ECONOMIC ANALYSIS

Coastal Hazard Strategy for Townsville City Council [Pilot Project]

OCT 2012

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Queensland Government
City of Townsville
LGAQ
Australian Government
Department of Climate Change and Energy Efficiency

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Table of contents

Table index

Figure index

Attachments

1. Introduction

1.1 Background

Queensland has a highly dynamic and complex coastal zone, featuring shallow coastal margins and complex estuary systems with significant exposure to coastal hazards, including erosion, storm tide inundation and long-term sea level rise. Many of Queensland's cities and towns are on the coast and are therefore particularly exposed to such hazards.

Climate change is expected to increase the frequency and intensity of these hazards along the coast. The Queensland State Coastal Planning Policies call for adaptation strategies for relevant coastal hazard areas to be reflected in local planning instruments.

GHD has been appointed by the Queensland Department of Environment and Heritage Protection (EHP) to prepare a Coastal Hazard Adaptation Strategy Study (CHAS) (the project) for Townsville as a pilot study to demonstrate how Queensland's coastal councils can better prepare their communities for projected sea level rise, storm tide inundation and erosion risks associated with climate change. The overall objectives of the project consist of three key stages:

1. To develop a compendium of coastal adaptation options suitable for the Queensland coast that Local and State authorities can utilise
2. To develop a CHAS for incorporation in Townsville City Council's (TCC) Planning Scheme, Infrastructure Plan, Community Plan and Financial Plan in close collaboration with key stakeholders and the Townsville community
3. To prepare a report of recommendations for updating the Queensland Coastal Adaptation Strategy Planning Guideline including a benefit-cost analysis methodology and best practice community engagement

This report provides an overview of the economic appraisal completed for the adaptation options considered and is a key supporting document to the Townsville CHAS.

1.2 Economic Appraisal

An integral part of the project is an economic appraisal of coastal hazard adaptation options developed for Townsville and surrounding coastal Localities. Economic appraisal focuses on assessing the merit of projects from the perspective of community wellbeing (as opposed to simply financial returns for private or public sectors). There are many different techniques available to assist decision makers in selecting projects with the greatest merit (see for example Rogers 2001). In the case of adaptation to climate change in coastal areas, the projects are the potential adaptation options under consideration in this study.

The most commonly used appraisal techniques are multi-criteria analysis (MCA) and benefit-cost analysis (BCA). While fundamentally, these approaches both seek to establish the relative social merit of options, the techniques and technical requirements differ significantly. MCA can require significant stakeholder input (to set criteria and weights), while BCA can require significant supporting research to quantify the scale of impacts and to understand the unit valuations of these impacts by the community. In short, BCA offers a greater level of sophistication, consistency and defensibility than MCA, but can take significantly more time, data, resources and technical understanding than can be at the disposal of some decision makers. Recognising these practical constraints – both for the pilot and for on-going use – GHD has adopted a methodology that combines the strengths of each assessment approach when determining the best adaptation options for implementation.

1.3 Development of Adaptation Options

1.3.1 Districts and Urban Localities

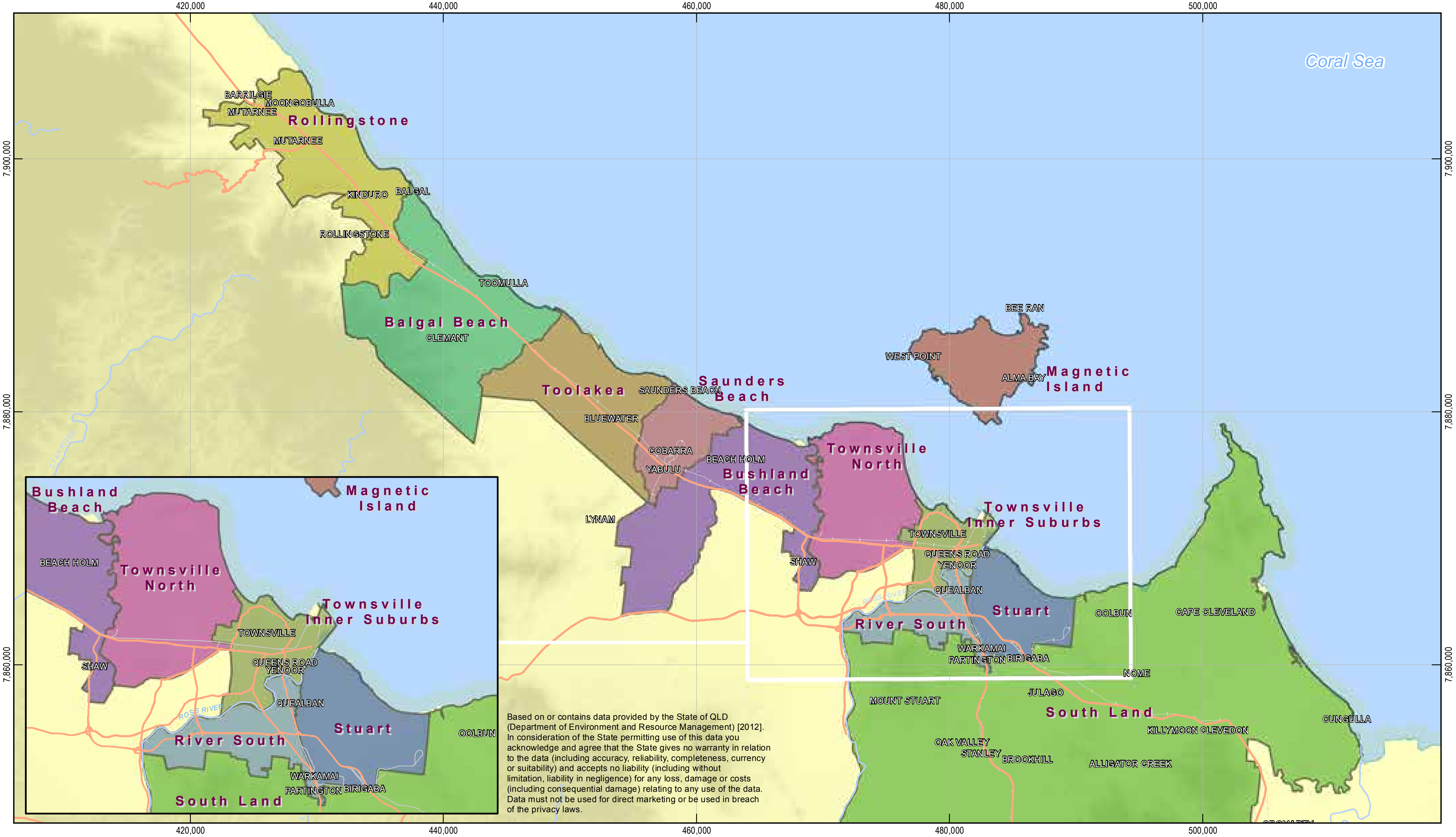
Coastal adaptation options have been developed for 11 separate coastal hazard districts (***Districts***) that in turn have been sub-divided into urban localities (***Localities***) which provide logical 'cells' for coastal protection and adaptation based on coastal morphology and existing TCC planning regions.

For the purposes of the strategy, a Locality is an area that is:

- Allocated as an urban footprint or rural living areas in a regional plan; or
- Zoned as urban or rural residential purposes in a local planning instrument equivalent to one of the standard suite of zones for urban development as under Queensland Planning Provisions (where there is no regional plan urban footprint) or
- An existing settlement or township (not designated as above).

At the request of TCC a number of key infrastructure items such as waste water treatment plants have also been assessed as part of the Townsville CHAS.

A summary of the Localities considered over the CHAS process is provided in the main body of the CHAS report and is thus not repeated here.



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0 2.5 5 10

Kilometres

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

N

- Watercourse
- Road
- Rail

TCC CHAS Districts

- Balgal Beach
- Bushland Beach
- Magnetic Island
- River South
- Rollingstone
- Saunders Beach
- South Land
- Stuart
- Toolakea
- Townsville Inner Suburbs
- Townsville North

Queensland Government

GHD

City of Townsville

Townsville City Council
Coastal Hazard Adaptation Strategy

Job Number	41-24069
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Coastal Hazard Districts in Townsville City Council

Figure 1

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Level 9, 145 Ann Street Brisbane QLD 4000 T +61 7 3316 3000 F +61 7 3316 3333 E bnemail@ghd.com W www.ghd.com

Data source: TCC/GHD, TCC CHAS Districts/2012. TCC, Rail/2011. GA, Watercourse © Copyright Commonwealth of Australia (Geoscience Australia)/2007. DERM, Place Names/2010, Elevation/2008. Created by:ihamilton

1.3.2 Defend, Accommodate, Retreat or Maintain Status Quo?

Coastal adaptation options have been developed for each Locality based on four broad strategies from the Compendium of Coastal Adaptation Options for Queensland Coastal Councils (the Compendium). These include either:

- **Defend:** Protect sectors of the coastal hazard area with either hard or assimilating coastal engineering structures to reduce[1] or remove storm tide inundation or erosion risks,**.** Defend strategies may include maintaining the existing use or intensifying development on the land. Coastal defence may combine long-term strategies for defence and maintenance including regenerative and structural options such as beach nourishment, dune construction, dykes and storm tide barriers.
- **Accommodate:** Maintain the current level of use within coastal hazard areas and raise the tolerance to periodic storm tide inundation or erosion events by means of innovative designs for buildings and infrastructure (e.g. elevating, strengthening or change in use). This entails undertaking actions that will reduce the impacts from coastal hazards to an acceptable level. Actions can generally be broken into two categories:
  - Works that will allow the current use to continue (e.g. upgrading drainage works and raising land levels when the existing use is redeveloped); and
  - Physical works and legislative amendments that provide for more appropriate future use of the land. For example changing the designated land use to one that can better tolerate the risk (e.g. rezoning land from residential to industrial use), or operational works to raise the height of developable land above the height of potential sea level rise.

  In the context of the Townsville CHAS, Accommodate has generally been defined as the construction of coastal protection works such as seawalls to reduce erosion due to increases in projected mean sea level, combined with improved flood resilience from storm tide by undertaking property raising in regions affected.
- **Retreat:** Includes actions to remove the assets at risk from the area impacted by the coastal hazard. This option could be achieved through various mechanisms such as relocating the community (e.g. through a land swap arrangement) or abandoning the area (e.g. through buy back mechanisms or rezoning the land to an open space or recreational use).

Maintain the Status Quo: Maintaining the status quo refers to a continuation of the existing use in an area while not supporting any further intensification of those uses. It does not restrict land owners from defending their own land (e.g. collaboratively with adjoining landowners) or accommodate the impact of coastal hazards. A decision to *Maintain* the *Status Quo* would necessarily be supported by actions such as:

- Planning scheme modifications (e.g. in the strategic framework) to reflect the decision not to intensify land use;
- Ongoing monitoring and review of hazards;
- Targeted public education on hazards;
- A hazard note on property searches;

[1] The current QCP requires immunity for the 100 y Return Period only. It is noted that water level events exceeding the 100 y Return Period are likely to occur during the study planning period 2012-2100.

- Regular review of the emergency plan of the Local and District Disaster Management Group, which recognises the changing risk profile;
- Regular update of the Council's infrastructure plan to reflect longer term intentions regarding services and infrastructure in the area as the risk profile changes; and
- Rates reduction of properties in the area.

A description of the adaptation options developed for each Locality for consideration in the Townsville CHAS is provided in the main body of the CHAS report and thus is not repeated here.

1.4 Option Evaluation Process

The economic analyses undertaken within this report represent the final stages of the adaptation option evaluation for the CHAS Pilot. Figure 2 provides an overview of where the economic assessment (comprised of the MCA and BCA) is placed within the overall CHAS decision process. An overview of each component of the option evaluation process is presented in Table 1 with further detail provided in Chapters 2 and 3.

Figure 2 Overview of the CHAS process. The MCA and BCA are based on the outcomes of a data gathering and consultation process between the project partners[2], TCC and external stakeholders.

[2] The project partners is made up of representatives from LGAQ, DEHP and GHD.

Table 1 Key Option Evaluation Milestones

Project Milestone	Date	Details
Project Workshop 1	(19/12/2011)	Approval of project economic methodology; Development of initial MCA criteria and weightings Discussion surrounding intent of CHAS
Internal GHD/TCC Adaptation Option Development Workshops	March 2012	Development of urban localities and potential coastal adaptation options
TCC Workshop 1	(26/04/2012)	Refinement of urban localities and adaptation options
TCC Workshop 2 (TCC Internal)	(25/05/2012)	Finalisation of urban localities and potential adaptation options. This was provided to GHD on 28/05/2012 for compilation for Stakeholder Workshop and MCA.
Stakeholder Workshop	(15/06/2012)	Project overview and feedback from stakeholders on adaptation options from TCC Internal Workshop 2
Councillor Presentation	(21/06/2012)	Presentation and overview of project to TCC Councillors
MCA Workshop	(11/07/2012)	MCA scoring workshop held at GHD's office. Further detail is provided in Chapter 2
BCA	(March-August 2012)	BCA modelling of selected adaptation options. Further detail provided in Chapter 3

2. Multi-Criteria Analysis

Multi-criteria analysis (MCA) is an appraisal technique that involves first deciding which objectives are relevant for adaptation options to achieve (known as 'criteria'), then assigning weights to each criterion according to the criterion's perceived relative importance in the achievement of community wellbeing (Dobes and Bennett 2009). Adaptation options are then each assigned scores against each criterion according to how effectively the project adaptation option achieves the criterion. Weighted scores are then computed for each adaptation option, with the highest scoring deemed to be the best project option for implementation.

In this instance the objective of the MCA is to reduce the options to 2 or 3 for comparison by BCA.

2.1 MCA Evaluation Process

This section describes the multi-criteria analysis process that has been adopted in order to assess the relative strengths and weaknesses and rank the various adaptation options. The generic multi-criteria decision analysis techniques (MCDA) process is provided in Table 2 and further detailed in the following sections.

Table 2 MCDA Process

Process	Description
Decision Criteria	Develop a set of social, environmental and economic criteria to score potential adaptation options
Scoring	Assess the expected performance of each option against the criteria. Then assess the value associated with the consequences of each option for each criterion
Weighting	Assign weights for each of the criterion to reflect their relative importance to the decision
Weighted Scoring	Combine the weights and scores for each option to derive an overall value
Sensitivity analysis	Conduct a sensitivity analysis: do other preferences or weights affect the overall ordering of the options?

2.2 Decision Criteria

The MCA process facilitates the evaluation of each option in respect of its performance against the chosen decision criteria. For the Townsville CHAS, these criteria were developed in Project Workshop 1 involving EHP, TCC, LGAQ, Department of Community Safety (DCS), Department of Local Government and Planning (DLGP) (former) and GHD on 19th December 2011 and subsequently refined both prior and during the MCA Workshop. Criteria were developed under the following categories: Adaptation effectiveness, Climate uncertainty, Social and environmental impacts, and Complexity and cost.

Originally the Adaptation effectiveness category included three criteria:

- *Frequency* of inundation of buildings and community infrastructure
- *Duration* of inundation of buildings and community infrastructure

- *Severity* of inundation on humans as well as buildings and community infrastructure

Review of the criteria prior to the MCA Workshop determined that the Adaptation effectiveness category was problematical, in that Severity of inundation is (at least in part) a function of Frequency and Duration and there was limited data available to define either Frequency or Duration within the CHAS Scope of Works.

It is important in MCA that criteria are as independent from each other as possible. Accordingly prior to the MCA Workshop, the Adaptation effectiveness category was amended by deleting Frequency and Duration and consolidating Severity as the sole criterion under this category. The final adopted category and criteria set are provided below in Table 3.

Table 3 Decision Criteria

Category	Criteria
Adaptation effectiveness	Severity of inundation on humans as well as buildings and community infrastructure
Climate uncertainty	Flexibility to respond to unexpected climate outcomes (upside / downside)
Social and environmental impacts	Impact on access to coastal areas for recreation (e.g. camping, fishing, swimming)
	Impact on natural coastal ecosystems
	Indirect economic / industry impacts (e.g. tourism, fishing)
	Impact on cultural heritage and landscape
Complexity and cost	Capital cost
	Complexity of implementation (technical, stakeholder / social, institutional)
	Operating and maintenance costs

2.3 MCA Scoring

Initially, options for each of the defined urban localities were developed and evaluated at TCC Internal Workshops 1 and 2 (refer Table 1). Evaluations were based on a ranking as follows:

(1) Highly undesirable, (2) Undesirable, (3) Neutral, (4) = Desirable, (5) = Highly desirable

Reason codes were recorded for each ranking as follows:

a. Best on Balance

b. Public Consultation Investment Required

c. Technically Sound, Current Laws Prohibit

d. Too Expensive

e. Must be Defended

f. Modification Required: This generally identified the need for further refinement of the adaptation option to achieve the required level of protection for a given Locality

g. Unrealistic

h. Other

Outputs from TCC Workshops 1 and 2 were then subject to the MCA Workshop and subsequent result processing that is the subject of this Chapter. The objective of the MCA is to rank the options in accordance with the chosen criteria with a view to reducing them to 2 or 3 for each location (i.e. a practical and manageable number for subjective group assessment). The options considered in the MCA phase are documented in Attachment A.

The MCA scoring process for Townsville CHAS occurred in two phases. The first involved the MCA Workshop at GHD's Brisbane office on 11th July 2012 attended by representatives of TCC, LGAQ and EHP, During the MCA Workshop scoring was completed for a number of urban localities that exemplified certain option sets (e.g. *Defend*, *Accommodate*, *Maintain Status Quo*) deemed typical of the remaining locations. This process served to establish a consistent approach to consideration of the issues and scoring. At the workshop a scoring protocol was adopted for certain criteria. This protocol established where criteria scores could be considered generic, and where they should be considered in the light of the specific circumstances pertaining to the location and adaptation option (i.e. case by case). These generic scoring rules are included as Attachment B.

Relative preference scales were used to produce scores. These are simply linear scales anchored at their ends by the most and least preferred options for a criterion. The most preferred option was assigned a preference score of 100, and the least preferred a score of 0. Scores were then assigned to the remaining options so that differences in the numbers represent differences in strength of preference.

At the time of the workshop GHD was only able to present preliminary information on adaptation and asset costs, and these were adopted without debate for that purpose.

For each Locality considered at the workshop, GHD presented the site-specific climate change information (the projected sea level rise and 100 y Return Period storm tide boundaries), and details of the proposed adaptation options (e.g. the location and nature of defences or accommodation measures). The consequences of the options were then discussed and the options scored by group consensus.

Subsequent to the MCA workshop GHD completed the MCA workbook for the remaining locations and updated the cost information to a higher level of detail. This was then provided to TCC, LGAQ and EHP for feedback prior to result processing and final ranking.

2.4 Weighting

The weightings applied to the decision criteria described in Section 2.2 are provided in Figure 3. This figure provides three separate weightings that were developed throughout the course of the project and are detailed as follows:

- **Original:** Weighting applied to the decision criteria as developed during Project Workshop 1
- **Revised:** These weightings were developed prior to the MCA Workshop and was the result of consolidation of the Frequency, Duration and Severity weightings
- **Preferred:** At the MCA workshop, a further discussion of the criteria was undertaken which led to a further refinement of the weightings. The MCA analysis of the options has been conducted using the Preferred values as the base case weightings.

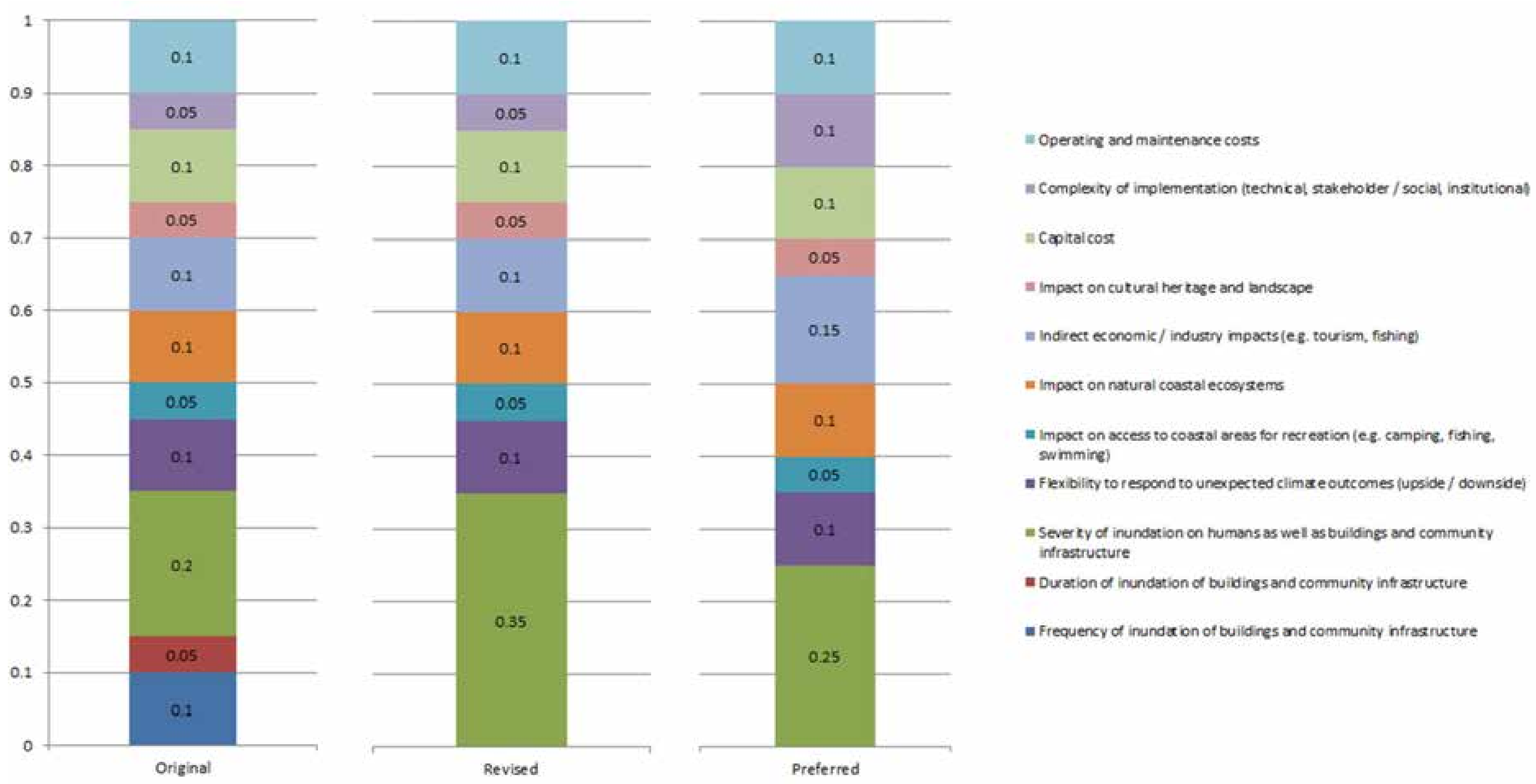


Figure 3 MCA Weightings

2.5 Weighted Scoring and Sensitivity Analysis

This section details the sensitivity testing that was completed in order to assess which adaptation options would be subject to further investigation in the BCA.

2.5.1 Option Comparison and Ranking

Comparison and ranking of options from the MCA workshop was based on MCDA and facilitated by use of the Catalyse HiView™ software package. The raw MCA Workshop score data was collected using an Excel workbook (included in Attachment A) and then input into Hi View™ for analysis and interpretation. Hi View™ facilitates a sensitivity analysis of the MCA weighted scores in respect of weightings. The below provides an example of the weightings sensitivity process using Pallarenda as a case study.

2.5.2 Example of MCA Weighting Sensitivity Analysis

During the MCA Workshop, three separate options were considered for Pallarenda: *Accommodate*; *Retreat;* and *Maintain Status Quo*. The resultant weighted score using the 'Preferred' MCA Weightings are provided in Figure 4 which indicates results of 69, 68 and 20 for *Accommodate*; *Retreat;* and *Maintain Status* respectively.

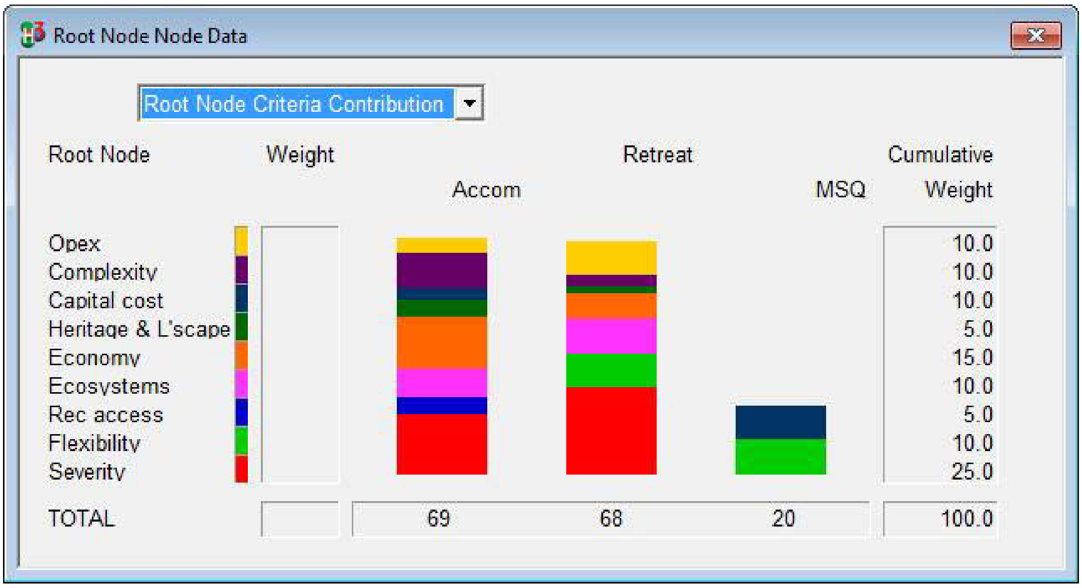


Figure 4 Weighted Score of Pallarenda Options from MCA Workshop

To understand the sensitivity of individual criteria weightings on the overall result, the software package HiView allows the weighting of each criterion to be either increased or decreased, whilst retaining the relative weightings of the other criteria. I.e. a 40% increase in the weighing of complexity would result in an equal 5% decrease in all the other 8 criteria. The presentation of this sensitivity testing is provided in Figure 5. The colour bands (red (±5%), yellow (±5-15%) and green (more than ±15%)) indicate the amount a particular criterion weighting would need to be modified to change the overall result from *Accommodate* to either *Retreat* or *Maintain Status Quo.*

Review of the results from Figure 4 and Figure 5 indicates:

- The most preferred option prior to sensitivity testing Figure 4 (although marginally) is *Accommodate*;
- An increase in the weighting of the operating and maintenance costs, flexibility to respond or severity of inundation criteria by 5% (red) would modify the most preferred option to *Retreat* (i.e. highly sensitive);

- A reduction of 5% (red) in the criteria weighting of the complexity of implementation, capital cost, impact on heritage and landscape, indirect economic impacts or impact on recreational access would also modify the most preferred option to *Retreat*;
- An increase between 5-15% (yellow) in the weighting for impact to ecosystems is required to modify the result to *Retreat;*
- An increase in the capital cost criterion weighting by more than 15% (green) would be required to result in *Maintain Status Quo* being more preferable to *Accommodate*;
- The most preferred option (*Accommodate* or *Retreat*) is highly sensitive to the adopted weightings; and
- Sensitivity testing has shown the overall result can be modified by sensitivities of less than 15% (red or yellow) *Accommodate* and *Retreat* are assessed as being required for further investigation in the BCA.

Importantly, this process of sensitivity testing has been used to determine the number of adaptation options that are input to the BCA for further investigation, i.e. for locations where changing the criteria weightings by less than 15% (red or yellow) has modified the preferred option, both options have been input to the BCA.

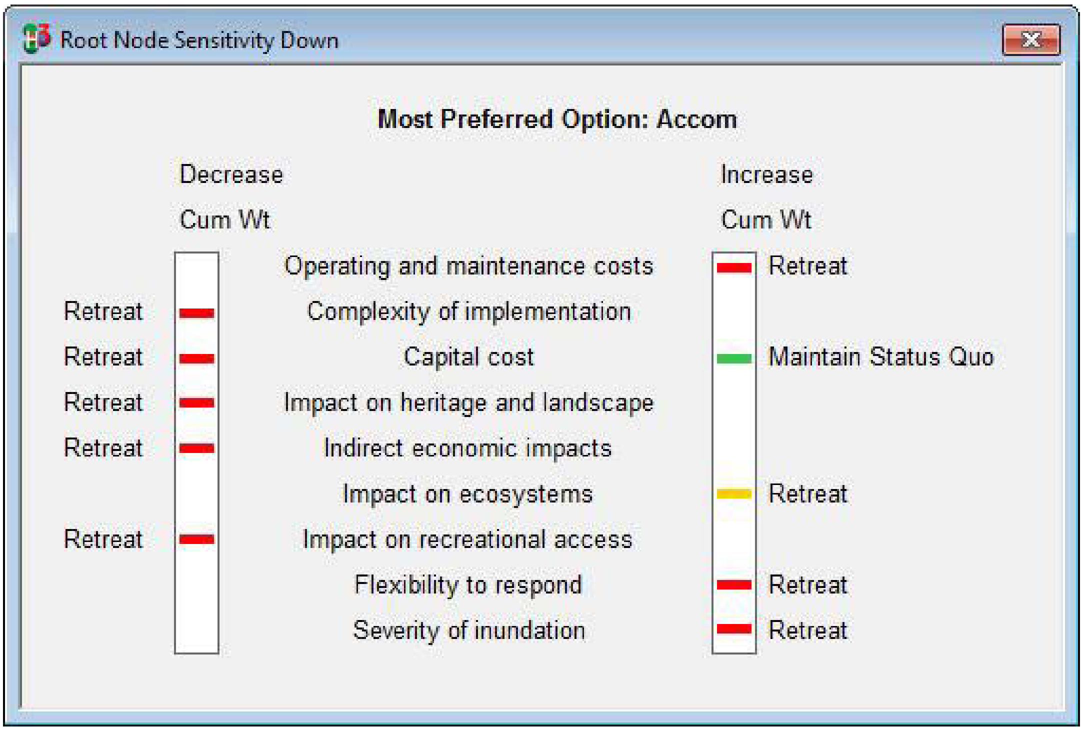


Figure 5 Sensitivity testing of Pallarenda MCA results.

2.6 MCA Results

A summary of the MCA results for each Locality is provided in Attachment C and includes:

- The previously assigned TCC ranking;
- The weighted scores for each option (consistent with the format provided in Figure 4);
- The results of a sensitivity analysis of the weightings (consistent with the format provided in Figure 5); and
- Recommended options to be further investigated within the BCA (assuming *Maintain Status Quo* is retained in all cases as a base case for comparison).

A summary of the final preferred options identified throughout the MCA process for input to the BCA are provided in Table 4.

Table 4 MCA Results - Summary of Options Identified for Input to the BCA

District	Locality	Preferred Adaptation Options for Input to the BCA
Rollingstone	Mutarnee	Retreat
	Rollingstone Beach	Retreat
Balgal Beach	Balgal Beach	Retreat
	Toomulla	Retreat
Toolakea	Toolakea	Retreat
	Bluewater Beach	Retreat
Saunders Beach	Saunders Beach	Retreat
Bushland Beach	Bushland Beach	Retreat
	North Shore (proposed development area)	Retreat
Townsville North	Pallarenda	Accommodate/Retreat
	Industrial Area	Defend
	Mt St. John Sewerage Treatment Plant	Defend
Townsville Inner Suburbs	The Strand	Accommodate/Retreat
	Ross Creek, South Townsville, Inner Suburbs, Railway Estate, Rowes Bay, Melrose Park and West End	Defend Option 1/Retreat
River South	Oonoonba	Defend/Retreat
Stuart	Stuart/Cleveland Bay Sewerage Treatment Plant	Defend/Accommodate
South Land	Cungulla	Retreat
Magnetic Island	Horseshoe Bay	Retreat
	Arcadia (Geoffrey Bay)	Retreat
	Nelly Bay	Defend
	Picnic Bay	Defend/Retreat
	Picnic Point Sewerage Treatment Plant	Defend
	West Point	Retreat
	Bolger Bay Pump Station	Defend
	Radical Bay	Accommodate
	Cockle Bay (LOTS)	Retreat*

*The Cockle Bay (LOTS) *Retreat* option was taken directly to the BCA.

3. Benefit-Cost Analysis

3.1 Introduction

The Department of Climate Change and Energy Efficiency (DCCEE) has commissioned a number of case studies that seek to appraise adaptation options using BCA (e.g. DCCEE 2010, 2011). These have recently been generalised into a single economic ‘framework’ for analysing climate change adaptation options. The framework outlines a range of steps that enable good BCA practice to be applied within the context of uncertain emissions projections, somewhat uncertain climate responses, probabilistic ‘events’ such as tropical cyclones/storm tides, long-lived infrastructure and diverse impacts on community wellbeing. This framework has been reviewed here and, as a general approach, is regarded as satisfactory. However, specific technical refinements have been necessary to achieve the desired project outcomes and these are detailed later.

The main outcome of this chapter is to estimate the optimal timing and economic viability of adaptation options as selected though the MCA process. These preferred options are tested using the application of the DCCEE, BCA framework, albeit tailored to the Townsville CHAS. Key components of the BCA detailed in this chapter include:

- Development of the BCA model and key assumptions;
- Development of sea level rise asset losses and storm tide damages for coastal communities as a function of water level;
- BCA modelling of urban localities without adaptation;
- BCA modelling of urban localities for selected[3] adaption options;
- Summary of proposed adaptation options for inclusion in the Townsville CHAS Report; and
- Sensitivity testing of a number of key model inputs

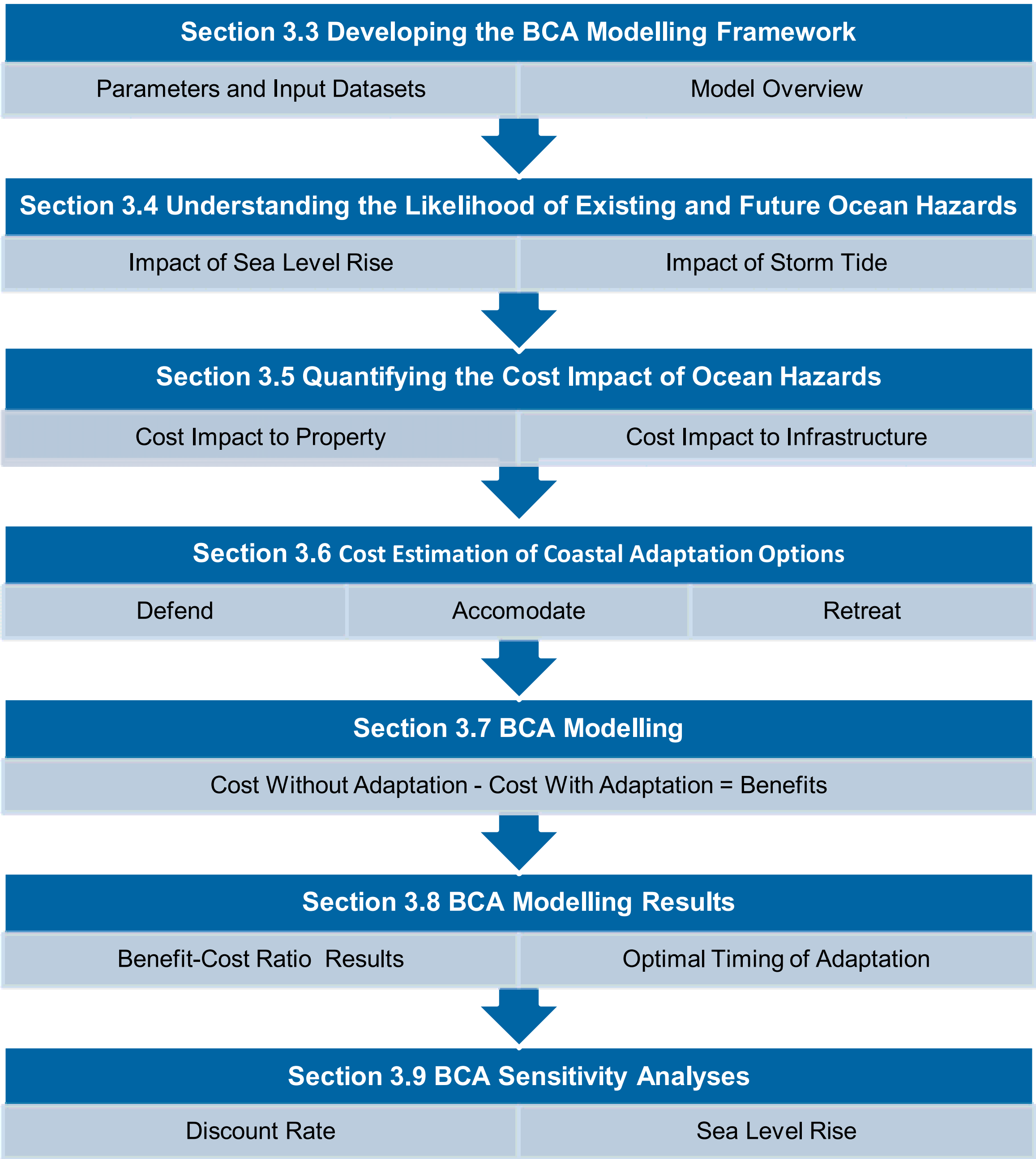
3.2 Chapter Overview

The main components of the BCA methodology are shown in the schematic below and detailed in the following sections. Mainly:

- **Section 3.3 Developing the BCA Modelling Framework**: This section provides detail of the modelling framework adopted
- **Section 3.4 Understanding the Likelihood of Existing and Future Ocean Hazards**: This section details the method by which existing and future sea level rise and storm tide hazards have been quantified
- **Section 3.5 Quantifying the Cost Impact of Ocean Hazards**: This section provides the method by which water level vs cost curves have been developed for each of the respective urban localities through the usage of various GIS datasets, TCC asset databases and property valuation data
- **Section 3.6 Cost Estimation of Coastal Adaptation Options**: This section details the method by which coastal adaptation strategies have been costed
- **Section 3.7 BCA Modelling**: This section provides detail on how adaptation options have been modelled and instruction on how to interpret the results presented in Section 3.8

[3] Selected adaption options are those which ranked highest following MCA scoring and weighting.

- **Section 3.8 BCA Modelling Results** This section provides the BCA results for each of the respective urban localities
- **Section 3.9 BCA Sensitivity Analyses**: This section provides a sensitivity analysis of key model inputs such as discount rate, projected sea level rise and population growth



3.3 Developing the BCA Modelling Framework

This section provides an overview of the BCA framework adopted.

