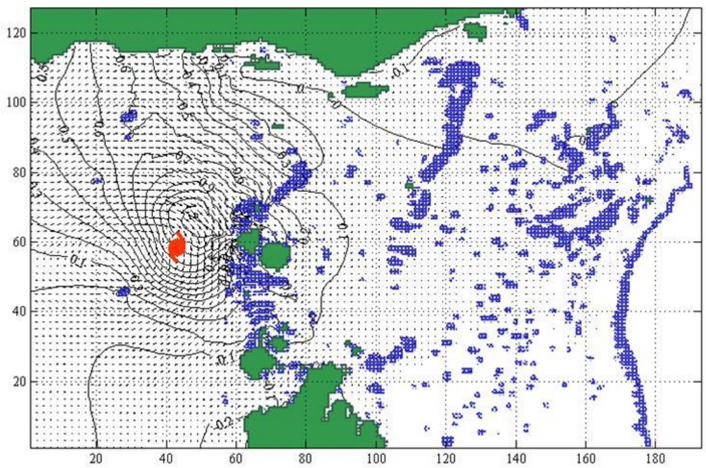
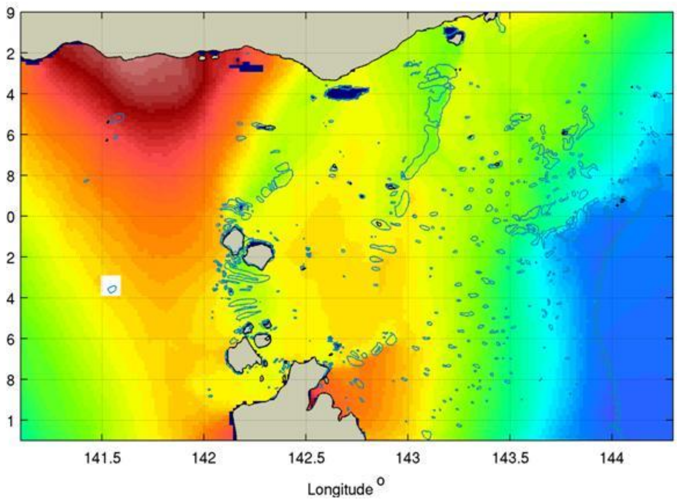
A Coastal Vulnerability Assessment Methodology for Torres Strait Communities – Pilot Study





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Cover Details:

Top: TSRA-supplied photographs of flooding by the sea at Saibai, January 2009 (D. Hanslow).

Bottom: Example modelled Category 4 tropical cyclone storm surge pattern (left) and simulated broadscale 100 year Return Period water level pattern (right) from SEA (2011).

Torres Strait Regional Authority

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Final Report

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The information contained in this publication is based on the application of conceptual computer models of atmospheric and ocean hazards and provides an estimate only of the likely impacts of such events. The analyses have been undertaken in accordance with generally accepted consulting practice and no other warranty, expressed or implied, is made as to the accuracy of the data and professional advice provided herein. The results should be interpreted by qualified professionals familiar with the relevant meteorological, oceanographic and statistical concepts.

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EXECUTIVE SUMMARY

This report presents a Coastal Vulnerability Assessment Methodology for Torres Strait Communities and considers Ngurupai (Horn) Island as an example Pilot Study. The purpose is to provide a tool to assist in decision making. The specific examples in this study are not necessarily the “answers”, but illustrate outcomes based upon the assumptions made. The user may wish to alter and refine these assumptions based upon a deeper appreciation of the values used.

The methodology utilises storm tide hazard estimates obtained from the previously completed probabilistic assessment of extreme ocean water levels and inundation hazard in Torres Strait (SEA 2011), together with the latest projections of future climate conditions and sea level rise (IPCC 2013). The methodology broadly follows that developed for Townsville (GHD 2012), which was supported by Local, State and Commonwealth authorities. The study was commissioned by the Torres Strait Regional Authority though its Land and Sea Management Unit.

The study focuses on the Wasaga community located on the north-west tip of Ngurupai, which is a major service provider for the Torres Strait communities, especially nearby Waiben (Thursday) Island. It provides the regional airport, marine transport services and the water supply to Thursday Island.

This exploratory study shows that the low lying nature of the present seaside community (and parts of its airport) are at a high risk of impacts from future projected climate change, mainly due to the anticipated slow rise in sea level, which will exacerbate the impacts of extreme weather events causing storm tides. Assuming that the community will not be abandoned in the face of rising sea levels, there will be accumulating costs over the coming decades to maintain or further develop its regional services and provide a safe and sustainable community.

The study combines information on the storm tide hazard, climate change projections, exposure of assets and their assumed vulnerability to those hazards in a rational quantitative assessment of potential economic damage and loss up to the year 2100. It also considers the economic effectiveness of community responses of *Planned Retreat* from the hazards and also *Defence* against the hazards.

The study suggests that based on current climate change projections and the other assumptions made in the analysis that it will likely be most cost effective to consider a *Forced Retreat* adaptation strategy.

The study does not claim to be comprehensive but to provide an outline of a robust methodology that can and should be further refined to enable

informed community and stakeholder discussions to be undertaken. This can then facilitate development of a comprehensive management plan that would detail the important planning and investment decisions that will be required over time.

The study assumptions and limitations are detailed to enable this process to proceed to the next stage of investigation and a risk analysis planning tool (RAPT) has been developed for use by TSRA.

1. Introduction

This report documents analyses undertaken to develop a *Coastal Hazard Assessment Methodology* suitable for application to Torres Strait communities. Appendix A contains the Scope of Work.

1.1 Aims and Objectives

This is a Pilot Study, using Ngurupai (Horn) Island as an example, to develop a methodology suitable for assessing the risks to community and infrastructure located in coastal hazard zones across the Torres Strait as a result of projected sea level rise and associated impacts, including:

- Assessment of what infrastructure/ services are at risk under several key sea level scenarios and several key return intervals
- Assessment of net present value of infrastructure at risk
- Fine scale assessment of average percentage time that a community is inundated under various sea levels
- Economic analysis of timeframes for investment.
- Potential adaptation options

The methodology is guided by the approach and recommendations developed for Townsville by the Local Government Association of Queensland, Townsville City Council and the Department of Environment and Heritage Protection, (GHD 2012).

1.2 The Study Location

Ngurupai, also known as Horn Island, is relatively flat compared with some nearby islands, covers approximately 53 square kilometres, and has a population of approximately 550 (Figure 1-1). The principal community of Wasaga is located on the north-western edge of the island.

The island contains the Torres Strait's primary airport, which regularly services daily flights from Cairns and the outer Torres Strait islands and supplies water to nearby Waiben (Thursday) Island. It also provides marine transport and repair services for the region and commerce, education and administrative services to its residents.

Ngurupai is administered by the Torres Shire Council, which is based on Waiben. The Traditional Owners are the Kaurareg people.

Figure 1-1 Ngurupai (Horn) Island and its nearby island communities

1.3 Definitions of the Coastal Hazards

This study addresses the impact of coastal hazards to the community, which principally manifest during extreme weather that causes a potential flooding event termed a *storm tide*, which is a combination of the normal *tide*, the *storm surge* and associated *breaking wave setup* impacts. This can allow the ocean to flood onto low lying land for periods of several hours, normally near the time of predicted high tide. Under the anticipated impacts of future climate change, the projected gradual rise in sea level will increase the frequency of such events over time and may lead to permanent erosion of the present shoreline, resulting in recession and gradual loss of amenity.

SEA (2011) presents a very comprehensive assessment of the regional storm tide hazard of the Torres Strait and provides a detailed explanation of the complex interactions over time (daily, seasonal, annual and multi-decadal) and space (location, proximity and geometric aspects of the island groups).

In summary, the total water level experienced at a coastal site during a severe weather event will be made up of relative contributions from a number of different effects, as depicted in Figure 1-2. The combined or total water level is then termed the *storm tide*, which is an absolute vertical level, referenced in this report to *Australian Height Datum* (AHD)[1]. Local potential flooding extent and inundation depths are then obtained by comparison with land elevation mapping, which is also prepared relative to AHD. The possible effects of wave runup have not been considered in this study but may pose specific threats worthy of further site-specific investigation.

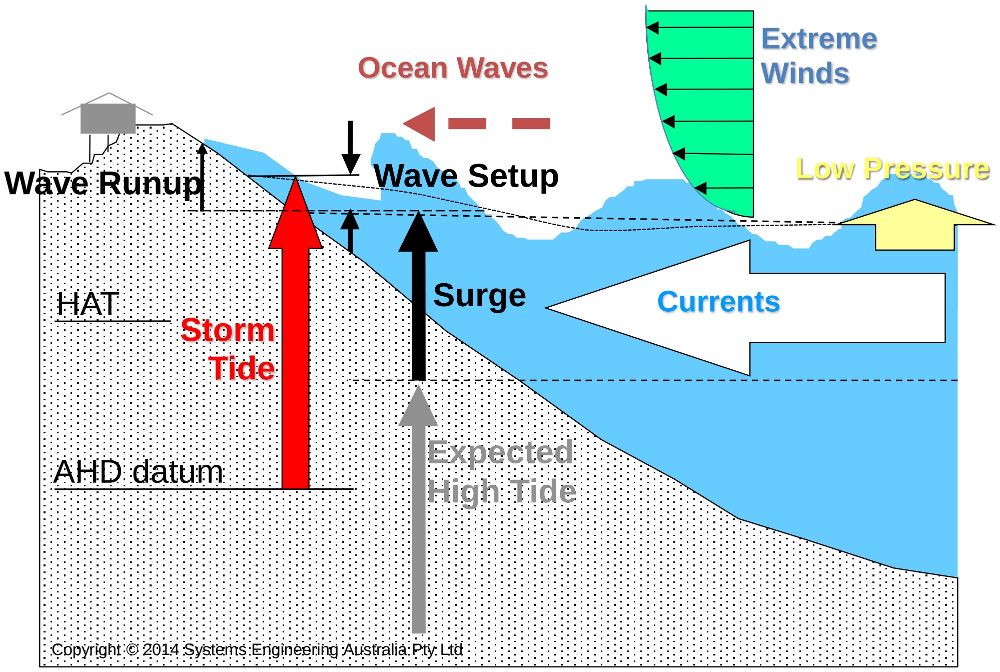

Figure 1-2 Water level components of an extreme storm tide.

The daily (astronomical) tide is the principal evidence of the frequent variation in the ocean level. This can have an alternating variation between successive high and low tides and a fortnightly variation of trending higher (so-called spring) and lower levels (so-called neap). The highest expected tide level at any location is termed the *Highest Astronomical Tide* (HAT) and occurs theoretically once each 18.6 y period, although across the Torres Strait this level is frequently exceeded annually because of the seasonally persistent presence of weather-related anomalies (or “mini storm surges”).

[1] AHD is normally similar to *Mean Sea Level* (MSL) but the Torres Strait region is complex and AHD datums are subject to change over time. Based on MSQ (2014) the assumed AHD offset from the SEA (2011) MSL modelling reference is the value published for nearby Thursday Island of -0.10 m.

2. Data Assembly and Review

The SEA (2011) region-wide investigation of the ocean inundation hazard of the Torres Strait communities commissioned by TSRA forms the basis of the present understanding of the potential coastal hazard impacts at Ngurupai (Horn) Island.

In addition, TSRA supplied GIS mapping at 0.25 m vertical resolution derived from LiDAR and aerial photography that enabled identification of community assets potentially exposed to coastal hazards.

An asset replacement report (B&M 2014) was provided that collated estimated asset replacement costs at Wasaga for three future water level scenarios.

2.1 Climate Change Science Review

Over the past two decades there has been a growing awareness of the potential impacts that human-induced global climate change may have, and especially its possible effects on the coastal environment (e.g. Harper 2012). The traditional statistical analysis of historical storm tide events for use in ocean inundation studies are based on an assumption that the natural environment, although highly variable, remains statistically static and that probability distributions for astronomical tides, tropical cyclones, persistent seasonal forcing (e.g. Monsoon and SE Trades) and local sea level itself are unchanging with the passage of time. However, the proven rise in atmospheric carbon dioxide levels and an increasing trend in mean air temperatures and rising sea levels points to the likelihood of the Earth being subject to an enhanced "greenhouse" effect, which means that these assumptions will be in error to some extent.

Consequently, consideration of the possible impacts of projected future climate change on modifying the storm tide hazard in the Torres Strait is required. However, with the exception of sea level rise projections and tropical cyclones, the currently available advice at the regional level for changes in other broadscale weather systems is typically highly variable, reflecting the complex nature of these effects.

