Commonwealth Attorney-General's Department

3 June 2010

Indian Ocean Territory Climate Change Risk Assessment

2010 Update Version

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Prepared for

Commonwealth Attorney-General's Department

Prepared by

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Disclaimer

AECOM has exercised reasonable care when completing this report. However, caution must be taken when considering our conclusions because significant uncertainty remains due to the inherent complexities involved in analysing the past climate and variables typically encountered when modelling future climate change. AECOM cannot guarantee the accuracy of the climate observations and projections described in this report and cannot be responsible for any third party's reliance upon on this information.

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List of Abbreviations

ABSLMP	Australian Baseline Sea Level Monitoring Project
AGD	Attorney-General's Department
AGO	Australian Greenhouse Office
AR4	(IPCC) Fourth Assessment Report
BoM	Bureau of Meteorology
CKI	Cocos (Keeling) Islands
CI	Christmas Island
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CZM	Coastal Zone Management
DFJ	December-January-February
GDP	Gross Domestic Product
IOT	Indian Ocean Territories
IOTHS	Indian Ocean Territories Health Services
IPCC	International Panel on Climate Change
JJA	June-July-August
MMA	March-April-May
OAGCM	Ocean-Atmosphere coupled General Circulation Model
SDA	Service Delivery Agreement
SLR	Sea Level Rise
SON	September-October-November
SRES	Special Report on Emission Scenarios
SST	Sea Surface Temperature
TAR	(IPCC) Third Assessment Report
TC	Tropical Cyclones

Key Terms

Adaptation	Actions in response to actual or projected climate change and impacts that lead to a reduction in risks or a realisation of benefits. A distinction can be made between a planned or anticipatory approach to adaptation (i.e. risk treatments) and an approach that relies on unplanned or reactive adjustments.
Adaptive capacity	The capacity of an organisation or system to moderate the risks of climate change, or to realise benefits, through changes in its characteristics or behaviour. Adaptive capacity can be an inherent property or it could have been developed as a result of previous policy, planning or design decisions of the organisation.
Climate change	Climate change refers to a change of climate that is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and that is in addition to natural climate variability observed over comparable time periods (United Nations Framework Convention on Climate Change)
Climate scenario	A coherent, plausible but often simplified description of a possible future state of the climate. A climate scenario should not be viewed as a prediction of the future climate. Rather, it provides a means of understanding the potential impacts of climate change, and identifying the potential risks and opportunities to an organisation created by an uncertain future climate.
Climatic vulnerability	Climatic vulnerability is defined by the International Panel on Climate Change (IPCC) as “the degree to which a system is susceptible to, and 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 change and variation to which a system is exposed, its sensitivity, and its adaptive capacity”
Mitigation	A human intervention to actively reduce the production of greenhouse gas emissions (reducing energy consumption in transport, construction, at home, at work etc.), or to remove the gases from the atmosphere (sequestration).
Risk	Risk is defined in general terms as the product of the frequency (or likelihood) of a particular event and the consequence of that event, be it in terms of lives lost, financial cost and/or environmental impact.
Hazard	A physically defined source of potential harm, or a situation with a potential for causing harm, in terms of human injury; damage to health, property, the environment, and other things of value; or some combination of these.
Sensitivity	Refers to the degree to which a system is affected, either adversely or beneficially, by climate related variables including means, extremes and variability.
Vulnerability	Vulnerability is a function of risk and response capacity. It is a combination of the physical parameter of the hazards and its consequences such as personal injuries, degradation of buildings and infrastructure and functional perturbations. It is also varying depending on non physical factors such as emergency preparation, education, and recovering capacity.

Executive Summary

The Vulnerability of the Indian Ocean Territories

As with many small islands around the world, the Indian Ocean Territories (IOT) – comprising Christmas Island (CI) and the Cocos (Keeling) Islands (CKI) – are vulnerable to the effects of climate change.

The Cocos (Keeling) Islands are a group of 27 low lying coral atolls located in the Indian Ocean approximately 2,950 km north-west of Perth and 3,700 km west of Darwin. Christmas Island is located approximately 975 km east-north-east of the Cocos (Keeling) Islands and is the top of a seamount rising to 361 m above sea level at its highest point. Christmas Island lies approximately 360 m south of Java.

Despite their different elevation and morphology, the two Island Territories share similarities (small physical size, vulnerability to natural disasters and climate extremes, remoteness and limited access, narrow economic base and low adaptive capacity) that add to their vulnerability to climate variability and changes.

Climate Change Observations & Projections

Both Territories experienced changes in the climate (such as air temperature and rainfall) over the past decades. These trends are likely to continue and even accelerate during the 21st Century.

The observed climate trends for the IOT include: an increase in annual and seasonal air temperature by 0.7°C for CKI and 0.4°C for CI since 1974; an increase in sea surface temperature by 0.5°C for both Territories, with a stronger warming trend during June, July and August (JJA); a significant decreasing trend in September, October and November rainfall on CI (- 420 mm since 1974); and sea level rise of between 4 mm/year (for the gauge tide station data, since 1992) and 5.7 mm/year (for the satellite altimetry data, since 1993) for CKI, and a 3.4 mm rise per year since 1993 for CI.

The future climate change projections for the IOT include:

- Increased seasonal air temperature ranging from 0.6°C warmer by 2030 to 1.8°C warmer by 2070;
- Increased sea surface temperature by 0.6°C in 2030 which may reach 1.8°C by 2070;
- Due to a high level of uncertainty, the projection of rainfall changes are difficult to identify, except that the driest seasons may become drier for both Territories and that the wet season may become wetter on Christmas Island;
- An average sea level rise of 14 centimetres in 2030 and 40 centimetres by 2070 for both Territories and up to 1.1 m by the end of the 21st Century (worst case scenario); and
- An increase in the number of intense tropical cyclones (TC) and storm events by 2030, and a decrease by 2070.

Sea Level Rise & Inundation

Sea level rise represents significant challenges for both Island Territories, especially the low lying Cocos (Keeling) Islands.

Sea level rise will represent significant challenges for the IOT, especially the low lying Cocos (Keeling) Islands. CKI has elevations between 1 – 4 m above sea level. Any change in the mean sea level, combined with the effects of storm surge associated with large storms or cyclones are likely to have dramatic consequences, especially for settlements on Home and West Islands.

Under current conditions, two out of 20 areas on Home Island are potentially flooded during a one in 10 year event, three areas during a 100 year event and seven areas during a 1000 year event.

In the future it is projected that the number of areas inundated on Home and West Islands is likely to increase quite dramatically with:

- Five out of 20 areas potentially being flooded during a 10 year event, two areas during a 100 year event and five areas during a 1000 year event by 2030; and
- Eight out of 20 areas, three areas for a 100 year event and three areas during a 1000 year event by 2070, and this would include all areas on Home Island.
- Fourteen out of 20 areas potentially flooded during a 10 year event (including eight areas out of nine for Home Island), sixteen for a 100 year event and eighteen areas during a 1000 year event by the end of the 21st Century, and this would include all areas on Home Island.

Christmas Island has a more rugged topography with a coastline mainly comprised of sheer, rocky cliffs from 10-20 m high, and a few small sand and coral rubble beaches. The interior is a slightly undulating plateau, from 160-360 m above sea level. It is not expected that CI will face the severe challenges projected for CKI; however, it is expected to experience issues relating to higher mean sea level and storm surge associated with extreme events, especially at Flying Fish Cove and other exposed beaches.

Extreme Events & Tropical Cyclones

Over 95 tropical cyclones have occurred within 500 kilometres of CKI, and 66 for Christmas since 1960.

Whilst the CSIRO projects a slight decrease in the number of cyclones and storm events in the IOT in the future, it is also expected that there will be an increase in the number of intense cyclones. A review of the Western Australia tropical cyclone data base found an overall increase of 42% in the intensity of cyclones (Category 3 and 4) between 1974 and 1998, and it is expected that the IOT will experience a similar trend into the future. It is projected that:

- The number of tropical cyclones occurring within 500 km of CKI and CI will decrease by 25% and 20% respectively by 2030, but the frequency of high intensity cyclones (Category 4 and 5) is expected to double.
- By 2070, the number of TC occurring within 500 km of CKI is expected to decrease by 73% and 68% for CI, while the frequency of high intensity cyclones is expected to decrease by between 12 – 28%.

Key Vulnerabilities

Vulnerability to Climate Change

The IOT are vulnerable to the potential impacts of climate change; however, the magnitude of exposure, sensitivity, vulnerability and risk associated with these changes is much greater for CKI.

Sea Level Rise & Inundation

Sea level rise is expected to exacerbate inundation, storm surge, erosion and other coastal hazards potentially threatening infrastructure, settlements and facilities on both Islands. CKI is especially vulnerable to inundation associated with storm and tidal surges, and this will very likely threaten public health and safety and possibly reduce the availability of fresh water.

Increased Damage to Coastal Areas

Increases in sea level, and the associated deterioration in coastal conditions from erosion of beaches are already extremely critical issues for both islands, especially CKI. These could become greater problems should climate changes result in 'unexpected' changes in ocean circulation patterns and local currents.

Coral Reefs

Increasing sea surface temperature, rising sea level, physical damage from storms and tropical cyclones, and decreases in growth rates due to the effects of higher CO_2 concentration (resulting in ocean acidification), are very likely to affect the health of coral reefs of the IOT, especially CKI.

Vulnerable Ecosystems & Biodiversity Loss

The IOT are home to distinctive ecosystems and a number of endemic species that are considered to be vulnerable to climate change. Terrestrial forests in particular, are highly sensitive to increases in temperature and humidity, and any changes in evapo-transpiration would affect soil moisture, forest cover, further pressure by introduced species and proneness to wildfire.

Risks to Water Supply

Water supplies could be adversely affected by changes in hydrologic cycles that result in more frequent droughts on both islands. However, there is strong evidence to suggest that under all of the projected climate change scenarios, water resources on Home Island in CKI are likely to be seriously compromised by inundation and seawater intrusion into freshwater lenses. The water supply on Home Island is already limited and under stress, and is likely to experience increased water stress in the future as a result of climate change.

Risks to Buildings & Infrastructure

Buildings and infrastructure in both Territories are considered to be sensitive to the effects of climate change. Almost all the buildings and infrastructure on CKI are sited along the coast, and are potentially exposed to sea level rise and inundation (even in relatively small events). In addition, with the exception of the airport on CI, almost all of the major transport infrastructure (jetties, wharfs and boat ramps) are potentially at risk from sea level rise and storm surge.

Risks to Economic Development and Tourism

It is likely that economic development of the IOT will be adversely affected by climate change, primarily due to the direct and indirect effects of climate change on tourism. Nature based tourism is a contributor to the economies of both Territories, and any negative impact on the islands' ecosystems, biodiversity, beaches, coral reefs and/or freshwater supplies will impact on tourism development and operations.

Implications for Culture and Traditions

Climate change is not likely to threaten the culture and traditions of the communities. However it is clear that cultural values, religion and belief systems in the IOT can and will potentially influence their responses to climate and climate change as well as their responses to mitigation and adaptation policies and strategies.

Risks to Human Health & Safety

The IOT are located in the tropics and already experience climatic conditions that are conducive to the transmission of tropical diseases such as malaria, dengue, filariasis, schistosomiasis, food- and water-borne diseases and to the promotion of other climate-sensitive diseases such as diarrhoea, heat stress, skin diseases, acute respiratory and infections. Whilst there has been no observed increase in these diseases to date, future climate projections suggest that both islands could possibly be affected by these changes. It is also highly likely that changes in the frequency, intensity, and tracks of tropical cyclones could have negative impacts on resident mortality and trauma rates in the short and medium term.

Cumulative Effects

The natural ecosystems appear to be the most vulnerable to the harmful effects of climate change. It is also likely that changes to natural systems will have negative consequences for the IOT economy, and play a major role in compounding existing socio-cultural challenges on the Islands, such as employment, livelihood and welfare.

Uncertainties and Unexpected Events

Significant uncertainties remain in the science underlying the climate change projections and the assessment of climate change risks. It is possible that the IOT will also face a number of unforeseen changes in the physical climate system (such as changes in ocean circulations) or ecological impacts that may not be anticipated, such as changes to individual species. Further research would improve understanding the ability to project societal and ecosystem impacts, and provide the IOT communities with additional useful information about options for adaptation. However, it is likely that some aspects and impacts of climate change will be totally unanticipated as complex systems respond to ongoing climate change in unforeseeable ways. On the other hand, some changes may be positive and represent potential opportunities.

Adaptation options

A range of adaptation options has been identified for each Territory. Adapting to climate change involves preparing for, responding to and coping with climate induces changes. This can be best achieved through government and community working together to improve the ability of island communities to cope with or respond to the impacts of climate change. Hence, it is strongly recommended that a community-based approach be implemented to dealing with climate change over the long term. Of course there are also a number of immediate short term issues, such as the protection of coastal infrastructure, life and property, and emergency preparedness that need to be addressed as a matter of urgency, and again it is imperative that community be given the opportunity to be involved in the adaptation planning and decision making process associated with these activities.

Part I – Introduction

1.0 Overview

1.1 The Indian Ocean Territories

The Indian Ocean Territories, which comprise Christmas Island and the Cocos (Keeling) Islands, are non self-governing Territories of Australia situated approximately 2,000 km west of Darwin in the Indian Ocean. These small islands have characteristics (such as their physical size, exposure to natural disasters and climate extremes, small economy and low adaptive capacity) that reduce their resilience and increase their vulnerability to climate change.

The provision of Australian Government services to the IOT is the responsibility of the relevant Australian Government agency, e.g. customs, quarantine and taxation.

The Department is responsible for the provision of all state type services to the IOT. State-type services are provided either directly by the Department, through Service Delivery Agreement (SDA) with the Western Australia Government or through contracted service providers.

Under the applied Western Australia local government legislation, each IOT has a local Shire Council that provides typical local government services, including road maintenance, waste management and some public work.

1.1.1 Cocos (Keeling) Islands

Cocos (Keeling) Islands are located in the Indian Ocean approximately 2,950 km north-west of Perth (12°30'S, 96°50'E), 3,700 km west of Darwin and about 975 km west-south-west of Christmas Island. The group consists of 27 low lying coral atolls with around 14 km^2 of emerged lands and 26 km of coastline, of which only two islands are inhabited. The island group is divided between 26 islands in the south and an isolated island, North Keeling Island, located 24 km to the north. North Keeling is a "C" shaped coral atoll of just over 1 km^2 of land area with a closed lagoon of around 0.5 km^2. The elevation of these low lying islands is generally below 5 m, and most of the islands are between 0 and 3 m above sea level.

1.1.2 Christmas Island

Christmas Island is located in the north-eastern part of the Indian Ocean (10°30'S; 105°40'E), approximately 360 km south of Java, 2,600 km north-west of Perth and 2,750 km west of Darwin. The island has an area of 135 km^2 with a coastline stretching over 139 km. Murray Hill is the highest point on the island at 361 m above sea level. The island is the flattened summit of a submarine mountain more than 4,500 m high. The island is all that remains of an extinct volcano, which is overlaid by limestone and coral rock which has accumulated over millions of years. Today most of the island is covered by tropical rainforest and 63% of the island has been classed as National Park in recognition of its outstanding biodiversity and conservation values.

Location of Cocos (Keeling) Islands and Christmas Island

Source: CIA World Fact Book

1.2 About the study

The Attorney-General's Department (AGD) engaged Maunsell AECOM (now AECOM), in association with the Australian Commonwealth Scientific and Industrial Research Organisation (CSIRO) and Coastal Zone Management (CZM) to conduct a comprehensive assessment of the risks associated with the future impacts of climate change on the IOT.

This climate change risk assessment for the IOT is the first step in the process of building an adaptation strategy for the Cocos (Keeling) Islands and Christmas Island.

1.2.1 Background

Findings of this project indicate that the climate in the Indian Ocean region is changing and that it is likely to accelerate throughout the 21st Century. This assessment provides a snapshot of how climate has changed in the region over the past decades, and to what extent it may change by 2030 and 2070. It also considers the possible impacts and risks associated with climate change now and into the future and analyses what island communities can do to adapt to an uncertain and changing climate.

1.2.2 Purpose of the Study

The purpose of this study is to research, identify, evaluate, prioritise, synthesise and report on the future impacts of climate change on the IOT (CKI and CI). In this context the study seeks to:

- Evaluate key climatic vulnerabilities of the IOT, in the context of other changes in the natural, social and economic environments;
- Gain a better understanding of the climate related impacts and risks apparent on both islands;
- Explore potential measures and options to adapt to climate change and seal level rise; and
- Identify the highest priority uncertainties about which we must know more to be able to respond to climate change in the future.

1.2.3 Scope of the Study

The scope of this risk assessment study includes:

1. The collection of relevant data pertaining to physical and biological characteristics of CKI and CI, and notably an evaluation of the known impacts of: sea level rise, storm surge, cyclonic activity and sea surface temperature rise.
2. The documentation and analysis of the latest climate change projections for two future times (2030 and 2070), including projections for: air temperature, rainfall, sea level rise, storm surge, cyclonic activity and sea surface temperature.
3. The present report (2010 science update) also includes a review of the latest development in terms of climate change science and more specifically to new projections of sea level rise.
4. The development of a comprehensive risk analysis of the potential impacts to the CKI marine environment, for the entire atoll, including reefs.
5. The development of a comprehensive risk analysis of the potential impacts to the CI environment, especially at Flying Fish Cove.
6. The development of a comprehensive risk analysis of the potential impacts to human settlement on CKI and CI including health, economic and infrastructure impacts.

1.3 Vulnerability, Risks & Adaptation

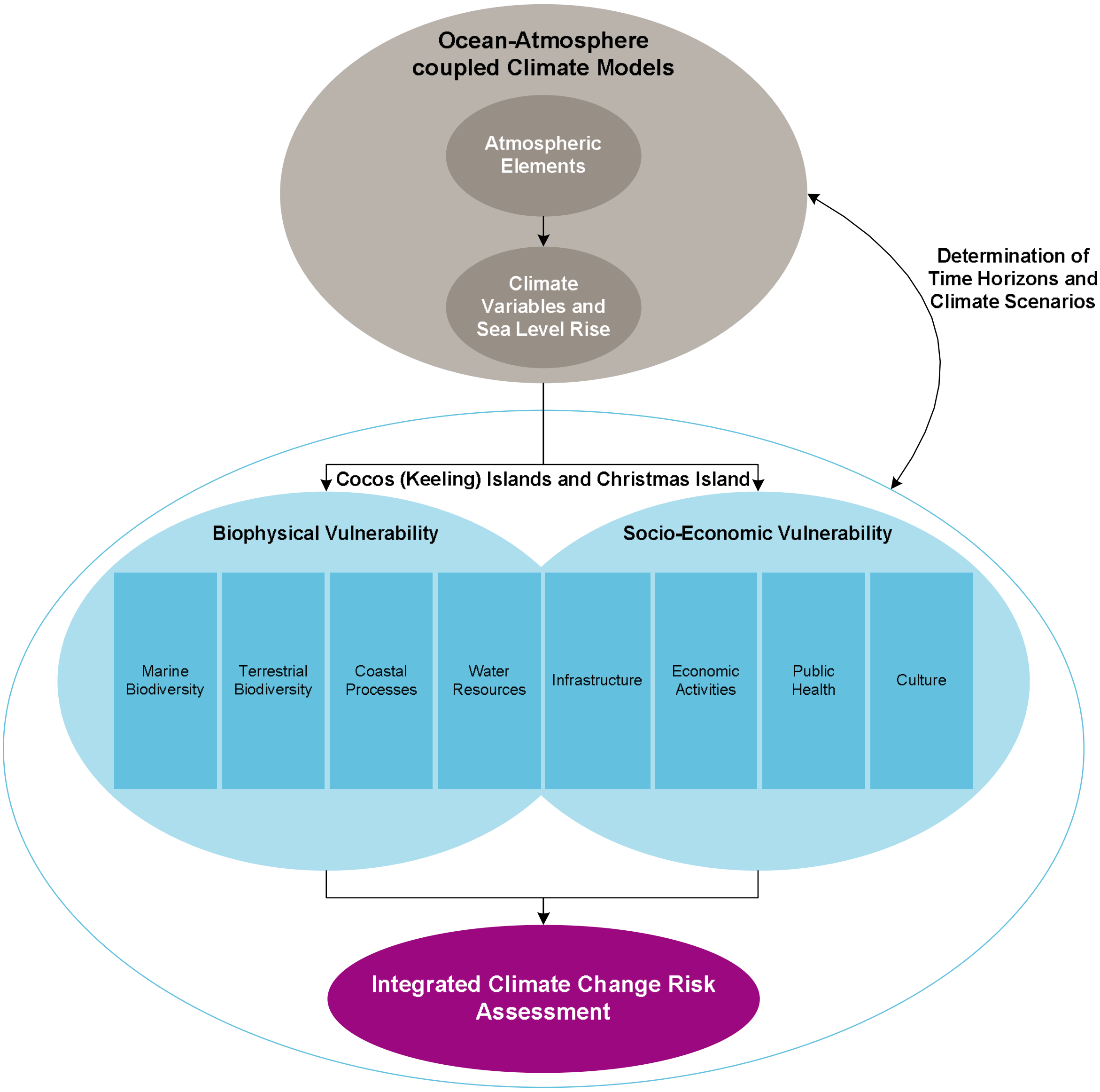
This study is an important first step in the process of developing a comprehensive adaptation strategy for the IOT.

The process adopted for the risk assessment involves three steps:

1. Assessing current vulnerability
2. Identifying and evaluating future risks
3. Exploring adaptation options

The approach adopted involved a blend of the approach outlined by the Australian Greenhouse Office (AGO) report "*Climate Change and Risk Management: A Guide for Business and Government*" in addition to a consideration of key tools proposed in the international climate change literature with respect to impact assessment. The assessment combined a vertical integration of climate change prediction information (Global→Regional→Local) with a horizontal integration of coupled assessment of climate change impacts on the natural and built environment. Figure 1 highlights the integrated assessment approach.

Figure 1 – The integrated assessment approach



1.3.1 Assessing Vulnerability to Climate Change

The risks posed to small islands by climate change are dependent on; the magnitude and severity of a given climate hazard, the likelihood of the hazard happening and the sensitivity of the stakes involved.

Sensitivity refers to the degree to which an island is affected either adversely or beneficially by climate change. The factors influencing sensitivity to climate change include; culture, tradition, gender, social networks, equity and governance. These can be broadly grouped into social, economic and geo-physical factors and they determine who is affected, how they are affected and the degree to which they are affected.

With climate change, there is little that small island communities can do to change the magnitude of a hazard, nor can they change the probability of the hazard occurring. However, island communities can invest in reducing risk – or the expected damage or loss due to the combination of vulnerability and hazards.

1.3.2 Identifying Future Risks

In the context of this study it is important to understand that vulnerability incorporates a number of dimensions; social, demographic, geographic, environmental, economic and cultural processes that influence how 'vulnerable' a community or system is to the effects of climate change.

As illustrated in Figure 1, the assessment of vulnerability begins with documenting the community's current exposure to climate-related risks, reflecting both the climatic conditions and location of human settlement, assets and infrastructure that place the community at risk. Vulnerability refers to the ability of a community or system to cope with the impacts of climate change and to recover. The vulnerability of a community is a function of:

- Exposure to climatic conditions and sensitivity to the impacts of climate change;
- The frequency, magnitude of climate-related risks to the community; and
- Response and adaptive capacity to deal with climate-related risks now and in the future.

The current capacity of the community to cope with climatic conditions is assessed by consulting local residents on how they understand the problem, what they do to prepare for, cope with or respond to climate-related risks. Together, the exposure to climate-related risks and the adaptive capacity characterise the vulnerability of the community.

2.0 Framework for the Risk Assessment

2.1 Climate Change Risk Assessment

People are considered at 'risk' when they are unable to cope with a hazard. A disaster occurs when a significant number of vulnerable people experience a hazard and suffer from severe damage and/or disruption of their livelihood system in such a way that recovery is unlikely without external assistance.

Risk is defined in terms of the probability of a particular climatic outcome multiplied by the consequences of that outcome. Defining risk by necessity involves making many subjective judgements, based on little available information and best judgement. It is necessary to weigh up the interests of different segments of society that may be impacted differently, of impacts incurred at different times in the future, and of impacts that cannot be readily costed in economic terms such as loss of species, heritage or sustainability. In this context it is important to note that climate change decision making is essentially about determining what the best course is for the near-term, given the expected long-term climate change and accompanying uncertainties, and this requires frequent revision as new information comes to hand which alters the level of uncertainty.

Table 1 provides a definition for the risk levels. These levels represent the degree or level of risk to which the Islands' natural system or human settlements are likely to be exposed if a given vulnerability occurs.

Table 1 – Qualitative measures of consequence

Level	Descriptor	Infrastructure Services	Community	Local Economy	Natural Environment
1	**Insignificant**	No infrastructure damage.	No adverse human health effects or complaint.	Minor negative impacts on key economic elements (i.e. phosphate mines, tourism)	No environmental damage
2	**Minor**	Localised infrastructure service disruption. No permanent damage. Some minor restoration work required. Early renewal of infrastructure by 5-10%. Need for new/modified ancillary equipment.	Short-term disruption to employees, customers and community. Slight adverse human health effects or general amenity issues. Isolated but noticeable examples of decline in social cohesion.	Temporary disruption to one key economic element (i.e. phosphate mines, tourism)	Minor instances of environmental damage that could be reversed i.e. negative impact on a specific species
3	**Moderate**	Widespread infrastructure damage and loss of service. Damage recoverable by maintenance and minor repair. Partial loss of local infrastructure. Early Renewal of Infrastructure by 10-20%.	Frequent disruptions to employees, customers or neighbours. Adverse human health effects. Minor public debate General appreciable decline in social cohesion	Temporary disruption to one or more key economic elements (i.e. phosphate mines, tourism)	Isolated but significant instances of environmental damage that might be reversed with intense efforts i.e. reduced fish stock

Level	Descriptor	Infrastructure Services	Community	Local Economy	Natural Environment
4	**Major**	Extensive infrastructure damage requiring extensive repair. Permanent loss of regional infrastructure services, e.g. a port facility washed away by a tropical cyclone. Early renewal of Infrastructure by 20-50%. Retreat of usable land i.e. residential and development land	Permanent physical injuries and fatalities may occur from an individual event. Significant public debate about climate change, constrained resources and services. Severe and widespread decline in services and quality of life within the community	A key element of the economy is disrupted for an extended period of time (i.e. phosphate mines, tourism)	Severe loss of environmental amenities and a danger of continuing environmental damage i.e. significant long term bleaching of coral reef
5	**Catastrophic**	Permanent damage and/or loss of infrastructure service across state. Retreat of infrastructure support and translocation of residential and commercial development.	Severe adverse human health effects – leading to multiple events of total disability or fatalities. Emergency response. Public outrage Region would be seen as unable to support its community	More than one key element of the economy is disrupted for an extended period of time (i.e. phosphate mines, tourism)	Major widespread loss of environmental amenity and progressive irrecoverable environmental damage i.e. death of coral reef

In this step, it is important how the degree of risk is determined. In some cases, a series of vulnerabilities combined to create the risk. In other cases, a single vulnerability created the risk. The determination of risk for a particular threat source is expressed as a function of 'likelihood' and 'impact'. Table 2 shows qualitative measures of likelihood.

Table 2 – Qualitative measures of likelihood

Level	Descriptor	Recurrent risks	Single events
5	**Almost Certain**	Could occur several times per year	More likely than not / Probability greater than 50%
4	**Likely**	May arise about once per year	As likely as not / 50/50 chance
3	**Possible**	May arise once in 10 years	Less likely than not but still appreciable / Probability less than 50% but still quite high
2	**Unlikely**	May arise once in 10 years to 25 years	Unlikely but not negligible / Probability low but noticeably greater than zero
1	**Rare**	Unlikely during the next 25 years	Negligible / Probability very low, close to zero

Various risk assessment methods and tools have been developed around the world, encompassing a broad range of application from cross cutting methods to specific sectoral methods, from a local to global scale.

Most methodologies are designed to evaluate risk according to morphological or economic terms, whereas social and ecological assessments have focused on vulnerability and sensitivity. In terms of small islands, there are primarily three main considerations when assessing risk, these being:

1) The economic vulnerability, to sea level rise and the consequences of storm surges;
2) The social vulnerability e.g. the incidence of extreme events with respect to mortality or social disruption; and
3) The ecological vulnerability that may be related to the disturbance of coastal systems, terrestrial ecosystems or coral reefs.

Table 3 presents the risk rating combining likelihood and consequences.

Table 3 – Risk rating matrix

		Consequences				
		Insignificant 1	**Minor 2**	**Moderate 3**	**Major 4**	**Catastrophic 5**
Likelihood	**Almost certain (5)**	M (5)	M (10)	H (15)	E (20)	E (25)
	Likely (4)	L (4)	M (8)	H (12)	H (16)	E (20)
	Possible (3)	L (3)	M (6)	M (9)	H (12)	H (15)
	Unlikely (2)	L (2)	L (4)	M (6)	M (8)	M (10)
	Rare (1)	L (1)	L (2)	L (3)	L (4)	M (5)

E = >20: Extreme risks demand urgent attention at the most senior level and cannot be simply accepted as a part of routine operations without executive sanction.

H = >12: High risks are the most severe that can be accepted as a part of routine operations without executive sanction but they will be the responsibility of the most senior operational management and reported upon at the executive level.

M = >5: Medium risks can be expected to form part of routine operations but they will be explicitly assigned to relevant managers for action, maintained under review and reported upon at senior management level.

L = <5: Low risks will be maintained under review but it is expected that existing controls will be sufficient and no further action will be required to treat them unless they become more severe.

2.2 Managing Risk through Adaptation

For this study, an integrated risk assessment approach that combines the processes of risk estimation for these three dimensions, combining bio- and geophysical with social, economic, and ecological data sets was adopted. This conceptual approach is based on and incorporates aspects from frameworks currently in use internationally for ecological and social risk assessment studies, and their associated terminology.

The application of this integrated risk assessment method should provide a solid base for managing climate change risk for the IOT in the future. In simple terms, risk management is about avoiding unacceptable consequences. Defining risk by necessity involves making many subjective judgements, based on little available information and best judgement. It is necessary to weigh up the interests of different segments of society that may be impacted differently, of impacts incurred at different times in the future, and of impacts that cannot be readily costed in economic terms such as loss of species, heritage or sustainability. In this context we make the important point that climate change decision making is essentially about determining what the best course is for the near-term, given the expected long-term climate change and accompanying uncertainties, and this requires frequent revision as new information comes to hand which alters the level of uncertainty.

