy rain and strong winds. Some of these systems had formal documentation around specific procedures (for example, cyclone procedures), others were passed on through experiential learning and habit (for example, coal stockpiling techniques) (Gladstone Wkshop, 26 Sept 2012).

In regard to these existing operational systems (environmental, occupational health and safety, risk and emergency), it was determined there was scope to influence them to improve their capacity to adapt to a changing climate (in essence, mainstreaming climate change considerations into existing policies). As part of improvement of these systems, the ports noted the need for improved tracking of extreme weather at their location, and better understanding and analysis of historical data.

The review and updating of these systems was stated by the ports to happen on an ongoing, regular basis. Gladstone, for example, mentioned they are continually updating their processes, such as reviewing the cyclone preparedness procedures, and also improving the general cleanliness around the port in preparation for the weather associated with nearby cyclones, so they don't have to undertake a "*mad clean-up*" (Gladstone 06, Sept 2012) as a cyclone approaches. It is important to note that this updating, or refinement, of organisational systems, is influenced by the skills and knowledge of the people undertaking the updating process, and the organisational culture within which they work.

Workshop participants noted the primary importance of organisational culture, driven by the CEO and executive, in facilitating climate adaptation action. "*We need support from the executive*" (Sydney Port Wkshp, 19 Sept 2012) and "*there needs to be a cultural re-orientation [to think about climate change]. [Here] it is very much in the organisation.*" (Port Kembla Wkshp, 20 Sept 2012). It was felt this influenced innovation towards testing and adapting new approaches in systems, and also subtly influenced individual learning and professional development. Adaptation literature stresses the importance of leadership in building adaptive capacity in organisations to climate change.

When discussing the individual level of skills and knowledge, the first question that needs to be addressed is "whose skills and knowledge?" recognising the roles and responsibilities of different members of the workforce. As outlined in Section 7 looking at Workforce Adaptive Capacity, the workforce at ports extends from management and administrative roles, to marine and logistics operations roles. The skills and knowledge requirements are very different across this diverse workforce. For example, a Port Kembla workshop participant noted that pilots were already undertaking training to navigate ships in choppy, more stormy conditions. Therefore, integrating climate change adaptation training, relevant to particular job roles, would best occur through particular industry associations and networks, such as Engineers Australia, and the Maintenance and Operations Group of the Australian Coal Terminals network (Port Kembla Wkshop, 20 Sept 2012, Gladstone Wkshop, 26 Sept 2012).

As a result of these interviews and workshops, the research determined that conducting training for extreme weather events was not warranted at this time. However, a number of opportunities exist to improve the awareness of climate change impacts at ports through different training approaches. These are outlined in the Training Recommendations section below.

8.3 Training recommendations

8.3.1 Executive Climate Risk and Adaptation Awareness

For climate change adaptation to be considered in ports, support is needed from the executive level management. Therefore, management need to have a good understanding not only of climate change per se, but a grounded understanding of climate change as it relates to their industry, and particularly their organisations (Lonsdale, 2010). The importance of peer-to-peer learning is also relevant for this target audience (recognising that adaptation is a learning process), as is the source of the training.

This research recommends an *executive climate risk and adaptation awareness program* be developed, specifically targeting executive level management at ports, delivered through a recognised and respected industry organisation such as Ports Australia.

Further evaluation would need to be undertaken, specifically engaging CEO's and executive management, to determine the precise content that would best inform their needs. However, preliminary discussions at the ports suggest any training needs to be underpinned by an evidence-based approach to identifying current and potential future impacts at ports. Due to the highly uncertain nature of future climate impacts, therefore particular port-specific impacts, this will require further research and data gathering on existing impacts at ports, to develop a business case for action.

Some inclusions in an executive training program would be:

- Understanding of the science, including such things as the IPCC scenarios, global climate models and uncertainties. This project found quite a high level of interest in discussing these topics during workshop presentations.
- Current weather (by relevant participant location) and future projections. Current weather information sourced from local observations and the Bureau of Meteorology would highlight weather variables of particular local interest. These may include intense rainfall events, average monthly precipitation and temperatures, extreme heat events, wind and storm activity. Future projections would be derived from Global Climate Models, with information sourced through the CSIRO.
- Presentation of accumulated port impact data (both direct impact, and indirect impact through the supply chain) in a visual, engaging manner. Ideally, this information would be regionally relevant, presenting the environmental and social impacts of climate events, and associated regulatory implications, but particularly, translating this to business costs for participants. This project identified that intangible impacts, such as influences on reputation, were an aspect of extreme weather delays that were acknowledged, but not necessarily

monitored. Presenting a generic business case for adaptation to climate change is a key feature of this training program, which would include an understanding of impacts of climate events.

- Discussion of market and legislative drivers for action on climate change, globally and regionally.

Any business case will include market and legislative considerations. In a globally competitive market, threats to supply lines and operation disruptions contribute to client assessments of a port. This project identified that clients sourcing coal through Gladstone decided to diversify their coal sourcing interests, subsequent to the disruptive rains in Queensland in 2010 and 2011. The disruption to the port's coal supply line caused by the floods proved to be a significant factor.