2.1.1 Projected Sea Level Rise and Coastal Recession

Global sea levels are expected to rise as a consequence of enhanced greenhouse warming of the earth (IPCC 2013, CSIRO-BoM 2014). The observed rate of global average sea level rise measured by satellite altimetry during the decade 1993 to 2012 was 3.2 ± 0.4 mm p.a., although there are large regional differences. This is close to the estimated total of 2.8 ± 0.7 mm p.a. for the following climate-related contributions, in order of decreasing contribution:

- An accelerating thermal expansion throughout the 21st century
- The melting of glaciers
- Retreat of the Greenland ice shelf
- Antarctic ice losses

The official projections of global average sea level rise by 2100 are in the range 0.28 to 0.98 m from the IPCC (2013) “Assessment Report 5” (aka AR5) and are relative to the average sea level in 1995[2]. This represents nominally 5% to 95% confidence levels for 5 RCP gas emission scenarios using the CMIP5 multi-model experiment.

Quoting IPCC (2013) directly, based on current understanding, only the collapse of marine-based sectors of the Antarctic ice sheet, if initiated, could cause global mean sea level to rise substantially above the likely range during the 21st century. There is medium confidence that this additional contribution would not exceed several tenths (30cm) of a metre of sea level rise during the 21st century.

These estimates represent increases in both the upper and lower limits of about 0.2 m over the previous IPCC (2007) assessment and exceed those previously recommended by DERM (2012) for Queensland 2050 by about 25% but are 11% below the DECC (2009) upper limit 1.1 m 2100 recommendation adopted by TSRA, both of which were based on interpretations of IPCC (2007). The reason TSRA support the use of the 1.1m figure as the upper limit for this study include 1) they have already mapped inundation to 1.1m based on the previous DECC recommendation, 2) IPCC estimates, are recognised as being inherently conservative (for example actual sea level rise faster than the median IPCC projection), and 3) there are major positive feedback mechanisms yet to be properly factored into global climate models, with implications for more rapid shifts in climatic conditions

The presently projected IPCC (2013) sea level trends are displayed in Figure 2-1, partly based on earlier IPCC assessments. Although the year 2100 is normally quoted, it is important to note that if greenhouse gas concentrations were stabilised (even at present levels), sea level is nonetheless predicted to continue to rise for hundreds of years due to thermal expansion alone.

Coastal recession of some sandy coasts under sea level rise remains likely, with associated horizontal inundation distances of the order of 50 to 100 times the indicated vertical sea level rise being indicated by simplified geometrical arguments (e.g. Brunn 1988). In specific locations though, the actual shoreline response will be highly variable and dependent on changes in the strength, direction and persistence of sediment-bearing currents, waves and winds. Together with the

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[2] The previous AR4 SLR estimate was relative to 1990 sea level.

geological substrate (e.g. rock, reef etc) and existing geomorphology (e.g. mangroves, dunes, cliffs etc) these changes will dictate any potential secular changes in the natural shoreline equilibrium, notwithstanding what may already be significant seasonal changes and/or responses to extreme weather events.

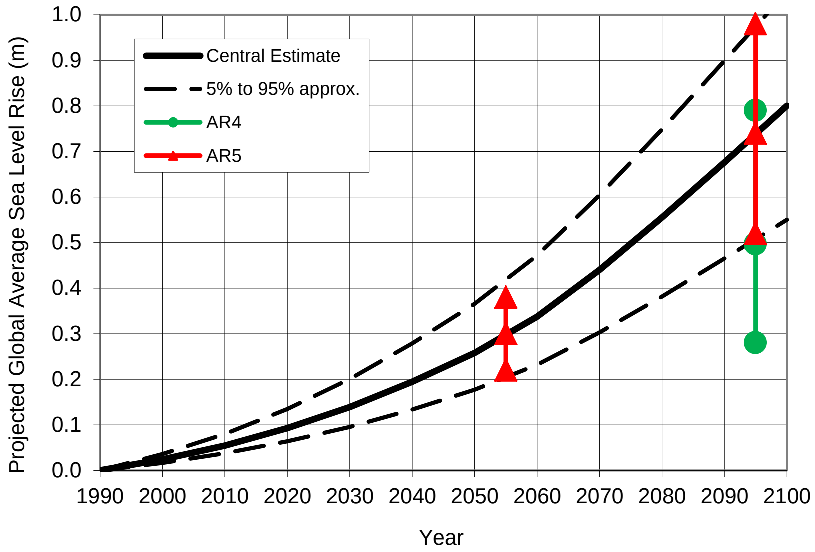


Figure 2-1 Changes to the IPCC projection of global average sea level rise (following Harper 2012).

2.1.2 Projected changes to the Monsoon or SE Trade Environment

SEA (2011) modelled the broadscale impact of the dominant summer monsoon and the SE Trade environments as it was represented by the available 60 year period of NCEP/NCAR surface wind and pressure reanalysis data (e.g. Kistler et al (2001), since 1948 as updated). This was re-sampled 20 times with varying tide sequences to provide the broadscale sea level response function that underpins the estimated frequency and intensity of non-cyclonic storm tide events.

IPCC (2013, TS.5.8.1) states that global measures of monsoon by area and summer rainfall are likely to increase in the 21st century, while the monsoon circulation weakens. Monsoon onset dates are likely to become earlier or not to change much while monsoon withdrawal dates are likely to delay, resulting in a slight lengthening of the monsoon season in many regions. The increase in seasonal mean rainfall is pronounced in the East and South Asian summer monsoons while the change in other monsoon regions is subject to larger uncertainties.

Overall, this provides little guidance as to the likely change in the broadscale monsoon or SE Trades forcing likely to impact the Torres Strait and the use of the 60 yr NCEP/NCAR reanalysis remains as robust as any other method. Likewise SEA (2011) concluded that available advice at that time in regard to potential changes in regional mean wind speed and direction was of minor significance compared with the modelling assumptions adopted or simply too qualitative to usefully incorporate into the analysis.

2.1.3 Projected changes to ENSO

SEA (2011) identified that there is a strong relationship between states of the El Niño-Southern Oscillation (ENSO) and the regional mean sea level of the Torres Strait over periods of decades.

IPCC (2013, TS.5.8.3) states that there is high confidence that ENSO will remain the dominant mode of natural climate variability with global influences in the 21st century, and that regional rainfall variability it induces will likely intensify. Natural variations of the amplitude and spatial pattern of ENSO are so large that confidence in any projected change for 2100 remains low. The projected change in El Niño amplitude is small compared to the spread of the change among models and confidence is low in changes in climate impacts on most of Asia, Australia and most Pacific Islands.

SEA (2011) likewise made no assumptions regarding a changed ENSO effect in future climates,

2.1.4 Projected Changes to Tropical Cyclones

IPCC (2013, TS.5.8.4) notes that global model projections for the 21st century show it is likely that the global frequency of tropical cyclones will either decrease or remain essentially unchanged, but there may be an increase in both global mean tropical cyclone maximum wind speed and rain rates. This is a significant change from IPCC (2007), which did not have the benefit of a World Meteorological Organization consensus statement formed in 2006.

Subsequently, a WMO-endorsed published study by Knutson et al. (2010) summarised the status of current research in this area and it was concluded that there is an agreed likely increase in the Maximum Potential Intensity (MPI) of tropical cyclones as the mean global temperature rises of 3 to 5% per degree Celsius. Assuming a 2 to 4 degree temperature range is possible, this may lead to an upper level increase in peak wind speeds of as much as 10% by (say) 2100. This could translate into a 20% increase in central pressure deficit.

Knutson et al. (2010) also reports that the consensus from many advanced modelling studies is actually for a potential reduction in the global number of tropical cyclones, although regional differences can be high. Regarding tracks, the most likely change might be a slight poleward movement in some regions. For the Torres Strait, it is not expected that there would be any specific change in storm tracks under future climate scenarios, but there may be fewer storms.

SEA (2011), aware of the WMO-endorsed research, simulated the effects of these projected changes according to Figure 2-2 in terms of

MPI and as summarised in Table 2-1. A nominal precautionary increase in storm frequency of 10% by 2100 was additionally added in spite of the indicated reducing trend in frequency based on the available global modelling.

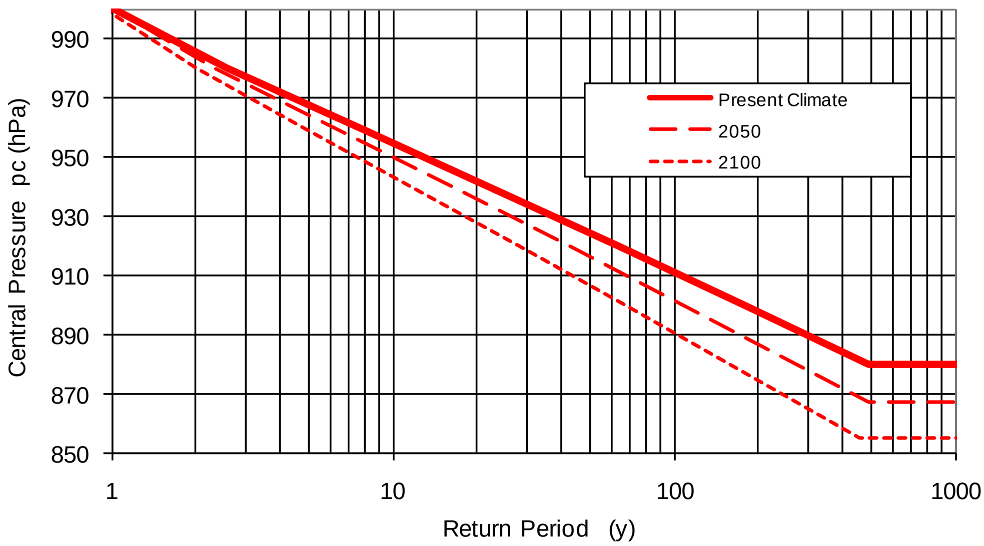


Figure 2-2 Estimated present and future climate TC intensity distributions within 500 km of Thursday Island.

Table 2-1 Available climate change hazard scenarios for Torres Strait.

IPCC (2013) AR5 Planning Year[3]	2050	2090
IPCC (2007) AR4 Planning Year[4]	2050	2095
MSL Increase relative to 2010 (m)[5]	0.30	0.80
Tropical Cyclone Max Potential Intensity Increase (winds)	5%	10%
Tropical Cyclone Frequency Change	0%	10%

[3] Equivalent, approximately, allowing for the new AR5 2055 95% +0.38m and 2095 +95% of 0.98m (both relative to1995 sea levels)

[4] AR4 MSL changes for 2095 were relative to the nominal 1990 sea level but no 2055 equivalent was published.

[5] These followed DERM (2012) recommendations derived from AR4

2.1.5 Projected Changes to the Astronomical Tide

SEA (2011) concludes that the astronomical tide in the region is extremely complex and is the dominant modulator of regional ocean water levels. Furthermore, the tide and weather-driven water level variations are largely independent: one is driven by gravity and the other by input from solar energy. Additionally the tide is largely predictable into the past and future given an accurate analysis of the tidal constituents.

IPCC (2013) appears silent on the matter of possible changes to the astronomical tide as a result of projected climate change scenarios. Notwithstanding this it can be expected that there will at least be small changes as a result of (1) increased water depths due to sea level rise in shallow regions like the Torres Strait modifying local wave propagation speeds (and hence component phasing and associated non-linear interactions) and (2) changes in ocean density patterns potentially modifying the wide scale tidal propagation.

In spite of these possibilities it is likely that the uncertainty in local bathymetry remains the dominant unknown and analysis of measured regional tidal data will remain the most reliable indicator of any changes into the future[6]. SEA (2011) assumed that the tidal characteristics will not alter significantly (relative to the current uncertainties) by the year 2100.

2.2 The 2011 Extreme Water Level Study Results

The previous section documents a number of climate-change related assumptions that were assumed in the SEA (2011) extreme water level study and that those assumptions are still consistent with the latest AR5 projections except that IPCC (2013) has raised the upper SLR estimates such that the "planning year" applicable to the adopted values has been brought forwards slightly. This minor change has been accounted for in the later analyses.

Figure 2-3 summarises the results from SEA (2011) that are applicable to the Wasaga community. This graph shows the estimated Total Storm Tide (tide plus surge plus breaking wave setup) water level in AHD as a function of the projected future sea level rise (SLR). These increasing SLR curves also embody the other climate change assumptions detailed in Table 2-1 that include changes to tropical cyclones. The horizontal axis is the estimated probability of exceedance of the indicated AHD level expressed as a *Return Period* in years, consistent with the terminology used in SEA (2011). Appendix B provides information on the interpretation of Return Periods (or *Average Recurrence Intervals* ARI), noting that they do not mean that events exceeding those levels

[6] Since SEA (2011) there have been a number of new tide gauges installed across the region which over time will lead to improved knowledge of the complex tidal behaviour in the region.

will only occur once each period of those many years. For example, the 100-year water level has a 1% chance of being exceeded in <u>any</u> year and the 1000-year water level also has a 0.1% chance of being exceeded in <u>any</u> year, which also exceeds the 100-year level. Multiple events can also occur in the same year.