In the climate change context there are two strategies or broad categories of responses or action which might be taken to avoid unacceptable consequences. These are adaptation and mitigation.

Adaptation is a strategy that reduces the adverse consequences, and increases the positive consequences, of any level of climate change. Mitigation is a strategy that reduces the level of climate change through reduction of greenhouse gases emissions, or, given uncertainty, reduces the probability of reaching a given level of climate change.

2.2.1 Identifying Adaptation Options

Also, given that even present climate variability leads to adverse impacts (such as the impact of tropical cyclones), a level of adaptation is necessary to cope with any unavoidable level of global warming and associated effects. Adaptation is thus a necessary strategy for at least coping with the inevitable climate changes.

This study focuses on identifying potential adaptation options and strategies for each island in order to reduce vulnerability to risks. The study also includes an assessment of the communities' adaptive capacity to accommodate future climatic conditions, and considers the community's current adaptive capacity, as well as the sustainability of current coping mechanisms.

2.3 Stakeholder Consultation

During the preparation of the Risk Assessment study, consultation was undertaken with a wide range of individual stakeholders, government agencies and non-government organisations. The aim of the consultation program was to:

1. Provide key stakeholders and the local island communities with opportunities to provide input into the Risk Assessment study;
2. Disseminate information on climate change and identify stakeholder issues;
3. Ensure that stakeholder concerns, opportunities and risks are identified and understood in a way that enhances the understanding of the impacts of climate change on both islands; and informs the development of the risk management strategies for the islands; and
4. Identify the priority issues, risks and potential impacts associated with climate change that AGD need to address as part of their broader plans.

Properly engaging stakeholders - including local people and government agencies, experts who participated in the assessment process, and target audiences or users of the assessment – was vital to the success of the assessment. Table 4 identifies the stakeholders who participated in the study.

Table 4 – Stakeholder consultation list

Stakeholder Groups
Federal Government Agencies
Department of Environment, Water, Heritage and the Arts
State & Local Government
Western Australian Department of Fisheries
Western Australian Department of Industry and Resources, Development Division
Western Australian Department of Environment and Conservation, EPA Service Unit
Western Australian Department of Environment and Conservation, Marine Ecosystems Branch
Shire of Christmas Island
Shire of Cocos (Keeling) Islands
Western Australian Water Corporation
Island Community Groups
Christmas Island Islamic Council
Cocos Congress (CKI)
Industry & Commercial Groups
CI Tourism Association
CI Economic Development Committee
CI Chamber of Commerce
Cocos (Keeling) Islands Tourism Association
Cocos (Keeling) Islands Economic Development Association
Phosphate Resources Ltd t/a Christmas Island Phosphates
Cocos Co-operative Society Ltd (CKI)
Industry & Commercial Groups
Forte Airport Management
Patrick (IOT) Port Management
Muslim Small Business Association (CKI)
Divers Association/Operators
Western Australian Fishing Industry Council
Ecowise water department
NGOs & Special Interest Groups
Marine and Coastal Community Network
Australian Conservation Foundation
Conservation Council WA
Australian Marine Conservation Society
Australian Coral Reef Society
Science Research Organisations
Curtin University Centre for Marine Science and Technology
Australian Institute of Marine Science, WA
Western Australian Museum, Aquatic Zoology Department

Part II – Climate Change in the Indian Ocean Territories

Climate Change: A Global Phenomenon

Climate change is a global phenomenon with resultant local trends and impacts. Its reality became more evident as the reports of the IPCC created a more accurate evaluation of climate change with compounding evidence of its consequences throughout the two last decades (1990, 1995, 2001 and 2007). Because of the inertia of the climate system, even if greenhouse gases releases in the atmosphere are dramatically reduced, the warming trend would be expected to continue during the 21st Century.

Origin of the Problem

Worldwide industrial development since the first industrial revolution in the 18th Century has caused greenhouse gases to be released into the atmosphere in great volumes. This enhancing of the natural greenhouse effect, combined with major land use changes and some natural climate variability has led to the contemporary climate change. To adapt to climate change, the first step is to understand how our climate is changing. There are many sources of information to help us in this process. The paleoclimatic reconstructions give us indications of how climate conditions have changed over very long period of time.

Past and Future Climate Change

Climate observations are obtained through meteorological networks. However, precise data sets with homogeneous measurement techniques are generally only available for the second half of the 20th Century. The climate models provide an indication of the potential future climate situations, based on variable emission scenarios. Much of the assumptions and hypothesis, that are used to estimate how the natural systems and human settlements might be impacted by climate change are subjects to uncertainty. Even if information about the future is uncertain, it remains valuable.

Emission Scenarios

Emission scenarios are estimation of the future quantity of greenhouse gases that may be released into the atmosphere. They are based on assumptions about future demographic evolution, the implementation and efficiency of energy policies. The scenarios are just assumptions and they are a primary source of uncertainties and are usually grouped into families. The IPCC developed scenarios in 1990, 1992 and 2000 (released as Special Report on Emission Scenarios, SRES). The SRES are used as input data for climate models. The IPCC emission scenarios are divided into four families (A1, A2, B1 and B2). A description of each scenario is given in Table 5.

Table 5 – SRES scenarios

<table>
<tr><th>SRES Scenario</th><th colspan="2">Description of Scenario</th></tr>
<tr><td>A1FI</td><td rowspan="3">Rapid economic growth, a global population that peaks mid 21st century and rapid introduction of new technologies</td><td>Intensive reliance on fossil fuel energy resources</td></tr>
<tr><td>A1T</td><td>Intensive reliance on non-fossil fuel energy resources</td></tr>
<tr><td>A1B</td><td>Balance across all energy sources</td></tr>
<tr><td>A2</td><td colspan="2">Very heterogeneous world with high population growth, slow economic development and slow technological change</td></tr>
<tr><td>B1</td><td colspan="2">Convergent world, same global population as A1 but with more rapid changes in economic structures toward a service and information economy</td></tr>
<tr><td>B2</td><td colspan="2">Intermediate population and economic growth, emphasis on development of solutions to economic, social and environmental sustainability</td></tr>
</table>

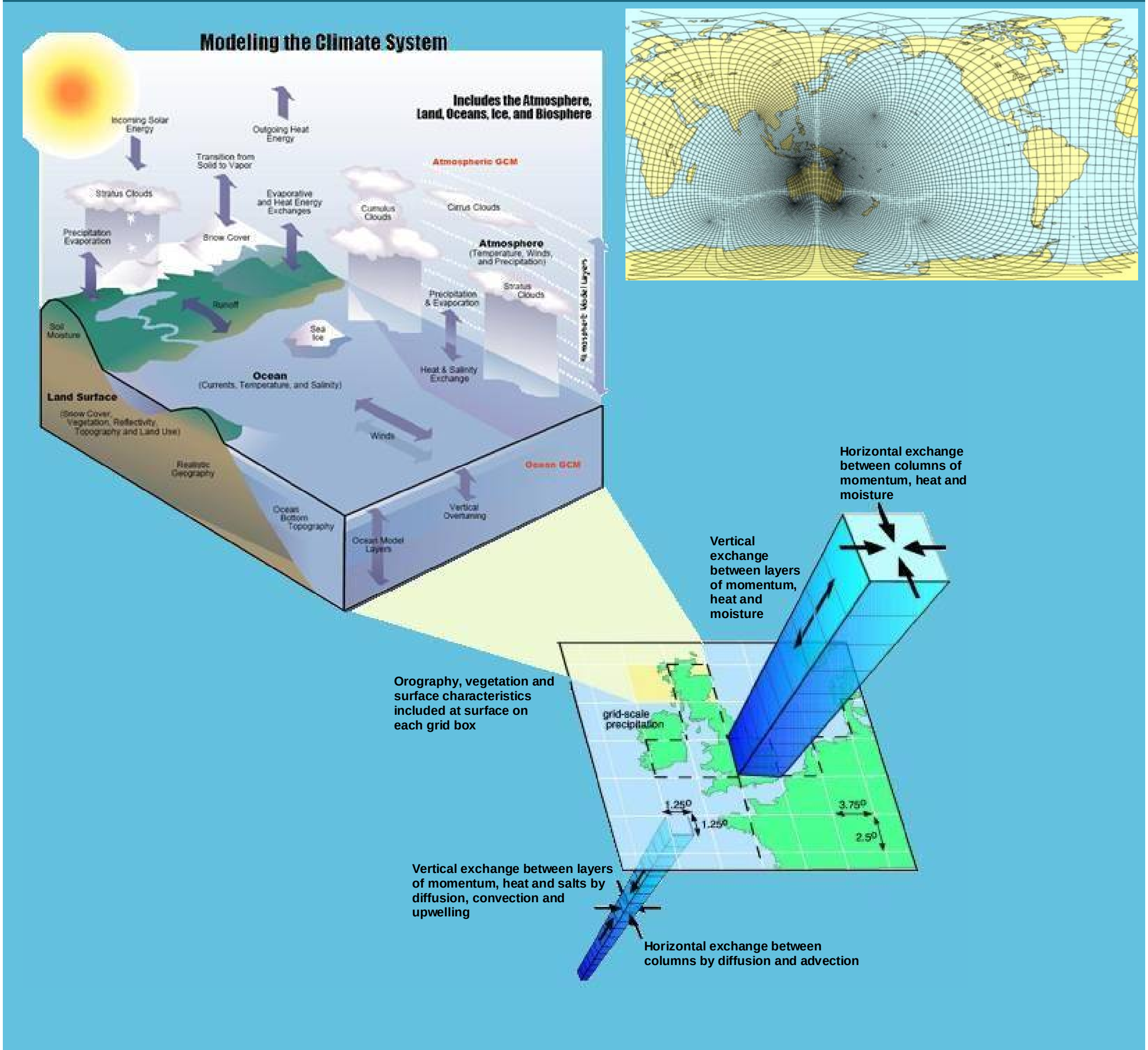
The IPCC developed scenarios in 1990, 1992 and 2000 (released as Special Report on Emission Scenarios, SRES). To reflect the last (and fast) changes of societies since 2000, new emission scenarios are currently under development. The SRES are used as input data for climate models.

Climate Models

The general circulation models are currently the best available tools to estimate what the future climate may be with increased concentration of greenhouse gases in the atmosphere. These are a simplified version of the physical and chemical processes driving our climate system through equation ensembles in a grid system covering the Earth (the grid has usually 200 kilometres of net size). Very often, they combine the processes taking place over the continent, the ocean and the existing relation between the large land and water masses. These are then called Ocean-Atmosphere coupled General Circulation Model (OAGCM).

The model still poorly integrates some features such as the topography, the cloud cover, the vegetation feedback or large scale driving climate pattern (El Niño Southern Oscillation). They propose a range of different future climates, depending on the emission scenarios chosen. The model results have to be considered as projections, rather than predictions. The climatic models will always be associated with a significant degree of uncertainty.

Climate models



Source: USGC 2004

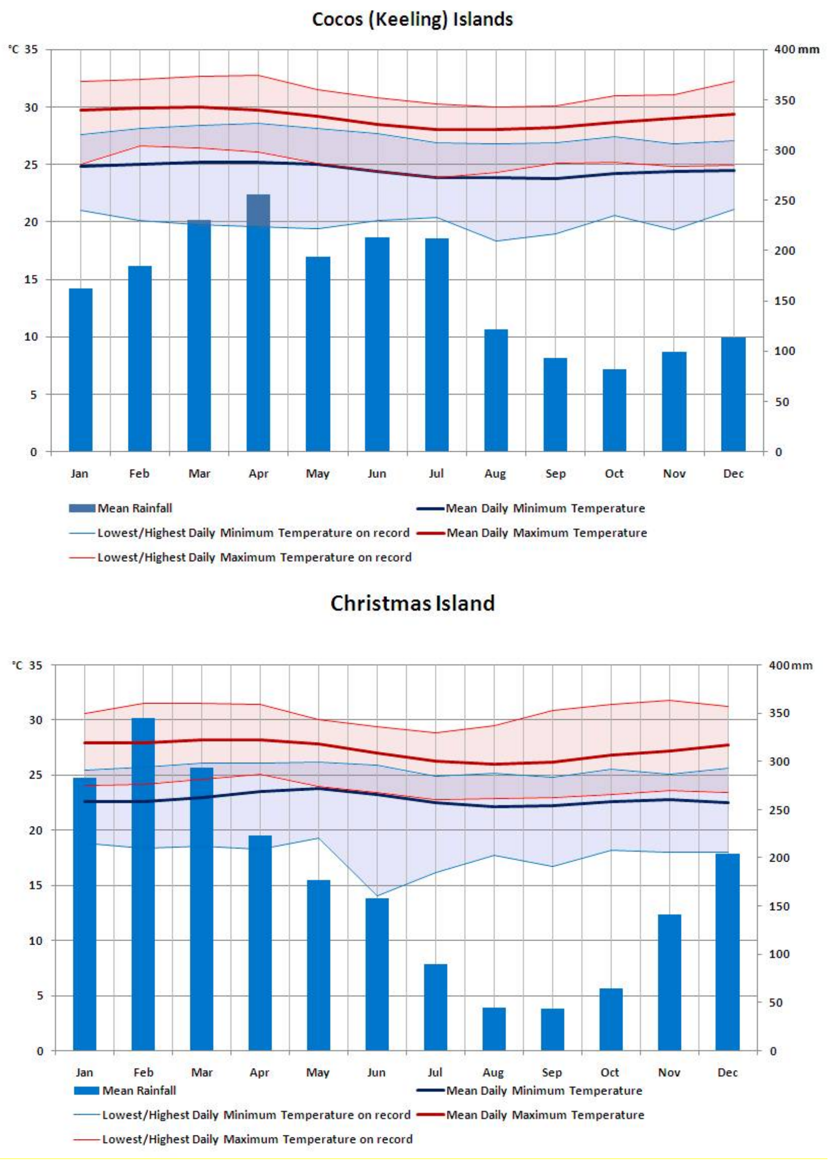
3.0 Climate Change: Scenarios for the Indian Ocean Territories

AECOM commissioned CSIRO to prepare a technical report detailing past and future climate trends in the IOT. CSIRO used data from the Bureau of Meteorology (BoM) to determine past climate trends. To perform the projections, the CSIRO Mark 3.0 climate model was used with the A2.

3.1 Current Climatic Conditions

The IOT are characterised by an equatorial oceanic climate with a wet and a dry season. Because of the strong oceanic influence, the thermal amplitude is very low. For CKI, the annual average daily maximum and minimum temperatures averaged respectively 29.0°C and 24.8°C over the 1974 – 2008 period. The temperature is slightly cooler for CI with the maximum average temperatures observed during the months of March and April (28°C) and the minimum average temperatures during the months of August and September (22°C). The mean annual precipitation for Cocos (Keeling) Islands amounts to 1,998 mm, most of which falls between January and July with March and April being the wettest months. The relative humidity fluctuates between 70% and 80%. On Christmas Island, the annual amount of precipitation is slightly higher with 2,154 mm, some falling as heavy downpours which last a couple of days (see Figure 2). The mean relative humidity varies little over the year and remains high at 80% to 90%. Southeast trade winds blow persistently from May to November.

Figure 2 – CKI and CI climate profile (Data: BoM 2010)



IOT Climate Change Snapshot

Climate Change Variable	Observed Trend 1953-2008 (CKI) 1974-2008 (CI)	Projections 2030	Projections 2070
Temperature	Warming of 0.7°C for the mean values with a strong warming (+ 1.1°C) of the minimum values	Mean, minimum and maximum values are projected to increase by 0.7°C in 2030 for all seasons	The trend continues and the warming reaches + 1.8°C in 2070
Precipitation	Decreasing trends in summer (- 100 mm) and winter (- 160 mm), no changes in spring and increased precipitation in autumn (+ 120 mm)	High uncertainties in the projections. The wetter season may become wetter and the driest season drier.	High uncertainties in the projections. The wetter season may become wetter and the direst season drier.
Sea surface temperature	The SST increased by 0.5°C with a stronger trend in winter (+ 0.8°C)	The annual SST may increase by 0.6°C in 2030	The annual SST may increase by 1.8°C in 2070 with autumn SST exceeding 30°C
Wind patterns	Decrease of 1.0m/s of the spring winds and increase of 1.0m/s of the autumn winds. 10° anticlockwise shift.	High uncertainties in the projections. If changes occur, they shouldn't exceed 0.72 km/h	High uncertainties in the projections. If changes occur, they shouldn't exceed 1.08 km/h
Sea level rise	Sea level rose between 3.4 mm/year to 9.8 mm/year since 1992, implying a rise between 5.4 and 15.7 centimetres	Expected rise of 13.9 centimetres by 2030	Expected rise of 40.1 centimetres by 2070
Waves pattern	Increase of the off coast waves height by 0.3 m since 1958 and slight decrease of the wave's frequency	High uncertainties in the projections. Potential increase of the swell waves in autumn and winter	High uncertainties in the projections. Potential increase of the swell waves in autumn and winter
Tropical cyclones	42% increase in the frequency of the intense TC (category 3 and 4) between 1974-1988 and 1989-1998	20-25% decrease in the number of TC, more than doubling in the frequency of intense TC (category 4 and 5)	68-73% decrease in the number of TC, and between 12-28% decrease in the frequency of intense TC (category 4 and 5)
Storm surge / tide	See Figure 8, page 31	See Figure 8, page 31	See Figure 8, page 31
Ocean acidification	pH value in the 1990s was 8.06 in the vicinity of CI/CKI	N/A	pH value is projected to decrease to 7.92 by 2070
Ocean current	Reduction in the strength of the Indonesian through Current	This trend should continue in the future. No quantitative projections	This trend should continue in the future. No quantitative projections.
Relative humidity	More humid trend observed in autumn, no trend for the other seasons.	High uncertainties in the projections. The assumptions point toward increase rather than decrease, changes would remain limited.	High uncertainties in the projections. The assumptions point toward increase rather than decrease, changes would remain limited.

3.2 Climate Change Observations and Projections (2030 & 2070)

3.2.1 Air Temperature

Air temperature evolution is important because it can have direct and indirect impacts on human activities. It is especially important as a source of numerous indirect impacts (from sea level rise to enhance cyclonic activities). Indeed, it is the main driving pattern of climate change impacts.

Observations

The mean annual daily temperature increased by 0.7°C for CKI and 0.4°C for CI. This warming trend has been more important during December-January-February (DFJ), with values reaching + 1.0°C, than during September-October-November (SON) with + 0.5°C for CKI. On CI, there are no seasonal specific trends.

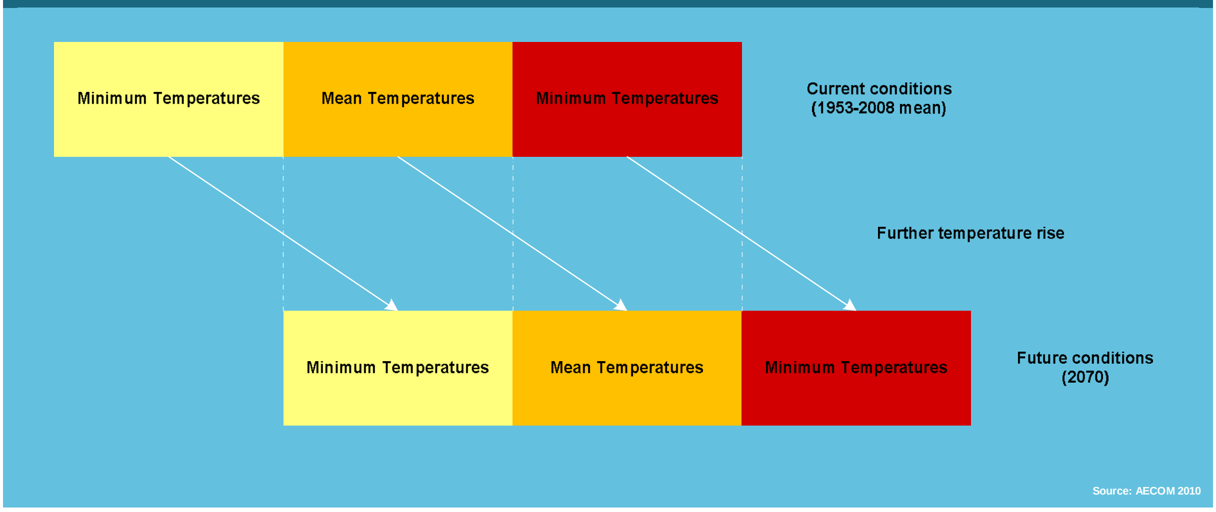
Even if the mean value trends are important to capture the magnitude of changes, the trends for the extreme values are generally more important in terms of risk assessment. The increase of the daily minimum temperatures is the main contributor to the mean increase for CKI with a 1.1°C increase since 1953. This warming trend has been less intense on CI with a 0.5°C annual increase since 1974, significant for all seasons except during SON exhibits the strongest change with a 0.8°C increase). On the other hand, the maximum temperature does not experience significant changes for either CKI or CI.

Projections

The warming trend observed during the second half of the 20th Century is expected to continue and may even accelerate throughout the 21st Century. By 2030, the mean temperatures are expected to be 0.7°C warmer for CKI and 0.6°C warmer for CI. The warming trend is similar at the seasonal level for both islands. By 2070, the mean temperatures are projected to increase by 1.8°C for both CKI and CI.

The projected trends for the minimum and maximum values are strictly identical to the mean values projections. By 2070, the minimum temperatures are expected to be close to the current mean temperature and the mean temperatures are expected to be close to the current maximum values, resulting in a shift shown.

Temperature shift



3.2.2 Sea Surface Temperature

The Sea Surface Temperature (SST) is defined as the water temperature at one metre below the surface. A warmer SST can increase cyclone proneness, induce coral bleaching events and have consequences on oceanic currents or distribution of fishing resources.

Observations

Since 1953, the annual value of the SST in the vicinity of CKI has increased by 0.5°C with a stronger warming during June-July-August (JJA) with + 0.8°C.

For CI, a significant warming of the SST has been observed for all seasons (0.5°C since 1974) except spring. JJA is again the season when the warming has been the strongest (+ 0.6°C).

The strongest warming trends of SST have been observed off the south-east and south-west coasts of mainland Australia.

Projections

The SST is projected to experience further warming during the 21st Century. By 2030, the SST may increase by 0.6°C for all seasons except JJA (+ 0.7°C) for both Territories. The autumn SST would then get closer to 30°C. By 2070, the warming might reach + 1.7°C for the annual average for CKI (+ 1.8°C for CI) and higher values for autumn with a + 1.9°C trend. In 2070, SST values are projected to exceed 30°C in summer and autumn for CI and in autumn for CKI.

3.2.3 Precipitation

Observations

At CKI, the year-to-year variability is so important that the trends based on measurements are not considered as "statistically significant". For example the averaged annual sum of precipitation tended to decrease by 140 mm over the 1953 – 2008 period but the margin is ranging from – 700 mm to + 420 mm, displaying opposite direction trends. On CI, DJF is the wettest season of the year and 42% of the annual precipitations fall during this time.

JJA and SON are the driest seasons with approximately 13% of the annual precipitation each. As for CKI, the very high year-to-year variability means that most of the evolution trends are considered to be non-statistically significant. SON is showing a significant trend with a 420 mm decrease since 1974.

Projections

For both Territories, the precipitation projections are associated with very high uncertainties. The models indicate controversial results with contradictory directions (increase and decrease at the same time). Scientists consider that decreasing trends during the driest seasons are more likely than increase for both territories. On CKI, the wettest season might also become wetter. The quantitative projections are of little use because of the high uncertainty.

3.2.4 Wind patterns

Any changes in wind pattern direction or intensity could results in local changes of wave's patterns or erosion.

Observations

The wind climate for CKI is dominated by south-easterly trade winds which are sustained for 85% of the year. The mean daily wind speed peaks in September (8 m/s) and is weaker in February (4.6 m/s).The observation data indicates a significant decline in spring wind speed with a 1.0 m/s decrease. Over the same period, there has been a significant increase of the autumn wind speed by 1.0 m/s. A 10° anticlockwise direction shift has also been observed since 1953.

The wind climate for CI is dominated by south-easterly trade winds between March and December and light north-westerly winds during the Monsoon season (December to February). The mean wind speeds peak in September (7 – 8 m/s) and is weaker in March (> 1m/s). For CI, wind direction and speeds do not exhibit any significant changes since 1975.

Projections

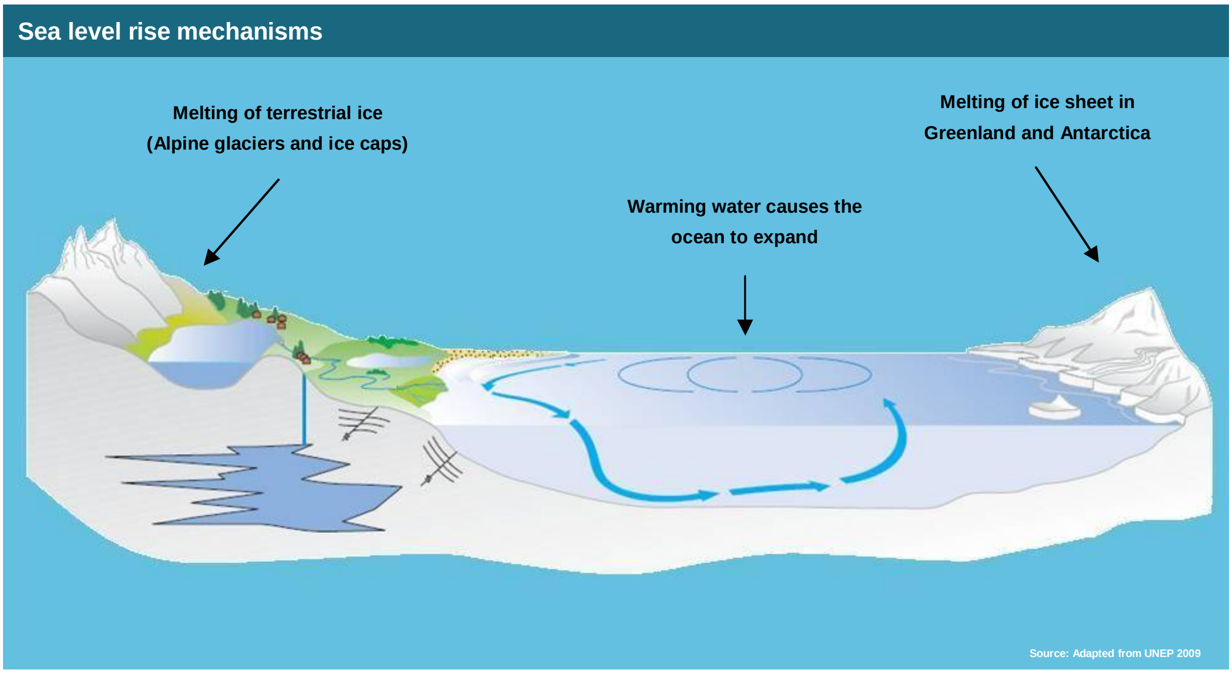
It is unclear if annual and seasonal wind speed will increase or decrease in the future. It is unlikely to change by more than 0.2 m/s (= 0.72 km/h) by 2030 for seasonal and annual values. By 2070, the projected wind speeds for the annual, winter and spring values should not change by more than 0.3 m/s (= 1.08 km/h). The projections for summer and autumn are more uncertain. The projections in terms of wind patterns are associated with significant level of uncertainties for CI. The climate models indicate a slight decrease of the wind speed.

3.2.5 Sea level

Sea level rise is particularly important for low lying areas as it enhances coastal erosion, proneness to inundation and increases storm surge/storm tide vulnerability.

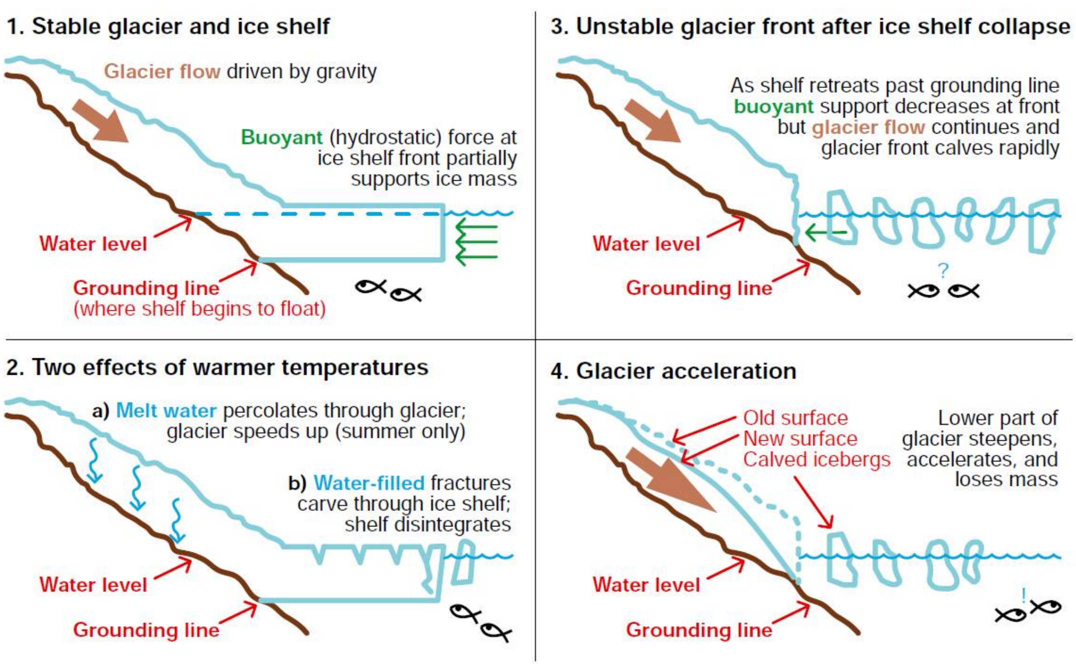
Causes

The observed sea level rise is mainly the consequence of the thermal expansion of ocean water. As the water gets warmer, it expands and the global sea level rises. The melting of alpine glaciers and icesheets (in Greenland and Antarctica) are also increasingly contributing to this rise.