Although local legislative frameworks do not require ports to complete a climate risk assessment, other jurisdictions are implementing this regulation. It is conceivable that Australia will introduce this requirement at some point in the future (the UK Climate Change Act 2008, for instance, now requires all major infrastructure owners – including seaports - to report on their risk assessment activity and proposed adaptation responses).

From a strategic planning and financial responsibility perspective, those ports who can demonstrate they understand their climate risks, and have a plan in place to address them over the short, medium and long-term, will have a competitive advantage in accessing financial products such as insurance and can demonstrate responsible strategic management to clients and governments.

- Consideration of the range of approaches to climate risk assessment and adaptation options undertaken in ports globally.

Investigating and assessing climate considerations through the risk assessment lens is a common approach to understanding the business impacts of climate change. However, there are variable approaches that ports may take, depending on their existing risk assessment approaches, and their internal culture. This session will explore some common approaches, and identify best practice examples.

Adaptation to climate change is context specific; however, presenting port executives with a range of adaptation options undertaken by other ports will help ground the training in real, actionable items. An online portal of “best practice” could be considered, and this may be something Ports Australia would be interested in hosting.

8.3.2 Strategic Futures Training

One of the tools often employed as part of climate adaptation planning, is scenario analysis. While many executives and managers are involved in future planning for their organisations, few have the skills to develop and analyse scenarios that consider the possible future operating environments for their organisations. Companies such as

Shell have pioneered the scenario approach to inform their strategic planning (Shell, n.d.).

The suggested inclusions for a *strategic futures training program*, which includes climate considerations, targeting executive, senior and middle managers involved in port planning, would be:

- Understanding scenarios, and why to use them (using the IPCC scenarios as an ongoing case study through the training).

The main purpose of scenarios is to help businesses explore what their future operating environment might look like, and the challenges and opportunities they might face. Managers can use scenarios to explore issues and drivers of concern, and consider how they might prepare their businesses to face these uncertain futures.

This session will include information on the IPCC scenarios and draw on the methodologies used for scenarios research undertaken by the Victorian Centre for Climate Change Adaptation Research.

- Understanding the assumptions inherent in scenarios

All scenarios are underpinned by assumptions that can sometimes get lost later when scenarios are used in strategic planning exercises. This element addresses this issue, and helps participants explore some underlying assumptions that may be pertinent to the port sector.

- Recognising uncertainty, conflicts and dilemmas

Many managers use the excuse of the uncertainty around climate projections to delay action; however, managers make decisions in conditions of uncertainty all the time, they may just be a little more comfortable with these uncertain elements. Scenario planning recognises uncertainty, and different views which may lead to conflicts and dilemmas. This element will explore these, and how to address them through the scenario process.

- Operational aspects of planning the scenario project, determining scope, assigning responsibilities, research to be undertaken.

Scenario building is a complex exercise that needs more than just bringing people together in one room to discuss the possible future. This session will help participants consider some of the elements that need to go into preparing an organisation for a scenario building exercise.

- Building scenarios

Ideally, this session will provide managers with skills to lead, and effectively participate in a scenario building exercise.

- Interpreting scenarios for inclusion in strategic planning for ports

Finally, understanding how to use scenarios in strategic planning, in an ongoing manner, requires a shift in thinking for many managers. This session will present tools and techniques to assist managers gain support and commitment to utilising scenarios in planning processes, and demonstrate how they can be used.

8.3.3 *Systems and Climate Integration – Training on how to adapt systems for climate change*

As noted in the Discussion section, most responses to extreme weather events occur within the framework of a management system, such as risk or emergency management. Developing the skills and knowledge to update and improve these systems to take climate considerations into account is therefore a key training opportunity for ports.

Personnel who manage the following systems would be targeted to improve their knowledge and awareness of climate change, and provided with the guidance to integrate climate change into these systems:

- Risk management
- EMS
- OHS
- Emergency Management

Some inclusions in a *systems and climate integration program* would be:

- Understanding of the science – IPCC scenarios, global climate models and uncertainties.
- Current weather (by relevant participant location if possible) and future projections. Current weather information sourced from local observations and the Bureau of Meteorology and future projections would be sourced through the CSIRO. Please refer to the 1) Executive Risk and Climate Awareness for more detail.
- Presentation of accumulated port impact data, relevant for the particular system, that is, environmental impacts, safety impacts and emergency impacts. For example, heavy rains may lead to increased contaminated water outflow from the site, or increased temperatures may lead to increased cooling and air-conditioning requirements, leading to increased greenhouse gas emissions. Safety impacts may include incidence of heat stroke in higher temperatures and slipping incidents related to rain events.
- Relevant current and potential legislative drivers.

This project recognised that drivers for system change come from both regulatory, and market imperatives. Management systems need to understand and embed legislated minimum standards. This element will look at current legislated requirements, but also look at what has been introduced in jurisdictions overseas, as this may provide an indication of what is on the horizon for Australia. For example, currently Australian ports do not need to prepare an Adaptation Strategy, however as previously noted, this is a recent regulated requirement in the UK.