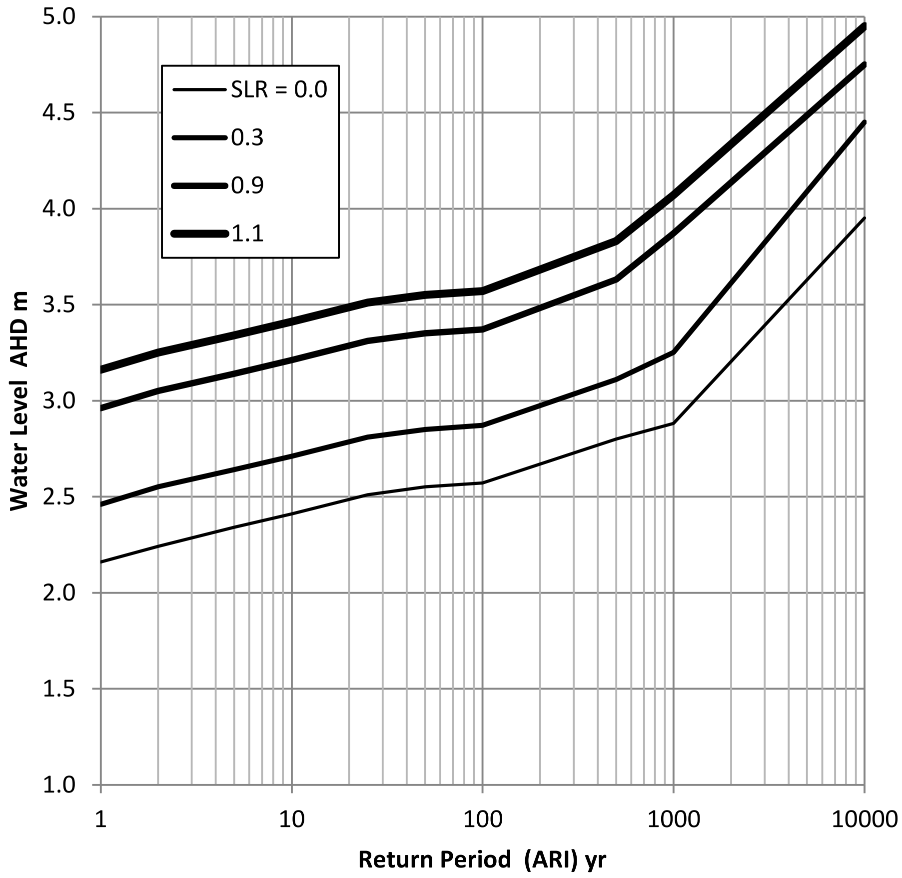


Figure 2-3 Estimated Total Storm Tide hazard levels applicable to the Wasaga community (from SEA 2011)

The shape of the curves in Figure 2-3 varies due to the relative impacts of the broadscale weather patterns (which control the lower part of the curves) and the more extreme impacts from tropical cyclones (which begin to dominate beyond the 100-year Return Period). The curves also vary as a function of the projected SLR (m) and, because wave setup is included, the simulated interaction of waves with the local land elevation.

The curve labelled as SLR=1.1 m has been additionally extrapolated from the SEA (2011) results to indicate the sea level reference used in the exploratory nationwide DECC (2009) risk study.

In terms of the threat to the Wasaga community, which is detailed in the following section, inundation commences around 2.25 m and

most of the community is located below 6 m AHD. This reflects the essentially annual occurrence of water levels that is known to sometimes impact operation of the marine facilities.

2.3 Persistence of Extreme Water Levels

The SEA (2011) simulation model, in addition to the summary water level exceedance data presented in the previous section, also estimated the time that any specific water level might be exceeded. Those details applicable to Wasaga have been recovered from the original study to provide some indication of the persistence of water levels at or above a range of ARI water levels.

Figure 2-4 presents the simulation results for *Present Climate* conditions, with a number of ARI curves shown that can be directly related to the indicated water level (m AHD) in the Legend. Taking the "annual" curve as an example (the 1 yr ARI) the curve shows that on-average (50% of the time on the horizontal axis) when the water level reaches <u>or exceeds</u> 2.15m AHD that it does so for about 1.5 hr (reading from the vertical axis). Moving to the left of the horizontal axis, 90% of the time it is at least 20 min, while moving to the more extreme case of only 10% of the time, it is about 5 hr. In the extreme case this increased period of inundation will be because the peak of the possible water level event is much higher than the annual event level of 2.15 m AHD.

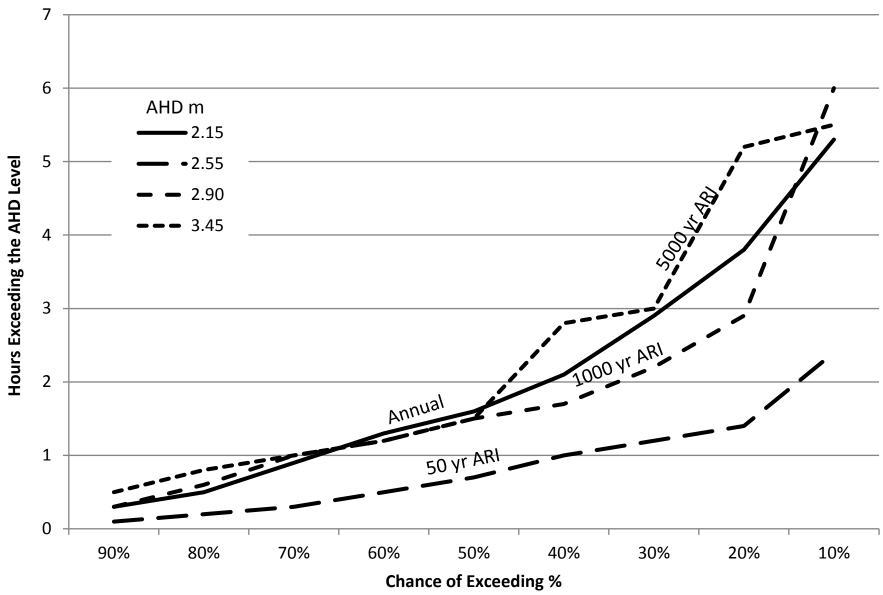
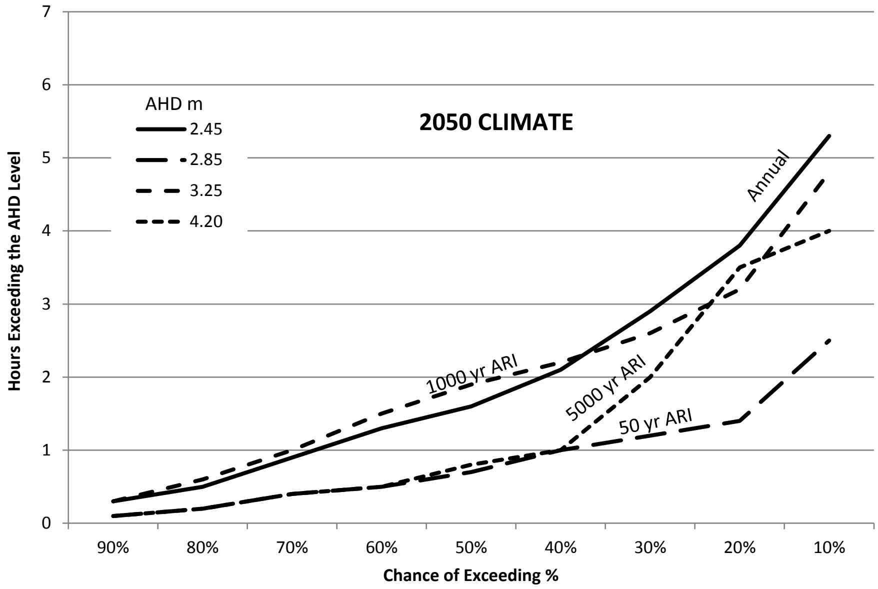


Figure 2-4 Simulated persistence of Total Storm Tide water levels for Present Climate conditions

The other curves show the results for the estimated 50 yr, 1000 yr and 5000 yr ARI water levels. Initially, as the water level being considered is higher than the annual value, the persistence of flooding tends to decrease relative to the annual. However, for more extreme water levels, where tropical cyclones tend to dominate, the periods of inundation are similar to the annual exceedance values.

The corresponding results for 2050 Climate and 2100 Climate are shown in Figure 2-5, noting the different assumptions that apply as summarised in Table 2-1. This behaviour is complicated because of the model's assumption that wave setup contributions will cease when the water level exceeds the "dune crest", which in SEA (2011) was set at a conservative level of 5 m AHD.



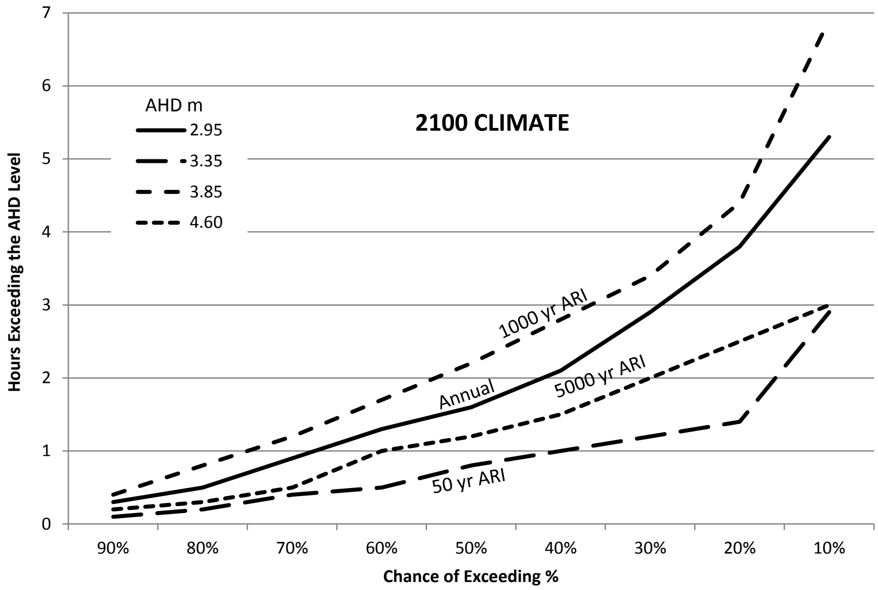


Figure 2-5 Simulated persistence of Total Storm Tide water levels for 2050 and 2100 Climate conditions

3. Vulnerability Assessment Methodology

The approach here broadly follows GHD (2012) and is consistent with the various State of Queensland guidelines (DEHP 2013a,b,c, and DEHP 2014).

The methodology considers the following coastal hazards:

- Coastal erosion: Shoreline recession due to sea erosion causing a permanent loss of land;
- Storm tide inundation: Temporary inundation of land by abnormally high ocean levels; and
- Sea-level rise inundation—periodic or permanent tidal inundation of land due to a rise in the mean sea level.

The methodology then entails:

1. Identifying and quantifying the coastal hazards;
2. Determining the community exposure to the hazards;
3. Assessing the vulnerability to the hazards, and
4. Developing an adaptation strategy and subsequent plan

An adaptation study would then follow to objectively consider the principal options of:

Defend: Protect sectors of the coastal hazard area with either hard or assimilating coastal engineering structures to reduce or remove storm tide inundation or erosion risks. Defend strategies may include maintaining the existing use or intensifying development on the land.

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.

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 land purchase mechanisms or rezoning the land to an open space or recreational use).

In practice a combination of these approaches will likely be optimal after considering intangible benefits to the community relating to lifestyle and environment (e.g. GU/GHD 2012 provides a compendium of options) but the “do nothing” case is also important to consider for a base case, as described below.

Abandonment: This is the most fundamental “do nothing” case, whereby the community is gradually abandoned due to the increasing encroachment from the rising sea levels and associated storm tide damage. This may be a logical outcome for some especially vulnerable locations that have no access to higher ground, do not provide an essential presence or purpose and the costs to preserve their situation are completely prohibitive.

Forced Retreat: This is a situation where the community gradually replaces its lost or damaged facilities and amenities over time as needed, in a way that ensures they will not be lost again in the foreseeable future. To adopt this strategy there must be practically accessible high ground in proximity to the existing community. This implies a continuation of the existing use in an area while not supporting any further intensification of those uses in the damage-prone areas. It need not restrict land owners from defending their own land (e.g. collaboratively with adjoining landowners) or attempting to Accommodate the impact of coastal hazards. It does not however consider any form of adaptation (or compensation). In the Townsville CHAS study (GHD 2012), this was referred to as the “status quo” scenario and became the “base case” for benefit-cost comparison of adaptation options. It is also selected here as the “base case” for Wasaga.

3.1 Hazard Identification and Quantification

For the present Pilot Study the issue of coastal erosion has not been explicitly considered because the Wasaga community is located at a low elevation and inundation events will likely outpace coastal erosion in terms of causing abandonment of nearshore areas. This may not be the case for other Torres Strait communities.

