TOWN OF COTTESLOE

Vulnerability of the Cottesloe Foreshore to the Potential Impacts of Climate Change

FINAL REPORT DRAFT 001

6 June 2008

coastal zone management pty ltd

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An overview of a project to assess Climate Change Vulnerability for the Cottesloe Foreshore, Perth, Western Australia is presented here. The Project was an initiative of the Town of Cottesloe, funded by Emergency Management Australia and was completed between August 2007 and June 2008

Motivation

The Town of Cottesloe is situated along a 3km coastal stretch approximately 12 km from the centre of Perth. It is famous internationally for its superb beach, scenic walkways and terraced lawns overlooking the Indian Ocean. The Cottesloe foreshore is seen as a West Australian icon and is heavily used for a variety of recreational purposes throughout the year. In addition, the suburb of Cottesloe has some of the highest priced property in Australia, the majority of which has sea frontage along the main coastal road, Marine Parade.

The Fourth Assessment Report (AR4) of the Intergovernmental Panel on Climate Change (IPCC) has confirmed that sea level rise and its associated impacts are expected through the 21st century and beyond due to human emissions of greenhouse gases. Southwest Western Australia may be particularly at risk to these projected impacts due to its unique metrological and oceanographic conditions, combined with the sensitivity of its coastal systems.

Global climate change impacts will likely include a rise in mean sea level with a possible increase in the frequency and magnitude of extreme events and associated storm surges and wave heights. Physical changes will be superimposed on an evolving coastal system, heavily influenced by human development.

Within the Perth metropolitan area, Cottesloe is potentially at risk from coastal erosion due to the proximity of development to the present shoreline. In light of this, the Town of Cottesloe commissioned the current study in order to ensure it is well informed and prepared to deal with any future challenges in the management and maintenance of its valuable coastal resources and infrastructure.

Aim & Objectives

The main aim of the Cottesloe Climate Change Vulnerability Assessment Project was to establish potential risk to existing key coastal infrastructure under a range of future climate scenarios. The overriding objectives to achieve this aim were:

- Analysis of contemporary coastal conditions (environmental conditions and resultant coastal change)
- Determination of scenarios for future climate change
- Prediction of impacts on the physical coastal environment
- Implications of physical change for existing infrastructure.

In addition, the possible strategic alternatives for adaptation were also considered.

Approach

The approach adopted merged international best practice in vulnerability assessment with the considerable advances made within Australia in climate change risk management over the past 12 months.

The framework applied broadly followed steps in the Australian Greenhouse Office (AGO) (Now Department of Climate Change) "Climate Change and Risk Management: A Guide for Business and Government" report. While this type of strategic approach provides a useful overview of important issues to be considered, it required considerable modification to deal with the focused nature of the specific coastal assessment undertaken in Cottesloe.

The Project proceeded through 3 main work phases:

- I – Risk Identification;
- II – Risk Assessment; and
- III - Risk Treatment.

This type of focused assessment makes it possible to resolve issues at a scale relevant to local government decision making as opposed to decision making at broader, regional or State scales.

Work carried out by the Project team was supported by a series of 3 Workshops held between February and May 2008. These workshops allowed maximum involvement and input from key stakeholders, with a focus on Town of Cottesloe personnel.

Phase I

Phase I was designed to provide a background for the ongoing project and define a baseline for many of the important attributes to be further considered within the study. Key outcomes of Phase I were:

- Division of the study area into 12 zones for further analysis;
- Assignment of three scenarios (High, Medium, Low) over two timeframes (2030 and 2070);
- Agreement on success criteria & consequence scales following AGO guidelines, with slight modification;
- Selection of 3 key elements on which to measure the consequences of physical coastal change: infrastructure, amenity and environment; and
- Consensus on categories for risk prioritization.

The outcomes of Phase I set the groundwork for subsequent analysis undertaken in Phase II.

Phase II

The risk assessment carried out within Phase II involved:

- Establishing physical coastal change;
- Analysing the impact of predicted change on key elements; and
- Evaluating the risk that impacts within a given zone posed to the Town of Cottesloe.

The overall methodology applied within Phase II is summarized below:

Physical Change

- Historical change was evaluated in the context of physical process data to understand system sensitivity.

- A model of geomorphic change was developed to establish possible physical impacts under each climate change scenario.
- Physical change lines to represent physical coastal change under each climate change scenario were subsequently developed along the length of the study area.

This information was used to produce a map for the Cottesloe coast illustrating the extent of potential change under each climate change scenario. The 'lines' represented in the change maps have been created based on an extrapolation of the peak coastal erosion per zone. This information was subsequently used to assess the impacts of coastal change on existing key elements along the Cottesloe Foreshore (discussed below).

Impacts on Key Elements

- The presence and absence of key elements in each Coastal Survey Zone was recorded.
- The impact of physical change lines on key elements was noted (as potential loss due to shoreline recession).

Risk Evaluation

- A percentage of total loss per zone or the total impact of climate change as a weighted percentage of the key elements was determined for each scenario.
- The overall consequences of this loss per zone from a Town of Cottesloe perspective were determined by evaluating the weighted loss of the zone against a consequence scale (measured against percentage loss).
- This 'consequence' rating was then evaluated on how probable it was that a given scenario would occur to give an overall risk priority level.

The key outcome of Phase II was a Risk Priority level for each Coastal Survey Zone.

Phase III

The range of options available to treat the risks identified during Phase II was subsequently considered. This process was undertaken through a workshop attended by the Project team and key Town of Cottesloe personell.

Risk treatment options relevant to Cottesloe were evaluated and grouped into four categories:

- Research
- Educational/behavioural
- Regulatory and institutional (planning)
- Structural and technological

These options were considered at four overriding timeframes for implementation:

- Immediate (now -2010)
- Short (2010-2015)
- Medium (2015-2030)
- Long (2030-2060)

The output from the Workshop was a summary of the range of actions associated with each potential risk treatment category considered for the Town of Cottesloe at each of these implementation scales. Commonly, the proposed actions to treat predicted climate change risk along the foreshore fell within the first two categories (immediate or short term). Consideration of this information highlighted the adaptive and iterative nature of the implementation process. That is, actions carried out in the immediate to short timeframes were viewed as a pre-requisite to inform ongoing actions relating to risk treatment in the medium and long term.

In light of this, subsequent analysis carried out by the Project team built on results from the workshop towards the production of an operational risk treatment plan for the Town of Cottesloe. The aim of this plan was to clearly align sequencing for immediate adaptation options with the key risk treatment measures previously identified. The timeframes associated with each action were grouped as follows:

- 0 to 3 months (shown in white)
- 3 to 12 months (shown in dark grey)
- Over 12 months (shown in light grey)

It is proposed that the Town of Cottesloe Manager Engineering Services will manage the implementation of adaptation actions. Adaptation actions will be reviewed on a regular basis to ensure that the objectives of the task have been met. This review and implementation approach is an adaptive and 'learning-by-doing' approach to management. This type of adaptive approach recognises the uncertainties associated with predicting the consequence of actions due to underlying constraints, for example poor or lacking information.

Summary

In summary, the Plan outlined in this report is a preliminary framework for the implementation of an adaptive management approach to climate change adaptation for the Town of Cottesloe. This process will allow the Town of Cottesloe to anticipate and take advantage of change, whilst learning from the outcomes of management activities.

A priority for the Town of Cottesloe over the coming 2-year period will be ensuring that this mode of planning is incorporated into council decision-making. This type of adaptation 'mainstreaming' will be crucial to ensure the continuation of climate change adaptation across all spheres of local government and should be considered a key area for future work.

Overall, the information presented here is intended to build on the ongoing work of the AGO (now the Department of Climate Change) to devise optimum V&A approaches for coastal local governments throughout Australia.

To quote Mr. Geoff Trigg, Manager of Engineering Services, Town of Cottesloe

"In a modern society where climate change is viewed by many as natures revenge this (approaches to assess and treat climate change risks) *will become an ever-pressing concern, if we wish to remain living, working and playing along Australia's spectacular coasts."*

1. Introduction

1.1. Purpose of this Document

This document has been produced as a **Final Report** detailing the work phases, outcomes, and key recommendations of a project to assess climate change vulnerability for the Cottesloe foreshore, Perth, Western Australia (the Project). The Project is an initiative of the Town of Cottesloe, funded by Emergency Management Australia and was completed between August 2007 and June 2008.

1.2. Motivation

The Town of Cottesloe (ToC) local government area is situated along a 3km coastal stretch approximately 12 kms from Perth CBD (Figure 1). It is famous internationally for its superb beach, scenic walkways and terraced lawns overlooking the Indian Ocean. The Cottesloe foreshore is seen as a West Australian icon that is heavily used for a variety of recreational purposes throughout the year.

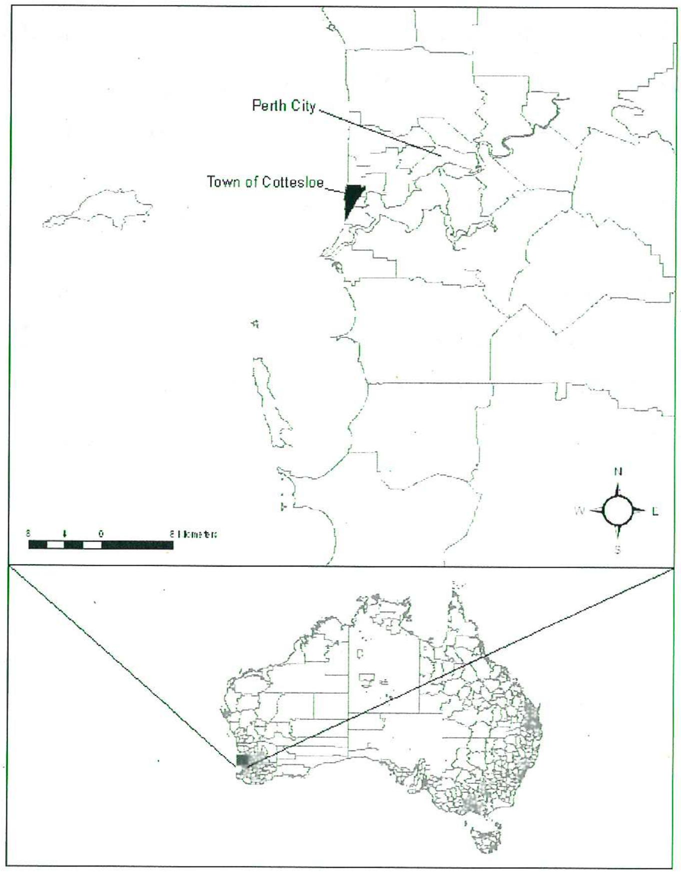

Figure 1: Map of study area

In addition, the suburb of Cottesloe has some of the most valuable property in the State, the majority of which has sea frontage along the main coastal road, Marine Parade (Figure 2).

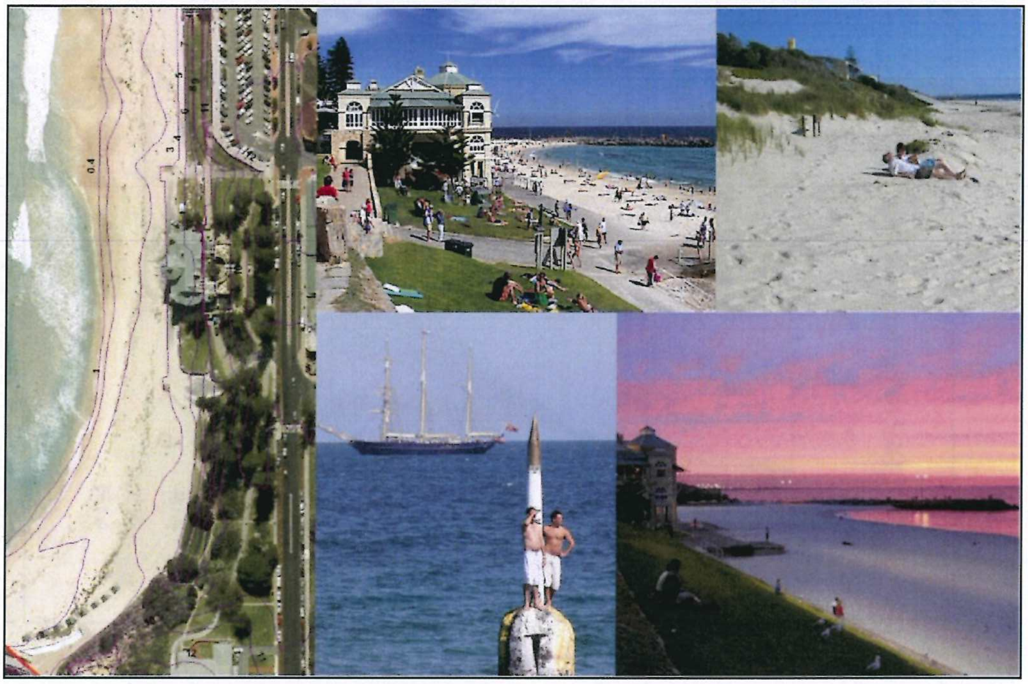

Figure 2: Cottesloe Coastal Zone[1]

The Fourth Assessment Report (AR4) of the Intergovernmental Panel on Climate Change (IPCC) has confirmed that sea level rise and its associated impacts are expected through the 21st century and beyond due to human emissions of greenhouse gases (Figure 3). Southwest Western Australia may be particularly at risk to these projected impacts due to its naturally low tide range and corresponding low morphology. Climate change impacts will likely include a rise in mean sea level with a possible increase in the frequency and magnitude of extreme events and associated elevated storm surges and wave heights (Table 1). Physical changes will be superimposed on an evolving coastal system, heavily influenced by human development.

Within the Perth metropolitan area, Cottesloe has been identified as an area potentially at risk from coastal erosion due to the proximity of development to the present shoreline (Jones & Hayne 2002). In the face of predicted global climate

[1] * Images clockwise from far left CZM (2008), Carmen Elrick (2008)

change the Town of Cottesloe will be presented with a set of challenges pertaining to the management and maintenance of its valuable coastal resources and infrastructure.

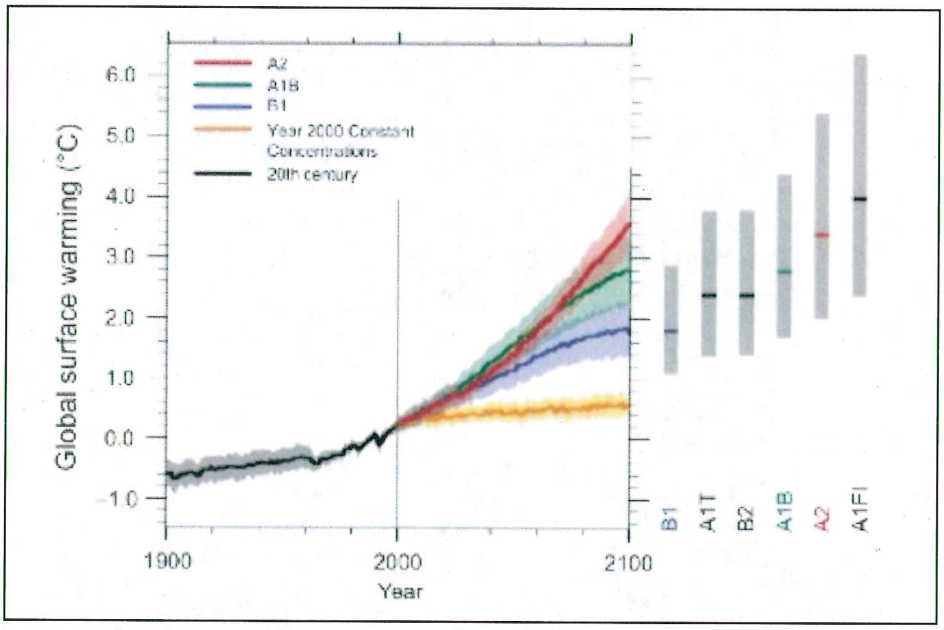

Figure 3: Multi-model averages and assessed ranges for surface warning (IPCC,2007)

Solid lines are multi-model global averages of surface warming (relative to 1980 – 1999) for the scenarios A2, A1B and B1, shown as continuations of the twentieth-century simulations. Shading denotes the plus/minus one standard deviation range of individual model annual averages. The orange line is for the experiment in which concentrations were held constant at year 2000 values. The grey bars at the right indicate the best estimate (solid line within each bar) and the likely range assessed for the six SRES marker scenarios. The assessment of the best estimate and likely ranges in the grey bars includes the AOGCMs in the left part of the figure, as well as results from a hierarchy of independent models and observational constraints. Source: IPCC (2007; p. 4)

Potential coastal erosion is likely to threaten key coastal infrastructure including the surf life saving facility, coastal restaurants, the coastal road and bike path, a main sewerage line and adjacent property development (Figure 4). In light of this, the assessment of coastal vulnerability to potential future climate change and the resulting impact on valuable coastal infrastructure has become a pressing concern.

Table 1: Impacts of Climate Change (Adapted from Abuodha and Woodroffe, 2006)

Climate Change Impacts	Effects on the Coastal Environment
• **Higher sea levels** • **Higher sea temperatures** • **Changes in precipitation patterns and coastal runoff** • **Changed oceanic conditions** • **Changes in storm tracks, frequencies and intensities**	**Bio-geophysical effects** • Displacement of coastal lowlands and wetlands • Increased coastal erosion Increased flooding • Salinisation of surface and groundwaters. **Socio economic impacts associated with climate change include:** • Loss of property and land • Increased flood risk/loss of life • Damage to coastal protection works and other infrastructure • Loss of renewable and subsistence resources • Loss of tourism, recreation, and coastal habitats • Impacts on agriculture and aquaculture through decline in soil and water quality. **Secondary impacts of accelerated sea level rise:** • Impact on livelihoods and human health • Decline in health/living standards as a result of decline in drinking water quality • Threat to housing quality **Impacts on infrastructure and economic activity:** • Diversion of resources to adaptation responses to sea level rise impacts • Increasing protection costs • Increasing insurance premiums • Political and institutional instability, and social unrest • Threats to particular cultures and ways of life

Figure 4: Proximity of development to shoreline and previous storm impacts

1.3. *Aims & Objectives*

The main aim of the Cottesloe foreshore climate change vulnerability assessment Project was to establish potential risk to key coastal infrastructure under a range of future climate scenarios. The overriding objectives to achieve this aim were:

- Elucidation of contemporary coastal conditions (environmental conditions & resultant coastal change);
- Determination of scenarios for future climate change;
- Prediction of impacts of these scenarios for change on the physical coastal environment; and
- Implications of physical change for existing infrastructure elements

In addition, possible strategic alternatives for adaptation were considered.

At the outset of the Project it was clearly recognised that a carefully tailored, systematic approach was required to fulfil this broad range of objectives within given time and budget constraints. Important considerations for the formulation of such an approach are presented in Section 2, in conjunction with an outline of the tasks involved in key project work phases and a detailed structure for the remainder of this report.

2. Project Approach

A key consideration in formulating an approach to this Project was the development of a transparent and transferable set of methods and tools that could readily apply to the current project, and subsequently be used by coastal local governments throughout Australia. Such an approach must be mindful of the markedly different capacities within local governments along the Australian coast and considerate of the fact that the majority of local governments are undertaking climate change vulnerability and adaptation (V&A) assessments for the first time.

It is important to note that when the Project proposal for this work was submitted in February 2007, there was little Australia-specific, up-to-date guidance on how to approach coastal vulnerability assessment. It was therefore assumed that a custom framework developed for this Project would incorporate three key elements:

- Frameworks used in recent years overseas, most notably as part of the National Communications Process of the UNFCCC, including techniques from Europe and North America.
- Approaches used during the initial Australian coastal vulnerability and adaptation (V&A) studies that took place in the mid 1990s.
- Any further developments or guidance developed on the conduct of vulnerability assessment in the interim.

The key components of a vulnerability assessment are considered here for the sake of completeness, followed by a brief overview of each of the elements listed above towards formulation of a tailored methodology for application along the Cottesloe foreshore.

2.1. *What is a Vulnerability Assessment?*

A vulnerability assessment is the process of identifying, quantifying, and prioritising the vulnerabilities in a system. Identifying vulnerabilities requires investigation of the biophysical and social elements of human-environment interactions. The assessments commonly cover: *exposure* to specific social/environmental stresses, associated *sensitivities*, and related *adaptive capabilities* (Polsky *et al.*, 2007).

The type of vulnerability assessment required in any given circumstance depends largely on the questions that are being asked. Broadly speaking, approaches to V&A include: sensitivity analysis, impact assessment and Risk Assessment (Table 2). In determining the appropriate approach, a number of questions should be considered (Lu 2006):

- Who are the targeted end-users of the results of the V&A assessment? (Answering this question will inform the level of technical detail required; methods for the treatment of uncertainties; and format for presenting results)
- What kind of output/information is expected from the assessment? (i.e. public awareness materials such as climate scenarios and their potential impacts; key vulnerabilities such as risk/vulnerability maps; a national/sectoral adaptation strategy; or a combination of the above).
- What resources are available to conduct the study (human and financial)?
- How much time is there to conduct the study?

These questions set the basis for determining the type of assessment and consequently the tools and data requirements to perform the assessment. The availability or ease of access to data and models must not define the type of assessment used, rather an assessment approach that meets stakeholder's needs should inform the selection of methods and models.

Table 2: Themed Approaches to vulnerability & adaptation (Source, Lu 2006)

Approach	Policy Questions	Methods, Tools and Data
Sensitivity Analysis	Does climate change really matter?	Trend analysis, synthetic scenarios
Impact Assessment	What are the potential impacts of unmanaged climate change?	Top down, scenario driven, sectoral assessment; climate and non-climate scenarios
Risk Assessment	How do we effectively manage climate change?	Critical threshold, coping range, stakeholder analysis, uncertainty, communication and management, integrated scenarios (including mitigation and adaptation scenarios)

2.2. *International Frameworks*

Internationally, there are a number of frameworks for vulnerability assessment that are commonly applied. The variation in frameworks is driven by spatial scale, subject matter and/or chronology (Figure 5). Top-down frameworks generally focus on the long-term (2100 or beyond) implications of climate change and are scenario driven.

Bottom-up frameworks address active concerns and are driven by issues identified through stakeholder consultations.

A comprehensive summary of the range of frameworks and methodologies currently used internationally is provided in Table 3 (UNFCCC Climate Change Compendium). The top-down approach has been applied in a number of regions; most commonly in the production of National Communications by Non-Annex I (NAI) countries (e.g. IPCC Common Methodology; Table 3). Key steps commonly applied in bottom-up frameworks are shown in Table 4 (e.g. UNDP Adaptation Policy Framework).

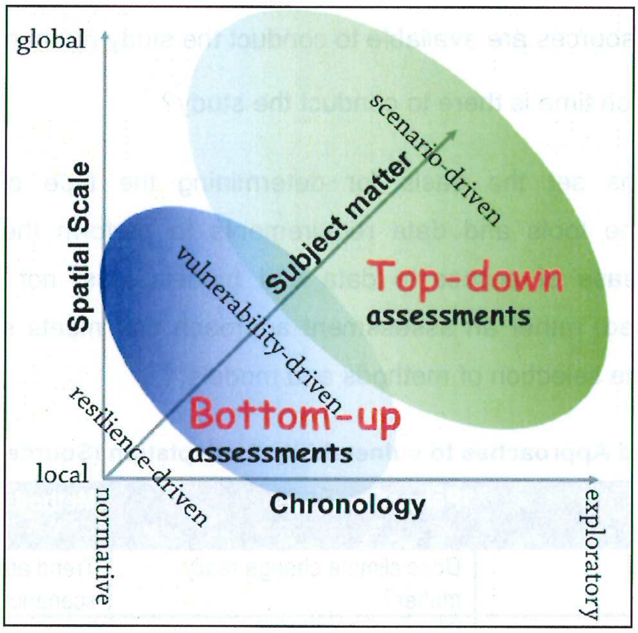

Figure 5: Conceptual Framework for Vulnerability Assessment (Source: Lu 2006)

Overall, to date, there is no universally recommended framework for vulnerability assessment. Rather, international good practise suggests a combination of both top-down and bottom-up approaches to ensure that both long term (2100 or beyond) and immediate implications of climate change are addressed (McLean, 2000).