3.3.1 BCA Model Overview

In order to assess the economic viability of potential adaptation options a BCA model has been developed within Microsoft Excel™ using the Palisade @RISK™ add-in. This software tool has been used to facilitate the statistical simulation of many thousands of years of potential storm tide impacts, including the effects of sea level rise. By subjecting proposed adaptation options to a large number of random storm events, an appreciation for the possible variance in potential costs and benefits up until the year 2100 has been obtained.

Figure 6 below provides an overview of the BCA modelling process.

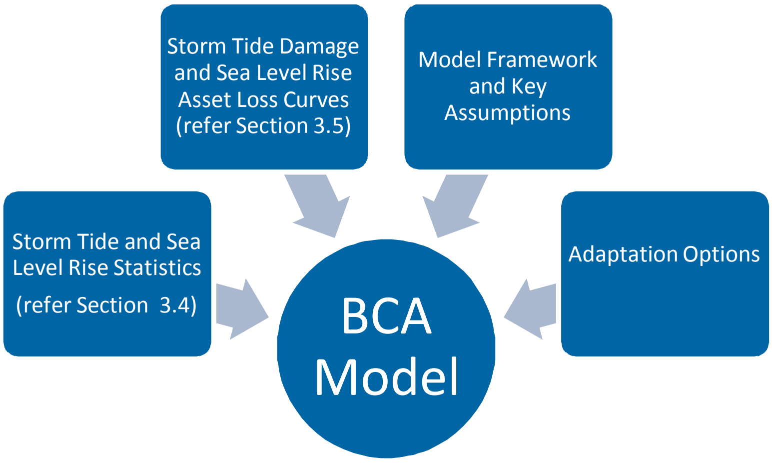


Figure 6 Key Inputs to the BCA Model

3.3.2 Economic Parameters

Key economic parameters adopted include:

- Appraisal period of 2012-2100 to align with modelling and assumed asset lives;
- Annual estimation of impacts;
- A relatively low base discount rate of 3% has been adopted in the BCA with sensitivity tests undertaken for 1%, 5%, 7% and 9%. The discount rate allows economic effects occurring at different time periods to be compared. Discounting converts each future dollar amount associated with an adaptation option into equivalent present dollar amounts (the so-called *Present Value* or PV). Because of the extended period of time relevant to climate change processes the choice of discount rate can have significant effects on the PV of alternative adaptation options and hence the recommendation as to which way to proceed. The Stern Review (2006) used a discount rate of 1.4%, while the Garnaut Review (2008, 2011) used a discount rate of 1.25 to 2.65%. By way of comparison, Infrastructure Australia recommends 7% with sensitivity tests at 4% and 9% for infrastructure projects (to account for the capital scarcity pressures); and
- All future costs and benefits of each adaptation option are discounted back to 2012 (present day) dollar values.

3.4 Understanding the Likelihood of Existing and Future Coastal Hazards

This section details the method by which existing and future sea level rise and storm tide hazards have been quantified for input to the BCA model.

3.4.1 Storm tide and sea level rise input datasets

In the context of the Townsville CHAS existing and future coastal ocean hazard can be attributed to either:

- Inundation and erosion due to projected sea level rise
- Periodic storm tide inundation, or
- A combination of storm tide exacerbated by projected sea level rise

Storm Tide

Combined non-tropical cyclone and tropical cyclone storm tide statistics have been developed here for each of the respective urban localities by sourcing data from both the GHD/SEA, 2007 Townsville/Thuringowa Storm Tide Study (GHD 2007) and the Hardy et al. (2004) Queensland Climate Change and Community Vulnerability to Tropical Cyclones - Ocean Hazards Assessment - Stage 3. It should be noted that non-cyclonic events dominate the statistics of water levels below the 100 y Return Period, but are gradually overtaken by the more extreme yet rarer tropical cyclone events. Figure 7 below provides an example combined return period curve for South Townsville.

The potential for increased tropical cyclone intensity over time due to climate change has been accounted for through the use of a scaling factor applied to storm tide events ranging from 1 in 2012 to 1.1 in 2100. This provides levels consistent with future climate storm tide estimates from the GHD/SEA 2007 study.

Sea Level Rise

A sea level rise projection of 0.8 m for the period 1990-2100 has been adopted. It is assumed that this occurs linearly throughout the planning period as is specified by the Queensland Coastal Plan (EHP 2011). Sensitivity testing has also been carried out for a 1.1 m sea level rise for the same period (refer Section 3.9.2).

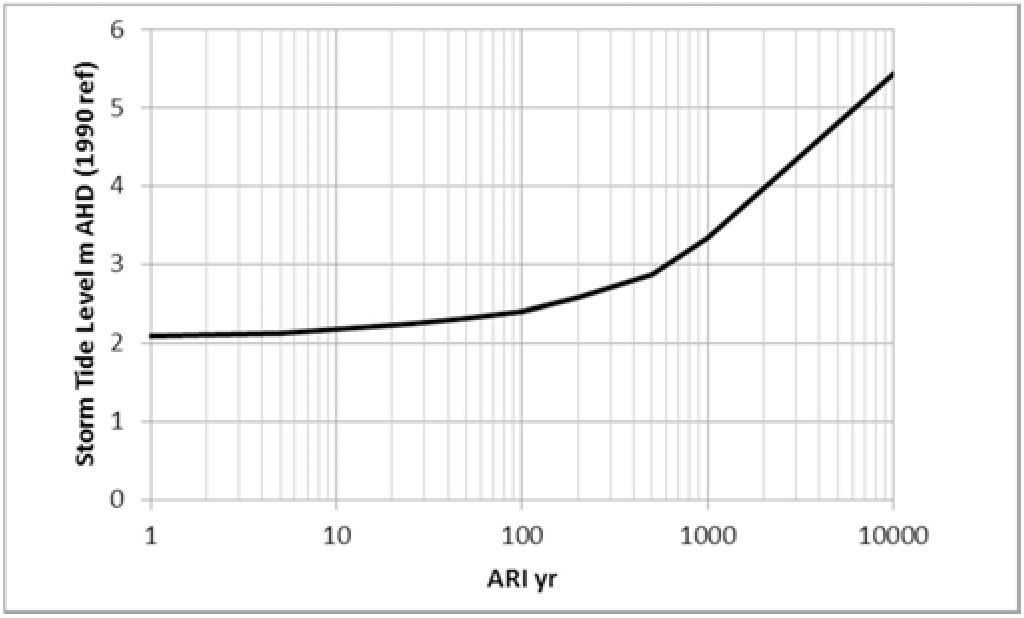


Figure 7 Example combined tropical cyclone and non-cyclonic tide plus surge only water level return period curve at South Townsville for the 2007 mean sea level

3.4.2 Probabilistic modelling of storm tide and sea level rise

There is inherent uncertainty associated with the prediction of potential storm tide events that could occur over the 88 y planning period (2012-2100). To address this uncertainty, the BCA model utilises a stochastic or *Monte Carlo* simulation approach whereby many thousands of separate realisations of 88 y periods can be generated based on knowledge of projected sea level rise and storm tide return period statistics. This allows the viability of proposed adaption options to be assessed under a range of water levels that could occur during the planning period.

Figure 8 below provides an example of four separate future realisations of 88 y. From the figure it can be observed that some 88 y periods may be relatively inactive while others i.e. (top right) may have a number of large storm tide events. Also to note is the linear increase in mean water level over time due to projected sea level rise.

Combining this water level simulation approach with knowledge of the damage or asset loss for a given water level (developed in Section 3.5), the generated peak water level event time histories form the basis for developing the cost of impacts from both existing and future coastal hazard experiences.

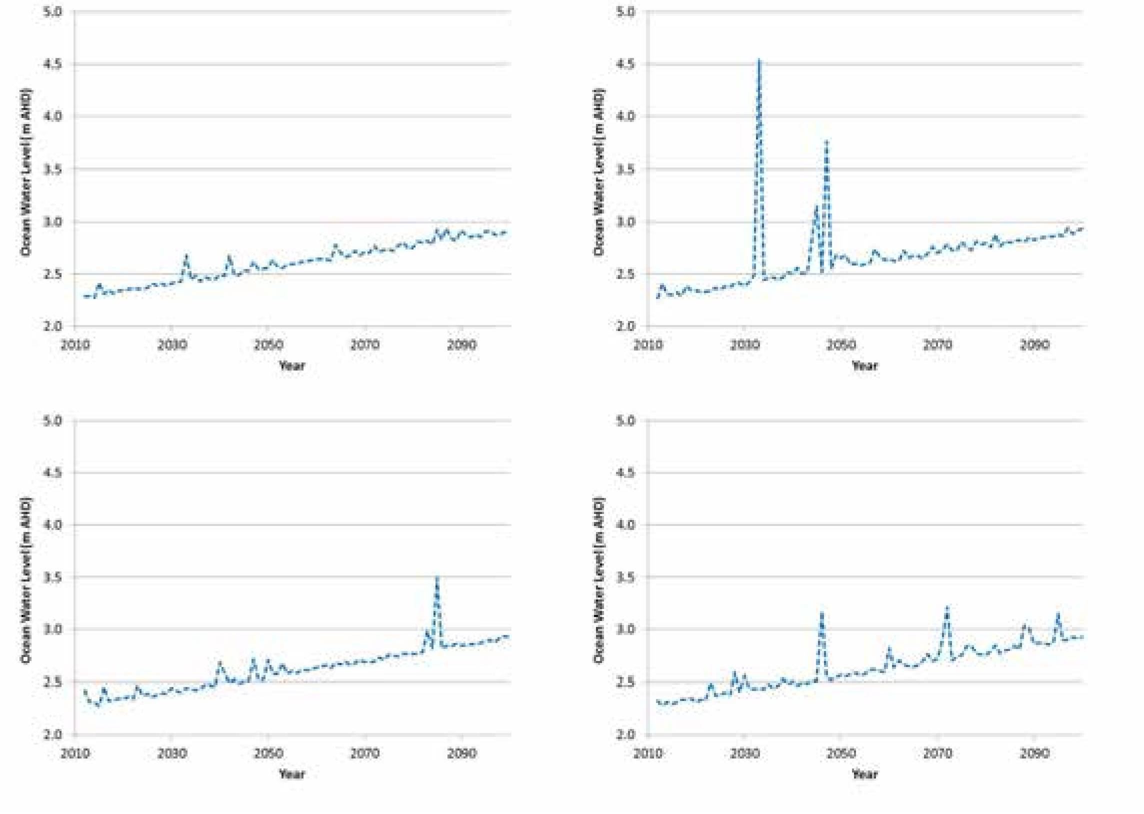


Figure 8 Example of four separate future 88 y water level realisations.

3.5 Quantifying the cost impact of ocean hazards

This section defines the method that storm tide and sea level rise damage and asset loss curves have been developed for input to the BCA model.

3.5.1 Overview

In order to assess the total damage or asset loss cost to the community during any given rendition of 88 y (refer Section 3.4.2) a series of cost curves have been developed as a function of water level for each of the respective urban localities. Examples of these cost curves are presented in Figure 9 with the left panel providing the asset loss expected due to sea level rise alone and the right panel showing storm tide damages. These need to be initially separated in order to apply the various adaptation rules in a consistent manner that accounts for the state of the planning over the 88 y period.

The development of these curves has been achieved through the use of TCC, EHP and GHD-developed GIS datasets, available property and infrastructure valuations and a number of storm tide and flood damage assessment methods. The process for developing cost curves is presented in the following sections and a summary of the process is provided in Figure 10.

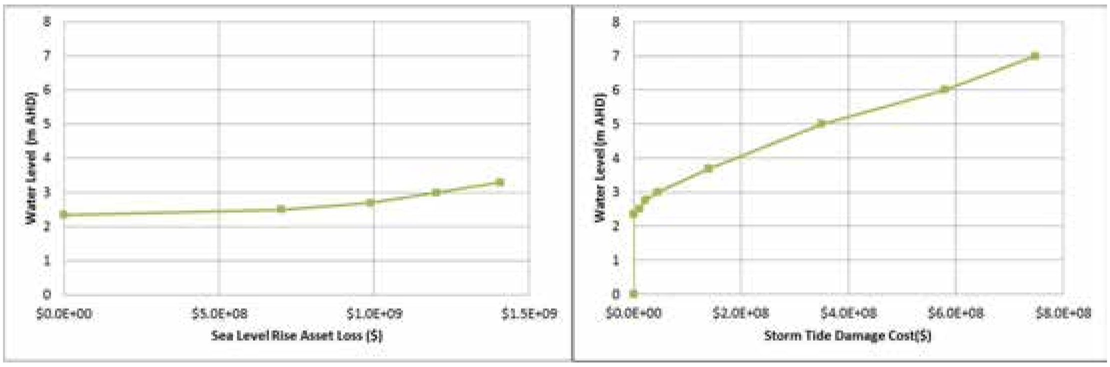


Figure 9 Example cost vs ocean water level for sea level rise assets loss (left) and storm tide damage (right)

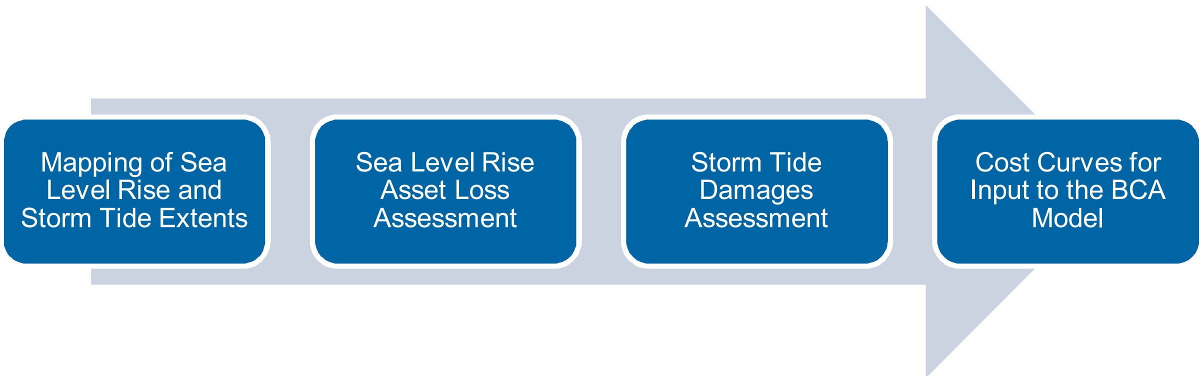


Figure 10 Overview of the process required to develop CHAS cost curves

3.5.2 Mapping of sea level rise and storm tide extents

Upon project inception a number of sea level rise and storm tide extent GIS layers were provided by EHP. These inundation extents provided the basis by which property and infrastructure losses and damages could be quantified. These included the:

- 2012 Highest Astronomical Tide (HAT) extent (2.2 m AHD[4])
- 2100 HAT with a 0.8 m sea level rise allowance, including erosion prone areas (3.0 m AHD)
- 2100 HAT with a 1.1 m sea level rise allowance, including erosion prone areas (3.3 m AHD)
- 2012 100 y storm tide extent (2.76 m AHD)
- 2100 100 y storm tide extent with a 0.8 m sea level rise allowance (3.68 m AHD)
- 2100 100 y storm tide extent with a 1.1 m sea level rise allowance (3.98 m AHD)[5]

These extents were provided by EHP with a focus on the nominal “100 year” event being the relevant risk level over the planning period (also approximately 100 years). However, as outlined in the BCA methodology, it is necessary to consider events that are more severe than a 100 y event in order to correctly assess the risks of adaptation decisions. In fact the “100 year event” has no specific relevance in this context and it is the full range of events that must always be considered, regardless of the planning period of interest. As noted below, some of the supplied surfaces also contained errors and these need to be assessed for any future use of these surfaces.

To provide further resolution on the sea level asset loss curve (refer left panel, Figure 9) and to allow for representation of events other than the 100 y Return Period storm tide event (refer right panel, Figure 9) GHD necessarily developed a number of additional sea level rise and storm tide extents including a:

- 2050 HAT with a 0.3 m sea level rise allowance (2.5 m AHD)
- 2075 HAT with a 0.55 m sea level rise allowance (2.75 m AHD)
- Storm tide extent representing an event of 2.5 m AHD at South Townsville[6]
- Storm tide extent representing an event of 3.0 m AHD at South Townsville
- Storm tide extent representing an event of 5.0 m AHD at South Townsville
- Storm tide extent representing an event of 6.0 m AHD at South Townsville

The development of additional surfaces was completed using a number of GHD-developed GIS geoprocessing models which have been extensively refined over a number of years (GHD/SEA 2007), (GHD/SEA 2009), (GHD 2010) and (GHD 2012).

It is noted that the datasets utilised on the Townsville CHAS represent the so called ‘bathtub’ mapping approach whereby offshore water level values are mapped inland and thus do not consider the potential dynamics of inundation events that might either result in a reduction of a bathtub extent or an extension of it, depending on the specific situation.

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[4] Bracketed values indicate approximate water level at South Townsville in m AHD based on the MSQ, 2012 tidal planes.

[5] Following review of this provided dataset a number of systematic errors were identified. As such the contribution of this layer to the cost curves was omitted.

[6] These layers were developed by vertically shifting the 2100 100 y, 0.8 m sea level rise extent, using South Townsville as the reference point. The resultant layers where horizontally extended to intersect the DEM where necessary.

3.5.3 Sea Level Rise Asset Loss Assessment

The following sections detail the method that property and infrastructure values have been assessed for input to the sea level rise (only) asset loss curves.

Residential values

Residential values are based on median house and land prices sourced from Australian Property Monitors (APM) for 2012[7].The data were collated on a Locality basis, and where required, inflated to present day levels using the Housing Consumer Index for Townsville (ABS 2012). Due to a lack of granularity in this data, a further median of the top 50% of values was used for Urban Localities which are located directly on the coast, to reflect the higher values of properties with sea views or with close proximity to the ocean. All other suburbs use median house prices. For a number of Urban Localities where data was unavailable (Industrial Area and unallocated lots) were assigned the Townsville LGA median value of $357,000.

Table 5 Adopted House and Land Property Value per Locality

Locality	Adopted House and Land Property Value ($)
Balgal Beach	$336,875*
Bluewater Beach	$534,432*
Bushland Beach	$700,000*
Cungulla	$220,000
Geoffrey Bay	$499,272*
Horseshoe Bay	$630,000*
Industrial Area	$355,000
Mutarnee	$357,000
Nelly Bay	$621,250*
Oonoonba	$282,000
Pallarenda	$577,500*
Picnic Bay	$595,000*
Radical Bay	$357,000
Rollingstone Beach	$357,000
Saunders Beach North	$380,625
Strand	$717,265*
Toolakea	$502,085*
Toomulla	$502,085*
Townsville Inner Suburbs	$331,667
West Point	$357,000

** These Localities have used the median of the top 50 % of property values.

Commercial and Industrial Values

Commercial and industrial values were derived from the *Knight Frank Valuation report (2008)* prepared for TCC.

Current market values were defined as “the estimated amount for which an asset should exchange on the date of valuation between a willing buyer and a willing seller in an arm’s length transaction after proper marketing, wherein the parties had each acted knowledgeably, prudently and without compulsion”.

[7] This data is based on property sales data for the 2011-2012 financial year. It is noted that the long term value of property for a given Locality may be biased dependant on the sample size of property sold and also temporal variation in property values.

Commercial and industrial values were derived from sales evidence across ten zones. Each of which consisted of various localities. Data were presented as a range and median for each zone based on a dollar per square metre basis. Using ABS inflation data, values were inflated to present day levels.

Infrastructure Costs

Infrastructure loss ('write down') of existing water, sewerage, stormwater, roads and park infrastructure is calculated on a per lot basis with $37,000 allowed for trunk infrastructure plus an additional $40,000 for local services (excluding power and telecommunications), (TCC 2012).

Key Limitations of Sea Level Rise Asset Loss Assessment

- Dependant on the projected rate and magnitude of sea level rise;
- 'Bathtub' method for sea level rise extents;
- Usage of median house and land prices;
- Difficultly in predicting property valuation following the impact of events; and
- It is assumed that current drainage infrastructure will still function under the influence of higher downstream tailwater conditions as a result of sea level rise. While a contingency of 10% has been applied in the cost estimation of *defend* and *accommodate* options this may underestimate the cost of adaptation.

3.5.4 Storm Tide Damages Assessment

Storm tide damage estimates have been derived using the following data sources:

- Ground level data of the study area;
- GIS property/landuse layer of Townsville;
- ANUFLOOD (Smith and Greenaway (1992)) empirical flood damage curves for residential and commercial properties; and
- Rapid appraisal method (RAM; DNRE 2000 for road damages).

The cost-damage curves sourced from the ANUFLOOD and RAM studies have been adjusted using the Housing Consumer Price Index for Townsville (ABS 2012). The Housing Consumer Price Index was chosen as being most relevant and conservative. Inflation rates were applied up to March 2012.

Residential and commercial storm tide damages

The derivation of tangible residential and commercial damages has been based on the methodology described in the Guidance on the Assessment of Tangible Flood Damages (DNRM, 2002) and the stage–damage curves developed for ANUFLOOD. Key steps in the determination of residential and commercial damages are as follows:

- Classify each of the residential properties into either a *small*, *medium* or *large* housing type
  - *Small* house: < 80 m^2 and/or 1–2 bedrooms
  - *Medium* house: 80–140 m^2 and/or 3 bedrooms
  - *Large* house: > 140 m^2 and/or 3+ bedrooms

For the purposes of this study it was assumed that all property represented a *large* house. Sensitivity testing was undertaken to understand the impact of this assumption by re-running the damages using a medium sized property. It was found that this assumption resulted in the overall damages being between 5-10% lower. This was deemed negligible when compared with the losses associated with sea level rise property loss.

- Classify each of the commercial properties into either a *small*, *medium* or *large* commercial property. The size categories for commercial properties are as follows:
  - *Small* commercial property: < 186 m^2
  - *Medium* commercial property: 186–650 m^2
  - *Large* commercial property: > 650 m^2
- Further classify each of the commercial properties according to the *value class* or type of commercial premises. For the purposes of this assessment, the medium sized commercial class three was adopted. Based on review of the available GIS landuse data this class was deemed as representative of commercial premises within the Townsville region.
- Develop a set of stage-damage curves for each residential and commercial classification based on the damage curves in ANUFLOOD
- Estimate floor levels for properties

Industrial Damages

Industrial damages have been estimated by multiplying the area of industrial land that is inundated by more than 0.30 m depth by a damage rate of $317 per m2. This damage rate is based on the suggested damages for large high-value non-residential buildings as outlined DNRM (2002). To better quantify industrial damages, a valuation survey of individual industrial premises would need to be undertaken.

Road Damages

Roads can be eroded during flood events and can suffer pavement damage due to water intrusion. For the purposes of this study, unit damages to roads due to flooding were also obtained from DNRE (2000*)*. Damage rates were adjusted for inflation and are reproduced in Table 6 below.

Table 6 Unit Damage for Roads and Bridges (per km road)

	Initial Road Repair	Subsequent accelerated deterioration of roads
Major Sealed Roads	$56,142	$28,071
Minor Sealed Roads	$17,546	$8,777

Infrastructure Damages

Key community assets at risk were identified through the use of TCC-provided GIS datasets. Infrastructure damage costs were then developed based on a number of sources including the recent Natural Disaster Relief and Recovery Arrangements asset valuations for the Cassowary Coast region and TCC-provided asset information. Flood damages to the following items were considered:

- Booster pumps, reservoirs;
- Pump stations and treatment plants;
- Road and rail infrastructure;
- Overhead power lines and substations; and

- Telecommunication exchanges.

Indirect Damages

In the absence of information provided by TCC on indirect damages, this study has expressed indirect damages as a function of the direct damage, as recommended in the ANUFLOOD model:

- Indirect residential damages = 15% of direct residential damages
- Indirect commercial damages = 55% of direct commercial damages

Key Limitations of Storm Tide Damage Assessment

- Bathtub method for deriving the flood extents;
- Building footprints not available to ensure intersection of extents and buildings;
- Use of generic stage-damage curves derived in other areas;
- Floor level database not available for all areas or properties;
- There is no allowance in the storm tide damage curves for the increased cost of direct wave breaking or of wind damage to property and infrastructure (i.e. damage is based on tide plus surge, plus wave setup only in specific areas);
- Catastrophic failure of property following extreme event was not assessed; and
- Limited available data on storm tide damages to infrastructure for the Townsville region.

3.6 Cost Estimation of Coastal Adaptation Strategies

The following details the method by which the cost of coastal adaptation implementation has been costed for the Townsville CHAS.

3.6.1 Coastal protection cost estimation and assumptions

Adaptation options requiring coastal protection intervention such as *accommodate* and *defend* options have been developed using the estimated industry rates provided in Table 7 and advice from TCC on the preferred extent of adaptation. It is noted that the development of coastal infrastructure cost estimates has been designed to only provide complete protection against the 2100, 100 y Return Period storm tide event as per the requirements of the Scope of Works.

Table 7 Coastal Protection Costs

Item	Rate (Includes 20 % Contingency)	Notes
Sea Wall	\$28,450 / m	
Sea Dyke	\$3,500 -\$8,600 / m	Dependant on ground elevation at location of proposed construction.
Beach Nourishment	\$4,200 / m	Assuming 150 m^3 / m
Storm surge gates	\$1.2M / m	
Groynes	\$1,000 / geotextile bag	Site specific but typically 9 bags used per groyne (Cungulla)
Road raising	\$4,200 / m	Assumes two lane sealed road.
Land filling	\$60 / m^3	

3.6.2 Accommodate costing and assumptions

Accommodate options have been developed based on the following assumptions:

- *Accommodate* options provide a level of coastal erosion protection to the projected 2100 sea level rise level;
- That properties whose current floor level is below the 2100 100 y Return Period storm tide level will be raised to be above the 2100 100 year Return Period storm tide level only i.e. events higher than the 100 y Return Period will still lead to storm tide damages of accommodated property. It is assumed that existing infrastructure will remain at its present day level.

The price to raise individual properties subject to *accommodate* strategies has been costed using two different approaches, depending on whether a structure is highset or of slab-on-ground construction. Classification of property has been based on landuse data and available JCU Cyclone Testing Station property survey data. Where limited property survey was available, the proportion of highset and slab-on-ground property per Locality has been estimated by TCC.

The cost of raising highset property has been estimated as $70,000[8] per property. The raising of slab-on-ground property is deemed impractical. Accordingly it is assumed that the property would be demolished, the land filled to a level exceeding the 2100 100 y Return Period storm tide level, and the house then reconstructed. The dwelling-only value required in this case has been calculated based on the ratio between the property valuation provided data in Table 5 and the EHP unimproved valuation of land for each of the respective urban localities. The cost of demolition of slab-on-ground housing has been assumed to be $25,000.

Table 8 Proportion of high set and slab-on-ground property

Locality	Slab on Ground (%)	Highset (%)
Rollingstone Beach	100	0
Balgal Beach	80	20
Toomulla	80	20
Toolakea	90	10
Bluewater Beach	90	10
Saunders Beach	70	30
Bushland Beach	100	0
Pallarenda	20	80
Industrial Area	100	0
Strand	75	25
Townsville Inner Suburbs	37	63
Oonoonba	38	62
Cungulla	50	50
Horseshoe Bay	80	20
Geoffrey Bay	80	20
Nelly Bay	80	20
Picnic Bay	30	70

3.6.3 Retreat costing and assumptions

To estimate the cost of retreat and relocation of communities a number of rules and assumptions have been applied. It is important to note at this point that differing rules have

[8] Indicative rate based on property raising in the Brisbane area following the 2011 floods.

been adopted dependant on whether *property* or *infrastructure* loss/relocation is occurring under *Maintain Status Quo* or *Retreat*. To assist the reader, either ***property*** or ***infrastructure*** has been highlighted under each bullet point below to clarify which assets are being described:

1. The total number of properties to be relocated for a given Locality under the *Retreat* strategy has been based on the maximum number of properties which are within either the 2100 100 y Return Period storm tide extent with an 0.8 m sea level rise allowance or the 2100 80 cm sea level rise inundation and erosion zone. Pallarenda represents an exception to this rule following advice[9] from Council (TCC 2012).
2. The costs simply due to sea level rise encroachment (ignoring storm tide events) have been developed using an asset loss approach utilising a combination of TCC-held property, landuse and infrastructure GIS datasets. It is assumed that once the Highest Astronomical Tide (HAT) level, which rises with the mean sea level, encroaches on a property footprint or infrastructure item, then the entire asset value is immediately lost. The total cost incurred by the community following loss of property or infrastructure and subsequent replacement is then dependent on the specific adaptation strategy being analysed, as follows:
   – The replacement cost of ***property*** subject to sea level rise alone is equivalent to the current market property value. The method for determining property values is provided in Section 3.5.3. and applies for all strategies.
   – ***Property*** loss and replacement following sea level rise under *Maintain Status Quo* assumes that an individual owner first loses their current property value and must then purchase another property of equal value. Therefore, the total cost is the loss of the existing property plus the replacement cost of the new property (i.e. double the existing market value) with a further 10% cost contingency applied to provide some allowance for disruption/inflation during relocation.. As previously discussed this rule also applies prior to the planned implementation of either retreat, accommodate or defend strategies.
   – ***Property*** loss and replacement following planned *Retreat* assumes that the property owner is compensated for the loss of their current property and then purchases another property of equal value. Therefore, the total cost per property is equivalent to the existing house and land value. A further 10% cost contingency has also been applied to provide some allowance for disruption/inflation during relocation.
   – ***Infrastructure*** loss ('write down') of existing TCC water, sewerage, stormwater, roads and park infrastructure has been calculated on a per lot basis with $37,000 allowed for trunk infrastructure plus an additional $40,000 for local services (excluding power and telecommunications), (TCC,2012).
   – The cost of ***replacement infrastructure*** for both *Maintain Status Quo* and *Retreat* is assumed to be included in the replacement property market value (i.e. the local services, water, stormwater, roads and parks and external headworks and infrastructure charges are borne by the developer and passed onto the land purchaser (the property owner in the case of *Maintain Status Quo* or the Council/Government in the case of *Retreat*).
3. Population that is required to relocate due to the *Maintain Status Quo* and *Retreat* strategies remain in the Townsville region and are relocated to an area well above future sea level rise and storm tide impacts.

[9] Discussion with TCC indicated that partial (ie only property within the 100 y storm tide extent) retreat of Pallarenda would not be feasible and that full relocation of the settlement would be required.

4. No cost factor has been applied to *Maintain Status Quo* to account for ad-hoc approaches that may be expected as landowners attempt to protect their property against storm tide events.

5. Impact prior to the implementation of adaptation options is equivalent to Maintain Status Quo Thus the further an adaptation option occurs into the future the more likely it is that assets will be affected by sea level rise and storm tide impacts.

3.6.4 Limitations of the Cost Estimation for Coastal Adaptation

A number of key limitations in the development of adaptation cost estimates include:

- The cost of *accommodate* and *defend* adaptation options have been developed based on the cost of coastal protection works, road raising and property raising. It is anticipated that further costs may be associated with the need for construction of or modification of services for a range of government and industry assets to provide functional coastal hazard adaptation. These associated costs could include upgrades to rail, road, communications, energy and other services and should be the subject of more detailed investigation during the periodic review of the Townsville CHAS.
- The approach to developing costing of options has not explicitly considered the potential for legal issues and associated costs which could affect the implementation and viability of options; and
- It is noted that fluvial flooding will impact the feasibility of the proposed adaptation options. For the current study the costs associated with pumping and/or detention of stormwater runoff has been excluded. It is recommended that future CHAS studies assess the combined hazard posed by fluvial and ocean hazard.

3.7 Economic Modelling

This section provides the detail on how adaptation options have been modelled and instruction on how to interpret the results presented in Section 3.8.

3.7.1 Economic Model

A stochastic economic model was utilised to determine the net present value (NPV) in each location for:

- The no adaptation option scenario (i.e. *Maintain Status Quo*); and
- Potential adaptation options.

The model was also used to determine the benefit-cost ratio (BCR) for each of the potential adaptation strategies.

The economic model is based on the @Risk™ software package and operates by:

- Simulating thousands of potential 88 year sea level and storm tide sequences between the years 2012 and 2100 (refer Section 3.4.2);
- Calculating the annual damage cost that occurs in each of the 88 years due sea level rise and storm tide (assuming no adaptation strategy in place).

  It is noted that:

  1) The impacts under a no adaptation option are considered to be equivalent to the impacts experienced under a *Maintain Status Quo* (forced retreat) approach. These impacts represent damages to property or infrastructure being subject to inundation from permanent Sea Level Rise (SLR) and periodic inundation from storm tide. Costs incurred during this period have been derived based on the *Maintain Status Quo* assumptions detailed in Section 3.6.3.

  2) Annual damage costs have been developed utilising the sea level only asset loss and storm tide hazard curves for the respective urban localities.
- Incorporating the cost of the adaptation investment. This cost is equivalent to the investment expense required to implement the adaptation strategy.
- Calculating the annual benefit (reduction in damages) and remaining residual damage due to implementation of the adaptation option. These benefits and costs are derived using the sea level only asset loss and storm tide curves.
- Estimating the NPV of the no adaptation option and estimation of the NPV for each adaptation option for each of the thousands of 88 year sea level and storm tide sequences considered. NPV's are calculated by discounting the future annual costs and benefits associated with each option over each 88 year period.
- Estimating the Benefit-Cost Ratio for each of the adaptation options.
- Producing probability distributions for the NPV and Benefit-Cost Ratios of each adaptation strategy.
- Determining the best year to implement the adaptation strategy.

3.7.2 Economic Model Formulas

The following formulas have been used in the economic model:

Equation 1 Net Present Value

$$Net\ Present\ Value\ (NPV) = PV\ Benefits - PV\ Damage\ Costs - PV\ Adaptation\ Invest.Costs$$

Equation 2 Present Value of Damage Costs

$$\text{Present Value Damge Costs } = \sum_{i=1}^{n} \frac{Annual\ Damage\ Costs_i}{(1 + Discount\ Rate)^i}$$

Where

- n = 88 y and the Discount Rate = 3 %[10]; and
- Annual damage costs have been determined from predicted water levels and the appropriate damage curves.

Equation 3 Present Value of Investment in Adaptation Option

$$Present\ Value\ of\ Adaptation\ Investment\ Cost = \sum_{i=1}^{n} \frac{Cost\ of\ Adaptation\ Option_i}{(1 + Discount\ Rate)^i}$$

Equation 4 Present Value of Benefits

$$\text{Present Value of Benefits} = \sum_{i=1}^{n} \frac{Annual\ Reduction\ in\ Damage\ Costs_i}{(1 + Discount\ Rate)^i}$$

Given that the annual reduction in damage costs is equivalent to the annual cost without adaptation minus the annual cost with adaptation, the Present Value of Benefits can also be written as:

Equation 5 Present Value of Benefits (Alternate form)

$$\text{Present Value of Benefits} = \sum_{i=1}^{n} \frac{Annual\ Cost\ without\ Adaptation_i - Annual\ Cost\ With\ Adaptation_i}{(1 + Discount\ Rate)^i}$$

Equation 6 Benefit Cost Ratio (Type 1)

$$Benefit\ Cost\ Ratio = \frac{Present\ Value\ of\ Benefits}{Present\ Value\ of\ Adaptation\ Investment\ Cost}$$

Equation 7 Benefit Cost Ratio (Type 2)

$$Benefit\ Cost\ Ratio = \frac{Present\ Value\ of\ Benefits}{Present\ Value\ of\ Adaptation\ Investment\ Cost + Residual\ Damage\ Costs}$$

[10] Sensitivity on this parameter is undertaken in Section 3.9.1.

3.7.3 Example Model Outputs

The economic model has been utilised to simulate many thousands of years of potential water level events which in turn provides many thousands of PV estimates for the costs and benefits associated with each of the adopted adaptation strategies. These present values for costs and benefits are then used by the model to determine the probability distribution of the NPV for the adaptation strategy in each location.

Figure 11 provides an example probability distribution of the PV of the damage costs predicted for a location without any adaptation strategy in place (or as experienced during *Maintain Status Quo)*. The positive skew in the distribution of costs above the mean value (which is approximately $1000 M) indicates those 88 y periods that could be quite 'active', whereby large storm tide events have caused significant damage. This result highlights the need to use a stochastic *Monte Carlo* simulation approach to provide insight into the full range of potential water level episodes and thus the costs that could be incurred during the planning period.

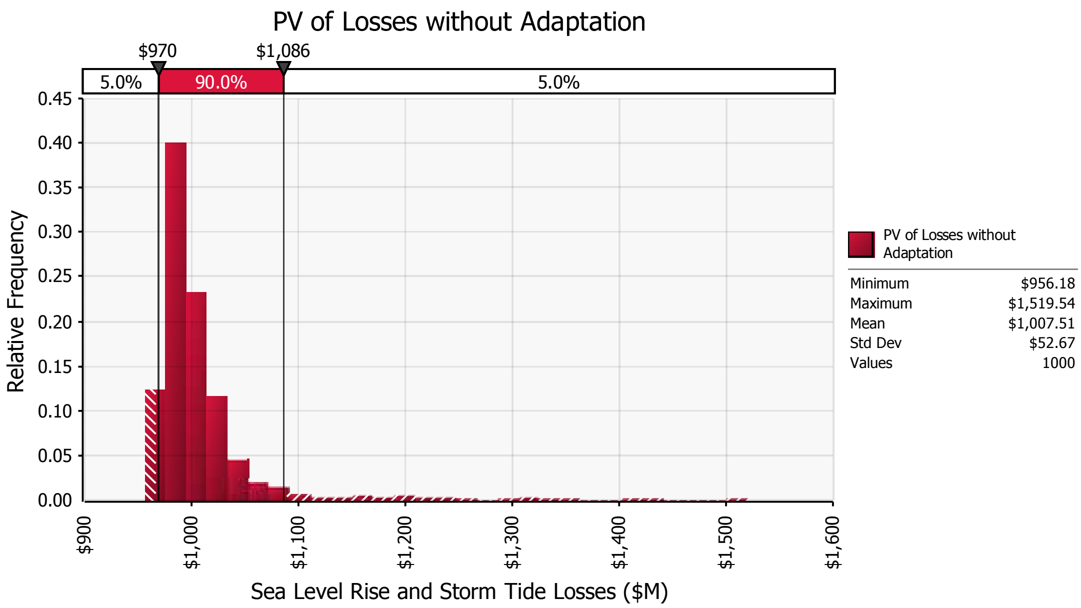

Figure 11 Distribution of PV damages/asset losses estimates based on 1,000 88 y water level renditions

Another example model result is provided in Figure 12 for the Townsville Inner Suburbs *Defend* option. In this example, implementation of the chosen adaptation option is assumed to be completed by 2030. The figure presents the resultant statistical distribution of BCR's based on a simulation of 1000 separate renditions of 88 year periods. The resulting mean BCR of 4.8 indicates that the benefits of implementing a *Defend* option in 2030 would be almost 5 times the cost of its implementation and thus represents a potentially economically viable project to have completed by this time (NPV also >0).