SEA (2011) and the former chapter addresses the remaining issues of storm tide inundation and sea level rise, which when converted into a timeline of potential ocean inundation hazard, takes on the form of Figure 3-1. This shows the series of curves that can be used to assess the changing level of hazard on an incremental (decadal) basis. The projected increase in the HAT level is also indicated (relative to the current AHD datum[7]).

[7] Over time, the AHD datum can be expected to be gradually revised or replaced by a new datum definition.

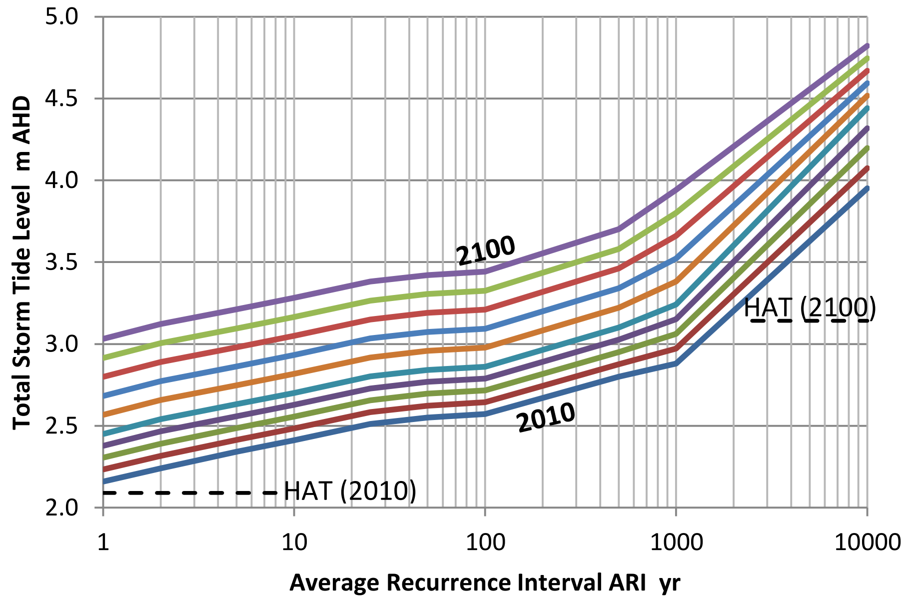


Figure 3-1 Ocean inundation hazard expressed as increasing over time (decades)

3.2 Tangible Community Exposure to Hazard

The present study builds on an Asset Replacement Report (B&M 2014) that collated estimated asset replacement costs at Wasaga for three future water level scenarios nominated by TSRA[8]:

- Scenario 1 - Inundation due to SLR of 1.1 m above present HAT
- Scenario 2 – Scenario 1 with a future 100-year ARI storm tide
- Scenario 3 - Scenario 1 with a future 1000-year ARI storm tide

The mapped extents of these inundation scenarios were provided by TSRA and, based on SEA (2011), these equate to water levels of approximately 3.2 m AHD, 3.6 m AHD and 4.1 m AHD respectively. Illustration of the B&M process and detailed imagery are reproduced in Figure 3-2, also noting what appears to be the lowest habitation level building at about 2.25 m AHD.

While this data provides basic information on the distribution of community assets between 3 m and 4 m AHD, it has been necessarily expanded here to enable consideration of the exposure across the full range of the hazard as indicated in Figure 2-3, namely 2 m AHD to 5 m AHD. This has been done by utilising the base B&M data and the

[8] A regular fine elevation stepping is needed to define the distribution of assets as a function of water level for quantitative assessment. A range of scenarios can then always be mapped based on that more complete information.

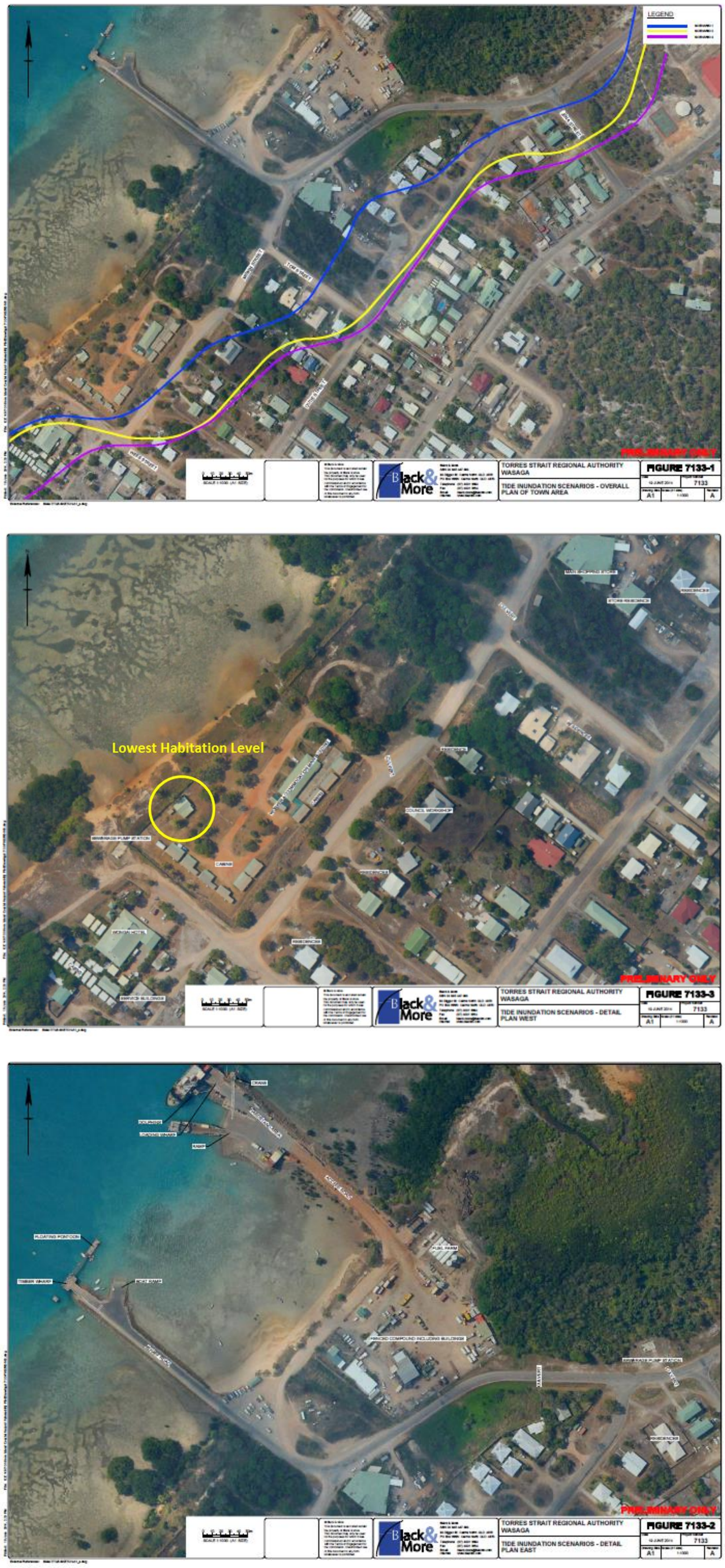


Figure 3-2 Illustrations from B&M (2014) asset assessment

supplied TSRA mapping to further subjectively allocate asset values across the categories used by B&M.

In addition, the TSRA mapping indicated that significant portions of the airport runways were also prone to inundation and preliminary estimates of this asset value were added to those prepared by B&M for completeness[9]. The expanded asset table is provided in Appendix C, and graphed in Figure 3-3, totalling about $80M in present dollar value up to 5 m AHD.

Based on the information provided, Table 3-1 highlights specific infrastructure that is located at a relatively low level and is subject to inundation by a 100 yr ARI event in 2100.

Table 3-1 Significant infrastructure at risk

Exposed Asset	Lowest Vulnerable Level
	m AHD
Horn Is Jetties (access)	2.00
Airport (N)	2.00
Lowest Habitation Level	2.25
Fuel Farm	2.25
Sewer Pump Station N	2.50
Marine Facilities	2.50
Main Shopping Store	2.75
Worker Accommodation	2.75
Airport (W)	3.00
Sewer Pump Station S	3.00
Council Workshop	3.25
Wongai Hotel	3.50

It can be noted that if projected sea level rise estimates by 2100 are realised then about 30% of the estimated total asset value presently below 5 m AHD will likely be impacted by the 1 yr ARI (annual) water level. Storm tide damage will be an additional cost.

[9] This estimate of the value of the airport runways represents about 30% of the assessed B&M loss for the rest of the community below 5 m AHD. It should be reviewed as part of the ongoing analysis of options and assumptions.

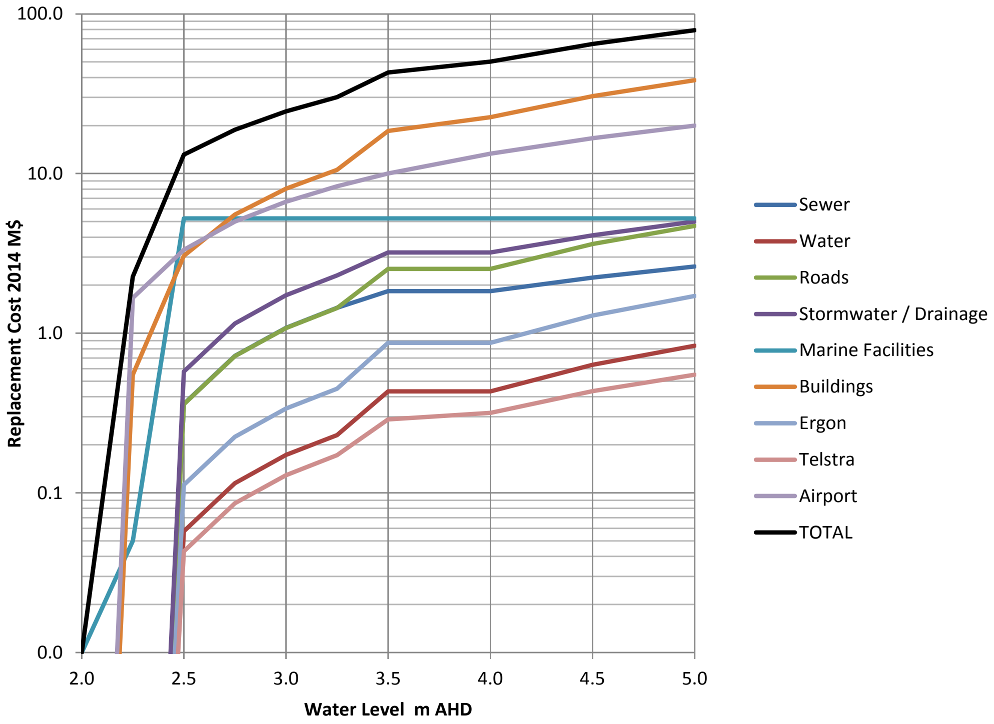


Figure 3-3 Derived asset exposure versus water level

3.3 Community Asset Vulnerability to Hazard

While the previous Section provides information on the tangible replacement cost in the event of total loss or abandonment, it remains to estimate the episodic vulnerability of the assets to the hazard prior to that eventuality. Long before abandonment due to sea level rise or complete destruction, numerous storm tide events escalating on the gradually rising sea level will encroach upon the community infrastructure and create damage that will require repair. It is important that the quantitative methodology accounts for these attritional costs over time, especially if they are unlikely to be covered by commercial insurance arrangements.

In the present assessment the damage is estimated in two ways:

- Where asset impairment commences essentially "at ground level" a simple 5% of the replacement cost[10] has been assumed, else
- Where asset damage increases with depth of inundation a "stage-damage" relationship is used.

For simplicity, all Building assets are treated as "stage-damage" while all remaining assets are treated as a % loss if inundated. Figure 3-4 illustrates the latter assumed damage costs that exclude Buildings.

[10] This assumption can be updated in the supplied risk analysis tool by more precise information.