Ice is a highly elastic material and as a result, glacier and ice sheet are very dynamic environments. Complex interactions and physical processes are involved in glacier and ice sheet movement. Researchers have recently highlighted dangerous feedback effect. Warming of the ocean and melting of ice due to warmer air temperature have the potential to accelerate the rate of melting of some calving glaciers (glaciers reaching the sea) and the Greenland and Antarctica ice sheet (see Figure 3).

Figure 3 – Glacier and ice shelf interactions (DCC 2009)



Observations

Sea level rise has occurred at a global mean rate of 1.7 mm per year for the past century, and more recently at rates estimated near 3.1 ± 0.7 mm per year (1993-2003) (Bindoff *et al. 2007)*. Current sea level rise is considered to be at least partly due to human-induced climate change which is expected to continue to increase sea levels this century. Increasing temperatures contribute to sea level rise due to the thermal expansion of water and the addition of water to the oceans from the melting of terrestrial ice sheets.

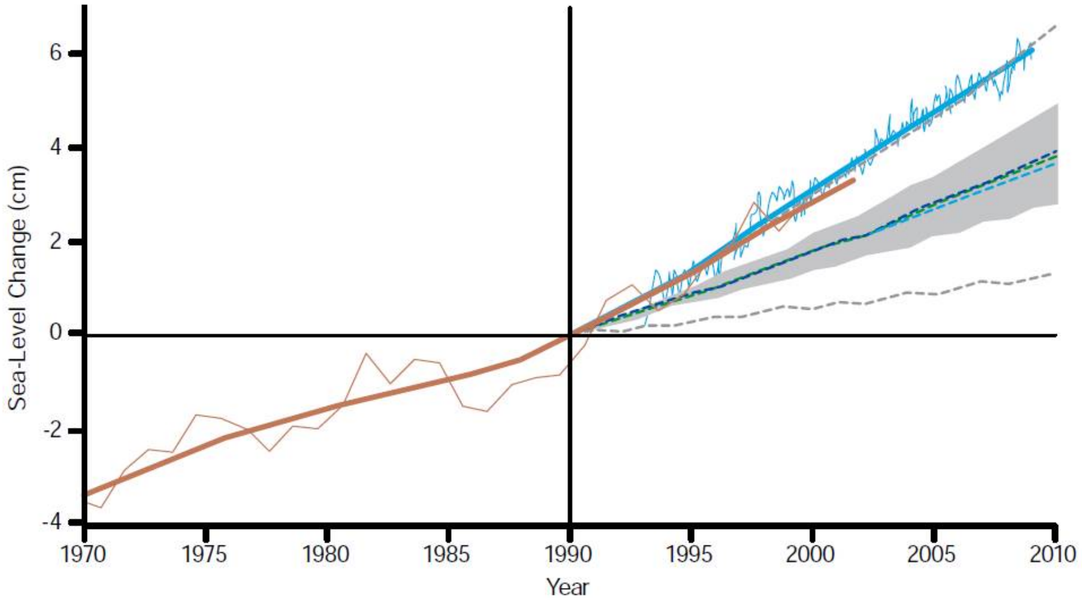
The Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (AR4) (2007) estimated sea level rise of 0.19-0.59 m by 2100, plus an additional 0.2 m from the potential melting of Greenland and Antarctic ice sheets.

Key developments that have occurred since the publication of the AR4 include:

- Global emissions of carbon dioxide have accelerated rapidly since approximately 2000, consistent with the high-end emission scenarios. The Garnaut Climate Change Review suggests that global emissions will exceed the highest IPCC scenarios under a business-as-usual scenario (Commonwealth of Australia, 2008).
- Sea level has been rising at close to the upper end of the IPCC projections (Church et al. 2004, p7):
    - "Sea level observed with satellite altimeters from 1993 to 2006 and estimated from coastal sea-level measurements from 1990 to 2001 are tracking close to the upper limit of the TAR [Third Assessment Report] projections of 2001, which included an allowance for land–ice uncertainties. Recent altimeter measurements indicate sea level is continuing to rise near the upper limit of the projections.
    - Recognising the inadequacies of the current understanding of sea-level rise, simple statistical models relating observed sea levels to observed temperatures have been developed and applied with projected temperature increases to project future sea levels. These have generally resulted in higher sea level projections for 2100, of up to 1.4 m.
    - There are suggestions that the glacier and ice cap contributions into the future may have been (moderately) underestimated."
- Concern is escalating about the potential instability of both the Greenland and the West Antarctic Ice Sheets leading to a more rapid rate of sea-level rise than current models project. It is important to note that the uncertainties related to changes in the ice sheets are essentially one-sided: the processes can only lead to a higher rate of sea-level rise than is currently estimated (Church et al. 2004).
- Recent research indicates that the climate system, in particular sea level, may be responding more quickly to increasing global temperatures than current climate models projections. In particular, the IPCC were unable to exclude larger sea level rise values and there is emerging evidence suggesting the TAR may have underestimated the future rate of sea level rise (Rahmstorf et al., 2007).

Figure 4 shows the global SLR changes (1970-2008) in comparison to the IPCC SLR projections. The graphic highlights how current rates of SLR are tracking well above the upper limit of the IPCC SLR projections.

Figure 4 – Global sea level change from 1970 to 2008 (DCC 2009)



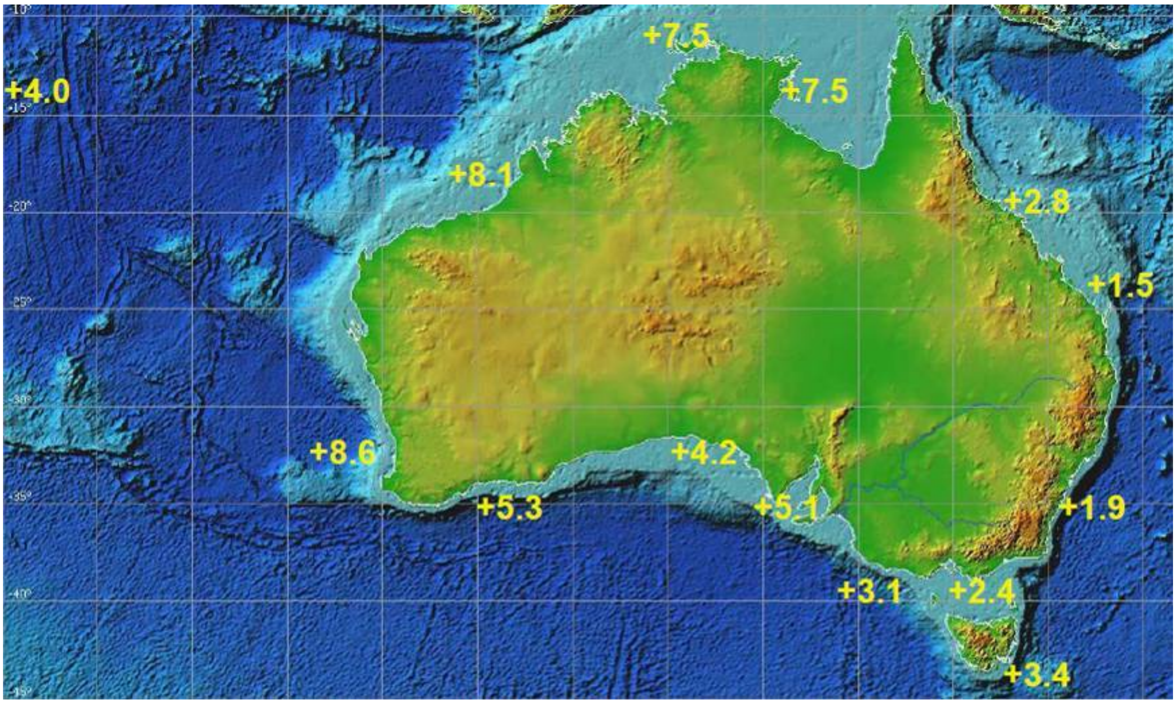
Note: The red and blue lines show observed global sea level rise from two different sources. The grey shaded area is showing the envelope of IPCC projections for sea level rise.

It is worth noting that increases in sea level will not occur uniformly across the globe, with some regions experiencing higher levels of sea level rise and others lower. Such differences can be the result of variations in broad-scale atmospheric and oceanographic circulation patterns. For example, a recent study by the CSIRO and the Department of Environment and Climate Change (McInnes et al., 2007) projected a regional variation in New South Wales to be above global levels of up to 8 cm by 2030 and 12 cm by 2070.

Since 1991, the Australian Baseline Sea Level Monitoring Project (ABSLMP) has been monitoring sea level rise at 14 points of the Australian coast line (12 stations in mainland Australia, one in Tasmania and one in Cocos (Keeling) Islands).

A tide gauge station has been installed on CKI since September 1992. The records show a rate of rise of + 4 mm/year between September 1992 and June 2009 (see Figure 5). The satellite data indicates a lower rate of rise with a value of + 5.7 mm/year since 1993. Despite being different, both trends are relevant. The sea level rise seems to be greater near the gauge tide station than in other locations of the coastline. This value has been corrected to take into account the effects of local inverse barometric pressure and vertical movement of the observation platform.

Figure 5 – Net relative sea level trend in mm/year after subtracting the effects of the vertical movement of the platform and the inverse barometric pressure (ABSLMP 2009)



As highlighted in the ABSLMP 2009 report, the length of the data series is relatively short from a climate perspective; however, it demonstrates a clear trend of sea level rise in the region which is consistent with satellite altimetry observation.

There is no tidal gauge station located at CI and the only available data has been obtained through satellite altimetry. This data indicate a sea level rise of 3.4 mm/year since 1993. However these values should be considered with caution.

Projections

Based on the above developments, further work has been done to estimate potential future sea level rise. Sea level rise projections presented to the March 2009 Climate Change Science Congress in Copenhagen ranged from 0.75 to 1.9 m by 2100 relative to 1990, with 1.1–1.2 m the mid-range of the projection (Rahmstorf, 2009). These projections are based on a statistical approach informed by the observed relationship between temperature and sea level. The mid-range value of 1.1 m was used in the Department of Climate Change's (2009) report *Climate Change Risks to Australia's Coast.* The report stated that "A sea-level rise value of 1.1 m by 2100 was selected for this assessment based on the plausible range of sea level rise values from post IPCC research" (Department of Climate Change, 2009, p 28).

Rahmstorf's projection of a 1.4m sea level rise by 2100 is also based on a statistical approach informed by the observed relationship between temperature and sea level (Rahmstorf et al, 2007). Another paper by James Hansen (2007) suggests that a 5m sea level rise by 2100 is plausible, based on the premise that increases in global average temperatures will become sufficient to cause ice sheets to begin disintegrating in a rapid, non-linear fashion on West Antarctica, Greenland or both, resulting in multiple positive feedbacks (Hansen, 2007).

An overview of recent sea level rise projections is provided in Table 6.

Table 6 – Sea level rise projections and their various sources

Source	2100 projection
IPCC 4AR (2007)	Up to 79 cm
Copenhagen Congress (2009)	1.1-1.2 m
Rahmstorf (2007)	1.4 m
Hansen (2007)	5 m

Sea level rise projections are similar for both Territories with a projected rise of approximately 14 centimetres by 2030 and approximately 40 centimetres by 2070. Additionally a worst case scenario of 1.1 metres sea level rise by the end of the 21st Century has also been considered for this study (a value aligned with the one selected for the Department of Climate Change's (2009) report *Climate Change Risks to Australia's Coast.* These figures are the best projections available and might evolute during the 21st Century as the understanding of the processes involved in sea level rise is improving.

3.2.6 Storm Surge and Storm Tide

The IPCC Fourth Assessment Report (FAR, 2007) defines a storm surge as "the temporary increase, at a particular locality, in the height of the sea due to extreme meteorological conditions." More specifically, the reduced atmospheric pressure resulting from a low-pressure system, as well as strong winds pushing on the ocean surface, may result in water levels rising to above mean sea level. The bathymetry of coastal zones also influences the formation of storm surges.

It is important to note that the most severe storm surge events typically occur in conjunction when these low pressure meteorological events occur in conjunction with high astronomical tides, as well as large wave swells generated by strong winds.

Storm surge

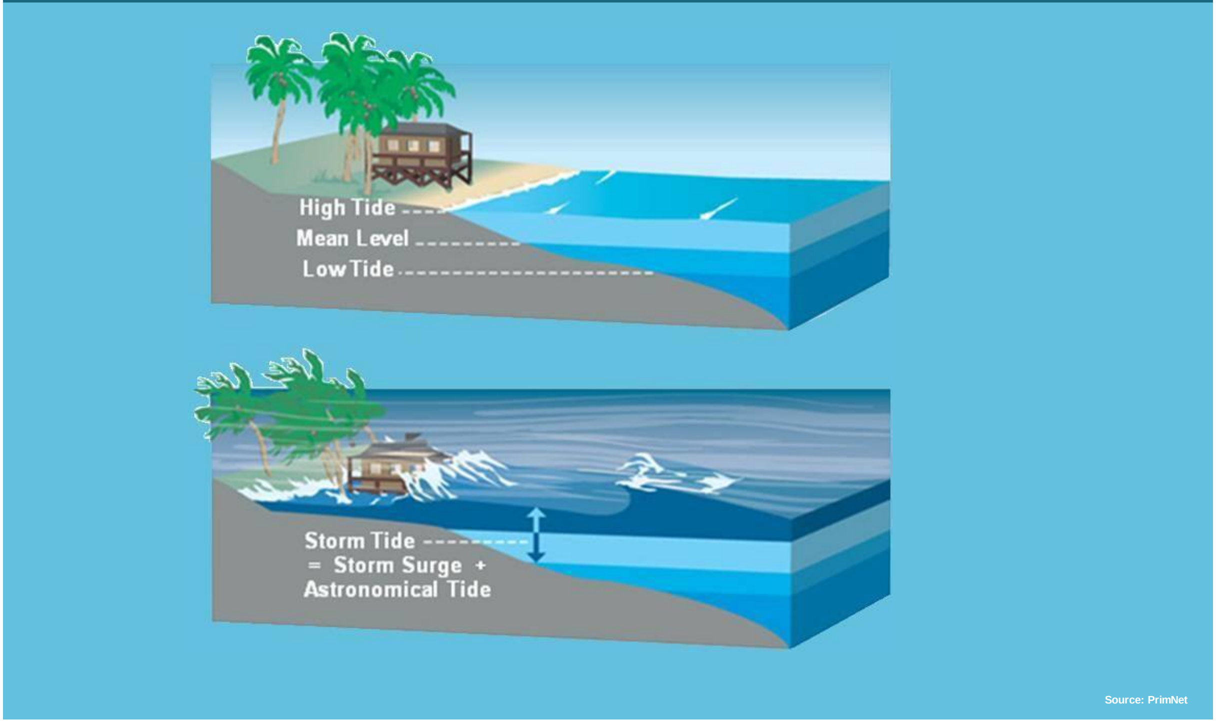
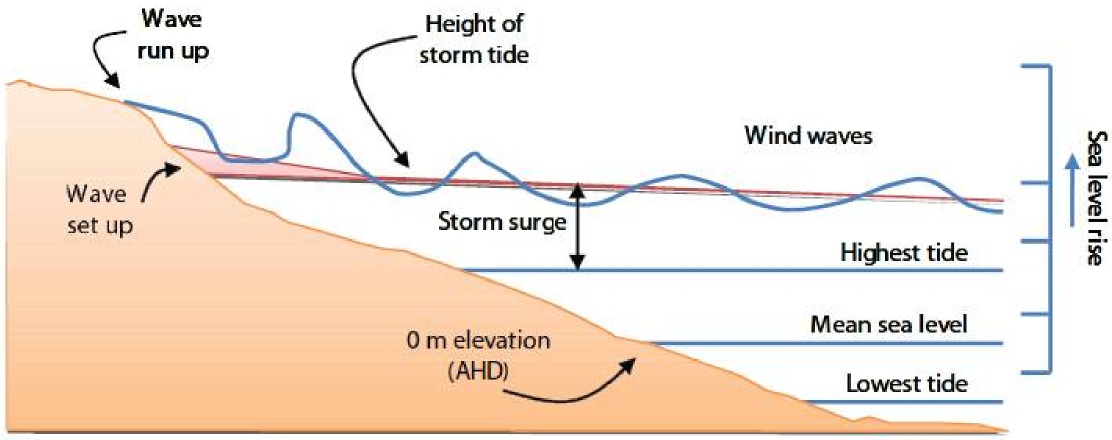


Figure 6 – Illustration of how storm surges, astronomical tides and sea level rise influence coastal water levels (DSE, 2009)



In the above figure, wave set up can be defined as an increase in the mean water level shoreward of the region in which breakers form at the seashore, caused by the onshore flux of momentum against the beach. Wave run-up is the maximum vertical extent of wave uprush on a beach or structure above the still water level. Storm surges are often accompanied by a further increase in water level due to the cumulative effect of wave setup and wave run-up.

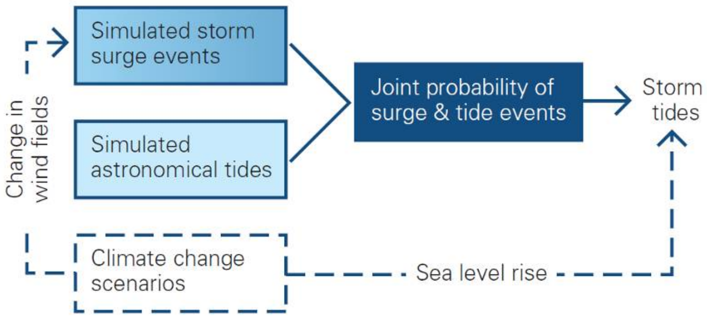
Storm surges are particularly damaging when they occur at the time of a high tide, particularly if there is a significant difference between low tide and high tide. If this is the case, the difficulty of predicting the magnitude of a storm surge increases since it requires weather forecasts to be accurate to within a few hours. Extra tropical cyclones can produce storm surges, although the most extreme storm surge events typically occur as a result of tropical cyclones.

Storm surge and climate change

Storm tide height may be significantly affected by climate change, with changes expected to be predominantly driven by sea level rise and to a lesser extent by changes in wind speed (Department of Climate Change, 2009). Increased wind speed due to climate change may also affect storm surge and storm tide heights. These changes are affected to increase inundation risk, which is best described as the likelihood of exceeding a given level of tide, surge and flood height over a particular time horizon. Frequency is traditionally measured as average recurrence intervals. However, this approach rests on the assumption that mean sea level will remain constant. Potential future sea level rise combined with increased wind intensity means that climate change is likely to increase the frequency of extreme sea level events.

The modelling of storm surge and extreme sea levels is improving, although CSIRO advise that to provide coastal managers and planners with more detailed information to address climate change, much higher resolution data sets defining coastal topography, bathymetry and meteorology, and detailed sea level and coastal ocean observations will be required (McInnes, Grady, Hubbert 2009). CSIRO's modelling of extreme sea levels takes account of sea level rise, storm surge and astronomical tides, but not local considerations such wave set up, wave run up and erosion or accretion of beach sediments (DSE 2010). CSIRO's modelling approach is illustrated in Figure 7, which has been applied in Victoria's Future Coasts Program. Modelling is not yet available for the IOT.

Figure 7 – An illustration of CSIRO's approach to assess potential climate change effects on extreme sea levels (DSE 2010)



Observations

For CKI, there is a large potential for wave setup to contribute to storm tide on the ocean facing coastlines that are exposed to waves from the dominant wave direction spanning from the southeast to the southwest. The last storm surge observed in CKI occurred on 27th November 1909. CI is far less vulnerable to storm surge/tide because of its volcanic origin and its surrounding cliffs. The coastal cliffs and the lack of shallow shelf around the island induce a low risk of storm surge and the wave setup would be the main contributor to extreme sea level. The most vulnerable parts of the island are the northeast settlements and port facilities. A section of the shore terrace (Kampong) is subject to surge risk, while some parts of Isabel Beach and Rocky Point are exposed to wave overspill. As no tropical cyclones have been monitored during the last 20 years, no trends in terms of storm surge/tide evolution are available.

Projections

A model based on 10 tropical cyclones passing within 150 km of Cocos (Keeling) Islands has been built to estimate the maximum sea level response to combined effect of air pressure, winds and tide effects during a tropical cyclone event. This estimation is based on a 1% wave setup value. This means that this level is exceeded only for 1% of the time. This value is considered as relatively conservative in terms of threat to life and existing properties. This analysis looked at 11 points located on the open coastline and 9 points located in the lagoon. The projections have been performed assuming a sea level rise of 14 cm by 2030, 40 cm by 2070 and a worst case scenario of 1.1 m by the end of the 21st Century (see Figure 8). There is no available projection of storm surge/tide for CI.

Figure 8 – Storm surge return periods – observations and projections (2030, 2070 and end of the 21st century). Figures indicating inundation for a 1 in 10 year vent are also inundated for a 1 in 50, 1 in 100, 1 in 500 and a 1 in 1000 year event. The beige icon shows area not inundated during storm surge events.

Current Storm Tide Return Periods

Projected 2030 Storm Tide Return Periods

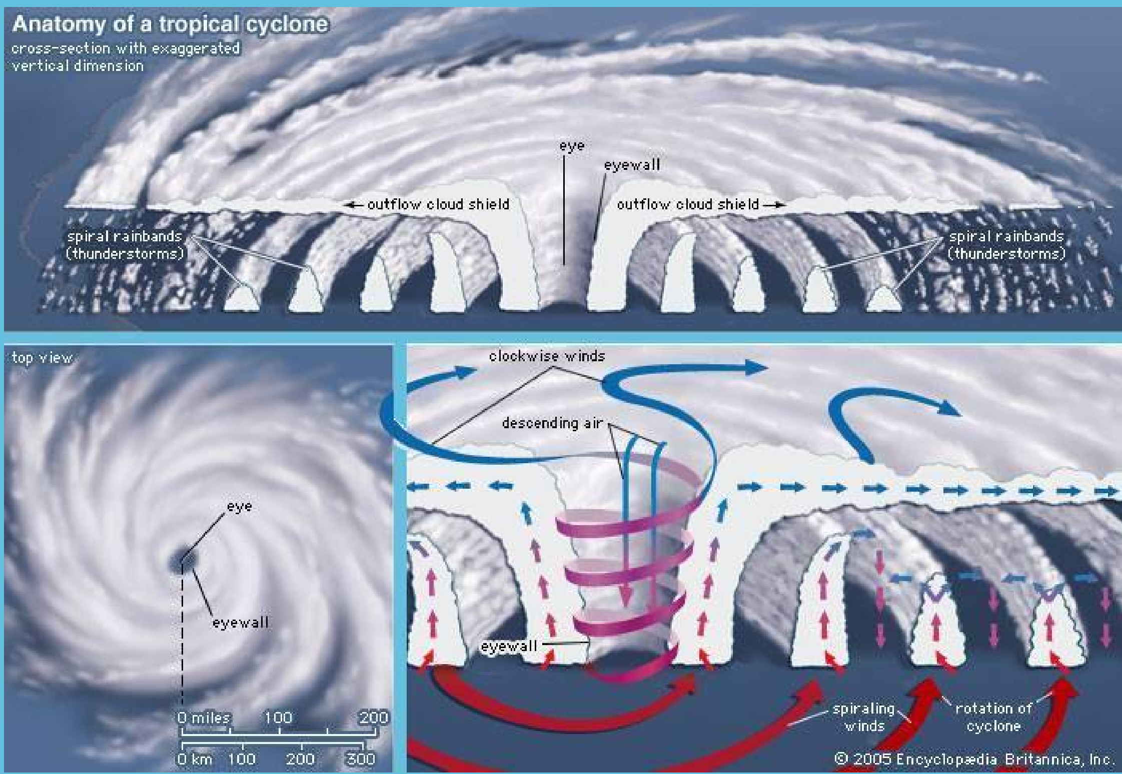
Projected 2070 Storm Tide Return Periods

End of 21st Century Storm Tide Return Periods

3.2.7 Tropical cyclones

A tropical cyclone is defined as a tropical depression of sufficient intensity to produce gale force winds, i.e. at least 63 km/h. Tropical cyclones are also called hurricane in the North Atlantic and Typhoon in the North Pacific. This kind of event is not only dangerous because it produces destructive winds but also because it is associated with torrential rains (often leading to floods), storm surge and wild sea conditions. Generally, sea surface temperatures need to be at least 26.5°C to initiate a cyclone, although the cyclone can then move over colder waters.

Tropical cyclone



Source: Encyclopaedia Britannica

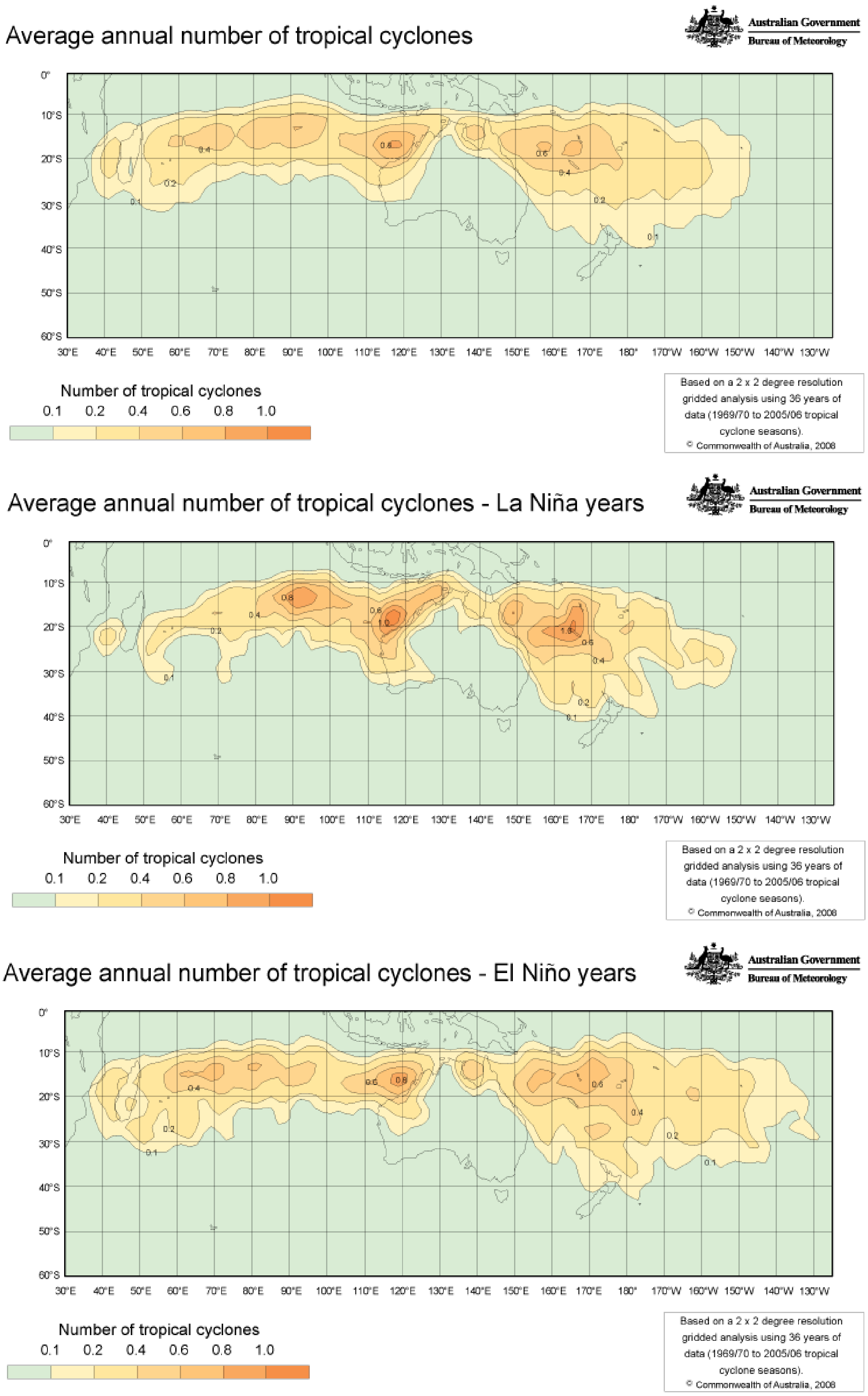
Cyclones are classified depending on the speed of their winds. An example of the classification is provided in Figure 9.

Figure 9 – Classification of the tropical cyclones based on BoM values

10 minutes sustained winds (knots)	BoM classification of tropical cyclones
< 28 (52 km/h) – 33 (61 km/h)	Tropical Low
34 (63 km/h) – 47 (87 km/h)	Tropical Cyclones (Cat. 1)
48 (89 km/h) – 63 (117 km/h)	Tropical Cyclones (Cat. 2)
64 (118 km/h) – 85 (158 km/h)	Severe Tropical Cyclones (Cat. 3)
86 (160 km/h) – 106 (196 km/h)	Severe Tropical Cyclones (Cat. 4)
107 (198 km/h) – 114 (211 km/h)	Severe Tropical Cyclones (Cat. 5)

In the eastern Indian Ocean region, the tropical cyclone activity is generally enhanced during La Niña events and lowers during El Niño events. Figure 10 shows the average annual number of tropical cyclones during normal years, La Niña years and El Niño years.