Table 3: International Frameworks for bottom-up vulnerability assessment

Framework	Key Steps
UNDP Adaptation Policy Framework (APF);	1. Scoping and designing the adaptation project 2. Engaging stakeholders in the adaptation process 3. Assessing vulnerability for climate adaptation 4. Assessing current climate risks 5. Assessing future climate risks 6. Assessing current and changing socio-economic conditions 7. Assessing and enhancing adaptive capacity 8. Formulating an adaptation strategy 9. Continuing the adaptation process Technical papers on each of these topics are freely available at: http://ncsp.undp.org/resources.asp
NAPA Guidance	1. Build multidisciplinary NAPA team that will (i) define goals and criteria (ii) review policies (iii) identify synergies 2. Synthesise available vulnerability assessment (i) impact assessments, (ii) coping strategies, (iii) past consultations, 3. Rapid participatory integrated assessment (i) current vulnerability (ii) potential increase in climate hazards and associated risks 4. Conduct public consultation aimed at identifying potential ideas for activities 5. Articulate potential NAPA activities based on ideas from consultation 6. Undertake criteria prioritisation process (ranking the criteria) 7. Rank projects/; activities and demonstrate integration into national policy frameworks and programmes 8. Develop project profiles and submit to NAPA
UKCIP Risk, Uncertainty, and Decision-making Framework	1. Identify problem and objectives 2. Establish decision-making criteria 3. Assess risk 4. Identify options 5. Appraise options 6. Make decision 7. Implement decision 8. Monitor, evaluate and review The framework contains cyclical iterations and involves self-assessment and review throughout the eight-step process

2.3. *Australian Coastal V&A Studies*

Strategies similar to those used overseas have previously been adopted in assessing the vulnerability of the Australian coastal zone to climate change. Testing of the IPCC Common Methodology (CM) for example was undertaken initially at Geographe Bay in Western Australia (Kay *et al.*, 1992), with subsequent studies completed on the Cocos (Keeling) islands, a coral atoll territory in the Indian Ocean

(Woodroffe and McLean, 1993). Application of the CM raised a number of concerns (e.g. McLean and Mimura, 1993) with misgivings ranging from minor operational shortcomings to more fundamental methodological concerns, e.g. narrow geographic conception of the coastal zone (Kay and Waterman, 1993). The National Coastal Vulnerability Assessment Case Studies Project (NCVACSP) was subsequently undertaken during 1994-95, comprising nine case studies, one study in each state, with two in each of Victoria and the Northern Territory.

The main approaches that have been adopted since the NCVACSP Project are summarised in the Table 4 below.

Table 4: Australian Vulnerability Assessment Methods

Approach	Geographical application	Principal methods	References
Wetland mapping	Northern and north-western coasts	Wetland mapping in Kakadu and elsewhere in the NT, in line with Ramsar wetland assessments	Finlayson et al. (2002) Eliot et al. (2005)
Landform mapping	South Australia	Holocene landform mapping as a guide to vulnerability	Bryan et al. (2001) Harvey et al. (1999)
Storm surge zones	Queensland	Queensland Climate Change and Community Vulnerability to Tropical Cyclones project	Queensland Government (2004)
Beach vulnerability	New South Wales	Fuzzy and probabilistic modelling	Cowell et al. (2006) Cowell and Zeng (2003)
Beach vulnerability	Tasmania	Mapping beaches for Bruun rule and assessing inundation risk	Sharples (2004)*

*The Sharples method is currently being applied Australia-wide (Sharples, 2007)

In addition, a framework used to analyse climate change drivers has been outlined by Engineers Australia in *Guidelines for Responding to the Effects of Climate Change in Coastal and Ocean Engineering* (NCCOE 2004). The NCCOE guidelines indicate key climate change variables or drivers (such as mean sea level, K1, wave climate, K4) and secondary, or process, variables (such as local sea level, S1, coastal flooding, S7). It has been suggested that a template of this kind could be used at national assessment scales, identifying interaction between mean sea level and its effect on local sea level (K1, S1), or the effect of temperature and ecological response (K6, S13) (Abuodha and Woodroffe 2006).

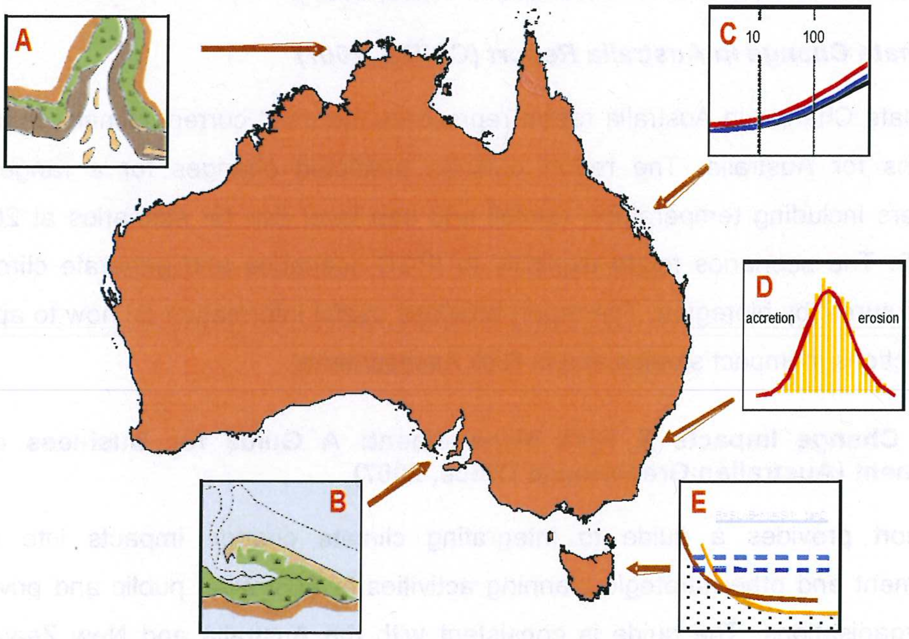

Figure 6: Approaches to Coastal Modelling in Response to Climate Change (Source: AGO, 2006)

The Figure shows:

- A – Wetland assessment (Eliot et al. 2005);
- B – Holocene geomorphological mapping as a guide to vulnerability (Bryan et al. 2001);
- C – Storm-tide evaluation as adopted by synthesis of storm levels in Queensland (Queensland Government, 2004);
- D – Probabilistic approach to coastal erosion (Cowell et al. 2006); and
- E – Bruun-type 2-D mapping (Sharples 2004).

2.4. *Recent Developments*

A number of important documents relating to climate change scenarios, impact assessments, and adaptation options within Australia, have recently been produced. Of particular relevance to this Project are:

- The Climate Change in Australia Report (CSIRO, 2007); and

- Climate Change Impacts & Risk Management: A Guide for Business and Government (Australian Greenhouse Office, 2007).

The Climate Change in Australia Report (CSIRO, 2007)

The Climate Change in Australia report represents the most current climate change predictions for Australia. The report outlines predicted changes for a range of parameters including temperature, rainfall and sea level rise for scenarios at 2030 and 2070. The scenarios relate explicitly to IPCC scenarios and generate climate change 'futures' by bioregion. The report provides useful information on how to apply the Projections in impact studies and in Risk Assessments.

Climate Change Impacts & Risk Management: A Guide for Business and Government (Australian Greenhouse Office, 2007)

This report provides a guide to integrating climate change impacts into risk management and other strategic planning activities in Australian public and private sector organisations. The guide is consistent with the Australia and New Zealand Standard for Risk Management AS/NZS 4360:2004 which is widely used in public and private sectors to guide strategic, operational and other forms of risk management. The guide describes how the routine application of the Standard can be extended to include the risks generated by climate change impacts.

The framework proposed for managing the increased risk to organisations due to climate change impacts outlines five key steps:

- Setting the context
- Identifying the risks
- Analyzing the risks
- Evaluating the risks
- Treating the risks

In addition, several useful publications aimed specifically at climate change issues affecting local governments have come to light. For example:

- A report by SMEC Australia to the Australian Greenhouse Office identified climate change adaptation actions that could be implemented by Australian local governments (AGO, 2007Ab).

- The Sydney Coastal Council produced a document detailing an assessment of Australian and NSW legislation and government policy provision relating to climate change relevant to regional and metropolitan local councils (Sydney Coastal Councils Group & NSW Environmental Defenders Office, 2008).
- A report by Griffith University presented an overview of the range of liabilities that are faced by local governments in the face of climate change as part of their Urban Research program (England, 2007); and
- The Local Government Association of Queensland have formulated a guide to help Councils throughout Queensland assess the likely effects of climate change on their diverse range of roles and responsibilities, and plan appropriate responses (LGA Queensland, 2007).

In summary, it is clear that the approaches to V&A outlined in Sections 2.1 to 2.3 provide important context and in some cases direct data sources for the Project reported on here. In addition, the suite of more recent documents reviewed in this Section also serve to fill many of the information gaps and methodological constraints previously faced by the Project Team in formulating a comprehensive framework for a site specific Risk Assessment necessary for the current project.

The approach ultimately adopted for this Project was based on a consideration of the implications of this range of available information and is presented in Section 2.5.

2.5. *Framework for V&A Assessment at Cottesloe*

On reflection, the approach of the Project Team was to adopt a blended approach that merged international best practice with regard to vulnerability assessment with the considerable advances made within Australia in the field of climate change risk management.

The risk management framework subsequently adopted broadly followed the key steps outlined in the Australian Greenhouse Office (AGO) "*Climate Change and Risk Management: A Guide for Business and Government*" report (Section 2.4)

These steps are represented in Figure 9. For the purposes of the current project, the Project Team considered the steps in the AGO framework within three work phases (Table 5). These steps are part of what is considered an 'initial assessment', a cost effective, yet rigorous method of identifying and appraising risks.

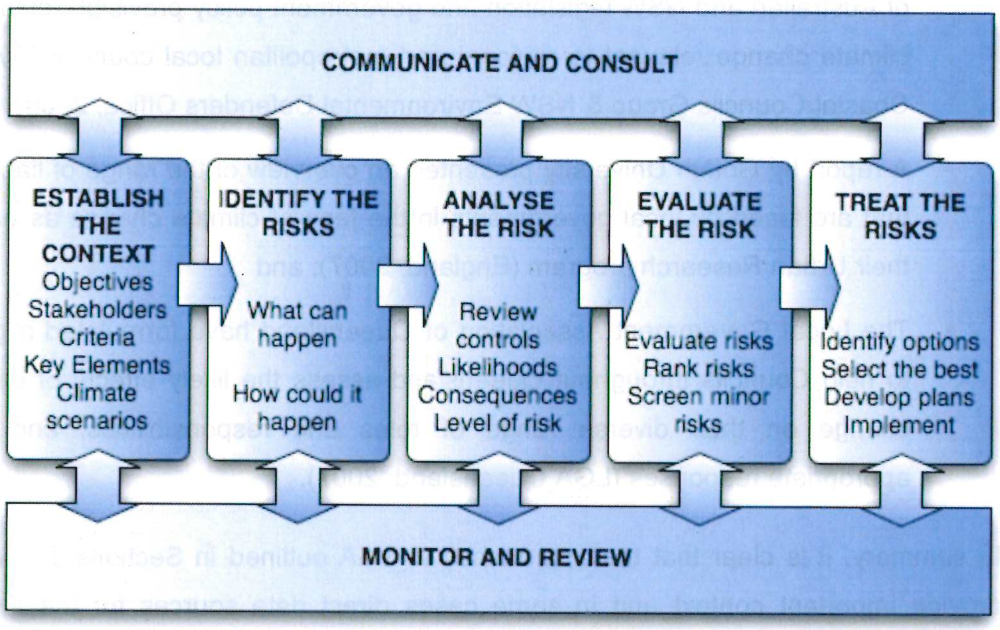

Figure 7: The AGO Climate Change Risk Management Framework

Table 5: Work Phases

Phase	AGO Steps
Phase I: Background	• Setting the context
Phase II: Risk Assessment	• Identifying the risks • Analysing the risks • Evaluating the risks
Phase III: Risk Treatment/Adaptation	• Treating the risks

These work phases incorporated the '5 steps' outlined to allow production of the framework presented in Figure 8, subsequently referred to as the Cottesloe Approach. By undertaking the V&A at this scale, it is possible to resolve issues at a scale suitable for making management decisions of the type that ***local governments*** are responsible for. In addition, it should be remembered that the AGO approach is general, rather than coast-focused. This is an important differentiation as scale affects the identification of values and it is widely recognized that coastal response needs to be looked at with relatively high spatial and temporal resolutions. Overall, it was decided that the optimum approach to achieve the discrete aims of the Project would be to run a series of workshops so as to gain maximum involvement and input from key stakeholders, namely Town of Cottesloe personnel. The timing of these workshops and their alignment to the steps and tasks envisaged for the overall approach are presented in Table 6.

Table 6: Tasks with proposed steps of the Project Team Approach

AGO Steps	Project Team Phases	Tasks	Action
1. Establish the context	**PHASE I: BACKGROUND**	• Define business/organisations to be assessed & scope of assessment • Clarify objectives of organisation • Identify stakeholders, their objectives and concerns • Establish success criteria against which risks to organisations objectives can be evaluated • Develop key elements of the organisation as a means of restructuring the process • Determine relevant climate change scenarios for the assessment	Risk context workshop – February 2008.
2. Identify the risks	**PHASE II: RISK ASSESSMENT**	• What can happen? • How could it happen? • Describe and list how climate changes impact on each of the key elements of the organisation.	Sensitivity assessment and scenario modelling.
3. Analyse the risks		• Review controls, management regimes, and responses already in place to deal with each specific risk • Assess the consequences of each risk against the organisations objectives and success criteria, taking into account the extent and effectiveness of existing controls • Form a judgement about likelihood of each identified risk leading to the consequences identified • Determine the level or risk to the organisation for each of the climate change scenarios used in the analysis.	Risk identification workshop – April 2008
4. Evaluate the risks		• Reaffirm judgements and estimates • Rank risks in terms of severity • Screen minor risks that can be set aside • Identify those risks that require more detailed analysis	Risk identification workshop – April 2008
5. Treat the risks	**PHASE III: RISK TREATMENT & ADAPTATION**	• Identify relevant options to manage or adapt to the risks and their consequences • Select best options, incorporate into forward plans and implement	Risk treatment workshop May 2008.

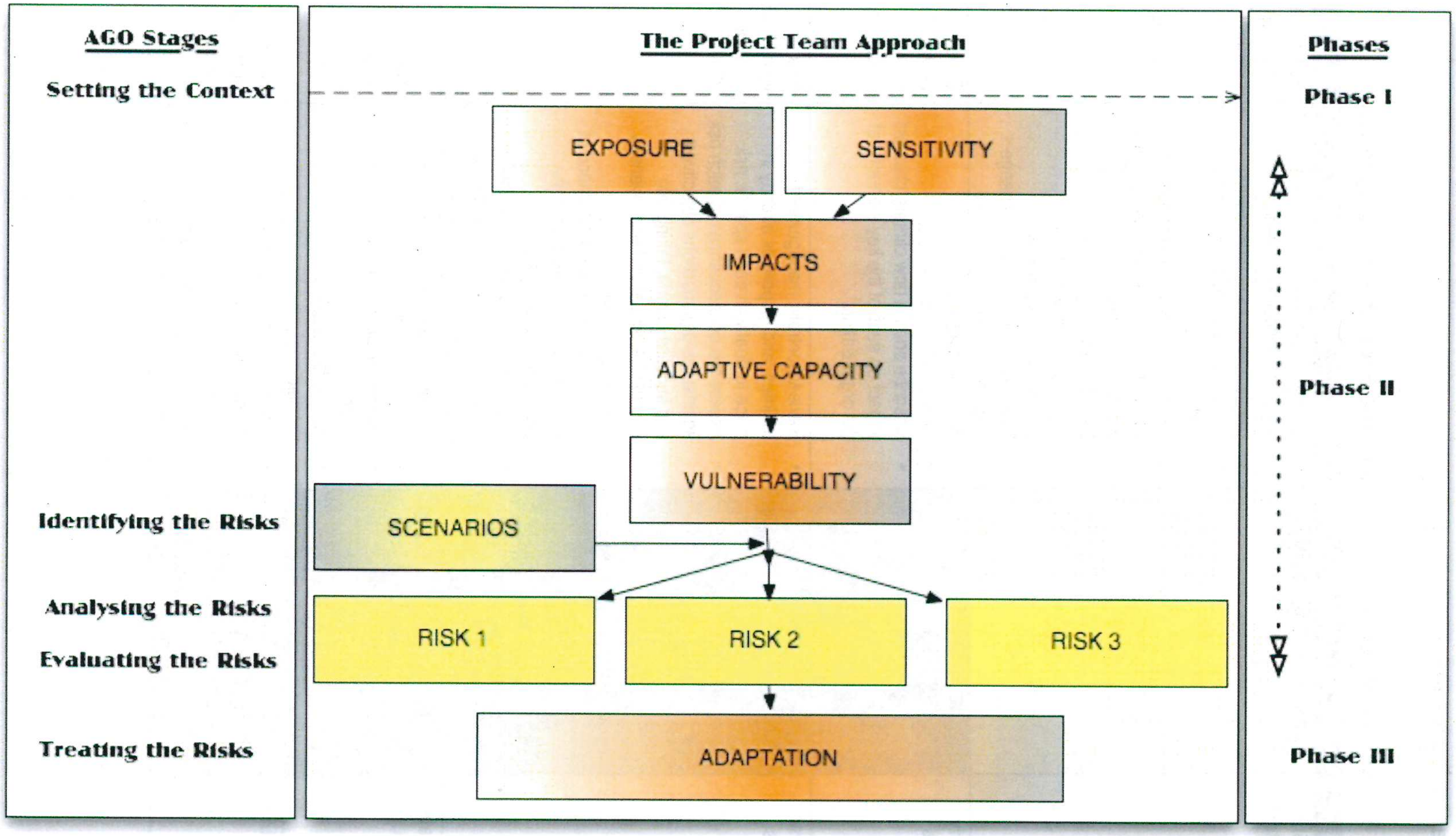

Figure 8: Approach to Cottesloe Vulnerability Assessment

3. Phase I: Background

Phase I was designed to provide a background for the ongoing project and define a baseline for many of the important attributes to be further considered within the study (Figure 9). The key objectives of this Phase according to the AGO guide are:

- Confirmation of terminology for levels of consequence of risk
- Definition of organisational objectives and success criteria
- Completion of consequence success tables
- Definition of likelihood scales
- Identification of key elements
- Determination of relevant scenarios for the evaluation of future climate change

The input of the organisation under consideration (in this case, Town of Cottesloe) is key to the elucidation of the above points. Workshop I was centred on a discussion of items 1-6. Attendees to Workshop I included representatives from the Town of Cottesloe as well as the Project Team from CZM and Damara WA.

Prior to Workshop I, it was also necessary to clearly define the overall scope of the assessment being undertaken and to delineate boundaries within which the study would operate. Outcomes of this process are summarised in Section 3.1.

The key outputs for Phase 1 are briefly summarised in Sections 3.2-3.6. A comprehensive account of key outputs for Phase I is contained in Appendix A to this document.

3.1. *Scope of Assessment and Study Area*

The Project focused on the Cottesloe coastal zone, defined here as: 'Lands and waters adjacent to the coast that exert an influence on the uses of the sea and its ecology, or whose uses and ecology are affected by the sea'. The Project did not include an assessment of the impacts and adaptation strategies for climate change beyond the coastal zone. As such, it did not discuss changes in patterns of fire occurrence, invasive species translocation, and/or health impacts due to changing weather conditions.

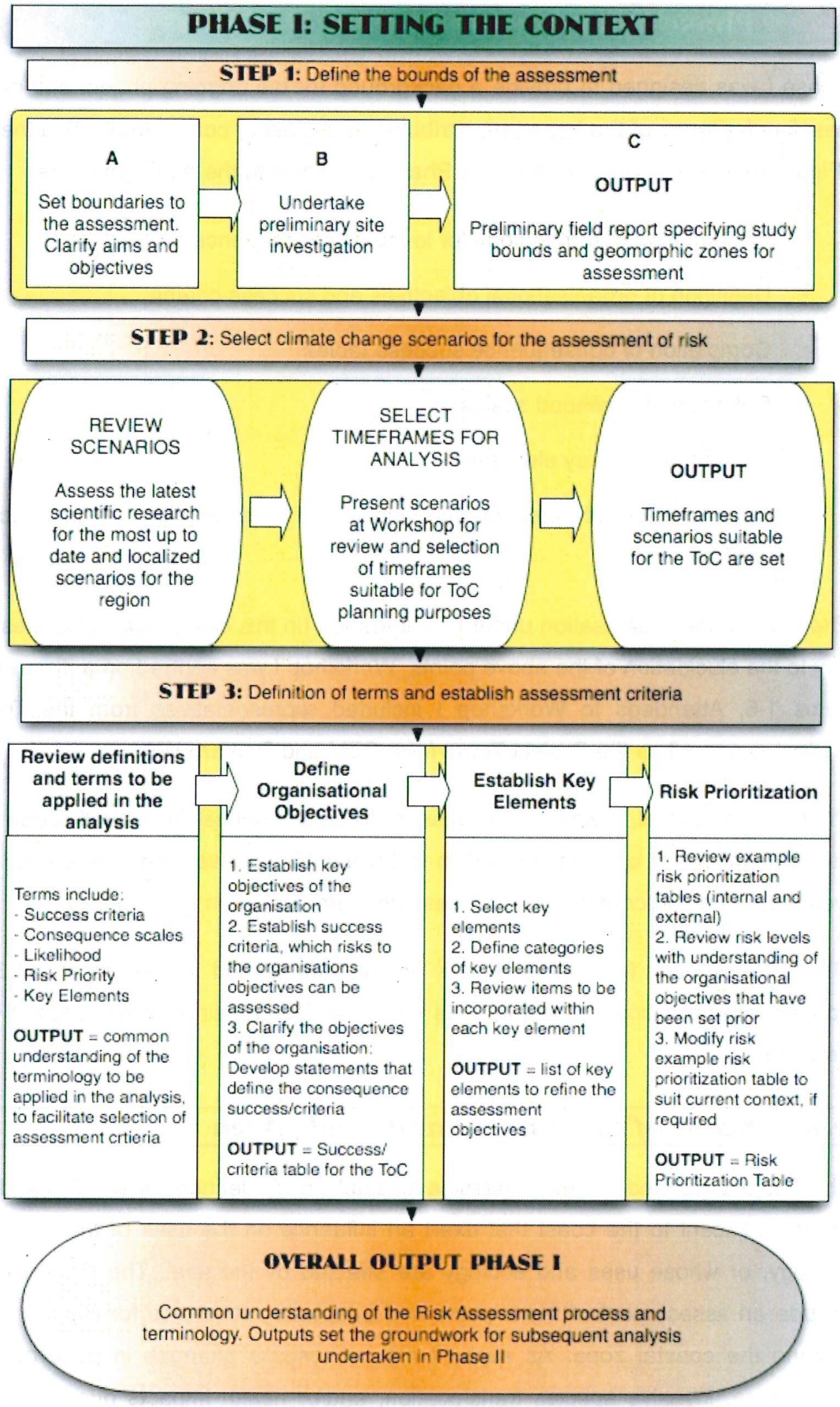

Figure 9: Approach to Phase I

The Cottesloe foreshore was divided into 12 discrete survey zones for the purposes of analysis (Figure 10). This division was based on geomorphic characteristics of the coastal zone gathered through field assessment and aerial photograph analysis and historic coastal management pressures.