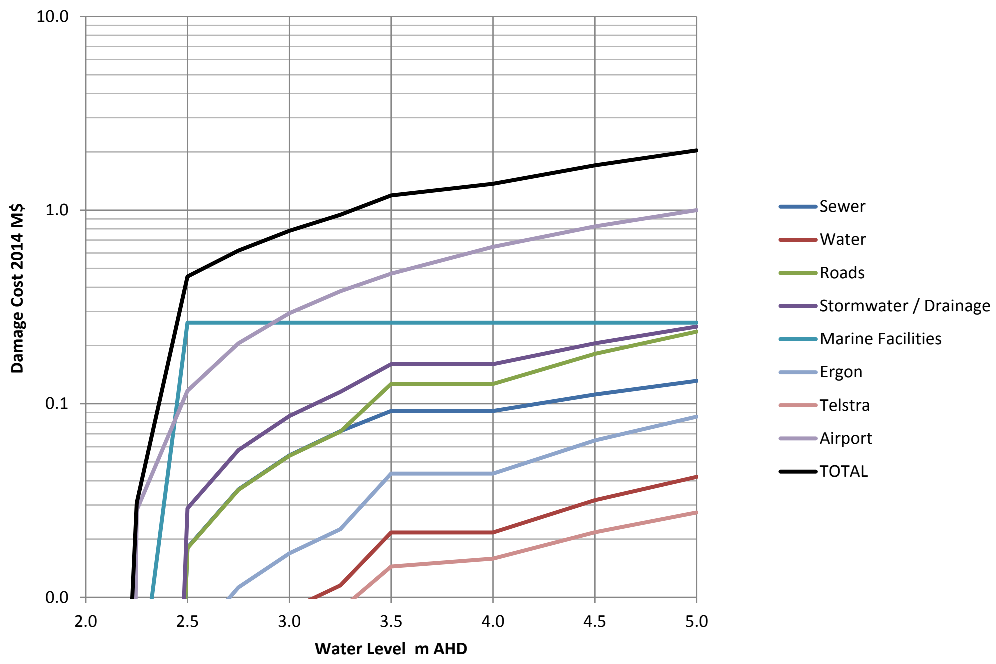


Figure 3-4 Assumed asset damage versus water level (excluding buildings) for individual events

There is a wide variety of empirical stage-damage relationships available in the national and international literature relating to depth and sometimes duration of flooding. There is less information on impacts of wave loadings in a coastal environment. For this study, the widely-used Smith and Greenaway (1994) relationships have been modified to represent proportional loss (rather than absolute loss) and an empirical wave damage relationship added based on past SEA research.

These stage-damage relationships have then been applied to all building assets and provide for sensitivity according to whether the building is "commercial" and "large" or "small", and/or "residential" and either high or low set. The potential "contents" loss within each building class is also implied by the adopted relationships (Figure 3-5).

Without any further information to hand within the time available, it has been assumed that:

- 10% of the building asset value is "commercial" in nature, and 60% of their total value is their "contents";
- 90% of the "commercial" assets are < 650 sqm;
- 90% of the building assets are residential and 50% are "high set" rather than "low set", and

- The “residential contents” represents only 10% of the “residential building” cost[11].

These are arbitrary yet likely reasonable assumptions based on the available visible mapping information and can be readily updated and revised within the supplied risk analysis planning tool (RAPT).

These assumptions regarding “contents” value at risk adds a further $5.5 M to the total asset value at risk within the community below 5 m AHD.

Considering the application of Figure 3-5, it can be seen that the stage-damage relationships imply that no building that is only subjected to flooding will suffer building (structure) damage more than 30% of its value, although up to 100% contents loss is possible depending on the water height above the floor. However, buildings subject to wave action can suffer 100% loss of structure depending on the inundation depth. The risk analysis tool further assumes floor heights for the various building types and accounts for whichever amount of structural building damage is the greater in any situation.

[11] This is considerably lower than capital city ratios but reflects the relatively high cost of building construction in the area.

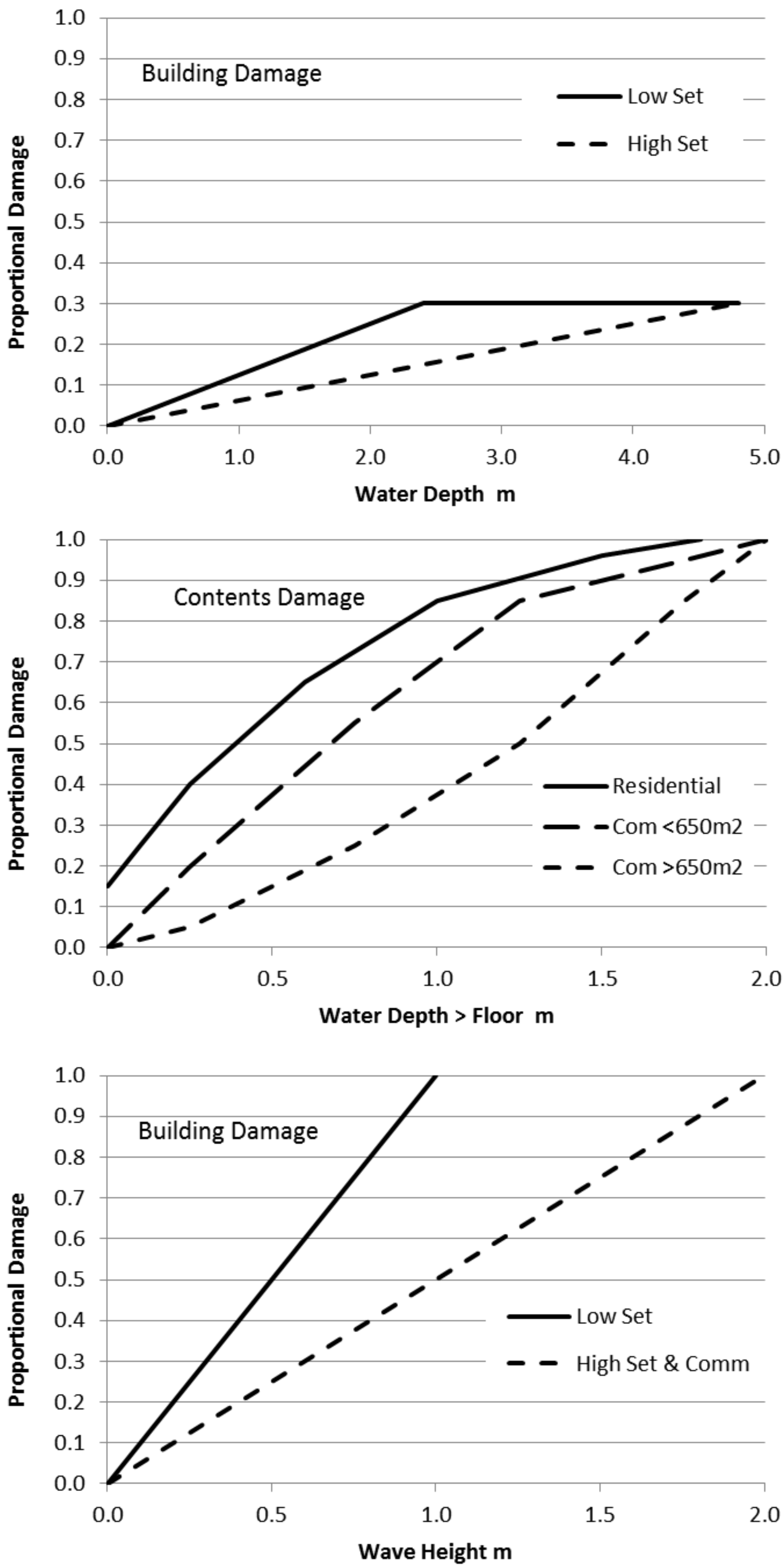


Figure 3-5 Adopted stage-damage relationship for Buildings

3.4 Probabilistic Damage Assessment

A prototype risk analysis tool has been developed that combines the variously assembled hazard, exposure and vulnerability data into a statistical context to provide insight into the likely experience of damage to community assets from now into the future. This approach is superior to simple scenario-based assessment as it includes the likelihood of damage from all of the possible storm tide events that can occur over an extended period, rather than simply a particular storm tide event (e.g. the traditional use of an arbitrary 100-year event or some such).

3.4.1 Changing Risks from 2010 to 2100

An example of the approach is provided in Figure 3-6, which contrasts the situations of 2010 (nominally the "present"), the year 2050 and the year 2100 when sea level rise may be around 1 m and storm tide events may have increased slightly in magnitude and frequency. This illustrates either of the Abandonment or Forced Retreat case, whereby no action is taken to change the potential risk (either the exposure or the vulnerability).

The graphs show the estimated water level probability of exceedance from Figure 3-1 (the blue line referenced to the RH axis) corresponding to the respective year. For the present level of hazard it extends from a 1 yr ARI of about 2.2 m AHD up to a possible 10,000 yr ARI of about 3.95 m AHD. By 2100 these levels are projected to extend from about 3 m to 4.75 m AHD.

Using the asset damage relationships described earlier, the red dashed line indicates the loss of value of any assets located below the projected 1 yr ARI water level. At present this is effectively zero (blue line RH axis), but by 2100, when the 1 yr ARI level is about 3 m AHD, the total (accumulated) lost value of assets is about $25M.

The solid red line then indicates the potential damage to assets that are currently located at the indicated water level and as a function of the probability of exceedance of the water level in any given year due to storm tide hazard.

In each case the damage component only starts to increase significantly beyond the 1,000 yr ARI event and reaches about $15M at the 10,000 yr ARI limit (about 4 m AHD).

To effectively combine the effects of the costs of the slowly rising sea level and the increasing storm tide damage hazard it is necessary to calculate the *Average Annual Damage (AAD)*. This provides a rational basis for preferring one adaptation option over another, notwithstanding that there may also be important intangible reasons for preference.

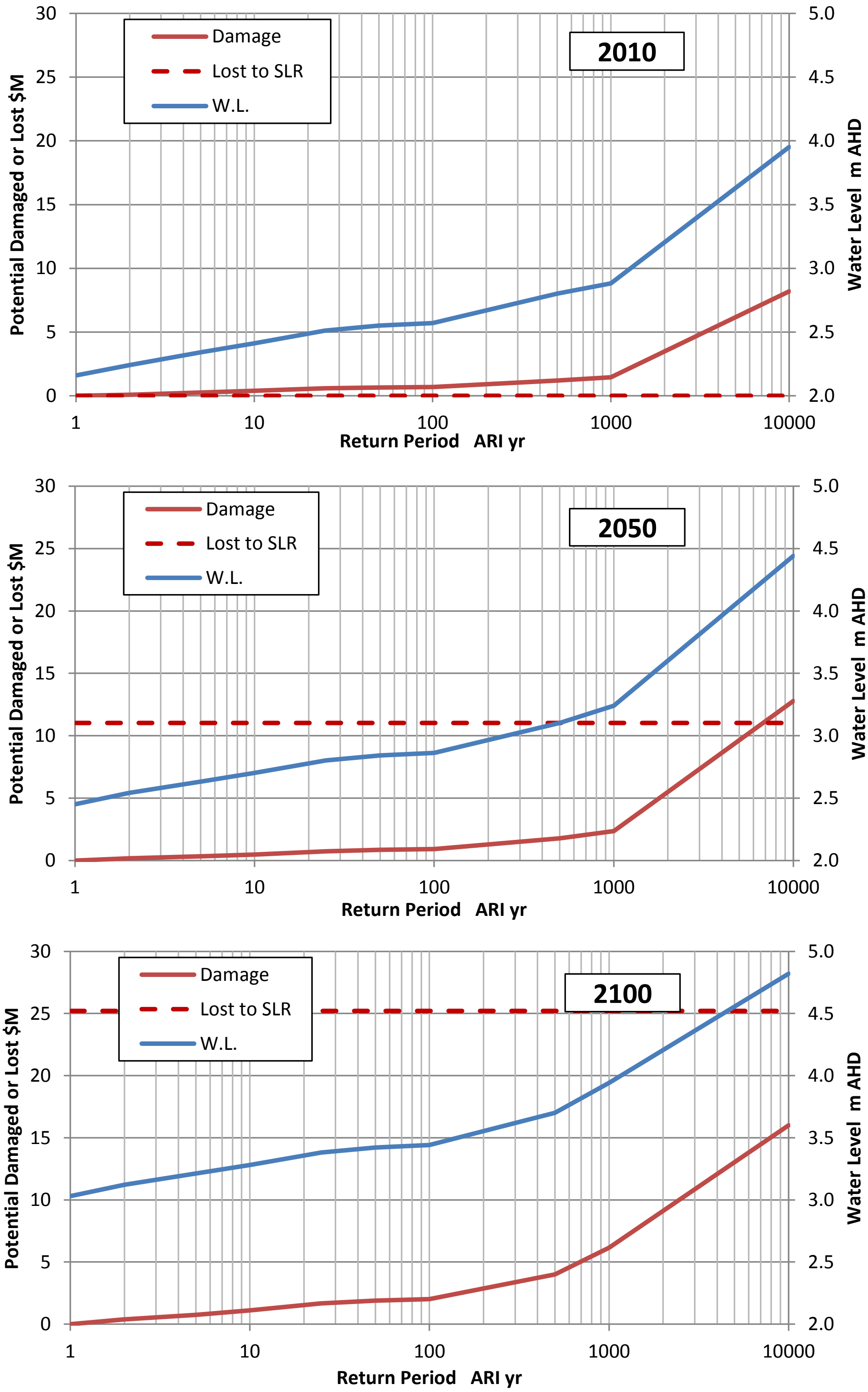


Figure 3-6 Changes in risk and projected lost asset value into the future without any adaptation

3.4.2 Annual Average Damage

The *Average Annual Damage* (AAD) is used here as the principal metric of interest. This is widely used in conventional flood studies and enables the probability of a flooding event to be accounted for when calculating the expected long-term damage and allows comparison of the costs of potential adaptation options. Mathematically, the AAD is the area under the Damage-Probability curve.