Ports are susceptible to regulations being imposed through community concerns and action. This element will explore some of the concerns emerging in communities around ports in Australia. Dust, noise and waste water discharge are three common environmental concerns already being monitored by government, and communities.

- Consideration of the range of adaptation options undertaken in ports globally that are relevant to the particular systems

Adaptation to climate change is highly context specific, however, a review and assessment of adaptation options that have been implemented in other ports (locally and overseas), will provide an opportunity to ground the training in real, future actions that may be of relevance to participants. The adaptation options selected will be relevant for the particular system being addressed, that is, environmental, OHS or emergency.

- Guidance to modify system policies, documents and communications (as the relevant systems require), to incorporate climate considerations.

This element will look at each of the system elements in turn, that is the overarching policies, embedded targets, strategies, procedures documents, training and communications elements and suggest how climate considerations can be embedded to be routinely considered in the management system.

The risk management training may need to be a little different, as there are emerging particular processes and techniques for undertaking climate risk assessments at ports.

The suggested inclusions for a *climate risk training program*, targeting port risk personnel (with a background in risk management) would be:

- Understanding of the science – IPCC scenarios, global climate models and uncertainties, basic climate change science (as identified earlier)
- Understanding scenario selection

This would not be a full “scenario training” session (as outlined earlier), however, it would explain why the different climate scenarios are important for the risk management process.

- Current weather (by relevant participant location if possible) and future projections. One approach to climate risk assessment looks at current vulnerability to climate variables, such as intense rain, storms and heatwave. Understanding current weather variability is therefore important. Some ports will already be collecting this information; whilst others may need to source it from reputable authorities such as the Bureau of Meteorology.

Once a future scenario has been selected, participants in this program will then be shown how to access and interpret relevant climate information for their region. With this will come an understanding of the limitations of downscaled climate models, and the potential variability between climate models. However, they will be able to confidently use the varying future climate projections for their risk assessment purposes.

- Future socio-economic conditions

Future climate scenarios are only one factor that needs to be considered as part of a future climate risk assessment. Ports need to also consider other elements of their future operating environment, such as population growth, trade and infrastructure trends and expectations. This element will look at what the important socio-economic and development drivers may be for ports, and where and how to access this information for future assessments.

- Understanding how to identify and evaluate climate vulnerability and climate risk. This involves consideration of changes to climate variables, their associated direct and indirect impacts, and the risks these pose for the organisation.

Participants in this training program will be taken through a hybrid climate vulnerability/risk assessment process, based on the ISO 31000 Risk Management Standard. Risk personnel will be familiar with this standard, and most elements of the approach, so the focus will be on embedding climate considerations within the steps of:

- Context setting (Current and Future)
- Current vulnerability identification
- Future risk identification
- Risk analysis (for current vulnerabilities and future risks)
- Risk evaluation (for current and future risks)
- Risk mitigation/ Adaptation option identification

- Evaluating climate risks alongside other organisational risks

Recognising the climate risks are just one type of risk faced by ports, it will be important for port personnel to evaluate climate risks alongside other emerging risks for ports. The key element here is to ensure that context parameters for

the risk assessments are comparable between broad organisational risks, and climate risks.

- Prioritising climate adaptation options

Adaptation options identified through the climate vulnerability/risk assessment process need to be prioritised, in line with other organisational risks. The most commonly favoured approach for prioritising options is a cost-benefit analysis. However, this approach needs to be able to factor in some key principles of adaptation, that is:

- Consider “low regrets” solutions that enhance co-benefits – that is, not only do they address climate risks, but perhaps address other risks or opportunities also, often with minimum cost.
- Avoid maladaptation – that is, actions that limit future adaptation options
- Start with minimising vulnerabilities to current weather variability (UKCIP, 2011)

8.3.4 General Awareness of Potential Climate Impacts

For those ports where the executive is proactively driving a consideration of climate change and its potential impacts on port operations, a more generic training for management, administrative and frontline staff would be appropriate. This training would aim to increase the awareness and understanding of climate change and its impacts generally. It will also assist port staff to identify the likely impact of climate change in different areas of the business, and the available adaptation options. The objective of this training is to assist staff ground the concept of climate change in their own reality, rather than it being a theoretical, removed concept. Additionally, those working outside at ports are more exposed to changes in weather, and have more practical experience of changing practice to adapt. Ensuring supportive processes to allow feedback into adaptation planning and implementation will add value to this training.

A general awareness of potential climate impacts program would be delivered in an interactive workshop format and could include:

- Understanding of the science – IPCC scenarios, global climate models and uncertainties, basic climate science (as outlined earlier)
- Recollections of current weather and extreme weather events, along with associated business impacts, and the response to these impacts.

This session would be delivered in an interactive workshop format, to encourage discussion and consideration of a broad range of extreme weather impacts. It enables participants to see how different areas of the business are affected, and may assist them reflect more deeply on how their work areas have been impacted.

- Understanding future weather projections (by location if possible)

This will provide an overview of the likely changes in weather their particular port will face. Following on from the “understanding the science” element, it will discuss the uncertainties inherent in determining future weather projections, but still provide some localised elements for consideration.