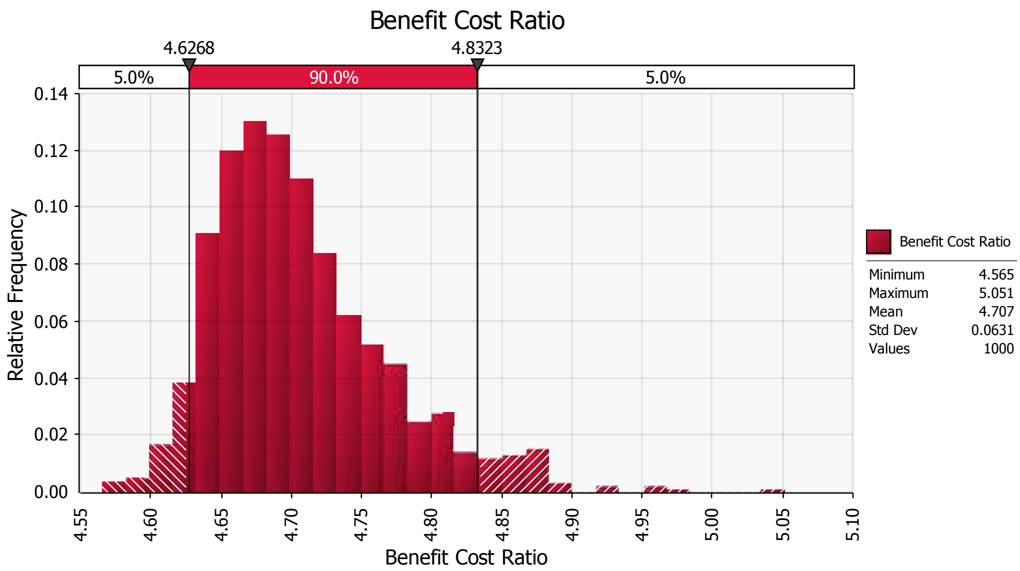

Figure 12 Distribution of benefit-cost ratio results of an adaptation option by 2030 based on 1000 separate 88 y renditions

3.7.4 Optimising the year of implementation

By systematically modifying the year of implementation, the mean NPV and mean BCR can be plotted as a function of the year. This has been undertaken using the Palisade™ Goal Seek function to find the year that maximises the NPV and BCR.

Again, using the Townsville Inner Suburbs *Defend* option as an example, Figure 13 provides the variation of the minimum, mean, maximum, 5 and 95 percentile BCR for the simulated planning period (refer Figure 12 for the context of these metrics relative to a mean value). Each simulation has assumed a different year of implementation of the adaptation option to obtain an understanding of when the maximum benefit can be achieved.

The results indicate that the NPV and BCR is maximised in the year 2027 and that the spread of the distribution (the difference between the 95% and 5% lines) is reasonably narrow.

The development of the NPV and BCR can be further appreciated by reviewing the different contribution to the NPV and BCR results as provided in Figures 13 and 14.

- The **purple line** indicates the mean PV[11] of damages incurred over the 88 y period without adaptation (under *Maintain Status Quo*). It is noted that as *Maintain Status Quo* is never actually 'implemented' there is no variation as a function of year. For Townsville this is estimated at $1008 M;
- The **blue line** provides the mean PV of the investment cost associated with implementing the *Defend* option, i.e. the cost of construction. For the Townsville *Defend* option the optimal year of construction is estimated at 2027 and results in a corresponding PV of $190 M;
- The **red line** indicates the mean PV of residual damage costs associated with the *Defend* option constructed. This would include damage/loss prior to implementation and any overtopping of the structure following implementation. Review of the figure indicates there is rapid increase in the total community loss if works are delayed beyond 2027. If the decision to adapt is deferred indefinitely, the cost of adaptation will eventually equal the loss without adaptation by 2100 (*Maintain Status Quo* costs);

[11] The plots in Figure 14 and those provided in Section 3.8 are based on the mean results from Monte-Carlo Analyses.

- The **green line** indicates the mean PV of the benefits due to construction of the *Defend* option. This is essentially the reduction in damage and loss due to construction of the *Defend* option (PV of loss without adaptation – PV of Loss with *Defend* option implementation (**purple – red**); and

- The **lighter blue line** provides the mean NPV for the project. This line represents the net present value of all of the costs and benefits associated with implementation of the adaptation strategy (the project).

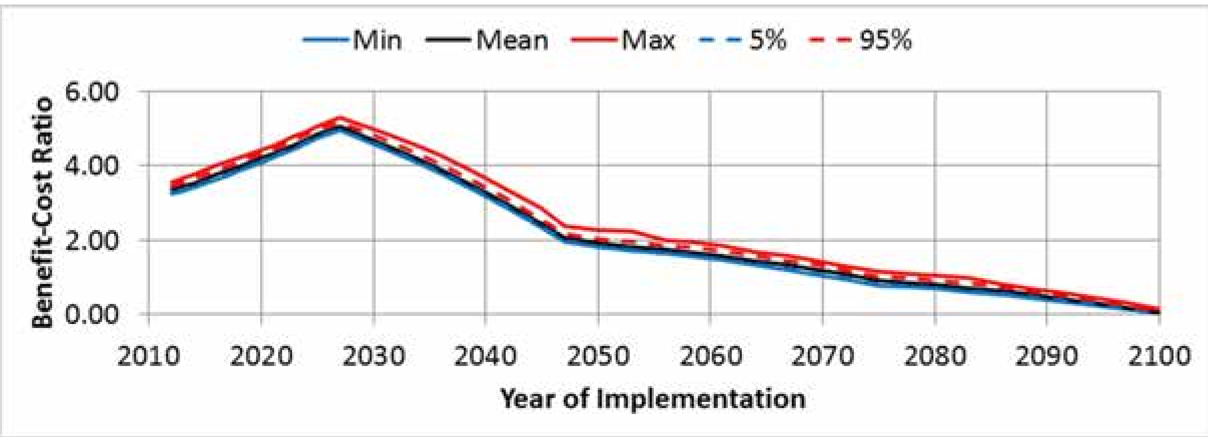

Figure 13 Example of multiple year simulations providing an appreciation of the potential optimal timing of an adaptation option.

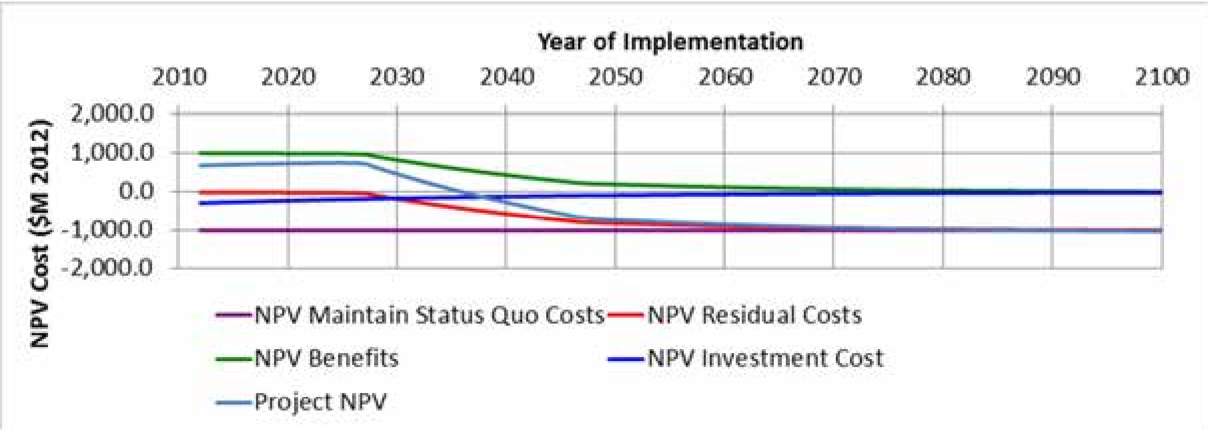

Figure 14 Example of multiple year simulations providing an appreciation of the potential optimal timing and PV cost variation throughout the 88 y study period.

The results for each locality have been presented in a similar manner and are provided in Section 3.8. It should be noted that there may not always be a single optimum timing for adaptation. This can occur where there is interaction between the sea level rise only effects and the storm tide impacts (such that an early adaptation can avoid future storm tide damage), the distribution of the vulnerability within the locality and the role of the discount rate. Saunders Beach *Retreat* is one such example.

3.7.5 Assessing the Economic Viability of Adaptation Options

To assess the overall economic viability of each adaptation option for a given locality, the following questions need to be considered:

- Does the adaptation option provide a positive NPV?
- Does the adaptation option provide an NPV that is greater than the Maintain Status Quo Option?
- Is the cost-benefit ratio of the project >1?
- Is the cost of implementing the adaptation option prohibitive?

As an example, each of the key economic results for the Townsville Inner Suburbs *Maintain Status Quo, Retreat and* Defend *Option 1* strategies are provided in Table 9.

The resulting NPV for each option is -$1008 M, -$215 M and +$724 M respectively. This indicates:

- As the NPV of the *Defend* option is positive, this is an economically viable option. This result is supported by a BCR of greater than one. The investment cost associated with the defend option is also less than the investment cost required for the retreat option. As such, further consideration should be given to this option to determine if and how it could be funded.
- The *Retreat* option while not economically viable due to a negative NPV still results in a saving of approximately $793 M to the Townsville community when compared with adopting a *Maintain Status Quo* option (i.e. $M 215-(-$M1008)=$M793).

Table 9 Key Economic Results for Townsville (all amounts in $M)

Adaptation Option	Optimal Timing of Adaptation (Year)	PV of Adaptation Investment Cost ($M2012)	PV Residual Damage or Loss ($M2012)	PV Total Adaptation Cost ($M2012)	PV Benefits ($M2012)	NPV ($M2012)	Benefit Cost Ratio (BCR)
Maintain Status Quo	NA	NA	NA	-1008.0	0.0	**-1008.0**	NA
Retreat	2027	-1132.2	-45.7	-1177.9	962.4	**-215.5**	0.9
Defend Option 1	2027	-190.2	-47.1	-237.3	961.2	**724.0**	5.1

Note: Tabulated negative values indicate costs or losses

3.8 Economic Modelling Results

A summary of the economic viability of each adaptation option is provided in Table 11. The full range of NPV and BCR results is provided in Attachment D.

Table 11 provides a summary of:

- The NPV of the 'Status Quo Approach';
- The NPV estimated for each adaptation option;
- The NPV benefit provided by the adaptation option when compared to the Status Quo Approach;
- The optimum year of implementation of the adaptation option;
- The PV of the adaptation investment cost;
- The PV of the residual damages/loss;
- The total cost of adaptation (investment + residual damage costs);
- The PV of adaptation benefits (reduction in damage or loss);
- The benefit cost ratios based on benefits / investment costs(B/C_1); and
- The benefit cost ratios based on benefits / total costs (B/C_2).

Results indicate that:

- As expected, the Project PV's of a *Maintain Status Quo* approach are negative and range from $M-0.8 (at Mutamee) to $M-1008 (at Townsville).
- In five(5) of the Localities, there exists an adaptation option that when implemented would result in a positive Project PV (and B/C ratio) outcome. These areas and the associated adaptation options include:
    - Townsville (*Defend*); NPV = $M 724M; $B/C_2 = 4.05$
    - Industrial area (*Defend*); NPV = $M167; $B/C_2 = 6.20$
    - Oonoonba (*Defend*); NPV = M$127; $B/C_2 = 8.75$
    - Picnic Point WTP (*Defend* Option); NPV = M$117; $B/C_2 = 11.6$
    - Mt St John (*Defend*); NPV = M$8.42; $B/C_2 = 3.33$

It is noted that all of these adaptation options are '*Defend* Options', and that positive NPV outcomes were not predicted for any *Retreat* or *Accommodate* options in any of the Localities.

Importantly, the positive NPV associated with each of the *Defend* strategies is also greater than the NPV of *Maintain Status Quo* at these 5 locations. This indicates that implementation of the *Defend* adaptation options at these locations has the potential to be economically viable.

In 18 of the Localities, it was found that none of the adaptation strategies considered would yield a positive NPV if implemented.

However, in 14 of these 18 study areas the NPV of the adaptation strategy (although negative) is greater (less negative) than then NPV of the *Maintain Status Quo* approach. This indicates there is potential to reduce the damage costs associated with the *Maintain Status Quo* approach by funding the implementation of adaptation options in these areas.

In these 14 study areas, the adaptation strategies are all *Retreat* strategies, except in the Pallarenda and Picnic Bay Localities where *Accommodate* and *Defend* are the more economically viable (yet negative NPV) options respectively.

Of these 14 study areas, five (5) of the study areas have positive benefit-cost ratios despite the negative NPV associated with the adaption strategy. The location, strategy and benefit-cost ratio for these locations is provided below:

- Rollingstone Beach (Retreat, B/C_1 =1.1);
- Toomulla (Retreat, B/C_1 =1.2);
- Bluewater Beach (Retreat, B/C_1 =1.1);
- North Shore (Retreat, B/C_1 =1.4); and
- Cockle Bay (Lots) (Retreat, B/C_1 =1.1)

However, it is noted that the benefit-cost ratios for each of these locations are marginal and when residual costs are taken into account the B/C_2 ratios revert to values less than 1.

In the remaining four (4) study areas, none of the adaptation options considered produced an NPV outcome that was greater than the NPV of *Maintain Status Quo*. These areas were:

- Cungulla;
- Arcadia (Geoffrey Bay);
- Nelly Bay; and
- Bolger Bay Pump Station.

The results at these four locations indicate that none of the adaptation options investigated are economically viable.

Table 10 Summary of BCA Results

District	Locality	Adaptation Option	NPV Maintain Status Quo(MSQ)	NPV Project	NPV Project - NPV Maintain Status Quo	Optimal Year of Adaptation Implementation	PV of Adaptation Investment	PV of Residual Damage	PV Total Adaptation Cost (Optimal Year)	PV Adaptation Benefits	B/C_1	B/C_2	Is NPV of Project Positive?	Is Project More Economically Viable than MSQ? (Y/N)	B/C_1>1 ?	B/C_2>1 ?
			[A]	[B]	[B]-[A]	[C]	[D]	[E]	[F]=[D]+[E]	[G]	[H]=[G]/[D]	[I]=[G]/[F]				
Townsville Inner Suburbs	Townsville Inner Suburbs	Defend Option 1	-$1,008.01	$723.98	$1,731.98	2027	-$190.19	-$47.07	-$237.26	$961.24	5.05	4.05	Yes	Yes	Yes	Yes
Townsville North	Industrial Area	Defend	-$218.71	$167.66	$386.37	2027	-$12.67	-$19.55	-$32.22	$199.88	15.78	6.20	Yes	Yes	Yes	Yes
River South	Oonoonba	Defend	-$149.98	$126.90	$276.88	2027	-$9.65	-$6.73	-$16.38	$143.28	14.85	8.75	Yes	Yes	Yes	Yes
Magnetic Island	Picnic Point WTP	Defend	-$138.19	$116.85	$255.04	2028	-$0.70	-$10.32	-$11.02	$127.87	183.78	11.61	Yes	Yes	Yes	Yes
Townsville North	Mt St John	Defend	-$12.25	$8.42	$20.66	2027	-$3.39	-$0.22	-$3.61	$12.03	3.54	3.33	Yes	Yes	Yes	Yes
Townsville Inner Suburbs	Townsville Inner Suburbs	Retreat	-$1,008.03	-$215.54	$792.50	2027	-$1,132.25	-$45.66	-$1,177.91	$962.37	0.85	0.82	No	Yes	No	No
River South	Oonoonba	Retreat	-$149.90	-$84.06	$65.84	2027	-$220.88	-$6.54	-$227.42	$143.36	0.65	0.63	No	Yes	No	No
Saunders Beach	Saunders Beach	Retreat	-$77.34	-$17.64	$59.70	2029	-$74.65	-$10.17	-$84.82	$67.17	0.90	0.79	No	Yes	No	No
Bushland Beach	Bushland Beach	Retreat	-$62.26	-$50.46	$11.81	2080	-$24.19	-$44.26	-$68.45	$18.00	0.74	0.26	No	Yes	No	No
Balgal Beach	Toomulla	Retreat	-$20.06	-$9.47	$10.60	2064	-$8.11	-$10.70	-$18.81	$9.34	1.15	0.50	No	Yes	Yes	No
Magnetic Island	West Point	Retreat	-$18.36	-$9.80	$8.56	2042	-$8.49	-$9.83	-$18.32	$8.52	1.00	0.47	No	Yes	Yes	No
Townsville North	Pallarenda	Accommodate	-$26.77	-$19.18	$7.59	2080	-$15.95	-$13.20	-$29.15	$9.97	0.63	0.34	No	Yes	No	No
Toolakea	Bluewater Beach	Retreat	-$10.34	-$3.20	$7.14	2034	-$5.92	-$3.81	-$9.73	$6.53	1.10	0.67	No	Yes	Yes	No
Magnetic Island	Horseshoe Bay	Retreat	-$19.66	-$12.58	$7.08	2036	-$16.36	-$7.94	-$24.30	$11.72	0.72	0.48	No	Yes	No	No
Bushland Beach	North Shore Green Field De	Retreat	-$9.46	-$4.33	$5.13	2039	-$2.88	-$5.46	-$8.34	$4.01	1.39	0.48	No	Yes	Yes	No
Rollingstone	Rollingstone	Retreat	-$5.38	-$1.86	$3.52	2036	-$2.80	-$2.22	-$5.02	$3.16	1.13	0.63	No	Yes	Yes	No
Balgal Beach	Balgal Beach	Retreat	-$19.24	-$16.03	$3.22	2080	-$11.00	-$12.10	-$23.10	$7.07	0.64	0.31	No	Yes	No	No
Toolakea	Toolakea	Retreat	-$15.11	-$12.09	$3.01	2080	-$7.63	-$9.78	-$17.41	$5.32	0.70	0.31	No	Yes	No	No
Magnetic Island	Cockle Bay (LOTS)	Retreat	-$1.08	-$0.16	$0.92	2027	-$0.76	-$0.24	-$1.00	$0.84	1.11	0.84	No	No	Yes	No
Rollingstone	Mutarnee	Retreat	-$0.83	-$0.61	$0.22	2053	-$0.54	-$0.45	-$0.99	$0.38	0.70	0.39	No	No	No	No
Magnetic Island	Picnic Bay	Defend	-$7.07	-$7.00	$0.08	2089	-$2.69	-$5.69	-$8.38	$1.39	0.51	0.17	No	No	No	No
Magnetic Island	Bolger Bay Pump Station	Defend	-$0.02	-$0.06	-$0.04	2089	-$0.06	-$0.01	-$0.07	$0.01	0.22	0.19	No	No	No	No
Magnetic Island	Picnic Bay	Retreat	-$7.15	-$7.78	-$0.63	2089	-$3.41	-$5.76	-$9.17	$1.39	0.41	0.15	No	No	No	No
Magnetic Island	Arcadia (Geoffrey Bay)	Retreat	-$6.36	-$7.06	-$0.69	2089	-$4.58	-$4.42	-$9.00	$1.94	0.42	0.22	No	No	No	No
Magnetic Island	Nelly Bay	Defend	-$5.83	-$7.38	-$1.56	2089	-$4.39	-$4.41	-$8.80	$1.41	0.32	0.16	No	No	No	No
South Land	Cungulla	Retreat	-$18.26	-$26.81	-$8.55	2047	-$25.93	-$9.57	-$35.50	$8.69	0.34	0.24	No	No	No	No
Townsville North	Pallarenda	Retreat	-$22.97	-$45.32	-$22.35	2080	-$41.48	-$13.40	-$54.88	$9.56	0.23	0.17	No	No	No	No

Notes:

(blue): Postitive Project NPV, and NPV of Project > NPV of Maintain Status Quo
(grey): Negative Project NPV, but NPV of Project > NPV of Maintain Status Quo
(pink): Negative Project NPV, and NPV of Project < NPV of Maintain Status Quo

3.8.1 Exclusions

Those areas not included in the BCA process are outlined in Table 11.

Table 11 Urban localities excluded from BCA

District	Locality	Reason for Exclusion
Balgal Beach	Balgal Beach South	Not intended for development intensification
	Toomulla South	Not intended for development intensification
Toolakea	Aquaculture Area	Privately held
Saunders Beach	Saunders Beach South	Not intended for development intensification
Bushland Beach	Batley Parade / Black River Settlement	Not intended for development intensification
Townsville North	Airport (Defence)	Defence
	Shelley Beach/Northern Tip (Common)	Not intended for development intensification
Townsville Inner Suburbs	The Strand	TCC have stated that the current coastal protection strategy will be continued at The Strand, a culturally significant area of Townsville. While an accommodate option was indicated by TCC to be the preferred option at this location, both property and infrastructure within this locality are not affected by the 100 y Return Period storm surge event. It is noted that larger events can impact the locality but adaptation to larger events is outside the scope of this study. Due to the existing seawall, sea level rise is unlikely to cause landward erosion and this avoids the need to retreat.
	Marina/Casino	Privately held.
	Port of Townsville	Port of Townsville
Stuart	Zinc Plant	Privately held
	Stuart/Cleveland Bay STP:	The datasets provided by EHP were unsuitable for analysis at this location
South Land	Cleveland Palms	Not intended for development intensification
Magnetic Island	Nelly Bay Harbour	DTMR
	Radical Bay	Currently undeveloped land. Risks associated with coastal hazards should be considered if land is proposed for development.

3.9 BCA Modelling – Sensitivity Analysis

3.9.1 Sensitivity Analysis to Discount Rate

Sensitivity testing of the assumed discount rate has been completed using the Townsville *Defend 1* option as an example. Figure 15 provides the results of stochastic modelling undertaken with a 1.4 (Stern 2006), 4.0, 7.0 and 9.0% discount rate. Review of the results indicates:

- Application of differing discount rates leads to variation in the peak mean BCR of between 2.72 and 6.56. As expected the usage of higher discount rates reduces the calculated benefits for future generations.
- The overall timing of optimal implementation of adaptation in 2027 does not markedly differ. A large driver of this timing is the rate of property loss due to projected sea level rise.

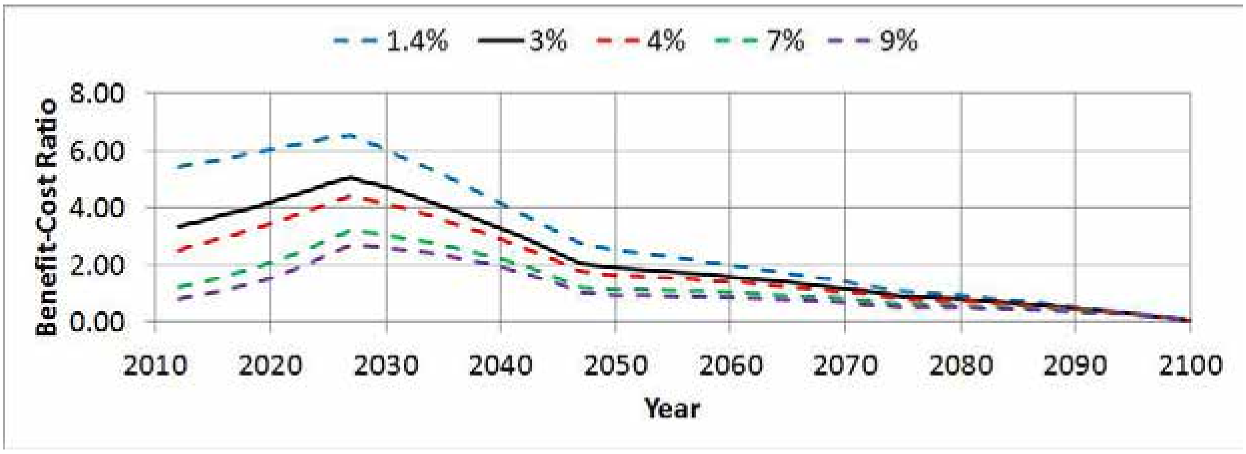

Figure 15 Mean benefit-cost ratios for Townsville Inner Suburbs Defend 1 with discount rates of 1.4 % (blue dash), 3% (black), 4% (red dash), 7% (green dash) and 9% (purple dash)

3.9.2 Sensitivity Analysis to Sea Level Rise Projections

Within this section the sensitivity to sea level rise uncertainty under a projected 0.8 and 1.1 m sea level rise by 2100 is investigated using the example locations of the Townsville Inner Suburbs (Refer Figure 16) and Pallarenda (refer Figure 17). Review of the results indicates:

- By increasing the severity of sea level rise by 2100, the benefits associated with intervention are also increased.
- By increasing the severity of sea level rise the optimal year of intervention is brought forward in time. This is as much as 20 y earlier in the case Pallarenda and between 5-10 y for the Townsville Inner Suburbs.
- This timing change is largely a function of the increased number of properties affected by sea level rise, i.e. storm tide impacts are not the major driver of optimal implementation timing.

Figure 16 Townsville Inner Suburbs Defend 1 and Retreat under 0.8 m and 1.1 m SLR

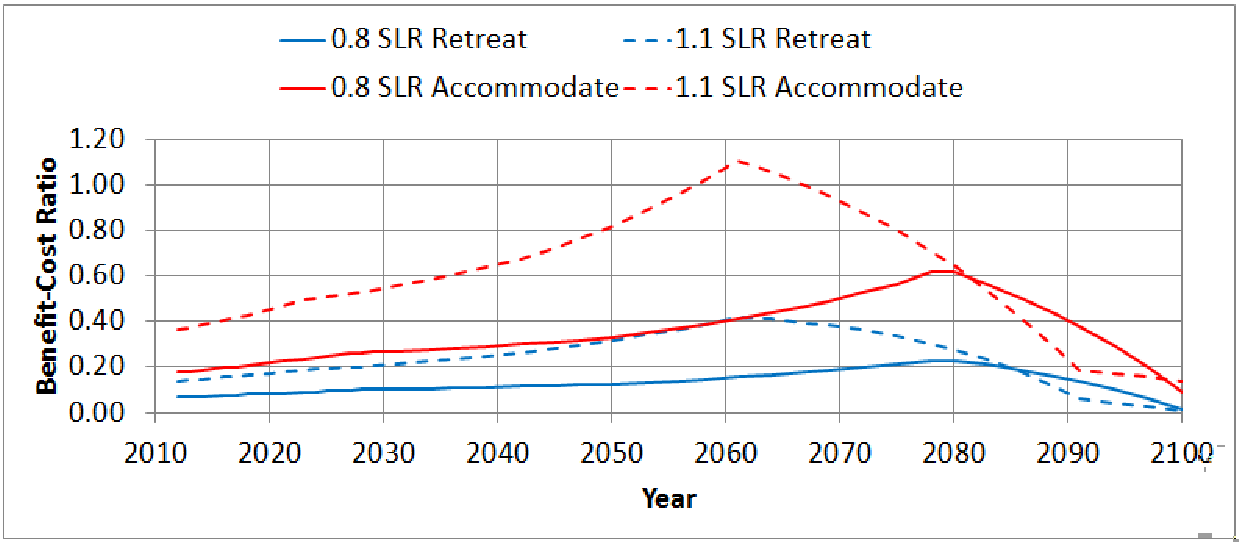

Figure 17 Pallarenda Accommodate and Retreat under 0.8 m and 1.1 m SLR

3.9.3 Sensitivity to Population Growth Assumptions

The advantage of adopting a *Defend* or *Accommodate* strategy is the potential for growth or intensification in the region landward of the proposed adaptation measure. This section details the method by which the applied population growth index was developed and uses Townsville *Defend 1* to test the economic result sensitivity to assumptions concerning population growth.

All available household and population projection data was sourced from Queensland Government's Office of Economic and Statistical Research (OESR) and the Australian Bureau of Statistics (ABS) with reports from other sources used to verify the projections (refer below).

Population data is based on:

Year	Data source	Reference
2006-2012	OESR. Estimated resident population (ERP) by local government area (LGA) and statistical local area (SLA), Queensland, 2001 to 2011. Townsville LGA	http://www.oesr.qld.gov.au/products/tables/erp-lga-reformed-qld/index.php
2012-2031	OESR. Projected population (medium series), by statistical area 3, Queensland, 30 June, 2011 to 2031.	http://www.oesr.qld.gov.au/products/tables/proj-pop-series-sd-qld/index.php

	Townsville LGA	
2032-2100	GHD Projections: Applying annual average Queensland projected population growth to 2056 using linear regression forecasting (ABS 3222.0; (projections) Queensland Government population projections, 2011 edition (medium series) data tables). Townsville LGA	http://www.abs.gov.au/Ausstats/abs@.nsf/mf/3222.0

Household data is based on:

Year	Data source	Reference
2006-2012	OESR Historical data: Projected dwellings (a) (medium series) by local government area, Queensland, 30 June, 2006 to 2012. Townsville LGA	http://www.oesr.qld.gov.au/products/tables/proj-dwellings-medium-series-lga-qld/index.php
2012-2031	OESR. Projected dwellings (a) (medium series) by local government area, Queensland, 30 June, 2006 to 2031 (ABS 3236.0). Townsville LGA	http://www.oesr.qld.gov.au/products/tables/proj-dwellings-medium-series-lga-qld/index.php
2032-2100	GHD Projections: Linear regression forecasting of Queensland projected household growth to 2031. Townsville LGA	http://www.oesr.qld.gov.au/products/publications/household-dwelling-proj-qld/index.php

Verification of the data series was undertaken, running correlations with national ABS projections and references from other reports such as the KPMG Demographic Analysis of Townsville (2011) and Past Demographic Trends in Australia and Population Projections to 2100.

The data is presented as an index as provided in Figure 18, with the base year 2012.

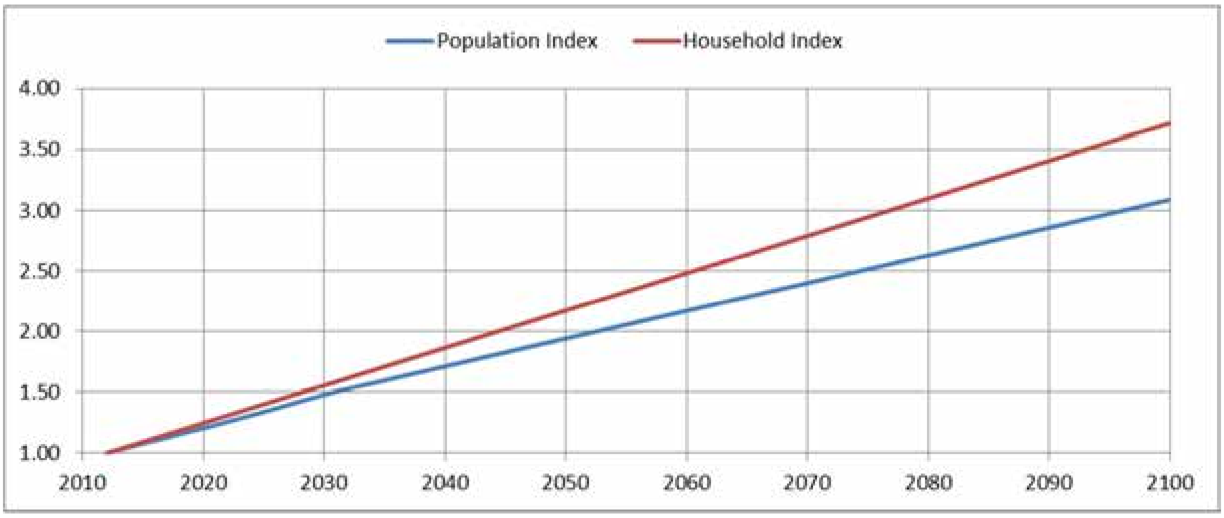

Figure 18 Population and Household Growth Index

The BCRs developed with and without growth allowances are provided in Figure 18 and indicate:

- The full economic benefit of adaptation is not realised unless the potential for growth/intensification in the lee of proposed accommodate and defend options is accounted for; and
- That the results provided in this report for accommodate and defend options likely underestimate the BCRs that would result if growth was fully considered.

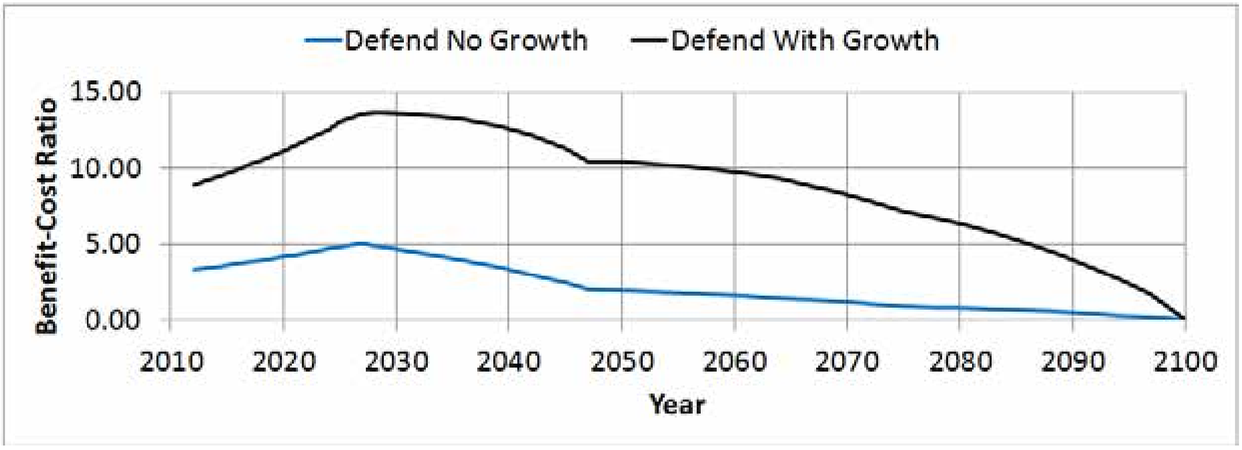

Figure 19 Townsville Inner Suburbs Defend 1 under population growth and no population growth assumptions

4. Conclusion

An integral component of the Townsville CHAS Pilot has been the economic evaluation of potential coastal hazard adaptation options for up to 11 coastal hazard areas. This economic evaluation has combined multi-criteria analysis (MCA) and benefit-cost analysis (BCA) to produce a methodology that uses the strengths of each assessment approach to determine the best adaptation options for implementation. The key output from this report is the selection of preferred climate adaptation options for future consideration by Townsville City Council.

Adaptation options for input to the MCA were developed through a number of GHD, Project Board, TCC and Stakeholder workshops with the final adaptation options for input to the MCA workshop provided in Attachment A. The MCA scoring workshop was undertaken at GHD's offices, which involved members of the project team from TCC, LGAQ, EHP and GHD. During this workshop each of the adaption options were scored under a range of environmental, social and economic sub-criterion. The highest ranking adaptation options from this workshop were identified and selected for further assessment within the BCA. In some cases where the results were sensitive to the adopted weighting more than one adaptation option was selected for input to the BCA. A summary of the MCA results are provided in Table 4.

To assess the economic feasibility and optimal timing of climate change adaptation intervention, selected adaptation options from the MCA were modelled using a CHAS specific BCA modelling framework for each Locality. This framework relied on stochastic/Monte Carlo simulation methods to generate many potential 88 y future water level timeseries, which provided an appreciation for the full range of possible storm tide impacts that could impact the Townsville region in association with the projected rate of sea level rise. The economic viability of options was assessed through the development of net present values and benefit –cost ratios.

To provide understanding of the economically optimal timing of intervention a further set of simulations were performed assuming different years of intervention ranging from 2012 to 2100 A summary of the BCA results are provided in **Error! Reference source not found.** and indicates:

- As expected, the economic viability of undertaking a *Maintain Status Quo* approach is limited and other forms of adaptation should be preferred over this option (although there are some exception mentioned below);
- In 5 Localities, there exists an adaptation option that when implemented would result in a positive economic outcome: This includes:
  - Mt St John (*Defend*);
  - Industrial area (*Defend*);
  - Townsville Inner Suburbs (*Defend Option 1*);
  - Oonoonba (*Defend*); and
  - Picnic Point WTP (*Defend* Option).
- In 18 Localities, it was found that none of the adaptation strategies considered would be considered as economically viable. However, in 14 of these 18 Localities the assessment indicates there is potential to reduce the damage or loss associated with the *Maintain Status Quo* approach by funding *Defend*, *Accommodate* or *Retreat* adaptation options in these areas;
- In the remaining four (4) study areas invested in the BCA, none of the adaptation options considered produced an outcome that was greater than the *Maintain Status Quo* result These areas were:

- Typically *Defend* or *Accommodate* options result in higher economic viability than *Retreat*, In the case of *Retreat*, low BCRs can be largely attributed to the fact that assets subject to a *Retreat* strategy are at some point actually lost or relocated from a given Locality. While benefits due to the *Defend* and *Accommodate* are due to the protection of assets, the benefits provided by *Retreat* are primarily due to the timely removal of assets to avoid future impacts from storm tide and sea level rise. Due to this affect, the viability of *Retreat* options should still be considered even if the BCR remains less than one;
- While Table 10 provides the 'optimal' year for implementation it is noted that the BCR of a particular option may remain economically viable for an extended period for consideration, e.g. Mt St John *Defend* results in BCRs of above 1 until approximately 2045 although the optimal year is indicated as 2027 (refer Attachment D); and
- To reduce impact on the community it may be beneficial to implement options prior to the 'optimal' economic timing which is based solely on the BCR. This prior implementation would consider the timing at which community assets are affected as indicated by the PV with adaptation results throughout Section 3.7.

The economic assessment outlined within this report provides a robust and repeatable method on which future CHAS studies can be based and, as will likely be necessary, made more detailed over time. While every effort has been made with the resources available in this study to obtain an objective analysis of the many complex alternatives, it is inevitable that there remains an element of subjectivity of some aspects.

Importantly, the BCA undertaken under CHAS is the first step of a long path to accurately define the total potential benefits and costs to the Townsville region. Should TCC decide to prepare a BCA for federal funding application (e.g. through Infrastructure Australia), further work will be required. Future CHAS studies should therefore be undertaken to further refine these analyses where warranted.