Importantly, the AAD of both the effects of rising sea level, which will lead to loss of land, assets and amenities, and the episodic loss due to damage to still-viable assets must be considered. In this study any asset impacted by the 1 yr ARI water level (i.e. an annual occurrence) is assumed to be effectively "lost to SLR" in its entirety.

Figure 3-7 shows how the AAD of the *Forced Retreat* option is expected to vary over time from the present time up until the year 2100. Also shown is the rising value of the 1 yr ARI water level, which is driving the "lost" component of the damage.

In this case the Total AAD of the present 2010 damage curve is about $0.16 M (dominated initially by the "damage" component), while the AAD of the 2050 is $0.9 M and by 2100 is about $1.0 M. The Total AAD is comprised of the contributions from:

- The "lost to SLR" value of the assets year by year;
- The "forced retreat" rebuilding costs[12] of those lost assets year by year; and
- The "expected average annual damage" each year from the storm tide hazard, over and above the "lost to SLR" asset value.

It may seem odd that the AAD can vary up and down over time. This is because the exposure of the assets to the hazards change as the sea level rises. Over some periods the exposure reduces because, say, the 1 yr ARI water level passes the first line of housing and is then crossing the next street over the following decade etc.

It should be noted that the AAD due to storm tide is a statistical estimate of the damage that would be experienced if that level of hazard and that level of exposure and vulnerability existed and remained constant for a very long period of time (100s to 1,000s of years). In any single year, depending on exactly what happens, the AAD due to storm tide may or may not be exceeded. Its use therefore is to compare the relative merits of various adaptation options having different costs and implementation timings in reducing the long term expected damage.

[12] Simply assumed here to be exactly equal to the value of the "lost to SLR" assets in present day dollars. Hence the two curves are overlaid in the graph.

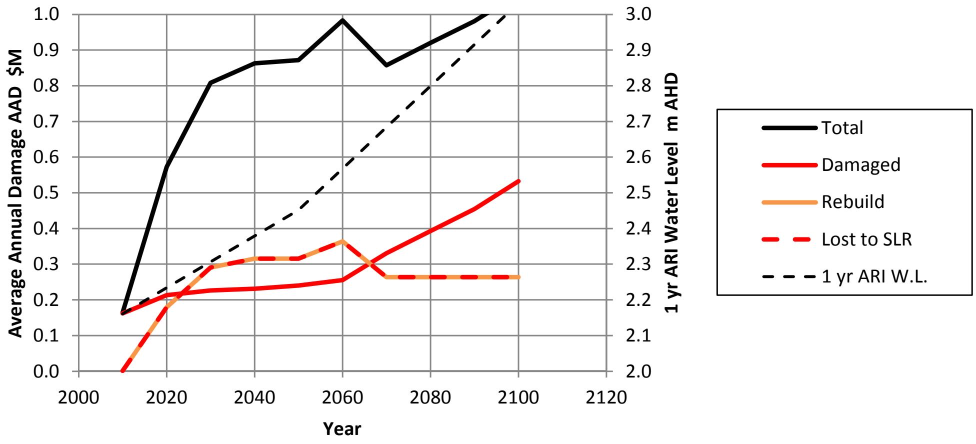


Figure 3-7 Changes in AAD under the Forced Retreat case

While the AAD is needed to form a consistent basis for comparison leading to a Benefit-Cost Ratio (BCR) analysis of any adaptation options, it is not so easy to interpret. Accordingly, Figure 3-8 shows the same information but the estimated cost components have been accumulated over the years. This shows that the combined SLR costs (lost and rebuilt) accumulate at approximately the same rate as the expected average damage due to storm tide hazard. The Total expected cost is then about three times any of these, being $75 M in present day dollars by 2100.

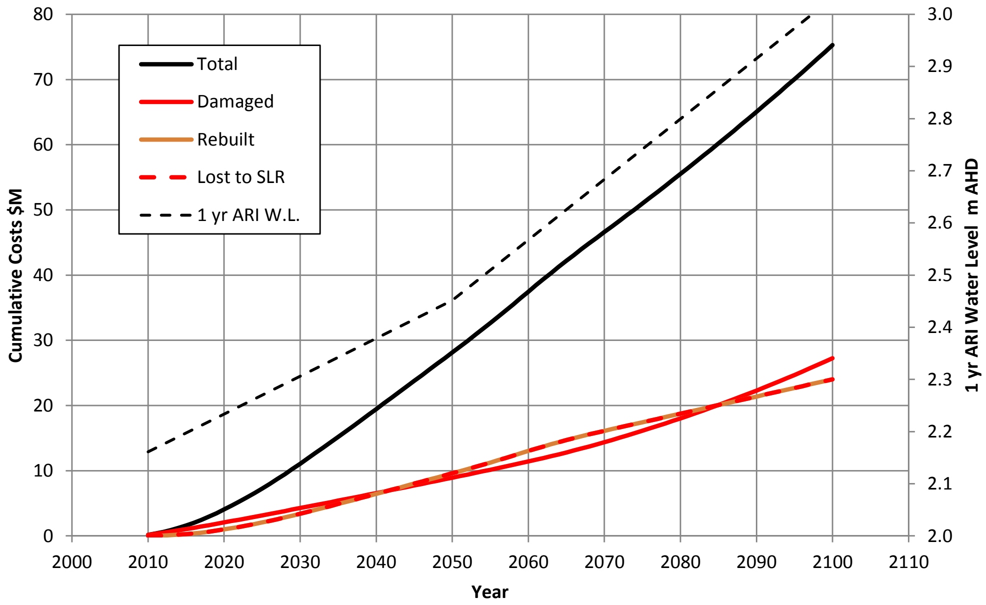


Figure 3-8 Cumulative damage and SLR costs under the Forced Retreat case (no adaptation)

3.4.3 Comparison of Possible Adaptation Options

By way of example, two adaptation options are explored:

- Defending by way of a bund and/or seawall built to a certain height by a certain year, and
- Planned Retreat of remaining assets below a certain height by rebuilding at a higher "safe level" by a certain year.

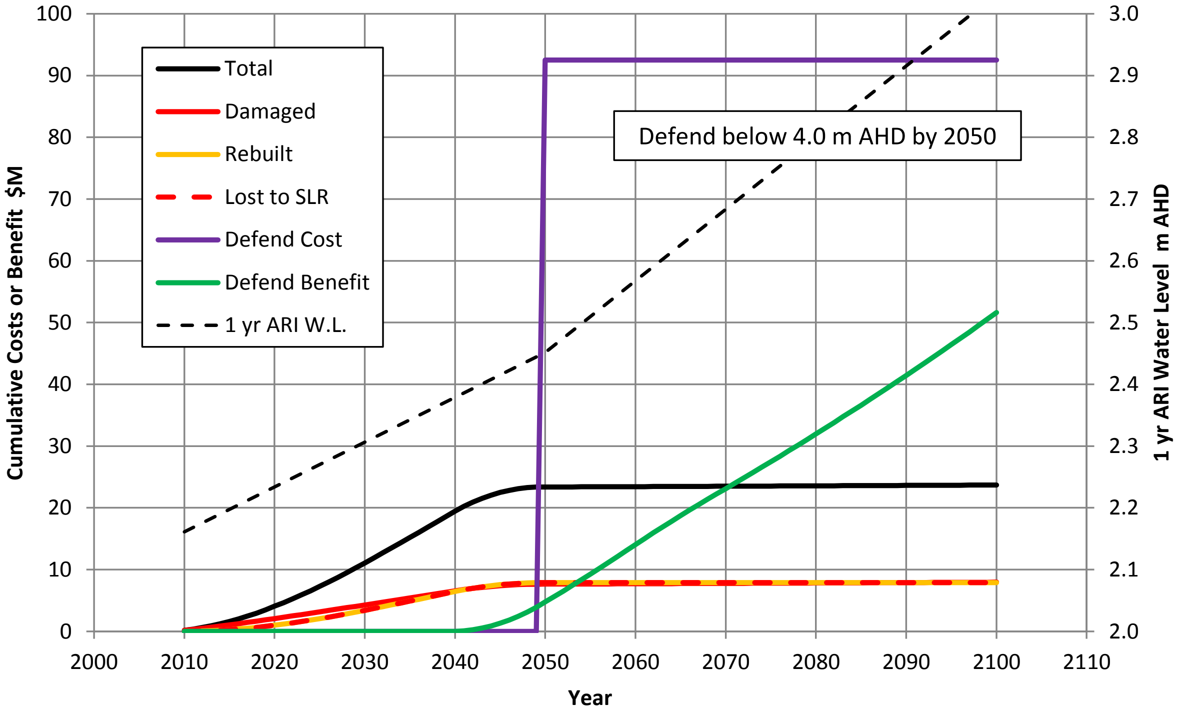
Firstly the effect of a specific Defence plan on the expected accumulated costs over time can be seen in the top graph of Figure 3-9. This example assumes that a bund/seawall would be built to protect up to 4 m AHD by the year 2050. It also assumes that before the protection is available that the Forced Retreat strategy would be adopted to maintain the community. The Total hazard-induced costs (black line) can be seen to initially increase (in accord with Figure 3-7) but after the protection is in place the damage cost increase ceases[13]. Meanwhile there is a significant Defend Cost of $92.5 M to build the bund/seawall in 2050. This is then offset somewhat by the Defend Benefit (avoided damage costs) as a result of the protection being put in place. Whether this is cost-effective is addressed in the next section.

The cost of the example Defend option is based on a crude estimation of the length and height of a possible bund/seawall to achieve a range of levels of protection. The cost for its construction is simply based on estimates from GHD (2012) for the Townsville area, factored by 2 to approximate likely local construction costs[14]. As summarised in Table 3-2 both the Wasaga township and the airport have been considered to form a single defence plan[15].

Table 3-2 Assumed cost of coastal defences

					Protection to AHD:		
Location to be Defended	Ht	Level	Length	Cost Estimate	2.5 m	3.5 m	4.5 m
	m	m AHD	km	$M/km	$M	$M	$M
Wasaga Township	1.0	2.5	1.0	15.0	15		
	1.5	3.5	1.5	20.0		30	
	2.5	4.5	2.0	30.0			60
Airport	1.0	2.5	0.5	10.0	5		
	1.5	3.5	1.0	20.0		20	
	2.5	4.5	2.5	30.0			75
				Totals:	20	50	135

[13] In practice, allowance must also be made for the ongoing maintenance and repair of the defence asset.
[14] Factor based on advice from David Moore of B&M.
[15] In a more comprehensive analysis with carefully estimated costs it would be appropriate to consider these sites separately.



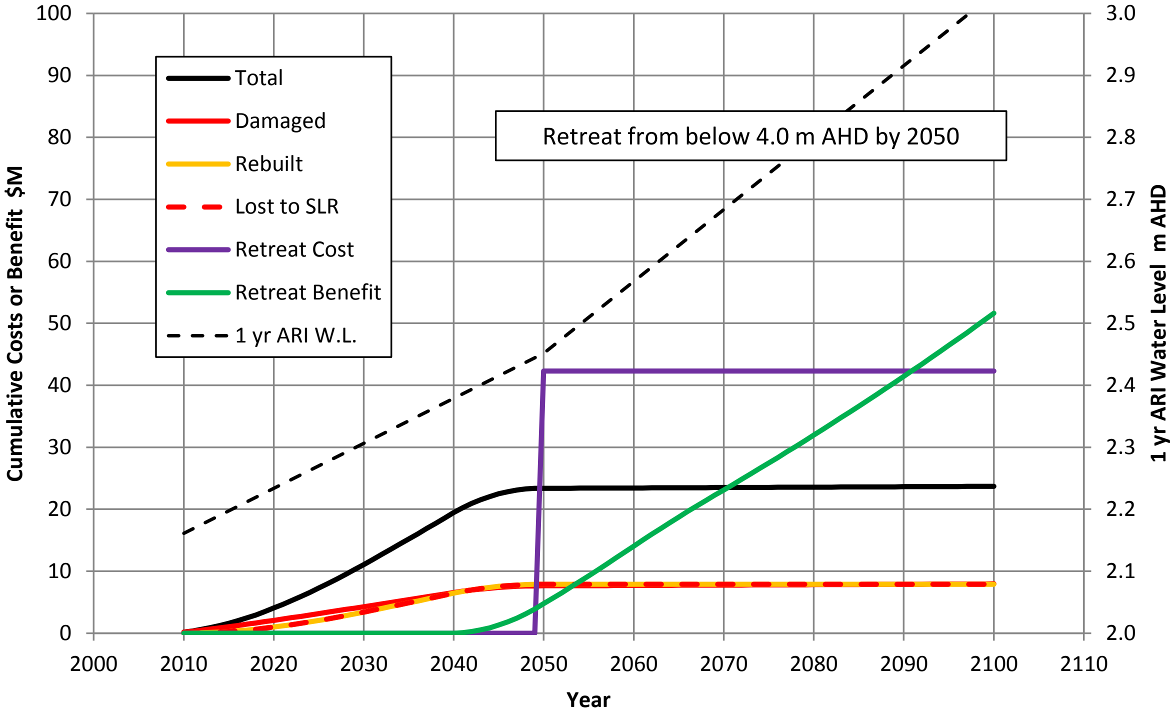


Figure 3-9 Cumulative damage and SLR costs under a Defend (top) and Planned Retreat (bottom) case example

Next, the effect of a specific Planned Retreat on the expected accumulated costs over time can be seen in the bottom graph of Figure 3-9. This example assumes that all assets located below the level of 4 m AHD by the year 2050, which are still viable, would be relocated/rebuilt at a much higher level that is expected to be well above the expected hazard level (e/g/ 10 m AHD). It also assumes that before the Planned Retreat is initiated that the Forced Retreat strategy would be adopted to maintain the community. The expected costs over time are similar to the Defend option, except that the Retreat costs are significantly lower at $42.3 M. This is then offset the Retreat Benefit (avoided damage costs) as a result of the assets having been removed from the hazard.