- Identifying and understanding impacts on ports future business

This element will be both a creative session, where participants will be encouraged to identify likely climate impacts relevant to their particular ports; but also will include examples of likely impacts at other ports around the globe, to stimulate discussion of non-linear impacts.

- Identifying adaptation options

To avoid training participants leaving a workshop feeling overwhelmed, this final session will help empower participants to identify possible adaptation options at their ports. We envisage that at the end of the session, each port will have prepared a summary document that outlines key future climate variables; associated impacts; and adaptation options. This creates a strong “take-away” message and tangible output for participants, and opportunity to inform adaptation strategies for the port (drawing on multiple sources of knowledge).

8.4 Summary

Ports work in a highly competitive environment, where the risks posed by climate change impacts are just one of many external pressures they must face. For attention to be paid to climate change issues, CEO’s and executive management need to understand the importance of climate change to their business. An awareness training program, targeted to executive staff would be an appropriate first step to improving the adaptive capacity of Australian ports. Recognising that many of the impacts to ports of extreme weather are dealt with through existing management systems, training focused on building climate change capacity into existing management systems, such as emergency, risk, environmental and occupational health and safety systems is recommended.

Additional training, focusing on building management capacity to develop, analyse and use scenarios relevant to their businesses was also identified. Although this is broader than just climate change training, WP2 suggest the scenario training be geared to focus on the inclusion of future climate considerations, as well as other relevant socio-economic, trade and political elements.

Finally, although there was not a large appetite identified for generic climate change training, it remains a possible training approach to help ground climate change for staff. That is, for it to be brought down to a local business impacts consideration, so that it is not a remote, theoretical concept, and an opportunity to contribute their personal experience and expertise.

9. CONCLUSION

This report presented the development of a transferable research methodology to assess the vulnerability of core port operations and logistics infrastructure to extreme weather events and rising sea levels in the context of Australian ports. WP2 examined the potential implications of extreme events for ports; the preparedness of port authorities to changes that are perceived as detrimental to port operations; and the approaches that are necessary to enhance the resilience of seaports to a changing climate.

9.1 *The approach*

A systematic approach to port selection was adopted project-wide to ensure that a range of port operations across the Australian ports and a diversity of geographic and climatic conditions were best represented. Meeting these criteria, the port authorities selected for the project were:

- Gladstone Ports Corporation
- Port Kembla Port Corporation
- Sydney Port Corporation

All three ports offered different work contexts in relation to the cargoes they process, the equipment they use and the core skills they employ.

Data for WP2 was collected and collated through a number of sources that employed a variety of methods. Drawing on high resolution LiDAR and aerial imagery databases, coupled with data collected through field surveys, a GIS based asset register was developed for one port location. This provided an innovative 2D and 3D capability to visualise the port assets and their perceived vulnerability to sea level rise.

An assessment of the perception of vulnerability and threats to port assets and logistics operations across key areas of sea-side, sea-land interface and land-side was undertaken using a survey questionnaire.

The adaptive capacity of the workforce was explored using semi-structured interviews with staff across the three case study ports. Through open-ended questions, respondents were invited to explain and discuss the relationship between climate impacts and port operations. In addition, a series of workshops held during September 2012 were organised to ascertain workforce adaptive capacity options with the objective of identifying possible training needs.

9.2 *Value/limitations/learnings from the approach taken*

Several limitations presented themselves as the approach unfolded, but also significant value. An important limitation was the reliance on a small and largely unrepresentative sample of case study ports, and the issues associated with the application of the raw data. Despite such limitations a transferable methodology for studying the impacts of climate change on port assets and operations was developed and, though not directly generalisable, important inferences can be made to the contexts of other ports in Australia.

The use of GIS simulation was well received by the ports, and created a valuable visual engagement tool. However, this approach was expensive, and could not be undertaken

for all potential climate impacts, and was also unable to be extended to all three case-study ports.

The survey technique used to develop the vulnerability matrix relies on the perceptions of the person completing the survey, and as such is subjective. Different ports approached this process in different ways. In some cases, an individual completed the survey from their own knowledge, whilst in others the survey was completed with the knowledge of several participating staff. The reliance on a single individual's knowledge can obviously lead to bias in the results. These perceptions were used within the CTOS, thus a flow on impact for the value of the CTOS was seen.

The semi-structured interviews with different port personnel, and the small workshops held, added significant value. They not only provided input to the research process, but they also allowed a sharing of knowledge about climate change impacts with the port representatives. Interviews were time-consuming however, and there was a limitation in gaining access to a wide variety of personnel at some of the ports. Additionally, some personnel were not able to attend the workshops, reducing the breadth of experience that could have been represented.

9.3 Project outputs

WP2 developed two software tools as part of the project: a GIS-enabled Asset Register for Port Kembla Port Corporation and a Container Terminal Operation Simulator (CTOS) for one particular terminal operating within the Sydney Port Corporation. A register of core operational assets and their climate vulnerability was also prepared.