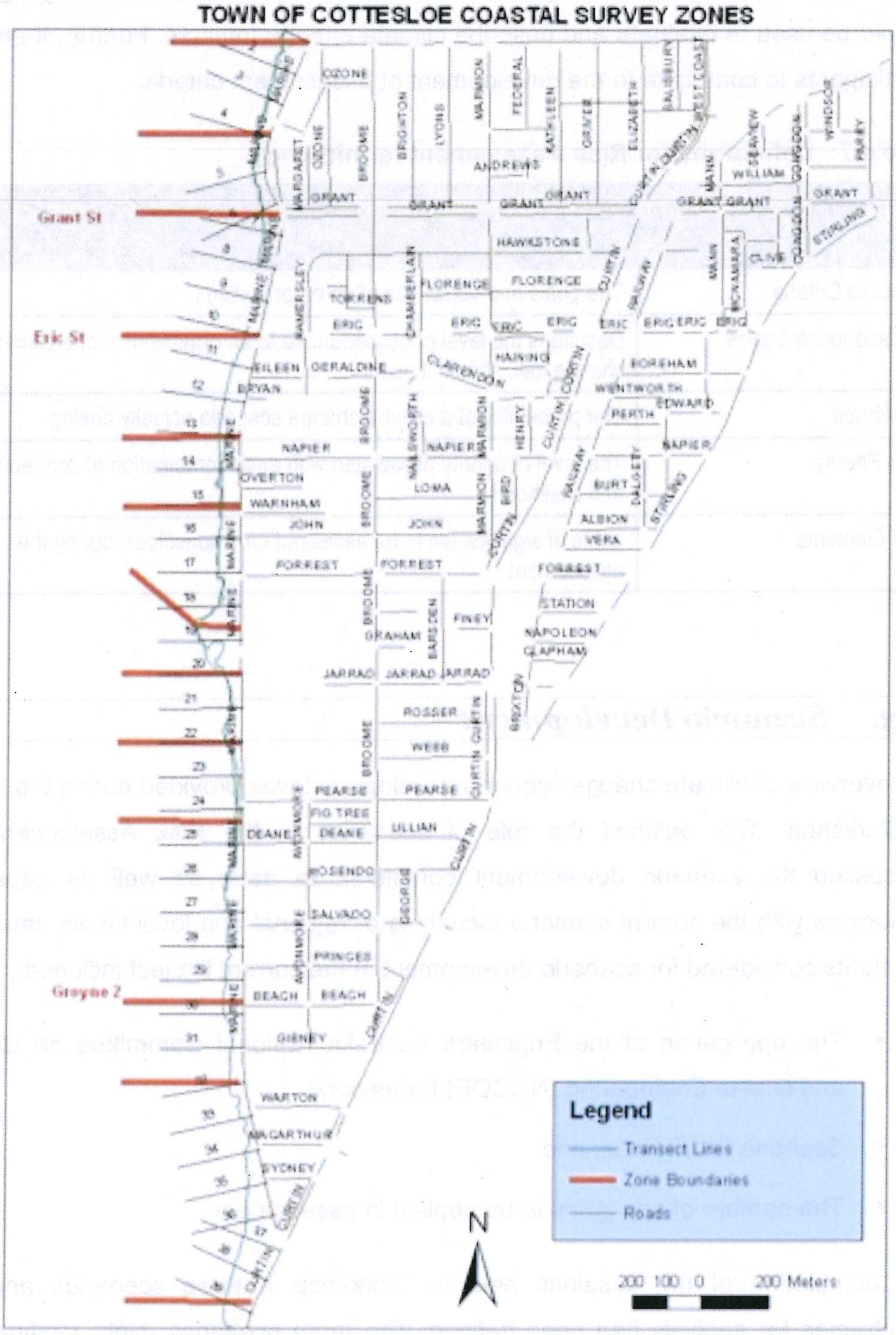

Figure 10: Town of Cottesloe Coastal Survey Zones. Zones are numbered 1-12 from north to south

3.2. *Definitions and Terminology*

During the initial sessions of Workshop I, participants were introduced to a range of Risk Assessment terminology, following the AGO Climate Change Risk Management Framework (Table 7). The terminology was defined at the commencement of the process to ensure that all participants had a clear understanding of the language that would be used to evaluate and describe climate change impacts. Further, it enabled participants to contribute to the development of assessment criteria.

Table 7: Definitions for Risk Assessment terminology

Term	Definition
Success Criteria	The goals and objectives of an organisation.
Consequence Scales	Describes the level of consequence to an organisation of a climate change risk, should it occur
Likelihood	The probability of a climate change scenario actually arising
Risk Priority	The level of priority associated with each combination of consequence and likelihood
Key Elements	Items of significance to be assessed for 'impact/loss' during the assessment

3.3. *Scenario Development*

An overview of climate change scenario development was provided during the Phase I Workshop. This outlined the role of scenarios in the Risk Assessment and discussed the scenario development completed to date, as well as gaps and limitations with the current scenario modelling at regional and local levels. Important elements considered for scenario development in the current Project included:

- The application of the Engineers Australia National Committee on Coastal and Ocean Engineering (NCCOE) framework;
- Scenario timeframes; and
- The number of scenarios to be applied in assessment.

On completion of the sessions held in Workshop I, three scenarios and two timeframes for analysis had been defined. The three scenarios: high, medium and low, matched the IPCC scenarios applied in the CSIRO *Climate Change in Australia Report*. The time frames for analysis were 2030 and 2070, with 2070 coinciding with the longest projection provided by CSIRO (2007). 2030 is a functional timeframe for active council planning, while 2070 was useful as a timeframe for trend planning, to help define council policies. Finally, there was discussion regarding whether the need existed to include a factor of safety in the application of climate change projections. For the purposes of this project, the superposition of natural climate variability upon predictions of future change at a high scenario level was deemed to adequately incorporate this factor of safety.

Following the selection of timeframes and scenarios, participants were advised that these would be circulated for expert review. Following this review, the final scenarios applied in the Risk Assessment were confirmed and subsequently provided to Workshop participants (Table 8).

3.4. *Defining Success Criteria and Consequence Scales*

Success criteria are used to assess climate change impacts on an organisations goals and objectives. During the workshop, participants were requested to define assessment criteria that incorporated the goals and objectives of the Town of Cottesloe. The AGO success criteria for Local Governments were provided to participants as a worked example. Participants discussed the application of these criteria and modified them to suit the Town of Cottesloe context. The resultant organisation success criteria for Town of Cottesloe were:

- Maintain and protect public safety
- Protect and enhance the local economy and growth
- Protect community and lifestyle
- Environment and sustainability
- Sound public administration & governance ensuring flexibility

Following the selection of success criteria, a consequence/success table was populated. The consequence/success table provides definitions for the success criteria against levels of consequence. The aim was to establish 'sample' impacts for each level of consequence to ensure clarity for all participants (Table 9).

Table 8: Climate Change Scenarios used for this Project

Key Variable	Code	Perth Coastal Scenario	Comment
Mean Sea Level	K1	Projected range of sea level rise (m) relative to 1990 baseline: IPCC (2007) scenarios using low, medium, & high emission scenarios to align with the CSIRO Climate Change in Australia report. These include the factors for 'scaled up ice sheet discharge (IPCC Table 10.7) factors for more rapid dynamical response of ice sheets to climate change (McInnes and Church, 2007, pers comm, IPCC 2007, Rahmsdorf, 2007): Scenario Likelihood 2030 2070 B1 50% 0.10 0.21m A1B 50% 0.11 0.28m A1F1 50% 0.14 0.33m Scenario Likelihood 2030 2070 B1 5% 0.07 0.14m A1B 50% 0.11 0.28m A1F1 95% 0.16 0.48m Importantly, the interim figures for 2030 and 2070 are based on estimates taken from interpolations provided by NIWA. The IPCC published figures are for 2100 only. The models used for projecting sea-level rise have been developed specifically for a 100-year time horizon (to the year 2100) and therefore the interpolation from the present to 2100 is indicative only.	Based on tide data analysis (Mitchell et al., 1999) Fremantle appears to be tracking to global average sea-level rise. Importantly, the decadal scale changes driven by climate variability are markedly different from global averages – by definition. This is important because these shorter-term fluctuations are likely to drive immediate changes (IOCI). As reported in the recent CC in Australia, through analysis of the climate models under the A1B1 scenario there appears not to a positive or negative factor than should be applied to global predictions of future SLR
Ocean Current and Temperature	K2	By 2030 the best estimate of sea surface temperature change is 0.4-1.0°C using the A1B scenario (CSIRO, 2007 Australia). Beyond 2030 the SST changes are dependent on the emission scenarios: Median values of SST (fig 5.49) Year 2030 2070 B1 0.3-0.6 1.0-1.5 A1B 0.6-1.0 1.5-2.0 A1F1 0.6-1.0 2.0-2.5	It is not clear at present, how potential climate-change driven changes to SSTs will affect the Leeuwin Current. As such, this has implications for SSTs immediately offshore of Perth, with implications for foreshore vulnerability (direct sea-level impact) and also primary productivity with potential implications for sediment supply.
Wind Climate	K3	Mean wind speeds are predicted to increase in south-west WA in summer and autumn by 2-5% under A1B scenarios and decrease in winter by 2-5%, with no changes in spring. Overall, the net effect is no less than +/- 2% change in annual means (CSIRO, 2007) Wind-speed (%) scenarios for Perth (CSIRO 2007: Table B11) are: 2030 2070 A1B A1FI Annual 0 -1 Summer +2 +8 Autumn +2 +1 Winter -4 -14 Spring -1 -3 However, Perth regional winds are highly event driven and influenced by local land sea-breeze cells (Pattiaratchi et al., 1996). Mean wind predictions will not represent these processes. Extreme winter wind projections are expected to reduce in a similar proportion to mean winter wind speeds. It is less certain whether	The interpretation of this data is to develop two scenarios of future wind climate driving coastal processes in Perth. These are: Larger decrease & extremes 5% mean Small decrease No change

		extreme summer winds will, or are likely to, increase corresponding to mean summer winds.	
Wave Climate	K4	No recent scenarios of the implications of climate change on local or swell-driven waves. Inferring wave climate from the wind climate projections (local wind wave component only) suggests a lower proportion of local wind-waves. Climate change scenarios move the swell-wave generation zone further south. At present the mean sea-wave is 2.5 m off the SW Capes and 1.5m off Shark Bay. Assuming that this North-South gradient of swell-wave energy is maintained in the future, it may be inferred that mean swell waves will decrease, and that greater decreases will occur under the higher emission scenarios.	These are initial interpretations only.
Rainfall / Runoff	K5	Rainfall changes % change (CSIRO, 2007): Summer: Year 2030 2070 B1 -2 to -5 -5 to -10 A1B -2 to -5 -5 to -10 A1F1 -2 to -5 -10 to -20 Winter: Year 2030 2070 B1 -5 to -10 -10 to -20 A1B -5 to -10 -20 to -40 A1F1 -5 to -10 -20 to -40	Increases in the frequency of occurrence of high intensity precipitation events are possible.
Air Temperature	K6	Rise in land surface air temperature (annual 50% probability): Year 2030 2070 B1 0.6-1 1.5-2 A1B 0.6-1 2-2.5 A1F1 0.6-1 2.5-3 Increase in degrees Celsius (CSIRO, 2007)	Increases are possible in the frequency of occurrence of extremely high temperatures with reductions in the frequency of very low temperatures.
Extreme Water Levels	K7	Analysis of historic extreme water levels at Fremantle show that there is a direct relationship between extreme event levels and mean sea-level changes. The frequency of high water level events on a decadal time scale is strongly modulated by tidal cycles and inter-annual mean sea level variations associated with ENSO. As a result it is likely, as mean sea-level rises in the future extreme water levels would increase correspondingly. As a result, during an extreme event in the future at Cottesloe, higher mean water levels enable greater erosion response for the existing shape of the coast. This is despite projections that winter wind speeds, and so local storm wave heights could decrease in the future.	

Table 9: Consequence/success table for the Town of Cottesloe

Scale	Success Criteria				
	Public Safety	**Local economy & growth**	**Community lifestyle**	**Environment & sustainability**	**Public administration**
Catastrophic	Avoidable loss of many lives (>10) and large numbers of serious injuries (>25) (requiring hospitalisation in multiple hospitals)	Economic impacts leading to widespread business failure (>10), loss of employment and hardship for long periods (>3 months) of time leading to economic relocation	The Town would be seen as very unattractive, moribund and unable to support its community	Major widespread loss of environmental amenity (>50% beach & foreshore loss) & progressive irrecoverable environmental damage	Public administration would become inoperative for a significant period (>2 weeks) and be unable to access areas of Town (>50 premises)
Major	Loss of a life (1-9) or some serious injuries (5-25) (dealt with by one hospital)	Stagnation such that businesses are unable to be maintained (<10) or loss of commercial opportunity	Severe widespread decline in services and quality of life within the community	Severe loss of environmental amenity (10-50% beach & foreshore loss) & danger of continuing damage (2+ years) to restore amenity incurring significant costs (>$100k)	Public administration would become inoperative for a period (<2 weeks) & be unable to access limited areas of Town (5-50 premises)
Moderate	Isolated numbers of injuries (1-5) (managed by doctors surgery)	Significant general reduction in economic performance relative to current forecasts and surrounding districts (>10% relative reduction)	General appreciable decline in services in whole Town	Isolated but significant instance of env. damage (<10% beach & foreshore loss) that might be reversed with intensive efforts (3 months - 2 years) and moderate costs ($20-100k)	Public administration would be under severe pressure on several fronts and be unable to access very limited areas of Town (1-5 premises)
Minor	Serious near misses or minor injuries (limited or no medical treatment)	Individually significant but isolated areas of reduction in economic performance relative to current forecasts and surrounding districts (1-5 days trading)	Isolated but noticeable examples of decline in services	Minor instances of environmental damage that could be reversed (<3 months) and moderate costs (<$20k)	Isolated instances of public administration being under severe pressure
Insignificant	Appearance of a threat but no actual harm	Insignificant, temporary shortfall relative to current forecasts and surrounding districts (1-2 hours trading)	There would be isolated areas temporarily unable to maintain current services (less than a day)	Signs of limited environmental damage or natural cycles will restore environmental amenity	There would be minor instances of public administration being under more than usual stress but it could be managed

3.5. *Key elements*

Key elements are elements of value/significance that were used as a baseline to assess the impacts of predicted coastal change associated with given scenarios. The impact on key elements relates to consequence of loss, as developed for organisational objectives. Therefore, in this context, key elements are the measurable elements that are required to sustain the organisational objectives.

Three categories of key elements were developed for the purposes of the assessment during Workshop I: environment, infrastructure and amenity. Following the selection of the three key element categories, the items incorporated within each category were reviewed. The outcomes of workshop discussions were further considered during Phase II, in order to refine the items included within the key element categories. These will be discussed further in Section 4.

3.6. *Likelihood and Risk*

'Likelihood' in the context of this Project relates to the likelihood that a given climate change scenario will actually occur. For the purposes of Phase I, likelihood was discussed in terms of its role in the assessment process and therefore its contribution to the assessment of risk. Risk is derived from the combination of **likelihood** and **consequence**. Therefore, the likelihood assigned to the climate change scenarios, and the consequence of predicted coastal change (measured through loss of key elements), results in a Risk Priority level.

During Phase I, participants reviewed the Risk Priority Level table in the AGO Climate Change Risk Management Framework. Subsequently, participants modified Risk Levels to represent an appropriate risk level for the Town of Cottesloe. The resultant Risk Priority table developed in Phase I is presented in Table 10.

Table 10: Risk Priority Matrix

	Consequence				
Likelihood	Insignificant	Minor	Moderate	Major	Catastrophic
Almost certain	Low	Medium	High	Extreme	Extreme
Likely	Low	Medium	Medium	Extreme	Extreme
Possible	Low	Low	Medium	High	High
Unlikely	Low	Low	Low	Medium	High
Rare	Low	Low	Low	Medium	Medium

3.7. *Summary: Phase I*

During Phase I the definitions and terminology to be applied throughout the analysis were defined. Further, the workshop process enabled consensus to be reached on the scenarios, success criteria, key elements and risk prioritisation to be used throughout the Project. The key outcomes of Phase I can be summarised as follows:

- Three scenarios (H, M and L) over two timeframes (2030 and 2070) were selected for further analysis. The NCCOE framework was used to guide scenario development (Table 8)
- Definitions of the consequence/ success scales were established (Table 9).
- Three key elements were selected: infrastructure, amenity and environment.
- The relationship between likelihood and consequence was defined
- The scale for risk prioritisation was set (Table 10)

The outcomes of Phase I set the groundwork for subsequent analysis in Phase II.

4. Phase II: Risk Assessment

The Risk Assessment carried out within Phase II of the Project involved 3 key components according to the terminology advocated by the AGO (2007):

- Risk Identification
- Risk Analysis; and
- Risk Evaluation

These components were aligned with the key tasks subsequently considered which included:

- Establishing Physical Coastal Change;
- Analyzing the impact of Predicted Change on Key Elements; and
- Evaluating the consequence and likelihood to prioritise discrete risks from a Town of Cottesloe perspective.

This process built on the background work and consensus building completed in Phase I. It involved a combination of technical analysis, carried out by the Project team, and further consultation with key stakeholders through a Risk Assessment Workshop (Workshop II).

Each step of the Risk Assessment is dealt with in turn in the Sections that follow. The key outcomes from Workshop II are also reviewed in this section.

4.1. Physical Coastal Change

An assessment of the likely physical impacts of climate change along the Cottesloe coast was undertaken through the completion of 2 phases of analysis:

- Sensitivity analysis of the contemporary coastal environment
- Geomorphic modeling of future coastal change

The methods employed through each of these steps and their subsequent outcomes are discussed in Sections 4.1.1 and 4.1.2. A detailed overview of the sensitivity analysis and determined future coastal change is presented in Appendix B, with supporting data in Appendix G.

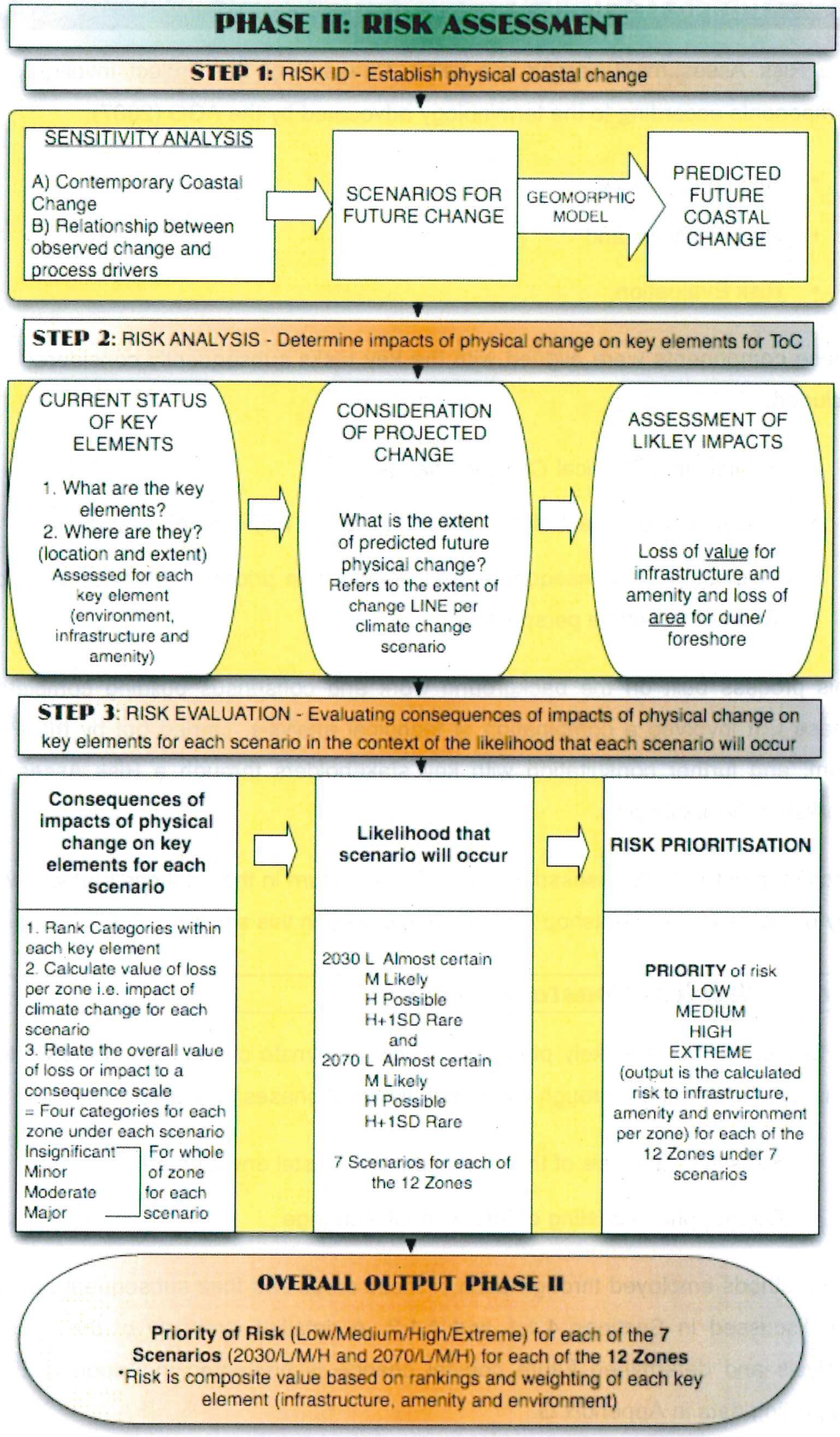

Figure 11: The Risk Assessment Process

4.1.1. Sensitivity Analysis

The sensitivity analysis conducted for the purposes of this Project incorporated an analysis of historical coastal change, in conjunction with an understanding of the range of processes that have caused change to occur (Figure 12). Due to the highly managed nature of the Cottesloe foreshore, it was necessary to distinguish, where possible, between changes brought about through human actions, and those that resulted from natural climate variations. The relative change associated with natural climate variations defines the relative sensitivity to climate parameters.

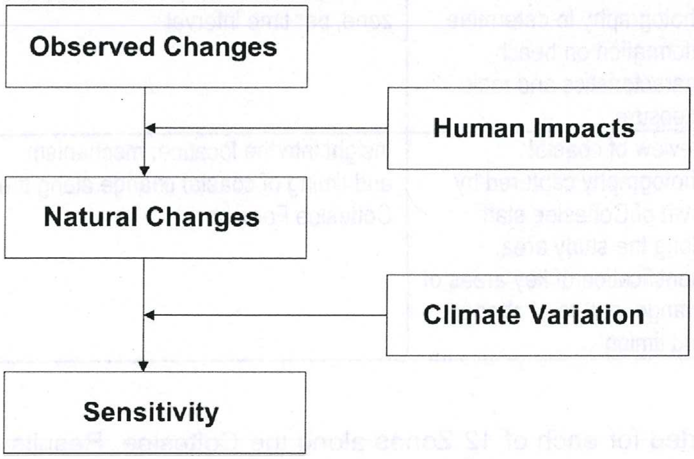

Figure 12: The sensitivity analysis process

Historical Change

The historical coastal change analysis was designed to answer 3 key questions:

1. **Where** has change occurred?
2. **What** is the nature of this change?
3. **When** did observed change take place?

Forms of analysis carried to address these questions are summarised in Table 11. In addition, a timeline showing the chronology of data used in the historical change analysis is presented in Figure 13. The area of coast under consideration along the Cottesloe foreshore has been subject to numerous changes over time (both natural and anthropogenic) and is one of Perth's favourite beaches. Historically, development on Cottesloe included a coastal road, boardwalks, tearooms and a jetty. A seawall was built to defend the coastal buildings along the foreshore and the

Cottesloe groyne was built to provide a stable beach and sheltered swimming area. Further groynes were later constructed to the south to help stabilise the beaches.

Table 11: Overview of historical coastal change analysis

Approach	Method	Output
Quantitative assessment of shoreline change	Digital Shoreline Analysis System (DSAS) in ArcGis 9.1	Rate of shoreline change (m/yr) Variability associated with discrete transects; Temporal signals associated with this change.
Qualitative assessment of beach behaviour	Review of aerial photography to determine information on beach characteristics and rock exposure.	Qualitative description of change per zone, per time interval
Assessment of discrete change as a response to extreme events.	Review of coastal photography captured by town of Cottesloe staff along the study area. Identification of key areas of change, nature of change and timing	Insight into the location, mechanism and timing of coastal change along the Cottesloe Foreshore

Historical change was reported for each of 12 Zones along the Cottesloe. Results of the historical change analysis are presented in Appendix B to this document and summarised below:

- Most change was observed to the North of the study area (Zones 3-6), to the South at Deane St, and in the vicinity of Wharton St. (Zones 10 & 12).
- Least shoreline change was observed in areas that had a rocky shoreline or where backed by engineered structures (Zones 2, 6, 7,9). However, these areas were prone to extensive beach lowering and shunting of sediment on, off and alongshore, in response to high-energy events.
- The 1979 shoreline showed widespread and significant shoreline recession throughout the North of the study area. Moving south, the impacts of the 'event' (most likely Cyclone Alby in April 1978) were not as significant.
- Although the southern transects show a pattern of net erosion (Zone 12), this appears to be a gradual and consistent decline over time, rather than sporadic increases and decreases that are apparent at other transects.