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Attachments

Attachment A MCA Scoring Workbook

			Adaptation effectiveness	Climate uncertainty	Social and environmental impacts				Complexity and cost						TCC
			AE3	C1	S&E1	S&E2	S&E3	S&E4	C&C1	C&C2	C&C3				
			Severity of inundation on humans as well as buildings and community infrastructure	Flexibility to respond to unexpected climate outcomes (upside / downside)	Impact on access to coastal areas for recreation (e.g. camping, fishing, swimming)	Impact on natural coastal ecosystems	Indirect economic / industry impacts (e.g. tourism, fishing)	Impact on cultural heritage and landscape	Capital cost	Complexity of implementation (technical, stakeholder / social, institutional)	Operating and maintenance costs				
			0.35	0.1	0.05	0.1	0.1	0.05	0.1	0.05	0.1	Revised			
Mutarnee			0.25	0.1	0.05	0.1	0.15	0.05	0.1	0.1	0.1		Preferred		
MITIGATION TYPE	ADAPTATION OPTIONS	DESCRIPTION	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11			Unweighted	
Retreat	Land swap	Agriculture to be moved out of inundated area	Ranked 1st	Ranked 1st	Ranked 1st	Ranked 1st	Ranked 1st	Ranked 1st	Ranked 2nd	Ranked 1st	Ranked 1st				3B
	Planning scheme modifications	(dyke impractical - likely issues with ground water and salinity)	100	0	0	100	100	0	0	100	100	70	70	56	
Maintain Status Quo	Property Searches include a hazard note		Ranked 2nd	Ranked 1st	Ranked 1st	Ranked 2nd	Ranked 2nd	Ranked 1st	Ranked 1st	Ranked 2nd	Ranked 2nd				5A
	Planning Scheme Modification		0	0	0	0	0	0	100	0	0	10	10	11	
	Public Education														
	Allow Natural Processes														
	Consider Public Response														
	Property Owners Responsibility														
	Rates review of properties within coastal hazard area														

Rollingstone Beach

MITIGATION TYPE	ADAPTATION OPTIONS	DESCRIPTION	AE3	C1	S&E1	S&E2	S&E3	S&E4	C&C1	C&C2	C&C3	Revised	Preferred	Unweighted	TCC
Accommodate	86	Including Beach Nourishment, Seawalls and Groynes either on their own or in combination. Raise as required to protect existing caravan park	Ranked 2nd	Ranked 2nd	Ranked 1st	Ranked 2nd	Ranked 1st	Ranked 2nd	Ranked 3rd	Ranked 1st	Ranked 3rd				3B
	Land filling above flood level	Natural higher areas to be further raised above permanent inundation level	50	0	100	50	100	50	0	100	0	45	50	50	
	House retrofitting and design standards	Raising habitable floor level													
	Flood proofing public infrastructure	Localised raising , and /or improved drainage and /or improved capping of connecting roads would also be required to maintain access													
	Planning scheme modifications														
Retreat	Land purchase and resumption Land-use change	Land Purchase and Resumption and/or Land swap for land that is permanently inundated	Ranked 1st	Ranked 1st	Ranked 2nd	Ranked 1st	Ranked 2nd	Ranked 1st	Ranked 2nd	Ranked 2nd	Ranked 1st				3B
	Planning scheme modifications	Land-use Change for areas not developed yet but under permanent risk	100	100	0	100	80	100	86	50	100	89	86	80	
		Planning Scheme Modifications to reflect land-use change													
	Flood proofing public infrastructure	Connecting road and services will need to be maintained during the period of retreat													
Maintain Status Quo	Property Searches include a hazard note		Ranked 3rd	Ranked 1st	Ranked 2nd	Ranked 3rd	Ranked 3rd	Ranked 3rd	Ranked 1st	Ranked 3rd	Ranked 2nd				4A
	Planning Scheme Modification		0	100	0	0	0	0	100	0	10	21	21	23	
	Public Education														
	Allow Natural Processes														
	Consider Public Response														
	Property Owners Responsibility														
	Rates review of properties within coastal hazard area														

			Adaptation effectiveness	Climate uncertainty	Social and environmental impacts				Complexity and cost						TCC
			AE3	C1	S&E1	S&E2	S&E3	S&E4	C&C1	C&C2	C&C3				
			Severity of inundation on humans as well as buildings and community infrastructure	Flexibility to respond to unexpected climate outcomes (upside / downside)	Impact on access to coastal areas for recreation (e.g. camping, fishing, swimming)	Impact on natural coastal ecosystems	Indirect economic / industry impacts (e.g. tourism, fishing)	Impact on cultural heritage and landscape	Capital cost	Complexity of implementation (technical, stakeholder / social, institutional)	Operating and maintenance costs				
			0.35	0.1	0.05	0.1	0.1	0.05	0.1	0.05	0.1	Revised			
Balgal Beach			0.25	0.1	0.05	0.1	0.15	0.05	0.1	0.1	0.1		Preferred		
MITIGATION TYPE	ADAPTATION OPTIONS	DESCRIPTION	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11			Unweighted	
Accommodate	Beach nourishment	Beach nourishment	Ranked 2nd 50	Ranked 2nd 0	Ranked 1st 100	Ranked 2nd 50	Ranked 1st 100	Ranked 2nd 50	Ranked 3rd 0	Ranked 1st 100	Ranked 2nd 20	47	52	52	4B
	Groynes	Groyne at north tip of the beach													
	Dune construction	Beach construction and regeneration													
		Increase height and width of dunal area (dune crest at storm tide level) without removing the possibility of the creek changing its course													
	Seawalls	Seawall at the south/west side of the northern properties along the creek to minimise risk of creek crossing through the community													
		North and South Balgal - protect the landward end of the pontoon for sea-level rise (keeping operational function during high water level)													
	Planning scheme modifications	Planning scheme modifications for remaining land under threat to avoid new development in hazard zone													
	House retrofitting and design standards	House retrofitting and design standards for central and southern Balgal where affected by storm tide													
		Retrofitting for fluvial flooding at North Balgal													
Retreat	Land purchase and resumption	Land purchase and resumption and/or Land swap for land that is permanently inundated for north and south Balgal	Ranked 1st 100	Ranked 1st 100	Ranked 2nd 0	Ranked 1st 100	Ranked 2nd 80	Ranked 1st 100	Ranked 2nd 29	Ranked 2nd 40	Ranked 1st 100	82.9	79	72	3A
	Land-use change	Land-use change for areas not developed yet but under permanent risk													
	Flood proofing public infrastructure	Connecting road and services will need to be maintained during the period of retreat													
	Planning scheme modifications	Planning Scheme Modifications to reflect land-use change													
Maintain Status Quo	Property Searches include a hazard note		Ranked 3rd 0	Ranked 1st 100	Ranked 2nd 0	Ranked 3rd 0	Ranked 3rd 0	Ranked 3rd 0	Ranked 1st 100	Ranked 3rd 0	Ranked 2nd 0	20	20	22	4A
	Planning Scheme Modification														
	Public Education														
	Allow Natural Processes														
	Consider Public Response														
	Property Owners Responsibility														
	Rates review of properties within coastal hazard area														

Toomulla – including Sewerage Treatment Plant															
MITIGATION TYPE	ADAPTATION OPTIONS	DESCRIPTION													
Accommodate	House Retrofitting and Design Standards	Modify house so habitable floor levels above storm tide level	Ranked 2nd 0	Ranked 2nd 0	Ranked 2nd 0	Ranked 2nd 0	Ranked 1st 100	Ranked 1st 0	Ranked 1st 100	Ranked 1st 100	Ranked 2nd 0	25	35	33	4 A B
	Flood Proofing Public Infrastructure	Raise connecting roads between two parts of Toomulla and highway for sea level rise													
		Protect sewerage treatment plan from storm tide inundation													
	Coastal Protection	Seawall along fronting beach between headlands													
		Potential creek mouth relocation, training wall to prevent erosion													
Retreat	Land purchase and resumption Land-use change	Land Purchase and Resumption and/or Land swap for land that is permanently inundated	Ranked 1st 100	Ranked 1st 100	Ranked 1st 100	Ranked 1st 100	Ranked 2nd 0	Ranked 1st 0	Ranked 2nd 0	Ranked 2nd 0	Ranked 1st 100	70	60	55	4 A B
	Planning scheme modifications Flood proofing public infrastructure	Land-use change for areas not developed yet but under permanent risk													
		Planning Scheme Modifications to reflect land-use change													
		Connecting road and services will need to be maintained during the period of retreat													

			Adaptation effectiveness	Climate uncertainty	Social and environmental impacts				Complexity and cost						TCC
			AE3	C1	S&E1	S&E2	S&E3	S&E4	C&C1	C&C2	C&C3				
			Severity of inundation on humans as well as buildings and community infrastructure	Flexibility to respond to unexpected climate outcomes (upside / downside)	Impact on access to coastal areas for recreation (e.g. camping, fishing, swimming)	Impact on natural coastal ecosystems	Indirect economic / industry impacts (e.g. tourism, fishing)	Impact on cultural heritage and landscape	Capital cost	Complexity of implementation (technical, stakeholder / social, institutional)	Operating and maintenance costs				
			0.35	0.1	0.05	0.1	0.1	0.05	0.1	0.05	0.1	Revised			
Toolakea			0.25	0.1	0.05	0.1	0.15	0.05	0.1	0.1	0.1		Preferred		
MITIGATION TYPE	ADAPTATION OPTIONS	DESCRIPTION	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11			Unweighted	
Accommodate	Coastal Protection	Including Beach Nourishment, Seawalls and Groynes either on their own or in combination. Raise as required to protect from sea level rise	Ranked 2nd	Ranked 2nd	Ranked 1st	Ranked 2nd	Ranked 1st	Ranked 2nd	Ranked 3rd	Ranked 1st	Ranked 2nd				5F
	House Retrofitting and Design Standards	Retrofit storm tide affected property	50	0	100	50	100	50	0	100	40	49	54	54	
	Flood Proofing Public Infrastructure	Increase level of road to maintain access													
Retreat	Land purchase and resumption Flood proofing public infrastructure	Land purchase and resumption and/or land swap for land that is permanently inundated	Ranked 1st	Ranked 1st	Ranked 2nd	Ranked 1st	Ranked 2nd	Ranked 1st	Ranked 2nd	Ranked 2nd	Ranked 1st				4 B F
	Land-use change	Connecting road and services will need to be maintained during the period of retreat	100	100	0	100	80	100	26	40	100	83	79	72	
	Planning scheme modifications	Land-use change for areas not developed yet but under permanent risk													
		Planning scheme modifications to reflect land-use change													
Maintain Status Quo	Property Searches include a hazard note		Ranked 3rd	Ranked 1st	Ranked 2nd	Ranked 3rd	Ranked 3rd	Ranked 3rd	Ranked 1st	Ranked 3rd	Ranked 3rd				4A
	Planning Scheme Modification		0	100	0	0	0	0	100	0	0	20	20	22	
	Public Education														
	Allow Natural Processes														
	Consider Public Response														
	Property Owners Responsibility														
	Rates review of properties within coastal hazard area														

Bluewater Beach															
MITIGATION TYPE	ADAPTATION OPTIONS	DESCRIPTION													
Retreat	Land Purchase and Resumption	Land Purchase and Resumption and/or Land swap for land that is permanently inundated	Ranked 1st	Ranked 1st	Ranked 1st	Ranked 1st	Ranked 1st	Ranked 1st	Ranked 2nd	Ranked 1st	Ranked 1st				4 B F
	Flood Proofing Public Infrastructure	Connecting road and services will need to be maintained during the period of retreat	100	0	0	0	100	100	0	100	100	65	65	56	
	Land-use Change	Land-use Change for areas not developed yet but under permanent risk													
	Planning Scheme Modifications	Planning Scheme Modifications to reflect land-use change													
Maintain Status Quo	Property Searches include a hazard note		Ranked 2nd	Ranked 1st	Ranked 1st	Ranked 1st	Ranked 2nd	Ranked 2nd	Ranked 1st	Ranked 2nd	Ranked 2nd				3B
	Planning Scheme Modification		0	0	0	0	0	0	100	0	0	10	10	11	
	Public Education														
	Allow Natural Processes														
	Consider Public Response														
	Property Owners Responsibility														
	Rates review of properties within coastal hazard area														

			Adaptation effectiveness	Climate uncertainty	Social and environmental impacts				Complexity and cost						TCC
			AE3	C1	S&E1	S&E2	S&E3	S&E4	C&C1	C&C2	C&C3				
			Severity of inundation on humans as well as buildings and community infrastructure	Flexibility to respond to unexpected climate outcomes (upside / downside)	Impact on access to coastal areas for recreation (e.g. camping, fishing, swimming)	Impact on natural coastal ecosystems	Indirect economic / industry impacts (e.g. tourism, fishing)	Impact on cultural heritage and landscape	Capital cost	Complexity of implementation (technical, stakeholder / social, institutional)	Operating and maintenance costs				
			0.35	0.1	0.05	0.1	0.1	0.05	0.1	0.05	0.1	Revised			
Saunders Beach			0.25	0.1	0.05	0.1	0.15	0.05	0.1	0.1	0.1		Preferred		
MITIGATION TYPE	ADAPTATION OPTIONS	DESCRIPTION	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11			Unweighted	
Accommodate	Coastal Protection	Including Beach Nourishment, Seawalls and Groynes and for Saunders Beach a Sea Levee either on their own or in combination. Raise habitable floor levels to reduce sea level rise impacts.	Ranked 2nd	Ranked 3rd	Ranked 1st	Ranked 2nd	Ranked 1st	Ranked 2nd	Ranked 2nd	Ranked 1st	Ranked 2nd				5F
	House Retrofitting and Design Standards	Retrofit storm tide affected property	50	0	100	50	100	50	21	100	40	51	56	57	
	Flood Proofing Public Infrastructure	Maintain access road													
	Planning scheme modification	Restrict further development in hazard areas													
Retreat	Land purchase and resumption Land-use change	Land Purchase and Resumption and/or Land swap for land that is permanently inundated	Ranked 1st	Ranked 1st	Ranked 1st	Ranked 1st	Ranked 2nd	Ranked 1st	Ranked 2nd	Ranked 2nd	Ranked 1st				4B
	Flood proofing public infrastructure	Land-use Change for areas not developed yet but under permanent risk Connecting road and services will need to be maintained during the period of retreat	100	100	0	100	80	100	0	40	100	80	76	69	
	Planning scheme modifications	Planning Scheme Modifications to reflect land-use change													
Maintain Status Quo	Property Searches include a hazard note		Ranked 3rd	Ranked 1st	Ranked 1st	Ranked 3rd	Ranked 3rd	Ranked 3rd	Ranked 1st	Ranked 3rd	Ranked 3rd	20	20	22	4B
	Planning Scheme Modification		0	100	0	0	0	0	100	0	0				
	Public Education														
	Allow Natural Processes														
	Consider Public Response														
	Property Owners Responsibility														
	Rates review of properties within coastal														

			Adaptation effectiveness	Climate uncertainty	Social and environmental impacts				Complexity and cost						
			AE3	C1	S&E1	S&E2	S&E3	S&E4	C&C1	C&C2	C&C3				
			Severity of inundation on humans as well as buildings and community infrastructure	Flexibility to respond to unexpected climate outcomes (upside / downside)	Impact on access to coastal areas for recreation (e.g. camping, fishing, swimming)	Impact on natural coastal ecosystems	Indirect economic / industry impacts (e.g. tourism, fishing)	Impact on cultural heritage and landscape	Capital cost	Complexity of implementation (technical, stakeholder / social, institutional)	Operating and maintenance costs		Weighted score	Unweighted score	TCC ranking
			0.35	0.1	0.05	0.1	0.1	0.05	0.1	0.05	0.1	Revised			
Main Residential Area			0.25	0.1	0.05	0.1	0.15	0.05	0.1	0.1	0.1				
MITIGATION TYPE	ADAPTATION OPTIONS	DESCRIPTION	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11				
Accommodate	Coastal Protection	Including Beach Nourishment, Seawalls and Groynes either on their own or in combination. to provide erosion and storm tide protection	Ranked 2nd 50	Ranked 2nd 0	Ranked 1st 0	Ranked 2nd 50	Ranked 1st 100	Ranked 2nd 50	Ranked 3rd 0	Ranked 1st 100	Ranked 2nd 50	45	50	44	3D
	House retrofitting and design standards	Raise habitable floor levels													
	Flood proofing public infrastructure	Maintain access road													
	Planning scheme modifications	Amend planning scheme to allow no future building below storm surge levels													
Retreat	Land purchase and resumption Land-use change	Land Purchase and Resumption and/or Land swap for land that is permanently inundated	Ranked 1st 100	Ranked 1st 100	Ranked 1st 0	Ranked 1st 100	Ranked 2nd 80	Ranked 1st 100	Ranked 2nd 2	Ranked 2nd 40	Ranked 1st 100	80.2	76.2	69	5B
	Flood proofing public infrastructure	Land-use Change for areas not developed yet but under permanent risk Connecting road and services will need to be maintained during the period of retreat													
	Planning scheme modifications	Planning Scheme Modifications to reflect land-use change													
Maintain Status Quo	Property Searches include a hazard note		Ranked 3rd 0	Ranked 1st 100	Ranked 1st 0	Ranked 3rd 0	Ranked 3rd 0	Ranked 3rd 0	Ranked 1st 100	Ranked 3rd 0	Ranked 3rd 0	20	20	22	5A
	Planning Scheme Modification														
	Public Education														
	Allow Natural Processes														
	Consider Public Response														
	Property Owners Responsibility														
	Rates review of properties within coastal hazard area														

New development area – North Shore (Greenfield Site)															
MITIGATION TYPE	ADAPTATION OPTIONS	DESCRIPTION	AE3	C1	S&E1	S&E2	S&E3	S&E4	C&C1	C&C2	C&C3	Revised	Weighted score	Unweighted score	TCC ranking
Retreat	Land purchase and resumption	Land Purchase and Resumption and/or Land swap for land that is permanently inundated	Ranked 1st 100	Ranked 1st 100	Ranked 1st 0	Ranked 1st 100	Ranked 2nd 40	Ranked 1st 0	Ranked 1st 100	Ranked 2nd 40	Ranked 1st 100	81	75	64	
		Connecting road and services will need to be maintained during the period of retreat													
	Land-use change	Land-use Change for areas not developed yet but under permanent risk													
	Planning scheme modifications	Planning Scheme Modifications to reflect land-use change													
Defend	Land filling above flood level	Raise any low lying land prior to development	Ranked 1st 100	Ranked 2nd 0	Ranked 1st 0	Ranked 2nd 0	Ranked 1st 100	Ranked 1st 0	Ranked 2nd 0	Ranked 1st 100	Ranked 2nd 0	50	50	33	5A
	Flood proofing public infrastructure	Ensure North Shore Bld is constructed at a level above inundation or raise above inundation level													
	Planning scheme modifications	Amend planning scheme to allow no future building below storm surge levels Relocating access road to higher land													
Maintain Status Quo	Property Searches include a hazard note		Ranked 3rd 0	Ranked 1st 100	Ranked 1st 0	Ranked 1st 100	Ranked 3rd 0	Ranked 1st 0	Ranked 1st 100	Ranked 3rd 0	Ranked 1st 100	40	40	44	4A
	Planning Scheme Modification														
	Public Education														
	Allow Natural Processes														
	Consider Public Response														
	Property Owners Responsibility														
	Rates review of properties within coastal hazard area														

			Adaptation effectiveness	Climate uncertainty	Social and environmental impacts				Complexity and cost						TCC
			AE3	C1	S&E1	S&E2	S&E3	S&E4	C&C1	C&C2	C&C3				
			Severity of inundation on humans as well as buildings and community infrastructure	Flexibility to respond to unexpected climate outcomes (upside / downside)	Impact on access to coastal areas for recreation (e.g. camping, fishing, swimming)	Impact on natural coastal ecosystems	Indirect economic / industry impacts (e.g. tourism, fishing)	Impact on cultural heritage and landscape	Capital cost	Complexity of implementation (technical, stakeholder / social, institutional)	Operating and maintenance costs				
			0.35	0.1	0.05	0.1	0.1	0.05	0.1	0.05	0.1	Revised			
The Strand			0.25	0.1	0.05	0.1	0.15	0.05	0.1	0.1	0.1		Preferred		
MITIGATION TYPE	ADAPTATION OPTIONS	DESCRIPTION	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11			Unweighted	
Accommodate	Beach Nourishment - Maintain existing foreshore protection system	Increase beach nourishment to maintain shore protection Modify buildings within Strand Park are potentially impacted	Ranked 2nd 0	Ranked 2nd 0	Ranked 1st 100	Ranked 2nd 0	Ranked 1st 100	Ranked 1st 100	Ranked 1st 100	Ranked 1st 100	Ranked 2nd 0	35	45	56	
Retreat	as per Townsville City		Ranked 1st 100	Ranked 1st 100	Ranked 2nd 0	Ranked 1st 100	Ranked 2nd 0	Ranked 2nd 0	Ranked 2nd 0	Ranked 2nd 0	Ranked 1st 100	65	55	44	

Townsville City: Ross Creek, South Townsville, Inner Suburbs, Railway Estate, Rowes Bay, Melrose Park, West End

MITIGATION TYPE	ADAPTATION OPTIONS	DESCRIPTION	AE3	C1	S&E1	S&E2	S&E3	S&E4	C&C1	C&C2	C&C3	Revised	Preferred	Unweighted	TCC
Defend 1 [Defend 1 seeks to defend Railway Estate, Rowes Bay and the rest of the city]	A. Ross River Levee B. Sea dikes and Storm tide barrier at Ross Creek (Defending here forms part of protection for the overall city in combination with Defence works at Rowes Bay and Railway Estate) C. Defend watercourse by providing sea dikes at Rowes Bay for all potential developable land taking into account drainage paths. Includes residential area along seafront, cemetery, and industrial area east of airport. Accommodate foreshore of Rowes Bay. (defending here forms part of protection for Melrose Park etc)	Defend by creating new road /levee. Levees	Ranked 1st 100	Ranked 3rd 0	Ranked 1st 0	Ranked 4th 0	Ranked 1st 100	Ranked 1st 100	Ranked 1st 100	Ranked 1st 100	Ranked 3rd 70	72	72	63	4B
Defend 2 [Defend 2 seeks to defend Railway Estate, Rowes Bay and the rest of the city from storm tide, while accommodating storm tide inundation within North Ward]	A. Ross River Levee B. Sea dikes and Storm tide barrier at Ross Creek (Defending here forms part of protection for the overall city in combination with Defence works at Rowes Bay and Railway Estate) C. Defend Captains Creek and accommodate at North Ward. Flood proofing public and private infrastructure Planning Scheme modifications	Defend by raising road levels (Railway Ave, Boundary St) Levees Raise housing habitable floor levels Increase height of public infrastructure (roads) Increase minimum housing habitable floor levels) (increase minimum housing	Ranked 2nd 80	Ranked 3rd 0	Ranked 1st 0	Ranked 4th 0	Ranked 2nd 85	Ranked 1st 100	Ranked 2nd 81	Ranked 2nd 90	Ranked 4th 60	60	61	55	4B
Defend 3 [Defend 3 seeks to, defend the city while accommodating in Rowes Bay and accommodation/ retreat in Railway Estate.]	A. Raise Railway Avenue and Boundary Street to act as Levees. B. Sea dikes and Storm tide barrier at Ross Creek (Defending here forms part of protection for the overall city in combination with Defence works at Rowes Bay and Railway Estate) Flood proofing public and private infrastructure Planning Scheme modifications	Defend by raising road levels (Railway Ave, Boundary St) Levees Raise housing habitable floor levels Increase height of public infrastructure (roads) Increase minimum housing habitable floor levels) (increase minimum housing	Ranked 2nd 80	Ranked 3rd 0	Ranked 1st 0	Ranked 4th 0	Ranked 3rd 70	Ranked 2nd 60	Ranked 4th 58	Ranked 3rd 60	Ranked 2nd 80	55	53	45	4B
Accommodate 1	Flood proofing public and private infrastructure	Localised dykes to protect against permanent inundation To maintain access and services	Ranked 4th 0	Ranked 2nd 40	Ranked 1st 0	Ranked 2nd 50	Ranked 4th 50	Ranked 3rd 50	Ranked 3rd 69	Ranked 4th 50	Ranked 5th 0	26	31	34	

		Cemetery - ground water drainage option need to be provided to maintain dry plots or consider above ground													
	Coastal Protection	Including Beach Nourishment, Seawalls , Sea Dykes and Groynes either on their own or in combination. to protect against erosion along foreshore													
	Planning Scheme Modifications	To limit development to areas above storm tide level													
	Land Purchase and Resumption	Land Purchase and Resumption and/or Land swap for land that is permanently inundated													
	Land use change	Land-use change for areas not developed yet but under permanent risk. Connecting road and services will need to be maintained during the period of retreat													
		Re-zone existing residential properties in affected areas													
		Dearness Road is inundated but does not cut access, alternate routes are still maintained													
		Planning Scheme Modifications to reflect land-use change													
		Raise habitable floor level and low lying areas to maintain access													
Accommodate 2 [Similar to defend 3 but coastal protection works to reflect sea level rise hazard]			Ranked 3rd	Ranked 2nd	Ranked 1st	Ranked 3rd	Ranked 5th	Ranked 4th	Ranked 5th	Ranked 5th	Ranked 4th				
			20	40	0	0	40	20	44	40	20	24	26	25	
Retreat	Flood proofing public and private infrastructure	Localised dykes to protect against permanent inundation	Ranked 1st	Ranked 1st	Ranked 1st	Ranked 1st	Ranked 6th	Ranked 5th	Ranked 6th	Ranked 6th	Ranked 1st				
		To maintain access and services	100	100	0	100	0	0	0	0	100	65	55	44	
		Cemetery - ground water drainage option need to be provided to maintain dry plots or consider above ground													
	Coastal Protection	Including Beach Nourishment, Seawalls , Sea Dykes and Groynes either on their own or in combination. to protect against erosion along foreshore													
	Planning Scheme Modifications	To limit development to areas above storm tide level													
	Land Purchase and Resumption	Land Purchase and Resumption and/or Land swap for land that is permanently inundated													
	Land use change	Land-use change for areas not developed yet but under permanent risk. Connecting road and services will need to be maintained during the period of retreat													
		Re-zone existing residential properties in affected areas													
		Dearness Road is inundated but does not cut access, alternate routes are still maintained													
		Planning Scheme Modifications to reflect land-use change													
		Raise habitable floor level and low lying areas to maintain access													

			Adaptation effectiveness	Climate uncertainty	Social and environmental impacts				Complexity and cost						TCC
			AE3	C1	S&E1	S&E2	S&E3	S&E4	C&C1	C&C2	C&C3				
			Severity of inundation on humans as well as buildings and community infrastructure	Flexibility to respond to unexpected climate outcomes (upside / downside)	Impact on access to coastal areas for recreation (e.g. camping, fishing, swimming)	Impact on natural coastal ecosystems	Indirect economic / industry impacts (e.g. tourism, fishing)	Impact on cultural heritage and landscape	Capital cost	Complexity of implementation (technical, stakeholder / social, institutional)	Operating and maintenance costs				
			0.35	0.1	0.05	0.1	0.1	0.05	0.1	0.05	0.1	Revised			
Pallarenda			0.25	0.1	0.05	0.1	0.15	0.05	0.1	0.1	0.1		Preferred		
MITIGATION TYPE	ADAPTATION OPTIONS	DESCRIPTION	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11			Unweighted	
Accommodate	House Retrofitting and Design Standards	Raising habitable floor level against storm tide inundation from creek	Ranked 2nd 70	Ranked 2nd 0	Ranked 1st 100	Ranked 2nd 80	Ranked 1st 100	Ranked 1st 100	Ranked 2nd 33	Ranked 1st 100	Ranked 2nd 50	66	69	70	4F
	Flood Proofing Public Infrastructure	Connecting road and services to south													
		Localised raising , and /or improved drainage and /or improved capping of connecting roads along seaward side will protect houses at front, and maintain service . Redesign of golf course to incorporate sea level rise													
	Coastal Protection	Including Beach Nourishment, Seawalls and Groynes either on their own or in combination. to provide protection from storm tide erosion and inundation for those blocks that are inundated by king tides and sea-level rise													
	Land Swap	Nursing home could be used for another purpose that doesn't require as high a level of access from safety perspective as nursing home													
	Planning scheme modifications	Amend planning scheme to allow no future building below storm surge levels Relocating access road to higher land													
Retreat	Land Purchase and Resumption	Land Purchase and Resumption and/or Land swap for land that is permanently inundated	Ranked 1st 100	Ranked 1st 100	Ranked 2nd 0	Ranked 1st 100	Ranked 2nd 50	Ranked 2nd 40	Ranked 3rd 0	Ranked 2nd 30	Ranked 1st 100	74	68	58	4 A B
	Land-use Change	Land-use Change for areas not developed yet but under permanent risk													
	Planning Scheme Modifications	Planning Scheme Modifications to reflect land-use change													
	Flood Proofing Public Infrastructure	Connecting road and services will need to be maintained during the period of retreat													
Maintain Status Quo	Property Searches include a hazard note		Ranked 3rd 0	Ranked 1st 100	Ranked 2nd 0	Ranked 3rd 0	Ranked 3rd 0	Ranked 3rd 0	Ranked 1st 100	Ranked 3rd 0	Ranked 3rd 0	20	20	22	4B
	Planning Scheme Modification														
	Public Education														
	Allow Natural Processes														
	Consider Public Response														
	Property Owners Responsibility														
	Rates review of properties within coastal hazard area														

Industrial Area

MITIGATION TYPE	ADAPTATION OPTIONS	DESCRIPTION	AE3	C1	S&E1	S&E2	S&E3	S&E4	C&C1	C&C2	C&C3	Revised	Preferred	Unweighted	TCC
Defend	Coastal Protection	See levees to protect Industrial Area and provide for expansion	Ranked 1st 100	Ranked 1st 0	Ranked 1st 0	Ranked 2nd 0	Ranked 1st 100	Ranked 1st 0	Ranked 1st 100	Ranked 1st 100	Ranked 1st 100	70	70	56	1 D G
	Land filling Above Flood Level	Land filling for new areas													
Accommodate	Building Retrofitting and Design Standards	Raising the operation level of industrial areas	Ranked 2nd 0	Ranked 1st 0	Ranked 1st 0	Ranked 1st 100	Ranked 2nd 0	Ranked 1st 0	Ranked 1st 0	Ranked 2nd 0	Ranked 2nd 0	10	10	11	4A
	Flood Proofing Public Infrastructure	Raise, and /or improve drainage and /or improve capping of roads locally													
	Retrofit Industy	Protect hazardous operations from storm surge													

Sewage Treatment Plant - Mt St John

MITIGATION TYPE	ADAPTATION OPTIONS	DESCRIPTION	AE3	C1	S&E1	S&E2	S&E3	S&E4	C&C1	C&C2	C&C3	Revised	Preferred	Unweighted	TCC
Defend	Sea dykes	Protect buildings to north of STP to allow for STP expansion	Ranked 1st 100	Ranked 1st 0	Ranked 1st 0	Ranked 1st 100	Ranked 1st 100	Ranked 1st 0	Ranked 1st 100	Ranked 1st 100	Ranked 2nd 0	70	70	56	F
	Bund wall														
Accommodate	Building modifications	Moving buildings within the site to higher ground	Ranked 2nd 0	Ranked 1st 0	Ranked 1st 0	Ranked 2nd 0	Ranked 2nd 0	Ranked 1st 0	Ranked 2nd 0	Ranked 2nd 0	Ranked 1st 100	10	10	11	4 A E

			Adaptation effectiveness	Climate uncertainty	Social and environmental impacts				Complexity and cost						TCC
			AE3	C1	S&E1	S&E2	S&E3	S&E4	C&C1	C&C2	C&C3				
			Severity of inundation on humans as well as buildings and community infrastructure	Flexibility to respond to unexpected climate outcomes (upside / downside)	Impact on access to coastal areas for recreation (e.g. camping, fishing, swimming)	Impact on natural coastal ecosystems	Indirect economic / industry impacts (e.g. tourism, fishing)	Impact on cultural heritage and landscape	Capital cost	Complexity of implementation (technical, stakeholder / social, institutional)	Operating and maintenance costs				
			0.35	0.1	0.05	0.1	0.1	0.05	0.1	0.05	0.1	Revised			
Oonoonba			0.25	0.1	0.05	0.1	0.15	0.05	0.1	0.1	0.1		Preferred		
MITIGATION TYPE	ADAPTATION OPTIONS	DESCRIPTION	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11			Unweighted	
Defend	Coastal Protection	Dyke to defend against permanent inundation level (not storm tide). Provision of drainage solution with sump and pump systems is standard practice for dyke design.	Ranked 2nd	Ranked 2nd	Ranked 1st	Ranked 1st	Ranked 1st	Ranked 1st	Ranked 2nd	Ranked 1st	Ranked 2nd				
	House Retrofitting and Design Standards	Raise habitable floor level	40	0	0	0	100	0	97	100	90	48	54	47	
	Land filling above flood level	Raising land above permanent inundation level													4B
	Flood proofing public infrastructure	Rail elevated (pier) to allow overland flood													
		Protect public infrastructure (roads, water, sewer, power)													
	Planning scheme modifications	No intensification of old Oonoonba													
	Land Use Changes	Buyback for worst affected areas													
		Building Standards													
Retreat	Land purchase and resumption Land-use change	Land Purchase and Resumption and/or Land swap for land that is permanently inundated	Ranked 1st	Ranked 1st	Ranked 1st	Ranked 1st	Ranked 2nd	Ranked 1st	Ranked 3rd	Ranked 2nd	Ranked 1st				
	Flood proofing public infrastructure	Rail elevated (pier) to allow overland flood	100	100	0	0	80	0	0	40	100	65	61	47	3B
		Protect public infrastructure (roads, water, sewer, power)													
	Planning scheme modifications	Land-use change for areas not developed yet but under permanent risk Connecting road and services will need to be maintained during the period of retreat													
		Planning Scheme Modifications to reflect land-use change													
Maintain Status Quo	Property Searches include a hazard note		Ranked 3rd	Ranked 1st	Ranked 1st	Ranked 1st	Ranked 3rd	Ranked 1st	Ranked 1st	Ranked 3rd	Ranked 3rd				
	Planning Scheme Modification		0	100	0	0	0	0	100	0	0	20	20	22	
	Public Education														4B
	Allow Natural Processes														
	Consider Public Response														
	Property Owners Responsibility														
	Rates review of properties within coastal hazard area														

Complete

			Adaptation effectiveness	Climate uncertainty	Social and environmental impacts				Complexity and cost						TCC
			AE3	C1	S&E1	S&E2	S&E3	S&E4	C&C1	C&C2	C&C3				
			Severity of inundation on humans as well as buildings and community infrastructure	Flexibility to respond to unexpected climate outcomes (upside / downside)	Impact on access to coastal areas for recreation (e.g. camping, fishing, swimming)	Impact on natural coastal ecosystems	Indirect economic / industry impacts (e.g. tourism, fishing)	Impact on cultural heritage and landscape	Capital cost	Complexity of implementation (technical, stakeholder / social, institutional)	Operating and maintenance costs				
			0.35	0.1	0.05	0.1	0.1	0.05	0.1	0.05	0.1	Revised			
Stuart/Cleveland Bay STP			0.25	0.1	0.05	0.1	0.15	0.05	0.1	0.1	0.1		Preferred		
MITIGATION TYPE	ADAPTATION OPTIONS	DESCRIPTION	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11			Unweighted	
Defend	Coastal Protection	Construction of sea levee to protect components of plant	Ranked 1st	Ranked 2nd	Ranked 1st	Ranked 1st	Ranked 1st	Ranked 1st	Ranked 2nd	Ranked 2nd	Ranked 1st				
	Flood proofing public infrastructure	Raise road to maintain access, sewer lines/pump stations to site to be upgraded if necessary dyke to protect low-lying areas of plant	100	0	0	0	100	0	0	0	0	45	40	22	4B
	Land filling above flood level	Land filling required if future expansion is required													
Accommodate	Coastal Protection	Construction of sea levee to protect components of plant (less area protected than the defend option)	Ranked 2nd	Ranked 1st	Ranked 1st	Ranked 1st	Ranked 2nd	Ranked 1st	Ranked 1st	Ranked 1st	Ranked 1st				4 A E
	Flood proofing public infrastructure	Raise road to maintain access, sewer lines/pump stations to site to be upgraded if necessary Increase level of existing dyke to protect low lying areas of plant	0	100	0	0	0	0	100	100	0	25	30	33	

			Adaptation effectiveness	Climate uncertainty	Social and environmental impacts				Complexity and cost						TCC
			AE3	C1	S&E1	S&E2	S&E3	S&E4	C&C1	C&C2	C&C3				
			Severity of inundation on humans as well as buildings and community infrastructure	Flexibility to respond to unexpected climate outcomes (upside / downside)	Impact on access to coastal areas for recreation (e.g. camping, fishing, swimming)	Impact on natural coastal ecosystems	Indirect economic / industry impacts (e.g. tourism, fishing)	Impact on cultural heritage and landscape	Capital cost	Complexity of implementation (technical, stakeholder / social, institutional)	Operating and maintenance costs				
			0.35	0.1	0.05	0.1	0.1	0.05	0.1	0.05	0.1	Revised			
Cungulla			0.25	0.1	0.05	0.1	0.15	0.05	0.1	0.1	0.1		Preferred		
MITIGATION TYPE	ADAPTATION OPTIONS	DESCRIPTION	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11			Unweighted	
Accommodate	Coastal Protection	Including Beach Nourishment, Seawalls , Sea Dykes and Groynes either on their own or in combination. to protect against erosion along foreshore	Ranked 2nd	Ranked 2nd	Ranked 1st	Ranked 2nd	Ranked 1st	Ranked 2nd	Ranked 2nd	Ranked 1st	Ranked 2nd				
	Flood proofing public infrastructure	Raise road to maintain access (including access to AIMS along Cape Cleveland road) or flood proof road (eg resilient material)	30	0	0	50	100	0	5	100	60	37	44	38	4B
	House retrofitting and design standards	Raise habitable floor level													
Retreat	Land purchase and resumption	Land Purchase and Resumption and/or Land swap for land that is permanently inundated	Ranked 1st	Ranked 1st	Ranked 1st	Ranked 1st	Ranked 2nd	Ranked 1st	Ranked 3rd	Ranked 2nd	Ranked 1st				
	Flood proofing public infrastructure	Connecting road and services will need to be maintained during the period of retreat	100	100	0	100	50	100	0	60	100	78	74	68	4B
	Land-use change	Land-use Change for areas not developed yet but under permanent risk													
	Planning scheme modifications	Planning Scheme Modifications to reflect land-use change (no intensification)													
Maintain Status Quo	Property Searches include a hazard note		Ranked 3rd	Ranked 1st	Ranked 1st	Ranked 3rd	Ranked 3rd	Ranked 1st	Ranked 1st	Ranked 3rd	Ranked 3rd				
	Planning Scheme Modification		0	100	0	0	0	100	100	0	0	25	25	33	4B
	Public Education														
	Allow Natural Processes														
	Consider Public Response														
	Property Owners Responsibility														
	Rates review of properties within coastal hazard area														