3.4.4 Benefit-Cost Ratios of the Adaptation Options

When choosing between these two options the costs and benefits of each must be considered, as well as the intangible costs/benefits as seen by the community. The timing of the implementation will also affect the benefit/cost ratio of the plan.

The risk analysis tool (RAPT) can then be used to explore the sensitivity of the benefit/cost ratio (BCR) of the two competing plans compared with the base case Forced Retreat strategy. The analysis also permits identifying the optimum timing of the adaptation investments. This is done by additionally considering the *Net Present Value* (NPV) of the AAD, which itself is calculated in “dollars of the day” without regard to the changing value of expenditure over time. Using a typically accepted investment *discount rate* of 3% (refer GHD (2012) and elsewhere for discussion on the choice of discount rates), the NPV of the AAD costs and benefits, and the BCR, can be compared over the period from 2010 to 2100. The benefits are the *avoided costs* of damage that would occur under the Forced Retreat condition.

The results for these examples are shown in Figure 3-10 and Figure 3-11, where the total of all the costs and benefits are plotted according to the LH axis and the BCR is plotted on the RH axis. The difference between the cost and benefit curves drives the BCR, which varies over time. The Defend option shows that the best time (highest BCR) to implement that strategy would be around the year 2035, but even then it has a very low BCR of 0.33. However the Retreat option has an optimal BCR of 0.71 if implemented in 2060. However, with a BCR < 1, neither of these options is clearly cost-effective and, unless there are intangible reasons for preferring either over the Forced Retreat option, then this would be the clear economic preference.

On further investigation using RAPT, and with more refined costs, other strategies for Ngurupai might prove more effective than the Forced Retreat. Likewise, other Torres Strait communities may well be better suited to either Defend, Planned Retreat or Accommodate strategies.

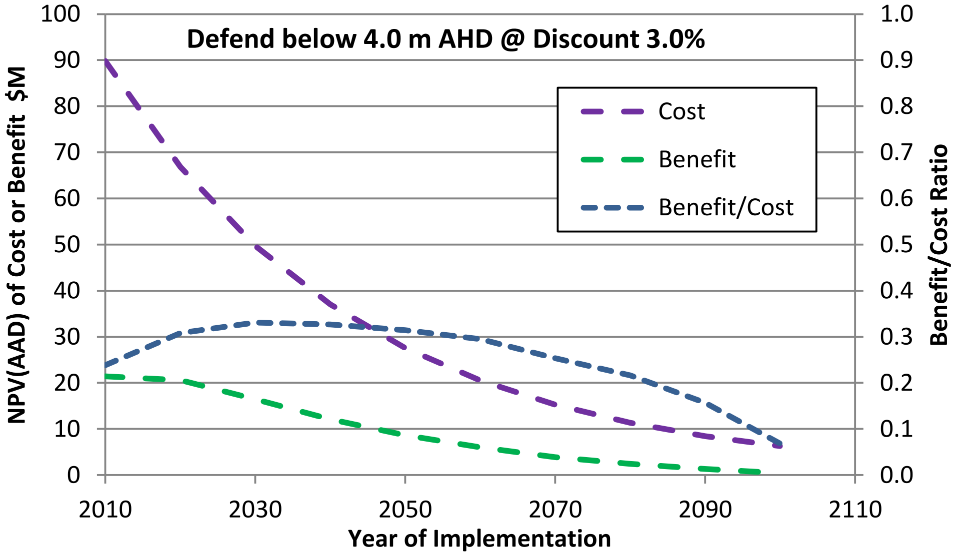


Figure 3-10 Changes in the NPV of AAD under a Plan to Defend to 4 m AHD by 2050 (plus earlier Forced Retreat)

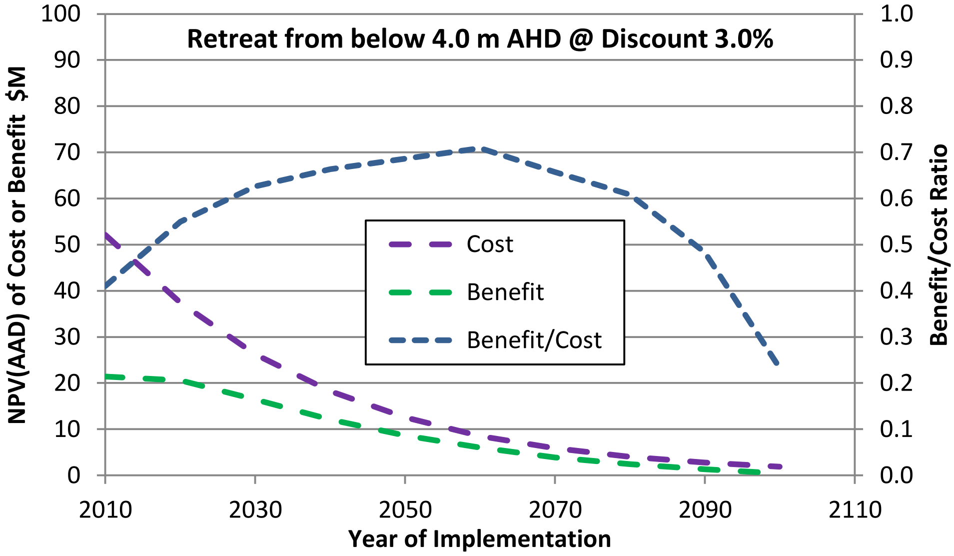


Figure 3-11 Changes in the NPV of AAD under a Plan to Retreat above 4 m AHD by 2050 (plus earlier Forced Retreat)

4. Conclusion and Recommendations

This report outlines a quantitative methodology that can be used to explore a range of adaptation options for Torres Strait communities, using Ngurupai (Horn) Island as an example. The study has identified that this community is likely to be principally impacted by projected sea level rise impacts over the next 100 years, although rare extreme storm tide events remain a possibility.

The methodology combines the following components:

- The water level hazard probability of exceedance
- The exposure of the community assets to the water level
- The vulnerability of the assets to inundation and damage

and provides a quantitative estimation of the Annual Average Damage (AAD) that enables comparison of the merits of various adaptation strategies. The Net Present Value (NPV) of the AAD is then used, assuming an acceptable discount rate, to estimate the Benefit/Cost ratio (BCR) and determine the optimum timing of the adaptation investment.

The present Pilot Study analysis does not consider a number of important issues that should be included in a more comprehensive study (e.g. GHD 2012). These include:

- Consideration of intangible aspects, which are best developed in consultation with stakeholders in a multi-criteria assessment that is informed by a tangible BCR assessment;
- Detailed costing of adaptation strategies;
- How to fund any proposed adaptation strategy;
- Constraints or requirements of existing planning schemes or management plans.

It is recommended that future studies:

- Use a GIS approach in identifying asset type and value at a fine vertical resolution;
- Incorporate accurate information on floor levels and high or low rise building forms;
- Review assumptions in regard to stage-damage relationships to ensure that they reflect a community’s true vulnerability;
- Develop more accurate estimates of damage to on-ground or in-ground assets such as water, sewage, electrical and telecommunication services;
- Utilise a full Monte-Carlo risk assessment of risk on an annual basis in preference to the more simplified AAD approach used in the Pilot Study so that the potential variability can be assessed.

5. References

B&M (2014) Horn Island Coastal Hazard Vulnerability Pilot – Asset Replacement Report. Prepared by Black and More Pty Ltd for TSRA, Doc 20120032, 25pp.

Bruun P. (1988) The Bruun rule of erosion by sea-level rise: a discussion of large-scale two- and three-dimensional usages. Journal of Coastal Research, Vol 4, 627-648.

CSIRO-BoM (2014) State of the climate 2014. CSIRO and the Australian Bureau of Meteorology, Mar, 16pp.

DECC (2009) Climate change risks to Australia's coast – a first pass national assessment. Australian Government, Department of Climate Change, 172pp.

DEHP (2013a) Coastal hazard technical guide – determining coastal hazard areas. Department of Environment and Heritage Protection, State of Queensland, Apr, 18pp.

DEHP (2013b) Guideline for preparing a coastal hazard adaptation strategy. Department of Environment and Heritage Protection, State of Queensland, Apr, 29pp.

DEHP (2013c) Guideline: A risk assessment approach to development assessment in coastal hazard areas. Department of Environment and Heritage Protection, State of Queensland, Apr, 10pp.

DEHP (2014) Coastal management plan. Department of Environment and Heritage Protection, State of Queensland, Mar, 21pp.

GHD (2012) Townsville City Council coastal hazard adaptation strategy study. Prepared by GHD Pty Ltd for the Local Government Association of Queensland, Townsville City Council and the Department of Environment and Heritage Protection, 369pp.

GU/GHD (2012) Coastal hazard adaptation options – a compendium for Queensland coastal Councils. Griffith University Centre for Coastal Management and GHD Pty Ltd, Oct, 192pp.

Harper B.A. (2012) Guidelines for responding to the effects of climate change in coastal and ocean engineering – 3rd Edition May 2012. Engineers Australia, National Committee on Coastal and Ocean Engineering, EA Books, 74pp

IPCC (2007) Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. *Cambridge University Press*, Cambridge, United Kingdom and New York, NY, USA, 996 pp.

IPCC (2013) Climate Change 2013: The physical science basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1535.

Kistler R., Kalnay E., Collins W., Saha S., White G., Woollen J., Chelliah M., Ebisuzaki W., Kanamitsu M., Kousky V., van den Dool H., Jenne R. and Fiorino M. (2001) The NCEP–NCAR 50–Year Reanalysis: Monthly Means CD–ROM and Documentation. *Bulletin of the American Meteorological Society*, 82, 2, Feb, 247–267.

Knutson T.R., McBride J.L., Chan J., Emanuel K., Holland G., Landsea C., Held I., Kossin J.P., Srivastava A.K. and Sugi M., 2010: Tropical cyclones and climate change. *Nature Geoscience*, 3, 15 –163.

MSQ (2014) Queensland Tide Tables 2014. Maritime Safety Queensland, *Department of Transport and Main Roads*, Queensland Government.

SEA (2011) Torres Strait Extreme Water Level Study. Prepared for Torres Strait Regional Authority by *Systems Engineering Australia Pty Ltd,* Jul, 387pp.

Smith, D.I. and Greenaway, M.A. (1994). Tropical Storm Surge, Damage Assessment and Emergency Planning - A Pilot Study for Mackay. Centre for Resource and Environmental Studies, Report No. 8. ANU. Mar.

Appendix A

Scope of Work

Proposal for:

A Coastal Vulnerability Assessment Methodology for Torres Strait Communities – Pilot Study

1. Client Scope

To help inform adaptation options to reduce impact of climate change risks on coastal communities and infrastructure in the Torres Strait, TSRA is seeking expert input into a methodology to assess the risks to infrastructure located in coastal hazard zones for sea level rise and associated impacts, including:

- Assessment of what infrastructure/ services are at risk under several key sea level scenarios and several key return intervals
- Assessment of net present value of infrastructure at risk
- Finer scale assessment of average percentage time a community is inundated under various sea levels
- Economic analysis of timeframes for investment.
- Thoughts on adaptation options

It is suggested that a pilot study could be appropriate for the Horn Island community, with a view to providing the results to a mid-year Workshop of stakeholders.