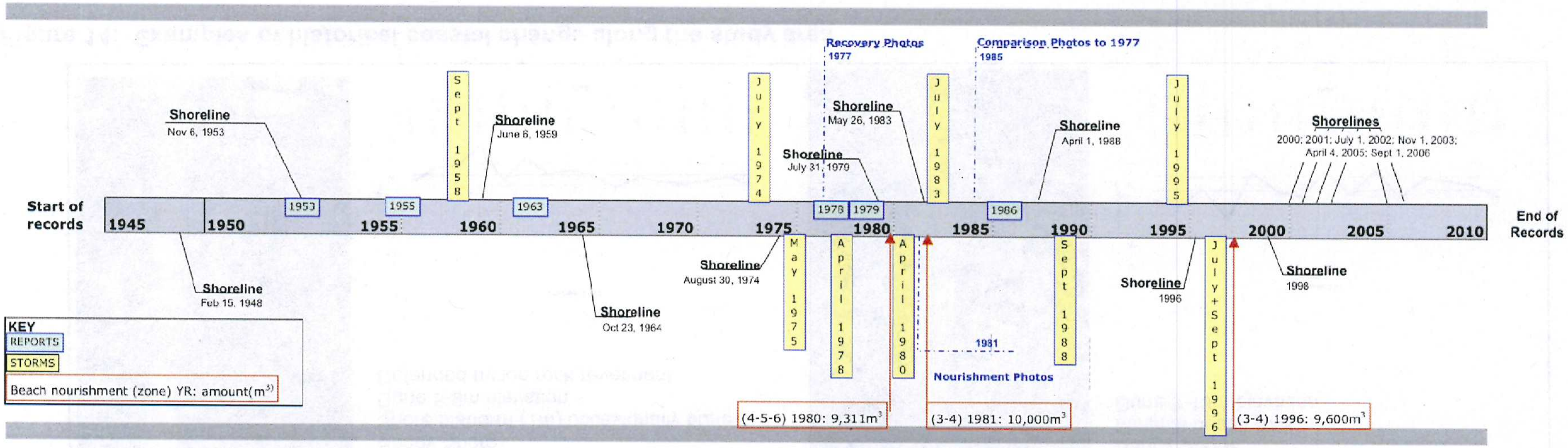

Figure 13: Nature and chronology of available data

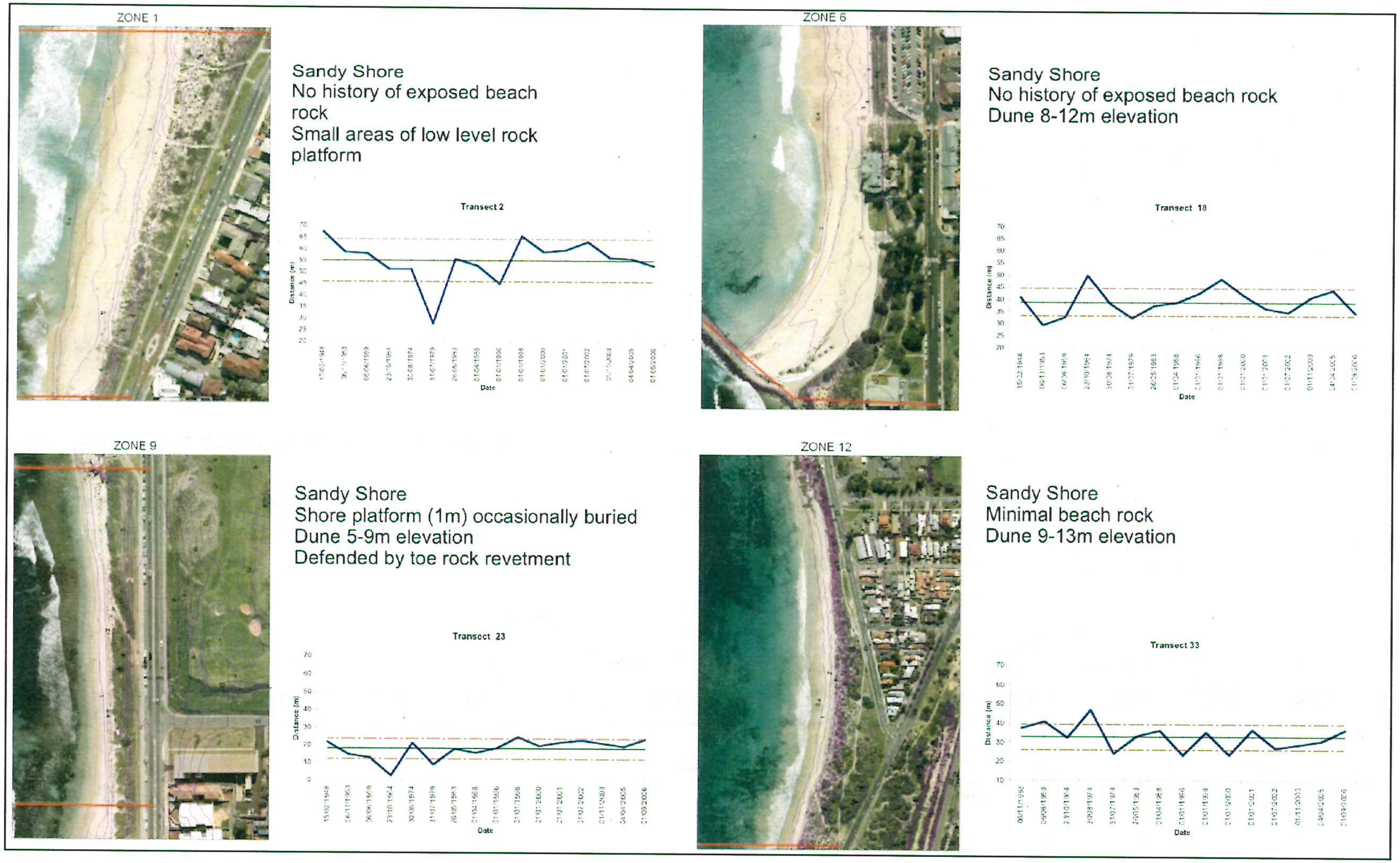

Figure 14: Examples of historical coastal change along the study area

Process Drivers

Of key interest to the current project is the relationship between the aforementioned historical coastal change and the processes driving this change along the Cottesloe coast. In this respect, an evaluation of environmental processes that affect the length of coastline under consideration over time was required. The coastal variables subject to climate change that are considered capable of driving biophysical coastal change are listed below (following from NCCOE, 2004). The key components considered for the purposes of the sensitivity analysis reported here were wave climate and water level, discussed further below.

Table 12: Coastal variables driving change

K1	Mean Sea Level
K2	Ocean Currents & Temperature
K3	Wind Climate
K4	Wave Climate
K5	Rainfall / Runoff
K6	Air Temperature

Historic Records of Coastal Variables

a) Wave Climate

Since 1994, the direct measurement of offshore wave conditions for Perth has been available from a permanently deployed wave-rider buoy (Lemm, 1996; Lemm *et al.* 1999). Prior to this, measurements were more sporadic in nature, generally for short-term, project specific deployments (Hamilton 1997). Wave hindcasting using the historic wind record was used to provide interpolation of the wave record over the period of interest to this Project. However, the absence of a long-term, stable consistent measure of the wave climate reduces the capacity to identify the effect of individual storm events prior to 1994.

The regional wave climate is seasonal, and is more energetic over May to October in association with winter storm events (Lemm, 1996; Lemm *et al.* 1999). However, within this broad pattern, the timing and intensity of severe wave events is highly variable. Analysis of the total winter wave energy, based on the equation below indicates a highly variable wave climate:

$$E_a \sim \left(\sum H_S^2 - \overline{\sum H_S^2}\right) \Big/ \sum H_S^2$$

Wave energy was more than 20% above the annual mean in 1996 and almost 15% below in 2001 (Figure 15). Observations off Garden Island from 1970 to 1975 identified seasonal peaks varying between June and October (Reidel & Trajer 1978). A similar analysis for the Rottnest offshore waverider buoy is included in Table 13.

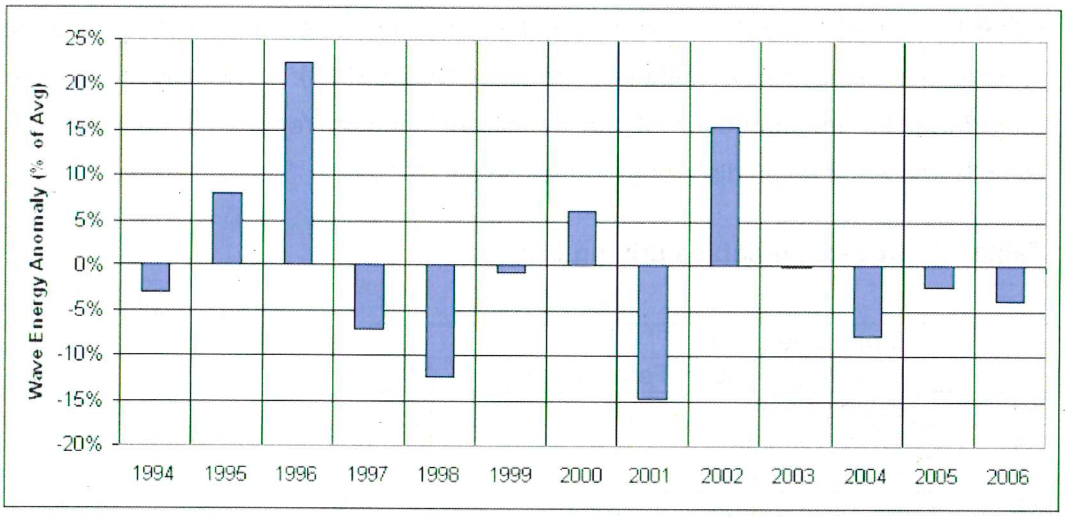

Figure 15: Wave energy anomalies from Rottnest waverider buoy, 1994-2006

1994	Jun			
1995			Aug	
1996		Jul		
1997	Jun			
1998			Aug*	
1999	Jun			
2000		Jul		
2001				Sep
2002		Jul		
2003				Sep
2004			Aug	
2005	Jun			
2006		Aug		

Table 13: Timing of annual wave energy peak from Rottnest waverider buoy, 1994-2006

b) Water Levels

Figure 16 illustrates the frequency of high water level events (from Eliot, 2005). This shows quasi-cyclic behaviour on an inter-annual basis, overlying a general increasing trend. Eliot (2005) and Eliot & Pattiaratchi (2007) presented a decomposition of the water level record from 1897 to 2003 using high and low pass time series to approximate tide cycles, mean sea level variation and surge.

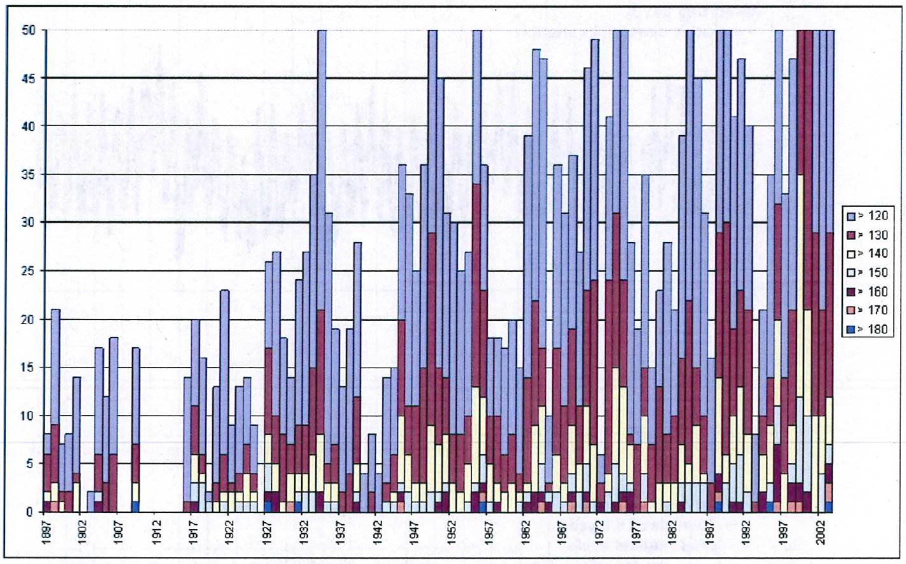

Figure 16: Count of high water level events 1897-2003

Figure 17 shows the mean sea level variation and tidal approximation from 1959 to 2007. Mean sea level is affected by climate-driven inter-annual sea level fluctuations, with approximately 0.25m range correlated to El Nino / La Nina conditions, overlain by seasonal cycle with an average range of 0.26m, peaking between May and July. The tidal signal comprises a series of cycles, with an 18.6-year lunar cycle, a biannual cycle peaking at the December and June solstices, and a month spring-neap cycle.

The mean sea level signal shows two significant features that were used for detecting coastal sensitivity to change:

- A gradual net rise in sea level over period 1959 to 2007 was observed. A total rise of 0.07m is estimated, at an average rate of 1.55 mm/yr.
- From 1993 to 2000, a significant inter-annual shift of climate conditions was experienced. This produced a 0.21m rise, at an average rate of 30 mm/yr (Eliot & Pattiaratchi 2005).

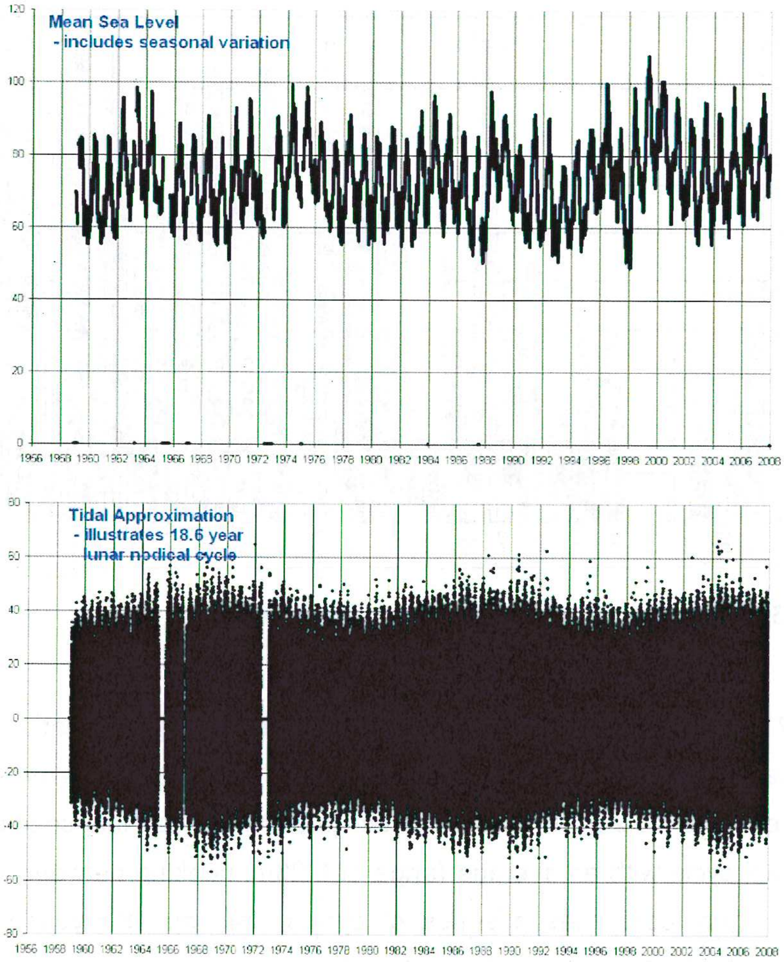

Figure 17: Decomposed water level signals – mean sea level & tide

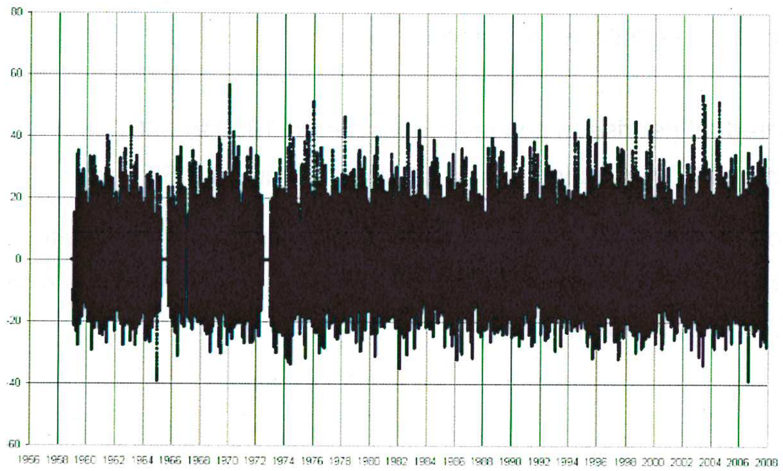

Figure 18: Surge approximation 1959 to 2007

The residual from the tide and mean sea level signals is an approximation for the surge (Figure 18). The surge approximation developed from the water level decomposition has been used to derive a storminess index for the Fremantle region for periods where no wave observations were available (Eliot 2005). This storminess index from 1897 to 2003 has been derived following the method of Bromirski *et al.* (1999) and correlated with Rottnest wave events from 1994 to 2003 (Eliot, 2005). This suggests occasional periods of enhanced activity, considered likely to be related to high intensity westerly storm events. By definition, a proxy for storminess is less reliable than direct measurement, such that the relationship between wave conditions and storminess for individual events may be relatively weak. However, the index provides a reasonable measure for a collective set of events, such as the annual variations in wave climate.

Coastal Response

The sensitivity of the coast to variable conditions has been considered by comparing vegetation line change between sequential historical aerial photographs. Coastal response was compared against wave, storminess and water level records for the period 1959 to 2007. This comparison showed a limited relationship, with no progressive change along the Cottesloe foreshore for the length of the record. Although erosion was typically associated with more energetic conditions, there was no direct relationship between response and intensity of conditions.

The conditions associated with known severe erosion events were examined, to develop an improved climate parameter-coastal response relationship. The information used was more qualitative in nature, based largely upon Town of Cottesloe records and site photographs. Considerable information and insight into the Cottesloe coast was provided by discussion with Malcolm Doig, former Manager of Engineering Services. Severe erosion events included:

- TC Alby in April 1978
- Winter storm July 1996
- Winter storm May 2003

An important feature identified within the coastal management history was the difference in behaviour of those segments of beach with significant shallow subtidal rock platforms, and those with a deeper rock substrate, making them effectively sandy. In general, less response was observed on those sections of coast where the rock platforms are higher and broader. The shoreline profiles were clustered into zones according to the relative presence of rock, or separation due to alongshore barriers including groynes and rocky headlands.

For the majority of the identified severe erosion events, the greatest shoreline retreat typically occurred on the south side of alongshore features. It was also identified that an ongoing program of active coastal management has been in place, particularly from the late 1970s, which includes renourishment and construction of coastal protection works. The behaviour of the beach zones has been interpreted with the intention to identify only natural shoreline variability.

A distinguishing feature of the severe erosion events was a high water level, exceeding 1.6m CD (Chart Datum). Review of the historic water level showed a number of high water level events for which severe erosion was not observed. However, severe erosion was typically identified after a sequence of several years in which high water levels were recorded.

High water levels require a combination of factors to occur simultaneously, which may include various combinations of high tides, elevated mean sea levels or high surges. The seasonal nature of tides and annual mean sea level variation have resulted in a relatively narrow window, from May to July, over which water levels will typically exceed 1.6 m CD.. It is noted that exceptions are possible, for example during TC Alby in April 1978. The seasonal nature of high water levels controls the relationship between wave conditions and coastal response, as storm activity may often occur outside the relatively narrow period during which high water levels are likely.

The significance of the short period over which high water levels may occur is that seasonal or annual indices of waves and storminess are inadequate to identify stresses to which the coast will respond. Instead, these indices have been used to estimate historic climate variability, and it is assumed that this variability will also be reflected in conditions driving erosion events which are a subset of the entire set of events.

For the sandy coast, a conservative estimate of the sensitivity of the beach to changes in wave energy was determined by assuming a direct ratio between the variability of the shoreline position and variability of wave energy. This approach effectively neglects photogrammetric error, or natural variation of shoreline change, which may result from atmospheric conditions or human impacts rather than coastal forcing (Galgano *et al.* 1998; Boak & Turner 2005). A further level of conservatism was adopted by using the most variable profile within the zone to estimate maximum change.

The response of sandy beaches to sea level rise was estimated by considering:

- Net trend over the historic period, in response to the overall mean sea level rise;
- Shoreline response to the 0.15m mean sea level rise from 1993 to 2000.

Sensitivity was estimated using the maximum of the two ratios of shoreline retreat to sea level rise (long-term and from 1993-2000). For those beaches that did not have significant coastal management actions, the ratio of shoreline retreat to sea level rise varied from 50 to 135. Beaches where significant renourishment and dune rehabilitation took place showed insignificant change. To remove the effect of human management, a minimum ratio of 50:1 shoreline change to sea level rise was adopted. This is notably less than the 100:1 ratio commonly applied using the Bruun Rule (Bruun 1962; WAPC 2003).

For Sections of shore protected by subtidal rock platforms, it was assumed the position of the beach toe was determined by wave conditions, which are affected by the depth and width of the platform. The sheltering provided by the platform was estimated using the relationships defined in GEMS (2005). The naturally occurring perched beaches all corresponded to approximately 35% wave dissipation across the platform under a 1.6m CD water level. Hence this ratio was used as a theoretical requirement for the shoreline response to changing wave and water level conditions.

4.1.2. Geomorphic modelling of future coastal change

Two discrete models were formulated to account for the significant difference in behaviour of rocky and sandy shores. The sandy beach model schematically illustrated below combines a direct response to both mean sea level and wave energy changes. The ratio of observed shoreline change to each parameter is multiplied by the Projected change in climate, as defined for each of the climate scenarios. The two components of response are added together.

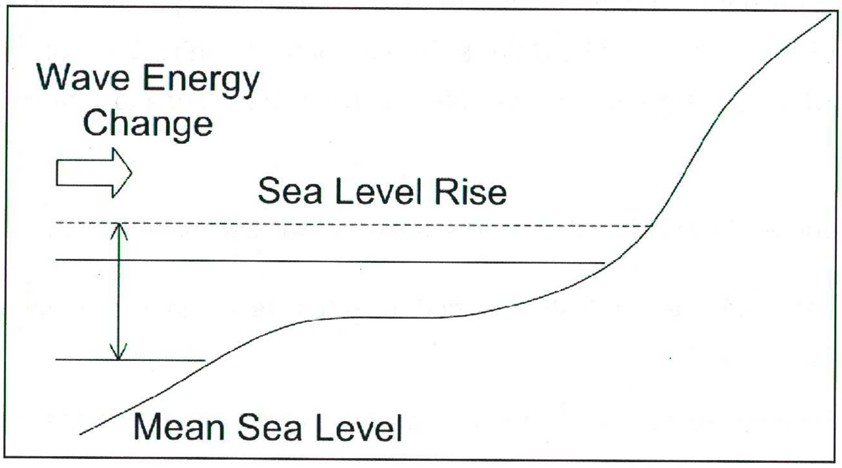

Figure 19: Sandy beach model for predicted coastal change

An example of calculations for Zone 1 when treated as a sandy shore are presented below:

Historic response to SLR	= 135
Shoreline variability	= 9m (s.d.)
2070 Moderate SLR	= 0.28m
2070 Moderate H	= -7%
Existing H variability	= 11%

$$[SLR] = [H_{SLR} + H_{CC}]$$

[135 x 0.28] + [9 * (0.28/0.9 – 0.07)/0.11] = 38m + 20m = **58m**

On the basis of these results, it is predicted that the shoreline in Zone 1 will have receded by approximately 58 m by 2070 under a moderate scenario for change.

For areas with extensive rock, a shore platform change model was formulated using the wave dissipation relationship across a platform (Figure 20).