Figure 10 – Cyclone frequency for all years, La Niña and El Niño years (BoM 2010)



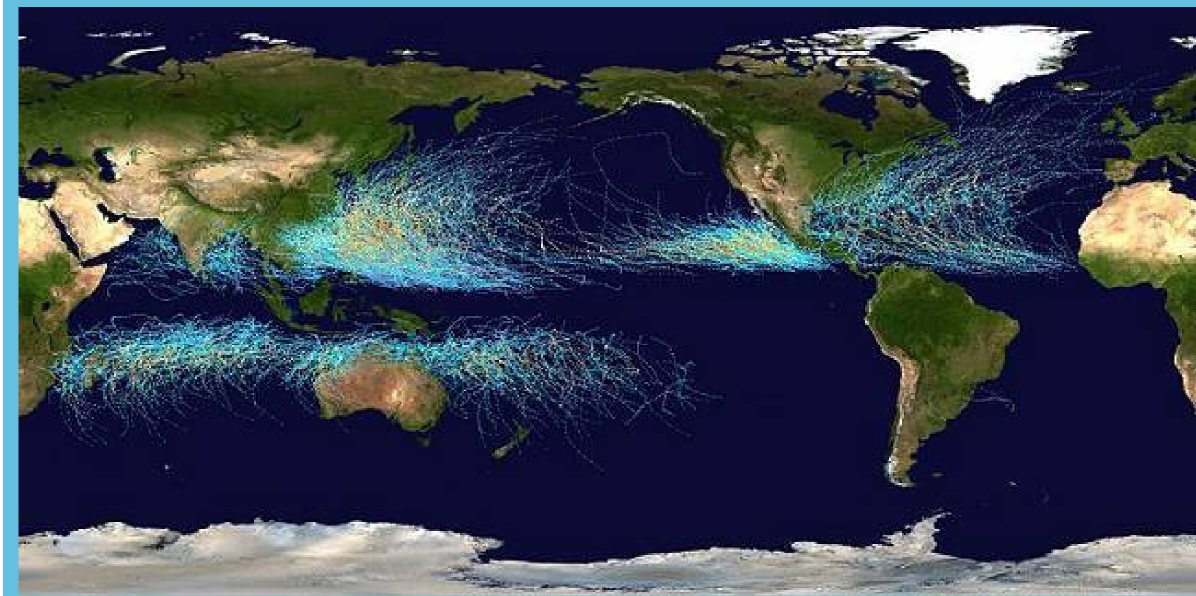
Observations

In the eastern Indian Ocean region, the tropical cyclone activity is generally enhanced during La Nina events and lowers during El Niño events. The worst tropical cyclone in CKI occurred in 1909 with winds gusts of 225 km/h. Since 1960, 97 tropical cyclones occurred within 500 km from CKI, representing an average of 2.4 TC/year.

The occurrence of tropical cyclones is lower near CI than CKI. Since 1960, 66 tropical cyclones occurred within 500 km of CI.

A review of the Western Australia Tropical Cyclone dataset indicates there has been a 42% increase of the Category 3 and Category.4 cyclones between the 1974 – 1988 period and the 1989 – 1998 period.

Global cyclone tracks



Source: USGC 2004

Projections

The General Circulation models have a too large grid (200 km on average) to propose an accurate evaluation of the future cyclonic activity. The projections proposed hereafter have to be considered as indicative only. They indicate direction of changes and the projected number of cyclones should not be considered as accurate forecasting of future situations.

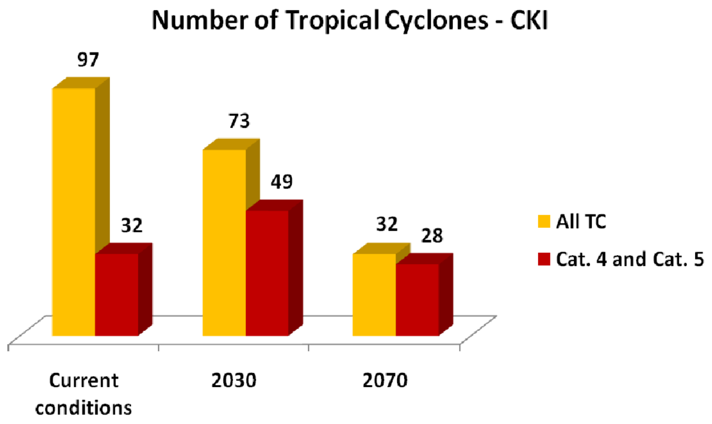
It has been assumed that in a warmer world the frequency of intense tropical cyclones would increase. Indeed, the frequency of tropical cyclones has increased over the North Atlantic (where they are referred as hurricanes) but the trends are less clear for other tropical cyclone regions (Indian Ocean, North and South Pacific). This is mainly because of the lack of robust data. Cyclones are a complex phenomena and their formation is the consequence of numerous factors. The sea surface temperature is important but the macro scale structure of the atmosphere also plays a significant role. Most models indicate a decrease of tropical cyclones for 2030 and 2070. By the second half of the 21st Century, mechanisms associated with the structure of the atmosphere may induce a decrease of the cyclonic activity in this part of the world. For instance, a change in the vertical wind shear may decrease the number of TC formed and the life time of formed TC; and an increase of the stability of the atmosphere would decrease the proneness to convection (and then to cyclone formation). CSIRO is still working to validate these assumptions and the current projections are associated with a significant degree of uncertainties.

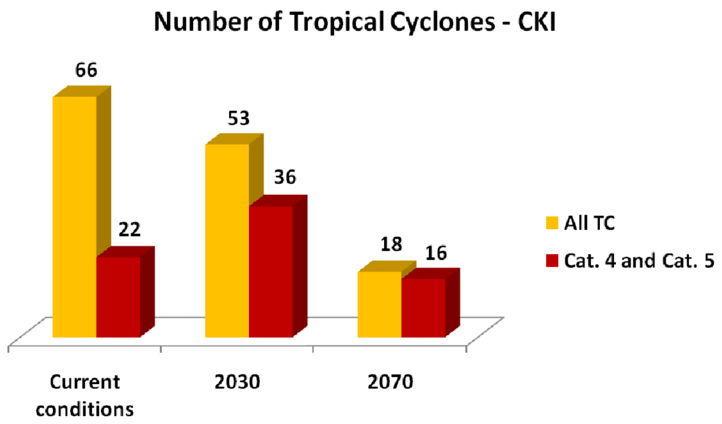
The General Circulation models have a too large grid (200 km on average) to propose an accurate evaluation of the future cyclonic activity. The projections proposed hereafter have to be considered as indicative only. They indicate direction of changes and the projected number of cyclones should not be considered as accurate forecasting of future situations.

As shown in Figure 11, the overall number of tropical cyclones is projected to decrease by 2030 for the events occurring within 500 km of CKI (- 25%) and within 500 km of CI (- 20%). The number of intense tropical cyclones (defined here as Categories 4 and 5 on the BoM scale) occurring within 500 km of CKI, is expected to double while the number of intense tropical cyclones occurring within 500 km of CI is projected to increase by 63%. The 30 year period centred on 2030 can be considered as critical in terms of future cyclonic activity.

This increasing trend should change for the 30 years period centred around 2070 with the number of tropical cyclones (all categories considered) occurring within 500 km of each Territory projected to decrease. The overall number of tropical cyclones is projected to decrease by 68% for the region around CKI and 73% for the region around CI. The number of intense tropical cyclone is expected to decrease by 12% for the region around CKI and 28% for the region around CI.

Figure 11 – Projections of the number of tropical cyclones for the IOT (CSIRO 2009)





Note: These figures show the number of tropical cyclones occurring within 500 km of each island during a 30 years period centred on present, 2030 and 2070.

3.2.8 Wave Patterns

Observations

For CKI, two main types of waves have been identified:

- The waves within the Cocos Lagoon which are generated by the local winds.
- The waves received on the oceanic coasts.

As no long term data is available for CKI the analysis has been focused on the offshore generated waves. There are two main modes:

- Short period (7 – 8 s) south-easterly waves generated by the local south-easterly winds.
- Longer period (> 12 s) south westerly swell waves generated by distant south Indian Ocean storms.

Wave heights of each mode are similar and the total mean height is approximately 2.4 m. The wave peak occurs during July and August with wave height > 3 m.

Since 1958, the mean wave height has increased by 30 cm for all seasons except spring, which experienced a lower increase (10 cm). The annual wave's period increased by 0.7 s since 1953. This increase of the wave period was higher for the autumn (+ 1.0 s) and winter (+ 0.9 s). This implies a slight decrease of the wave's frequency. There has also been a significant shift in the winter wave's direction with a + 8.3° shift (clockwise). There has been no significant shift for the annual direction or for the three other seasons.

For CI, the available data (satellite altimetry) indicate the offshore waves are dominated by long period (> 12 s) south-west swell waves generated in the southern Indian Ocean. There is little evidence of locally generated waves. The wave height peaks during July-August (3 m) and are lower during December-February (< 2 m). The annual wave height increased significantly by 30 cm since 1953. This increasing trend was slightly higher (+ 40 cm) in autumn and lower in spring (+ 20 cm). Over the same period, the annual mean wave period increased significantly by 0.7 s, with a significant increase of 0.9 s in autumn and winter. The trends are not significant for the other seasons. The mean wave direction has not changed significantly over the last 50 years.

Projections

The slight changes expected in terms of wind patterns should not have any consequences on the future wave conditions. Any changes in the future wave pattern would be the consequence of changes along the wave track in the Indian Ocean. There might be a potential increase of the swells waves during the autumn and winter periods. No quantitative evaluation is available and this projection should be considered as a possible evolution rat her than a solid assumption.

3.2.9 Other Climate Variables

Ocean current

The main ocean current in the vicinity of CKI and CI are the Indonesian Throughflow (which flows in a westerly direction to the south of CKI) and the South Java Current. Observations over the last 50 years indicate a reduction in the strength of the Indonesian Throughflow. Results from climate models indicate that this trend should continue in the future.

Eastern Indian ocean currents

Source: CSIRO

Ocean acidification

The ocean absorbs CO_2 naturally from the atmosphere. This mechanism acts as a buffer effect for increasing atmospheric CO_2. However, the ability of the ocean to absorb CO_2 will decline over time leading to more CO_2 concentrations in the atmosphere and enhanced warming of the air temperature. A negative side effect of the CO_2 absorption is ocean acidification. One of the main concerns of ocean acidification is that it might cause some marine organisms to be unable to develop their calcium carbonate shells. The future pH in the ocean will be mainly driven by atmospheric CO_2 concentrations rather than the degree of warming. The average pH observed in the vicinity of the IOT in the 1990s was 8.06 (global average between 8.0 and 8.2). This pH value for the Cocos and Christmas Islands region is projected to decrease to a 7.92 value by 2070.

Relative Humidity

Relative humidity is a measure of the air's ability to hold water moisture. A low value of relative humidity indicates that there is little water in the air relative to its capacity to hold moisture, while a high value indicates that the air is saturated with water.

The average value of the relative humidity for CKI was approximately 75% to 80% over the 1955 – 2007 period with March-April-May (MMA) being the wettest season and spring the driest. CI exhibits the same trends with higher values of relative humidity (80% to 85% over the 1974 – 2005 period). On CKI, MMA tended to be wetter but there are no significant changes for the other seasons. On the other hand, on CI, there has been a significant decrease of the relative humidity during all season since 1974, resulting in a significant decrease of the annual values of relative humidity.

The future evolution of relative humidity is not very clear at the moment. The assumption is that relative humidity is more likely to increase than decrease and that any changes would be limited.

Evaporation

Projections of changes in terms of evaporation have been undertaken recently by the CSIRO for mainland Australia and Tasmania. However, the method developed for these territories is not currently appropriate for small oceanic islands. Thus, no quantitative evaluation is available. The expected increase of air temperature and slight changes of relative humidity and solar radiation are consistent with future increase in evaporation.

Part III – Cocos (Keeling) Islands: Impact, Vulnerability & Risk

4.0 Impacts on Natural Systems – Biophysical Vulnerability

AECOM commissioned CZM to prepare a technical report detailing current IOT biodiversity and coastal geomorphology and assessing potential climate change impacts on the natural systems. The following sections are based on the key findings of this technical report combined with additional literature and stakeholder consultation.

4.1 Changes in Coastal Geomorphology

4.1.1 Current Conditions

Many of the coastal areas and beaches on CKI are potentially threatened by a combination of human pressures, climate change and sea-level rise, increases in sea surface temperature, and possible increases in extreme weather events. Future impacts on these low-lying coastal areas will almost certainly include changes in island geomorphology, through accelerated coastal erosion, sedimentation in the lagoon and coastal embayment, and increased flooding from the sea and storm surge.

It has long been recognised that islands on coral atolls are especially vulnerable to this combination of impacts associated with climate change and sea level rise, and that the risk from climate-induced factors constitutes a dangerous level of climatic change to atoll island geomorphology. It is highly likely that, with sea-level rise, that a number of CKI's coastal shores will be eroded and sediment re-deposited further lagoon ward, and that chronic island erosion may result in some areas as a result of increased water depth across reefs with sea-level rise.

While erosion is intuitively the most common response of island shorelines to sea-level rise, it should be recognised that coasts are not passive systems. CKI's sandy shorelines and beaches have historically changed over time in response to a combination of geomorphological and oceanographical factors. In particular there is evidence from the satellite imagery to indicate that the coastline of West Island for example has undergone significant geomorphological change over the last 100 years.

The predominant coastal processes operating in the region include:

- Northerly littoral drift along the east and west ocean coasts due to prevailing swell and wind wave direction.
- Southerly movement of material transported into the lagoon at the Northern tip of West Island. Wave refraction drives movement of sediment as a sand slug along the eastern lagoon shore.
- Transport of material generated on the Southern reef margins through the south entrance into the lagoon.
- Onshore movement of fragmented coral debris as a result of swell induced transport.
- Erosion and inundation due to heavy swell and rough seas generated by cyclones that can carry increased quantities of sand and shingle alongshore as well as offshore.

4.1.2 Observed Change

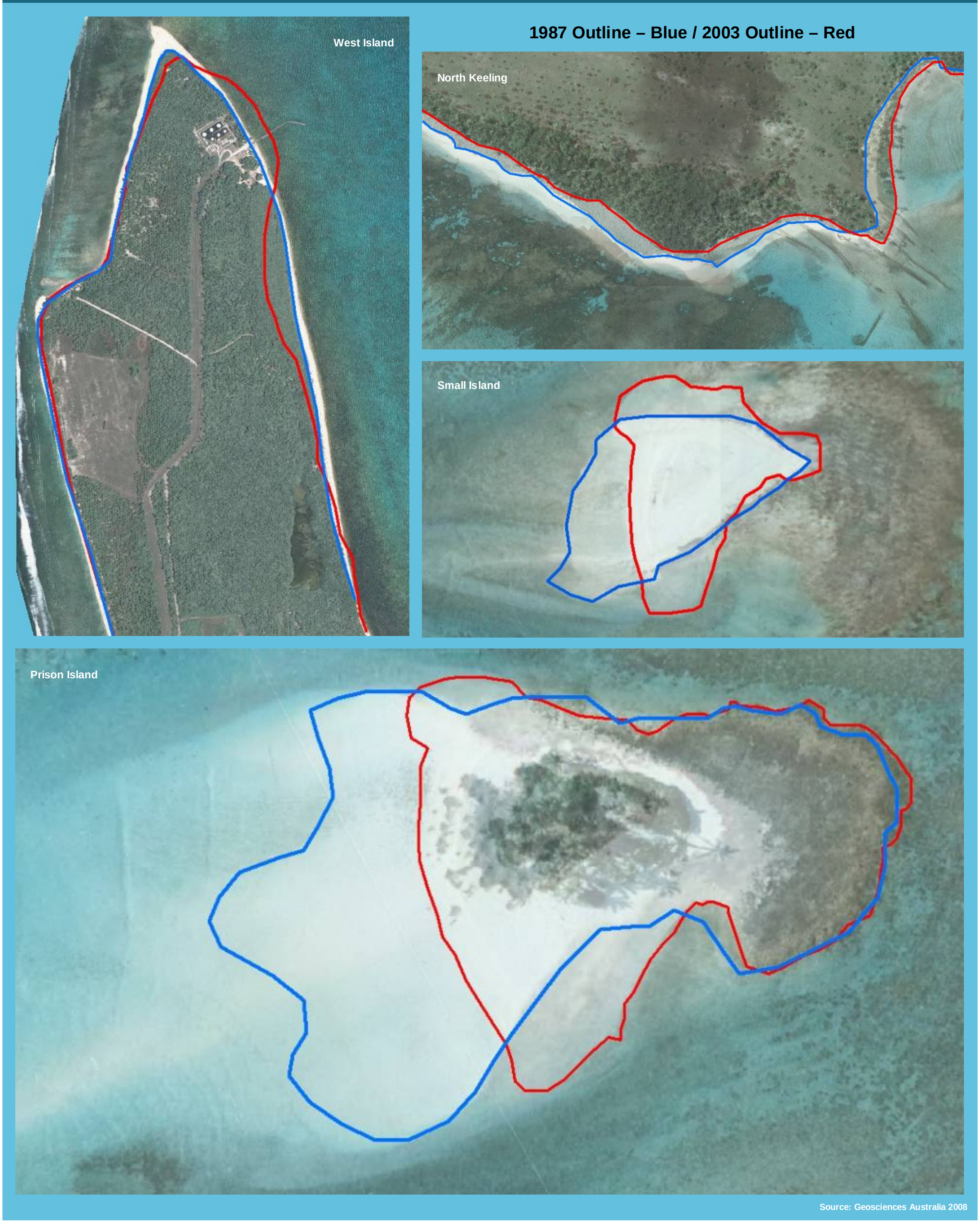
Although a comprehensive assessment of the mode and amount of change occurring in discrete atoll environments in CKI has yet to be undertaken, the direction of this change under current conditions may be inferred from an examination of available evidence in historic reports, aerial photography and anecdotal accounts from key stakeholders. It general, it appears that erosion and accretion occur in cycles with little net change apparent except when in response to extreme events.

Overall, physical change for discrete areas on the island in response to contemporary conditions may be summarised as follows:

1. The relatively exposed lagoon coast on the western rim of the southern atoll is subject to erosion in the north and accretion in the south under modal conditions. This has been pronounced in the area around North Point Jetty. During extreme events and even during spring tides, many locations along this lagoon coast are inundated by elevated water levels e.g. Rumah Baru.
2. The more sheltered eastern lagoon coast is generally not subject to modal flooding to the same extent as the western side of the lagoon. Here, sedimentation of the southern end of the lagoon in the vicinity of South Island appears to have accelerated over recent times. During extreme events, inundation due to storm surge is an issue, particularly at Kampong on Home Island where much of the infrastructure has little buffer with the shore.

3. Areas on wave dominated, relatively exposed ocean coasts appear to be subject to progressive erosion with overtopping and increased wave action causing significant damage during extreme events e.g. in the vicinity of settlement and runway.
4. The flow dominated Islands of the eastern rim are generally accreting on their western edges in horseshoe configuration. While they are subject to redistribution of sediment during extreme events, net change remains as extension in a westerly direction.

Coastal changes at CKI



4.1.3 Future Impacts on Coastal Areas

The potential geomorphic response of discrete areas of the Islands to the projected impacts of climate change will differ depending on the type of profile in a given location (i.e. profile shape – in association with the substrate of which it is composed). Overall, from an assessment of exposure, geomorphic characteristics and evidence of previous change, sensitivity of discrete areas of interest to projected changes in climate may be summarised as follows:

Projected increases in sea level and the frequency of extreme cyclone events will likely exacerbate observed trends in areas currently susceptible to change. Most islands are protected along the ocean side by the presence of solid conglomerate platform, outcrops of cemented beach rock or a high shingle and rubble ridge. These shorelines would only be subject to substantial retreat if barriers were eroded or overtopped. It is likely that exposed ocean shorelines that do not have the natural protection afforded by the above factors will be potentially more vulnerable to sea level rise.

Shore wave energy and the magnitude of beach profile change can be expected to increase as a consequence of increased water depth over the reef crest, while build up of stony coral growth on the reef flat will be slow. This will lead to increased recession of the coastline around North Point on West Island for example and along the West coast of West Island.

Inundation, in combination with increased erosion, will potentially lead to island breaching in other lower lying locations e.g. Southern area of West Island. In addition, elevated water levels and coincident storm surges will likely cause flooding at many locations such as Rumah Baru and Scout Beach on West Island and Kampong on the Western lagoon side of Home Island. In general, the projected changes in climate reviewed here will likely lead to physical coastal impacts that will potentially threaten crucial infrastructure including the airfield, and in time, the settlements on Home and West Island.

Table 7 provides details on the sensitivity of natural systems to climate on Cocos (Keeling) Islands.

Table 7 – Natural systems sensitivity to climate change

Location	Expected Coastal Sensitivity to Projected Changes in Climate
Exposed Lagoon Coast	• Accelerated movement of sediment slug from north to south is likely with more energetic wave conditions as a result of more intense storms. • Possible loss of storm erosion buffer to north leading to exposure of tree roots, tree felling, infrastructure damage and loss of beach amenity & ecosystem loss. However, erosion here will be markedly less than on exposed ocean coasts. • Deposition of sediment in the southern end of the lagoon is likely to continue initially as slug accumulates to the south. • Lower lying areas such as Rumah Baru are likely to be subject to inundation both as result of sea level rise and superimposition of elevated surges in extreme events. Overtopping and ponding inland at Basin type profiles in particular
Sheltered Lagoon Coast	• Relatively low-lying areas of the sheltered lagoon coast likely to be prone to inundation risk due to sea level rise. • Flooding may lead to reduction of narrow, low lying beaches in particular along the coast of West island where artificial reinforcements mean there is no room for horizontal beach adjustment. • Sedimentation of the lagoon is likely to be initially accelerated as material eroded from the ocean side and deposited on the lagoon side of the eastern and south eastern rim.
Exposed Ocean Coast Western Rim	• Possible erosion of beaches with undermining of tree line/tree felling, loss of coastal vegetation, degradation of coastal protection works and progressive loss of coastal land.

Location	Expected Coastal Sensitivity to Projected Changes in Climate
	• Increased overtopping of existing sea wall along settlement, decrease in buffer zone between wave action and infrastructure. Potential surface overflow over land with subsequent ponding, particular in basin profile locations. • Combination of this effect with inundation on opposite lagoon side may lead to narrowing the distance between the lagoon and ocean side of Islands.
Exposed Ocean Coast Eastern Rim	• It is likely that changes in sea level and flow along the islands of the eastern rim of the southern atoll will not result in net erosion or accretion. Rather, the islands are subject to redistribution perhaps with a reconfiguration of the horseshoe shape currently extending from east to west. • Conversely, on Home Island, although some protection is offered along some of its Oceanside by conglomerate platform & high ridge, erosion is likely where platform is not continuous. Sand ridge not as stable as shingle or rubble.

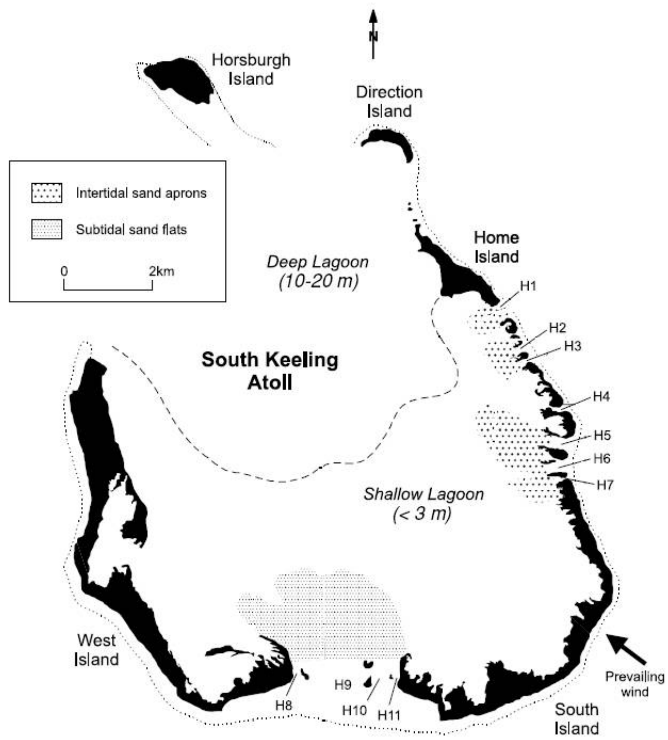
4.1.4 Impacts on the Lagoon

The lagoon is connected to the ocean by shallow channels that also often separate reef islands and act as conduits of water and sediments. There are commonly known as “Hoa”, a Polynesian word. Tropical cyclones and storms are an important component of the dynamic of these channels, generating, reactivating or closing them.

The Southern atoll of CKI presents more than a dozen Hoas, especially between West Island and South Island and around the islets between South Island and Home Island. Significant sand deposits expend between 500 and 1500 m lagoon ward of the Hoa and are a result of the sediment transport through these channels. The amount of sediment varies greatly between 268 kg/day for a Hoa on the East and 2.2 kg/day for a Hoa on the South.

There is a dominance of ocean-to-lagoon flows through the Hoa at CKI. The Hoa dynamic is also showing little correlation with the winds patterns but are clearly tidally modulated and strongly perturbed during cyclone events (probably through wave patterns and inducing increase sediment transport).

Figure 12 – Location of some Hoas at Cocos (Keeling) Islands (Kench and McLean 2006)



4.1.5 Other Stresses

However cyclones are not able to transfer large quantities of materials because of the limited availability of sediment and the efficiency of these channels under fair weather conditions. Furthermore, cyclones in the CKI region tend to reset the transport efficiency and morphology of Hoa rather than closing them.

The increase of wave’s height (+ 30 cm) could slightly increase the intensity of the sediment transport although the reduced frequency of the waves may slightly counterbalance this mechanism. The projected increase of the tropical cyclones is likely to favour the Hoa dynamic and should not lead to the closing of the Hoas (phenomena observed in other coral atoll, like in the Pacific). This would also contribute to the increased sedimentation of the lagoon that is also expected for the South and Southeast parts of the lagoon. Larger amounts of sediment deposits may have flow-on effects on the sea grass beds and coral reefs by slowing down their growth process.

An initial assessment of the sensitivity of CKI's coasts to sea level rise concluded that the majority of the coastline is highly sensitive. An acceleration in sea-level rise will exacerbate the current rate of beach erosion and could potentially have an adverse effect on the beach sediment budget in the lagoon and lead to the infilling of lagoon channels and embayment.

It must be stressed that this is not a simple relationship between sea-level rise and horizontal movement of the shoreline, and sediment budget in the lagoon and this is one area where more research is required to fully understand the impacts and implications of climate change and sea level rise on CKI. As sea-level rises, the equilibrium in the lagoon may shift raising the bed, and hence may potentially change the tidal exchange patterns and levels in the lagoon.

Climate change is also creating a number of other stress factors that are very likely to influence the health of coral reefs around islands, as a result of increasing sea surface temperature and sea level, damage from tropical cyclones, and possible decreases in growth rates due to the effects of higher CO_2 concentrations on ocean chemistry. Impacts on coral reefs from those factors will not be uniform throughout the small-island realm.

Of particular concern is that mass coral mortality from rising sea surface temperatures may result in a reduction in the level of the fringing reef surface, a consequent rise in wave energy over the reef, and increased coastal erosion. Further declines in reef health are expected to accelerate this trend.

Anthropogenic activities have intensified beach erosion on both West Island and Home Island. Much of the observed erosion is associated with shoreline development, clearing of coastal vegetation and mining of beach sand and coral. The synergistic effects of various other pressures, particularly human impacts such as over-fishing, appear to be exacerbating the thermal stresses on reef systems and, at least on a local scale, exceeding the levels beyond which coral is replaced by other organisms.

4.2 Impacts on Ecosystems & Biodiversity

4.2.1 Current Biodiversity

The Cocos (Keeling) Islands are comprised of 27 islands in two atolls: North Keeling and Cocos atoll. North Keeling atoll is classified as a National Park, called Pulu Keeling NP and is managed by Parks Australia North. Ecosystems of CKI include outer reef, coral reef and seagrass flats in Cocos Lagoon, pioneer vegetation on the edges of islands and forest inland. Biodiversity values of the Islands include:

- Pulu Keeling NP being recognised as an internationally important seabird rookery and a Ramsar Wetland of International importance;
- One of the world’s largest remaining populations of the red-footed booby (*Sula sula*) at North Keeling;
- A population of the endemic and endangered land bird, Cocos buff-banded rail (*Gallirallus philippensis andrewsi*) at North Keeling Island;
- Habitat for migratory birds at North Keeling;
- Hawksbill turtles *(Eretmochelys imbricata)* and breeding population of green turtles (*Chelonia mydas)*; and
- Coral reef and associated fauna at both atolls.

4.2.2 Vulnerable Ecosystems

Literature on climate change and ecology suggests that some ecosystems and species are likely to be more susceptible to climate change than others, such as:

- Species or ecosystem types that are threatened or endangered due to small population sizes and other factors making them more vulnerable to extinction;
- Forest ecosystems;
- Migratory species, especially those with migratory events dependant on seasonal changes;
- Geographically restricted species such as coral reefs;
- Island birds, as they tend to have smaller populations than continental species, have no opportunities for dispersal and recolonisation beyond the island and have a restricted area of habitat, and
- Endemic species with limited climatic range, small populations or restricted habitat, especially those restricted to islands.

This background on significant ecosystems and species, and generic characteristics of ecosystems and species more susceptible to climate change, informed the development of a short list of ecosystems and species potentially susceptible to climate change, provided in the following section.

Unique and vulnerable ecosystems of CKI, i.e. ecosystems more likely to be susceptible to climate change than others, include:

- *Pisonia* forest at North Keeling Island, which is the last intact remnant of original Cocos (Keeling) Islands' flora, is important habitat to seabirds and has previously been damaged by cyclone winds;
- Relict vegetation at West Island, which persists as very small populations of individual trees or small clumps;
- The Rip (at Direction Island), which has an abundance of coral and fish species;
- Corals (in the lagoon and ocean ward side of islands) and associated fish fauna, which is geographically restricted and isolated such that the coral and fish rely on self-recruitment; and
- Seagrass flats, on which turtles depend for foraging.

4.2.3 Threatened Species

Species more likely to be susceptible to climate change than others include:

- Native flora at North Keeling Island, which includes endemic species and subspecies;
- The Cocos buff-banded rail, an endemic and endangered species with a small population on North Keeling, and is rare on the southern atoll;
- Migratory water birds, occasionally sighted at North Keeling, as migratory species are more sensitive to seasonal changes than resident species;
- Seabirds, especially the red-footed booby, which is the most numerous seabird species on North Keeling and is a protected migratory bird, dependant on seasonal patterns, and the Round Island petrel, which is critically endangered and possibly already extirpated from CKI;
- Clams, which remain in low densities due to over harvesting and long breeding cycles; and
- Turtles (associated with breeding grounds at North Keeling Island and forage in seagrass beds at both atolls), which are endangered, highly migratory and have temperature dependant sex determination.