			Adaptation effectiveness	Climate uncertainty	Social and environmental impacts				Complexity and cost						TCC
			AE3	C1	S&E1	S&E2	S&E3	S&E4	C&C1	C&C2	C&C3				
			Severity of inundation on humans as well as buildings and community infrastructure	Flexibility to respond to unexpected climate outcomes (upside / downside)	Impact on access to coastal areas for recreation (e.g. camping, fishing, swimming)	Impact on natural coastal ecosystems	Indirect economic / industry impacts (e.g. tourism, fishing)	Impact on cultural heritage and landscape	Capital cost	Complexity of implementation (technical, stakeholder / social, institutional)	Operating and maintenance costs				
			0.35	0.1	0.05	0.1	0.1	0.05	0.1	0.05	0.1	Revised			
Horseshoe Bay			0.25	0.1	0.05	0.1	0.15	0.05	0.1	0.1	0.1		Preferred		
MITIGATION TYPE	ADAPTATION OPTIONS	DESCRIPTION	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11			Unweighted	
Accommodate	Beach nourishment	Beach nourishment for erosion	Ranked 2nd	Ranked 2nd	Ranked 1st	Ranked 3rd	Ranked 1st	Ranked 2nd	Ranked 2nd	Ranked 1st	Ranked 2nd				4B
	Flood proofing public infrastructure	Raise road to maintain access	20	0	100	0	100	0	79	100	60	41	49	51	
	House retrofitting and design standards	Properties to east of Horseshoe Bay will lose beach access													
		Raise habitable floor level													
Retreat	Land purchase and resumption	Land Purchase and Resumption and/or	Ranked 1st	Ranked 1st	Ranked 2nd	Ranked 1st	Ranked 2nd	Ranked 1st	Ranked 3rd	Ranked 2nd	Ranked 1st				3B
	Land-use change	Land swap for land that is permanently inundated													
		Land-use Change for areas not developed yet but under permanent risk	100	100	80	100	80	100	0	30	100	84	79	77	
	Flood proofing public infrastructure	Connecting road and services will need to be maintained during the period of retreat													
	Planning scheme modifications	Planning Scheme Modifications to reflect land-use change													
Maintain Status Quo	Property Searches include a hazard note		Ranked 3rd	Ranked 1st	Ranked 3rd	Ranked 2nd	Ranked 3rd	Ranked 2nd	Ranked 1st	Ranked 3rd	Ranked 3rd				3B
	Planning Scheme Modification		0	100	0	80	0	0	100	0	0	28	28	31	
	Public Education														
	Allow Natural Processes														
	Consider Public Response														
	Property Owners Responsibility														
	Rates review of properties within coastal hazard area														

Arcadia (Geoffrey Bay)															
MITIGATION TYPE	ADAPTATION OPTIONS	DESCRIPTION													
Accommodate	Coastal Protection	Buried seawall abutting road and beach nourishment (as necessary) for erosion protection along beach front	Ranked 2nd	Ranked 2nd	Ranked 1st	Ranked 3rd	Ranked 1st	Ranked 2nd	Ranked 2nd	Ranked 1st	Ranked 2nd				4 A B
		Raise existing Harbour Wall and extend to higher ground to protect from permanent inundation and storm tide	20	0	100	0	100	0	42	100	60	37	45	47	
	Flood proofing public infrastructure	Upgrade Marine Parade at Hordern Ave providing tidal gates to stop inundation near bowls club													
		Assume Sooning St Bridge is above flood level and access is maintained													
	House Retrofitting and Design Standards	Raising Habitable floor levels for storm tide													
		Raising land filling above flood level for bowls club when redeveloped													
Retreat	Land purchase and resumption	Land Purchase and Resumption and/or Land swap for land that is permanently inundated	Ranked 1st	Ranked 1st	Ranked 2nd	Ranked 1st	Ranked 2nd	Ranked 1st	Ranked 3rd	Ranked 2nd	Ranked 1st				3B
	Flood proofing public infrastructure	Connecting road and services will need to be maintained during the period of retreat	100	100	80	100	80	100	0	30	100	84	79	77	
	Land-use change	Land-use Change for areas not developed yet but under permanent risk													
	Planning scheme modifications	Planning Scheme Modifications to reflect land-use change													
Maintain Status Quo	Property Searches include a hazard note		Ranked 3rd	Ranked 1st	Ranked 3rd	Ranked 2nd	Ranked 3rd	Ranked 2nd	Ranked 1st	Ranked 3rd	Ranked 3rd				3B
	Planning Scheme Modification		0	100	0	80	0	0	100	0	0	28	28	31	
	Public Education														
	Allow Natural Processes														
	Consider Public Response														
	Property Owners Responsibility														
	Rates review of properties within coastal hazard area														

Nelly Bay

MITIGATION TYPE	ADAPTATION OPTIONS	DESCRIPTION													
Defend	Coastal Protection	Sunken Seawalls along roadside to provide erosion and storm surge protection along beach front catering for future development	Ranked 1st	Ranked 2nd	Ranked 2nd	Ranked 2nd	Ranked 1st	Ranked 1st	Ranked 2nd	Ranked 1st	Ranked 1st				
		Beach nourishment from Gustav Creek	100	0	0	0	100	0	0	100	100	60	60	44	
	Flood proofing public infrastructure	Raise and protect The Esplanade to maintain access and provide protection for landward housing from erosion and storm tide													
	House Retrofitting and Design Standards	Raise habitable floor level for lot 1a (Backpackers Hostel)													
Maintain Status Quo	Property Searches include a hazard note		Ranked 2nd	Ranked 1st	Ranked 1st	Ranked 1st	Ranked 2nd	Ranked 1st	Ranked 1st	Ranked 2nd	Ranked 2nd				
	Planning Scheme Modification		0	100	100	100	0	0	100	0	0	35	35	44	
	Public Education														
	Allow Natural Processes														
	Consider Public Response														
	Property Owners Responsibility														
	Rates review of properties within coastal hazard area														

Picnic Bay

MITIGATION TYPE	ADAPTATION OPTIONS	DESCRIPTION													
Accommodate	Coastal Protection	Buried Seawalls with beach nourishment to provide erosion and storm surge protection along beach front catering for future development	Ranked 2nd	Ranked 2nd	Ranked 1st	Ranked 2nd	Ranked 2nd	Ranked 2nd	Ranked 2nd	Ranked 1st	Ranked 2nd				
	Flood Proofing Public Infrastructure	Raise and protect The Esplanade to maintain access and provide protection for landward buildings from erosion and storm tide	20	0	100	60	70	50	56	100	50	43	50	56	3B
	Building Standards/Retrofit	Raise habitable floor levels													
Retreat	Land Purchase and Resumption	Land Purchase and Resumption and/or Land swap for land that is permanently inundated	Ranked 1st	Ranked 1st	Ranked 2nd	Ranked 1st	Ranked 3rd	Ranked 1st	Ranked 4th	Ranked 3rd	Ranked 1st				
	Land-use Change	Land-use Change for areas not developed yet but under permanent risk	100	100	0	100	40	100	100	30	100	86	79	74	3B
	Flood Proofing Public Infrastructure	Connecting road and services will need to be maintained during the period of retreat													
	Planning Scheme Modifications	Planning Scheme Modifications to reflect land-use change													
Defend 1	Seawall – erosion protection only		Ranked 1st	Ranked 2nd	Ranked 1st	Ranked 3rd	Ranked 1st	Ranked 2nd	Ranked 3rd	Ranked 2nd	Ranked 3rd				3F
			100	0	100	50	100	50	23	80	30	67	66	59	
Maintain Status Quo	Property Searches include a hazard note		Ranked 3rd	Ranked 1st	Ranked 2nd	Ranked 4th	Ranked 4th	Ranked 4th	Ranked 1st	Ranked 4th	Ranked 4th				
	Planning Scheme Modification		0	100	0	0	0	0	100	0	0	20	20	22	
	Public Education														
	Allow Natural Processes														
	Consider Public Response														
	Property Owners Responsibility														
	Rates review of properties within coastal hazard area														

WTP Picnic Point

MITIGATION TYPE	ADAPTATION OPTIONS	DESCRIPTION													
Defend	Coastal Protection	Construct Sea dyke around plant If expansion required	Ranked 1st	Ranked 1st	Ranked 1st	Ranked 1st	Ranked 1st	Ranked 1st	Ranked 2nd	Ranked 1st	Ranked 1st				
	Land filling Above Flood Level		100	0	0	0	100	0	0	0	100	55	50	33	
	Flood proofing public infrastructure	Subsequent upgrades are mindful of hazard when setting levels for vulnerable plant and buildings.													

MITIGATION TYPE	ADAPTATION OPTIONS	DESCRIPTION													
Accommodate	Coastal Protection Land filling Above Flood Level Flood proofing public infrastructure	Provide Sea wall around plant to protect against sea level rise hazard but not storm tide inundation Subsequent upgrades are mindful of hazard when setting levels for vulnerable plant and buildings.	Ranked 2nd 0	Ranked 1st 0	Ranked 1st 0	Ranked 1st 0	Ranked 2nd 0	Ranked 1st 0	Ranked 1st 100	Ranked 1st 0	Ranked 2nd 0	10	10	11	4E

West Point

MITIGATION TYPE	ADAPTATION OPTIONS	DESCRIPTION													
Retreat	Land purchase and resumption Land-use change Flood proofing public infrastructure Planning scheme modifications	Land Purchase and Resumption and/or Land swap for land that is permanently inundated Land-use Change for areas not developed yet but under permanent risk Connecting road and services will need to be maintained during the period of retreat Planning Scheme Modifications to reflect land-use change	Ranked 1st 100	Ranked 1st 0	Ranked 1st 0	Ranked 1st 100	Ranked 1st 100	Ranked 1st 100	Ranked 2nd 0	Ranked 1st 100	Ranked 1st 100	75	75	67	
Maintain Status Quo	Property Searches include a hazard note Planning Scheme Modification Public Education Allow Natural Processes Consider Public Response Property Owners Responsibility Rates review of properties within coastal hazard area		Ranked 2nd 0	Ranked 1st 0	Ranked 1st 0	Ranked 2nd 0	Ranked 2nd 0	Ranked 2nd 0	Ranked 1st 100	Ranked 2nd 0	Ranked 2nd 0	10	10	11	

Bolger Bay Pump Station

MITIGATION TYPE	ADAPTATION OPTIONS	DESCRIPTION													
Defend	Sea dykes Land filling Above Flood Level	Provide bund around plant If expansion required	Ranked 1st 100	Ranked 1st 0	Ranked 1st 0	Ranked 1st 0	Ranked 1st 100	Ranked 1st 0	Ranked 1st 100	Ranked 1st 100	Ranked 1st 100	70	70	56	
Accommodate	Sea dykes	Provide bund around plant Suggest subsequent upgrades are mindful of hazard when setting levels for vulnerable plant and buildings.	Ranked 2nd 0	Ranked 1st 0	Ranked 1st 0	Ranked 1st 0	Ranked 2nd 0	Ranked 1st 0	Ranked 2nd 0	Ranked 2nd 0	Not ranked 0	0	0	0	

Radical Bay (north of Florence Bay)

MITIGATION TYPE	ADAPTATION OPTIONS	DESCRIPTION													
Accommodate	Land Use Planning Coastal Protection	Keep new development outside hazard areas Buried seawall to protect against erosion.	Ranked 1st 100	Ranked 2nd 0	Ranked 1st 100	Ranked 2nd 0	Ranked 1st 100	Ranked 2nd 0	Ranked 2nd 0	Ranked 1st 100	Ranked 2nd 100	65	65	56	
Maintain Status Quo	Property Searches include a hazard note Planning Scheme Modification Public Education Allow Natural Processes Consider Public Response Property Owners Responsibility Rates review of properties within coastal hazard area		Ranked 2nd 0	Ranked 1st 100	Ranked 2nd 0	Ranked 1st 100	Ranked 2nd 0	Ranked 1st 100	Ranked 1st 100	Ranked 2nd 0	Ranked 1st 0	35	35	44	

Attachment B Generic MCA Scoring Rules

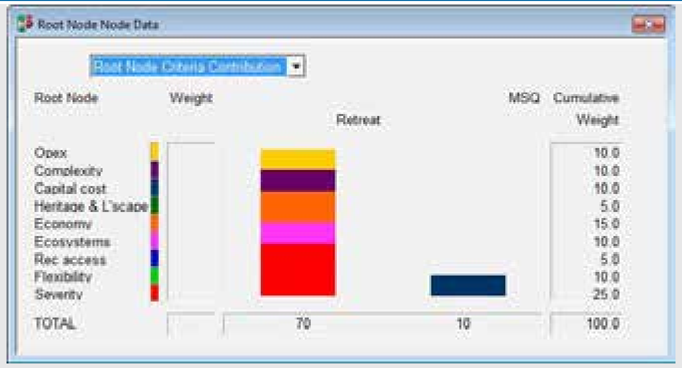
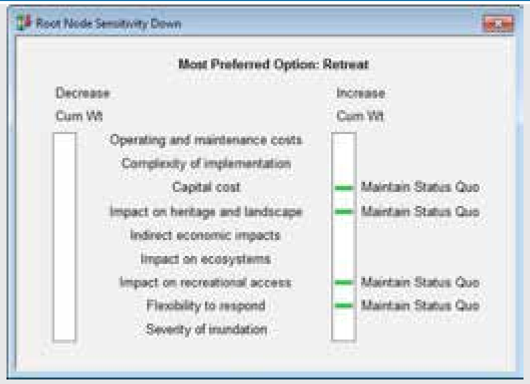
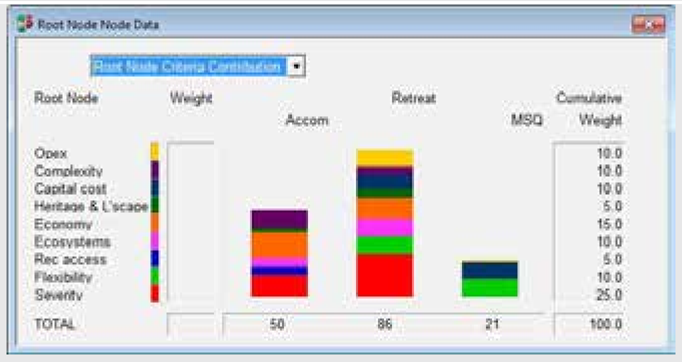
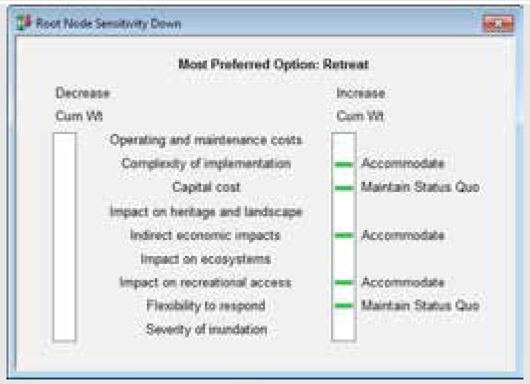
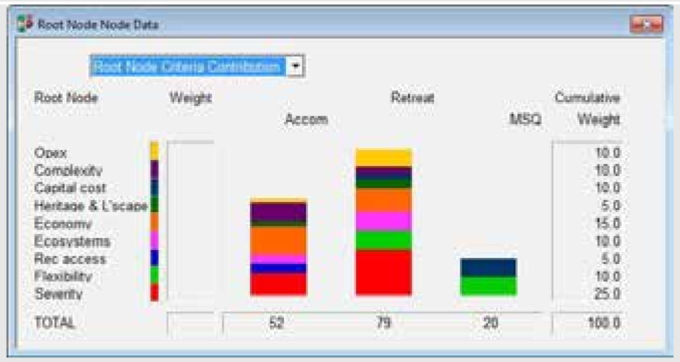
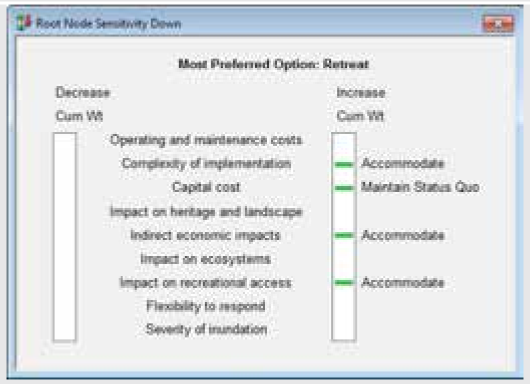
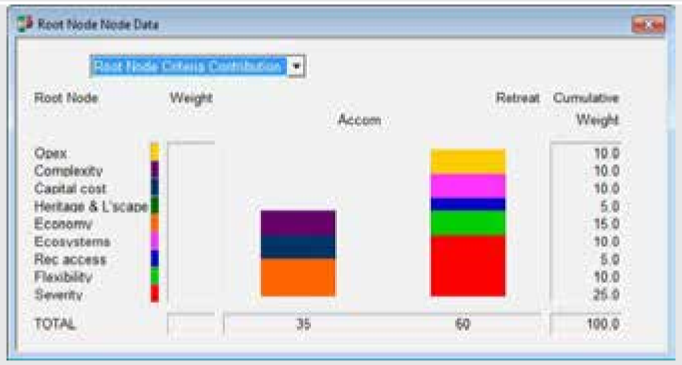
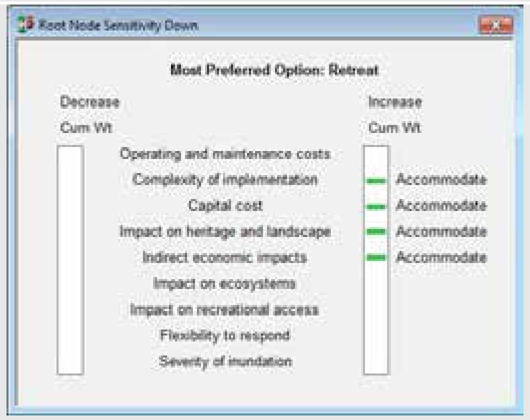
Attachment B Townsville CHAS MCA Workshop

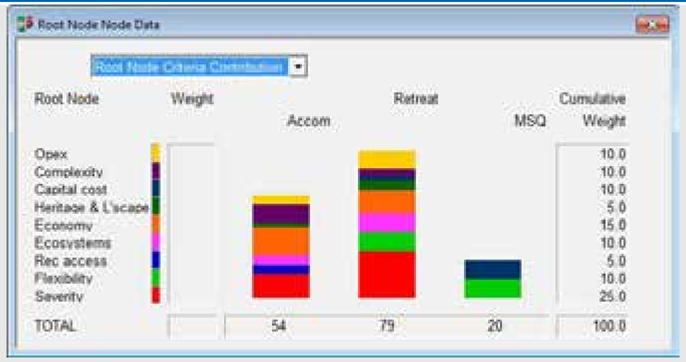
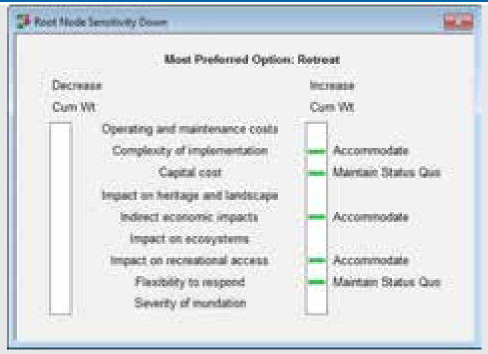
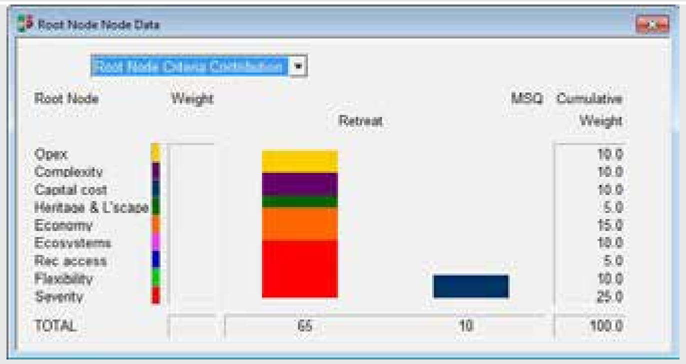
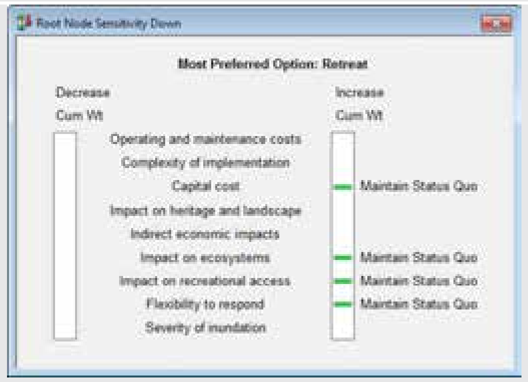
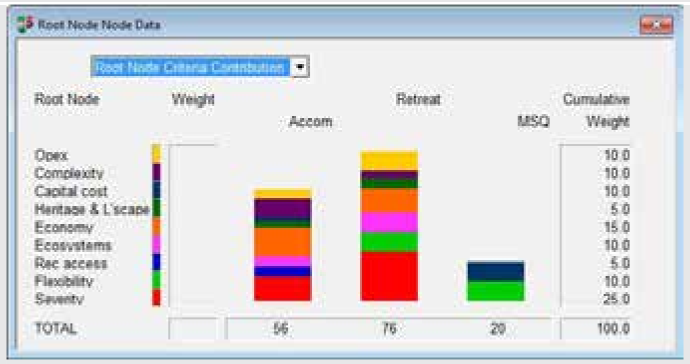
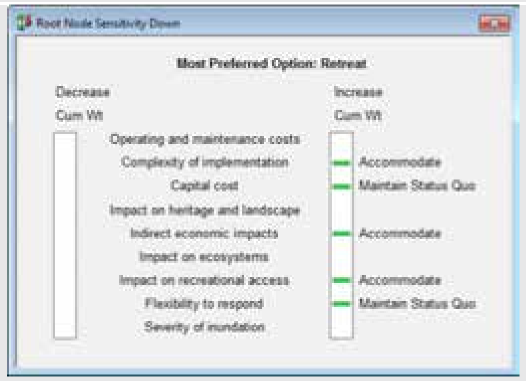
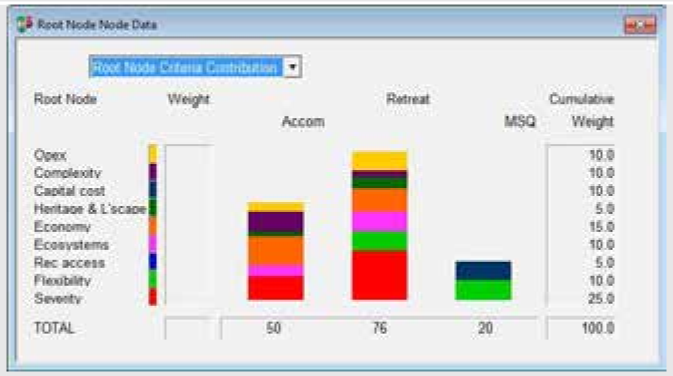
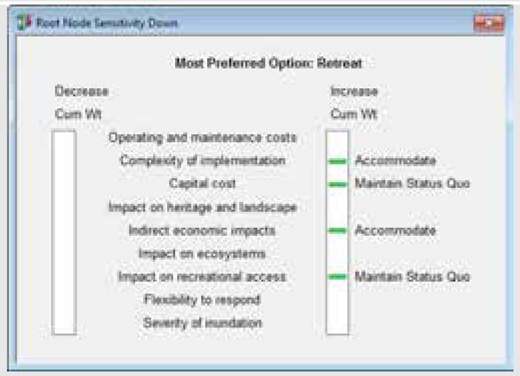
MCA Criteria and Generic Scoring Rules

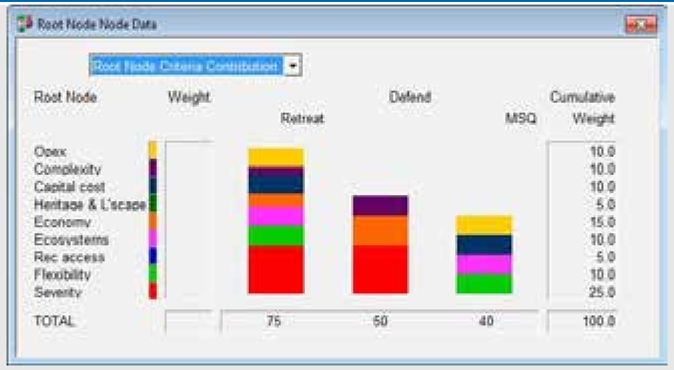
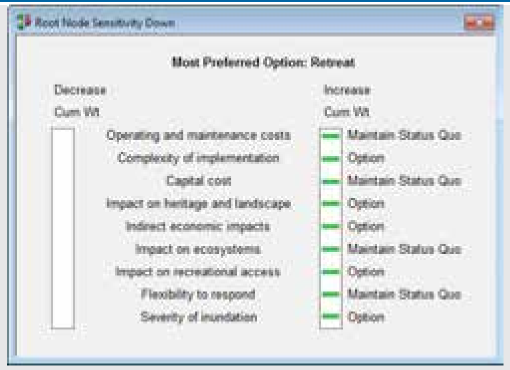
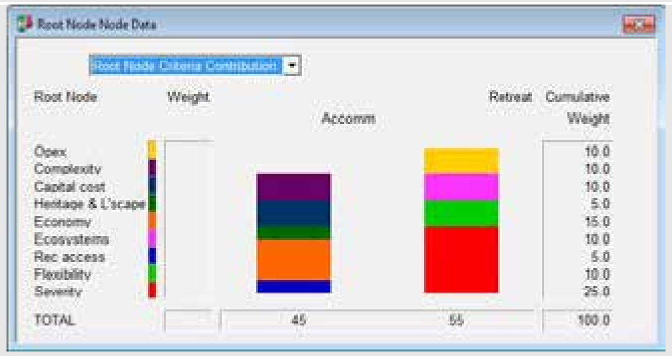
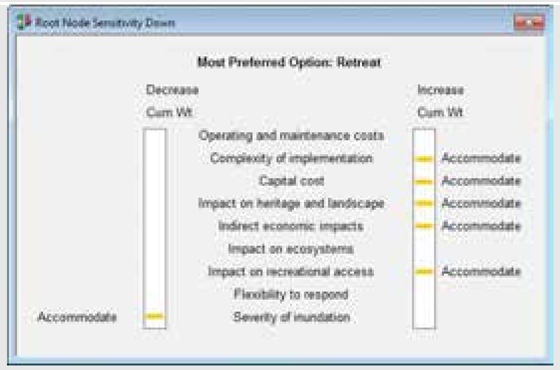
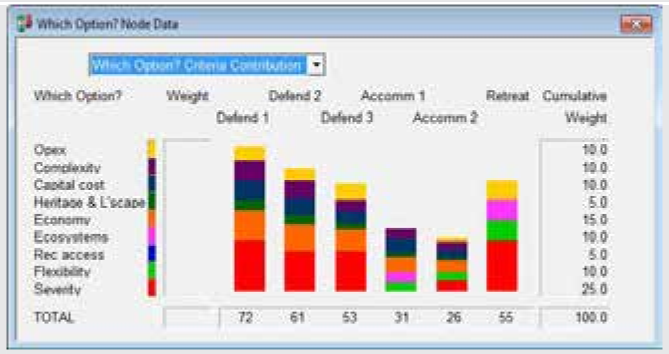
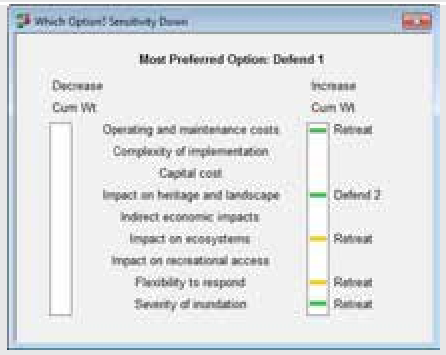
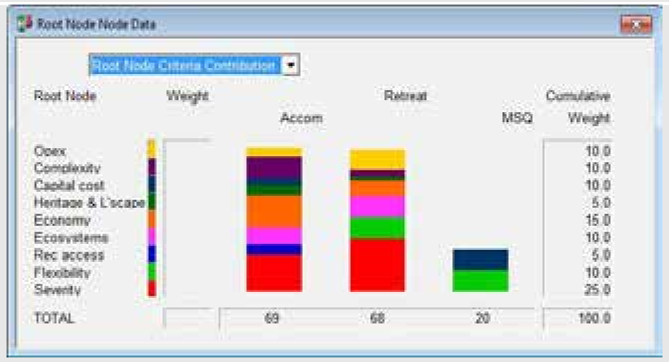
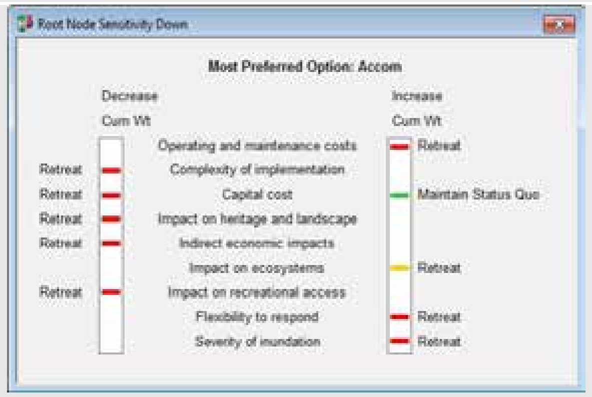
<table>
<tr><th></th><th colspan="9">CRITERIA</th></tr>
<tr><th></th><th>Severity of inundation on humans as well as buildings and community infrastructure</th><th>Flexibility to respond to unexpected climate outcomes (upside / downside)</th><th>Impact on access to coastal areas for recreation (e.g. camping, fishing, swimming)</th><th>Impact on natural coastal ecosystems</th><th>Indirect economic / industry impacts (e.g. tourism, fishing)</th><th>Impact on cultural heritage and landscape</th><th>Capital cost</th><th>Complexity of implementation (technical, stakeholder / social, institutional)</th><th>Operating and maintenance costs</th></tr>
<tr><td>Defend</td><td>Equal Best
Same as retreat (for 100 y return period) and better than accommodate</td><td>Case by Case</td><td>Case by Case</td><td>Case by Case</td><td>Best</td><td>Case by Case</td><td>Case by Case</td><td>Case by Case</td><td>Case by Case</td></tr>
<tr><td>Accommodate</td><td>Next Best</td><td>Case by Case</td><td>Case by Case</td><td>Case by Case</td><td>Next best</td><td>Case by Case</td><td>Case by Case</td><td>Case by Case</td><td>Case by Case</td></tr>
<tr><td>Retreat</td><td>Equal Best
Same as defendt (for 100 y return period) and better than accomodate</td><td rowspan="2">Equal best
All strategies remain available</td><td rowspan="2">Equal
to each other</td><td>Case by Case</td><td>Next Worse</td><td>Case by Case</td><td>Case by Case</td><td>Next worst
Compensation etc</td><td>Case by Case</td></tr>
<tr><td>Maintain status quo</td><td>Worst
Most people / assets affected</td><td>Case by Case</td><td>Worst</td><td>Case by Case</td><td>Best
As least capital intensive option</td><td>Worst
Uncertainty will exist over all land use decisions</td><td>Case by Case</td></tr>
</table>

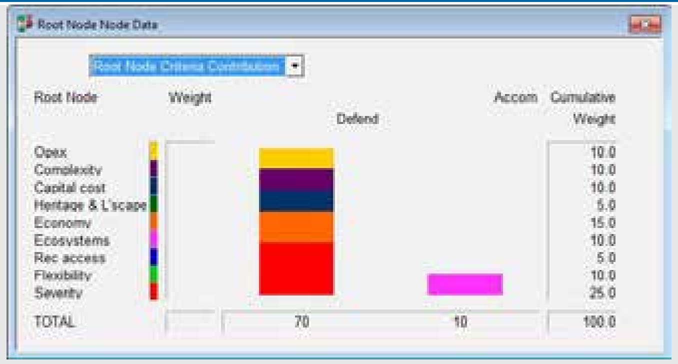
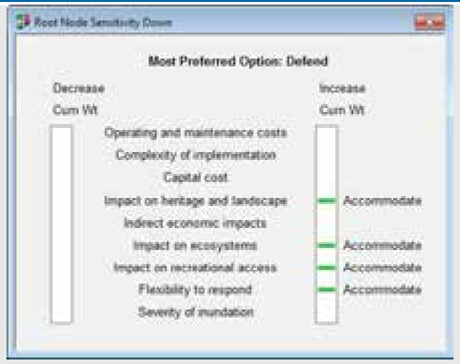
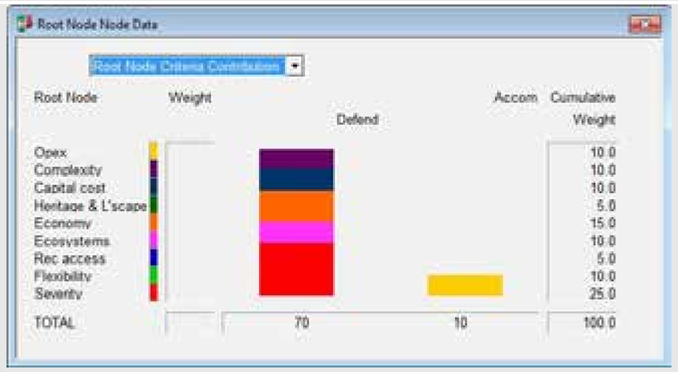
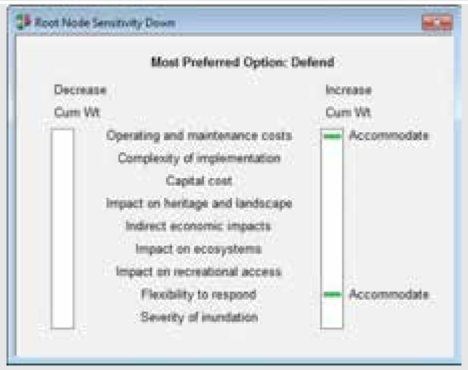
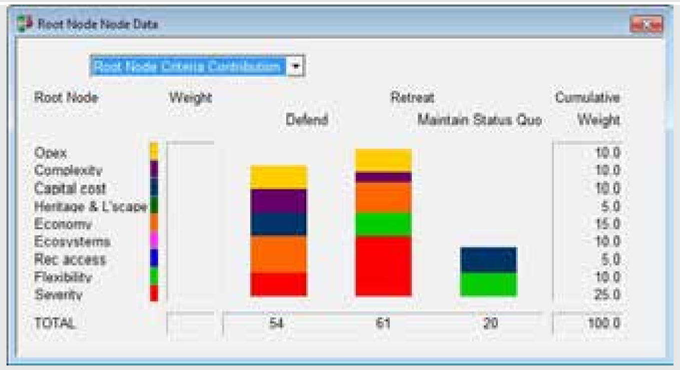
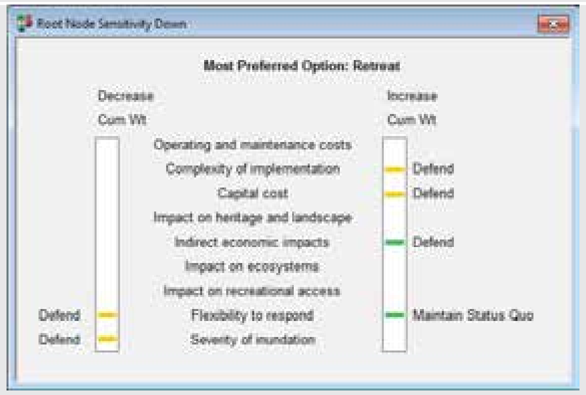
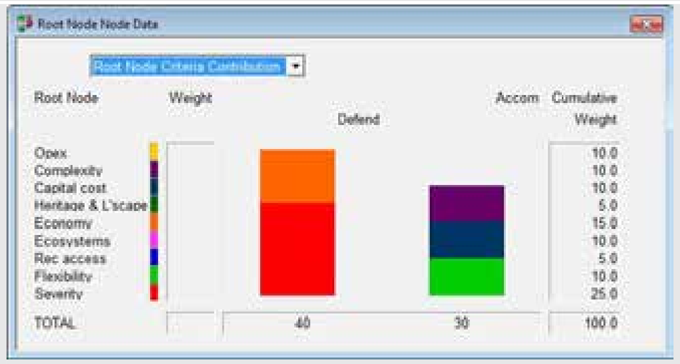
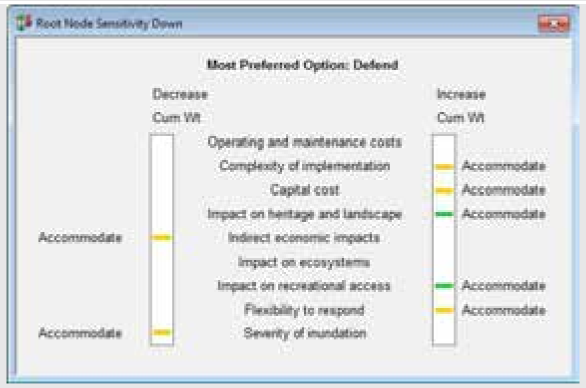
Attachment C MCA HiView Results