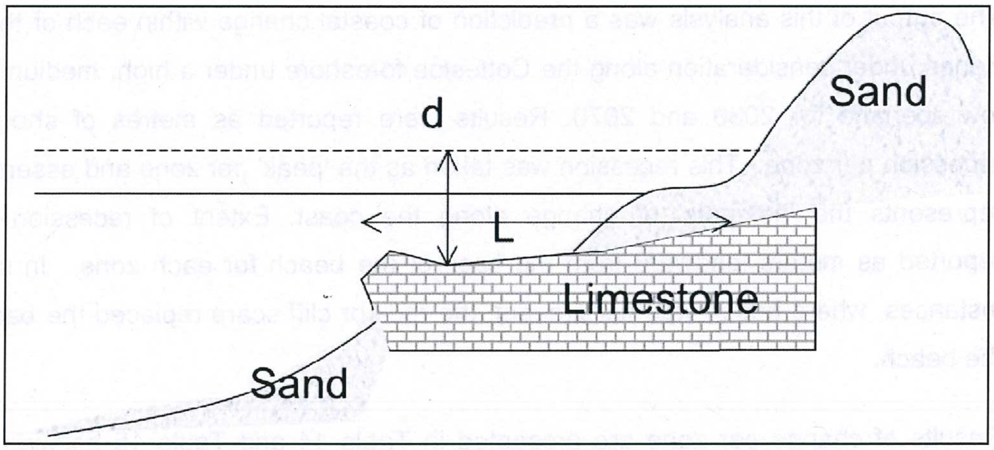

Figure 20: Shore platform change model

Here, wave dissipation is a function of platform width and depth H = *f*(Hi, L, d). Erosion is estimated to be the increased L such that the same equivalent wave height is experienced given changes to incident wave height and depth. Where the coast is protected by natural or artificial rock, wave dissipation of 35% was required.

Applying this model to Zone 1 (i.e. treating zone 1 as a rock platform), the following values were calculated:

Existing Width to Beach	= 43m
Shore Platform Level	= 0.3m CD
2070 Moderate SLR	= 0.28m
2070 Moderate H	= -7%
Required Platform Width	= 65m
Corresponding Erosion	= 22m

Comparing the output of the sandy beach and rocky platform models of change for Zone 1, it is clear that erosion would be greatest for the sandy shore (58 m) and least when rock is assumed present (22m).

Each Zone within the study area was evaluated and a decision made on weather a sandy or rocky model should be used for the prediction of coastal change. In the case of Zones 1 and 4, both models were applied.

The output of this analysis was a prediction of coastal change within each of the 12 Zones under consideration along the Cottesloe foreshore under a high, medium and low scenario for 2030 and 2070. Results were reported as metres of shoreline recession per zone. This recession was taken as the 'peak' per zone and essentially represents the 'hotspots' of change along the coast. Extent of recession was reported as meters landward from the back of the beach for each zone. In some instances, where beach was not present, the rock or cliff scarp replaced the back of the beach.

Results of change per zone are presented in Table 14 and Table 15 below. This information was subsequently used to produce a map for the Cottesloe Coastal Zone illustrating the extent of potential change under each of the aforementioned climate change scenarios (e.g. Figure 21). The 'lines' represented in the change maps have been created based on an extrapolation of the peak recession per zone. This information was subsequently used to assess the impacts of coastal change on existing key elements along the Cottesloe Foreshore (discussed below).

Table 14: Shoreline recession when treated as rock platform

Zone	2030 B1	2030 A1B	2030 A1F1	2070 B1	2070 A1B	2070 A1F1
SLR	0.07m	0.11m	0.16m	0.14m	0.28m	0.48m
Wave	0%	-4%	-8%	0%	-7%	-14%
Z1	6m	10m	14m	12m	22m	36m
Z2	6m	10m	14m	12m	22m	36m
Z2 (high)	0m	0m	0m	0m	0m	19m
Z3						
Z4	9m	11m	14m	13m	22m	33m
Z7	0m	0m	0m	0m	0m	0m
Z8	7m	11m	16m	14m	27m	43m
Z9	0m	0m	0m	0m	0m	3m
Z10	5m	8m	11m	10m	19m	30m
Z11	6m	10m	14m	12m	22m	36m
Z12	6m	10m	14m	12m	22m	36m

Table 15: Shoreline recession when treated as sandy shore

Zone	2030 B1	2030 A1B	2030 A1F1	2070 B1	2070 A1B	2070 A1F1
SLR	0.07m	0.11m	0.16m	0.14m	0.28m	0.48m
Wave	0%	-4%	-8%	0%	-7%	-14%
Z1	16m	22m	30m	32m	58m	97m
Z2						
Z3	10m	12m	16m	20m	34m	56m
Z4	13m	18m	24m	27m	48m	80m
Z5	11m	13m	17m	21m	36m	60m
Z6	7m	9m	12m	14m	25m	42m

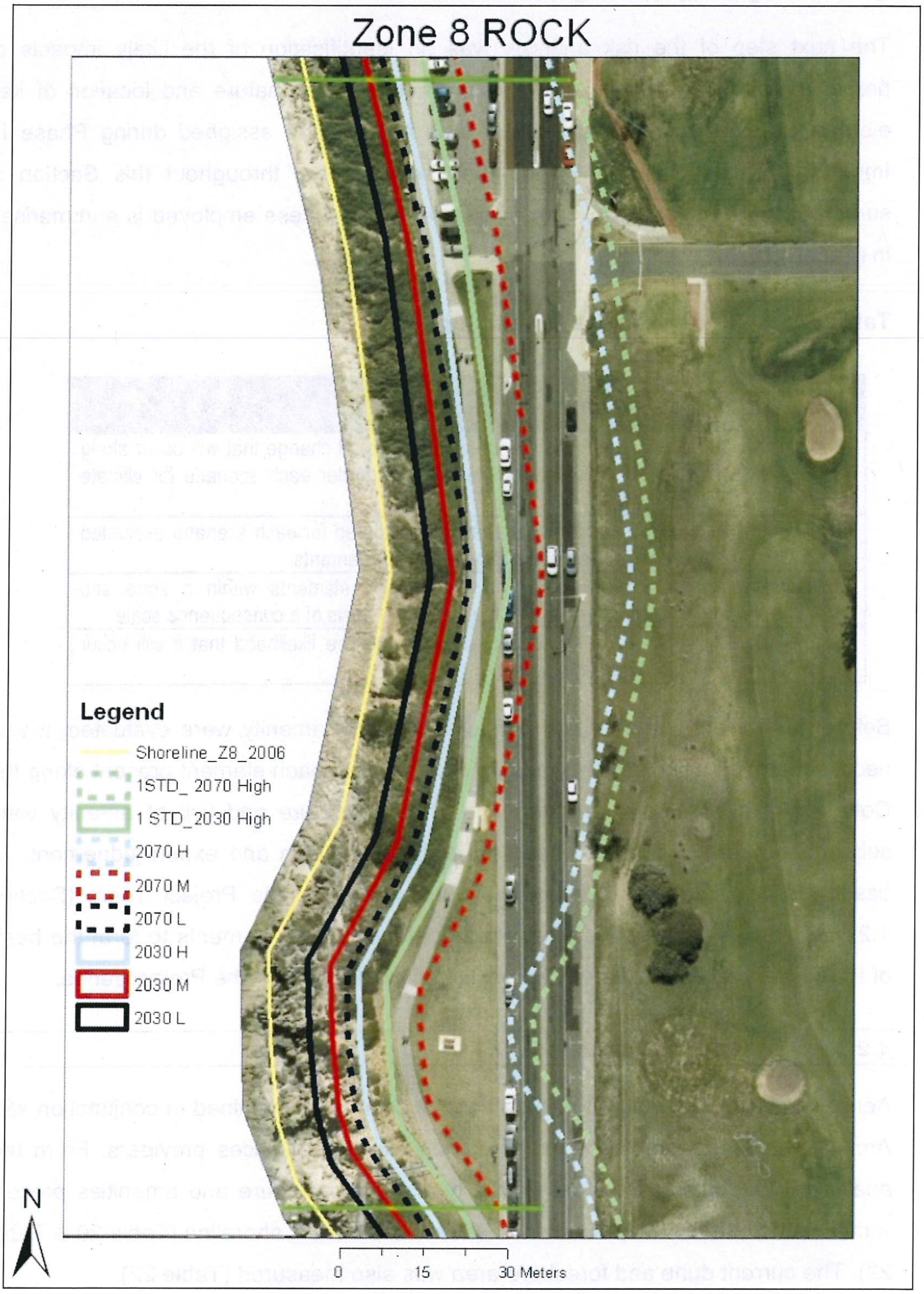

Figure 21: Example of change lines for Zone 8

4.2. *Impacts on Key Elements*

The next step of the risk analysis was an identification of the likely impacts of predicted coastal change (Section 4.1) on the current nature and location of key elements (environment, infrastructure, and amenity, as assigned during Phase I). Important terminology adopted by the Project Team throughout this Section is summarised in Table 16 while an overview of the process employed is summarised in (Table 17).

Table 16: Risk Assessment Terminology

Term	Explanation
Physical change	Assessment of the predicted physical change that will occur along given segments of the coastline under each scenario for climate change
Impact	Predicted physical change considered for each scenario evaluated on the basis of the location of key elements
Consequence	Overall weighted % loss of key elements within a zone and evaluates what this means on the basis of a consequence scale
Risk	Scale of the consequence against the likelihood that it will occur under each scenario

Before the current status of both infrastructure and amenity were evaluated, it was necessary to identify discrete 'types' or categories of each element present along the Cottesloe foreshore. Eleven categories of infrastructure and five of amenity were subsequently decided upon, based on group discussion and expert judgement. A baselining exercise was subsequently undertaken by the Project Team (Section 4.2.1). This was followed by an evaluation of loss of key elements to form the basis of the Risk Evaluation work carried out within Workshop II in the Project series.

4.2.1. Baselining Key Elements

Aerial photography for the Cottesloe coastal zone was examined in conjunction with ArcGIS shapefiles, maps and plans supplied by key services providers. From this analysis it was possible to identify the type of infrastructure and amenities present within each zone and their location relative to the current shoreline (Table 20 & Table 22). The current dune and foreshore area was also measured (Table 22).

Table 17: Establishing the current status of Key Elements along the Cottesloe foreshore

Element	Approach	Methodology	Output
Infrastructure	**Presence/absence** of infrastructure within each zone was determined	11 categories of infrastructure were identified through group consultation (Table 5) The location of current infrastructure was determined through an analysis of shape files in ArcGis overlaid on the 2006 aerial photography and 'dial before you dig' drawings provided by key service providers (Figure 2) The total number of infrastructure elements per zone was collated using this information (Table 6) The discrete 'types' or categories of infrastructure present within each zone were recorded - each 'type' of infrastructure was given a code from 1-10 and relevant codes were noted per zone.	Table with total number of infrastructure elements per zone & type of discrete infrastructure present in each Map with location of existing infrastructure relative to current coastal environment
Amenity	**Presence/absence** of each determined within each zones	5 categories of amenities were identified through group consultation (Table 6) The location of current amenities was determined through an analysis of shape files in ArcGis and the 2006 aerial photograph of the study area. The total number of amenities per zone was collated (Table 7). The results of 3 independent assessments were compared in order to represent the range of amenities available per zone in as subjective a manner as possible. The discrete categories of amenities present within each zone were recorded (categories were coded 1-10)	Table with **total number** of amenities per zone and descriptions of each amenity per zone Map with location of existing infrastructure relative to current coastal environment
Environment: **Beach** **Dune** **Foreshore**	Existing **area** established	Polygons calculated for each in ArcGis9.1 (Table 4) Beach: HWL to veg line Dune: veg line to back of dune (end of vegetation) Foreshore: Marine parade to back of dune	Table of area in msq per zone ArcGis map with area polygons on 2006 aerial photograph

Table 18: Infrastructure categories

ID	Item	Characteristics
1	Dual Use Walkways	Path lying parallel to Marine Parade
2	Coast Perpendicular Access Paths	Beach access path, includes disabled access
3	Roads	Includes roads and on-street parking
4	Reticulated grass	Grassed foreshore and grassed terrace
5	Street Furniture	Benches, picnic tables, exercise equipment, play equipment, lookouts, monuments, bus shelters, path fencing, showers.
6	Dune Management	Dune fencing and stabilisation works only
7	Commercial Development	Restaurants, cafes, surf life saving club etc
8	Residential Development	Private housing
9	Services	Gas/ water/electricity mains, communications, sewerage
10	Coastal Defence	Seawall, groyne, breakwater
11	Off street Parking	Off street car parks

Table 19: Amenity classifications

New ID	Category	Subcategory	Example Activities
1	Water Recreation	-	Swimming, Water board activities
2	Beach Recreation	Passive	Sunbathing, relaxing, socialising on beach
3		Active	Volley ball, soccer, little nippers swimming classes, walking/running on the beach
4	Foreshore Recreation	Passive	Picnicking and playing, socialising and eating, relaxing and watching the view
5		Active	Walking, running, cycling/ roller blading

Table 20: Existing infrastructures per zone

Zone	Infrastructure Currently Included
1	1,2,3,4,5,8,9
2	1,2,3,4,5,6,7,8,9
3	1,2,3,4,5,7,9
4	1,2,3,4,5,6,9
5	1,2,3,4,5,6,7,8,9
6	1,2,3,4,5,7,8,9,10
7	1,2,3,4,5,9
8	1,3,4,5,9
9	1,2,3,5,8,9,10
10	1,2,3,4,5,6,8,9
11	1,2,3,5,6,8,9,10
12	1,2,3,4,5,8,9

Table 21: Existing amenities per zone

Zone	Amenities Currently Included
1	1,2,3,4,5,6,7,8,11
2	1,5,7,8,11
3	1,4,5,6,7,8,10,11
4	1,5,6,7,8,9,11
5	1,5,6,7,8,9,11
6	1,2,5,6,7,8,9,10,11
7	7,8,11
8	2,6,7,8,11
9	2,4,5,6,7,8,11
10	1,2,3,4,5,6,7,8,9,11
11	4,7,8
12	1,3,4,5,6,7,8,11

Table 22: Existing Beach, Dune & Foreshore area (m^2).

Zone	Beach Area	Dune Area	Foreshore Area
1	8956	8117	2852
2	2585	5273	2280
3	8573	7760	6157
4	9303	7148	5152
5	6837	5008	4621
6	13463	139	19067
7	5349	9018	7585
8	3099	3602	1744
9	2407	4232	720
10	15267	9395	9423
11	973	4622	3214
12	11716	20875	11934

4.2.2. Loss of Key Elements under Discrete Scenarios

Impacts of projected climate change under each scenario were establishing by determining the loss of key elements as a result of predicted coastal change. This was undertaken by reviewing 'peak change lines' for each scenario, and determining when and where they overlaid the key elements identified in the baselining exercise. If an amenity or infrastructure element was located seaward of a 'peak change line' for any given scenario, that element was deemed to be 'absent' from that zone for the sake of analysis. The elements lost under each climate scenario, within each zone, were recorded (see Table 23 for example). In addition, the percentage of area of dune or foreshore lost in response to shoreline recession under each scenario was calculated.

This information was subsequently used as the basis for working sessions during the afternoon of Workshop 2, held on 9 April 2008 to undertake practical aspects of the Risk Evaluation phase.

4.3. Risk Evaluation

Information generated through risk Identification and analyses were used as a basis to undertake risk evaluation. This involved completion of a number of key tasks carried out by the Project Team with the assistance of key stakeholders during working sessions of Workshop II. These included:

1. Assessment of the ***consequences*** of the impacts of physical change on key elements for each scenario.
2. Determination of the ***likelihood*** that a given scenario would occur.
3. Assignment of a subsequent ***risk priority rating*** for each of the 12 zones under the 7 climate change scenarios under consideration.

The steps associated with each of these tasks are summarised in Figure 11.

Table 23: Recording of key element loss under each of the climate change scenarios

Zone	Currently Included	2030 L Excluded	2030 M Excluded	2030 H Excluded	2070 L Excluded	2070 M Excluded	2070 H Excluded	2030 H 1SD Excluded	2070 H 1SD Excluded
1S	1,2,3,4,5,8,9	1,2,5	1,2,3,4,5	1,2,3,4,5,9	1,2,3,4,5,9	1,2,3,4,5,9	1,2,3,4,5,8,9	1,2,3,4,5,8,9	1,2,3,4,5,8,9
1R	1,2,3,4,5,8,9	2	2	2,5	2	1,2,3,4,5	1,2,3,4,5,9	1,2,3,4,5,9	1,2,3,4,5,8,9
2R	1,2,3,4,5,6,8	1,2, 5	1,2,4,5,6	1,2,3,4,5,6	1,2,3,4,5,6	1,2,3,4,5,6	1,2,3,4,5,6,9	1,2,3,4,5,6	1,2,3,4,5,6,9
	HIGH ROCK (as above)	0	0	0	0	0	1,2,3,4,5,6,9	-	1,2,3,4,5,6
3S	1,2,3,4,5,7,8,9,11	1,2	1,2	1,2,7	1,2,7	1,2,4,5,7	1,2,3,4,5,7,9,11	1,2,4,5,7	1,2,3,4,5,7,8,9,11
4S	1,2,3,4,5,6,9,11	1,2,5,6	1,2,5,6	1,2,4,5,6	1,2,4,5,6	1,2,3,4,5,6,9	1,2,3,4,5,6,9	1,2,3,4,5,6,9	1,2,3,4,5,6,9
4R	1,2,3,4,5,6,9,11	2	2	1,2	1,2	1,2,4,5,11	1,2,4,5,11	1,2,4,5,11	1,2,3,4,5,11
5S	1,2,3,4,5,6,7,8,9	2,6	2,6	2,6,5	1,2,6,5,11	1,2,3,4,5,6,11	1,2,3,4,5,6,9,11	1,2,3,4,5,6,11	1,2,3,4,5,6,7,8,9,11
6S	1,2,3,4,5,8,9,11	2,4,7	2,4,7	2,4,7	2,4,7	1,2,3,4,5,7,10	1,2,3,4,5,7,9,10	1,2,3,4,5,7,9,10	1,2,3,4,5,7,9,10
7R	1,2,3,4,5,9,11								
8R	1,3,4,5,9	0	1,5	1,4,5	1,5	1,3,4,5	1,3,4,5,9	1,3,4,5	1,3,4,5,9
9R	1,2,3,5,8,9,10	0	0	0	0	0	2,10	0	2,3,5,10
10R	1,2,3,4,5,6,8,9,11	2,6	2,5,6	1,2,5,6	1,2,5,6	1,2,3,4,5,6,11	1,2,3,4,5,6,9,11	1,2,3,5,6,11	1,2,3,4,5,6,9,11
11R	1,2,3,5,6,8,9,10	2,5,6	2,5,6	1,2,5,6,10	1,2,5,6,10	1,2,3,5,6,10	1,2,3,5,6,9,10	1,2,3,5,6,10	1,2,3,5,6,9,10
12R	1,2,3,4,5,8,9	2	2	2,9	2	1,2,3,4,5,9	1,2,3,4,5,9	1,2,4,5,9	1,2,3,4,5,9

4.3.1. Consequences of Physical Impacts

An assessment of consequence involved:

- **Ranking** of categories within each key element group
- Calculations of value of **loss per zone** (impacts) – i.e. the composite impact of climate change for each scenario based on loss of all key elements.
- Relating overall value of loss (or impacts) to a **consequence scale**

Ranking of Key Element Categories

Ranking was carried out to ensure that the importance of each key element category was encapsulated within the Risk Assessment. For example, in the infrastructure table, roads may be of greater significance/value than street furniture.

Once consensus was reached on the categories of key elements, workshop participants attempted to rank the resultant categories in terms of importance from 1-5 (5=most important; 1=least important). The results of the infrastructure ratings are presented in Table 24, with the amenity ratings in Table 25.

Table 24: Ratings for infrastructure categories

ID	Category	G1	G2	G3	G4	G5	G6
1	Dual Use Path	2	3	2	2	2	1
2	Coast Perpendicular Access Paths	1	3	2	2	2	2
3	Roads	4	5	5	5	5	5
4	Reticulated grass areas	2	1-2	1	2	3	1
5	Street Furniture	1	1-2	1	1	1	3
6	Dune Management	1	1-2	1	3-4	2	4
7	Commercial Development	5	4	4	5	5	3
8	Residential Development	5	4	3	5	5	5
9	Services	4	5	5	5	5	5
10	Coastal Defence	2	5	4	4-5	5	4
11	Car Parks	3	3	2	2	4	3

Note: G = group. The participants broke into six small groups to complete the ranking exercise. Each column presents the results of each group.

Table 25: Amenity rankings

New ID	Category	Subcategory	Example Activities	Ranking
1	Water Recreation	-	Swimming, Water board activities	5
2	Beach Recreation	Passive	Sunbathing, relaxing, socialising on beach	4
3		Active	Volley ball, soccer, little nippers swimming classes, walking/running on the beach	2
4	Foreshore Recreation	Passive	Picnicking and playing, socialising and eating, relaxing and watching the view	3
5		Active	Walking, running, cycling/ roller blading/ skateboarding	1

Loss Per Zone

The rankings assigned to each key element were then used to calculate a value of 'loss' associated with each element for each zone. Subsequently, a percentage of total loss per zone or the total impact of climate change as a weighted percentage of the key elements was determined for each scenario (see Appendix D for results tables).

This weighted percentage was developed through a consideration of the relationship between key elements and success criteria. As seen in Table 26, environment is required across all success criteria (5), followed by infrastructure (4) and amenity (3).

Table 26: Aligning key elements to success criteria

Success Criteria	Key Elements Required to Sustain Success Criteria		
	Environment	Infrastructure	Amenity
Public Safety	X	X	
Local economy and growth	X	X	X
Community and lifestyle	X	X	X
Environment and sustainability	X		X
Public administration	X	X	

The relative weighting of each of the key elements (to enable calculation of one overall value of risk per zone) was denoted as follows:

- Environment: 42%
- Infrastructure: 33%
- Amenity: 25%

Evaluation of loss relative to consequence scale

The consequence associated with any given scenario for change was then determined by evaluating the weighted loss within the zone, against an arbitrary consequence scale (Table 27), where consequence is measured against percentage loss. For example, a low total percentage loss of key elements per zone (1-10%) has an insignificant consequence for the Town of Cottesloe whereas a high percentage loss of key elements (71-100%) is considered to have catastrophic consequences.

In this way, the consequences of the impacts of climate change per zone have been assigned categories between 1-5 per scenario.

Table 27: Aligning consequence with key element loss

Consequence	Percent Loss Scale
Insignificant	0 to 10
Minor	11 to 25
Moderate	26 to 50
Major	51 to 70
Catastrophic	71 to 100

The results for each zone and under each scenario were mapped against this scale to assess level of consequence (Table 28 and Table 29).

Table 28: Consequence levels for each coastal survey zone for the 2030 climate change scenarios

	No.	2030L	2030M	2030 H	**2030 H 1SD Excluded**
Insignificant	0 to 10	1R, 4R, 8, 9,10, 12	1R, 4R, 8, 12,9	9	9
Minor	11 to 25	1S, 2,3,4S,5,6,8,9	2R, 3, 4S, 5, 10, 11	1R, 4R,5,10,11,12	
Moderate	26 to 50		1S, 6	2R,3,4S,6,8	1R, 4R,8,11,12
Major	51 to 70			1S	3,10
Catastrophic	71 to 100				1S, 2R,4S,5,6

Table 29: Consequence levels for each coastal survey zone for the 2070 climate change scenarios

	No.	2070L	2070M	2070H	**2070 H 1SD Excluded**
Insignificant	0 to 10	1R, 12,9	9	9	
Minor	11 to 25	4R, 10			9
Moderate	26 to 50	2R,3, 4S, 5,6,8,11	1R,4R,11,12	4R,12	12
Major	51 to 70	1S	2R,3,6,8	1R,6,11	1R,11
Catastrophic	71 to 100		1S,4S,5,10	1S,2R,3,4S,5,8,10	1S, 2R,3,4S, 4R,5,6,8,10

4.3.2. Scenario Likelihood

For the purposes of this report, risk has been assessed through a consideration of the relationship between consequence and likelihood. In this respect, likelihood is a critical component of the Risk Assessment. While the AGO framework assigns likelihood to climate change scenarios, the most recent report of the IPCC (AR4) has reported that no climate change scenario is more likely than another. In light of this, the likelihood components of the AGO framework (referenced to IPCC, 2001) were no longer considered directly applicable for the purposes of this Project.