The register of core operational assets together with the GIS visualisation capability contributed to vulnerability mapping of assets at Port Kembla Corporation. The case of a rise in sea level was demonstrated using the GIS-based visualisation capability.

The CTOS enabled a systematic assessment of various 'what if' scenarios associated with extreme weather events that are of most concern to port operations, out to the time period 2030. The outputs of this simulation were a set of Key Performance Indicators (KPIs) that allowed the levels of operational performance (e.g. crane rates, straddle productivity, truck queue length, yard utilisation) and the overall throughput within the container handling process to be compared when subject to different climate-related perturbations. The CTOS has been designed and coded in a manner that permits its modification such that it can be applied to other port contexts.

A selection of training options for port personnel was also identified. These options addressed various awareness, knowledge and skill needs, across different port roles and functions.

Finally, a hybrid risk/vulnerability assessment process was outlined (in a separate report), to assist ports understand their climate change risks, and prepare appropriate adaptation strategies.

9.4 Key research findings

- The modelling of sea-level rise shows the impact for Port Kembla would probably be low to moderate, resulting in minor inundation and reduced

capacity of some of the operational assets. Further 'ground truthing' at the asset level however has been recommended.

- The climate variables identified as 'of most concern' were tropical cyclones (Gladstone), high wind speeds (Port Kembla), and storm surge and tides (Sydney). The assets of most concern related significantly to high impact technical equipment, shore and ship cranes and some physical protection assets. This study uncovered varying perceptions about the role of sea-level rise as a threat to all assets.
- The results of the simulations highlighted that while the impact due to high temperature, rain, high wind and flooding were non-significant on the container related operations, rain and high wind had the most impact while flooding in the yard area impacted operations of the straddle carriers leading to backlog queues being created for trucks.
- Using annual hot days occurring at present and projected for 2030 the likely annual impact due to high temperature days was calculated by CTOS. The estimated impact of a heatwave scenario resulted in a productivity loss of 183 containers per year, which will increase to 241 containers per year based on the projected number of hot days in 2030. This figure is less than 0.01% of the annual container trade of the port.
- Ports view climate change and its impacts from a sustainability perspective. All ports identified the need for incremental learning and change of the emergency response systems as climate extremes change. Such change was seen by ports' to be essential for addressing emerging extreme weather events. A shift to mainstream climate change considerations into corporate risk management strategies more explicitly is needed.
- The importance of having executive support for an organisational culture to embrace climate change adaptation was highlighted across all three ports.
- Existing procedures for dealing with weather related impacts on the workforce were mostly based on OHS and environmental management frameworks and emergency response systems.
- All ports regarded new technologies, particularly relating to work automation, as a mechanism for mitigating the disruptive impacts of extreme weather conditions. Automation was also seen to improve OHS onsite, as it removes workers from potentially hazardous situations.

9.5 Research gaps and future work

The CTOS developed offers a versatile tool for estimating performance implications of extreme weather-related disruptions to port operations. The modelling outputs however, are sensitive to ongoing operational changes and potential errors in existing data. Thus, realistic determination will have to be dynamic and reiterated as new data become available. Future research endeavours should focus on the extension of this modelling framework to include measuring the vulnerability, and cascading impacts, of climate events on a wider supply chain network and the resultant simulated freight flow perturbation and logistics disruptions. Integration of historical data on the impact of extreme weather events on efficiency levels of terminal equipment and operations will further enhance the reliability of the results produced by CTOS.

The adaptive capacity of the workforce predominantly involved interviews and workshops with management/middle management. Future work interviewing and engaging with front-line staff would add robustness to the assessment of the workforce adaptive capacity, and potentially provide a wider array of adaptation and training options.

In sum, the report recommends more research in this area and that ports utilise a more systematic and detailed approach to data gathering, particularly as it relates to extreme weather conditions and related disruptions, asset registers and GIS-ready data.

9.6 Implications for policy and practice

One of the most striking practice recommendations to come out of the study, is the need for ports to work collaboratively with their supply chain and local council representatives to appropriately assess their climate risk, and develop collaborative adaptation strategies to mitigate their risks. Although this study did not explicitly research off-site impacts of climate change these were frequently mentioned.

Although a voluntary approach to climate risk assessment is preferred, a key policy recommendation would be for government to mandate climate risk assessments for significant infrastructure (such as ports). The UK experience has shown that mandating a climate risk assessment for all significant ports produces useful results.

Additionally, the report recommends a set of adaptation strategies to assemble a more adaptive workforce with greater capacity to respond to a changing climate. This was based on our investigation of the adaptive capacity elements of knowledge/skill/education, organisational customs/norms, and the organisational management systems and structures related to, and affected by, port operations.