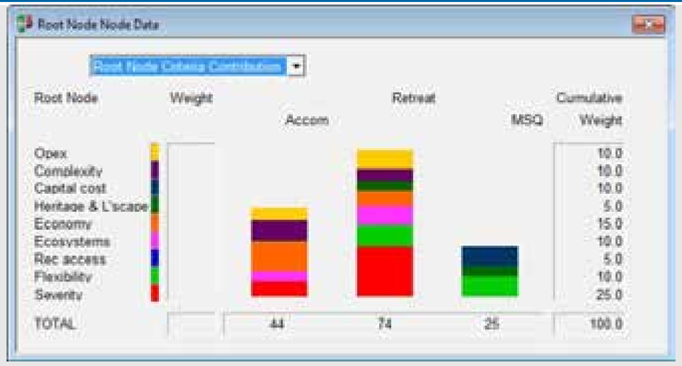
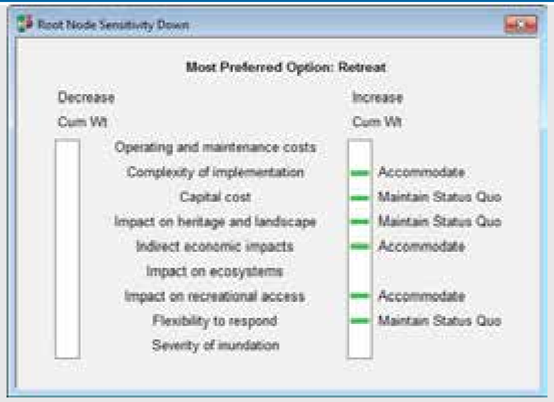
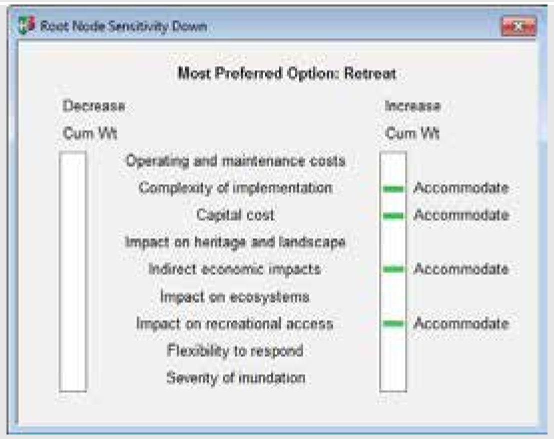
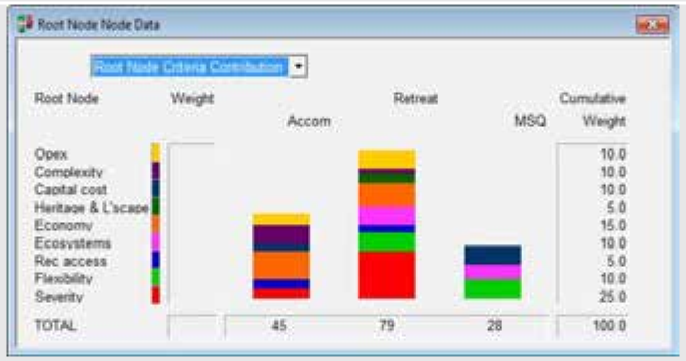
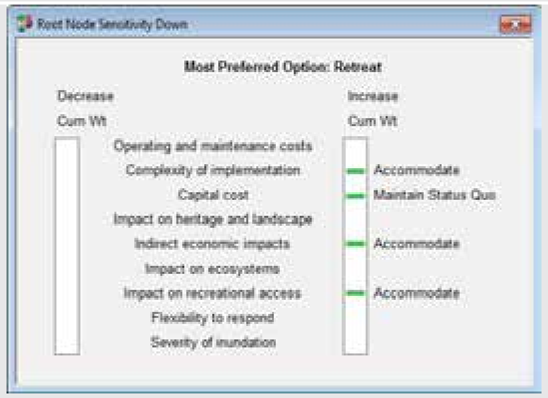
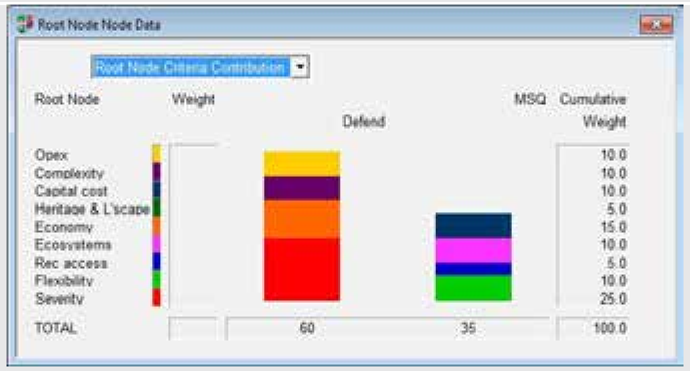
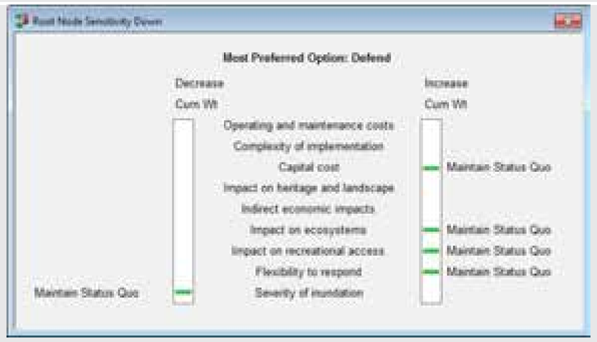
Table 12 MCA Results and Recommendations

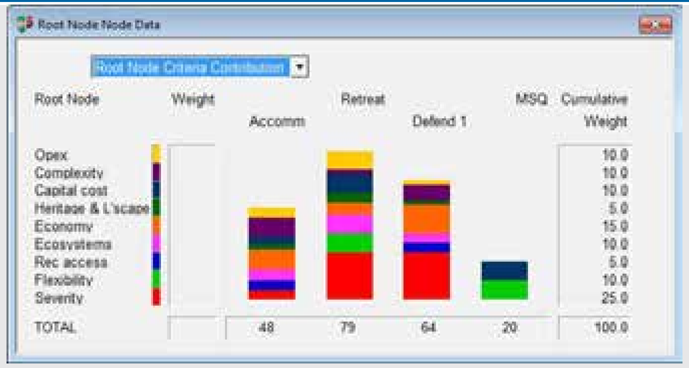
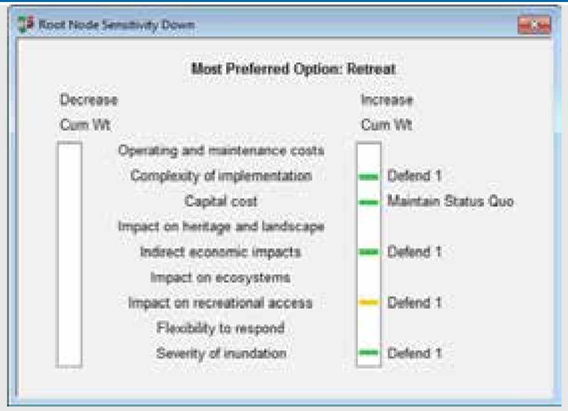
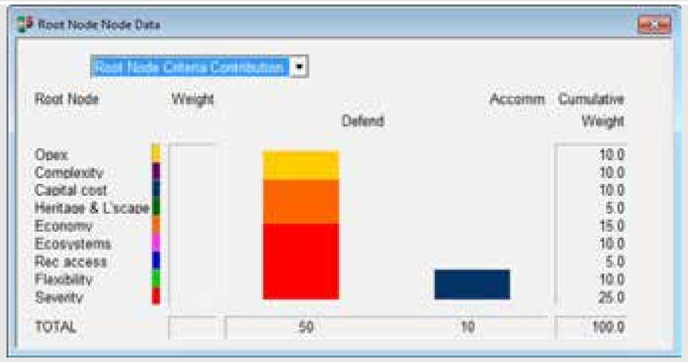
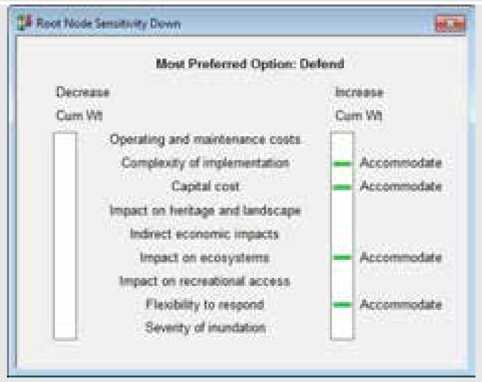
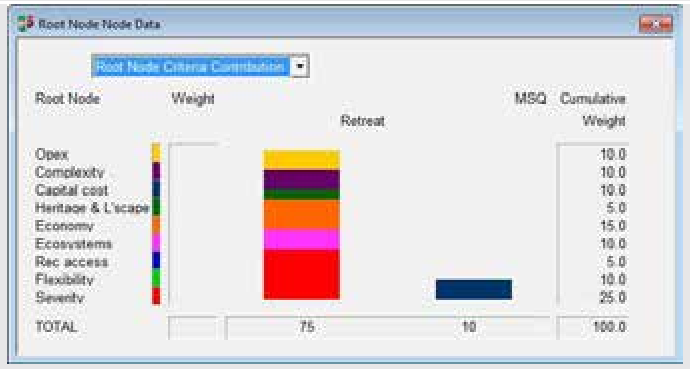
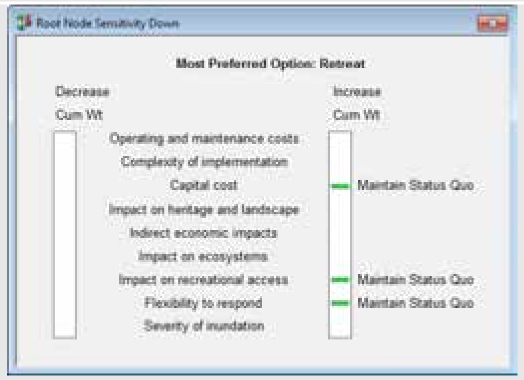
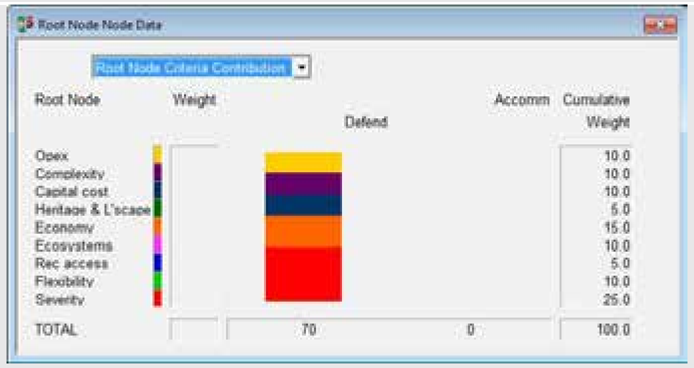
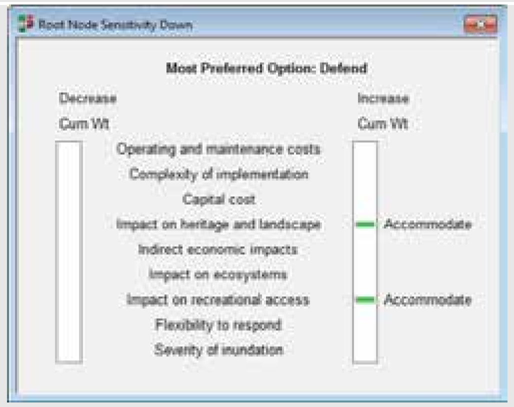
Area / Location	Options (those in **bold** are recommended for CBA)	TCC ranking	Discussion	Weighted MCA scores	Preferred Option / Sensitivity Analysis
Rollingstone - Mutarnee	**Retreat** Maintain Status Quo	3B 5A	Retreat ranked highest for severity of inundation and coastal ecosystem impact. MSQ ranked highest for capital cost and was equally ranked for all other criteria. MCA results were insensitive to weightings.		
Rollingstone - Rollingstone Beach	**Retreat** Maintain Status Quo Accommodate	3B 4A 3B	Accommodate ranked highest for recreational access, indirect economic impact and complexity of implementation. Retreat ranked highest for severity of inundation, coastal ecosystem impact, cultural heritage impact and opex. MSQ ranked highest for capital cost. Accommodate and MSQ ranked equal highest for flexibility to respond. MCA results were insensitive to weightings		
Balgal Beach - Balgal Beach	Accommodate **Retreat** Maintain Status Quo	4B 3A 4A	Accommodate ranked highest for coastal recreation impact, indirect economic impacts and complexity of implementation. Retreat ranked highest for severity of inundation, coastal ecosystem impact, cultural heritage impact and Opex. MSQ and retreat ranked equal highest for flexibility to respond. MCA results were insensitive to weightings		
Balgal Beach - Toomulla	Accommodate **Retreat**	4AB 4AB	Accommodate ranked highest for indirect economic impacts, capital cost and complexity of implementation. Retreat ranked highest for all other criteria. MCA results insensitive to weightings.		

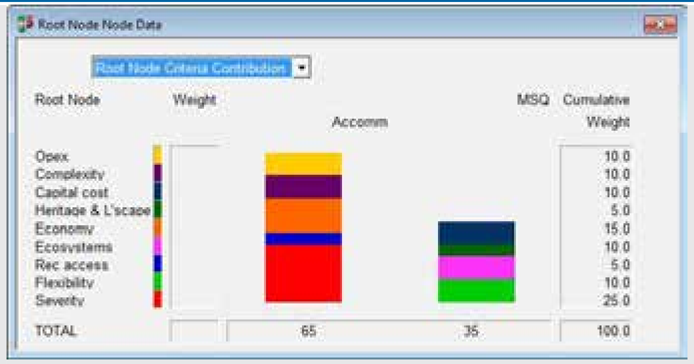
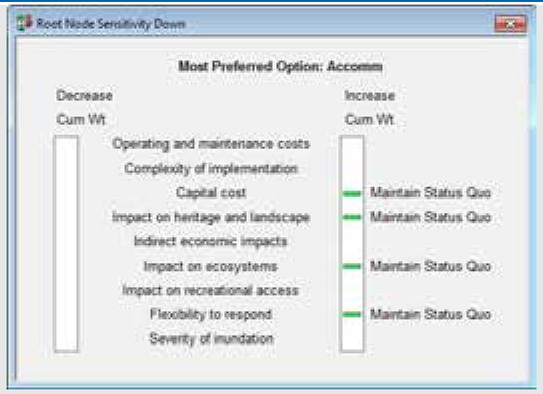
Area / Location	Options (those in **bold** are recommended for CBA)	TCC ranking	Discussion	Weighted MCA scores	Preferred Option / Sensitivity Analysis
Toolakea - Toolakea	Accommodate **Retreat** Maintain Status Quo	5F 4BF 4A	Accommodate ranked highest for coastal recreation access, indirect economic impacts and complexity of implementation. Retreat ranked highest for severity of inundation, coastal ecosystem impact, cultural heritage impact and Opex. MSQ ranked highest for capital cost. MSQ and retreat ranked equal highest for flexibility to respond. MCA results were insensitive to weightings.		
Toolakea - Bluewater Beach	**Retreat** Maintain Status Quo	4BF 3B	Retreat ranked highest for severity of inundation, indirect economic impact, cultural heritage impact and complexity of implementation. MSQ ranked highest for capital cost. Retreat and MSQ ranked equally for other criteria. MCA results were insensitive to weightings.		
Saunders Beach	Accommodate **Retreat** Maintain Status Quo	5F 4B 4B	Accommodate ranked highest for coastal recreation access, indirect economic impacts and complexity of implementation. Retreat ranked highest for severity of inundation, coastal ecosystem impact, cultural heritage impact and Opex. MSQ ranked highest for capital cost. Retreat and MSQ ranked equal highest for flexibility to respond. Results were insensitive to weightings.		
Bushland Beach - Main Residential Area	Accommodate **Retreat** Maintain Status Quo	3D 5B 5A	Accommodate ranked highest for indirect economic impacts and complexity of implementation. Retreat ranked highest for severity of inundation, coastal ecosystem impact, cultural heritage impact and Opex. MSQ ranked highest for capital cost. Retreat and MSQ ranked equal highest for flexibility to respond. MCA results were insensitive to weightings		

Area / Location	Options (those in **bold** are recommended for CBA)	TCC ranking	Discussion	Weighted MCA scores	Preferred Option / Sensitivity Analysis
Bushland Beach - New Development Area	**Retreat** Defend Maintain Status Quo	N/A 5A 4A	Retreat ranked equal highest with defend for flexibility to respond. Retreat ranked equal highest with MSQ for Severity of inundation, coastal ecosystem impacts, capital cost and Opex. Defend ranked highest for indirect economic impacts and complexity of implementation. MCA results were insensitive to weightings.		
Townsville Inner Suburbs - The Strand	**Accommodate** **Retreat**	N/A	Accommodate ranked highest for coastal recreation access, indirect economic impacts, cultural heritage impacts, capital cost and complexity of implementation. Retreat ranked highest for severity of inundation, flexibility to respond, coastal ecosystems impact and Opex. The MCA result is somewhat sensitive to weighting of several criteria. Changes to these weightings result in accommodate becoming the highest ranking option.		
Townsville Inner Suburbs - Townsville City	**Defend 1** Defend 2 Defend 2 Accommodate 1 Accommodate 2 **Retreat**	4B 4B 4B	Defend 1 ranked highest for severity of inundation, indirect economic impacts, capital cost and complexity of implementation. Defend 1 and 2 ranked equal highest for cultural heritage impacts. Retreat ranked highest for severity of inundation, flexibility to respond, coastal ecosystem impacts and Opex. The result is somewhat sensitive to weightings for flexibility to respond and ecosystem impacts. Changes to these weightings result in retreat becoming the highest ranking option		
Townsville North - Pallarenda	**Accommodate** **Retreat** Maintain Status Quo	4F 4AB 4B	Accommodate ranked highest for coastal recreation access, indirect economic impacts, cultural heritage impacts and complexity of implementation. Retreat ranked highest for severity of inundation, coastal ecosystems impact and Opex. Retreat and MSQ ranked equal highest for flexibility to respond. MSQ ranked highest for capital cost. The result is highly sensitive to the weightings of several criteria. Changes to these weightings result in retreat becoming the highest ranking option		

Area / Location	Options (those in **bold** are recommended for CBA)	TCC ranking	Discussion	Weighted MCA scores	Preferred Option / Sensitivity Analysis
Townsville North - Industrial Area	**Defend** Accommodate	1DG 4A	Defend ranked highest for severity of inundation, indirect economic impacts, capital cost, complexity of implementation and Opex. Accommodate ranked highest for coastal ecosystem impacts. Defend and accommodate ranked equal highest for all other criteria. The MCA results are insensitive to weightings		
Townsville North Mt St John STP	**Defend** Accommodate	1F 4AE	Defend ranked highest for severity of inundation, coastal ecosystem impacts, indirect economic impacts, capital cost and complexity of implementation. Accommodate ranked highest for Opex. Defend and accommodate ranked equally for other criteria. MCA results are insensitive to weightings.		
River South - Oonoonba	**Defend** **Retreat** Maintain Status Quo	4B 3B 4B	Defend ranked highest for indirect economic impacts and complexity of implementation. Retreat ranked highest for severity of inundation, flexibility to respond and Opex. MSQ ranked highest for flexibility to respond and capital cost. All options ranked equally for other criteria. The results are somewhat sensitive to weightings for several criteria. Changes to these weightings result in defend becoming the highest ranking option.		
Stuart - Cleveland Bay STP	**Defend** **Accommodate**	4B 4AE	Defend ranked highest for severity of inundation and indirect economic impacts. Accommodate ranked highest for flexibility to respond, capital cost and complexity of implementation. The options ranked equally for other criteria. The results are somewhat sensitive to weightings for several criteria. Changes to these weightings result in accommodate becoming the highest ranking option.		

Area / Location	Options (those in **bold** are recommended for CBA)	TCC ranking	Discussion	Weighted MCA scores	Preferred Option / Sensitivity Analysis
South Land - Cungulla	Accommodate **Retreat** Maintain Status Quo	4B 4B 4B	Accommodate ranked highest for indirect economic impacts and complexity of implementation. Retreat ranked highest for severity of inundation, coastal ecosystem impacts and opex. MSQ ranked highest for capital cost. Retreat and MSQ ranked equally highest for flexibility to respond and cultural heritage impacts. The results are insensitive to weightings.		
Magnetic Island - Horseshoe Bay	Accommodate **Retreat** Maintain Status Quo	4B 3B 3B	Accommodate ranked highest for coastal recreation access, indirect economic impacts and complexity of implementation. Retreat ranked highest for severity of inundation, coastal ecosystem impacts, cultural heritage impacts and Opex. MSQ ranked highest for capital cost. Retreat and MSQ ranked equal highest for flexibility to respond. MCA results are insensitive to weightings.		
Magnetic Island - Arcadia (Geoffrey Bay)	Accommodate **Retreat** Maintain Status Quo	4AB 3B 3B	Accommodate ranked highest for coastal recreation access, indirect economic impacts and complexity of implementation. Retreat ranked highest for severity of inundation, coastal ecosystem impacts, cultural heritage impacts and Opex. MSQ ranked highest for capital cost. Retreat and MSQ ranked equally highest for flexibility to respond. MCA results are insensitive to weightings.		
Magnetic Island - Nelly Bay	**Defend** Maintain Status Quo		Defend ranked highest for severity of inundation, indirect economic impacts, complexity of implementation and Opex. Defend and MSQ ranked equally for cultural heritage impact. MSQ ranked highest for all other criteria. MCA results are insensitive to weightings.		

Area / Location	Options (those in **bold** are recommended for CBA)	TCC ranking	Discussion	Weighted MCA scores	Preferred Option / Sensitivity Analysis
Magnetic Island - Picnic Bay	Accommodate **Retreat** **Defend 1** Maintain Status Quo	3B 3B 3F	Accommodate ranked highest for complexity of implementation. Retreat ranked highest for coastal ecosystems impact, cultural heritage impact and Opex. Defend ranked highest for indirect economic impacts. Defend ranked equal highest with accommodate for coastal recreation impact. Defend and Retreat ranked equal highest for severity of inundation. MSQ ranked equal highest with retreat for flexibility to respond and capital cost. The results were somewhat sensitive to criteria weightings for several criteria. Changes to these weightings result in defend becoming the highest ranking option.		
Magnetic Island - Picnic Point STP	**Defend** Accommodate	 4E	Defend ranked highest for severity of inundation, indirect economic impacts and Opex. Accommodate ranked highest for capital cost. The options had equal ranking for all other criteria. MCA results are insensitive to weightings.		
Magnetic Island - West Point	**Retreat** Maintain Status Quo	NA	Retreat ranked highest for severity of inundation, coastal ecosystems impact, indirect economic impacts, cultural heritage impact, complexity of implementation and Opex. MSQ ranked highest for capital cost. The options ranked equally for all other criteria. MCA results are insensitive to weightings.		
Magnetic Island - Bolger Bay Pump Station	**Defend** Accommodate	NA	Defend ranked highest for severity of inundation, indirect economic impacts, capital cost, complexity of implementation and Opex. The options ranked equally for flexibility to respond, coastal recreation impact coastal ecosystems impact and cultural heritage impact. MCA results are insensitive to weightings.		

Area / Location	Options (those in **bold** are recommended for CBA)	TCC ranking	Discussion	Weighted MCA scores	Preferred Option / Sensitivity Analysis
Magnetic Island Radical Bay (north of Florence Bay)	**Accommodate** Maintain Status Quo	NA	Accommodate ranked highest for severity of inundation, coastal recreation impact, indirect economic impacts, complexity of implementation and Opex. MSQ ranked highest for all other criteria. MCA results are insensitive to weightings.		

Attachment D BCA Results

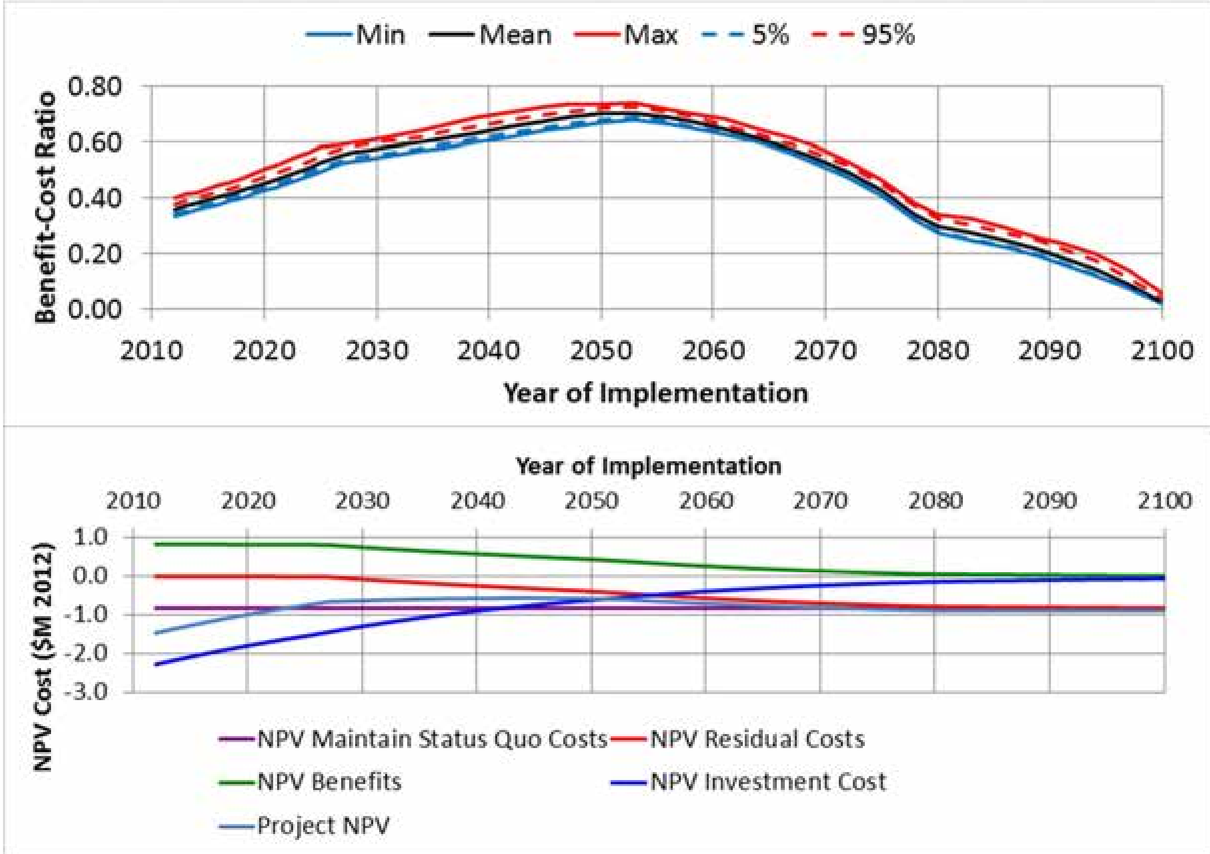


Figure 20 Mutarnee Retreat

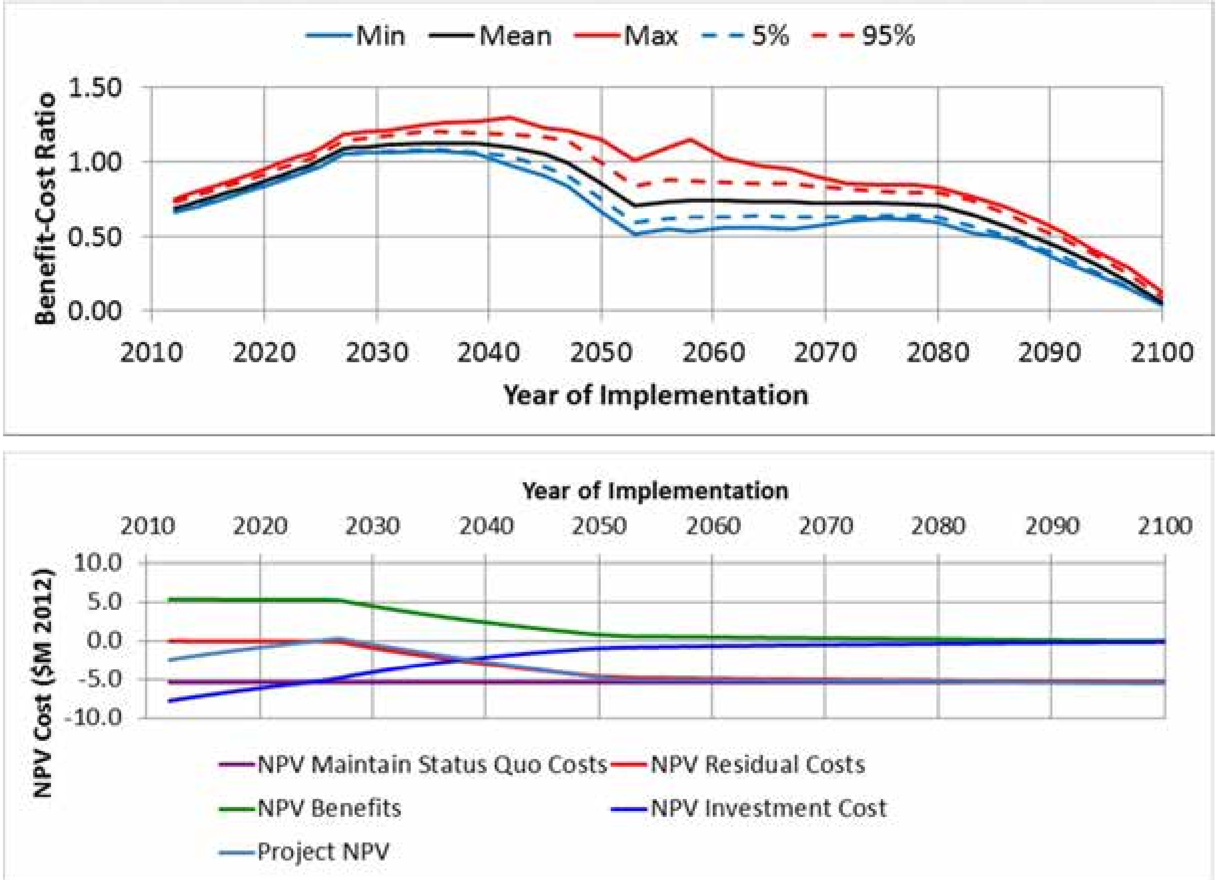


Figure 21 Rollingstone Retreat

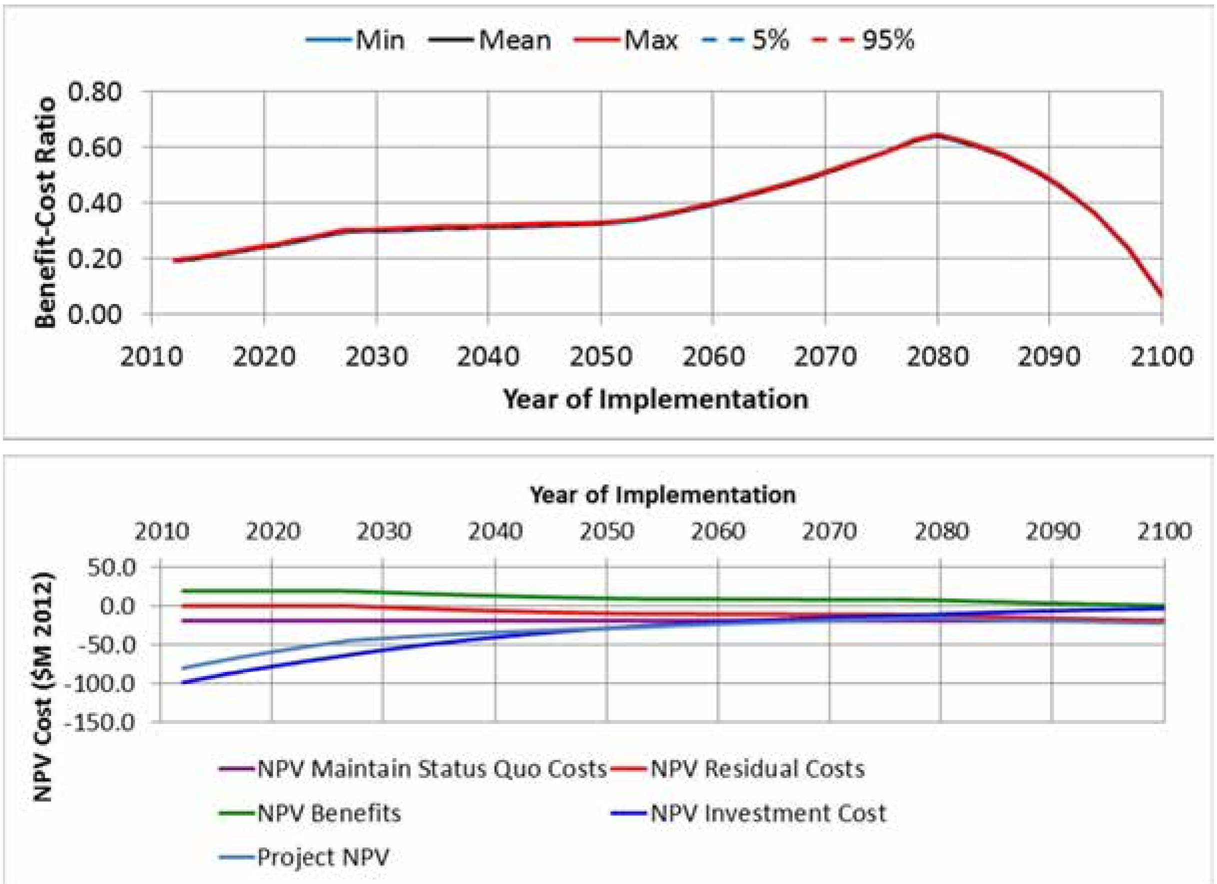
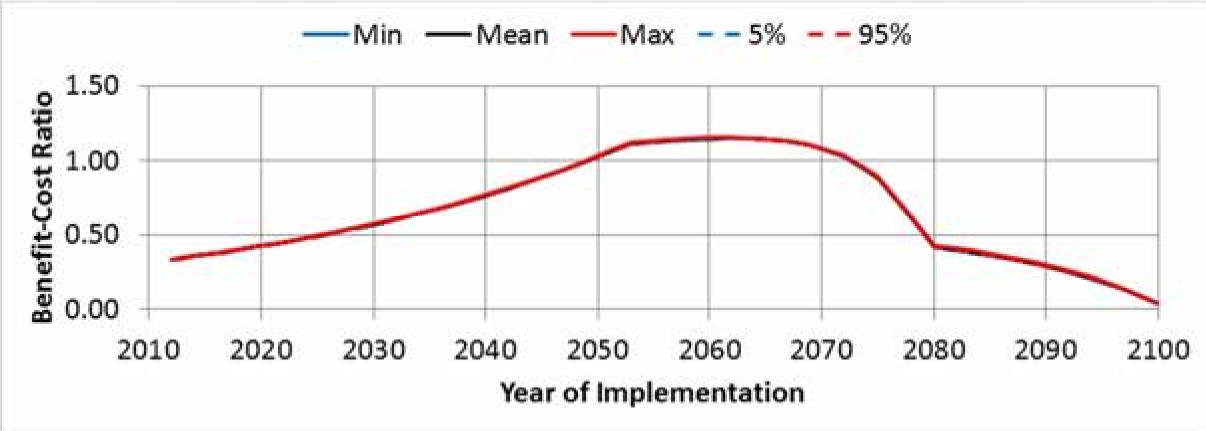


Figure 22 Balgal Beach Retreat



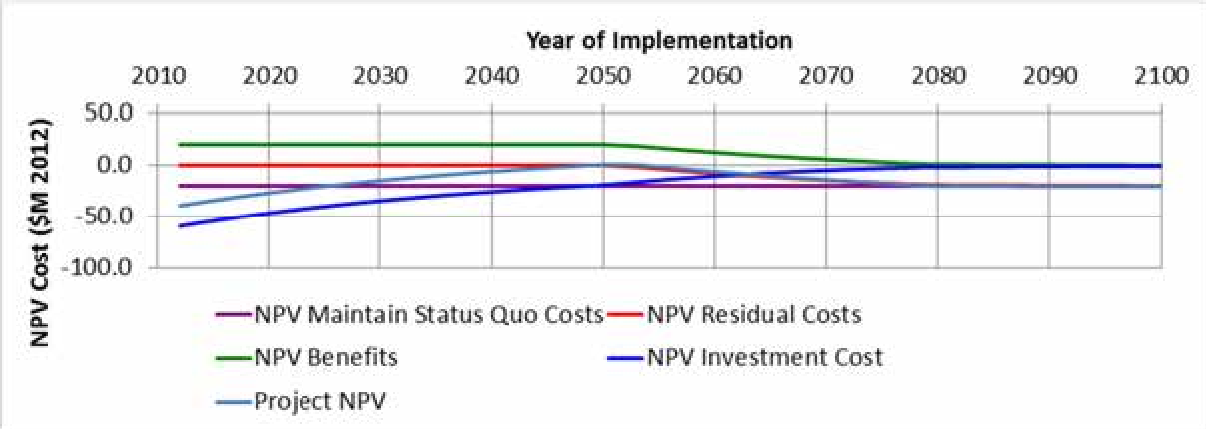
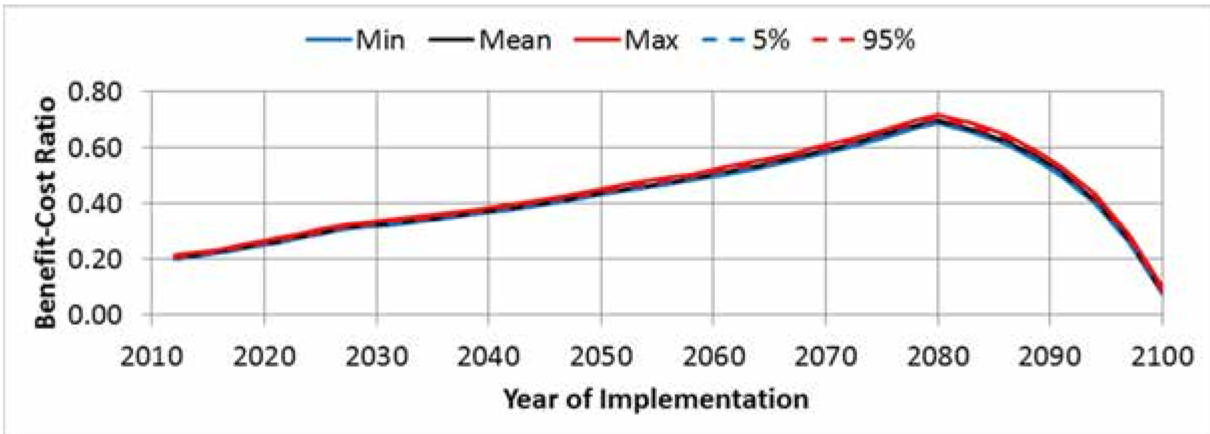