Rather than exclude likelihood altogether, the Project Team produced a likelihood scale that blended scenario confidence levels and natural climatic variability (Table 30). A measure of likelihood was established using the confidence intervals defined for each scenario to identify the relative likelihood of exceedance. A high likelihood scenario (most likely to occur) was developed by using the lowest 5% confidence level from the three scenarios. A moderate likelihood scenario was developed using the median of the median for each of the three scenarios. A low likelihood scenario (least likely to occur) was developed by using the highest 95% confidence level from the three scenarios.

The high likelihood scenario has been identified as almost certain to occur based upon available recent climate observations. The 2030 Low scenario approximately matches current global trends in eustatic sea level rise supported by local tide gauge data, the 2030 Low scenario would appear almost certain to occur. By definition, larger confidence level scenarios would be less likely to be exceeded. It has been assumed here that simple increments of likelihood can be applied to this 'base' case, both along the vertical axis of low to high scenarios and horizontal axis of one and two standard deviations of natural climate variability for both wave energy and mean annual water level (Table 31). In this context, one standard deviation above average for both wave energy and mean water level represents a situation that has been exceeded once over the last fourteen years. Consequently, it is estimated that this represents a 1 in 10 year sustained event in the present climate. Two standard deviations above average for both wave energy and mean water level is estimated to be a 1 in 100 year sustained event.

The relative difference in probability between the different climate scenarios, or the climate variability, is likely to vary in response to coast type and configuration. When interpreting the relationship between vegetation line change and climate variations, it is also recognised that the shoreline change records typically respond only to stormy conditions, with several years of recovery following. Consequently, the "Zero SD" climate effectively includes moderate storm conditions, estimated to correspond to 3 - 5 year Average Recurrence Interval (ARI) events.

Table 30: Likelihood scale for Cottesloe Vulnerability Assessment

Scenario	+ Zero SD	+ 1 SD	+ 2 SD
Low	Almost Certain	Likely	Possible
Medium	Possible	Unlikely	Rare
High	Rare	Extreme	Beyond extreme – not categorised

This table was presented to participants during Workshop II. The issue of likelihood subsequently generated a great deal of debate, especially as it related to the methods used to assess the relationship between standard deviations and likelihood for sand and rock coasts.

Following the workshop, the likelihood table was reviewed to select increments of natural variability. Two likelihood tables were then developed, one for rocky coasts and one for sandy coasts (Table 31 and Table 32). The different probability assigned to each type of coast is a response to the methodology of how the sensitivity analysis was applied to sandy coasts rather than any real difference in probability. More specifically, the calculation of change on sandy coasts is considered to follow a more conservative approach. In this respect, the probability for each type of coast is based on responsiveness of the shore.

It is further noted that the selection of the most variable profile within a zone to represent change may effectively exaggerate the likelihood of occurrence. In the event that only one third of a zone is highly susceptible to change, the likelihood may be exaggerated by a factor of three. However, in general, variability between profiles was moderate and would not have such severe effect on likelihood.

Table 31: Likelihood for rocky coasts

Scenario	+ Zero SD	+ 1 SD	+2 SD
Low	Almost Certain	Likely	Possible
Medium	Likely	Possible	Unlikely
High	Possible	Unlikely	Rare

Table 32: Likelihood for sandy coasts

Scenario	+ Zero SD	+ 1 SD	+2 SD
Low	Almost Certain	Possible	Rare
Medium	Likely	Unlikely	Beyond rare – not categorised
High	Possible	Rare	Beyond rare – not categorised

4.3.3. Risk Prioritisation

Risks were rated and prioritised after consequence and likelihood were establishing. The risk results were formulated through:

- Recording the consequence rating for each zone under each scenario, as generated through the key element assessment (Table 28 and Table 29), then;
- Aligning consequence and likelihood, following the risk priority matrix as established at Workshop 1, to determine the levels of risk.

Note that the likelihood is presented in the header column against each climate change scenario. The final results are presented in Table 33, Table 34, Table 35 and Table 36.

Table 33: 2030 Results: Sandy Coast

Zone	Item	Almost Certain (2030L)	Likely (2030M)	Possible (2030H)	Rare (2030H +1SD)
Z1S	Consequence	Minor	Moderate	Major	Catastrophic
	Risk	Medium	Medium	High	Medium
Z3S	Consequence	Minor	Minor	Moderate	Major
	Risk	Medium	Medium	Medium	Medium
Z4S	Consequence	Minor	Minor	Moderate	Catastrophic
	Risk	Medium	Medium	Medium	Medium
Z5S	Consequence	Minor	Minor	Minor	Catastrophic
	Risk	Medium	Medium	Low	Medium
Z6S	Consequence	Minor	Moderate	Moderate	Catastrophic
	Risk	Medium	Medium	Medium	Medium

Table 34: 2030 Results Rocky Coasts

Zone		Almost Certain (2030L)	Likely (2030M)	Possible (2030H)	Unlikely (2030H +1SD)
Z1R	Consequence	Insignificant	Insignificant	Minor	Moderate
	Risk	Low	Low	Low	Low
Z2R	Consequence	Minor	Minor	Moderate	Catastrophic
	Risk	Medium	Medium	Medium	High
Z4R	Consequence	Insignificant	Insignificant	Minor	Moderate
	Risk	Low	Low	Low	Low
Z7R					
Z8R	Consequence	Insignificant	Insignificant	Moderate	Moderate
	Risk	Low	Low	Medium	Low
Z9R	Consequence	Insignificant	Insignificant	Insignificant	Insignificant
	Risk	Low	Low	Low	Low
Z10R	Consequence	Insignificant	Minor	Minor	Major
	Risk	Low	Medium	Low	Medium
Z11R	Consequence	Minor	Minor	Minor	Moderate
	Risk	Medium	Medium	Low	Low
Z12R	Consequence	Insignificant	Insignificant	Minor	Moderate
	Risk	Low	Low	Low	Low

Table 35: 2070 Results: Sandy Coast

Zone		Almost Certain (2070L)	Likely (2070M)	Possible (2070H)	Rare (2070H +1SD)
Z1S	Consequence	Major	Catastrophic	Catastrophic	Catastrophic
	Risk	Extreme	Extreme	High	Medium
Z3S	Consequence	Moderate	Major	Catastrophic	Catastrophic
	Risk	High	Extreme	High	Medium
Z4S	Consequence	Moderate	Catastrophic	Catastrophic	Catastrophic
	Risk	High	Extreme	High	Medium
Z5S	Consequence	Moderate	Catastrophic	Catastrophic	Catastrophic
	Risk	High	Extreme	High	Medium
Z6S	Consequence	Moderate	Major	Major	Catastrophic
	Risk	High	Extreme	High	Medium

Table 36: 2070 Results Rocky Coasts

Zone		Almost Certain (2070L)	Likely (2070M)	Possible (2070H)	Unlikely (2070H +1SD)
Z1R	Consequence	Insignificant	Moderate	Major	Major
	Risk	Low	Medium	High	Medium
Z2R	Consequence	Moderate	Major	Catastrophic	Catastrophic
	Risk	High	Extreme	High	High
Z4R	Consequence	Minor	Moderate	Moderate	Catastrophic
	Risk	Medium	Medium	Medium	High
Z7R					
Z8R	Consequence	Moderate	Major	Catastrophic	Catastrophic
	Risk	High	Extreme	High	High
Z9R	Consequence	Insignificant	Insignificant	Insignificant	Minor
	Risk	Low	Low	Low	Low
Z10R	Consequence	Insignificant	Minor	Catastrophic	Catastrophic
	Risk	Low	Medium	High	High
Z11R	Consequence	Moderate	Moderate	Major	Major
	Risk	High	Medium	High	Medium
Z12R	Consequence	Insignificant	Moderate	Moderate	Moderate
	Risk	Low	Medium	Medium	Low

As an independent assessment of these results, the Town of Cottesloe Manager of Engineering Services was asked to examine change maps and subsequently rank consequences. This assessment confirmed the outputs produced by the Project team.

Finally, risk screening undertaken by the Project Team and the Cottesloe Chief Engineer subsequently confirmed that all levels of risk were to be considered for the purposes of this Project. The results presented here were used to inform adaptation planning, discussed further in Section 5 below.

4.4. Summary: Phase II

The key outcome of Phase II was a Risk Priority level for each Coastal Survey Zone (Tables 33-36). The Risk Priority level was established through review of (i) physical change, (ii) impacts of physical change on key elements and (iii) evaluation of impacts.

Physical Change

- Historical change was analysed against physical process data to understand system sensitivity.
- A model of geomorphic change was developed to assess impact of each climate change scenario.
- Physical change lines were developed to represent physical coastal change under each climate change scenario.

Impacts on Key Elements

- Key elements categories were established.
- The presence and absence of key elements in each Coastal Survey Zone was recorded.
- The impact of physical change lines on key elements was noted.

Risk Evaluation

- A percentage of total loss per zone or the total impact of climate change as a weighted percentage of the key elements was determined for each scenario

- Consequence was determined by evaluating the weighted loss of the zone against an arbitrary consequence scale, where consequence is measured against percentage loss.
- This 'consequence' rating was then evaluated on how likely it is to occur (likelihood) to give an overall **RATING OF RISK** per zone.
- Consideration of this information enabled identification of the **PRIORITY** given to each risk, in terms of a combination of the consequence and likelihood categories.

The Risk Priority derived through Phase II is the tool used to inform Risk Treatment, discussed in Phase III below.

5. Phase III: Treating the risk

A range of options available to treat the risks identified during Phase II was subsequently considered. This process involved an overview of the theoretical approach to risk treatment or adaptation planning as outlined by the AGO (2007) and considers its applicability in the Cottesloe context. In addition, the results of the Risk Treatment workshop held as a half-day working session with key Town of Cottesloe staff are also reported here. Following the workshop, results were evaluated in light of the production of a risk treatment plan. The aims of the plan were to clearly align overall roles, responsibilities and time frames for adaptation considering the key risk treatment measures previously identified.

5.1. Theoretical Approach

"Risks' in this context are the impacts on key elements along the Cottesloe foreshore and the likelihood that these impacts will occur under the range of climate change scenarios considered. Theoretically, the approach to treating these risks is based on their priority (low, medium, high, extreme).

Key questions to be addressed within any approach to risk treatment may be summarised as follows:

- What is the risk?
- How can we treat it?
- How can we decide which option is appropriate?
- Having decided on an option, what will this entail?
- Who is responsible for carrying out these tasks and when should they be carried out?

The AGO framework used to inform much of the approach adopted throughout this Project essentially operates in a strategic **'top down'** manner to address these questions. This involves consideration of the outputs from risk prioritisation to inform the selection of a broad range of adaptation options that could be implemented. Overriding options are related to discrete categories of risk priority (low, medium, high, extreme priority risks). Subsequently, the applicability of each option is assessed through a range of pertinent data and information sources to inform the decision making process. A relevant series of implementation measures are subsequently established in conjunction with an assignment of responsibility for discrete measures and timeframes for their completion Figure 22.

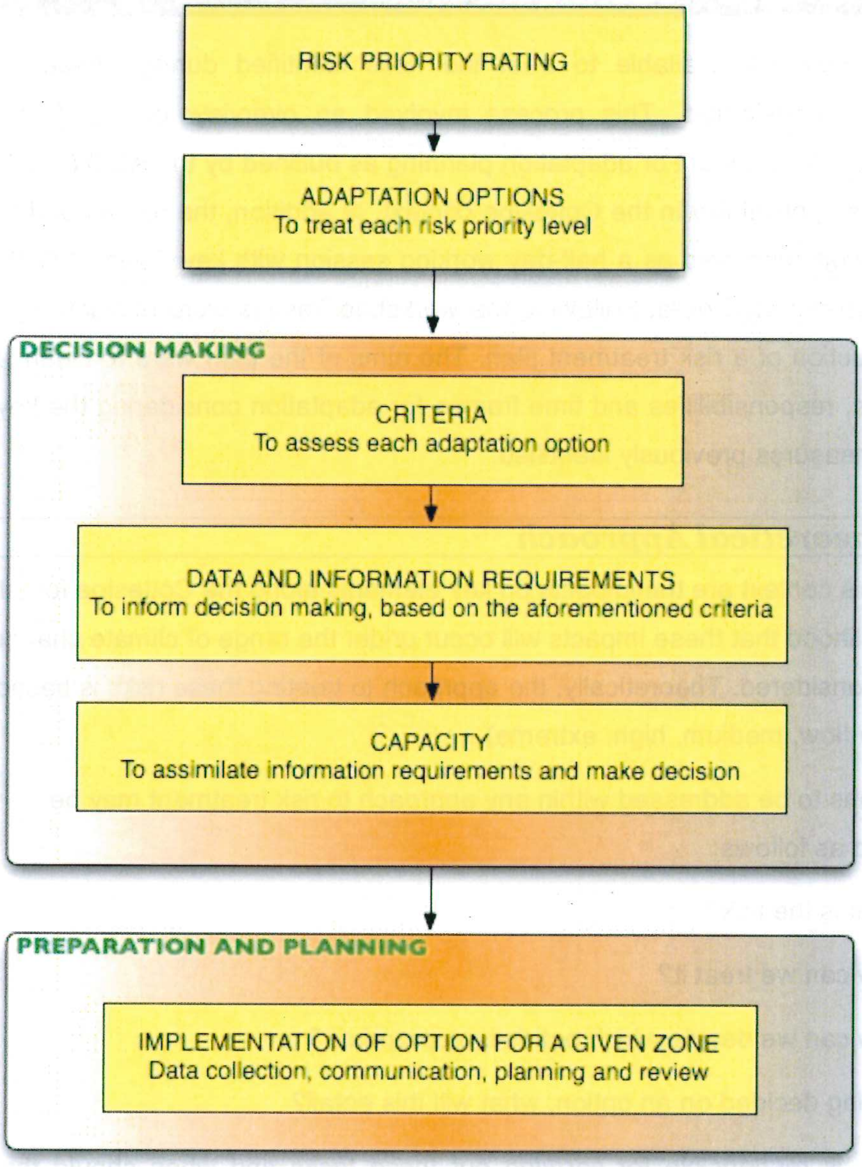

Figure 22: Top Down Model for Risk Treatment

5.1.1. Alignment of a top-down method with the current project

Underlying the top-down approach outlined above is the assumption that the risk prioritisation undertaken in Phase II is an adequate basis on which to focus the adaptation decision-making process. It is important to point out that this was an assumption adopted by the Project Team for the completion of the Risk Treatment Phase of this work. Constraints associated with this approach will be outlined in detail in the Limitations Section that follows (Section 6) in conjunction with recommendations for an improved approach for future coastal climate change risk studies.

The stages in the top-down process outlined in Figure 22 have been expanded and aligned with the specific objectives of the current project. The steps involved in this process are presented in Figure 23 along with the tasks associated with each key step.

- Step 1: Evaluate risk treatment options
- Step 2: Identification of specific actions to allow implementation of the treatment options evaluated in Step 1, at a range of scales.
- Step 3: Formulation of a risk treatment plan for the Town of Cottesloe.

Each of these steps will be outlined in further detail in the Sections that follow.

5.2. Evaluation of Risk Treatment Options

The range of possible options available to treat coastal climate change risks were considered in conjunction with how applicable these options would be in treating the discrete categories of risk priority, identified at the end of Phase II. The risk treatment types considered for this Project follow those outlined by AGO (2007) (Table 37).

Each treatment option was subsequently evaluated on the basis of specially formulated assessment criteria based on information from international and national climate change adaptation literature, including the UNDP adaptation policy framework, Queensland local government adaptation guide and the AGO framework followed throughout this Project (Table 38).

For example, it was assessed that research and education options are achievable with minimum budget constraints. Conversely, structural measures can face a number of barriers to implementation, in particular when considered from the perspective of budget and 'no regrets' criteria. It is also likely that there would be community opposition to structural solutions, albeit likely to have greater acceptance when the risk is extreme, for example when private property is threatened.

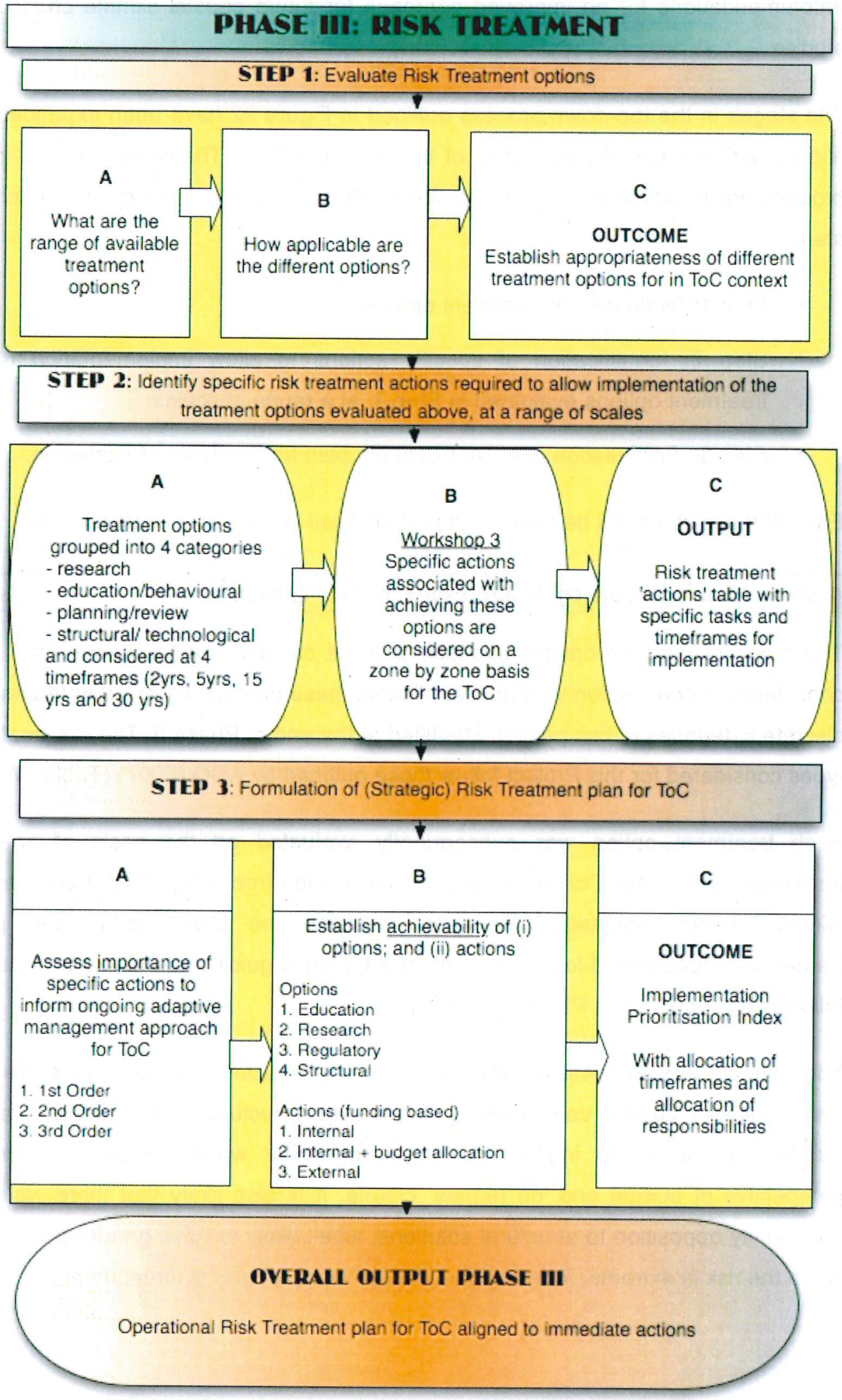

Figure 23: Approach to Phase III

Table 37: Risk Treatment Options

Treatment Type	Description and examples
Spread Risk	**Insurance and diversification strategies** - Use of financial products that off-lay the risk - Geographical diversification
Structural and technological	**Prevent effects through engineering solutions and changed practises** - Increase reserve capacity - Implement energy demand management measures - Scale up coastal protection measures - Change design of storm water systems - Build more resilient housing
Regulatory and institutional	**Prevent or mitigate effects through revised regulations and planning** - Adopt integrated planning approaches - Amend local planning schemes to give greater weight to erosion risk - Revise guidance notes for urban planners - Amend building design standards - Increase resources for coastal planning - Factor climate change into criteria for designation of species or ecosystems requiring increased protection - Improved contingency and disaster planning - Lengthen strategic planning horizons (from say 5-10 years to 20-30 years)
Avoidance	**Avoid or exploit changes in risk** - Migration of people away from high risk areas - Change location of new housing developments - Improve forecasting systems to give advance warning of extreme climate events
Research	**Research to improve understanding of relationship between climate change and risk** - Improve knowledge of relationship between past and present variations in climate and performance of economic, social and environmental systems - Improve modelling of regionally-based climate change impacts - Improve knowledge of the probability of frequency and magnitude of changes to extreme climate events and other climate variables under climate change - Improve understanding of the relationship between changes to frequency and magnitude of extreme events and critical thresholds for individual risks
Education/ behavioural	**Educate and inform stakeholders about the risks of climate change** - Increase public awareness about the potential impacts and adaptation measures - Educate and inform management and personnel about risks & adaptation measures

Table 38: Criteria for assessing adaptation options

Criteria	Description
No regrets	The option is beneficial in the absence of climate change
Statutory requirements	The option can take place without any policy or legislative changes
Community acceptability	Will measures will be amenable primarily to Rate Payers and secondarily to visitors
Budget	Council can pay for this itself within its existing budget
Cost benefit	The benefits of adaptation clearly exceed its costs (strategic estimate only)

5.3. *Identification of Risk Treatment Actions*

For the purposes of the Risk Treatment Workshop, the range of potential risk treatment options relevant to Cottesloe were evaluated and grouped into four categories:

- Research
- Educational/behavioral
- Regulatory and institutional (planning)
- Structural and technological

Categories were derived from the review of risk treatment options presented above (Table 37). The categories 'Spread the Risk' and 'Avoidance', were not considered as viable options for the treatment of coastal climate change risks in the Town of Cottesloe and thus excluded from the analysis. The reasoning for this was related to the fully-developed nature of the coast at Cottesloe. As such, options that could be available for other Councils with undeveloped 'greenfield' coastal locations, were not considered available to the Town of Cottesloe.

In setting the context for the discussion on specific risk treatment options within given coastal survey zones for the Town of Cottesloe, the finalised categories were presented to participants at Workshop III for review and comment (Table 39).

Following the review of available options, timeframes for their implementation were developed. Expert judgement, based on a consideration of the range of options appropriate in the Cottesloe context, identified four overriding timeframes for implementation:

- Immediate (now – 2010) 2 years
- Short (2010 – 2015) 5 years
- Medium (2015-2030) 15 years
- Long (2030 – 2060) 30 years

Table 39: Examples of Risk Treatment Actions associated with overriding treatment options

Risk Treatment Options	Example Risk Treatment Actions
Research	Coastal change monitoring
	Scientific studies or reviews
	Geotechnical assessment
Education/behavioural	General community awareness campaign
	Targeted awareness campaign (specify groups and issues)
	Key stakeholder collaboration and awareness raising (to encourage planning and review)
Regulatory and institutional	Town Planning Scheme (TPS) policy review (internal process by Town of Cottesloe)
	Town Planning Scheme (TPS) review
	Disaster plan review
	Encourage: regional planning reviews
	Encourage: plan reviews of adjoining Councils
	Encourage: State or Federal planning & policy review
	Building standards review
	Infrastructure design standard review (e.g. upgrading of structures West of Marine Parade)
	Infrastructure design standard review (utilities)
	Develop storm response Reserve Fund that rolls over year-on-year
	Monitor insurance provisions of residents & business owners
Structural and technological	Scale up coastal protection measures
	Change design of storm water systems
	Build more resilient developments

The timeframes follow a logarithmic scale to encourage review of short-term timeframes at a finer resolution. Furthermore, this time division takes into account the sequential nature of tasks, where an immediate task may inform the implementation of a short or medium term task.

5.3.1. Workshop III Results

During the workshop session the specific actions associated with achieving these options were considered zone by zone under each of the above timeframes. Participants reviewed the physical change lines generated during Phase II to assess individual risks associated with key infrastructure elements and recorded these in worksheets similar to the template below (Figure 24).