- Ports need to integrate climate change adaptation as part of their wider risk management strategies, as well as their sustainable development agenda.
- The ability to act on sustainability and climate change requires a workforce culture receptive to climate adaptation. This may require the development of sound business cases for climate adaptation action at a localised level, and would be enhanced by more structured awareness training at all levels of the port organisation. Not surprisingly, CEO and senior executives have an important role to champion the organisational cultural change necessary for meeting climate challenges.
- The capacity of the ports' to adapt will be enhanced by incorporation of climate considerations in risk evaluation processes, workforce management and operational systems. This would include re-assessment of climate thresholds for ongoing enhancement of OH&S procedures and guide the actions, behaviours and practices of port workforces.
- Automation of operations in ports is perceived as a measure to reduce the cost of carrying staff during downtimes, including those caused by the impact of severe weather. It is also considered a strategy to reduce injury rates, as it removes people from contact with extreme-weather related hazards at ports.

Resilient ports need to act as functional nodes in the supply chain to allow greater consolidation of freight; while more vulnerable ports should adopt a 'trans-loading' strategy to outsource some logistics activities to inland container port hubs to reduce the amount of freight handling.

A re-assessment of port infrastructure design with reference to standards, specifications and procurement of assets could explicitly incorporate climate-proofing considerations. This is work required by both the ports, and governing authorities.

There needs to be a better integration of seaports located close to each other, as alternatives for freight diversion to proactively respond to a weather disruption.

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APPENDIX 1: Climate impact assessment matrix for Port of Gladstone

	CORE FUNCTION	OPERATIONAL ASSET	CLIMATIC EVENTS								
			Storm surge (wave)	Tidal changes	Flash floods	(streams and creeks)	High speed winds	Severe Tropical	Heat wave	Sea-level rise	Fog
Sea											
	Navigation and Pilotage										
		Boats	3	2	2	2	4	4	2	1	3
		Helicopters	1	1	2	2	4	4	2	1	3
		Automatic Tide Gauges	4	2	2	2	2	4	2	1	1
		GPS Base Station Pilot Navigation Aid	1	1	2	2	4	4	2	1	2
Sea-Land											
	Navigation and Pilotage										
		Pilot/ Port Control Room / VTS	1	1	1	1	1	3	1	1	3
	Leading Lights										
		Wild Cattle Cutting	1	1	1	1	1	4	1	1	3
		Boyne Cutting	1	1	1	1	1	4	1	1	3
		Golding Cutting	1	1	1	1	1	4	1	1	3
		Gatcombe Channel	1	1	1	1	1	4	1	1	3
		Auckland Channel	1	1	1	1	1	4	1	1	3
		Clinton Channel	1	1	1	1	1	4	1	1	3
		Targinnie Channel	1	1	1	1	1	4	1	1	3
		Rio Berthing Leads	1	1	1	1	1	4	1	1	3
		Clinton Swing Basin Leads	1	1	1	1	1	4	1	1	3
		Clinton Bypass Channel upstream	1	1	1	1	1	4	1	1	3
		Clinton Bypass Channel downstream	1	1	1	1	1	4	1	1	3
		Gatcombe Bypass Channel	1	1	1	1	1	4	1	1	3
		Golding Bypass Channel	1	1	1	1	1	4	1	1	3
		Communication Equipment	1	1	1	1	1	4	1	1	3

	CORE FUNCTION	OPERATIONAL ASSET	CLIMATIC EVENTS								
			Storm surge (wave)	Tidal changes	Flash floods	(streams and creeks)	High speed winds	Severe Tropical	Heat wave	Sea-level rise	Fog
	Docking										
	RG Tanna Coal Terminal										
	Berth 1	Mooring bitts (bollards)	1	1	1	1	1	1	1	1	
		Dolphins	1	1	1	1	2	1	1	1	
	Berth 2	Mooring bitts (bollards)	1	1	1	1	1	1	1	1	
	Berth 3	Mooring bitts (bollards)	1	1	1	1	1	1	1	1	
	Berth 4	Mooring bitts (bollards)	1	1	1	1	1	1	1	1	
	Auckland Point Terminal										
	Berth 1	Mooring bitts (bollards)	3	1	1	1	1	1	1	1	
		Dolphins	3	1	1	1	2	1	1	1	
	Berth 2	Mooring bitts (bollards)	3	1	1	1	1	1	1	1	
		Capstan winch	3	1	1	1	1	1	1	1	
	Berth 3	Mooring bitts (bollards)	3	1	1	1	1	1	1	1	
	Berth 4	Mooring bitts (bollards)	3	1	1	1	1	1	1	1	
	Swing mooring buoys										
		Friend Point	1	1	1	1	1	1	1	1	
		Quoin Channel	1	1	1	1	1	1	1	1	
		Facing Channel	1	1	1	1	1	1	1	1	
		Marina	1	1	2	1	2	4	1	2	
	Mooring piles										
		Auckland Creek	1	1	2	1	2	4	1	2	
Land											
	Cargo transfer										
	Gantry loader										
		RG Tanna coal terminal	1	1	1	1	3	4	1	1	
		Auckland point	3	1	1	1	3	5	1	1	
		Dozers	3	1	1	1	1	1	1	1	
	Cargo transport										