Figure 23 Toomulla Retreat



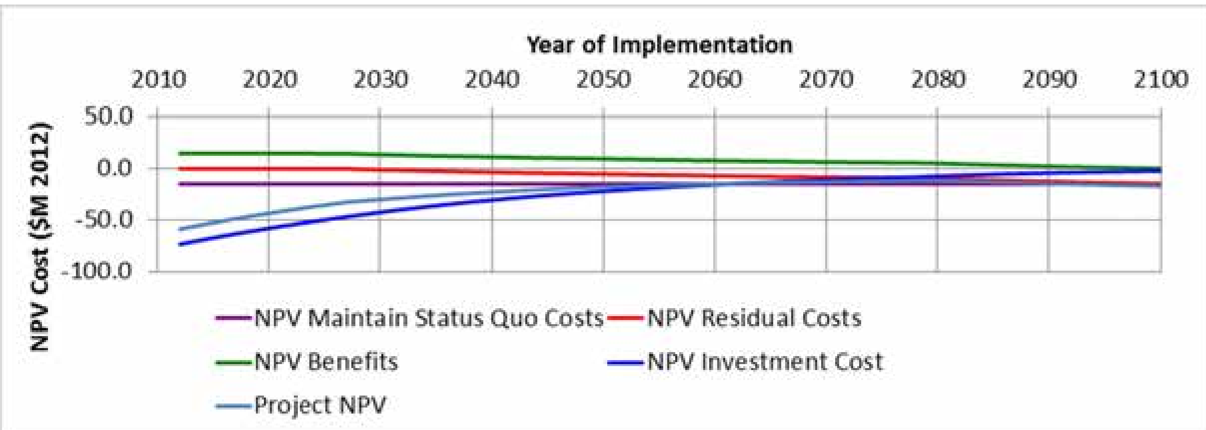


Figure 24 Toolakea Retreat

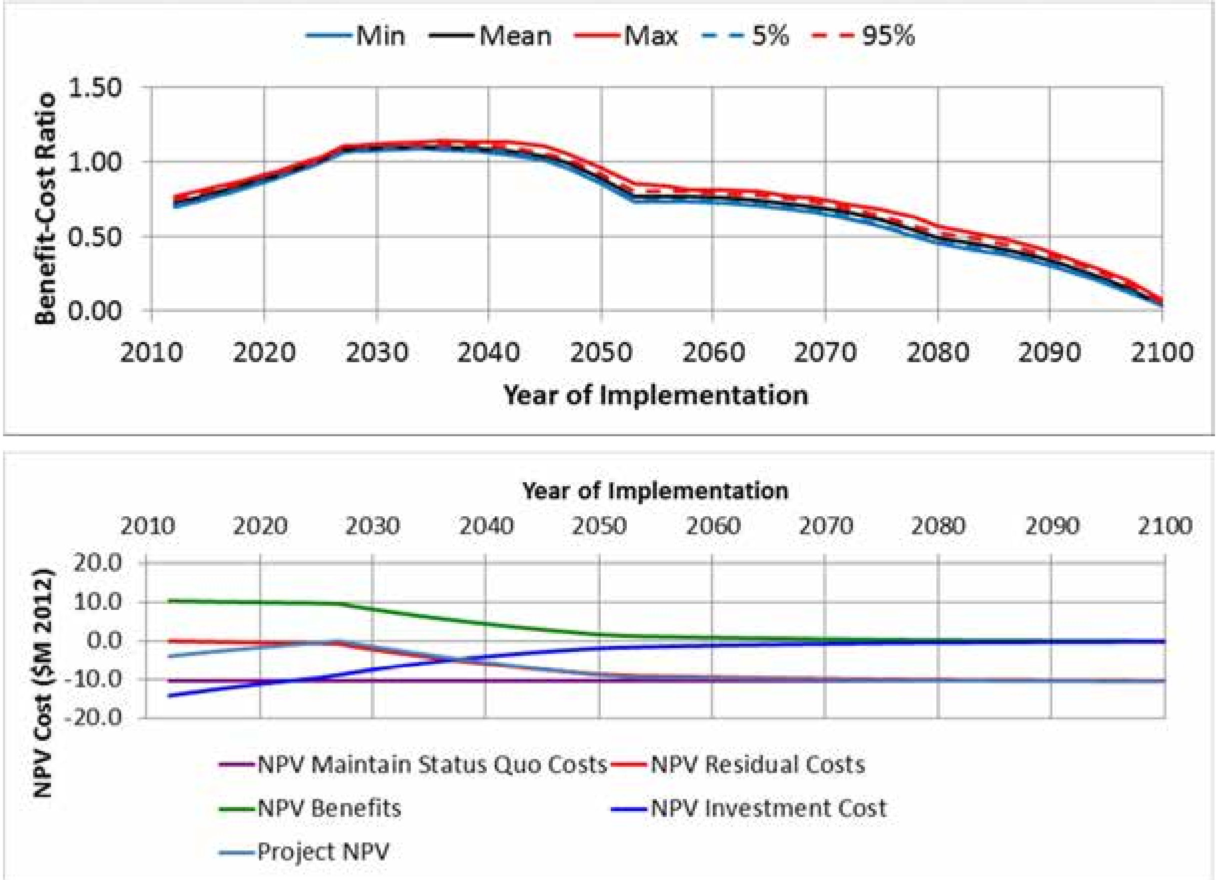


Figure 25 Bluewater Beach Retreat

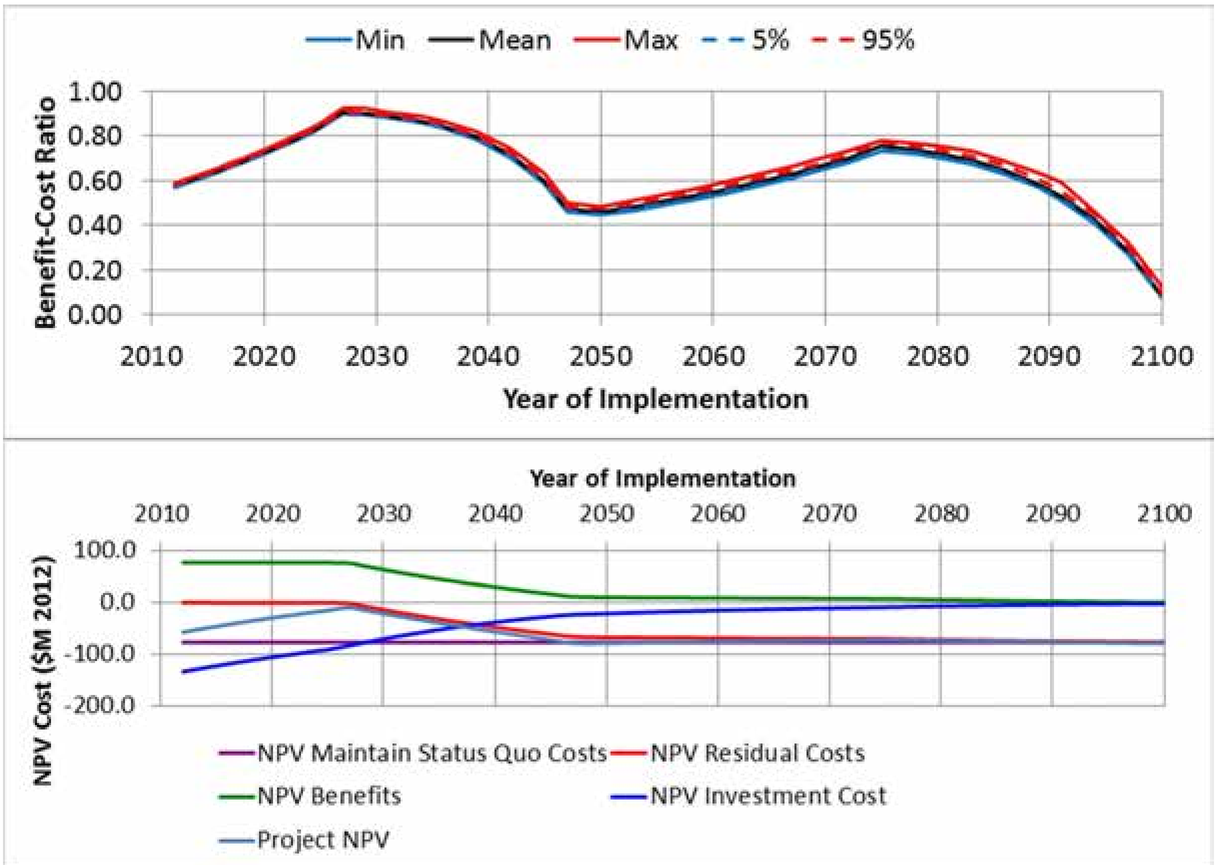


Figure 26 Saunders Beach Retreat

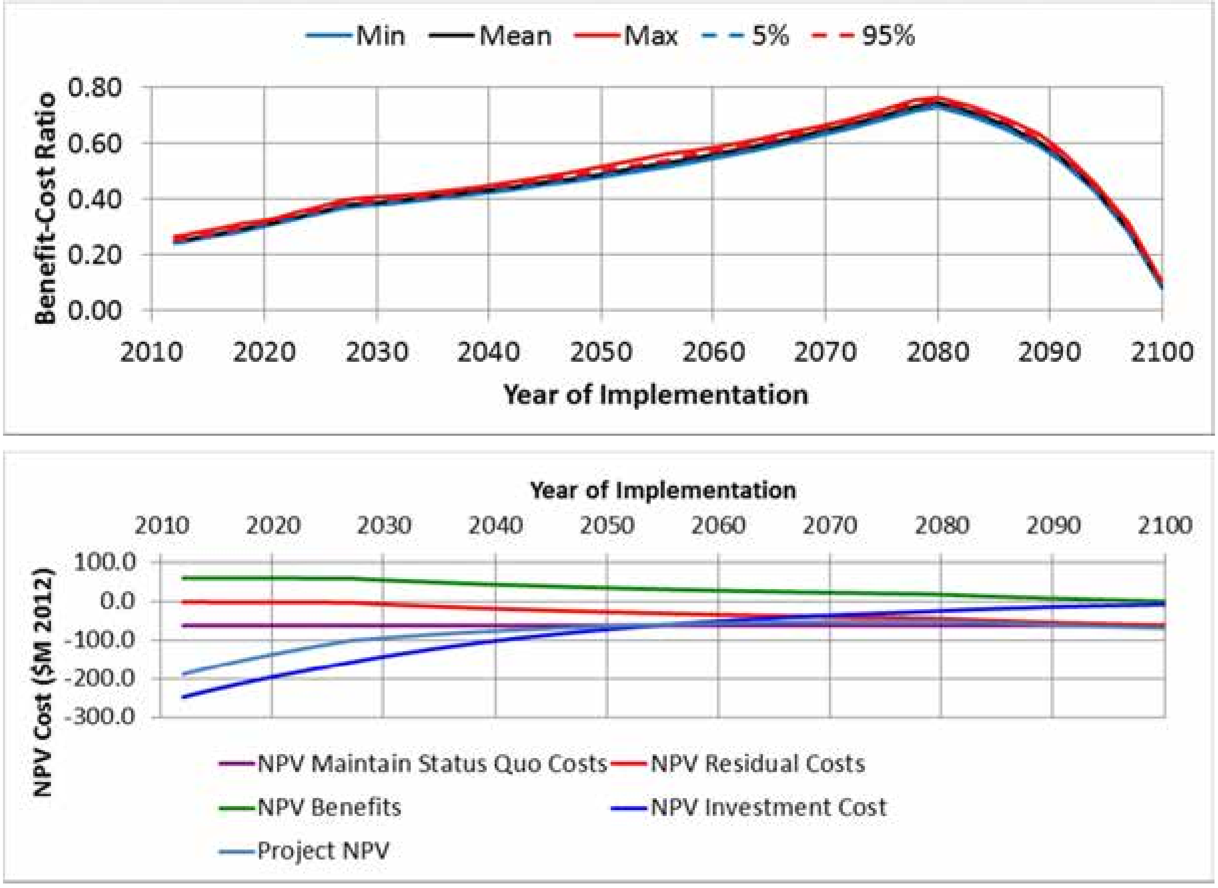


Figure 27 Bushland Beach Retreat

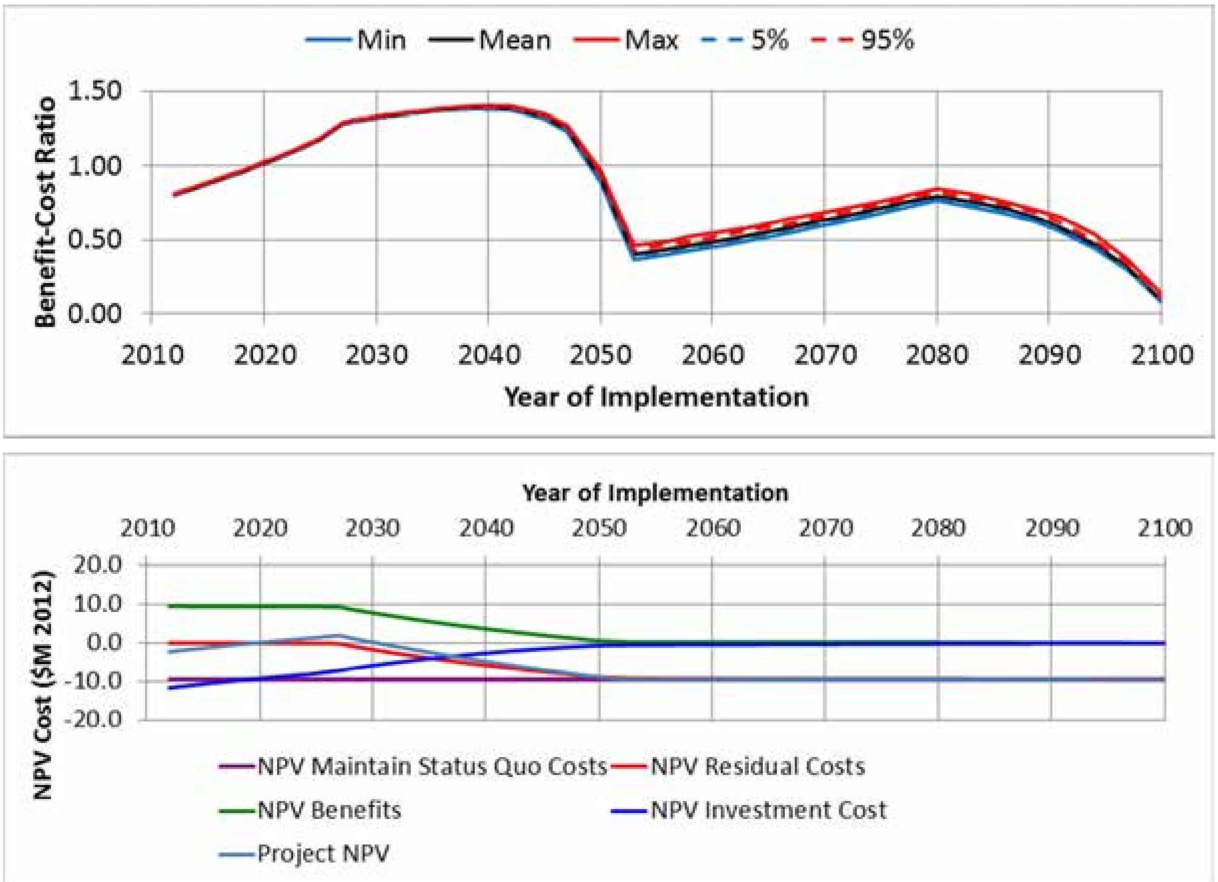


Figure 28 North Shore Greenfield Development Site Retreat.

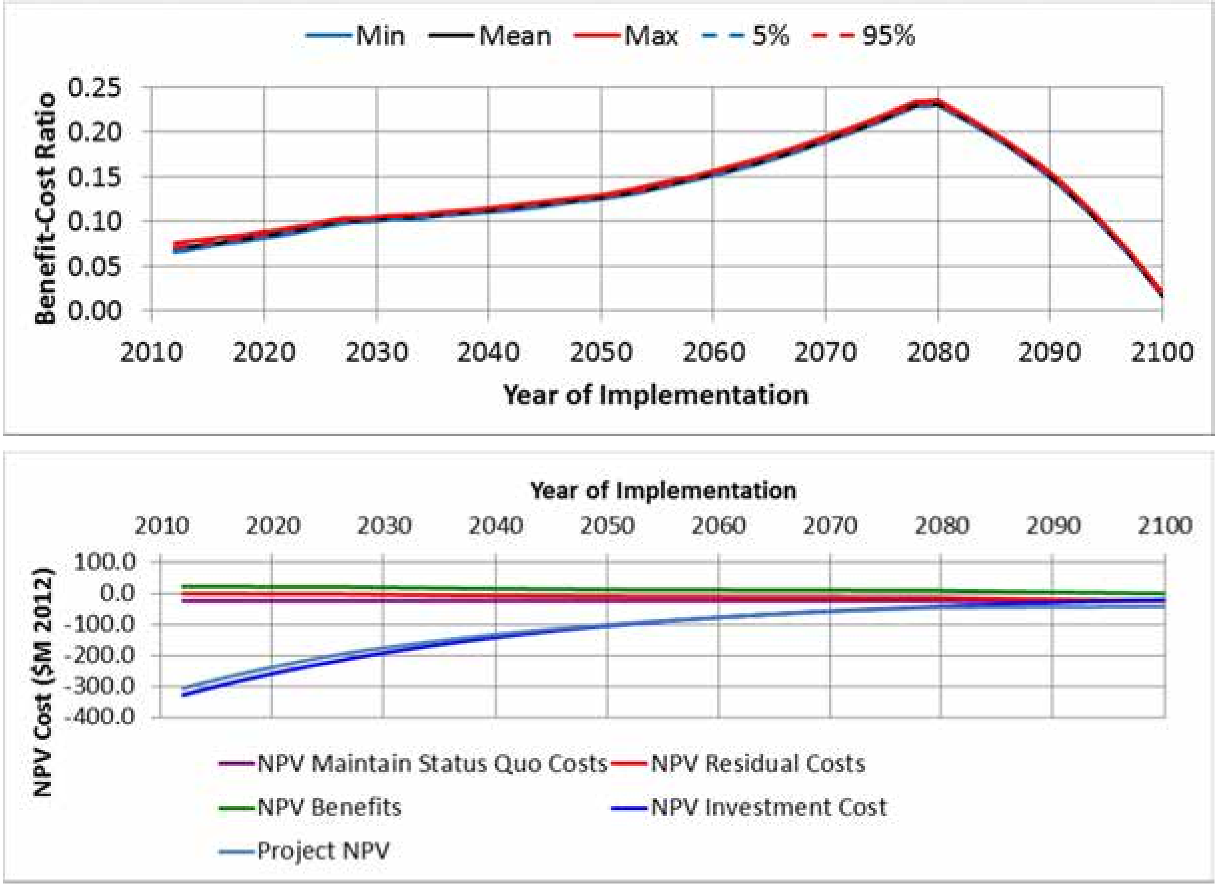


Figure 29 Pallarenda Retreat

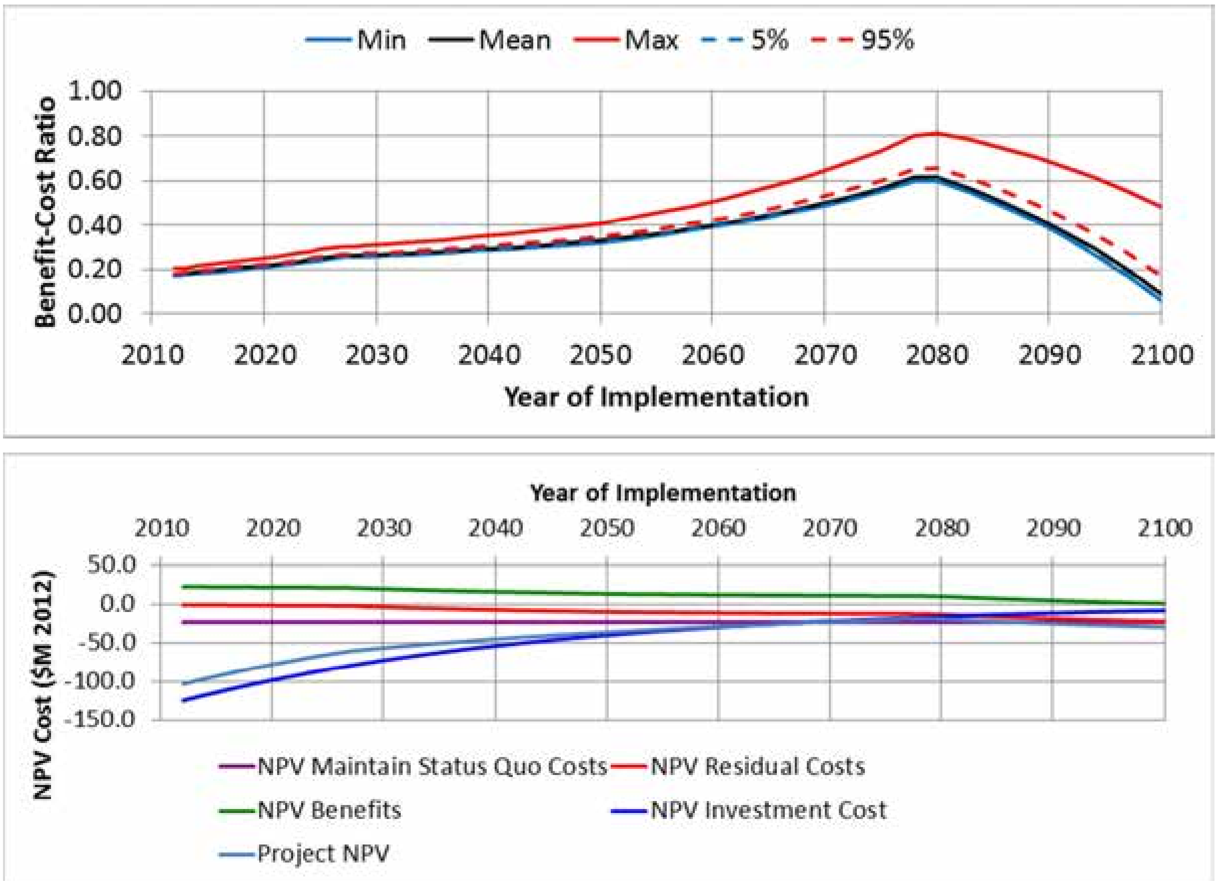
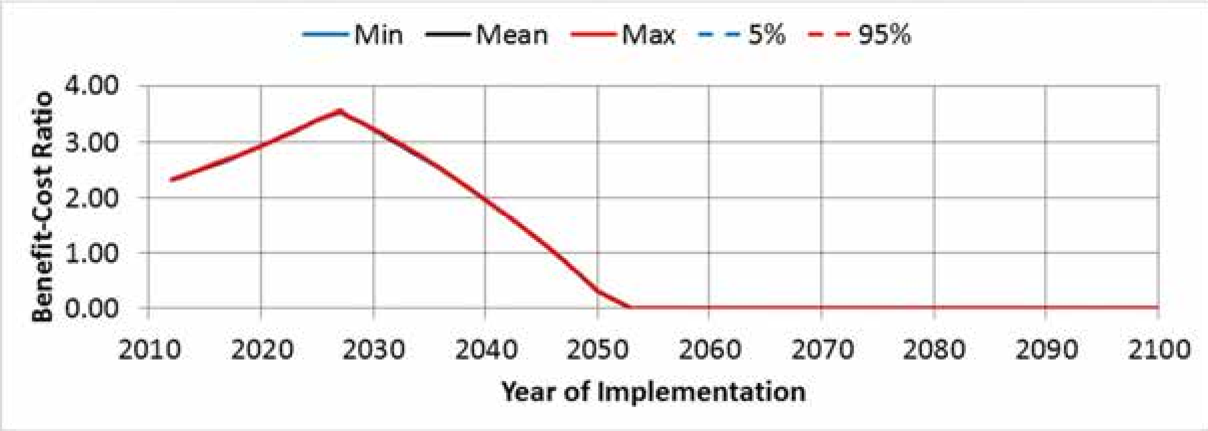


Figure 30 Pallarenda Accommodate



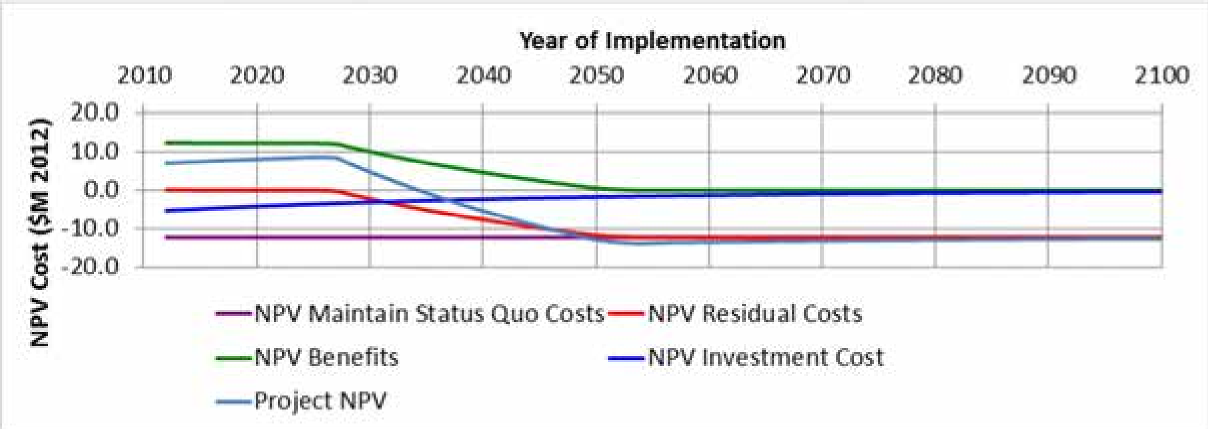
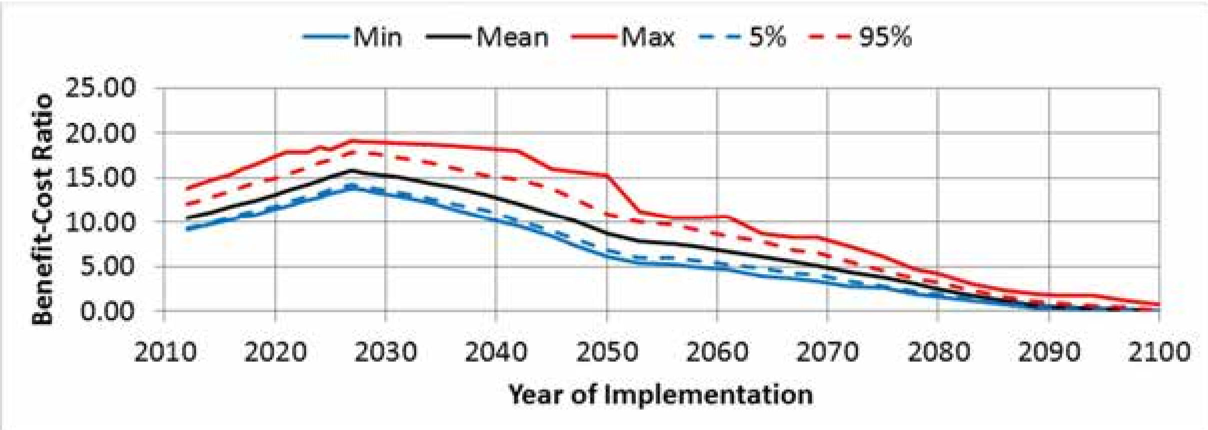


Figure 31 Mt St John Defend



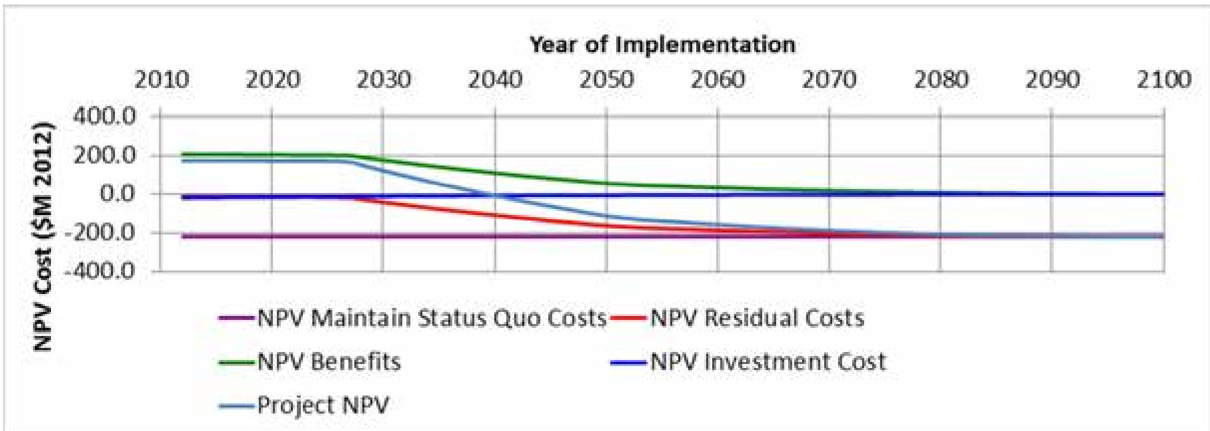


Figure 32 Industrial Area Defend

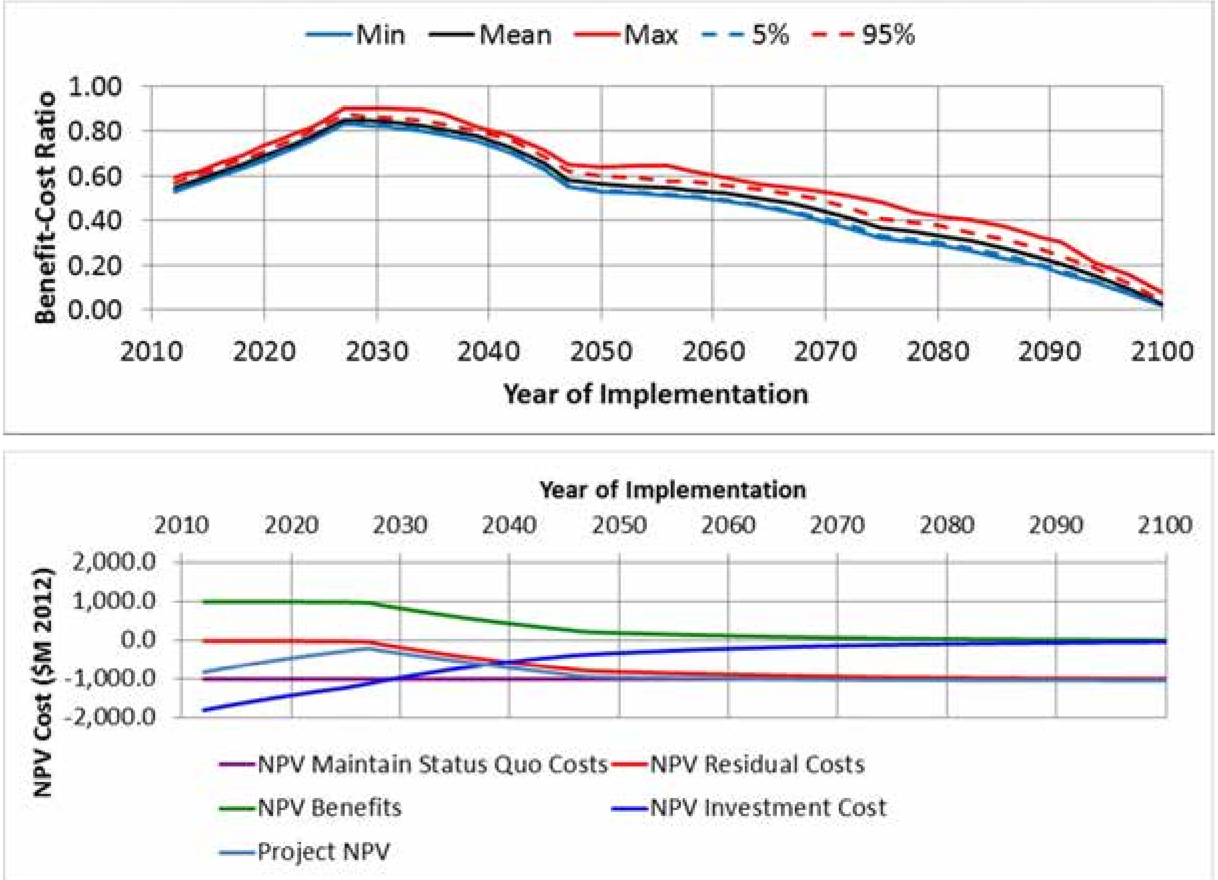


Figure 33 Townsville Inner Suburbs Retreat

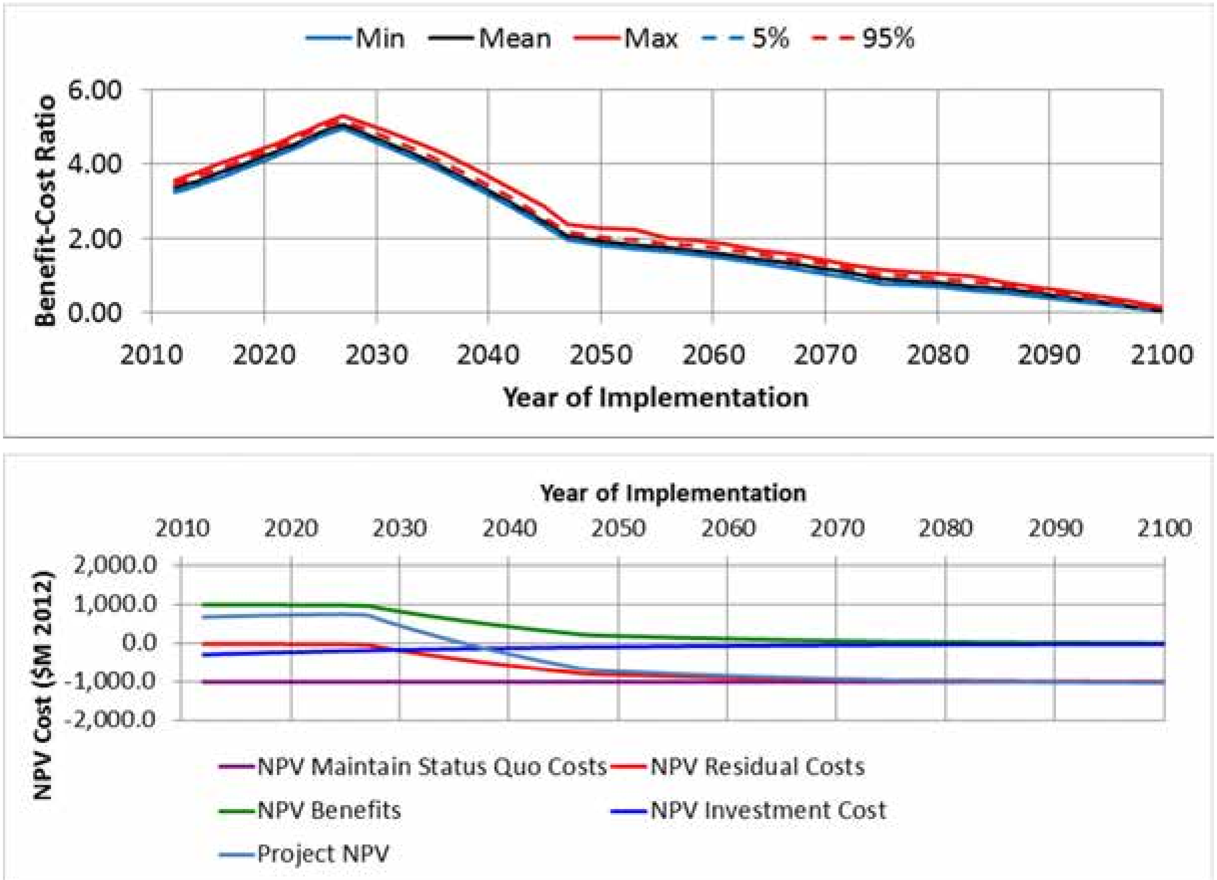
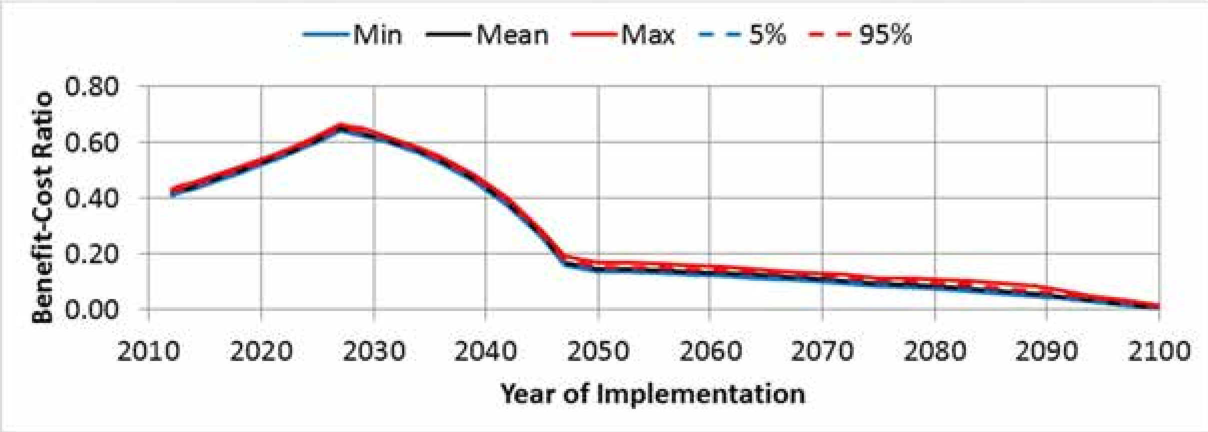