4.2.4 Observed Change and Future Impacts

West Island relict vegetation communities, North Keeling native flora and the migratory water birds were not further considered regarding susceptibility to climate change impacts due to a lack of information. Ecosystem change under current conditions was inferred from examination of existing literature and from information derived from stakeholder consultations on site. Ecosystem change due to natural drivers, over the past 50 years, has included:

- North Keeling's *Pisonia* forest had some tree and canopy loss as a result of winds from intense cyclones that crossed close to the island in 1989 and in 2001. In 2001, 14% of trees and 60% of the canopy was destroyed;
- The North Keeling lagoon closed and became shallower between the early 2000s and 2007, and vegetation succession from grassland to shrub land occurred in the southeast corner between the 1940s and 1980s;
- Seabird populations at North Keeling declined after the 1989 cyclone, for example 40% of chicks and 2% of adult red-footed booby birds were killed by the cyclone and the nest numbers were decreased by 60% the following year. Red-footed booby numbers recovered after four years. The numbers of seabird has been increasing over the past 20 years;
- Coconut forest (originally plantation) at the southern atoll has become denser since harvest stopped;
- There has been physical damage to corals in the outer reef from wave action related to cyclone activity in 2007/8 especially at Cabbage Patch;
- Coral bleaching event occurred in 1997 at parts of the outer reef (before the world wide bleaching event of 1998) because of doldrums conditions and higher than normal sea surface temperature. Plate corals died and did not return, recovery was via growth of soft corals;
- The Rip is accreting as sand collects in the middle of the Rip and is not removed by wave action;
- Mass fish kill incidents occurred in approximately 30 years intervals in 1876, 1961, 1983 and 2007 (El Niño years); and
- The green turtle population is increasing, and turtles have recently begun nesting again at the southern atoll (having ceased breeding there in the early 1900s).

The main natural drivers of ecosystem change have been high intensity cyclonic activity, which has caused damage to vegetation and bird mortality, and higher than normal sea surface temperatures which has caused mass fish kill events and coral bleaching. Overall, the ecosystems and species populations at North Keeling remain in good to excellent condition, apart from the Cocos buff-banded rail, which is in very low numbers, and the Round Island Petrel (*Pterodroma arminjoniana*) that has not been sighted in years and may be locally extinct. There has been minimal human impact on North Keeling Island, however, there have been major impacts from humans at the southern atoll and has had a greater impact to ecosystems than any natural changes, and includes:

- Conversion of the natural forest on the southern atoll islands to coconut plantation;
- Introduction of exotic plant species; Siam weed (*Chromolaena odorata*) is particularly problematic;
- Historic hunting of seabirds, coupled with extensive habitat conversion to coconut plantation, caused seabirds to be eliminated from the southern atoll by the late 1800s, and put pressure on the red-footed booby at North Keeling; and
- Overfishing has impacted fish and shellfish stocks especially in the Cocos lagoon.

4.3 Impacts on Terrestrial Ecosystems

The projected impacts to ecosystems and species should be taken only as an indication of directions of change based on projections for climate change in 2030 and 2070. No analysis of degree or likelihood of ecological change has been undertaken in this study. Descriptions of potential sensitivity presented in the tables are based on climate change projections for 2030. Detailing the thresholds for ecological change was beyond the scope of this report due largely to constraints in available data on species and ecological processes at pertinent temporal and spatial scales. In light of this, it is only possible to infer that directions of change described here will be similar for 2070 projections but likely more pronounced.

Possible impacts from projected climate change for CKI is most relevant to North Keeling Island, where the highest biodiversity values are held, and possible impacts are particularly critical for species and subspecies with small population sizes that are restricted in distribution, such as the Cocos buff-banded rail. The projected climate change for Cocos Keeling Islands is likely to impact upon terrestrial ecosystems, particularly at North Keeling Island, in Pulu Keeling National Park (Table 8).

Table 8 – Potential impacts to terrestrial species and ecosystems from projected climate changes at Cocos (Keeling) Islands

Ecological Classification	Description/Current Condition	Risk / Sensitivity Description
North Keeling Island *Pisonia* forest	• 15-20 metres high *Pisonia* trees interspersed with coconut and ironwood trees • Nesting habitat for seabirds • Some non-indigenous species in low abundances	**Possible decrease in forest quality** • Loss of land to sea level rise results in loss of equivalent area of vegetation • With increased frequency of high intensity cyclones, there may be a higher chance of high intensity cyclones directly hitting the island and causing canopy and tree loss. It has been suggested that a direct hit from a Category 5 cyclone could remove almost all standing vegetation (Commonwealth of Australia, 2004) • It is possible that non-indigenous plant and animal species (e.g. the exotic plant species and the yellow crazy ant that occur in low abundance on the island currently) may be favoured by changed conditions in temperature and rainfall, especially if coupled with human disturbance or further introduction of non-native species.
Cocos buff-banded rail **(*Gallirallus philippensis andrewsi*)**	• Endemic subspecies of land bird • Small population at North Keeling, rare at southern atoll • Forages at lagoon shore	**Possible decline in, or loss of, Cocos buff-banded rail population** • Land bird - cannot escape cyclones – thus with increased frequency of high intensity cyclones, there may be a higher chance of high intensity cyclones directly hitting the island and causing bird mortality and population decline or loss • The subspecies is endemic to CKI, so localised extinction would equate to subspecies extinction

4.4 Impacts on Marine & Coastal Ecosystems

Possible impacts to the marine ecology from projected climate changes focus on the coral, fish and shellfish, seabirds and turtles as shown in Table 9.

Table 9 – Potential impacts to marine species and ecosystems at Cocos (Keeling) Islands

Ecological Classification	Description/ Current Condition	Risk / Sensitivity Description
Cocos Lagoon		
Coral	• 99 species of coral	**Some possibility of decrease in coral abundance and/or quality in Cocos Lagoon** • With a projected rise in SST, if there are more frequent periods of increased SST (e.g. over 30°C) coupled with doldrums, this may lead to coral bleaching, although the lagoon has experienced SST around 36°C before and has not experienced bleaching • It is unknown whether coral will be able to grow fast enough to track sea level rise • With a projected increase in frequency of high intensity cyclones, there may be increased incidence of physical damage to coral reef structure from cyclone related wave action during high intensity cyclone and storm events, however, overall cyclone frequency is projected to decrease so overall frequency of damage by cyclone related wave action may decrease
Fish and shellfish	• 528 species of fish	**Possible decline in fish and shellfish stock** • With a projected rise in SST, if there are more frequent periods of increased SST coupled with doldrums conditions, there may be increased frequency of mass fish kill events
Seagrass bed	• In the southern part of the Cocos lagoon • Foraging habitat for turtles	**Possible reduction in extent of seagrass bed** • With a projected increase in frequency of high intensity cyclones, there may be increased incidence of physical disruption to the seagrass bed from wave action and sediment runoff during high intensity cyclone and storm events, however, overall cyclone frequency is projected to decrease so overall frequency of damage by cyclone related wave action may decrease • Geomorphic analysis suggests that projected climate change will exacerbate deposition of sediment in the southern end of the lagoon, which is where seagrass beds are located, thus they may be impacted by sediment if growth cannot match accretion
The Rip	• An area southeast of Direction Island with high coral and fish species diversity, relative to other locations at CKI	**Decline in quality of The Rip** • With a projected rise in SST, if there are more frequent periods of increased SST (possibly over 30°C) coupled with doldrums, this may lead to coral bleaching, however the strong tidal current at The Rip may make the area less susceptible to bleaching
Outer Reef (North Keeling and Cocos atoll)		
Coral	• Fringing reef • 99 species of coral	**Possible decrease in coral abundance and/or quality in outer reef** • With a projected rise in SST, if there are more frequent periods of increased SST (possibly over 30°C) coupled with doldrums, this may lead to coral bleaching (such as the bleaching episode experienced in 1997) • It is unknown whether coral will be able to grow fast enough to track SL rise

		• With a projected increase in frequency of high intensity cyclones, there may be increased incidence of physical damage to coral reef structure from cyclone related wave action during high intensity cyclone and storm events, however, overall cyclone frequency is projected to decrease so overall frequency of damage by cyclone related wave action may decrease
Fish and shellfish	• 528 species of fish, including the endemic Cocos angelfish (*Centropyge joculator*)	• Flow on effect from any impacts to corals from projected climate change to species that rely on coral for habitat or foraging
North Keeling		
Seabirds	• North Keeling Island is recognised as an internationally important seabird rookery • Species include the red-footed booby, and the endangered Round Island petrel, which was recorded as a small, possibly breeding, population in 1986 but has not been sighted since	**Possible short term declines in seabird population** • With a projected increase in frequency of high intensity cyclones, there may be a higher chance of a high intensity cyclone directly hitting the island, which would cause loss of nesting habitat, seabird chick and adult mortality and reduced breeding success in the subsequent year. • Seabirds are entirely dependant on the ocean for food. Breeding success has been positively correlated to incidence of cold water upwelling, which results in rich food resource. Any significant changes to currents and sea surface temperature from projected climate changes may alter seabird breeding success. • Given the very small population size of the Round Island petrel, a direct hit from a high intensity cyclone could cause extirpation of this species (though it may already be extirpated from the islands)
Turtles	• Breeding population of green turtle (*Chelonia mydas*) at North Keeling Island • Both the green turtle and hawksbill turtle (*Eretmochelys imbricata*) forage at seagrass beds in Cocos Lagoon	**Possible decline in turtle population** • Increased temperature may lead to increased sand temperature which would influence the temperature controlled sex determination, and skew populations by favouring females • Loss of breeding area (sandy beach at North Keeling and West Island) to sea level rise • Flow on effects from changes to seagrass beds in which turtles forage

CKI – Summary of Risks to Natural Systems and Biophysical Vulnerability

Classification	Risk	2030	2070
Exposed lagoon coast (West)	Increase movement of sediment	Medium	High
	Loss of storm erosion buffer effect resulting in higher erosion of the coastline	Medium	Medium
Sheltered lagoon coast (East)	Reduction of narrow beaches	Medium	High
Lagoon	Sedimentation is likely to be enhanced, especially in the South and Eastern parts	Medium	High
Coral reefs	Proneness to bleaching events because of increased temperature and sedimentation and constrained growth because of more acid ocean	High	Extreme
Coral reefs associated fauna	Decrease in the abundance and diversity of coral associated fauna and flora (reef acting as a nursery and a feeding area)	Medium	High
Seagrass beds	Increased physical disruption and increased deposition of sediment constraining growth	Medium	Medium
Introduced species	Greater pressures because better climatic tolerance range and opportunistic species	Medium	Medium
Endangered and endemic species	Highly vulnerable species; any threats would put greater pressures on them (important non climatic component)	Medium	Medium
Seabirds	Loss of nesting habitat and potential decrease of food availability	Medium	Medium
Fish population	Mass fish kill events, change in the food availability, reproduction cycles, migration patterns	Low	Low
Turtles	Skewed gender ratio and loss of breeding area	Medium	Medium

5.0 Impact on Human Systems – Socio-economic Vulnerability

5.1 Human Settlements

The Home Island settlement is particularly vulnerable to inundation associated with storm and tidal surges. This is very likely to threaten public health and safety and possibly reduce the availability of fresh water. In addition to this the majority of houses are low-set, and are potentially exposed to inundation and flooding even during relatively low level events.

Storm surge inundation at CKI

This mapping is indicative and should not be considered as an accurate projection of the potential situation in 2070. This mapping cannot be used for planning purpose.

Source: AECOM 2009

Under current conditions:

- Two out of 20 areas on Home Island are subject to being flooded during a one in 10 year event, three areas during a 100 year event and seven areas during a 1000 year event.

In the future it is projected that the number of areas inundated on both islands are likely to increase quite dramatically with:

- Five out of 20 areas potentially flooded during a 10 year event, two areas during a 100 year event and five areas during a 1000 year event by 2030; and
- Eight out of 20 areas potentially flooded during a 10 year event, three during a 100 year event and three areas during a 1000 year event by 2070, and this would include all areas on Home Island.
- Fourteen out of 20 areas potentially flooded during a 10 year event (including eight areas out of nine for Home Island), sixteen for a 100 year event and eighteen areas during a 1000 year event by the end of the 21st Century, and this would include all areas on Home Island.

The estimates indicate that under the scenarios developed by the CSIRO, large part of Home Island settlement, and a high (but uncertain percentage) of the settlement on West Island could be subject to inundation during extreme events by 2070 or under a worst case scenario of a sea level rise of 1.1 m (see Table 10, Table 11, Table 12, Table 13 and Figure 8).

For West Island, significant impact on housing and infrastructure is not be expected to occur until 2070 under a worst-case scenario, but it could then become substantial, with the combined effects of coastal erosion and storm surge potentially threatening the airstrip and other key facilities, and other government buildings and important facilities such as hospitals located close to the shore. Evidence from satellite imagery indicates that all of CKI is undergoing some degree of shoreline displacement from coastal erosion and sedimentation. The islands are expected to become narrower, with West Island facing shoreline displacement on almost 70% of the Island shoreline, primarily from erosion on the seaward side and sedimentation in the lagoon and coastal embayment. Higher rates of erosion could arise if the intensity of long shore currents increases or coral reefs is weakened by climate change.

Table 10 – Current storm tide return periods using 1% wave setup values (see text for discussion). Reproduced from GHD (2001). Yellow shading indicates where the estimated water level exceeds approximate ground level.

Location	Ground level (approx)	Storm tide level (m) for the return period indicated				
		10yr	50yr	100yr	500yr	1000yr
Open coast-line						
Trannies Beach	2.0	1.37	1.69	1.80	2.03	2.15
Quarantine North	3.2	1.38	1.73	1.86	2.19	2.26
North Park	3.5	1.36	1.66	1.77	2.05	2.11
Airport Settlement	4.0	1.33	1.69	1.82	2.07	2.18
Airport South	2.8	1.26	1.61	1.74	2.00	2.07
Southern Entrance	0.3	1.39	1.73	1.91	2.43	2.62
South Island Outer	0.6	1.48	1.83	1.99	2.38	2.51
Home Island SE	3.0	2.07	2.57	2.80	3.25	3.46
Home Island North	3.0	1.93	2.36	2.53	2.93	3.11
Direction Island N	3.0	1.73	2.11	2.25	2.62	3.00
Horsburgh North	2.5	2.09	2.56	2.73	3.16	3.30
Lagoon						
West Island Jetty	1.5	0.79	0.89	0.90	1.11	1.20
Rumah Baru	1.1	0.89	0.91	0.95	1.18	1.30
Airport North	2.5	0.89	0.96	1.01	1.31	1.45
South Lagoon	1.0	0.89	0.95	1.01	1.20	1.45
South Island Inner	1.0	0.89	0.94	0.98	1.15	1.26
Home Is. South	1.0	0.79	0.89	0.90	1.06	1.20
Home Island Jetty	1.5	0.89	0.89	0.89	0.99	1.08
Direction Is. Jetty	1.5	0.89	0.89	0.89	0.91	0.94
Horsburgh South	1.5	1.37	1.68	1.79	2.12	2.32

Table 11 – Storm tide return periods using 1% wave setup values for 2030 assuming a mean sea level rise of 0.14 metres.

Location	Ground level (approx)	Storm tide level (m) for the return period indicated				
		10yr	50yr	100yr	500yr	1000yr
Open coast-line						
Trannies Beach	2.0	1.51	1.83	1.94	2.17	2.29
Quarantine North	3.2	1.52	1.87	2.00	2.33	2.40
North Park	3.5	1.50	1.80	1.91	2.19	2.25
Airport Settlement	4.0	1.47	1.83	1.96	2.21	2.32
Airport South	2.8	1.40	1.75	1.89	2.14	2.21
Southern Entrance	0.3	1.53	1.87	2.05	2.57	2.76
South Island Outer	0.6	1.62	1.97	2.13	2.52	2.65
Home Island SE	3.0	2.21	2.71	2.94	3.39	3.60
Home Island North	3.0	2.07	2.50	2.67	3.07	3.25
Direction Island N	3.0	1.87	2.25	2.39	2.76	3.14
Horsburgh North	2.5	2.23	2.70	2.87	3.30	3.44
Lagoon						
West Island Jetty	1.5	0.93	1.03	1.04	1.25	1.34
Rumah Baru	1.1	1.03	1.05	1.09	1.32	1.44
Airport North	2.5	1.03	1.10	1.15	1.45	1.59
South Lagoon	1.0	1.03	1.09	1.15	1.34	1.59
South Island Inner	1.0	1.03	1.09	1.12	1.29	1.40
Home Is. South	1.0	0.93	1.03	1.04	1.20	1.34
Home Island Jetty	1.5	1.03	1.03	1.03	1.13	1.22
Direction Is. Jetty	1.5	1.03	1.03	1.03	1.05	1.09
Horsburgh South	1.5	1.51	1.82	1.93	2.26	2.46

Table 12 – Storm tide return periods using 1% wave setup values for 2070 assuming a mean sea level rise 0.40 metres.

Location	Ground level (approx)	Storm tide level (m) for the return period indicated				
		10yr	50yr	100yr	500yr	1000yr
Open coast-line						
Trannies Beach	2.0	1.77	2.09	2.20	2.43	2.55
Quarantine North	3.2	1.78	2.13	2.26	2.59	2.66
North Park	3.5	1.76	2.06	2.17	2.45	2.51
Airport Settlement	4.0	1.73	2.09	2.22	2.47	2.58
Airport South	2.8	1.66	2.01	2.14	2.40	2.47
Southern Entrance	0.3	1.79	2.13	2.31	2.73	2.92
South Island Outer	0.6	1.78	2.13	2.39	2.78	2.91
Home Island SE	3.0	2.47	2.97	3.20	3.65	3.86
Home Island North	3.0	2.33	2.76	2.93	3.33	3.51
Direction Island N	3.0	2.13	2.51	2.65	3.02	3.40
Horsburgh North	2.5	2.49	2.96	3.13	3.56	3.70
Lagoon						
West Island Jetty	1.5	1.19	1.29	1.30	1.51	1.60
Rumah Baru	1.1	1.29	1.31	1.35	1.58	1.70
Airport North	2.5	1.29	1.36	1.41	1.71	1.85
South Lagoon	1.0	1.29	1.35	1.41	1.60	1.85
South Island Inner	1.0	1.29	1.34	1.38	1.55	1.66
Home Is. South	1.0	1.19	1.29	1.30	1.46	1.60
Home Island Jetty	1.5	1.29	1.29	1.29	1.39	1.48
Direction Is. Jetty	1.5	1.29	1.29	1.29	1.31	1.34
Horsburgh South	1.5	1.90	2.08	2.19	2.52	2.72

Table 13 – Storm tide return periods using 1% wave setup values by the end of the 21st Century assuming a mean sea level rise of 1.1 metres.

Location	Ground level (approx)	Storm tide level (m) for the return period indicated				
		10yr	50yr	100yr	500yr	1000yr
Open coast-line						
Trannies Beach	2.0	2.47	2.79	2.90	3.13	3.25
Quarantine North	3.2	2.48	2.83	2.96	3.29	3.36
North Park	3.5	2.46	2.76	2.87	3.15	3.21
Airport Settlement	4.0	2.43	2.79	2.92	3.17	3.28
Airport South	2.8	2.36	2.71	2.84	3.10	3.17
Southern Entrance	0.3	2.49	2.83	3.01	3.53	3.72
South Island Outer	0.6	2.58	2.93	3.09	3.48	3.61
Home Island SE	3.0	3.17	3.67	3.90	4.25	4.56
Home Island North	3.0	3.03	3.46	3.63	4.03	4.21
Direction Island N	3.0	2.83	3.21	3.35	3.72	4.10
Horsburgh North	2.5	3.60	3.66	3.83	4.26	4.40
Lagoon						
West Island Jetty	1.5	1.89	1.99	2.00	2.21	2.30
Rumah Baru	1.1	1.99	2.01	2.05	2.28	2.40
Airport North	2.5	1.99	2.06	2.11	2.41	2.55
South Lagoon	1.0	1.99	2.05	2.11	2.30	2.55
South Island Inner	1.0	1.99	2.04	2.08	2.25	2.36
Home Is. South	1.0	1.89	1.99	2.00	2.16	2.30
Home Island Jetty	1.5	1.99	1.99	1.99	2.09	2.18
Direction Is. Jetty	1.5	1.99	1.99	1.99	2.01	2.04
Horsburgh South	1.5	2.47	2.78	2.89	3.22	3.42

5.2 Impacts on Economy & Society

5.2.1 Society & Culture

The 2006 Census identified 572 inhabitants on Cocos (Keeling) Island with about 80% of them living on Home Island. Relative to mainland Australia, the Territory exhibits a large underrepresentation of the people in the 15 to 19 years age range. This is explained by the fact that young people are leaving the island because of their studies. Compared to Christmas Island, the proportion of the population aged between 20 to 24 years old is better represented.

5.2.2 Economy

Because of the limited opportunities for employment, the population between 20 and 24 years old is fairly low. There are very few people aged over 65 years on the Island. Considering the low values of the total number of inhabitants, the population demographic is difficult to compare with more classic population demographic profiles.

The Cocos Malay people constitute most of the population of Cocos (Keeling) Islands. These are descendants of the Malaysians brought to the island to work in the Coconut plantations. They developed a culture based on Muslim belief and local folklore (more than three quarters of the population of these islands are Muslim). Significant communities of Cocos Malay also exist on mainland Australia (mainly in Western Australia) and in Malaysia. The inhabitants of West Island are mainly of European origin.

The economy of Cocos (Keeling) Islands is basic and mainly driven by the public sector which provides the majority of employment and economic values. The Gross Domestic Product (GDP) is significantly smaller than the one of Christmas Island, with only $15 million of which 42% is provided by the service industry. The transport and utilities sectors are the second and third generators of wealth on the islands. There are no agriculture, fishing, mining or manufacturing activities on Cocos (Keeling) Islands. Unlike Christmas Island, the construction sector is almost non-existent. As on Christmas Island, most of the spending by individuals, businesses and government is undertaken outside of the island economies.

The 2006 census indicated a workforce of 236 people with 24 people unemployed, which corresponds to a high rate of unemployment (approximately10%). There are assumptions that the real number of unemployed persons is even higher, the difference between the official figures and the real figures being explained by some masking effects such as community support, the fact that not everyone is seeking a job and thus is not registered.

There is a high rate of part-time employment (more than a third) and a low rate of full time employment (56%). The public sector is the main employer of the islands, especially through education and training and public administration and safety functions. The National Park and conservation services provide less employment than on Christmas Island with only four permanent staff (ACIL Tasman 2008).

The incomes on Cocos (Keeling) Islands are relatively low (significantly lower than on Christmas Island), a situation notably explained because of the important part-time employment, and that Government and tourism sectors tend to provide lower wages than the mining and construction industries.

Vulnerability to climate change varies with economic, social and institutional conditions: particularly in a socio-economic context. The climate-change vulnerabilities of settlements and society on CKI are mainly related to extreme weather events rather than to gradual climate change.

Aside from major extreme events, climate change is seldom the main factor in considering stresses on the sustainability of settlements and society

5.2.3 Impacts on communities

The central issues facing communities on CKI relate to whether climate-change impacts are likely to require responses that go beyond normal adaptations to varying conditions, if so, for whom, and under what conditions responses are likely to be sufficient to avoid serious effects on people and the sustainability of their ways of life. It is increasingly recognised that social impacts associated with climate change will be mainly determined by how the changes interact with economic, social and institutional processes to exacerbate or ameliorate stresses associated with human and ecological systems.

With regard to the two settlements on CKI it is evident that Home Island and the Cocos Malay population are potentially more vulnerable to the impacts of climate change, and have less adaptive capacity than the corresponding community on West Island.

Hence it is highly likely that a higher socio-economic burden will be imposed on the Home Island community by climate-related hazards and disasters, and that this burden will be exacerbated due to inequalities in adaptive capacity associated with socio-cultural and religious differences and barriers and constraints to adaptation.

The Cocos Malay population face a range of challenges typical for ethnic minorities such as low socio-economic status, high dependency on welfare support, insufficient access to commercial markets and employment, together with cultural, religious and linguistic isolation that frequently limit their ability to cope with threats.

Social systems on CKI are also vulnerable, especially to extreme events. Storms and floods can damage cultural assets such as burial sites, and disrupt social networks and means to sustain traditions and livelihoods (such as marriage feasting).

Whilst the Cocos Malay community are historically accustomed to variability in environmental conditions, and in many ways they have become resilient to it when it is a part of their normal experience; if the risks of such impacts are more extreme or persistent than that previously experienced, then these impacts may indirectly threaten traditional livelihoods and culture.

5.2.4 Tourism Impacts

Currently CKI has a small but growing tourism industry primarily centred on 'sea, sun and surf'. The major attractions on the islands are coastal and marine based attractions, and tourism activities include diving, surfing, kite surfing and leisure. The Islands heritage, including cultural heritage, are also tourist attractions.

Climate change is unlikely to affect inbound tourist numbers to CKI over the short to medium term. Whilst climate is a major factor for many tourists when choosing a destination, it is unlikely that the small increase in temperatures predicted for CKI will act as a deterrent for those tourists seeking 'sea, sun and surf'. Over the long term however, sea-level rise and increasingly frequent and intense weather extremes may influence tourism directly via the decision-making process by influencing tourists to choose different destinations, or indirectly as a result of the indirect impacts of sea-level rise on beaches and reefs. Extreme climate events in particular, such as tropical storms and cyclones, could have substantial effects on both tourist infrastructures on the Islands, as well as on the quality of tourist attractions and natural settings.

5.3 Impacts on Infrastructure

5.3.1 Infrastructure on CKI

CKI transport infrastructure includes two ports, bitumen and unsealed road and an airport which is located on West Island. There is currently a project to build a new passengers and freight facility at Rumah Baru on West Island that should be completed by 2009. Most of the road network comprises paved roads in the settlements, and along the Sydney Highway running the length of West Island The electricity on West Island is generated by a diesel fired power station and a part of the electricity of Home Island is produced by a wind turbine.

5.3.2 Sensitivity of Infrastructure to Climate Change

A sensitivity analyses was completed for infrastructure classes, results of which are shown in Table 14.

Table 14 – Sensitivity of Cocos (Keeling) Islands infrastructure to climate change risks

	Temperature	Wind	Rainfall	Sea Surface Temperature	Ocean Acidification	Ocean Circulation	Sea Level	Humidity	Storm Surge	Currents	Waves	Cyclone
Water Resources	Definite	Negligible	Definite	Negligible	Negligible	Negligible	Definite	Negligible	Negligible	Negligible	Negligible	Definite
Power Resources	Definite	Definite	Negligible	Negligible	Negligible	Negligible	Definite	Definite	Definite	Negligible	Negligible	Definite
Transport - Ports	Definite	Negligible	Negligible	Definite	Definite	Negligible	Definite	Definite	Definite	Negligible	Negligible	Definite
Transport - Roads	Negligible	Definite	Negligible	Negligible	Negligible	Negligible	Definite	Negligible	Definite	Negligible	Negligible	Definite
Transport - Airport	Definite	Definite	Negligible	Negligible	Negligible	Negligible	Definite	Definite	Definite	Negligible	Negligible	Definite
Buildings	Definite	Definite	Negligible	Negligible	Negligible	Negligible	Definite	Definite	Definite	Negligible	Negligible	Definite
Comms	Definite	Definite	Negligible	Negligible	Negligible	Negligible	Definite	Definite	Definite	Negligible	Negligible	Definite

Negligible Risk – Presents "negligible" risk within the probability of natural variation

Definite Risk – Presents "definite" risk within the probability of natural variation

5.3.3 Impacts on Power Resources

Power resources are predominantly sensitive to the impacts from extreme weather events such as cyclones and storm surges as these affect their above ground power generators, distribution and substations which can lead to a loss of electricity supply on CKI. The power generators are likely to be damaged by flooding as a result of a cyclone.

Increased temperature and humidity may accelerate the degradation of electricity and transport fuel assets. These impacts of climate change on their assets may lead to the early replacement of assets due to increased corrosion. Structural fatigue may result from the increased intensity of storm and cyclone events which will require significant capital investment to replace and renew these assets. Fuel storage is also vulnerable to storm damage and higher corrosion rates both of which may result in the loss of fuel and fuel storage capacity. Damage to fuel storage will potentially cause a fuel spill having serious environmental implications. CKI is highly reliant on external fuel supply.

Following an extreme weather event fuel supply may not be able to be delivered to the island due to damaged port facilities leaving the island potentially on fuel rations.

CKI is geographically isolated and resource dependant on mainland Australia. This dependence on the mainland may lead to delays in maintenance and repair of power resources after extreme events as specific components need to come from mainland Australia. In the event of a severe cyclone access to CKI may be restricted due to damage to port or airport– further delaying the repair of the power resources

5.3.4 Impacts on Ports & Jetties

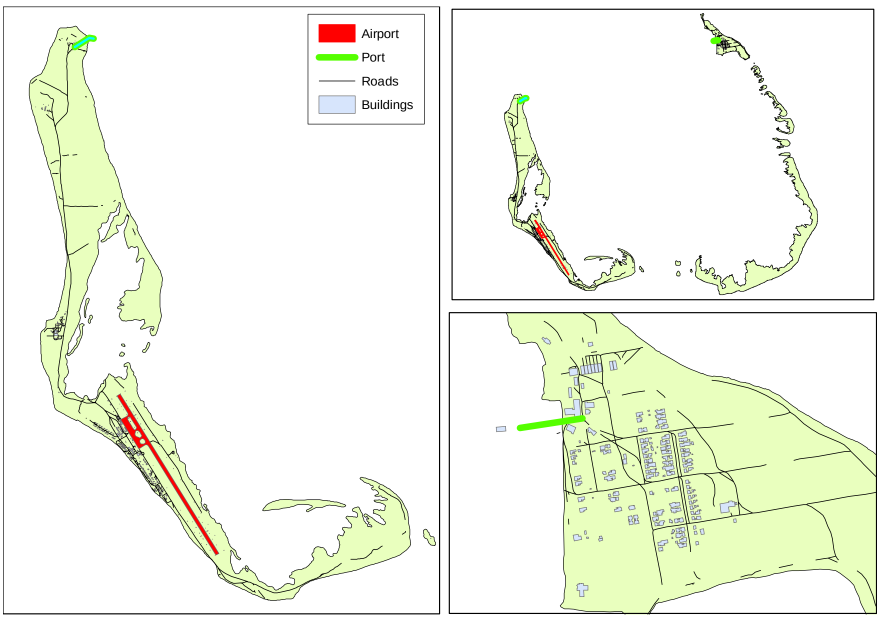
Port facilities are predominantly vulnerable to increases in extreme events such as cyclones and storm surges. Some of the port facilities such as piers, barges, boats and sea wall protection are particularly vulnerable to wave and wind damage associated with storm events. Increased air temperature, sea surface temperature and humidity will accelerate the degradation of port assets through increased corrosion. Port assets will also suffer from increased fatigued structures due to increased storm intensity. This will further reduce asset lives and increase potential failure during extreme storm events. Sea level rise changes the corrosive zones on assets exposing components of the assets to corrosion which were not designed for this level of corrosive impact. Sea level rise also prevents existing port facilities from functioning effectively as it reduces their freeboard making them more vulnerable to overtopping from waves and storm surges.