	CORE FUNCTION	OPERATIONAL ASSET	CLIMATIC EVENTS								
			Storm surge (wave)	Tidal changes	Flash floods	(streams and creeks)	High speed winds	Severe Tropical	Heat wave	Sea-level rise	Fog
		<i>Rail tracks RG Tanna</i>	3	1	3	1	1	1	1	1	1
		<i>Roadways RG Tanna /Auckland Pt</i>	3	1	2	1	1	1	1	1	1
	Storage										
		<i>Stockpiles</i>	3	1	4	1	1	2		1	1

Data received on 7 June 2012

Vulnerability rating	Rating description
1	Not at all vulnerable
2	Somewhat vulnerable
3	Moderately vulnerable (Operation down for hours)
4	Significantly vulnerable (Operation down for days)
5	Operation ceased (Operational down for weeks or more)

APPENDIX 2: Climate impact assessment matrix

	CORE FUNCTION	OPERATIONAL ASSET	CLIMATIC EVENTS
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for Port Kembla

			Storm surge (wave)	Tidal changes	Flash floods	Floods (streams and creeks)	High speed winds	Heat wave	Sea-level rise
Sea									
	Navigation and Pilotage	<i>Buoys</i>	2	1	1	1	1	1	1
		<i>Pilot boats</i>	3	1	1	1	2	1	1
		<i>Pilot station (buoy/ mark)</i>	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	Docking	<i>Tugboats</i>	2	1	1	2	2	1	1
	Channel transit	<i>cargo vessel/ship</i>	4	2	1	2	4	1	1
		<i>Mooring boats</i>	2	1	2	2	2	1	1
Sea-Land									
	Navigation and Pilotage	<i>Pilot/ Port Control Room / VTS</i>	1	1	1	1	1	1	1
		<i>Leading lights</i>	4	1	1	1	1	1	1
		<i>Lighthouse</i>	n/a	n/a	n/a	n/a	n/a	n/a	n/a
		<i>Communication Equipment</i>	4	2	1	1	2	2	2
		<i>Breakwater</i>	4	2	1	1	1	1	2
	Docking	<i>Mooring bitts</i>	1	1	1	1	1	1	1
		<i>Berths\Terminals</i>	3	2	2	2	4	2	2
		<i>Dolphins</i>	1	2	2	2	1	2	2
		<i>Fenders</i>	1	2	1	1	1	1	2
	Cargo transfer	<i>Shore cranes</i>	1	3	1	1	4	2	3
		<i>Ship cranes</i>	4	2	2	2	4	2	1
		<i>Bucket wheel reclaimer</i>	1	1	2	1	3	2	1
		<i>Grab Unloaders</i>	1	2	1	2	4	1	3
		<i>Grain loaders</i>	1	2	1	1	3	1	3
		<i>Coal loaders</i>	1	2	1	1	3	1	3
	Cargo transport	<i>Multi-trailers (roll trailers)</i>	2	2	2	2	2	2	1
		<i>Conveyor belts</i>	1	1	1	1	3	2	1
	Services	<i>Power supply</i>	1	1	2	2	2	2	1
		<i>Water Mains</i>	1	1	2	1	1	1	2
Land									

	Cargo transfer	<i>Yard cranes</i>	1	1	2	1	4	2	1
		<i>Hoppers</i>	1	2	2	1	4	2	1
		<i>Stackers</i>	1	1	2	1	3	2	1
	Cargo transport	<i>Trains</i>	1	1	2	1	2	1	1
		<i>Rail tracks</i>	1	1	3	1	1	3	1
		<i>Trucks</i>	1	1	3	1	3	1	1
		<i>Roadways</i>	1	1	3	1	1	2	1
	Storage	<i>Storage areas</i>	1	2	3	1	3	1	1
		<i>Warehouses</i>	1	1	2	1	2	1	1
		<i>Silos</i>	1	1	1	1	1	1	1

APPENDIX 3: CLIMATE IMPACT ASSESSMENT MATRIX FOR SYDNEY PORT TERMINAL OPERATOR

	CORE FUNCTION	OPERATIONAL ASSET	CLIMATIC EVENTS							
			Storm surge (wave)	Tidal changes	Flash floods	Floods (streams and creeks)	High speed winds	Heat wave	Sea-level rise	Fog
Sea										
	Navigation and Pilotage	Buoys	3	3	3	3	3	3	3	3
		Pilot boats	3	3	3	3	3	3	3	3
		Pilot station (buoy/ mark)	3	3	3	3	3	3	3	3
	Docking	Tugboats	3	3	3	3	3	3	3	3
	Channel transit	cargo vessel/ship	3	3	3	3	3	3	3	3
		Mooring boats	3	3	3	3	3	3	3	3
Sea-Land										
	Navigation and Pilotage	Pilot/ Port Control Room / VTS	3	3	3	3	3	3	3	3
		Leading lights	3	3	3	3	3	3	3	3
		Lighthouse	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
		Communication Equipment	1	1	1	1	1	1	1	1
		Breakwater	3	3	3	3	3	3	3	3
	Docking	Mooring bitts	2	2	2	2	2	2	2	2
		Berths\Terminals	2	2	2	2	2	2	2	2
		Dolphins	2	2	2	2	2	2	2	2
		Fenders	2	2	2	2	2	2	2	2
	Cargo transfer	Shore cranes	4	4	4	4	4	2	4	3
		Ship cranes	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a