Figure 34 Townsville Inner Suburbs Defend Option 1



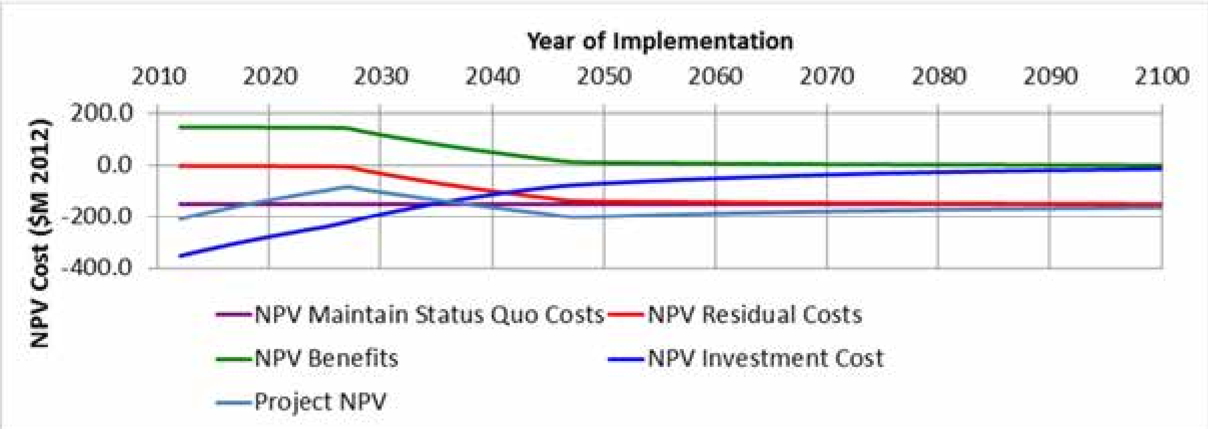
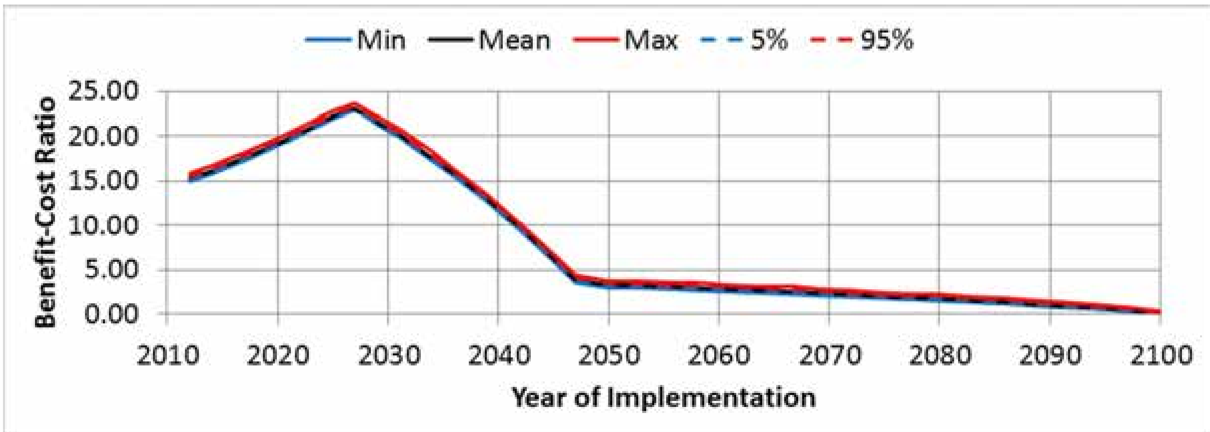


Figure 35 Oonoonba Retreat



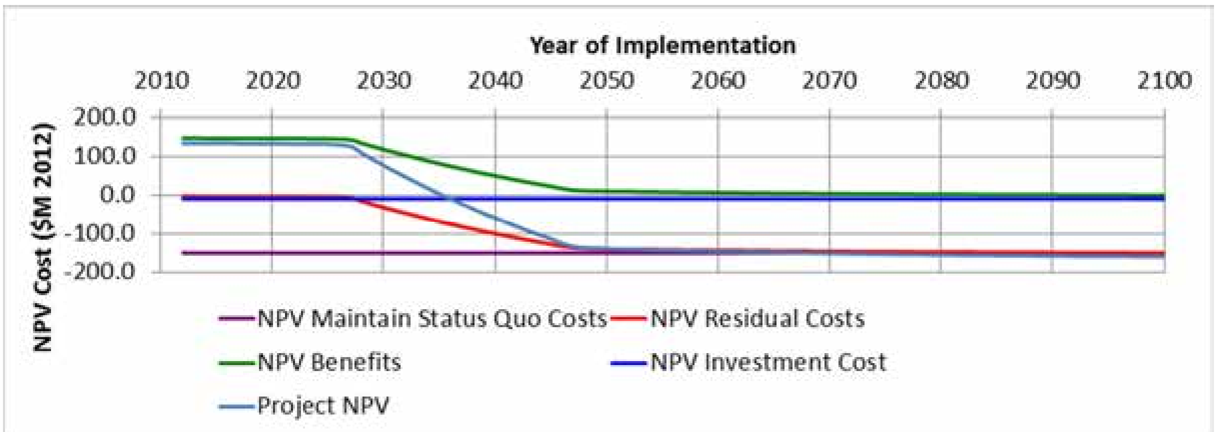


Figure 36 Oonoonba Defend

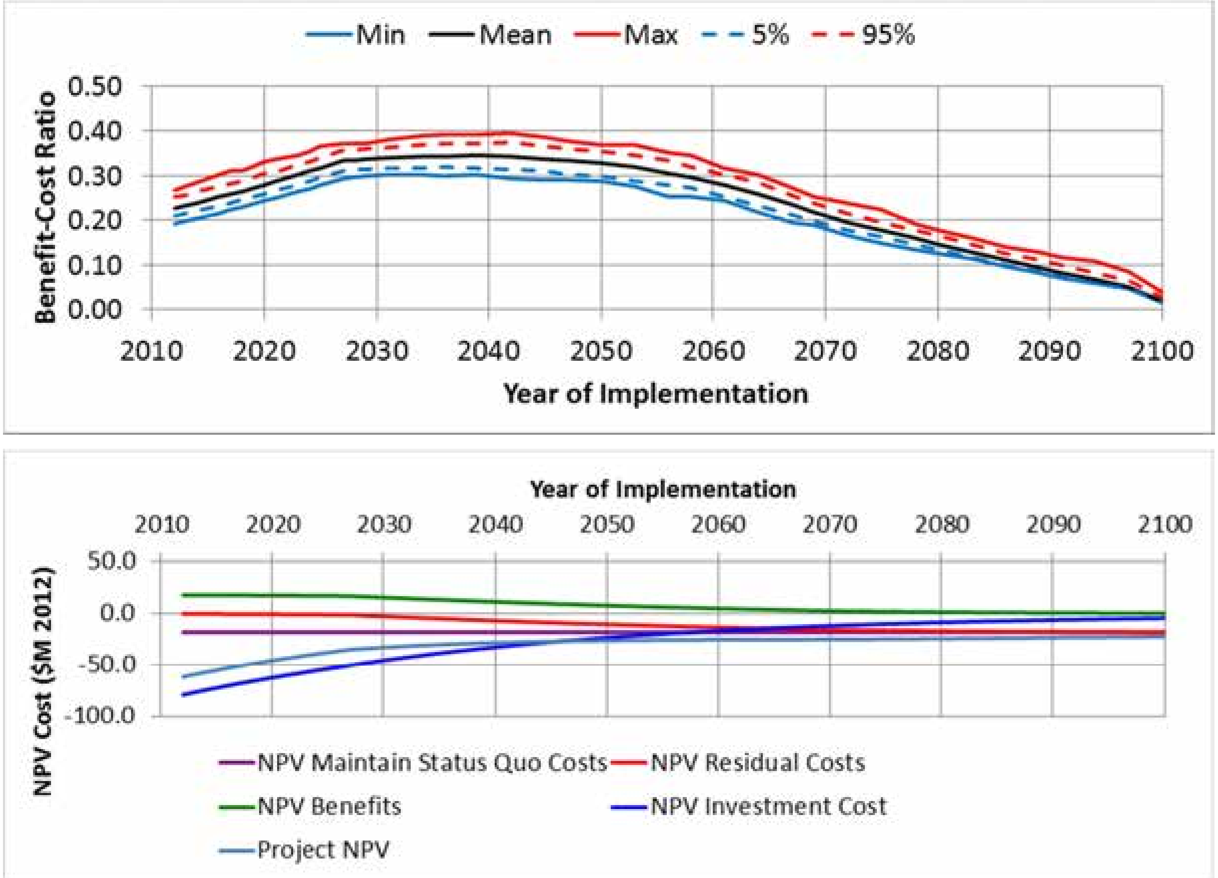


Figure 37 Cungulla Retreat

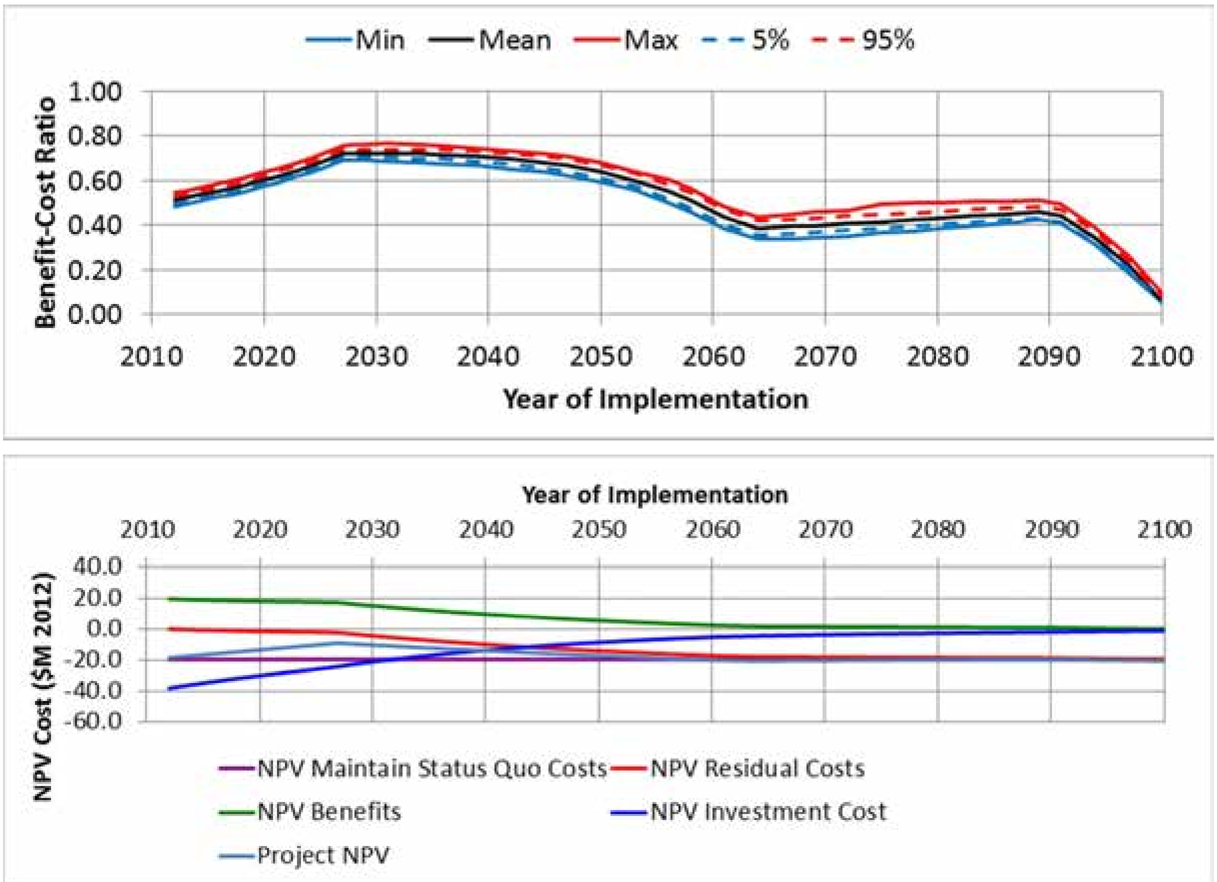


Figure 38 Horseshoe Bay retreat

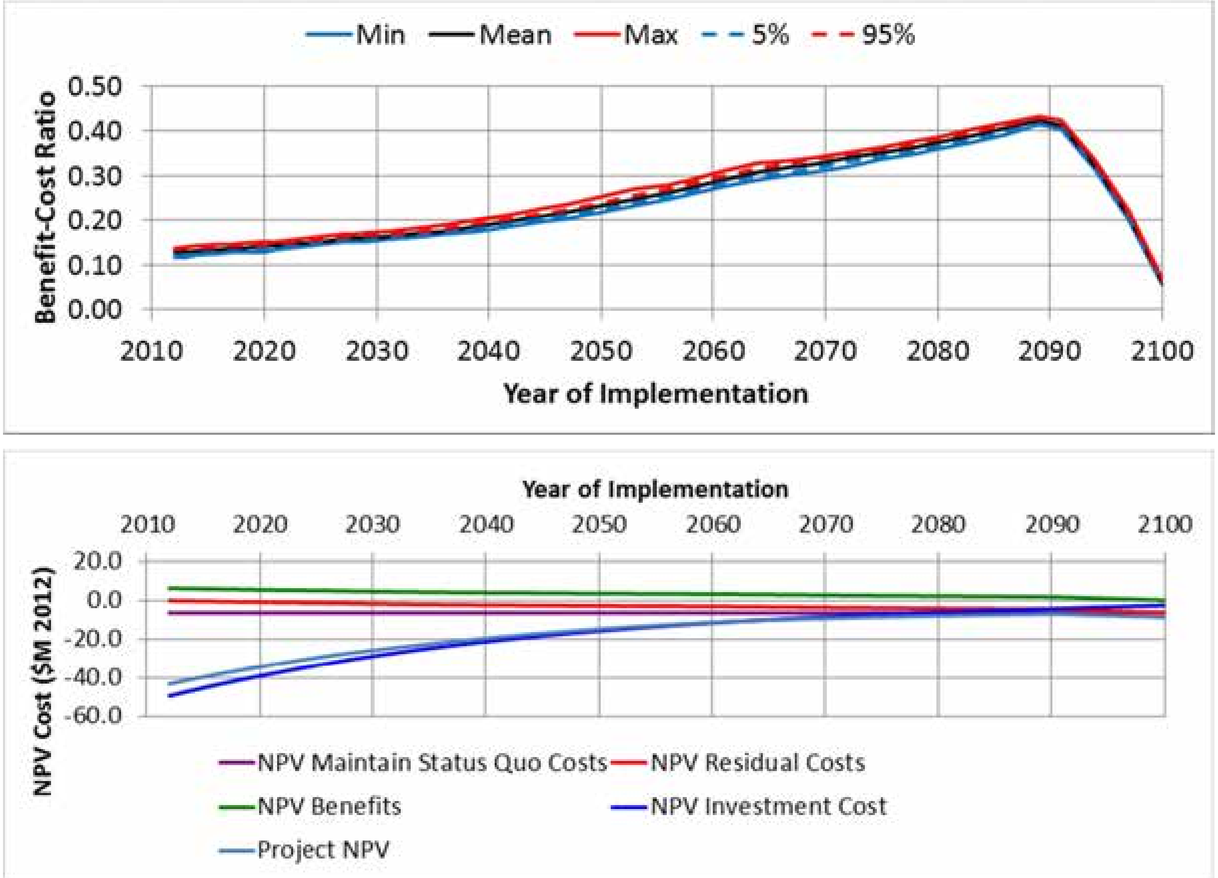


Figure 39 Arcadia (Geoffrey Bay) Retreat

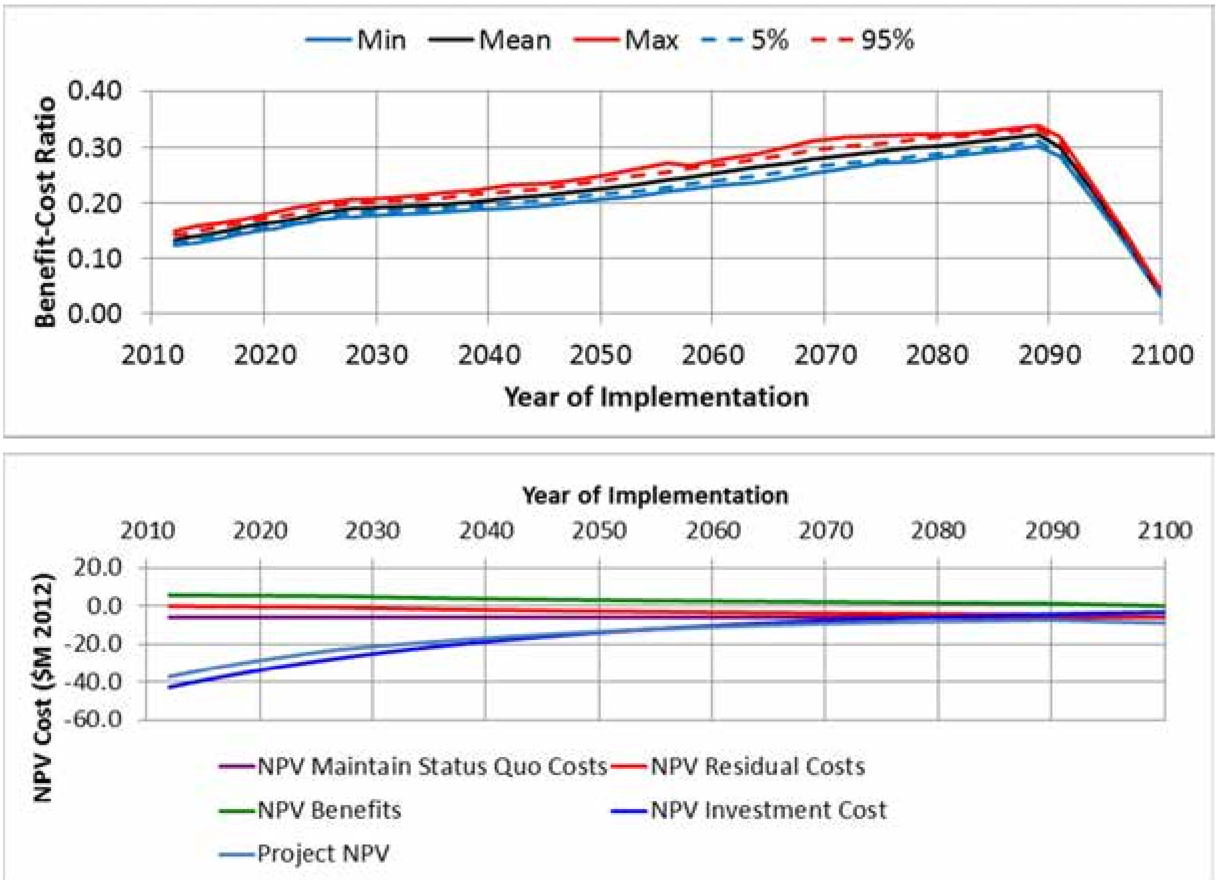


Figure 40 Nelly Bay Defend

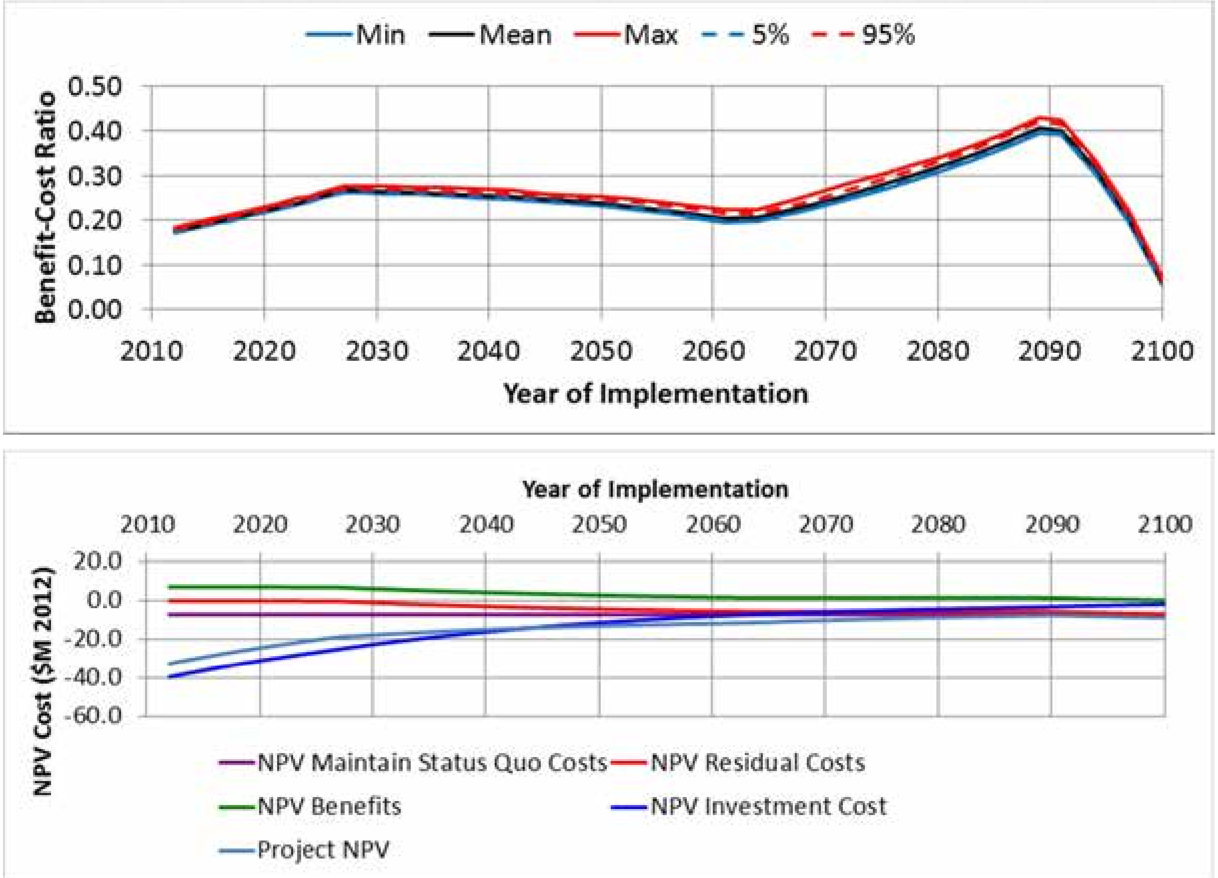


Figure 41 Picnic Bay Retreat

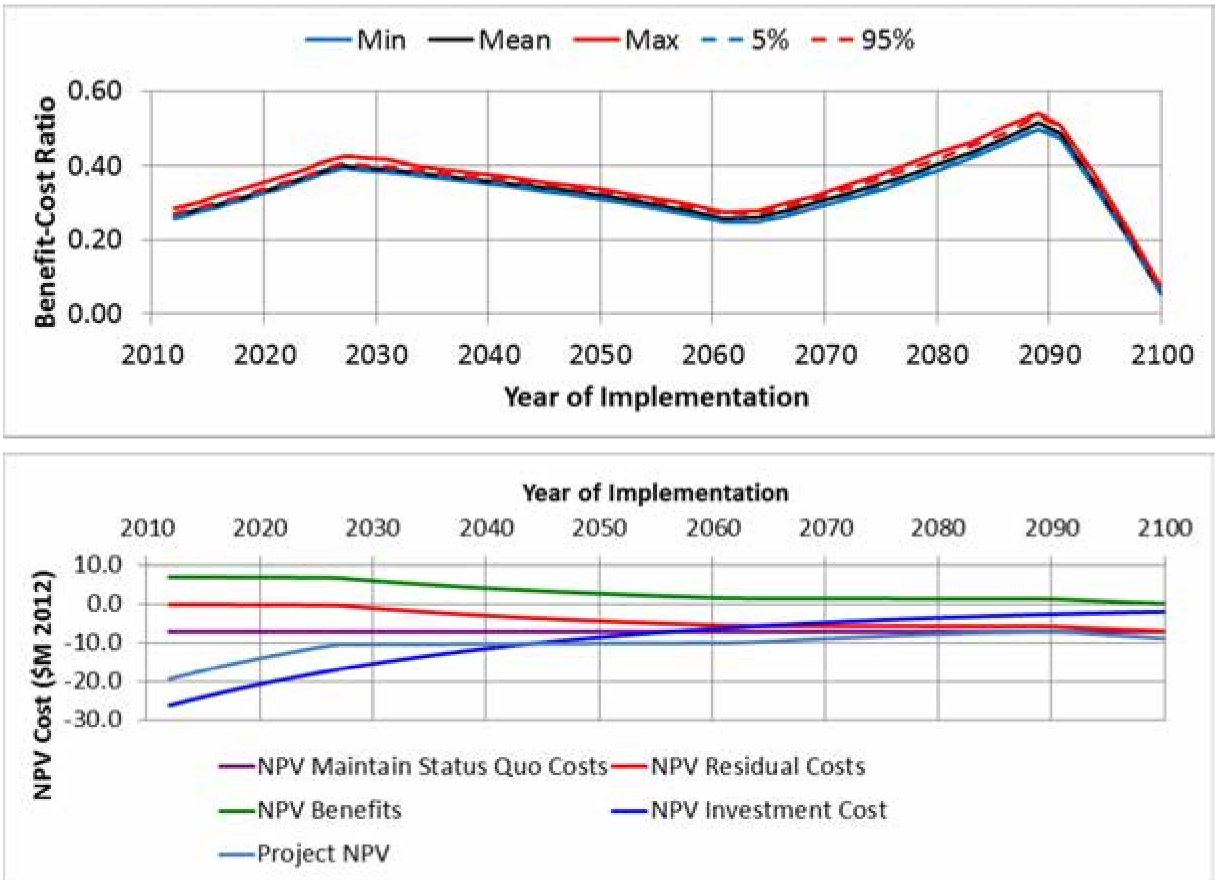


Figure 42 Picnic Bay Defend

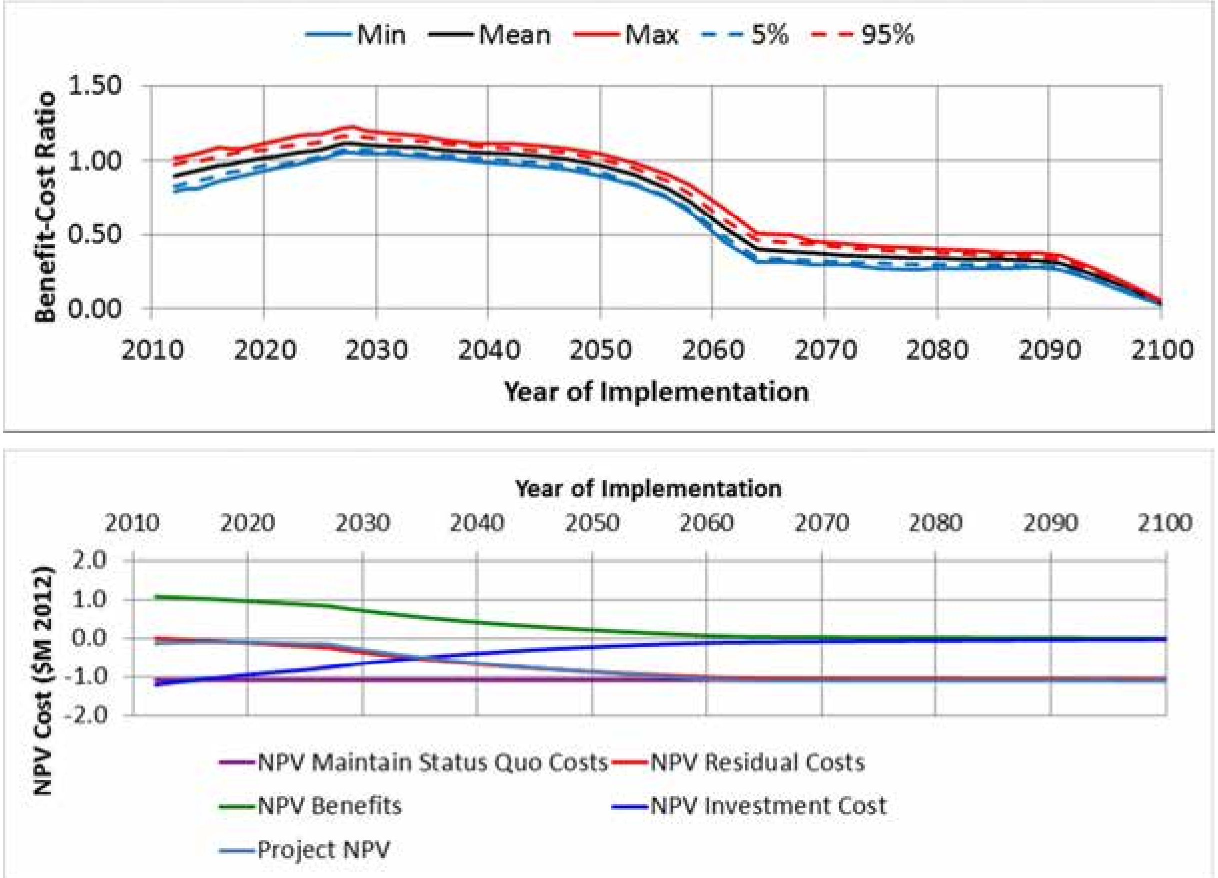


Figure 43 Cockle Bay (Lots) Retreat

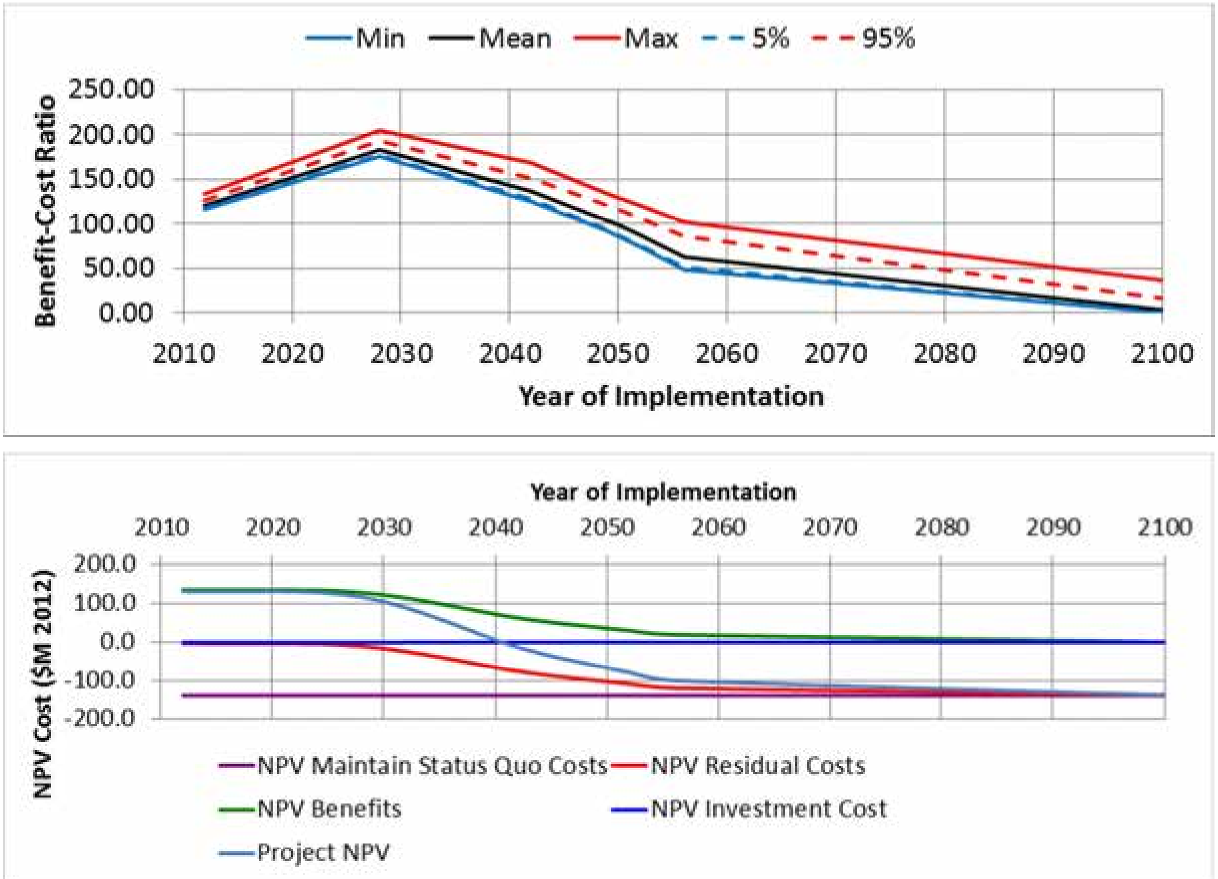


Figure 44 Picnic Point WTP Defend

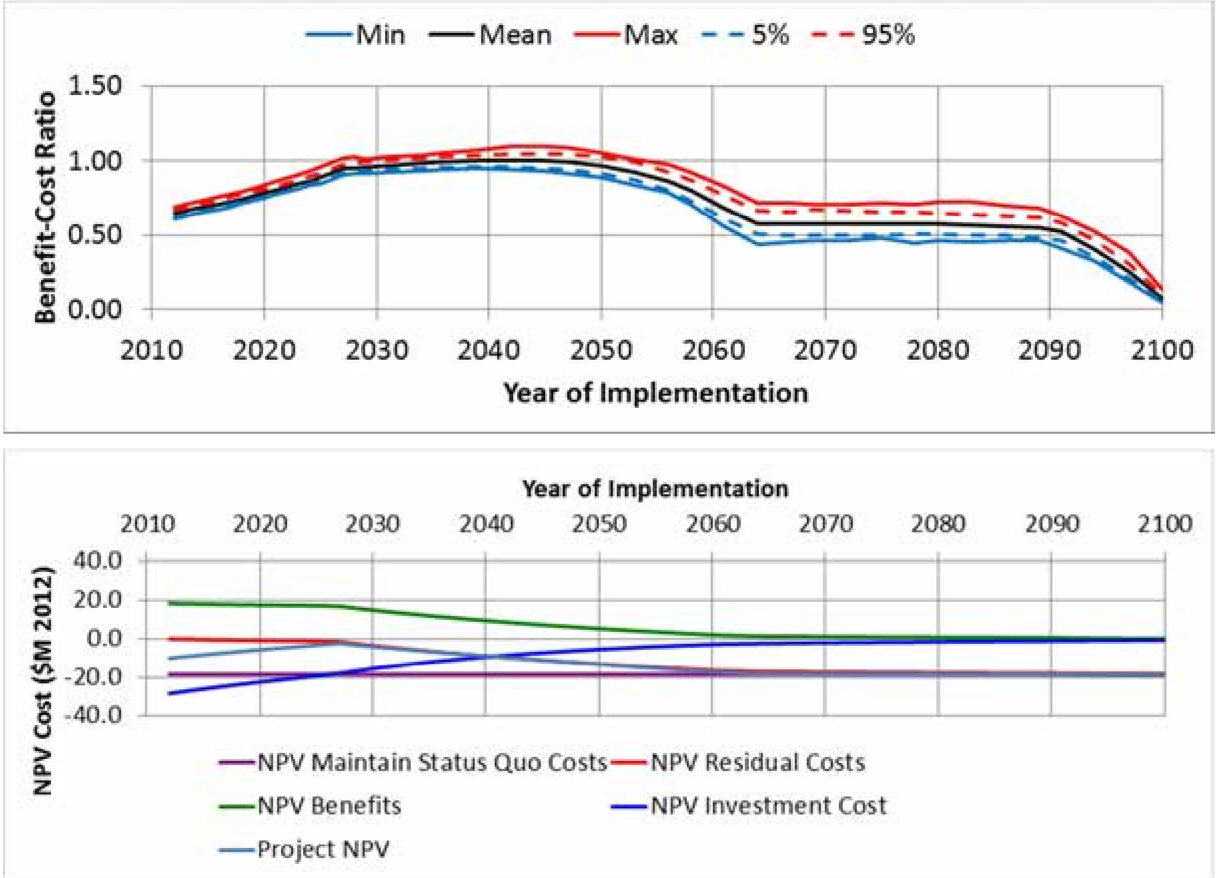


Figure 45 West Point Retreat

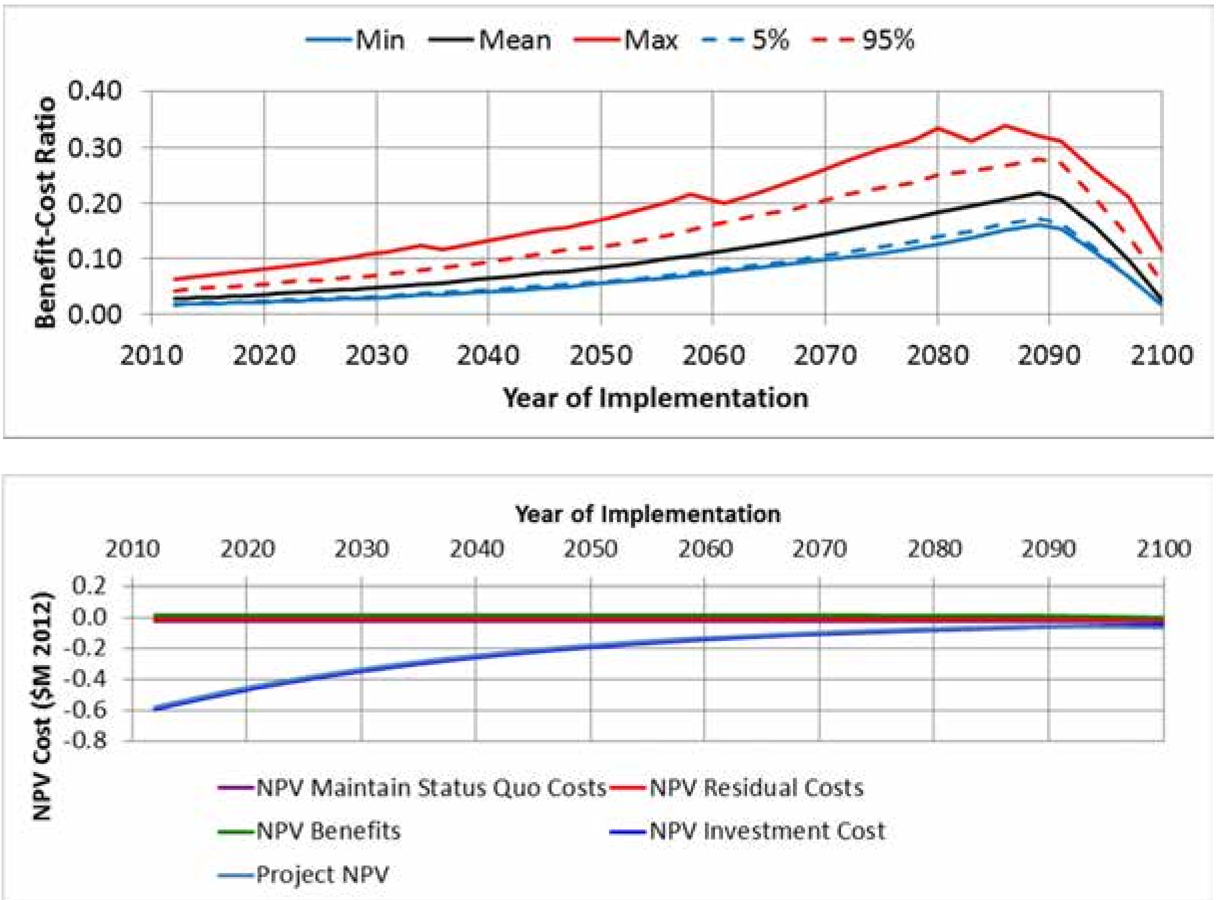


Figure 46 Bolger Bay Pump Station Defend

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