The loss of key port facilities such as pier structures, barges and ferry boats will inhibit access to the Islands. This may hinder shipping freight supplies arriving at the island resulting in significant social and economic implications for the island.

5.3.5 Impact on Roads

Roads are predominantly affected by the ongoing impacts from reduced rainfall, increased temperatures and increased ground movement which cause the road pavement and surface to deteriorate. The road surface is especially vulnerable to erosion from large storm surge events and cyclones. It is expected that the potential damage to road assets will increase with sea level rise. Any significant damage to road assets will hinder access between Settlement and the Southern part of West Island as well as hinder access between Home Island foreshore and the cemetery. This will have large social implications for the Islanders.

Figure 13 – Road, jetties & airport infrastructure



5.3.6 Impact on the Airport

The biggest risk to the CKI airport is the projected increase in the frequency of intense cyclones up until 2030. The airport is currently not cyclone rated and is therefore particularly vulnerable. Cyclones could potentially damage the runway through erosion and debris as well as impact the communications towers and other airport building facilities.

5.3.7 Impact on Buildings

CKI building structures are predominantly impacted by storm events which are associated with the increasing frequency of intense cyclones. Other factors affecting buildings are; permanent coastal erosion, extreme rainfall, storm surge flooding, sea level rise and wind damage associated with cyclones. Building materials are also impacted by increased corrosion as a result of increased temperatures and humidity and structural fatigue resulting from the intensity of storm events, both of these impacts lead to reduced asset life. Any such alterations to asset life will increase maintenance requirements and renewal of assets.

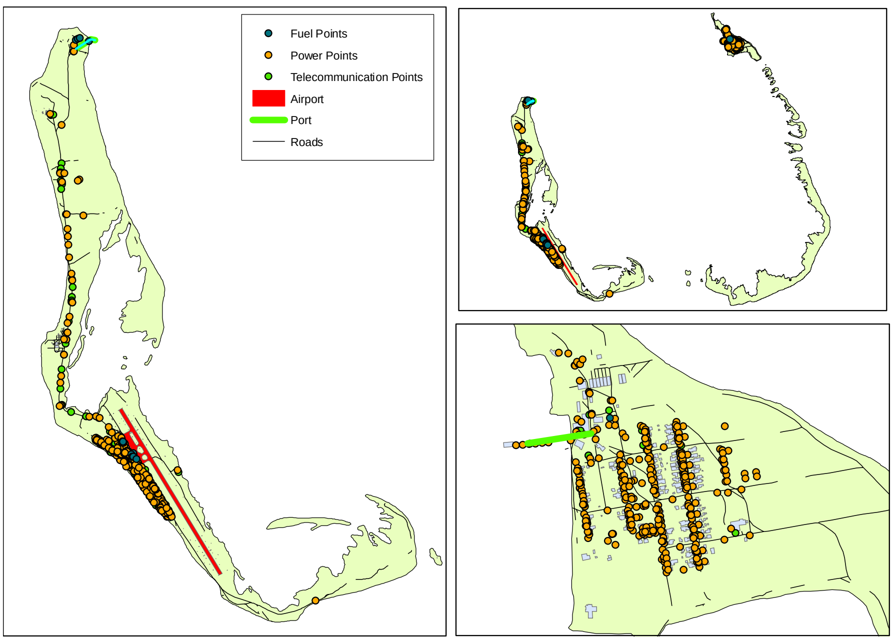
It is likely that there will be an increased need for air conditioners in order to make the current buildings comfortable during heatwaves. It should be noted that the use of air conditioner has dramatically increase in the past years because they became cheaper. Current building design could present a health risk to elderly, infants and the population with pre-existing medical conditions.

Home Island residential buildings are especially prone to flooding and storm damage due to their exposed location. Currently none of the buildings on CKI are designed to cyclone ratings. The existing cyclone shelters on Home and West Island are inadequate as they are likely to be impacted by windblown debris during storms. The cyclone shelter on West Island could potentially be hit by the communications tower should this structure fall during a severe cyclone event. Other urban facilities such as the airport terminal, shops and health centres are also not cyclone rated and many are subject to storm surge and flooding impacts.

5.3.8 Impact on Communications

CKI communications infrastructure is vulnerable to the impacts from cyclones. Increased wind and wave activity and storm surges associated with an intense cyclone event could potentially damage the communications tower as well as inundate its support structures. The extreme winds experienced during a Category 4 and 5 cyclones are likely to cause the communications tower to fall – potentially causing significant damage depending on in which direction the tower falls. CKI have limited backup communication available which makes their existing infrastructure particularly vulnerable. If the communication equipment is significantly damaged the repair process is likely to be slow as limited or no replacement communication equipment is available on the Island. Their only backup will be the satellite phones which are likely to remain operational.

Figure 14 – Fuel, power & communications infrastructure



5.4 Freshwater Resources

The freshwater resources on CKI are particularly sensitive as the Islands are entirely reliant on freshwater lenses (there is no ground water on the Islands). The combination of increased temperatures decreased annual rainfall and rising sea levels is likely to cause water shortages as less potable water will be available in the water lenses. These issues may be compounded by sea level rise (inducing saline intrusion and decrease of island area collecting water). These direct and indirect effects of climate change are likely to have consequences both on water quality and quantity.

Water shortages are already a reality on the Islands with Home Island having water restrictions already in force due to a recent trend of drier conditions. An existing micro scale desalination plant currently operates on the West Island but provides limited capacity as an alternative water source.

The projected increase in cyclones and storm surges for 2030 will potentially hinder community access to potable water. Increases in storm surges will also expose more land to flooding which will hinder access to potable water. During intense cyclones and storm surge damage to power infrastructure may lead to the loss of pumping capability to access ground water as pumping stations on West and Home Island cannot be manually operated. The current portable power generation sets that are present on the Island will enable some short term operation of pumping stations but this is not sufficient to minimise the risk.

5.4.1 The current use and conditions of the water lenses

The current state of water lens is much more of a concern on Home Island. During summer and at low tide, it is not possible to pump because the level is too low, especially on the edge of the Island. Furthermore, the sustainable level of water pumping is thought to be almost reached. This has led to the decision to develop a desalination water plant.

Although the desalination plant will provide a source of freshwater, the capacity might not be sufficient if the population was to increase and there are some concerns about the ability of the station to function during extreme events due to limited power supply. The transfer of potable water during crisis periods between Home Island and West Island is entirely dependent on the remaining boats (and possible debris in the lagoon) after an extreme climatic event and should not be considered as a permanent solution.

The quality of the water is also affected by non-climatic factors such as runoff from the airport and the power station and the fact that people are living above the water lenses. There are concerns regarding public health and the water quality is tested (for chlorine) every day.

5.4.2 Potential changes in water resources quantity

The observations and the projections in terms of precipitation are associated with very high degree of uncertainty. Any decrease or increase of annual precipitation amount would influence the recharge of the groundwater resources. Meantime, an increase of the evaporation because of higher temperature would also reduce the overall quantity of water resources (although any changes might be limited). These effects would be further enhanced during dry spells. The loss of land due to sea level rise may also reduce the quantity of water collected on the Islands. However, no quantitative estimations are available at this stage.

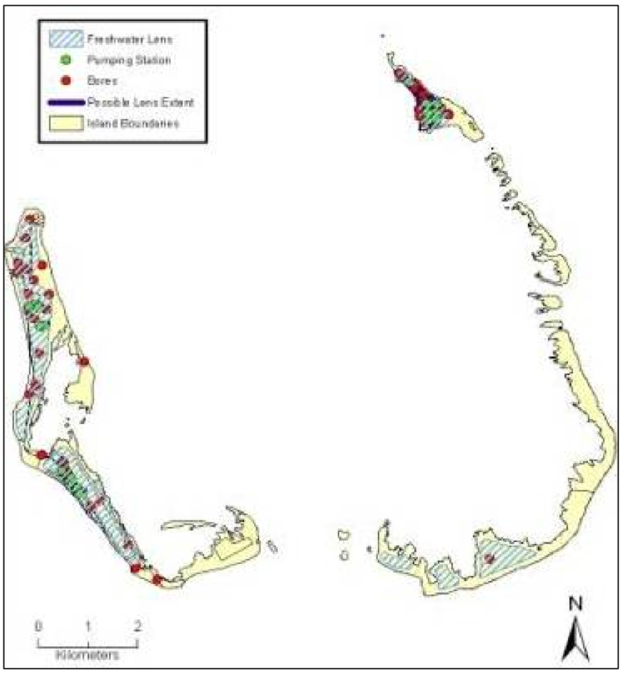


Figure 15 – Freshwater lenses on Cocos (Keeling) Island

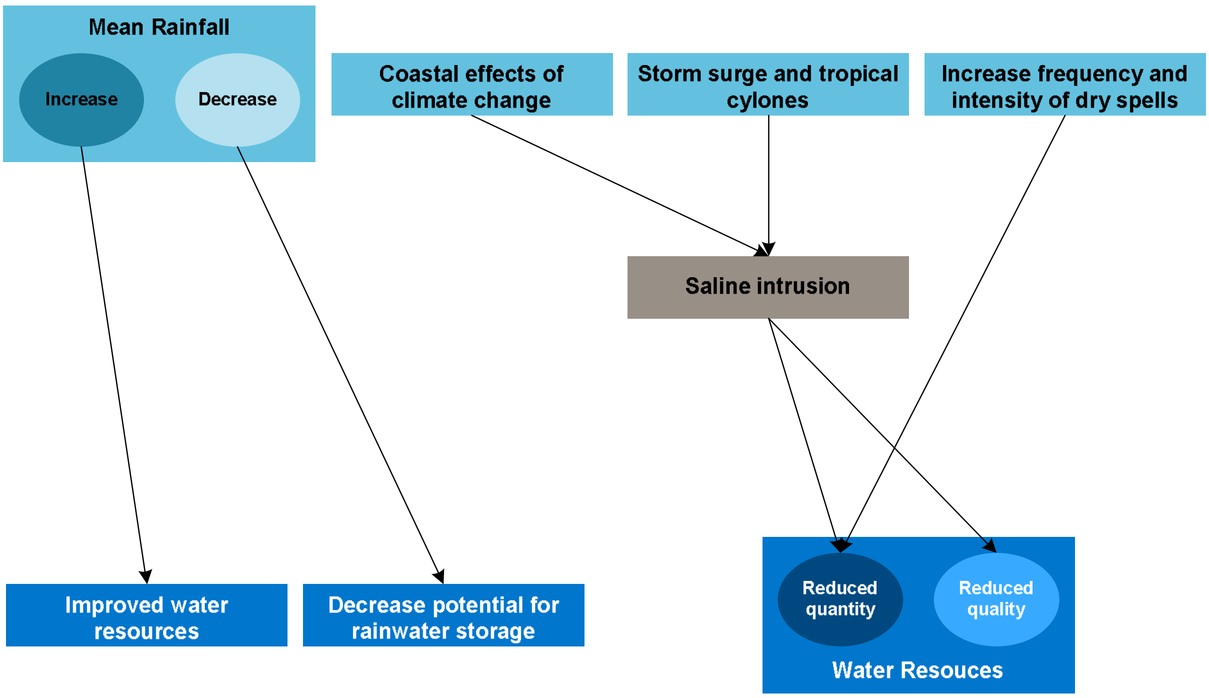
5.4.3 Potential changes in Water Resources Quality

The main problem regarding water quality on CKI is linked to saline intrusion in the water lenses on Home and West Islands. The existing pumping systems already put pressure on the resources by increasing salt gradient through excessive extraction (salinity tended to increase lately). The projected sea level rise and potential inundation during storm surge events might induce more important saline intrusions. Generally, heavy precipitations follow such events and “wash” the lenses. However, if no precipitation occurs straight after the event, the situation can get worse.

For example on Puka-Puka in the Pacific Ocean, no rainfall occurred 5 months after the cyclone Pierce in 2005, the effects of the event on water lenses were still noticeable after 12 months and only marginal after 24 months.

The pumping of water has no major effects on the South water lens of West Island. There is spare capacity for the water lens (consumption is thought to be about 1/5 of the sustainable level) and although five pumping galleries out of six have been closed, the remaining gallery (Number 4, near the police station) can pump at a much higher rate. The conditions are very stable except during drought events. The North lens of West Island (estimated to be about half of the volume of the south one) also shows spare capacity and is actually not under pressure by pumping. The situation is a slightly worse on the lagoon side of the water lens.

Figure 16 – The dynamics of freshwater resource



5.5 Impacts on Human Health

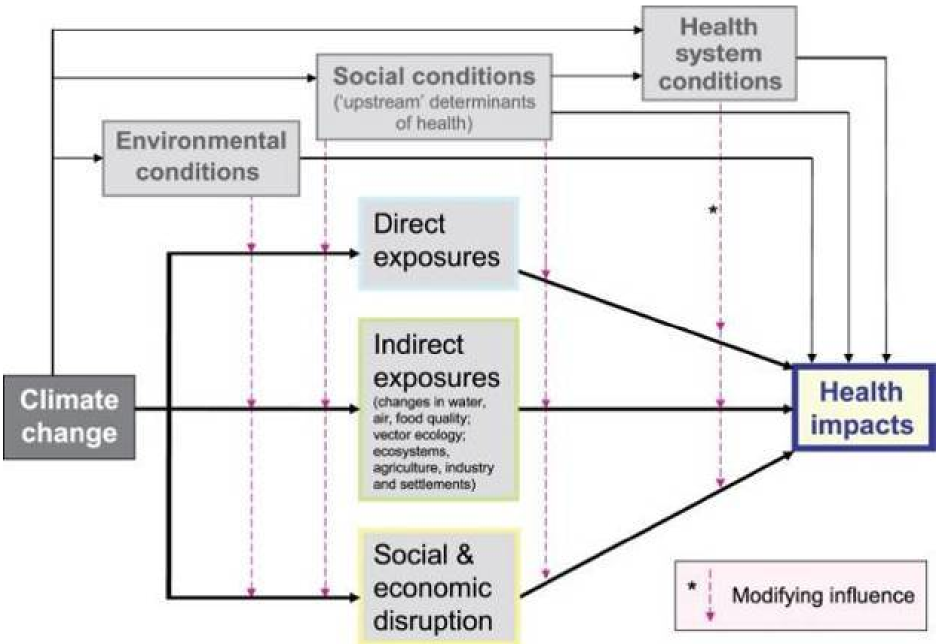
5.5.1 Health Facilities & Service

Health Centres, operated by the Indian Ocean Territories Health Service (IOTHS) are located on both Home and West Island and are staffed by a doctor, nurses, health workers, a community services officer, and a dental assistant. The Health Centres operate as clinics providing outpatient and consultation facilities. Some specialist visits occur on a regular basis, however arrangements can be made for patients to travel to CI or Perth as necessary. Emergency situations that require treatment beyond what can be provided on-island are addressed by evacuation to Perth.

5.5.2 Health Impacts

Currently CKI does not suffer severe health burdens from climate-sensitive diseases, including morbidity and mortality from extreme weather events, certain vector-borne diseases, or water-borne diseases. Climate related exposures of greatest significance to human health on CKI will be related to extreme weather events, sea level rise, and food- and water-borne diseases. While still requiring consideration, the islands populations will be less sensitive to extreme weather (increased temperatures) and vector-borne diseases.

Figure 17 – Schematic diagram of pathways by which climate change affects health, and concurrent direct-acting and modifying (conditioning) influences of environmental, social and health-system factors (IPCC 2007, WGII, Ch.8)



The potential impact of climate change on human health on Cocos (Keeling) Islands are summarised below.

Health Impact	Discussion
Extreme weather events	CKI comprises low-lying, long and narrow island atolls and the inhabitants are at particular risk from these changes and acute events such as cyclones, storm surges, and flooding. Injury and death due to drowning and trauma are possible direct and severe impacts here. Projections for precipitation and wind and wave patterns are highly uncertain but the potential is for increases to occur. Category 4 and 5 tropical cyclones are projected to increase in frequency by a factor of two to three.
Temperature-related deaths	Exposure to prolonged and excessive heat can lead to heat stroke and other temperature related health effects and are most keenly felt in those populations rarely exposed to high temperatures. Heatwaves are associated with short-term increases in mortality. Variables that confound the temperature – mortality relationship include medical, social and environmental factors. The elderly, young, poor, and those bedridden or those with existing medical conditions are most at risk. The Cocos (Keeling) Island population is well adapted to living in tropical conditions and are not reliant on air conditioning. The mean, minimum, and maximum temperatures are projected to increase by 0.7°C and 1.8°C for 2030 and 2070, respectively, which are not significant increases as the current maximums will become the mean temperatures. Aside from those who are most at risk, it is likely that the local population is relatively resilient to direct effects of these elevated temperatures.
Vector-borne diseases	Vector-borne diseases, such as dengue and malaria, are those diseases transmitted by an animal or an insect (e.g. the bite of an infected arthropod), and are widespread and sensitive to climate. While other factors contribute to distribution of vectors, climate-change has altered the distribution or range of some infectious disease vectors. Vector-borne diseases are reportedly not prevalent on the CKI. However as there is uncertainty about the impact climate change may have on the range of the vectors, prevention measures could be considered e.g. mosquito nets and availability of treatment medicines.
Water borne diseases	Water-related diseases can be water-borne (ingested) and water-washed (poor hygiene). Extreme rainfall and warm temperatures influence microbial and chemical contamination of coastal, recreational and surface water.
Food borne diseases	Increased temperature increases risk of certain types of food poisoning and water-borne diseases e.g. salmonellosis and diarrhoeal diseases. Contact between food and pests (flies, cockroaches, and rodents) are also temperature sensitive. Increased sea-surface temperature can lead to poisoning of shellfish and seafood due to toxins from Harmful Algal Blooms and the methylation of mercury.
Micro algae bloom	Micro algae often constitute the basis of marine food web. However, a small proportion of them constitute a danger for reef fishes and indirectly, human. The disease is contracted by consuming reef fish that have been contaminated by ciguatoxins. Considering that the local fish represent up to a third of the diet for the residents, this issue is significant. An increase in water temperature (SST is expected to increase by 0.6°C in 2030 and 1.8°C by 2070) could potentially lead to faster development of some opportunistic species. Furthermore, degraded coral reefs (following repetitive bleaching events) are considered to provide optimal breeding ground for the development of these microalgae.

CKI – Summary of Risks for Human Systems and Socio-economic Vulnerability

Classification	Risk	2030	2070
Human Settlements	Direct impacts of sea level rise & extreme events	High	Extreme
Society & Culture	Indirect effects of sea level rise & extreme events	Low	Medium
Economy & Tourism	Indirect effects of environmental degradation	Medium	High
Water Resources	Water shortage	High	Extreme
	Loss of access to water	Medium	Medium
Power Resources	Loss of electricity supply	Low	Medium
	Increased corrosion of power assets	Low	Medium
	Storm and fire damage to fuel storage and power facility	Medium	Medium
Ports	Storm damage to port facilities	High	Medium
	Corrosion of port facilities	Low	Medium
Roads	Storm and sea level rise damage to roads	High	Medium
Airport	Storm damage to airport	Medium	Low
Buildings	Storm and sea level rise damage to buildings	High	Extreme
	Heatwave impacts	Medium	Medium
	Corrosion of buildings and facilities	Low	Medium
Communications	Storm damage to communications equipment	Low	Medium
	Corrosion of communications equipment	Low	Low
Human Health	Direct effects of temperature rise and indirect effects of extreme events	Low	Medium

Part IV – Christmas Island: Impact, Vulnerability & Risk

6.0 Impacts on Natural Systems

6.1 Impact on Coastal Areas

6.1.1 Island Geomorphology

Overall, the geomorphology of Christmas Island is characterised by a series of stepped terraces that rise to an inland plateau approximately 250 to 300 m in elevation. The nature of the island as a plateau means that it is susceptible to much less geomorphological change over a medium to short time scale than that observed on the Cocos (Keeling) Islands.

In this respect rocky areas of coast are divided into those that are made up of steep cliffs with evidence of erosional features (sea stacks, caves, undercutting) and those that are fronted by an intertidal and/or subtidal rock platform, often associated with a more gradually sloping cliff face and exposed rock berm in the supratidal area between the cliff line and the edge of landward vegetation.

Key areas considered for further analysis for the purposes of this project were restricted to low-lying areas around Flying Fish Cove; the area of Settlement (north of Flying Fish Cove) and specific locations along the East coast with a focus on Waterfall Bay, Dolly Beach and Ethel Beach. Cliffs in the absence of shore platforms characterise the Settlement and the coast around Dolly Beach and Waterfall Beach; Platforms have been identified from Lily Beach to Ethel Beach on the northeast coast; and conversely, Flying Fish Cove provides an example of an engineered coastal zone where a relatively narrow, coarse sandy beach is backed by an unstable area of cliffs prone to rock fall.

A distinct seasonal shift in swell conditions exists between the wet and dry seasons. During the wet or ‘swell’ season, increased wave energy results in overtopping at Settlement and progressive undercutting of the cliffs in this area. Gale force winds and heavy seas from the northwest have implications for the management of the Port facility at Flying Fish Cove.

In general, the East coast is subject to more energetic conditions during the dry season when the southeast trade winds are at their strongest. During this time erosion of pocket beaches and undermining of high erosive cliff lines occurs. Conversely, during the wet season this coastline is more sheltered and, while still subject to energetic wave conditions, less visible erosion has been documented.

Although CI is not officially considered a ‘cyclone prone’ location, stakeholders on the Island consulted during the preparation of this report described two significant cyclone events in recent times (March 1988 and April 2008).

6.1.2 Observed Change

Overall, the direction of change under current conditions may be inferred from an examination of available evidence in historic reports, aerial photography and anecdotal accounts from key stakeholders. A tendency towards erosion and undercutting of the limestone cliff line and a progressive loss of beach sediment was identified within Flying Fish Cove. In addition, the Police Station and coastal road at Settlement have been subject to impacts of overtopping in high swells. The adjacent limestone terrace is prone to ongoing undercutting and susceptible to instabilities. A consideration of available imagery for the Flying Fish Cove area also illustrated the magnitude of wave and surge conditions during extreme events, namely cyclones occurring in March 1988 and April 2008.

Storm surge associated with these cyclones is a serious issue especially for low-lying areas along Flying Fish Cove. The 1988 cyclone pushed from northwest and damaged loading structures for mines. The seawall was slightly damaged in this event and needed some minor repairs.

6.1.3 Projected Changes in Climate and Expected Coastal Impacts

During the April 2008 cyclone the storm tracked from the south with impact from swell and wind. Water encroached to the front of the flats in Kampong, over the road and into the grassed area extending up to 100 metres onshore. The seawall in Kampong was also damaged with accommodation adjacent to the foreshore becoming flooded. In addition, rocks and mooring buoys were thrown up onto the road. Storm water also represents a major problem with current drainage systems not sufficient and water draining onto the cliff face at Settlement.

Each of the three areas under consideration for the purposes of this report (Flying Fish Cove, Settlement and the beaches of the eastern coast from the Waterfall to Dolly Beach) is characterised by a discrete level of sensitivity dictated by underlying geologic structure, geomorphology and exposure to prevailing and dominant conditions. Overall, from an assessment of exposure, geomorphic characteristics and evidence of previous change (both modal and in response to extreme events) sensitivity of discrete areas of interest to projected changes in climate and are summarised in Table 15.

Table 15 – Coastal sensitivity to climate change

Location	Coastal Sensitivity to Projected Changes in Climate
Medium relief cliff fronted by beach	• Possible decrease in beach sediment adjacent to sea wall leading to a loss of amenity and protection afforded to coastal infrastructure e.g. jetty foundations; sea wall. • Increased likelihood of overtopping of low sea wall during the wet season swell. • Exacerbated flooding of Kampong area during extreme events is probable. Currently, water has been recorded extending up to 100m inshore with resulting flooding of flats. SLR and higher waves will exacerbate this during storm conditions. • Likely increased deposition of rocks and storm debris along foreshore during storm events with implications for structural integrity and human safety. • Increased wave damage in swell season likely due to landward movement of process boundary with resultant impacts on physical environment. Continued undercutting of cliffs to north and south likely. • More rain will likely contribute to slope instability and potentially lead to rock fall.
High Cliff with relatively narrow platform	• Further damage to buildings close to cliff line expected. For example, the police station and houses in the South of Settlement are currently susceptible to impacts of wave overtopping in swell season and during extreme events. This will likely be exacerbated by rise in MSL and increased intensity of storm waves during cyclones. • Potential for deposition of boulders and other debris on cliff top thrown up by power of storm waves – potential damage to property and risk to human life. • Progressive undercutting of cliff will likely lead to increased instability.
Beaches with platform and low relief cliff and terrace in backshore	• Erosion of beach sediment with undermining of tree line/tree felling, damage to coastal vegetation is expected to occur as sea level rises and process boundary moves landward.
Beaches with no platform backed by steep cliff	• Undercutting of cliffs is likely. • Reduction in beach area and volume expected– beach is not capable of recession due to presence of steep cliff line.

In summary, CI is less vulnerable to the impacts of rising sea levels than CKI due to its greater height above sea level. Well-lithified rock shores that protrude high above sea level do not generally have an erosion problem. Limestone shores fronted by reef shelf are generally also afforded good self-protection against erosion provided that solid rock also extends to well above sea level. However, in the case of CI, much of the shoreline is cavernous and irregular at the present sea level and would erode significantly with sea level rise.

Storm surge is a serious issue especially for low-lying areas along the foreshore. The main problem faced by flat, low-lying areas of the island such as Flying Fish Cove is the fact that they are backed by high rock. In light of this, they have nowhere to erode in response to an elevation in process boundaries. Communities that live in these areas are currently affected by storm surges and may be inundated under future scenarios for climate change.

Increased wave action and storm surges associated with more intense storms may have damaging effects on the coral reef systems which fringe the island. This damage may reduce the ability of these systems to protect the physical environment along the coastal zone, which lead to increased undermining and cliff collapse along high stand rocky coastlines. Areas with shore platforms already exposed to surge and wave action will likely erode more.

Impacts on Ecosystems & Biodiversity

6.2.1 Current Biodiversity

CI ecosystems include rainforest, subterranean systems and coral reef. Two thirds of the Island is protected as National Park. Biodiversity values of the Island include:

- Approximately 450 plant species including 18 endemic, and 28 rare or threatened species;
- Ramsar listed Wetland of International Importance;
- Two endangered mammal species;
- Seven endemic land bird species, including two that are endangered;
- Nine seabird species and subspecies that nest on the island, including two endemic and endangered;
- A diversity and abundance of land crabs that is not matched on any other island, and includes an endemic land crab;
- Fringing coral reef and associated fauna, and
- Marine species, including manta rays (*Manta birostris*), whale sharks (*Rhincodon typus*) and green turtles (*Chelonia mydas*).

6.2.2 Vulnerable Ecosystems

Literature on climate change and ecology suggests that some ecosystems and species are likely to be more susceptible to climate change than others, such as:

- Species or ecosystem types that are threatened or endangered due to small population sizes and other factors making them more vulnerable to extinction;
- Forest ecosystems;
- Migratory species, especially those with migratory events dependant on seasonal changes;
- Geographically restricted species such as coral reefs;
- Island birds, as they tend to have smaller populations than continental species, may have no opportunities for dispersal and recolonisation beyond the island and have a restricted area of habitat, and
- Endemic species with limited climatic range, small populations or restricted habitat, especially those restricted to islands.

This background on significant ecosystems and species, and generic characteristics of ecosystems and species more susceptible to climate change, informed the development of a short list of ecosystems and species potentially susceptible to climate change.

Unique and vulnerable ecosystems of CI, i.e. ecosystems more likely to be susceptible to climate change than others, include:

- Primary and terrace rainforest, and rare and endemic plants associated with the rainforest;
- Mangrove at Honsie's Spring, which is a unique and restricted habitat on the island and is a Ramsar listed Wetland of International Importance;
- Cave environments and associated fauna, which are poorly understood and are described as vulnerable ecosystems (Commonwealth of Australia, 2002), and
- Coral, which is present as a fringing reef and is an isolated and geographically restricted community.

6.2.3 Threatened Species

Species more likely to be susceptible to climate change include:

- Endangered and endemic species and subspecies, including two mammals, the Christmas Island shrew (*Crocidura attenuata trichura*) and Murray's pipistrelle bat (*Pipistrellus murrayi*), and two birds of prey, Christmas Island hawk-owl (*Ninox natalis*) and the goshawk (*Accipiter fasciatus natalis*);
- Crabs, especially the red land crab (*Gecarcoidea natalis*), which is an endemic species and responds to seasonal triggers to initiate migration and reproduction;

- Seabirds, including two endemic species, Abbott's booby (*Papasula abbotti*) and Christmas Island frigatebird (*Fregata andrewsi*), and
- Species such as manta rays (*Manta birostris)* and whale sharks (*Rhincodon typus*) and particularly green turtles (*Chelonia mydas)*, which are endangered, highly migratory and have temperature dependant sex determination.

Manta rays and whale sharks are not further considered regarding susceptibility to climate change impacts, due to a lack of information regarding these species in CI waters.

6.2.4 Observed Change and Future Impacts

Ecosystem change under current conditions was inferred from examination of existing literature and from information from stakeholder consultation on Island. Ecosystem change due to natural drivers, at CI over the past 50 years, has included:

- Canopy dieback, or drying, in the primary rainforest and the terrace forest, and an increased leaf litter layer;
- Some canopy damage, tree fall and seabird chick mortality due to wind impacts during Cyclone Rosie in April 2008;
- Physical damage to coral from wave action related to cyclone events, for instance in December 2007 and February and April of 2008, and particularly on the north coast, with higher strata plate corals more susceptible to damage than other corals;
- Coral bleaching in 1998, with up to 100% bleaching in some areas, and growth of new plate corals to 0.5 metres taking ten years. Another bleaching event occurred in the swell season of 2005, when the water was around 30-32^{o}C for two weeks, cooled, and warmed again and affected around 1% of *Acropora* (a genus of plate and branching corals), particularly corals in shallow waters. The corals did not die in this event, but healed and recovered;
- Increase in coral disease (Pink Spot, which affects *Porites* corals, and White Syndrome) and increased numbers of Crown of Thorn starfish, and
- A move from one mass migration of red crabs with the first rain of the wet season, to a split migration in the past few years.