		<i>Bucket wheel reclaimer</i>	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
		<i>Grab Unloaders</i>	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
		<i>Grain loaders</i>	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
		<i>Coal loaders</i>	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	Cargo transport	<i>Multi-trailers (roll trailers)</i>	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
		<i>Conveyor belts</i>	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	Services	<i>Power supply</i>	n/a	n/a	n/a	n/a	n/a	n/a	n/a	1
		<i>Water Mains</i>	n/a	n/a	n/a	n/a	n/a	n/a	n/a	1
Land										
	Cargo transfer	<i>Yard cranes</i>	4	4	4	4	4	2	4	3
		<i>Straddle carrier</i>	2	2	1	1	3	1	2	3
		<i>Hoppers</i>	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
		<i>Stackers</i>	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	Cargo transport	<i>Trains</i>	2	2	2	2	2	2	2	2
		<i>Rail tracks</i>	2	2	2	2	2	2	2	2
		<i>Trucks</i>	2	2	2	2	2	2	2	2
		<i>Roadways</i>	2	2	2	2	2	2	2	2
	Storage	<i>Storage areas</i>	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
		<i>Warehouses</i>	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
		<i>Silos</i>	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a

Data acquired on 2 August 2012

APPENDIX 4: Climate impact assessment matrix for Sydney Port Corporation

	CORE FUNCTION	OPERATIONAL ASSET	CLIMATIC EVENTS							
			Storm surge (wave)	Tidal changes	Flash floods	Floods (streams and creeks)	High speed winds	Heat wave	Sea-level rise	Fog
Sea										
	Navigation and Pilotage	Buoys	2	2	2	2	2	2	2	2
		Pilot boats	2	2	2	2	2	2	2	2
		Pilot station (buoy/ mark)	2	2	2	2	2	2	2	2
	Docking	Tugboats	2	2	2	2	2	2	2	2
	Channel transit	cargo vessel/ship	2	2	2	2	2	2	2	2
		Mooring boats	2	2	2	2	2	2	2	2
Sea-Land										
	Navigation and Pilotage	Pilot/ Port Control Room / VTS	2	2	2	2	3	3	3	3
		Leading lights	2	2	2	2	2	2	2	2
		Lighthouse	2	2	2	2	2	2	2	2
		Communication Equipment	2	2	2	2	3	3	2	2
		Breakwater	2	2	2	2	2	2	2	2
	Docking	Mooring bitts	2	2	2	2	2	2	2	2
		Berths\Terminals	2	2	2	2	2	2	2	2
		Dolphins	2	2	2	2	2	2	2	2
		Fenders	2	2	2	2	2	2	2	2
	Cargo transfer	Shore cranes	4	4	4	4	4	3	2	3
		Ship cranes	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
		Bucket wheel reclaimer	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a

		<i>Grab Unloaders</i>	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
		<i>Grain loaders</i>	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
		<i>Coal loaders</i>	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	Cargo transport	<i>Multi-trailers (roll trailers)</i>	3	3	3	3	3	3	2	3
		<i>Conveyor belts</i>	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	Services	<i>Power supply</i>	2	2	2	2	3	3	2	1
		<i>Water Mains</i>	2	2	2	2	2	2	2	1
Land										
	Cargo transfer	<i>Yard cranes</i>	4	4	4	2	3	2	2	3
		<i>Straddle carriers</i>	3	3	3	2	3	2	2	3
		<i>Hoppers</i>	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
		<i>Stackers</i>	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	Cargo transport	<i>Trains</i>	2	2	3	3	2	3	2	3
		<i>Rail tracks</i>	4	2	4	3	2	4	3	3
		<i>Trucks</i>	3	2	3	3	2	3	2	3
		<i>Roadways</i>	4	2	3	3	2	3	3	3
	Storage	<i>Storage areas</i>	2	2	3	1	3	3	2	3
		<i>Warehouses</i>	2	2	3	1	3	3	2	3
		<i>Silos</i>	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a

Data acquired on 9 October 2012

APPENDIX 5: Sample vulnerability rating template

Climate Event	Impact (disruptiveness) 1 to 5 where 1=least, 5=most na = not applicable	Frequency (V, O, N, R, na)	Capability: Response and mitigation (how did you/could you handle the event?)		Comments	10 yrs	20 yrs	50 yrs
			PAST	FUTURE				
Flash floods								
Floods (stream and creeks)								
Storm surge (wave)								
High speed winds								
Tropical cyclone								
Fog								
Heat wave								
Sea-level rise								
Tidal changes								

RATING KEY FOR FREQUENCY

V = Very often (four times per year *ie per yearly weather season*)

O = Often (two times per year)

NO = Not often (once every 5 years)

R = Rarely (once every 50 or more years)

RATING KEY FOR CAPABILITY

VW = Very well (no significant disruption – work continues as normal)

W = Well (minor disruption – work continues as normal)

A = Adequate (major disruption – work did/would not resume for hours)

P = Poorly (major disruption – did/would not resume for days)