	Immediate (now-2010) 2 years	Short (2010-2015) 5 years	Medium (2015-2030) 15 years	Long (2030-2060) 30 years
Research				
Educational/behavioural				
Regulatory and institutional (planning)				
Structural and technological				

Figure 24: Risk Treatment Table Template

Upon review, participants assigned risk treatment actions to timeframes for implementation. Overall, the output from Workshop III was a summary of the range of actions associated with each potential risk treatment category considered for the Town of Cottesloe, at a range of implementation scales (see Table 40) (complete workshop results are available in Appendix E). Commonly, the proposed actions to treat predicted climate change risk along the Cottesloe foreshore fell within the first two columns of the worksheet, indicating they were to be implemented in the immediate to short term. Although some adaptation actions were noted in the medium term, the implementation of these actions could only proceed through the completion of actions in the immediate to short term.

Overall, participants felt it was inappropriate to assign Risk Treatment actions in the medium to long-term without the knowledge that would be derived from immediate to short-term actions. Therefore, the actions outlined in the finalised worksheets promote an adaptive management approach, where the immediate to short-term actions inform the longer-term development of actions. This adaptive management approach is a 'learning-by-doing' approach to management. As new information is obtained, current management processes are reviewed, and new management methods are formulated (Kay and Alder 2005). Key findings from the workshop as they relate to discrete adaptation options are summarised below.

Table 40: Workshop II Adaptation Actions and Timeframes for implementation

Adaptation Option	ID	Adaptation Action	Immediate	Short	Medium	Long
Research	A1	Write a letter to DPI regarding the existing beach monitoring program. Find out where Cottesloe fits in the program to ensure that it is included and to also ensure that the monitoring can be combined with the work to be undertaken under the Cottesloe monitoring program	X			
	A2	Develop partnership with local universities to encourage research in Cottesloe	X			
	A3	Establish Coastal Monitoring Program - that includes regular beach width monitoring and photographic monitoring. Records of photographic monitoring should be compiled with the historic photographic database. This will require insertion of benchmarks		X		
	A4	Write Terms of Reference for the completion of a 'Management Options' study with Town of Cottesloe. The study should present all options so that Council is informed prior to committing to a defence plan. Information on the type of options available and the anticipated effects of these options (changes to amenity and environment) should be outlined. May consider the realignment of the dual use path, and identifying sand sources to maintain beach amenity.	X			
	A5	Source funding for the completion of the 'Management Options' study	X			
	A6	Commission study to explore Management Options within Town of Cottesloe.	X			
	A7	Write Terms of Reference for Engineering Assessment on key infrastructure - for example, seawall in front of Indiana's teahouse	X			
	A8	Source funding for the completion of Engineering Assessment of key infrastructure	X			
	A9	Commission study to review existing defence structures. This will inform additional management actions, where required.	X			
	A10	Ensure that there is regular review of existing and potential technology that may increase information and aid decision-making. For example, underground radar technology or seismic techniques may be used to locate rock rather than exclusive-use of drilling.	X	X		

Adaptation Option	ID	Adaptation Action	Immediate	Short	Medium	Long
	A11	Request detailed geotechnical information from service providers in format suitable for review and analysis in council	X			
	A12	Review geotechnical information and establish information gaps and needs	X			
	A13	Develop Terms of Reference for Geotechnical works along the Cottesloe Foreshore	X			
	A14	Source Funding for Geotechnical works along the Cottesloe Foreshore	X			
	A15	Commission Geotechnical investigations along Cottesloe foreshore	X			
Education/behaviour	B1	Present outcomes of the study to key stakeholders; ie surf life saving club, WAPC/DPI, Indiana's, Utility providers and representatives from other Local Government Authorities	X			
	B2	Write a letter to Watercorp requesting information on the implications for council if their facilities are damaged - in particular the sewerage line.	X			
	B3	Continue dialogue with Service Providers to develop 'shared care' approach to the management of the impacts of climate change on key services within Town of Cottesloe	X			
	B4	Initiate dialogue with Coastcare. There needs to be recognition from a Coastcare perspective that there will be increased pressure on providing stabilised dunes.	X			
	B5	Initiate Regular Meetings/conference with key agencies to foster the creation of expertise (to enable council to undertake some of the required technical works) and to build relationships with other agencies to share information. The aim is to build local knowledge and expertise.	X			
	B6	Request LEMAC (in writing or at meeting) to undertake an emergency management scenario in Cottesloe	X			
	B7	Request information on the step-by-step actions that would be required in a disaster situation. For example, evacuation measures, informing businesses of risk etc	X			
	B8	Undertake desktop scenario of potential climate change impacts on Town of Cottesloe and ensure outcomes of practice are incorporated into the disaster response plan		X		
	B9	Review options to disseminate results of the current study to the community	X			

Adaptation Option	ID	Adaptation Action	Immediate	Short	Medium	Long
	B10	Develop information dissemination plan for the delivery of current study information to the community	X			
	B11	Create Community Awareness program – envisioned as a 5 year plan. Information and awareness raising for: the outcomes of the current research (Phase I); the importance of monitoring aiming for volunteer support (Phase II); the outcomes of the management review		X		
Regulatory and institutional	C1	Review Utility forward plans (i.e. Watercorp) at regular intervals to ensure that they are addressing the potential effects of climate change	X			
	C2	Review insurance coverage of council facilities	X			
	C3	Review natural areas management plan to ensure that it incorporates the potential effects of climate change. This will inform management efforts (i.e. shift effort, abandon effort or increase effort).		X		
	C4	Initiate request for coastal protection plan and supporting materials (a guide to defence works - a manual of proven techniques)	X			
	C5	Develop Management, Protection, Plan for the Cottesloe Foreshore - this action is linked to the outcomes of 'Research" actions		X		
	C6	Ensure that the disaster response plan is adaptively managed. Review plan annually to ensure response options incorporate current climate change information	X			
	C7	Initiate dialogue with the State government to ensure that there is action towards new policy and planning regimes that include a 'defendable line'	X			
	C8	Continue dialogue with State government to review progress towards developing a coastal protection plan. A policy is in place but there is no plan. The plan should include sufficient detail to initiate detailed design		X		
	C9	Modify council planning approval process to incorporate a requirement for geotechnical information for developments close to the shore to be provided to Council	X			
	C10	Initiate dialogue with key stakeholders to facilitate the development of Memorandums of	X			

Adaptation Option	ID	Adaptation Action	Immediate	Short	Medium	Long
		understanding for data sharing				
	C11	Develop Memorandums of Understanding with key stakeholders. Aim is to ensure that the geotechnical data, which is collected by State and others, is fed back to council effectively.		X		
Structural	D1	Design new low cost and relocatable coastal access pathways and dune fencing		X		
	D2	Consider new alignment of the dual use path			X	
	D3	Review defence works for valuable infrastructure			X	
	D4	Review the applicability of the toe revetment as a management tool in southern zones		X		
	D5	Install defence works in southern zones (Zones 8-12) that are known to be successful (toe revetment)			X	
	D6	Consider identification of sand sources to maintain beach amenity	X			
	D7	Undertake engineered management works based on outcomes the 'Research' and 'Regulatory and Institutional' actions			X	

Research

A key priority for the Town of Cottesloe is to gather information on the location of subsurface rock. This information is required to enable a more accurate appreciation of the impacts of projected climate change scenarios. Currently, only two survey zones have been modelled as rock and sand shore types. This provides an appreciation of the difference between impacts on rock and sand shores. However, it is anticipated that many of the Coastal Survey Zones modelled as sand are supported by subsurface rock. Knowledge on the location of subsurface rock would enable the Town of Cottesloe to select appropriate adaptation options and prioritise their implementation.

A number of actions to achieve this objective were suggested during Workshop III. The preliminary task is to determine what geotechnical information currently exists for the Town of Cottesloe. Therefore, the agency likely to hold this information will be contacted. Upon review of the information gathered, Terms of Reference will be developed to apply for funding to complete geotechnical assessments, where required. The ultimate outcome is to gather geotechnical information for the length of the Cottesloe foreshore.

Education/ behavioural

A given adaptation option can have significant social and environmental implications. It is important that social and environmental implications associated with risk treatment options are known and communicated to key stakeholders. In this respect, partnerships with key stakeholders (i.e. service providers and local community) are vital. During Workshop III, the following information dissemination and education requirements were noted:

- Providing community information to increase social acceptance of the potential management changes required.
- Gaining information on community perception of different management approaches, to inform implementation.
- Informing service providers and State government stakeholders of the outcomes of this study as a preliminary action towards generating partnerships to deal with the impacts of climate change.

Actions identified to achieve these objectives included the development of a five-year community consultation plan, with the primary action of disseminating the results of this study to the local community. Further, written communication and information sharing workshops were recommended to open communication channels between Local government, service providers and the State. Increased communication will ensure clarity can be gained on the recommended Risk Treatment options and outline the agencies responsible for their implementation.

Regulations and Institutions

To ensure effective climate change adaptiation, planning and policy reviews are required at Local and State government levels. A review and development of specific planning guidelines will inform the selection of Risk Treatment options within the Town of Cottesloe. Thus, a priority action is to develop a coastal management plan for the Town of Cottesloe. The plan would incorporate a review of different structural management controls (both hard and soft). Primary actions to ensure the development of this plan include: sourcing information on the management controls appropriate for the Town of Cottesloe; initiating dialogue with Coastcare and Swan River NRM; and review the Town of Cottesloe Natural Areas Management Plan.

State government policy informs planning and management at the Local government level. Therefore, its was stressed the Western Australian State government develop plans and policies for climate change adaptation, to enable Local government to make informed and supported decisions. Although Local Government cannot directly contribute to the development of new State policy, it can undertake a number of actions to facilitate development. Such actions identified through the Workshop included: establishing communication channels with the State government to promote policy review and the development of plans; and promoting meetings or conferences to foster the creation of expertise and build relationships.

Structural Solutions

Structural solutions are not strongly advocated in the Risk Treatment Plan. This is largely due to the information constraints shaping the ability to make an informed decision on the selection of an appropriate Structural Risk Treatment Option. Despite this, it was recognised that Structural solutions would likely be required in Zones 3 and 6, as a priority. However, a decision on the selected treatment option will follow a review of the outcomes of the immediate and short-term actions; namely the outcomes of the community awareness program (concentrating on community perceptions of different management options), and the development of a management/protection plan for the Town of Cottesloe.

5.4. *Operational Risk Treatment Plan for Town of Cottesloe*

Workshop III produced a series of actions aligned to overall risk treatment options at a range of timescales. The adaptation actions specified through the workshop were, in general, focused on immediate and short-term implementation scales. Consideration of this information highlighted the adaptive and iterative nature of the implementation process. That is, actions carried out in immediate to short timeframes were viewed as a pre-requisite to inform ongoing actions relating to risk treatment in the medium and long term.

In light of this, subsequent analysis carried out by the Project Team attempted to add a further level of detail to the broad sale adaptation plan produced in the workshop setting. This was done by outlining an operational risk treatment plan for Town of Cottesloe for implementation within an 'immediate' timeframe. This plan is intended to act as a guide for key council representatives to initiate the process of climate change risk adaptation towards more focused and targeted site-specific treatment of risks in the future.

The plan itself should be reviewed annually. Upon review, an implementation prioritisation activity (as undertaken here) can be completed for the subsequent 2-year, or 'short' time period.

5.4.1. Implementation Prioritisation Index

As outlined above, the adaptive approach or 'learning-by-doing' approach involves a review of the outcomes of a specific action, in order to inform subsequent actions. In this respect, there are a number of preliminary actions that can be undertaken by the Town of Cottesloe presently that will inform subsequent action and planning in terms of risk treatment over the coming 2 years.

In light of this, the relationship between tasks and their importance in terms of informing an ongoing adaptive management approach for Town of Cottesloe was reviewed along a three stages.

- Stage 1 actions 'establish the baseline' or 'set the context'. These actions are required to gather information on existing data; policy and/or planning that will inform adaptation within the Town of Cottesloe.

- Stage 2 actions analyse and review this information and set the steps towards developing implementation plans or follow up tasks that will achieve the final objective. For example, the development of Terms of Reference to commission works in areas where the review has shown limited information is available.
- Stage 3 actions meet the final objective. For example, undertake geotechnical works.

Outcomes of the review of the relationship between tasks and their overall sequencing in an adaptive management approach are presented in Table 41. The ID numbers within the table relate to the Risk Treatment action IDs assigned following the workshop (Table 40).

Table 41: The order in which risk management actions are to be completed by Town of Cottesloe to inform an adaptive management approach

Objective	STEP 1	STEP 2	STEP 3
Establish Monitoring Program	Al	A2	A3
Develop Management Plan	C4, C2, B4	A4, A5, C3	A6, C5
Review Stability of Existing Infrastructure		A7, A8	A9
Complete Geotechnical Assessments	A10, A11, C10	A12, A13, A14, C11, C9	A15
Establish Collaborative Partnerships	B1, B2, C1, C10	C11, B3	B5
Maintain Community Awareness	B9	B10	B11
Encourage State Government Planning	C7	C8	
Update Emergency Management Procedures	B6, B7	B8	C6
Implement Structural Options	B11,C5	D1	D7

NOTE: the table above reviews ALL adaptation actions, not only those in the immediate timeframe.

Implementation of achievability was assessed following a review of the 'importance' of each action in informing adaptive management. Overall achievability associated with an adaptation ***option*** was quantified in Step 1 of the current work phase (Section 5.2), using the criteria outlined in Table 38. Specific ***actions*** associated with each of the treatment options were further evaluated on the basis of budget considerations, given overriding importance to the financial capacity of the Town of Cottesloe for their implementation.

Budget is broken into three categories for the purposes of this assessment:

1. Can be completed by Council within current capacity and budget allocation
2. Can be competed within Council but requires additional resourcing
3. Requires external assistance

Commonly, the adaptation tasks identified through the workshop process do not fall under one of the discrete divisions above (i.e. *Council Capacity* or *External Assistance*). Rather, in many cases preliminary work towards the achievement of an adaptation action can be initiated in council within the current budget. However, there are additional tasks required towards completion of the adaptation action that may require further council budget or external support.

Values attributed to the importance of actions, overall achievability associated with each option and the specific achievability of a given action from a financial perspective, were subsequently evaluated to produce an overall ***Implementation Prioritisation Rating***. This rating informed the sequence in which the range of 'immediate' timeframe, risk treatment actions, should be carried out by the Town of Cottesloe. The final output is presented in Table 42. The timeframe associated with each action has been shaded: as follows:

- 3-4 = 0 to 3 months (white)
- 5-6 = 3 to 12 months (Dark grey)
- 7-9 = Over 12 months (Light grey)

Categories	ID	Task	Importance	Option	Action	Implementation prioritisation index
Research	A1	Write a letter to DPI regarding the existing beach monitoring program. Find out where Cottesloe fits in the program to ensure that it is included and to also ensure that the monitoring can be combined with work under the Cottesloe monitoring program	1	2	1	4
	A2	Develop partnership with local universities to encourage research in Cottesloe	2	2	1	5
	A4	Write ToR for the completion of a 'Management Options' study with ToC. The study should present all options so that Council is informed prior to committing to a defence plan. Information on options and the anticipated effects of these options (changes to amenity and environment) should be outlined. May consider the realignment of the dual use path, sand sources to maintain beach amenity etc	3	2	1	6
	A5	Source funding for the completion of the 'Management Options' study	2	2	1	5
	A6	Commission study to explore Management Options within ToC.	3	2	3	8
	A7	Write ToR for Enginnering Assessment on key infrastructure - for example, seawall in front of Indiannas teahouse	2	2	1	5
	A8	Source funding for completion of Engineering Assessment of key infrastructure	2	2	1	5
	A9	Commission study to review existing defence structures. This will inform additional management actions, where required.	3	2	3	8
	A10	Ensure that there is regular review of existing and potential technology that may increase information and aid decision-making. For example, underground radar technology may be used to locate rock rather than drilling.	1	2	1	4
	A11	Request detailed geotechnical information from service providers in format suitable for review and analysis in council	1	2	1	4
	A12	Review geotechnical information and establish information gaps and needs	2	2	1	5
	A13	Develop ToR for Geotechnical Works along the Cottesloe Foreshore	2	2	1	5
	A14	Source Funding for Geotechnical Works along the Cottesloe Foreshore	2	2	1	5
	A15	Commission Geotechnical investigations along Cottesloe foreshore	3	2	3	8
Education/ behaviour	B1	Present outcomes of the study to key stakeholders; ie surf life saving club, WAPC/DPI, Indiannas, Utility providers and representatives from other LGAs	1	1	2	4

	B2	Write a letter to the Watercorp requesting information on the implications for council if their facilities are damaged - in particular the sewerage line.	1	1	1	3
	B3	Continue dialogue with Service Providers to develop 'shared' approach to the management of the impacts of climate change on key services within Town of Cottesloe	2	1	1	4
	B4	Initiate dialogue with Coastcare. There needs to be recognition from a Coastcare perspective that there will be increased pressure on providing stabilised dunes.	1	1	1	3
	B5	Initiate Regular Meetings/conference with key agencies to foster the creation of expertise (to enable council to undertake some of the required technical works) and to build relationships with other agencies to share information. The aim is to build local knowledge and expertise.	3	1	3	7
	B6	Request LEMAC (in writing or at meeting) to undertake an emergency management scenario in Cottesloe	1	1	1	3
	B7	Request information on the step by step actions that would be required in a disaster situation. For example, evacuation measures, informing businesses of risk etc	1	1	1	3
	B9	Review the options available to disseminate results of the current study	1	1	1	3
	B10	Develop information dissemination plan for the devliery of current stiudy information to the community	2	3	2	7
Regulatory and institutional	C1	Review Utility forward plans (i.e. Watercorp) at regular intervals to ensure that they are addressing the potential effects of climate change	1	3	1	5
	C2	Review insurance coverage of council facilities	1	3	1	5
	C4	Initiate request for coastal protection plan and supporting materials (a guide to defence works - a manual of proven techniques)	1	3	1	5
	C6	Ensure that the disaster response plan is adaptively managed. Review plan annually to ensure repsonse options incorporate current climate change information	3	3	1	7
	C7	Initiate dialogue with the State government to ensure that there is action towards new policy and planning regimes that include a 'defendable line'	1	3	1	5
	C9	Modify council planning approval process to incorporate requirement for geotechnical information for developments close to shore	2	3	2	7
	C10	Initiate dialogue with key stakeholders to facilitate the development of MOUs for data sharing	1	3	1	5

Table 42: Operational risk treatment plan for Town of Cottesloe aligned to immediate treatment actions

5.4.2. Responsibility

The Risk Treatment Plan was developed in consultation with the Town of Cottesloe's Manager of Engineering Services, Mr Geoff Trigg. The Town of Cottesloe is managed across three key departments:

- Engineering Services
- Corporate Services; and
- Development Services

It was anticipated that adaptation measures would be assigned to each of these departments according to their respective roles and responsibilities. However, when aiming to align adaptation measures to key personnel responsible for implementation and review, Mr Trigg noted that he would be responsible for implementation of **all** adaptation measures. Therefore, all actions and measures developed and logged in the Risk Treatment Plan will be managed by him. It is anticipated that implementation may be undertaken through devolution of measures to staff within Mr Trigg's department or in consultation with other departments where required, for example, Development Services.

Protocols need to be established to enable adaptation measures to be managed across the whole of council. Such organisation-wide incorporation of climate change management objectives, also known as mainstreaming adaptation, is recognised as vital to the continuation of climate change adaptation across all spheres of local government responsibility, rather than the confined incorporation into coastal management, as developed in this Project. Initiation of such an integrated and mainstreamed approach to climate change adaptation for the Town of Cottesloe is beyond the scope of the current project. However, it should be considered as a key area for future work.

5.5. *Phase III Summary*

The range of options available to treat risk along the Cottesloe foreshore was considered during Phase III. These options were reviewed and evaluated according to pre-determined criteria, and actions required to achieve discrete measures were discussed in detail during the final workshop in the Project series. Although risk treatment actions were considered at a range of scales, a review of the workshop results indicated that the majority of those discussed, required implementation at short or immediate timeframes.

Subsequent to the workshop, a plan for the implementation sequence of immediate risk treatment actions was formulated. The Town of Cottesloe Manager of Engineering Services will be responsible for managing the implementation of these adaptation actions. These actions will be reviewed on a regular basis to ensure that the objectives of the task have been met. This review and implementation approach is an adaptive 'learning-by-doing' approach to management. Adaptive approaches recognise the uncertainties associated with predicting the consequence of actions under information constraints. Thus, they are integral towards the management of the potential effects of climate change.

In summary, the Plan outlined here is a preliminary framework for the implementation of an adaptive management approach to climate change adaptation for the Town of Cottesloe. The process will allow the Town of Cottesloe to anticipate and take advantage of change, whilst learning from the outcomes of management activities.

6. Constraints & Opportunities for Improvement

An important component of this Project has been the testing of a new approach to coastal V&A assessment in Australia at a Local Government scale. As such, the modification of the broad, strategic approach outlined by the AGO (2007) and application of the resulting framework used throughout this project, have highlighted several limitations. This Section of the report describes these limitations and the actions undertaken to address them.

A summary of constraints and the mitigation measures adopted by the Project Team is presented in Table 43. Each is explored briefly below, under the phase in which they occurred, followed by an overview of outstanding issues.

6.1. Constraints and Mitigation measures

At the commencement of the Project there was no recommended framework for local scale climate change Risk Assessment. There were a number of regional based vulnerability assessment frameworks available, but limited guidance on how to apply a regional assessment model to local government scale. Further, questions were raised as to whether a risk management framework or coastal vulnerability and adaptation assessment approach should be adopted. The resultant risk management framework adopted followed a top down approach to risk management and was focussed at broad scale climate change impact assessment. Therefore, the framework was modified to ensure that it incorporated coastal specific assessment processes.

6.1.1. Phase I

The lack of up-to-date climate information for the region was partially overcome with the publication of the CSIRO (2007) document that gave predictions of sea level rise and precipitation changes throughout the country. This information was used by the Project Team to estimate likely predictions for the Perth area.

Information from the CSIRO report was then considered from the perspective of the NCCOE (2004) matrix in an attempt to localize related impacts to process drivers within the study area. In particular, other elements like storm surge, wind climate and water level changes were considered.