It is apparent that the main natural drivers of ecosystem change have been: cyclonic activity and storms, which has caused canopy loss, seabird chick mortality and damage to corals; and short-term rises in sea surface temperature coupled with doldrums conditions, which has led to coral bleaching events. Drier conditions may have led to forest canopy dieback, though anthropogenic changes may also be the cause. Likewise, it is unclear whether increases in coral disease are due to warmer sea surface temperatures during the warmer part of the year (around February) or due to other factors.

In addition to climatic driven ecological change, there has been a large impact to the CI ecosystems from human activity, and climate change impacts cannot be considered in isolation of these other anthropogenic impacts. Non-climate related human impacts have included:

- Clearance of around 25% of the primary rainforest for mining operations, and the flow on effect to fauna inhabiting that vegetation community;
- Weed infiltration in forest areas adjacent to clearings for phosphate mining, and
- Effects of the yellow crazy ant (*Anoplolepis gracilipes*), an exotic invasive species that is now widespread across the rainforest on the island, and in the 1990s, formed high density 'super colonies'. Ground dwelling animals, including the red crab, robber crabs, blue crabs, nesting sea birds and reptiles have been severely impacted, and even locally eliminated. As these crab species are the forest detritivores, the flow on effect from the crazy ant has been a change to the forest composition and structure, and an increased litter later, in infested areas. The feeding activities of the ants can stress large trees to point of death, and may be the cause of apparent canopy dieback on the island. It is unclear whether drying of the forest and increased litter layer is related to climatic changes or the yellow crazy ant.

The projected climate change for Christmas Island is likely to impact upon species in a number of ways, with potential impacts affecting red crabs, birds of prey, seabirds and turtles (Tables 17 and 18). Impacts are particularly critical for species and subspecies with small population sizes that are restricted in distribution, such as Murray's pipistrelle bat, the Christmas Island shrew (*Crocidura attenuata trichura*), Abbott's booby and the Christmas Island frigatebird.

6.2.5 Impacts on Terrestrial Ecosystems

The projected impacts to ecosystems and species should be taken only as an indication of directions of change based on projections for climate change in 2030 and 2070. Descriptions of potential sensitivity presented in the tables are based on climate change projections for 2030. Detailing the thresholds for ecological change was beyond the scope of this report due largely to constraints in available data on species and ecological processes at pertinent temporal and spatial scales. In light of this, it is only possible to infer that directions of change described here will be similar for 2070 projections but likely more pronounced.

The projected climate change for CI is likely to impact upon terrestrial ecosystems in a number of ways, including potential impacts to the rainforest and terrace forest (see Table 16).

Table 16 – Potential impacts to terrestrial species and ecosystems from projected climate changes for CI

Ecological Classification	Description	Risk / Sensitivity Description
Rainforest	• Tall evergreen forest, inland on deeper soils, sheltered from sea spray • Habitat for endangered mammals, red crab and seabirds	**Possible decrease in rainforest quality** • Projected increased average, minimum and maximum air temperature may cause further decline in abundance, or loss, of moisture reliant rare and threatened understorey plants • Changed conditions towards slightly warmer air temperature and changed rainfall patterns may favour non-native plant and animal species, including the yellow crazy ants, and a favouring of the crazy ants would have flow on effects to crabs, other animals and the forest structure • With a projected increase in frequency of high intensity cyclones, there may be intensive canopy loss and tree fall during high intensity cyclones (and canopy gaps take up to 10 years to close). However, it is projected that there will be less incidence of cyclones overall, so cyclone caused damage to the forest may occur less frequently overall
Endangered mammals	• Endemic endangered mammals • Murray's pipistrelle bat (*Pipistrellus murrayi*) • Christmas Island shrew (*Crocidura attenuata trichura*)	**Possible decline in, or loss of, Pipistrelle bat and Christmas Island Shrew populations** • As the bat is restricted to foraging and breeding in the primary rainforest, any impacts to the rainforest from projected climate change will have flow on effects to the bat • Christmas Island Shrew may be extinct already, if it does remain, its tiny population would be very susceptible to being extirpated in a direct hit high intensity cyclone event
Goshawk ***(Accipiter fasciatus natalis*)**	• Endemic • Endangered • Bird of prey • Inhabits primary and marginal rainforest	**Possible population decline or loss of goshawk** • The goshawk is restricted to breeding in the primary rainforest, so any impacts to the rainforest from projected climate change will have flow on effects to the goshawk population

Ecological Classification	Description	Risk / Sensitivity Description
Red Crab *(Gecarcoidea natalis)*	• Land crab • Endemic • Inhabits primary and regrowth forest • Plays major role in forest dynamics, as main detritivores	**Possible decline in red crab abundance** • Red crab migration is triggered by the arrival of the first rains of the wet season (and lunar cycle), so the crabs would be sensitive to a change in seasonal onset, and to reduction in rainfall. Projected changes to rainfall patterns may cause even more pronounced split migration
Terrace forest	• Dry forest that occurs on the terraces • Nesting habitat for the Christmas Island frigatebird	**Possible decline in quality of the terrace forest** • Projected changes to rainfall patterns and increased air temperatures may cause the terrace forest to become more prone to fire (though it is thought the high humidity will prevent this). Fire is rare but has occurred in the terrace forest in 1994 and 1997 during long dry seasons • With a projected increase in frequency of high intensity cyclones, there may be intensive canopy loss and tree fall during high intensity cyclones (and canopy gaps take up to 10 years to close). However, it is projected that there will be less incidence of cyclones overall, so cyclone caused damage to the forest may occur less frequently overall
Mangrove	• *Bruguiera gymnorhiza* and *B. sexangula* dominant, and are among the largest of their species ever recorded • At Honsie's Spring (Ramsar listed), Greta and Dolly beaches and terrace above Dean's Point • Maintained by a permanent freshwater spring	**Possible canopy damage and tree fall** • With a projected increase in frequency of high intensity cyclones, there may be a high level of canopy loss and tree fall during high intensity cyclones. However, it is projected that there will be less incidence of cyclones overall, so cyclone caused damage to the mangroves may occur less frequently overall

6.2.6 Impacts on Marine & Coastal Ecosystems

Projected climate change at CI may affect the marine and coastal ecosystems, particularly the coral and associated fish communities (Table 17).

Table 17 – Potential impacts to marine species and ecosystems from projected climate changes for CI

Ecological Classification	Description/Current Condition	Risk / Sensitivity Description
Coral	• Fringing coral reef • Relatively low species diversity	**Possible decrease in coral abundance or quality** • With a projected rise in SST, if there are more frequent periods of increased SST (possibly over 30^{o}C) coupled with doldrums, this may lead to coral bleaching • It is unknown whether coral will be able to grow fast enough to track SL rise with a projected increase in frequency of high intensity • cyclones, there may be increased incidence of physical damage to

Ecological Classification	Description/Current Condition	Risk / Sensitivity Description
		coral reef structure from cyclone related wave action during high intensity cyclone and storm events, especially on the exposed north coast, however, overall cyclone frequency is projected to decrease so overall frequency of damage by cyclone related wave action may decrease • Projected rise in SST may lead to increased coral disease (white syndrome, pink spot)
Fish	• Fish species associated with coral reef • Pelagic species	**Possible decline in populations of fish associated with coral reef** • Flow on effect from any impacts to corals from projected climate change to species that rely on coral for habitat or foraging
Abbott's booby (*Papasula abbotti*)	• Now endemic to Christmas Island • Endangered • Small-sized and declining population • Nests in tall emergent trees of the primary rainforest	**Possible population decline, or loss, of Abbott's booby** • Abbott's booby only nest in the tall emergent trees of the rainforest – if high intensity cyclones cause canopy damage and tree fall, there will be less breeding ground for the species, and reduced breeding success until the forest recovers • Loss of this species to the Island would mean extinction of the species as CI is the only remaining location with breeding habitat • Seabirds are entirely dependent on the ocean for food. Breeding success has been positively correlated to incidence of cold water upwelling, which result in rich food resource. (Reville et al., 1990 cited in Hill and Dunn, 2004). Any significant changes to currents and sea surface temperature from projected climate changes may alter seabird breeding success • Given the small population size of Abbott's booby, a direct hit from a high intensity cyclone could cause extirpation of this species and thus, extinction
Christmas Island frigatebird (*Fregata andrewsi*)	• Endemic • Critically endangered • Breeds in terrace forest • Three breeding colonies (with two thirds of all nests at the golf course)	**Possible population decline, or loss, for CI Frigatebird** • With high intensity cyclones increasing in frequency, there is increased chance of a direct hit intense cyclone. Two thirds of the population is in one colony (at the golf course), thus prone to being wiped out by an intense cyclone event • Seabirds are entirely dependent on the ocean for food. Breeding success has been positively correlated to incidence of cold water upwellings, which result in rich food resource. (Reville et al., 1990 cited in Hill and Dunn, 2004). Any significant changes to currents and sea surface temperature from projected climate changes may alter seabird breeding success • Loss of this species to the Island would mean extinction of the species as it is endemic to CI
Green turtle (*Chelonia mydas*)	• Endangered • Breeding populations nest at Dolly and Greta beach	**Possible decline in turtle abundance** • Projected increased air temperature may lead to increased sand temperature which would influence temperature controlled sex determination, and skew populations by favouring females • Projected sea level rise will cause loss of beach area at Dolly and Greta beaches, thus reducing available area for turtle nesting

CI – Summary of Risks to Natural Systems and Biophysical Vulnerability

Classification	Risk	2030	2070
Limestone cliffs	Increase undercutting for cliffs without beaches or rock platform	Medium	High
	Increase undercutting for cliffs with beaches or rock platform	Low	Medium
Coral reefs	Proneness to bleaching events because of increased temperature and constrained growth because of more acid ocean	High	Extreme
Coral reefs associated fauna	Decrease in the abundance and diversity of coral associated fauna and flora (reef acing as a nursery and a feeding area)	Medium	High
Red crabs	More pronounced split migration (effects unknown)	n/a	n/a
Rainforest	Decline in moisture dependent plants	Medium	Medium
	Exposure to intense cyclones, proneness to fire events	Low	Low
Endangered and endemic species	Highly vulnerable species; any threats would put greater pressures on them (important non climatic component)	Medium	Medium
Introduced species	Greater pressures because better climatic tolerance range and opportunistic species	Medium	Medium
Seabirds	Loss of nesting habitat and decrease of food availability	Medium	Medium
Fish population	Mass fish kill events, change in the food availability, reproduction cycles, migration patterns	Low	Low
Turtles	Skewed gender ratio and loss of breeding area	High	Extreme

7.0 Impact on Human System

7.1 Current situation

7.1.1 Demography of Christmas Island

The 2006 Census recorded 1,348 residents on CI. However, the 2008 population is possibly under 1,000 people due to the completion of the Detention Centre and the uncertain prospect of mining activities on the island. Similarly to Cocos (Keeling) Islands, Christmas Island is characterised by a lack of people in the 20 to 30 years age range. This age band is mainly leaving the Island to seek employment and attend post secondary school education, mainly in Perth. On the other hand, the proportion of persons between 40 to 64 years is over represented and the over 65 years' band is largely underrepresented. The demography of the island is related to major projects such as the casino and the detention centre. Demographic trends also follow the boom-bust trend of the economic cycle.

The religious affiliation of the Christmas Islanders is divided between Buddhist (30%), Christian (25%) and Muslim (20%). Most of the people are of Chinese ethnicity while the remaining are people of European or Malay origin.

There are three distinct urban areas on Christmas Island, located in the north of the Island, these being:

- Settlement and Kampong on the on the western shore terrace of and to the north of flying fish cove;
- Poon Saan and Silver City located on the central plateau; and
- Drumsite situated on the central plateau.

Only Settlement and Kampong are vulnerable to storm overtopping and inundation associated with storm surge, and this has the potential to threaten public health and safety.

7.1.2 Economy of Christmas Island

The economy of CI is relatively small and is highly influenced by any major project. The re-opening of the mine, the construction and operation of the Casino in the late 1980s, and its closure in 1998 and the completion of the Immigration Detention Centre has resulted in up and down trend in terms of economic activity, along with significant fluctuations of the Island's population.

Today, the main driver of the CI economy is mining and associated activities. It represents slightly more than a third of CI GDP (with 34% of CI $71 Millions of annual GDP). Phosphate Resources Ltd (the company owning and operating the Christmas Island mine) currently exports around 800,000 tonnes of phosphate a year. Their main customers are on mainland Australia, New Zealand, Thailand and Indonesia. The CI mine lease expires in 2019.

The second sector generating GDP is the service industry with 28%. The education, conservation and national parks sectors represent a fair share of the services delivered. The tourism industry is mainly centred on nature-based activities, the red crab migration still representing one of the main attractions of the Island. About half of the visitors are business tourists, a third are leisure tourists and the remaining proportion is visiting friends and relatives. However, much of the spending by individuals, businesses and government is undertaken outside of the Island economies.

The third significant sector is represented by the construction industry. It should be noted that the service and construction industries sectors are fairly dependent upon mining activities. The agriculture and fisheries activities do not represent any source of GDP and the manufacturing and utilities industries are almost nonexistent.

After the 2006 census, the Christmas Island had a workforce of 714 people of which 34 were unemployed (4.8%), a relatively low figure. Around three quarters of the working population is employed on a full-time basis. Twenty two percent of the population is not in the workforce. The two main employers of the island are the construction and mining industries. The provision of education services was employing 37 persons in 2006. The conservation and national parks services also represent a significant employer on the Island with more than 20 employees full time, complemented by casual workers for the rehabilitation work carried out each year.

The incomes on CI are considered to be relatively high with almost 30% of the population earning more than $1,000 per week. This is explained by the high level of full time employment, more especially in the Construction and Mining industries (ACIL Tasman 2008).

7.2 Impacts on the Economy & Tourism

The economic development of CI is highly dependent on the mining industry evolution, and it is unlikely that climate change will have a significant impact on any industry other than tourism.

Tourism is widely seen as having the most potential to compensate for the decline in the economy resulting from the cessation of mining activities. Currently Christmas Island has a small but growing tourism industry primarily centred on nature based activities, especially the annual Red Crab migration. The Island's heritage, including cultural heritage, are also tourist attractions.

Similar to the situation on CKI, climate change is unlikely to affect inbound tourist numbers to CI. However, climate change will affect many natural attractions and nature based tourism activities currently on offer on the Island.

This is known this from local accounts and observations of effects in the past. However, the impact of climate change on a particular attraction or activity depends on its vulnerability and adaptability, and at this point of time we are uncertain how some species are likely to respond to climate change – and therefore it is hard to predict what if any effect climate change will have on the developing nature-based tourism industry on CI.

7.3 Impacts on Infrastructure

7.3.1 Infrastructure on Christmas Island

The airport comprises a single runaway of 2,100 metres that is used both for passengers and freight traffic. The airport is currently being upgraded.

Although the port located at Flying Fish Cove is one of the most appropriate locations, the ocean swells can be so strong that the port is not accessible all year round. Most of the non-perishable goods, fuel and heavy equipment are delivered by sea.

In terms of road facilities, there are no roads on CI that meet the Mains Roads Western Australia definition of a highway or a main road. The roads linking the main population centres of the island and the key infrastructure assets are generally sealed. The rest of the roads are unsealed and are considered to be fairly maintained. There are also single use track serving the mining facilities, the National Park and the resort.

7.3.2 Sensitivity of infrastructure to climate change

For key infrastructure types a sensitivity analyses was completed. Results are presented in Table 21.

These risks have been explored in more detail and each of the risks has been rated for the timeframe 2030 and 2070. Table 18 provides a snapshot of the risk ratings for 2030 and 2070.

Table 18 – Christmas Island climate change risks to infrastructures

	Temperature	Wind	Rainfall	Sea Surface Temperature	Ocean Acidification	Ocean Circulation	Sea Level	Humidity	Storm Surge	Currents	Waves	Cyclone	Bushfire
Water Resources	Red	Yellow	Red	Yellow	Yellow	Yellow	Red	Yellow	Red	Yellow	Yellow	Red	Yellow
Power Resources	Red	Red	Red	Yellow	Yellow	Yellow	Red	Yellow	Red	Yellow	Yellow	Red	Red
Transport - Ports	Red	Red	Red	Red	Red	Red	Red	Red	Red	Red	Red	Red	Yellow
Transport - Roads	Yellow	Yellow	Red	Yellow	Yellow	Yellow	Red	Yellow	Red	Yellow	Yellow	Red	Yellow

	Temperature	Wind	Rainfall	Sea Surface Temperature	Ocean Acidification	Ocean Circulation	Sea Level	Humidity	Storm Surge	Currents	Waves	Cyclone	Bushfire
Transport - Airport	Definite	Definite	Definite	Negligible	Negligible	Negligible	Negligible	Definite	Negligible	Negligible	Negligible	Definite	Definite
Buildings	Definite	Definite	Definite	Negligible	Negligible	Negligible	Definite	Definite	Definite	Negligible	Negligible	Definite	Definite
Kampong	Definite	Definite	Definite	Negligible	Negligible	Negligible	Definite	Definite	Definite	Negligible	Negligible	Definite	Negligible
Mine Infrastructure	Definite	Definite	Definite	Definite	Definite	Negligible	Definite	Definite	Definite	Negligible	Negligible	Definite	Negligible
Comms	Definite	Definite	Definite	Negligible	Negligible	Negligible	Negligible	Definite	Negligible	Negligible	Negligible	Definite	Negligible

Negligible Risk - Presents "negligible" risk within the probability of natural variation

Definite Risk - Presents "definite" risk within the probability of natural variation

7.3.3 Impacts on Power Resources

Power resources are predominantly sensitive to the impacts from extreme weather events such as cyclones and storm surges as these affect their above ground power generators, distribution and substations which can lead to a loss of electricity supply on CKI. The power generators are likely to be damaged by flooding as a result of a cyclone. Increased temperature and humidity could accelerate the degradation of electricity and transport fuel assets. Impacts of climate change on assets may lead to the early replacement due to increased corrosion. Structural fatigue may result from the increased intensity of storm and cyclone events which will require significant capital investment to replace and renew these assets. Fuel storage is also vulnerable to storm damage and corrosion both of which may result in the loss of fuel and fuel storage capacity. Damage to fuel storage may potentially cause a fuel spill or leakage, with possible serious environmental implications.

The IOT are highly reliant on external fuel supply. Following an extreme weather event fuel supply may not be able to be delivered to the Island due to damaged port facilities, leading to potential fuel rationing. Christmas Island is geographically isolated and resource dependent on mainland Australia. This dependence on Australia may lead to delays in maintenance and repair of power resources after extreme events as specific components need to come from mainland Australia. In the event of a severe cyclone access to Christmas Island may be restricted due to damage to port or airport– further delaying the repair of the power resources.

7.3.4 Impacts on Ports & Jetties

Port facilities are predominantly vulnerable to increases in extreme events such as cyclones and storm surges. Some of the port facilities such as piers, barges, boats and sea wall protection are particularly susceptible to wave and wind damage associated with storm events. Increased air temperature, sea surface temperature and humidity will accelerate the degradation of port assets through increased corrosion. Port assets will also suffer from increased fatigue structures due to increased storm intensity. This will further reduce asset life and increase potential failure during extreme storm events. Sea level rise changes the corrosive zones on assets exposing components of the assets to corrosion which were not designed for this level of corrosive impact. Sea level rise also prevents existing port facilities from functioning effectively as it reduces their freeboard making them more vulnerable to overtopping from waves and storm surges.

The loss of key port facilities such as pier structures, barges and ferry boats will inhibit access to the Islands. This may hinder shipping freight supplies arriving at the Island resulting in significant social and economic implications for the Island.

7.3.5 Impact on Roads

Roads are mainly affected by the ongoing impacts from reduced rainfall, increased temperatures and increased ground movement which cause the road pavement and surface to deteriorate. The road surface is especially vulnerable to erosion from large storm surge events and cyclones. It is expected that the potential damage to road assets will increase with sea level rise. Any significant damage to road assets will hinder access between Settlement and the Southern part of West Island as well as hinder access between Home Island foreshore and the cemetery. This may have large social implications for the Islanders.

7.3.6 Impact on the Airport

The biggest risk to the CI airport will be the projected increase in the frequency of intense cyclones up until 2030. The airport is currently not cyclone rated and is therefore particularly vulnerable. Cyclones could potentially damage the runway through erosion and debris as well as impact the communications towers and other airport building facilities.

Figure 18 – Airport, buildings & ports

7.3.7 Impact on Buildings

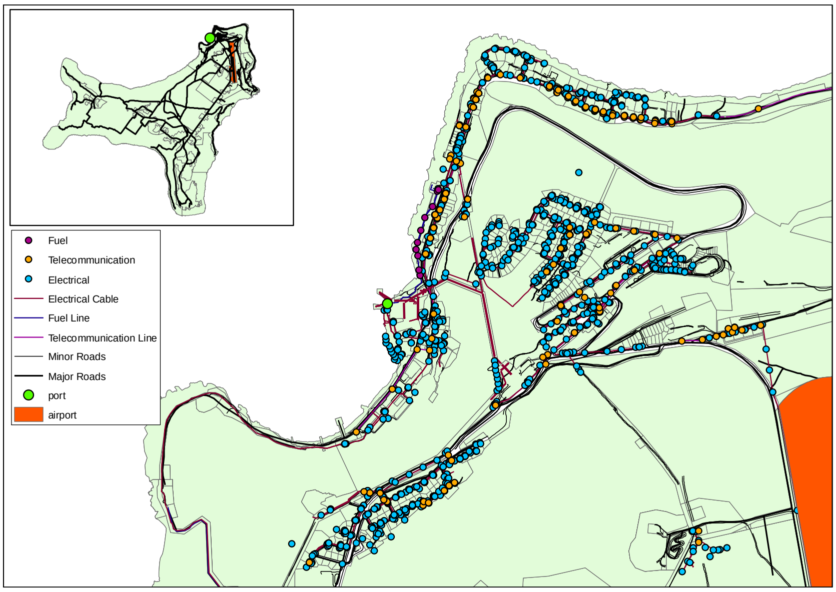
Building structures on CI are predominantly vulnerable to storm events which are associated with the potential increased frequency of intense cyclones. Other factors affecting buildings are; permanent coastal erosion, extreme rainfall, storm surge flooding, sea level rise and wind damage associated with cyclones. Building materials may also be impacted by increased corrosion as a result of increased temperatures and humidity and structural fatigue resulting from the intensity of storm events, both of these impacts lead to reduced asset life. Any such alterations to asset life will increase maintenance requirements and renewal of assets.

Currently none of the buildings on CI are designed to cyclone ratings. Other urban facilities such as the airport terminal, shops and health centres are also not cyclone rated and many are subject to storm surge and flooding impacts.

7.3.8 Impact on Communications

The communications infrastructure on CI is vulnerable to the impacts from cyclones. Increased wind and wave activity and storm surges associated with an intense cyclone event could potentially damage the communications towers as well as inundate its support structures. The extreme winds experienced during category 4 or 5 cyclones are likely to cause the communications towers to fail – potentially causing significant damage depending on in which direction the tower falls. CI has limited backup communication available which makes their existing infrastructure particularly vulnerable. If the communication equipment is significantly damaged the repair process is likely to be slow as limited or no replacement communication equipment is available on the island. Their only backup will be the satellite phones which are likely to remain operational.

Figure 19 – Fuel, power & communication Infrastructure



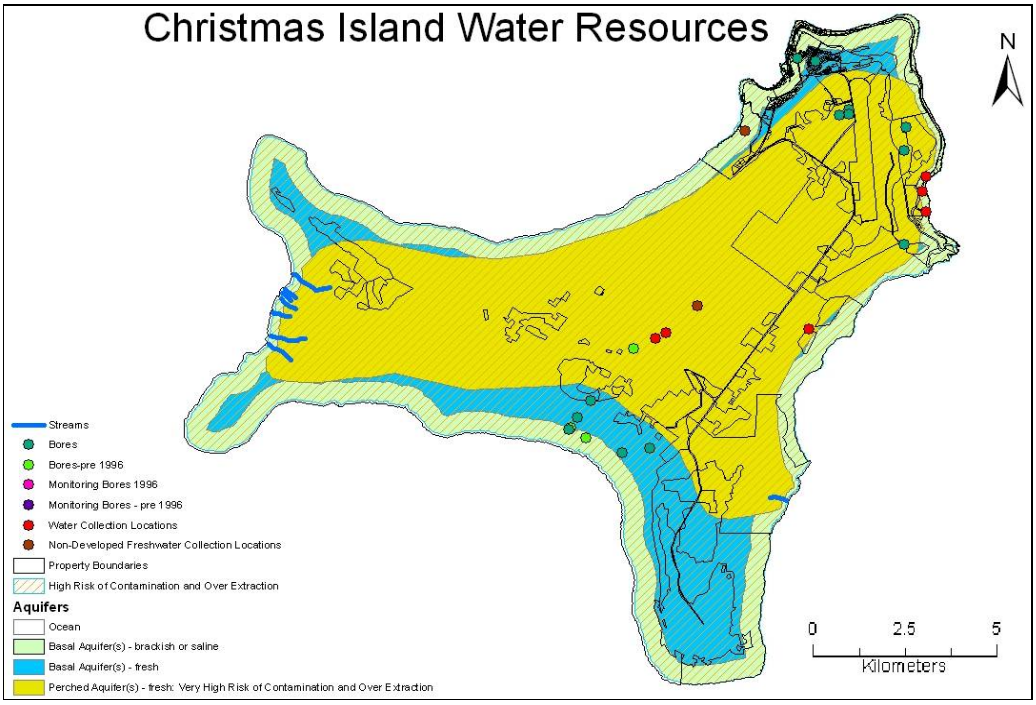
7.4 Impacts on Freshwater Resources

7.4.1 Water Resources

CI shows far less sensitivity in terms of water resources than CKI. The main concern is due to decreased rainfall (observed during SON over the last 25 years), increased temperature and as a consequence, increases of evaporation and decrease in humidity. All these trends have been observed in the last 25 years and are likely to continue during the 21st century. This would induce a slight decrease in the water recharge and a slight decrease of the average spring flows. The water collection points at the centre of the island would be the first one to dry up. This chain of effects would be the most important impacts on water quantity due to climate change.

The water quality is not likely to be clearly impacted by climate change as the aquifers are not at risk of saline intrusion. Around the airport and the human settlements, there are concerns over spilling of chemical and other products that may impact upon the water quality, although this is not related to climate change.

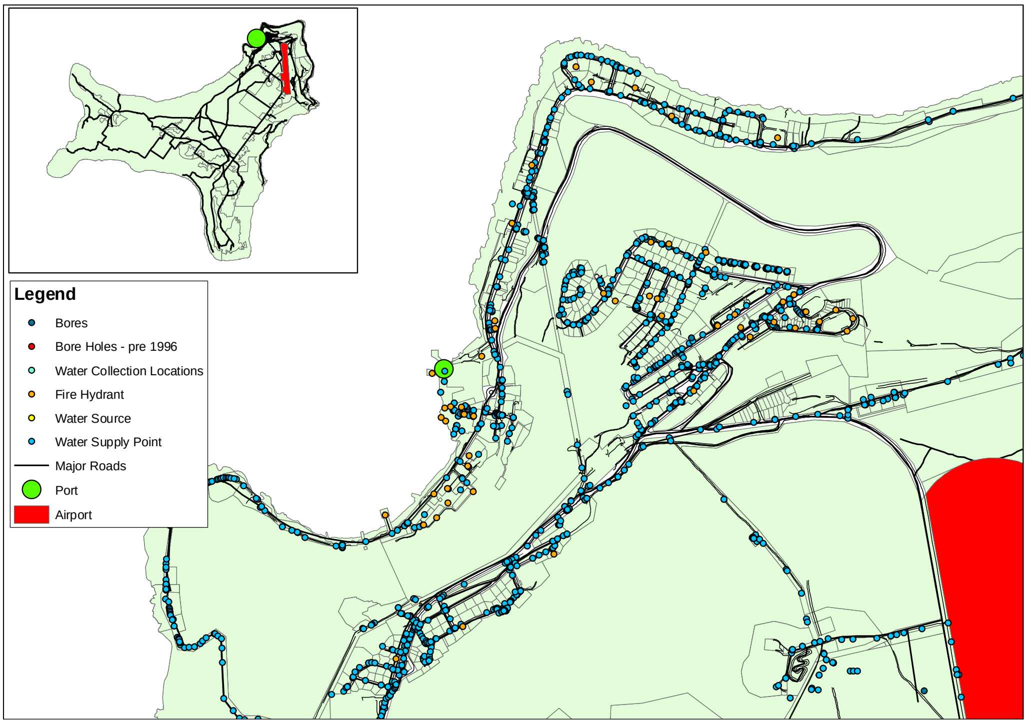
Figure 20 – Water resources of Christmas Island



The main potential impact of climate change is through degradation of the water assets. The geographic location of the water assets means that they are vulnerable to rock fall. Enhanced rainfall events and increased tropical cyclones have the potential to increase rock falls. Decreased rainfall combined with increased temperatures may cause ground movement which will adversely affect the water assets. Furthermore, the power supply for the water pumps is an issue during tropical cyclone. The jetty area has a long electric line particularly at risk while the North-East installations are less exposed.

The Kampong area presents a specific sensitivity because sea level rise and storm surge are expected to pose a significant risk to their low lying water supply, sewer and drainage system. Some of the associated impacts include increased corrosion of piper, change in salt gradients and overflow of sewer system during periods of flooding. As the Kampong area has limited drainage capabilities these impacts are likely to be exacerbated.