2. Proposed Methodology

It is recommended that any assessment of coastal vulnerability should be based on a quantitative approach that seeks to address both the tangible (physical impacts, costs and damage etc) and the intangible (social disruption, stress, loss of amenity etc). The recent Townsville Coastal Hazard Adaptation Strategy (CHAS) study undertaken by GHD Pty Ltd for the Local Government Association of Queensland (LGAQ) serves as a guide to all coastal communities for conducting such studies. The study received recognition in the 2013 Engineers Australia Excellence Awards for the quality of the approach and the practicality of the outcomes to assist in future planning. As the Project Director for that study when at GHD, together with my past involvement in the TSRA extreme water level study, I propose to develop a CHAS methodology best suited to the situation and available data for the Torres Strait.

The proposed Phases of the work would be:

Data Assembly and Review

This will involve receipt and review of all supplied TSRA material (refer later) relevant to a coastal hazard assessment of the community and infrastructure elements of Horn Island.

A review of the latest IPCC/AR5 and any other (e.g. CSIRO) relevant projections of sea level rise and ocean-related issues for the region.

Development of the Vulnerability Assessment Methodology

The available data will be assessed with regard to the Townsville CHAS approach, recommendations and learnings and will be tailored to the Torres Strait and Horn Island in particular.

A simple Excel-based tool will be developed that will demonstrate the quantitative methodology, and enable consideration of the various elements of sea level rise, extreme water level statistics, wave impacts, tidal exceedances (frequency and duration) and their intersection with the identified vulnerabilities, expressed in economic terms where possible. The tool will enable estimation of the Net Present Cost of adaptation options such as retreat, accommodate and defend for the identified key assets as well as optimum investment timing.

Reporting and Documentation

Progress and final reporting, review and presentation material.

3. Deliverables

The proposed deliverables include:

- A comprehensive report on the work done, including the methodology, key data, assumptions, options and recommendations;
- Presentation material in support of the report.

4. Client Supplied Material

It is understood that TSRA has extensive mapping products based on high-resolution (LiDAR-based) ground elevation data that covers their areas of community impact and that this mapping will be made freely available for the study. The mapping will need to include layers that identify, inter alia:

- Critical infrastructure assets, such as roads, wharves, jetties, water, sewerage, electricity, airport and telecommunications assets;
- Community assets, such as public buildings, schools, government offices, commercial properties, recreational, cultural and environmental spaces;
- Residential assets such as domestic housing;
- Agricultural assets etc

In order to include an economic impact assessment, the mapping will need to be supported by estimates of (a) the existing value of these assets, (b) the costs to operate and/or maintain their present operation and (c) their replacement or upgrade costs.

It is expected that TSRA will also supply any available information on existing or historical impacts due to coastal flooding that may be relevant.

Appendix B

A Note on the Interpretation of Statistical Return Periods

B.1 General

This study has presented its analyses of risk in terms of the so-called *Return Period* (or *Average Recurrence Interval ARI*). The return period is the "average" number of years between successive events of the same or greater magnitude. For example, if the 100-year return period storm tide level is 3.0 m AHD then on average, a 3.0 m AHD level storm tide *or greater* will occur due to a single event once every 100 years, but sometimes it may occur more or less frequently than 100 years. It is important to note that in any "N"-year period, the "N"-year return period event has a 64% chance of being equalled or exceeded. This means that the example 3.0 m storm tide has a better-than-even chance of being exceeded by the end of any 100-year period. If the 100-year event were to occur, then there is still a finite possibility that it could occur again soon, even in the same year, or that the 1000 year event could occur, for example, next year. Clearly if such multiple events continue unchecked then the basis for the estimate of, say, the 100 year event might then need to be questioned, but statistically this type of behaviour can be expected.

The *Annual Exceedance Probability* (AEP) is also commonly used for expressing statistical risk, especially fluvial flooding, and is sometimes preferred. For "large" Return Periods (> 10 yr) the AEP is simply the reciprocal of the ARI, such that a 100-year ARI is described as a 1 in 100 year AEP, or alternatively equals 0.01 or is the 1% exceedance event level.

A more consistent way of considering the above (NCCOE 2012) is to include the concepts of "design life" and "encounter probability" which, when linked with the return period, provide better insight into the problem and can better assist management risk decision making. These various elements are linked by the following formula (Borgman 1963):

$$T = - N / \ln [1 - p]$$

where p = encounter probability $0 \leq 1$

N = the design life (years)

T = the return period (years)

This equation describes the complete continuum of risk when considering the prospect of at least one event of interest occurring. More complex equations describe other possibilities such as the risk of only two events in a given period or only one event occurring.

Figure B.1 illustrates the above equation graphically. It presents the variation in probability of at least one event occurring (the encounter probability) versus the period of time considered (the design life or planning horizon). The intersection of any of these chosen variables leads to a particular return period (ARI) and a selection of common return periods is indicated. For example, this shows that the 200-year return period has a 40% chance of being equalled or exceeded in any 100-year period.

The level of risk acceptable in any situation is necessarily a corporate or business decision. Table B.1, based on Figure B.1, is provided to assist in this decision making process by showing a selection of risk options. Using Table B.1, combinations of design life and a comfortable risk of occurrence over that design life can be used to yield the appropriate return period to consider. For example, accepting a 5% chance of occurrence in a design life of 50 years means that the 1000-year return period event should be considered. A similar level of risk is represented by a 1% chance in 10 years. By comparison, the 100 year return period is equivalent to about a 10% chance in 10 years. AS1170.2 (Standards Australia 2011), for example, dictates a 10% chance in 50 years criteria or the 500-year return period as the minimum risk level for wind speed loadings on engineered structures and AS4055 also adopts this for residential housing.

B.2 References

NCCOE (2012) Guidelines for responding to the effects of climate change in coastal and ocean engineering – 3rd Edition May 2012. Engineers Australia, National Committee on Coastal and Ocean Engineering, EA Books, 74pp.

Borgman L. (1963) Risk Criteria. Journal of the Waterway, Port, Coastal and Ocean Division, ASCE, Vol 89, No. WW3, Aug, 1 - 35.

Standards Australia (2011) AS/NZS 1170.2:2011 : Structural design actions - Wind actions. 90pp, as amended.

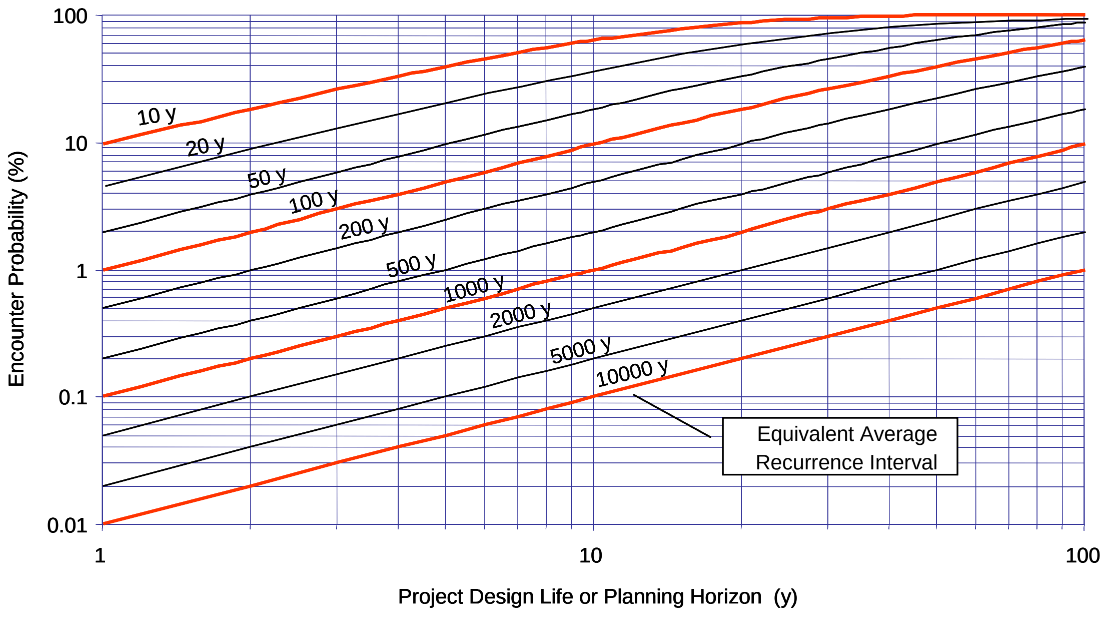


Figure B.1 Relationship between Return Period (or ARI) and Encounter probability

Table B.1 Risk selection based on encounter probability concepts.

Considered Design Life or Planning Horizon	Chosen Level of Risk of at Least One Event Occurring					
	% Chance					
y	1	2	5	10	20	30
	Equivalent Return Period or ARI (y)					
10	995	495	195	95	45	29
20	1990	990	390	190	90	57
30	2985	1485	585	285	135	85
40	3980	1980	780	380	180	113
50	4975	2475	975	475	225	141

Appendix C

Assessed Asset Distribution for Ngurupai (Horn) Island

Ground Level	THESE VALUES ARE CUMULATIVE OVER THE WATER LEVEL									
AHD m =	2.17	2.25	2.50	2.75	3.00	3.25	3.50	4.00	4.50	5.00 m AHD
Sewer	0.00	0.00	0.36	0.72	1.08	1.44	1.84	1.84	2.23	2.62 $M
Water	0.00	0.00	0.06	0.12	0.17	0.23	0.43	0.43	0.63	0.84 $M
Roads	0.00	0.00	0.36	0.72	1.08	1.44	2.53	2.53	3.62	4.71 $M
Stormwater / Drainage	0.00	0.00	0.58	1.15	1.73	2.31	3.21	3.21	4.11	5.01 $M
Marine Facilities	0.01	0.05	5.24	5.24	5.24	5.24	5.24	5.24	5.24	5.24 $M
Ergon	0.00	0.00	0.11	0.22	0.34	0.45	0.87	0.87	1.29	1.71 $M
Telstra	0.00	0.00	0.04	0.09	0.13	0.17	0.29	0.32	0.43	0.55 $M
Airport	0.00	1.67	3.33	5.00	6.67	8.33	10.00	13.33	16.67	20.00 $M
Buildings	0.00	0.55	3.05	5.55	8.05	10.55	18.50	22.58	30.53	38.48 $M
(Commercial)	0.00	0.06	0.31	0.56	0.81	1.06	1.85	2.26	3.05	3.85 $M
Contents=	0.00	0.03	0.18	0.33	0.48	0.63	1.11	1.35	1.83	2.31 $M
(Residential)	0.00	0.50	2.75	5.00	7.25	9.50	16.65	20.32	27.47	34.63 $M
Contents=	0.00	0.05	0.27	0.50	0.72	0.95	1.67	2.03	2.75	3.46 $M
Sub Total=	0.00	0.63	3.51	6.38	9.26	12.13	21.28	25.96	35.10	44.25 $M
Total Replacement (incl Contents)=	**0.01**	**2.35**	**13.59**	**19.64**	**25.70**	**31.75**	**45.68**	**53.73**	**69.33**	**84.93** $M
Discrete Interval Costs=	**0.01**	**2.34**	**11.24**	**6.05**	**6.05**	**6.05**	**13.93**	**8.05**	**15.60**	**15.60** $M
% of the Total	**0.01**	**2.75**	**13.24**	**7.13**	**7.13**	**7.13**	**16.41**	**9.48**	**18.37**	**18.37** %

Appendix D

Using the Risk Analysis Planning Tool (RAPT)

D.1 General

The Risk Analysis Planning Tool (RAPT) has been provided in the form of a Mircrosoft Excel™ 2010 workbook. It has several hidden sheets and each visible sheet has been protected to prevent modification, other than by user-allowable inputs. This model only applies to Ngurupai (Horn) Island as it is linked to the storm tide hazard profile and assumed elevation ranges.

D.2 Hazard and Adaptation Worksheets

Step 1 WL Hazard

The user may change the projected Sea Level Rise increase by 2050 and 2100.

This will alter the storm tide hazard functions. The IPCC default 95% upper limits are shown as the default that could be used.

Forced Retreat Costs

This shows a graph with the estimated costs of a Forced Retreat (Base Case) using the Step 1 values, expressed in present day dollars.

Step 2 Adaptation Options

The user may change:

- the economic Discount Rate % (which affects the NPV and the BCR timing)

- the year that the Adaptation occurs

- the elevation (m AHD) at which the Adaptation is effective

The graphs show the estimated cumulative costs (present day dollars) of either Defend or Retreat. The NPV of the Total Costs and Benefits is shown, plus the BCR.

To produce a varying BCR as a function of the year of adaptation this process will need to be repeated as required and the BCR values saved.

D.3 Asset Exposure, Vulnerability and Adaptation Cost Worksheets

These are data tables that can also be modified (with care):

Asset Exposure & Vulnerability

The distribution of estimated asset replacement value with elevation, assumptions about building type proportions, contents value and vulnerability parameters.

Estimated Adaptation Costs

Estimates of foreshore protection and/or levee or bund costs as a function of elevation and the assumed "rebuilding cost factor".

No responsibility can be taken for user changes to the supplied model.