Table 43: Constraints and opportunities

Preliminary Constraint	Mitigation Measure Adopted in the Project	Outstanding Issues	Strategies To Address Outstanding Issues
Approach			
Lack of frameworks for local scale climate change impact assessment	Review of frameworks for risk assessment and vulnerability assessment at a variety of scales, and a framework developed	Chosen framework applies broad scale climate change assessment approach, with limitations in application to at a site specific scale	A preliminary framework for a bottom up approach to CC adaptation has been discussed here. However, this framework requires refinement before application to subsequent studies.
Phase I			
Scenarios not at applicable scale for assessment.	Partially overcome by publication of the CSIRO (2007) document. This information was used by the Project Team, together with the NCCOE (2004) framework supplemented by expert Peer Review, to localise process drivers within the study area.	Could only apply timeframes used in the CSIRO report (2030 and 2070). Could not apply 2100, as would have been desired by the Town of Cottesloe. *CSIRO (2007) failed to address key local drivers of coastal change, including the wave climate, storminess and land-sea breeze circulation.*	IOCI-Phase 3 proposed to develop improved regional scenarios for Western Australia, including wave climate.
The relationship between terminology and final outputs was difficult for participants to see early in the process. This may have impacted the applicability of the chosen criteria and terms for the assessment	Workshop process to ensure as much stakeholder involvement as possible.	Timing of the criteria selection activities and population of risk priorisation matrix within Phase I not conducive to fine scale risk treatment planning	It is suggested that future studies of this kind adopt an amended approach that considers the priorisation of risks at the outset of Phase III.
Phase II: There are three components to Phase II; (i) physical coastal change, (ii) impacts on key elements, and (iii) risk assignment and evaluation. The limitations within each are discussed in turn			

Preliminary Constraint	Mitigation Measure Adopted in the Project	Outstanding Issues	Strategies To Address Outstanding Issues
Physical coastal change			
Shoreline change analysis error prone	Supplement shoreline change analysis with historical beach photograph record and review of historical reports	To improve analysis methods, there is the need for detailed in situ beach profiles along the shoreline at regular timeframes. Best practise would be a nested monitoring plan, with monthly beach width measurements, in conjunction with monitoring prior to after extreme events.	Implementation of local monitoring plan (Risk Treatment action for the Town of Cottesloe)
Lack of site specific data for process drivers	Data from applicable monitoring systems used in analysis		
Perth specific climate change scenarios do not include some key processes, including wave conditions and storminess	Downscaled from CSIRO report and supplemented with coastal specific data	No Perth specific climate change scenarios	To be developed through IOCI-3
Available geomorphic models of coastal change have not been validated for Western Australian coasts	A model developed for the purposes of this study – specific to Cottesloe only	Geomorphic models specific to Western Australia and validated for WA conditions are required	To be developed through WAMSI node 6.1
Predicted change lines incorporate error	The error is made explicit through the project.	Could only be addressed through the availability of site specific data: process data, coastal change data, scenarios and geomorphic model	To be collected and analysed for a series of case studies around the country funded by Dept. of Climate Change. However, should be focused at site-specific scale on as-needs basis in the future.
Impacts on Key Elements			
When establishing key element categories there was disagreement between stakeholders.	An agreement was reached during the workshop process	Key element categories were deemed inappropriate during the final risk treatment phase (Phase III)	The allocation of key elements should be carefully considered on a case-by-case basis for future projects keeping in mind what will ultimately form the basis of the risk treatment/risk prioritisation exercise

Preliminary Constraint	Mitigation Measure Adopted in the Project	Outstanding Issues	Strategies To Address Outstanding Issues
Baselining the 'amenity' key element from aerial photography was subjective	Recorded rationale for the inclusion or exclusion of each amenity category per zone to ensure transparency	The use of amenity as a key element category should be reassessed	
When baselining key elements a decision had to be made on the methods to record elements.	A presence versus absence approach was adopted.	This approach excludes record of the 'amount/level' of key element present in each zone. When recording key element loss under different climate change scenarios, there was no record of the 'amount' of loss, just whether loss occurred or not Packaging up the information in categories meant that a degree of information was lost in the process.	Develop a new approach that operates from a more 'bottom-up' perspective to address these problems
When defining boundaries for the key element 'environment', questions were raised as to whether these should be included as key elements. The argument was that they were encompassed in the assessment of physical change and therefore were the drivers of the impacts on key elements	Boundaries for the environment key element were delineated: i.e. beach, foreshore and dune. Their validity as a key element was noted, however, as stakeholders saw this as an important aspect for the Town of Cottesloe (from Workshop I) it was kept within the study, with recognition that its value in the assessment would be reviewed on completion		Future assessments might find it beneficial to view environment as a DRIVER of change with regard to key elements from an organisational objective as opposed to an element against which the **consequences** of climate change impacts should be measured (i.e first order as opposed to second order impacts)
A decision had to be made on how to evaluate the impacts of physical change on key elements	A 'loss' versus 'no loss' approach was adopted. If a section of the road was impacted, roads were considered impacted for the purposes of assessment. Or more broadly speaking, any item impacted	There was no record of the percent loss per zone. Therefore 1 zone could loose 100 items and the other could lose 10 and they would both be attributed the same Loss.	

Preliminary Constraint	Mitigation Measure Adopted in the Project	Outstanding Issues	Strategies To Address Outstanding Issues
	by change was considered lost due to the fact that a management action would be required		
The decision on how to evaluate loss was particularly problematic for the amenity category due to the subjective nature of the category	Amenity was related directly to the presence or absence of infrastructure to assess its 'presence or absence'. For example, if there was no beach access, then all beach amenity was considered loss for the purposes of the assessment		
The evaluation of beach loss, as part of the environment category, was difficult	The 'beach' item was removed from the environment key element category, with only dune and foreshore 'loss' being measured.	Application of environment as a key element category due to its relationship with physical coastal change.	Develop an amended approach that explicitly addresses potential beach loss. However, this is linked with the need for enhanced models of coastal change discussed above.
Risk Evaluation			
The key elements had to be weighted to align to the success criteria. There was disagreement on the weighting used by the Project Team in Workshop II	An alternate approach was not available and Town of Cottesloe commented that they where happy to proceed with the Project Team approach	The alignment should requires review	See new approach notes
Lack of other guidance on methods to alignment consequence scale and value of key element loss	Scale developed by Project Team	There were problems with the scale applied, and these remain.	Review process – particularly the original definition of objectives and the selection of key elements
AGO approach assigned likelihood to scenarios, however post publication of IPCC Fourth Assessment Report, it was recognised that no scenario is more likely than another	Likelihood assigned to scenarios by using confidence intervals for SLR predictions, rather than the median. Also included natural variability as a 'factor of safety'	Use of conservative techniques within geomorphic model is likely to exaggerate likelihood.	Consider average of multiple profiles – assuming spatial connection along shore. Would require higher resolution change estimation.
Risk Prioritisation: aligning likelihood and consequence to generate a risk priority rating			
The risk prioritisation value did not provide the information required to	Additional prioritisation of Risk Treatment Actions was completed	The scale of the framework applied does not match the scale of the	The approach needs to be carefully directed such that collating the

Preliminary Constraint	Mitigation Measure Adopted in the Project	Outstanding Issues	Strategies To Address Outstanding Issues
develop Risk Treatment actions solely on the basis on the Prioritisation Value		assessment.	disparate elements of the study does not obscure the detail required to make informed decisions
Phase III: Risk Treatment			
Risk prioritisation undertaken in Phase II provides an adequate basis on which to focus the adaptation decision-making process	Acceptance of assumption but acknowledgement of associated limitations	See above – risk prioritisation	

6.1.2. Phase II

Sensitivity Analysis

Historical coastal change was assessed through shoreline change analysis. It is commonly recognised that there is error associated with the measurement of shoreline change from aerial photography. This error is often compounded through photogrammetric error (aerial photograph scanning and rectification), shoreline identification and digitisation. The temporal spacing between aerial photographs can also be problematic. Finally, there are recognised limitations in using the shoreline as a means of assessing coastal response. In light of these limitations, the shoreline change analysis was supplemented with detailed analysis of historical photographs and historical reports. It was assumed that the historical photographs were taken at periods when the Town of Cottesloe was required to undertake management works, i.e. following extreme events. There may have been additional events during the photographic record where photographs were not taken and thus information from such events was excluded from the analysis.

The outcomes of the sensitivity analysis are derived from aligning the historical analysis with process drivers. The process drivers applied in the analysis were not recorded in the field, but taken from the nearest suitable monitoring station. Further, in the absence of site-specific data throughout the whole historic period, the variability of the wave climate was inferred from a combination of direct wave observations, proxy data for storminess and modelled projections for ambient winds .

The simplified relationship assumed between historical change and process drivers likely contributed to conservatism within the subsequent analytical phases.

A more complete relationship between process drivers and coastal response could be established through a high frequency observation system, such as by photographic record or regular beach surveys. This would enable the identification of the effects of individual storm events, shown to be significant from the historical records of coastal management.

Geomorphic Modelling

Predicted coastal change was determined through combining the results of the sensitivity analysis, with scenarios for climate change, through a geomorphic model.

The climate change scenarios applied in the analysis were obtained from Perth specific scenarios developed by CSIRO (2007). For the purposes of this analysis, the NCCOE (2004) framework was fostered, where local climate data was incorporated within the predictions of change .

There is presently no geomorphic model specifically developed and validated for the conditions occurring widely through south-west Western Australia. These include micro tides, low wave energy, reef shelter, rocky shore platforms and high carbonate sediment coast. The Bruun Rule has been widely applied to predict shoreline change (Jones & Hayne 2002; MP Rogers & Associates 2005). However, the prevalence of rock shore platforms and dominance of alongshore sediment controls restricts the viability of the Bruun Rule application to southwest Western Australia (van Rijn 1998; Pilkey *et al.* 2003). Local shoreline change observations were used to develop a site specific model for this study to overcome this issue.

Predicted change

The predicted change lines therefore contain several sources of uncertainty, derived from the aforementioned analytical process. This creates a variable risk profile along any given line. However, the analysis has focused on 'hot spots' or 'maximum areas of change' in a zone. In this respect, the predicted change can be seen as a conservative estimate, where the maximum is modelled rather than the mean. The use of a conservative model has been adopted to cater for those areas that may be at greater risk. Development of a more refined model would likely enable equivalent lines shoreward of the lines presented here.

Further, predicted change was represented through rudimentary lines drawn relative to the existing shoreline. These lines indicate a maximum extent of erosion within the timeframes, as it is recognised that shoreline retreat is not uniform across a reach. Consequently, the likelihood associated with 'impact' of these scenarios on infrastructure or amenity is exaggerated.

The approach taken throughout this analysis applied the best available technique to assess coastal change. The key limitations relate specifically to an absence of robust scientific understanding of perched beach systems, a lack of site specific, high-resolution profile and process data.

Risk Assessment

The outputs of the predicted coastal change were used to assess the level of risk on key elements. There were a number of issues arising through this process. In particular, the selection of key element categories and methods to assess impact. The key categories selected at the commencement of the process (Phase I) contained elements of ambiguity, particularly in relation to the 'amenity' key element. Further, a decision had to be made on how to evaluate impacts of physical change on key elements. This involved determining 'what constitutes a loss?' In this case, any item that was impacted by a physical change line was considered lost because a management action would be required. However, there was no record of the per cent loss, therefore one Zone could loose 100 items of infrastructure or amenity and the other could loose 10 and they would both be attributed the same Loss. This is a recognised limitation with the framework applied, where detailed information was collated for assessment purposes, but in the process information was lost.

Risk Evaluation

Difficulties were faced in aligning the results of the 'key element loss' to the success/consequence scale developed in Phase I. A consequence scale was developed to enable alignment. However, it is recognised that this approach should be reviewed in future assessments.

Risk Priority

Risk priority level is evaluated through aligning consequence and likelihood. The AGO (2007) framework assigns likelihood to climate change scenarios. However, since the publication of this report, the IPCC (2007) has reported that **NO** climate change scenario is more likely than another. Therefore, the likelihood component of the AGO (2007) framework was no longer directly applicable. Rather than exclude likelihood altogether, the Project team produced a likelihood scale that blended scenario confidence levels and natural climate variability. It was recognised that the relative difference in probability between the different climate change scenarios, or the natural climate variability, is likely to vary in response to coast type and configuration. Thus, two different likelihood tables were developed for each shore type. It was also recognised that the shoreline change records typically respond to stormy conditions, with several years of recovery following. Consequently, it was considered that shoreline changes associated with the "Zero SD" climate are likely to include typical response to 3 - 5 year Average Recurrence Interval (ARI) events.

6.1.3. Phase III

Underlying the top-down approach outlined adopted throughout this Project, is an acceptance that the risk prioritisation undertaken in Phase II provides an adequate basis on which to focus the adaptation decision-making process. To appreciate the implications of this assumption, it is necessary to reconsider the process to decide on categories for risk prioritisation adopted ***for this Project*** and the specific attributes of the risks that were assigned under each priority category.

The risk prioritisation proposed under the AGO approach had the following limitations:

- There was no spatial component to the prioritisation. Therefore each zone was treated as equal value.
- The compilation of ratings was problematic. There was no record of the 'amount' of loss within zones rather this was 'loss' or 'no loss'.
- Categories were not appropriate. All original key element items used in the assessment were not subsequently required.

Limitations relate to the detailed scale of the assessment undertaken here, rather than limitations to the framework as a broad scale tool for climate change Risk Assessment. The limitations were partially addressed in the current project through additional prioritisation of Risk Treatment Actions.

6.2. *Outstanding Issues and Opportunities for Improvement*

There are a number of outstanding issues that are largely related to the overriding framework advocated by AGO and employed by the Project Team. Where possible, opportunities for improvement have also been outlined in the Table 44. These measures relate to ongoing or planned research activities in Western Australia, or to operational recommendations formulated by the Project Team.

6.2.1. Ongoing and planned research activities

Data constraints faced during Phase II are currently being addressed under WAMSI node 6.1 and IOC-3. In particular, the development of a Western Australian specific geomorphic model to address the recognised limitations associated with application of the Bruun rule and the development of locally specific climate change scenarios.

6.2.2. Recommendations towards a Local Government specific framework for climate change Risk Assessment

On reflection, the assignment of categories for risk prioritisation in the Cottesloe context was potentially completed too early in the process to act as an effective basis on which to conduct risk treatment planning. This was partially addressed in the current project through additional prioritisation of Risk Treatment Actions. However, it may have been more appropriate to decide on the categories of risk priority following completion of the Risk Assessment phase. This would have allowed the opportunity to evaluate whether additional prioritisation categories were required.

When considering the specific objectives of the risk treatment and adaptation process, it became clear that the physical change-lines denoting the predicted extent and likelihood of shoreline recession were the key components necessary for Town of Cottesloe to undertake an assessment of individual risks associated with key infrastructure elements. In this respect, the bulk of the information produced at the conclusion of Phase II was essentially discarded in favour of simply assessing which key infrastructure elements were a) most important and b) most at risk within a given zone. This means that the prescribed process used in Phase II was not overly complicated for the prioritisation of risk as it relates to adaptation or risk treatment within the fine spatial resolution under consideration for this Project.

6.3. Summary

This Section of the report has reviewed the limitations associated with the methodology applied to complete this work, and the Project data constraints encountered by the team.

Key limitations associated with the AGO approach are summarised as follows:

1. The AGO approach on which this Project was based is a broad risk management framework that has not been formulated specifically for coastal applications.

2. When considering the complex relationships between form and process within a coastal zone, fine resolution information at both the spatial and

temporal scales is required. The incorporation and analysis of this information is not covered in the AGO framework.

3. Interpreting adaptive response requires a finer resolution of scale than the outputs of Phase II, Risk Assessment and Evaluation, enabled.

4. Through the Risk Treatment workshop, it was shown that the compartmentalisation of information was unnecessary, and hindered the selection of Risk Treatment options. Completing risk prioritisation subsequent to risk identification may have helped to address this issue.

5. Upon review of the outcomes it was clear that infrastructure was the key component/criteria under which impacts were evaluated. In light of this it appears that the process used for amenity ranking may be redundant.

Although formulation of an alternative approach is beyond the scope of this report, it is recommend that the limitations identified here be carefully considered and incorporated into an amended approach, in order to deal more specifically with detailed scale vulnerability assessments in the coastal zone. Overall, decision makers are now considerably better placed to further advances made thorough this Project that will build on the important work of the AGO (now the Department of Climate Change) and will hopefully complement ongoing attempts to devise optimum V&A approaches for coastal Local governments throughout Australia.

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9. References

Abuodha, P. A. and C.D. Woodroffe (2006), *International assessments of the vulnerability of the coastal zone to climate change, including an Australian perspective.* Report for the Australian Greenhouse Office in response to RFQ 116/2005 DEH. 69 pp.

Australian Greenhouse Office (AGO) (2007a), *Climate Change Impacts & Risk Management: A Guide for Business and Government,* report prepared for the Australian Greenhouse Office, Department of Environment and Water Resources, Commonwealth of Australia.

Australian Greenhouse Office (AGO) (2007b), *Climate Change Adaptation Actions for Local Government*, report by SMEC Australia to the Australian Greenhouse Office, Department of Environment and Water Resources, Commonwealth of Australia.

Boak, E.H. and I.L. Turner (2005), 'The shoreline detection-definition problem: a review', *Journal of Coastal Research,* 21 (4).

Bromirski, P. D., R. E. Flick, and N. Graham (1999), 'Ocean wave height determined from inland seismometer data: Implications for investigating wave climate changes in the NE Pacific', *J. Geophys. Res.*, 104 (C9), 20, pp. 753 – 20,766.

Bruun, P. (1962), 'Sea-level rise as a cause of shore erosion', *Journal Waterways and Harbours Division*, 88 (1-3), pp. 117-130.

Bryan, B, Harvey, N, Belperio, A & Bourman, B (2001), 'Distributed process modeling for regional assessment of coastal vulnerability to sea-level rise', Environmental Modeling and Assessment, vol. 6, pp. 57-65.

Cowell, P.J., B.G. Thom, R.A. Jones, C.H. Everts and D. Simanovic (2006), 'Management of Uncertainty in Predicting Climate-Change Impacts on Beaches', *Journal of Coastal Research* 22: pp 232-245.

Cowell, P.J. and Zeng, T.Q. (2003), 'Integrating uncertainty theory with GIS for modelling coastal hazards of climate change', *Marine Geodesy*, pp 26: 1-14.

CSIRO (2007) *Climate Change in Australia: Technical report 2007*, Commonwealth Scientific and Industrial Research Organisation, Canberra, 148pp

Finlayson, C.M., G.W. Begg, J. Howes, J. Davies, K. Tagi, and J. Lowry (2002), *A Manual for an inventory of Asian wetlands: Version 1.0*, Wetlands International Global Series 10, Kuala Lumpur, Malaysia.

De Vriend, H.J., M. Capobianco, T. Chesher, H.E. DeSwart, B. Latteux and M.J.F. Stive (1993), 'Approaches to long-term modelling of coastal morphology: a review', *Coastal Engineering* 21, pp. 225–269

England, P. (2007) *Climate Change: What are Local Governments Liable for?* Urban Research Program, Griffith University, Queensland.

Eliot MJ & Pattiaratchi CP (2007) Ocean Water Level Variability, BP Refinery, Kwinana. School of Environmental Systems Engineering, University of Western Australia & Damara WA.

Eliot,M., 2005. Storminess of the Fremantle Coastline 1898-2003. *Indian Ocean Marine Environment Conference*, Perth, 14 February 2005.

Eliot,M., 2005. Coastal Flooding in the Swan River Region. *WA Coastal Conference*, Busselton, 16-18 November 2005.

Eliot, IG, Saynor, MJ, Eliot, M, Pfitzner, K, Waterman, P & Woodward, E (2005), *Assessment and development of tools for assessing the vulnerability of wetlands and rivers to climate change in the Gulf of Carpentaria, Australia*, report prepared by the Environmental Research Institute of the Supervising Scientist and the National Centre for Tropical Wetland Research for the Australian Greenhouse Office, Canberra.

Galgano F, Douglas B & Leatherman S. 1998. Trends and Variability of Shoreline Position. *Journal of Coastal Research*. Special Issue No. 26. 282-291.

Global Environmental Modelling Systems Pty Ltd. 2005. *Tuvalu Wave Risk Study*. GEMS Report 29/04. Prepared for South Pacific Applied Geoscience Commission.

Hamilton LJ. 1997. Bibliography of Wind-Wave Data and Publications for the Coastal Regions of Australia. Defence, Science & Technology Organisation.

Harvey, N., T. Belperio, B. Bourman, and B. Bryan (1999), 'A GIS-based approach to regional coastal vulnerability assessment using Holocene geological mapping of the northern Spencer Gulf, South Australia', Asia Pacific Journal on Environment and Development, vol 6, pp. 1-25.

IOCI (2002) *Climate variability and change in southwest Western Australia*. Indian Ocean Climate Initiative Panel, 34pp

Jones, A.T. and M. Hayne (2002), 'Modelling coastal erosion at Perth due to long-term sea level rise', Proceedings of Australia's National Coastal Conference (Coast to Coast) – Source to Sea, Tweed Heads, pp. 225–28.

Kay, R. and Alder, J (2005) *Coastal Management and Planning*, 2nd Edition, Taylor and Francis, New York

Kay, R. C., I. Eliot and G. Klem (1992), Analysis of the IPCC Sea-Level Rise Vulnerability Assessment Methodology Using Geographe Bay, SW Western Australia as a Case Study. Coastal Risk Management International Ltd Report to the Department of Arts, Sports, Environment and Territories, Canberra: 24pp.

Kay R, I. Eliot, B. Caton, G. Morvell and P. Waterman (1996), 'A review of the Intergovernmental Panel on Climate Change's common methodology for assessing the vulnerability of coastal areas to sea-level rise', *Coastal Management*, 24 (2) pp. 165-188.

Kay, R.C. and J.E. Hay (1993) Possible future directions for integrated coastal zone management in the Eastern Hemisphere: a discussion paper. In: *Eastern Hemisphere Workshop on the Vulnerability Assessment of Sea Level Rise and Coastal Zone Management*, N. Mimura and R. McLean (eds). Intergovernmental Panel on Climate Change Regional Workshop, Tsukuba, Japan, 181-194.

Kay, R. and P. Waterman (1993), Review of the applicability of the common methodology for assessment of the vulnerability to sea level rise to the Australian coastal zone. In McClean, R. & Mimura, N. (eds) *Proceedings of the IPCC Eastern Hemisphere Workshop on Vulnerability Assessment to Sea Level Rise and Coastal Zone Management:* 237–248. Geneva: IPCC Secretariat/World Meteorological Organisation.

Klein, R.J.T. and R.J. Nicholls (1999), 'Assessment of coastal vulnerability to climate change', *Ambio*, 28 (2), pp 182-187

Lemm A. 1996. *Offshore wave climate, Perth, Western Australia*. Hons Thesis. University of Western Australia. Dept of Environmental Engineering.

Lemm A, Hegge BJ & Masselink G. 1999. *Offshore wave climate, Perth, Western Australia*. Marine & Freshwater Research, 50 (2), 95-102. (wave climate)

LGA Queensland (2007) *Adapting to Climate Change: A Queensland Local Government Guide*, Local Government Association of Queensland Inc.

Lu, X. (2006) Overview of Methodological Frameworks for Vulnerability and Adaptation Assessment, presentation to Consultative Group of Experts on National Communications from Parties not Included in Annex I to the UNFCCC (CGE), Hands-on Training Workshop on Vulnerability and Adaptation for Asian and Pacific Countries, 20~24 March 2006, Jakarta, Indonesia

McLean, R.F. (2000), *Australia's coastal vulnerability assessment studies: recent upscaling or downscaling?*, Proceedings of APN/SURVAS/LOICZ Joint Conference on coastal impacts of climate change and adaptation in the Asia-Pacific region, Kobe, Japan, November 14-16, 2000, pp. 29-33.

McLean, R. and Mimura, N. (eds.) 1993. Vulnerability Assessment to Sea Level Rise and Coastal Zone Management. Proceedings, IPCC/WCC'93 Eastern Hemisphere Preparatory Workshop, Tsukuba, Aug. 1993. Department of Environment, Sport and Territories, Canberra.

The National Committee on Coastal and Ocean Engineering (NCCOE) (2004) *Guidelines for Responding to the Effects of Climate Change in Coastal and Ocean Engineering*, Engineers Australia, pp 58.

Panizza V. 1983. *Westerly storms of the Perth metropolitan coast, Western Australia*. Hons Thesis. University of Western Australia, Dept of Geography.

Pattiaratchi CP & Eliot MJ. 2005. How our regional sea level has changed. Indian Ocean Climate Initiative. Climate Note 9/05.

Local Government Association of Queesland Inc (2001) Adapting to climate change. A Queensland Local Government Guide.

Riedel H & Trajer F (1978) Analysis of Five Years of Wave Data, Cockburn Sound. Proceedings of the Fourth Australian Conference on Coastal and Ocean Engineering, 8-10 November, 1978. (wave climate)

Sharples, C. (2007) *National Shoreline Geomorphic and Stability Mapping Project*, briefing paper prepared for the Australian Greenhouse Office of the Department of the Environment and Water Resources.

Sharples, C 2004, Indicative mapping of Tasmanian coastal vulnerability to climate change and sea level rise: explanatory report, Tasmanian Department of Primary Industries, Water and Environment, 126pp.

Steedman & Associates Pty Ltd. 1982. *Record of Storms, Port of Fremantle 1962-1980*. Report No. R112, Steedman & Associates, Perth.

Sydney Coastal Councils Group & NSW Environmental Defenders Office (2008) *Coastal Councils Planning for Climate Change: An assessment of Australian and NSW legislation and government policy provisions relating to climate changerelevant to regional and metropolitan councils*, a report prepared for the Sydney Coastal Councils Group by the NSW Environmental Defenders Office.

UNFCCC Climate Change Compendium [Online] Available from: http://unfccc.int/adaptation/nairobi_workprogramme/compendium_on_methods_tools/items/2674.php

Western Australian Planning Commission (2003). Coastal Planning Policy. Statement of Planning Policy SPP2.6.

Woodroffe, C.D. and R.F. McLean (1993), *Cocos (Keeling) Islands: vulnerability to sea-level rise*. Report to the Department of Environment Sports and Territories, Canberra.

Appendices A-G Provided on Attached Data CD