Figure 21 – Water resource infrastructure



7.5 Impacts on Human Health

7.5.1 Current Situation

CI has a well-equipped, eight-bed hospital which includes an operating theatre, and radiology and pathology facilities. Some specialist visits occur on a regular basis, however arrangements can be made for patients to travel to Perth as necessary. Emergency situations that require treatment beyond what can be provided on-island are addressed by evacuation to Perth. There are two doctors on CI, a Director of Nursing, and other ancillary staff. The staffing mix and levels are reportedly satisfactory and meet current needs in this remote location. For maternity care, however, women are routinely flown to Perth mid-pregnancy and at 36 weeks gestation for delivery. This is due to a lack of suitably qualified staff, rather than a lack of facilities. The impact of climate change on human health on CI is similar to that for CKI, and these impacts are summarised below.

7.5.2 Potential Impacts

Health Impact	Discussion
Extreme weather events	Christmas Island is at risk from changes in the intensity of cyclones and extreme events. Injury and death due to drowning and trauma are possible direct and severe impacts here. Projections for precipitation and wind and wave patterns are highly uncertain but the potential is for increases to occur. Category 4 and 5 tropical cyclones are projected to increase in frequency by a factor of two to three times.
Temperature-related deaths	As temperature is rising, heat stress diseases are often mentioned as a raising risk for public health in numerous countries (including Mainland Australia). However, the community living on both Christmas are already used to cope with high temperature. Furthermore, the expected warming for both territories (around 0.6°C for 2030 and 1.8°C by 2070) should not change radically the temperature conditions. However, the ageing process of the population is likely to increase the proportion of persons prone to heat stress. The most vulnerable groups (elderly and young children) have to be monitored and managed specifically to limit exposure.
Vector-borne diseases	Vector-borne diseases, such as dengue and malaria, are those diseases transmitted by the bite of an infected animal or arthropod, and are widespread and sensitive to climate. While other factors contribute to distribution of vectors, climate-change has altered the distribution or range of some infectious disease vectors. Vector-borne diseases are reportedly not prevalent on the CKI. CI is listed as a Malaria free Territory in the World Malaria Risk Chart (published by the International Association for Medical Assistance to Travellers). CI is listed as endemic area of dengue fever. Higher temperature might induce an increase in the biting rate of mosquitoes and decrease the incubation period of the virus, leading to enhanced risk for the exposed population.
Water borne diseases	Water-related diseases can be water-borne (ingested) and water-washed (poor hygiene). Extreme rainfall and warm temperatures influence microbial and chemical contamination of coastal, recreational and surface water.
Food borne diseases	Increased temperature increases risk of certain types of food poisoning and water-borne diseases e.g. salmonellosis and diarrhoeal diseases. Contact between food and pests (flies, cockroaches and rodents) are also temperature sensitive. Increased sea-surface temperature can lead to poisoning of shellfish and seafood due to toxins from harmful algal blooms.

CKI – Summary of Risks for Human Systems and Socio-economic Vulnerability

Classification	Risk	2030	2070
Human Settlements	Impacts on Kampong & Settlement	High	High
Society & Culture	Minor impacts on economy and livelihood	Low	Medium
Economy & Tourism	Degradation of natural attraction and iconic species	Low	Medium
Water Resources	Degradation of water assets	Low	Medium
Power Resources	Loss of electricity supply	Low	Low
	Increased corrosion of power assets	Low	Low
	Storm and fire damage to fuel storage and power facility	Low	Medium
Ports	Storm damage to port facilities	High	High
	Corrosion of port facilities	Low	Low
Kampong	Storm damage to Kampong	Medium	High
Airport	Storm damage to airport	Low	Medium
Settlement	Storm damage to settlement	Medium	Medium
Buildings	Storm damage to buildings	Medium	High
	Corrosion of buildings and facilities	Low	Medium
Communications	Storm damage to communications equipment	Low	Low
	Corrosion of communications equipment	Low	Low
Mines	Storm damage to mine facilities	Medium	Medium
Human Health		Low	Medium

Part V – Towards Adaptation: Responding to Climate Change

8.0 Adaptation Options

8.1 Cocos (Keeling) Islands Adaptation Options

Option 1 – Protection of settlements

Erosion of the coastline, sea level rise and inundation are key risks to the Cocos (Keeling) Islands. In order to protect the coastline from further erosion and damage, sea wall protection needs to be built to protect key assets. Specifically, the airport and settlement need to be prioritised for the development of sea wall protection. Sea wall protection already exists on Cocos Island, but currently the walls are not lasting long enough as the high quality materials that need to be used are very expensive, so lesser quality materials are used. Whilst the costs of protection of buildings and infrastructure on Home and West Island are likely to be prohibitive, relocation or modification of structures to accommodate surface flooding could be considered where possible and/or feasible. In some areas such as the southern end of West Island strategies to allow overwash sediment to naturally increase the elevation of the island may help offset the impacts of inundation. Where new developments are under consideration, such as the new tourism development proposal at Trannies Beach, new structures should be set back from the shoreline and/or elevated to allow for periodic flooding.

Adaptive capacity

Cocos Island is well placed to progress the uptake of sea wall protection around the island as it already has sea walls in place. The existing sea walls can be upgraded and their coverage extended to protect key assets.. This will require accurate mapping of coastal hazard areas for erosion and inundation using climate change scenarios.

Recommended intervention

1. *Undertake detailed coastal hazard and shoreline dynamic (e.g.* currents and sand accumulation) *mapping for the Home Island and West Island settlement areas, including detailed assessment of threat to buildings and infrastructure.*
2. *Develop a strategy for sea wall protection of key assets and settlement to secure medium and long term utilisation of Cocos (Keeling) Islands.*

Option 2 – Relocation and resettlement

The high vulnerability of Home Island warrants the consideration of relocating people and assets over to West Island through a transition process over the next 20 to 30 years. The additional infrastructure required on West Island to accommodate the relocation will obviously need to include appropriate climate change specifications in their design. As part of the relocation exercise it is imperative that the planning zones on West Island are reviewed and revised. An up to date planning scheme needs to be developed which identifies high and low risk zones to support climate ready development while protecting and identifying retrofits of existing infrastructure. If all other measures fail on CKI, population relocation may need to be considered either to Christmas Island or the mainland. While some communities may opt to move on their own, population relocation will pose immense social and political risks for the government.

Adaptive capacity

Long term transition and a staged approach are vital. The Cocos Malay community on Home Island have a significant connection to the island and have noticed recent changes to sea level and storm surge. The community would not respond well to purely short term relocation but as asset services are planned and provided for them on West Island, transition will occur naturally. A mosque development will need to be the centre of this relocation.

Recommended intervention

1. *Develop a relocation and resettlement strategy for CKI.*
2. *Engage and maintain a dialogue with CKI communities on relocation potential*

Option 3 – Erosion control

Shoreline protection, in areas where it is essential to retain overwash sediments, through protection and replanting of coastal vegetation to promote shoreline accretion, closing or narrowing selected passages between the lagoon and the ocean, and the strategic use of groynes to help minimize the transfer of sediments from the ocean side to the lagoons. Groynes, however, should be used only in key locations, such as the passage edges of islands as they may cause downstream erosion and require continuing maintenance. In some areas the use beach nourishment and relocation of infrastructure might be preferable.

Adaptive capacity

A number of Coastcare projects incorporating 'soft' erosion control solutions have been successfully implemented on the island, and the potential exists to expand this program to areas most under threat.

Recommended intervention

3. *Develop a comprehensive erosion control and revegetation plan for Home and West Islands, and seek funding for a Coastcare program.*

Option 4 – Improving coral reef management and coastal protection

Adaptation strategies should involve communities protecting coral reefs and lagoonal areas, primarily through the establishment of community-based monitoring of marine and coastal resources.

Adaptive capacity

Limited capacity currently exists to undertake coastal and marine conservation activities. However, a number of Reefcheck surveys have been conducted for the federal Department of Environment and Heritage that could form the basis for an extended program.

Recommended intervention

4. *Develop a community based monitoring program in collaboration with Parks Australia and the Local Council, with the aim increasing community awareness and involvement in the management of coastal reefs and marine areas.*

Option 5 – Planning policies and development control

Urban planning policies should encourage any new development away from low-lying and high-risk coastal areas through the use of coastal hazard mapping and development control specifications and measures. Climate change specifications need to be included in all tenders and redevelopment of infrastructure such as ports, roads, airport and water facilities. On Cocos (Keeling) island specifically the design criteria need to include; coastal storm surge and cyclone protection into design, material selection to ensure assets last their design life in changing climatic conditions, and a built in redundancy for changing climatic conditions. The building of sea wall protection and airport upgrades could be a short term priority.

Adaptive capacity

Currently there are no specific climate change adjustments to planning design and operation of infrastructure on Cocos Islands. The procurement processes for new assets and maintenance of existing assets can be effectively utilised to reduce the vulnerability of critical infrastructure and thereby increasing resilience of the human settlements. The Port redevelopment should be a priority to include climate change in design and development. Design criteria for climate change can be adjusted to the life of specific assets.

Recommended intervention

5. *Develop a range of specific climate change design and maintenance criteria for insertion in tender documents for infrastructure assets.*

Option 6 – Protection of freshwater resources

Water shortages on Home Island are likely to become progressively worse. Cost effective but short term adaptation options include encouraging the installation of water tanks. Such short term water shortage solutions on Home Island need to take into consideration in their design the potential relocation. Infrastructure that will be able to be moved to West Island will be most cost effective and durable. The water bores need to be operational without grid power in order to ensure the Island maintains access to freshwater during storm events. Water quality and human health concerns also need to be considered in the water strategy.

Adaptive capacity

Water tanks are currently being established on the island but their water holding capacity is not enough to meet the Island's demand. The community is already on water restrictions and understand that water conservation is required. Any solution to the existing water shortage is likely to be welcomed by all Islanders.

Recommended intervention

6. *Develop a strategy for short term and long term water security for CKI*

Option 7 – Improved disaster preparedness and emergency response

The Cocos Island emergency response procedures need to be reviewed for the projected increased frequency of category 4 & 5 cyclones. It is imperative that emergency response procedures involve the whole Island community in order to build resilience. To reduce the reliability on the mainland during extreme weather event recovery, Cocos (Keeling) Islands need to have sufficient backup material to enable rapid recovery.

Adaptive capacity

The existing Disaster Management Plan provides a good foundation that needs to be updated and cyclone planning scenarios need to be completed. The response capability is present but will require an informed and empowered community to effectively respond to worst case scenarios.

Recommended intervention

7. *Review and update the Disaster Management Plan, incorporating climate change impacts and the need for increased cyclone response capacity throughout the community.*

Option 8 – Diversifying sources of income through tourism development

CKI has a small but growing tourism industry primarily centred on 'sea, sun and surf'. The major attractions on the Islands are coastal and marine based attractions, and tourism activities include diving, surfing, kite surfing and leisure. Climate change and sea level rise potentially threaten the integrity of the natural attractions on the Island, particularly coastal beaches and coral reefs. Tourism development would assist in building resilience to climate change by broadening the economic base and expanding employment opportunities.

Adaptive capacity

Currently CKI does not have a comprehensive tourism development strategy for the Island, nor does it receive guidance or support from tourism agencies on the mainland. Significantly more effort is required to develop and promote tourism opportunities on the island. Consideration should be given to ecotourism and niche marketing of the tourism products.

Recommended intervention

8. *Develop an integrated nature-based tourism development strategy for Cocos (Keeling) Islands.*

Option 9 – Building understanding and adaptive capacity

Capacity Building: - a community approach for development of adaptation measures To build capacity to respond to climate change impacts requires the involvement and ownership of solutions by community and institutional service providers and leaders.

Adaptive capacity

The community on Cocos (Keeling) Islands are well connected and cohesive. However, the physical separation between Home and West Island may hinder collaborative responses and planning. To best achieve capacity building, it is important that action based programs are used where possible.

Recommended intervention

9. *Develop and deliver a capacity building program for the Cocos Islands*

Option 10 – Raising awareness on climate change

In order to build resilience to climate change impacts it is important that the local community is educated on the impacts of climate change on their island community. The risks to the islands as a result of climate change will be reduced by a well informed and responsive community.

Adaptive capacity

The existing schools and community briefings are effective mechanisms on the island through which increased community understanding may be facilitated.

Recommended intervention

10. *Develop and deliver a community education and awareness program for the Cocos Island to build community resilience.*

8.2 Christmas Island Adaptation Options

Option 1 – Protection of ports

"The port at Flying Fish Cove is limited in the capacity of vessel it is able to handle, difficult and dangerous in inclement weather and particularly during the "swell season" (December to April), and the port cannot be classified as a "safe port" in all weather conditions" (Christmas Island – local planning strategy, 2003). The port is under increasing pressure from climate change as cyclones become more intense and sea level rise accelerates the degradation of the rock shelf that key port facilities are situated on.

Adaptive capacity

In order to ensure that Christmas Island maintains freight access it is important that two cranes, for the unloading of ships, are operable on the Island. One port facility is located at Flying Fish Cove and the other near the Casino. The port facility developed near the casino site has not been utilised and has no crane to load and unload freight. It was originally developed to provide safer port access during swell season as it is protected from predominant swell at this time. This port needs to be maintained to ensure port trade is effective throughout most of the year.

Recommended intervention

1. *Ensure all port facilities are operational and maintained under climate change conditions*

Option 2 – Planning policies & development control

Urban planning policies should encourage any new development away from low-lying and high-risk coastal areas through the use of coastal hazard mapping and development control specifications and measures. Climate change specifications need to be included in all tenders and redevelopment of infrastructure such as ports, roads, airport and water assets. Design criteria needs to allow for changing climatic conditions. The building of sea wall protection and airport upgrades could be a short term priority.

Adaptive capacity

Currently there are no specific climate change adjustments to planning design and operation of infrastructure on Cocos Islands. The procurement processes for new assets and maintenance of existing assets can be effectively utilised to reduce the vulnerability of critical infrastructure and thereby increase resilience of the human settlements. The Port redevelopment should be a priority to include climate change in design and development. Design criteria for climate change can be adjusted to the life of specific assets.

Recommended intervention

2. *Develop a range of specific climate change design and maintenance criteria for insertion in tender documents for infrastructure assets.*

Option 3 – Protection of freshwater resources

Powerlines to the freshwater pumping station are currently above ground and at high risk from storm damage. In order to reduce this risk power lines should be progressively installed underground to reduce vulnerability to storm events.

Adaptive capacity

The majority of the power supply is underground (but not the line alimenting the pumping station). The pumping stations could be supported by a portable generator or if power supply failed this would be a short term solution.

Recommended intervention

3. *Secure power supply to water pumping stations by installing power supply underground.*

Option 4 – Improved disaster preparedness and emergency response

Christmas Island emergency response procedures need to be reviewed for the projected increased frequency of category 4&5 cyclones. In order to build resilience it is imperative that emergency response procedures involve the whole Island community. To reduce the reliability on the mainland during extreme weather event recovery, Christmas Island needs to have sufficient backup equipment and material to enable rapid recovery. The health services for the Island need to be integrated into the emergency management process.

Adaptive capacity

The various Christmas Island emergency response strategies need to bring together the Christmas Island Phosphate Mining Company; Christmas Island Phosphates, the Councils and the AGD. Each of these response strategies provides a good basis for response and recovery. The community would benefit from scenario planning involving community leaders. The storm surge impacts to Kampong during the cyclone in April 2008 highlighted the communication difficulties in community response to cyclones and expectations not being met.

Recommended intervention

4. *Develop an integrated Emergency management Plan and increase communication and scenario planning including key community leaders.*

Option 5 – Diversifying sources of income through tourism development

Currently Christmas Island has a small but growing tourism industry primarily centred on nature based activities, including the annual Red Crab migration. The Island's heritage, including cultural heritage, is also a tourist attractions. Tourism is widely recognised as having the most potential to compensate for the decline in the economy resulting from the cessation of mining activities. Climate change and sea level rise potentially threatens the integrity of the natural attractions on the island. Tourism development would assist in building resilience to climate change by broadening the economic base and expanding employment opportunities.

Adaptive capacity

Christmas Island tourism and visitor education programs are well developed in some areas; for example, the historical tours. However, tourism development on the Island would benefit considerably from the development of a strategic marketing and development plan, together with investment to upgrade and maintain visitor facilities. Formal training may be able to be accommodated in existing facilities on the Island. If tourism is further marketed around the natural environment, national park and heritage, the Island may be more frequently selected as an educational destination.

Recommended intervention

5. *Develop a strategic nature based tourism development plan for Christmas Island, and develop tourism training opportunities.*

Option 6 – Building understanding and adaptive capacity

Capacity Building: - a community approach for development of adaptation measures To build capacity to respond to climate change impacts requires the involvement and ownership of solutions by community and institutional service providers and leaders.

Adaptive capacity

The community is well connected and cohesive. It is important that capacity is built by action based programs where possible..

Recommended intervention

6. *Develop and deliver a capacity building program for the Christmas Island community.*

Option 7 – Raising awareness on climate change

In order to build resilience to climate change impacts it is important that the local community is educated on the potential impacts of climate change on the community. The risks to the island as a result of climate change will be reduced by a well informed and responsive community.

Adaptive capacity

The Christmas Island community has several informal and formal communication and education programs. The schools, Christmas Island Phosphates and council have well developed channels for community education.

Recommended intervention

7. *Develop and deliver a community education program for the Christmas Island to build community resilience.*

Option 8 – Revised planning zones

Planning zones on Christmas Island need to be reviewed and revised. An updated development needs to identify high risk zones where future development will be prohibited and existing infrastructure which needs to be redeveloped to reduce risk. The increasing risks from storm surge impacts to Kampong and overspilling and undercutting of rock shelf for Settlement require the selection of development areas on safer and more stable land.

Adaptive capacity

The Christmas Island Planning Strategy 2003 is due for upgrade and renewal. The existing strategy indicates that *"wave action on the shore terraces has resulted in "honeycombing" of the bedrock with blowholes and subsurface caves being frequent on the Island and new holes forming periodically. The Settlement is particularly at risk of "honeycombing" and future development on the terraces needs to be subject to geotechnical assessment to determine the extent of honeycomb risk".* (Christmas Island – local planning strategy, 2003). Staged retreat from Kampong and Settlement is required. The communities at Kampong and Settlement are unlikely to want to move irrespective of the increasing risk due to climate change. A longer term transition plan is recommended given cultural and community issues with relocation. The geotechnical assessment of the Settlement rock shelf is a priority to determine the existing and future risk to the community.

Recommended intervention

8. *Develop a Climate Change overlay for planning development in Christmas Island including a longer term transition plan for Kampong and Settlement.*

Option 9 – Bushfires management

Bushfire management plans need to be developed with particular focus on Settlement, Poon Saan and the Power Station. The increase in bushfire danger for the fringe of the forest and the coastal zone needs to be monitored and managed.

Adaptive capacity

The capacity to respond to bushfires on Christmas Island is very low as no bushfire has occurred on the Island since settlement. Two minor fires occurred in the last few years. The Island may experience a significant bushfire in the due to drier conditions. The community is currently not prepared for a bushfire. If the community knew how to prevent or respond to a bushfire the risk of significant damage would be significantly reduced. The rainforest core of the island is less likely to be vulnerable to bushfires due to high levels of moisture.

Recommended intervention

9. *Develop a Bushfire Management Plan for Christmas Island, and introduce basic bushfire training programs for Council and other emergency management personnel.*

Part VI – Summary of Key Findings & Recommendations

Key Findings

Vulnerability to Climate Change	The IOT are vulnerable to the potential impacts of climate change; however the magnitude of exposure, sensitivity, vulnerability and risk associated with these changes are much greater for CKI.
Sea Level Rise & Inundation	Sea level rise is expected to exacerbate inundation, storm surge, erosion and other coastal hazards potentially threatening infrastructure, settlements and facilities on both Islands. Due to its lower elevation, CKI is especially vulnerable to inundation associated with storm and tidal surges, and this will very likely threaten public health and safety and possibly reduce the availability of fresh water.
Increased Damage to Coastal Areas	Increases in sea level, and the associated deterioration in coastal conditions from erosion of beaches are already extremely important issues for both islands, especially CKI. These could become greater problems should climate changes result in 'unexpected' changes in ocean circulation patterns and local currents.
Coral Reefs	Increasing sea surface temperature, rising sea level, damage from tropical cyclones, and decreases in growth rates due to ocean acidification, are very likely to affect the health of coral reefs on both islands, especially CKI.
Vulnerable Ecosystems & Biodiversity Loss	The IOT are home to remarkable ecosystems and a number endemic species that are considered to be vulnerable to the projected rate and magnitude of climate change. Terrestrial forest in particular, are highly sensitive to increases in temperature and humidity, and any changes in evapo-transpiration are certain to affect soil moisture, forest cover, further pressure by introduced species and the incidence of wildfire.
Risks to Water Supply	Water supplies could be adversely affected by changes in hydrologic cycles that result in more frequent droughts and/or floods on both islands. However, there is strong evidence to suggest that under all of the projected climate change scenarios, water resources on Home Island are particularly likely to be seriously compromised from inundation and seawater intrusion into freshwater lenses. The water supply on Home Island is already limited and under stress, and hence are likely to experience increased water stress in the future as a result of climate change.
Risks to Buildings & Infrastructure	Buildings and infrastructure on both islands are considered to be sensitive to the effects of climate change. Almost all the buildings and infrastructure on CKI are sited along the coast, and are potentially exposed to sea level rise and inundation (even in relatively small events). In addition, with the exception of the airport on CI, almost all of the major transport infrastructure (jetties, wharfs and boat ramps) are potentially at risk from sea level rise and storm surge associated with an increase in extreme events.

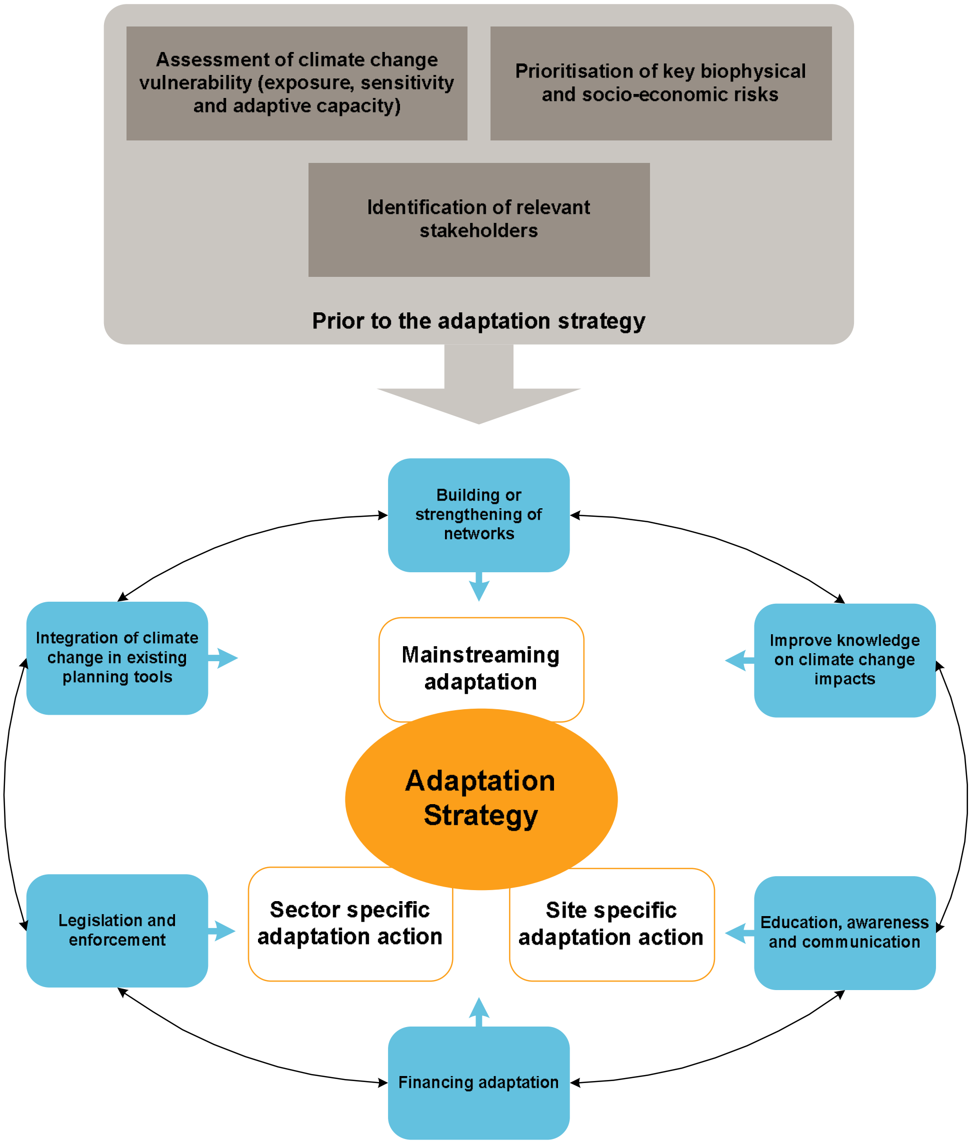
Risks to Economic Development and Tourism	The IOT vulnerability to climate events is growing, independently of climate change due to a narrow economic base and declining industrial conditions. Current trends point to a continuing rise in vulnerability in the future which will be exacerbated by climate change. It is likely that economic development in the IOT will be affected by climate change, primarily due to the direct and indirect effects of climate change on tourism. Nature based tourism is a major contributor to the economies of both islands, and any negative impact on the Islands' ecosystems, biodiversity, beaches, coral reefs and/or freshwater supplies will impact on tourism industry development. The IOT vulnerability to climate events is growing, independently of climate change due to a narrow economic base and declining industrial conditions. Current trends point to a continuing rise in vulnerability in the future which will be exacerbated by climate change. It is highly likely that economic development in the IOT will be adversely affected by climate change, primarily due to the direct and indirect effects of climate change on tourism. Nature based tourism is a major contributor to the economies of both islands, and any negative impact on the islands ecosystems, biodiversity, beaches, coral reefs and/or freshwater supplies will impact on tourism development.
Implications for Culture and Traditions	Culturally, the IOT are very distinctive. Climate change does not threaten the culture and traditions of the IOT, however it is clear that cultural values, religion and belief systems on the IOT can and will potentially influence their responses to climate and climate changes as well as their responses to preventive or ameliorative policies and strategies. Climate change may also affect livelihoods by altering fishing activities.
Risks to Human Health & Safety	The IOT are located in the tropics and already experience climatic conditions that are conducive to the transmission of tropical diseases such as malaria, dengue, filariasis, schistosomiasis, food- and water-borne diseases and to the promotion of other climate-sensitive diseases such as diarrhoea, heat stress, skin diseases, acute respiratory infections and asthma. Whilst there has been no appreciable observed increase in these diseases to date, future climate projections suggest that both Islands could possibly be affected by these changes. It is also highly likely that changes in the frequency, intensity, and tracks of tropical cyclones could have negative impacts on island mortality and trauma rates in the short and medium term.
Cumulative Effects	Whilst the natural ecosystems appear to be the most vulnerable to the harmful effects of climate change, it is also likely that changes to natural systems will have negative consequences for CKI and CI's economy, and play a major role in compounding existing socio-cultural problems on the islands, such as unemployment and welfare. Climate change is also likely to impose major incremental social and economic costs on IOT. In disaster years the impact could be particularly high, causing significant economic and social problems.
Uncertainties and Unexpected Events	Significant uncertainties remain in the science underlying the climate change projections and the assessment of climate change risks. It is possible that the IOT will also face a number of unforeseen changes in the physical climate system or ecological impacts that were not anticipated. Further research would improve understanding and the ability to understand impacts, and provide the IOT communities with additional useful information about options for adaptation. However, it is likely that some aspects and impacts of climate change will be totally unanticipated as complex systems respond to ongoing climate change in unforeseeable ways. On the other hand changes may be positive in nature and represent potential opportunities.

9.0 Recommendations for Implementing Adaptation

1. Develop a comprehensive adaptation strategy for the IOT.

AGD should consider developing an adaptation plan, aimed at increasing the natural resilience of the islands and reducing their vulnerability to present-day weather events and future climate change. Measures could include the management of critical coastal ecosystems (coastal zones and coral reefs), protection of buildings and infrastructure, control of urban development in sensitive areas, water resource management, conservation, and disaster management. Under such a plan, the IOT Shires would take adaptation goals into account in future expenditure and development planning. Insofar as these measures help reduce existing vulnerability (independently of climate change), AGD would be justified in using the plan for the development of adaptation programs and the reallocations of public expenditures to fund these activities. The risk assessment performed by AECOM is the first step toward an adaptation strategy, as outlined in Figure 22.

Figure 22 – Strategic Planning Process for Climate Change Adaptation



This approach shows that as well as the technical adaptation option that can be implemented for some site specific adaptation or eventually sector specific adaptation; there is a strong need for “immaterial” actions to develop a mainstreaming adaptation process. Indeed, a tailored adaptation strategy often combines soft and hard adaptation actions.

2. ***Adopt a more inclusive community-based process for implementing adaptation.***

It is recommended that AGD adopt a more inclusive approach to implementing adaptation that recognises the individual socio-cultural needs of each community, and incorporates a process of regular consultation with community representatives, the private sector, and other civil society institutions. Such an approach involves creating a partnership with community in order to implement adaptation activities, and could include: preparation of the Adaptation Plan; developing an integrated coastal management program; developing an integrated community based coastal and marine monitoring program; or developing proactive nature based tourism development strategies for the IOT.

3. ***Create a more transparent and enabling policy, legal and administrative framework for implementing adaptation.***

This may include prioritising adaptation into Territory planning instruments and Service Delivery Agreements, and providing the necessary legal and technical support for community-based adaptation programs, as well as other measures such as the management of coral reefs and marine areas.

4. ***Strengthening local institutions.***

Local Government on both CKI and CI are very capable organisations. However, there is a need to strengthen the links between AGD, the local governments and the local communities so that the communities increasingly gain a voice in planning and budgetary decisions. Local communities should also be encouraged to work across community boundaries to reach consensus on the adaptive strategies that need to be applied to larger areas - particularly if relocation is likely to be necessary.

5. ***Emergency response planning and disaster management.***

Both IOT have detailed and adequate disaster management plans. However, these need to be updated in respect to the findings of this report, and adaptation measures need to be incorporated into early warning systems and disaster mitigation programs, as well as improvements in primary health care, and coastal protection in areas.

6. ***Community awareness and education programs.***

Public awareness and education programs involving community representatives could help convey information about the impacts of climate change and gain consensus on the adaptation options. Of special importance would be awareness efforts aimed at engaging communities in a manner that is culturally sympathetic and appropriate to the individual IOT communities.

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