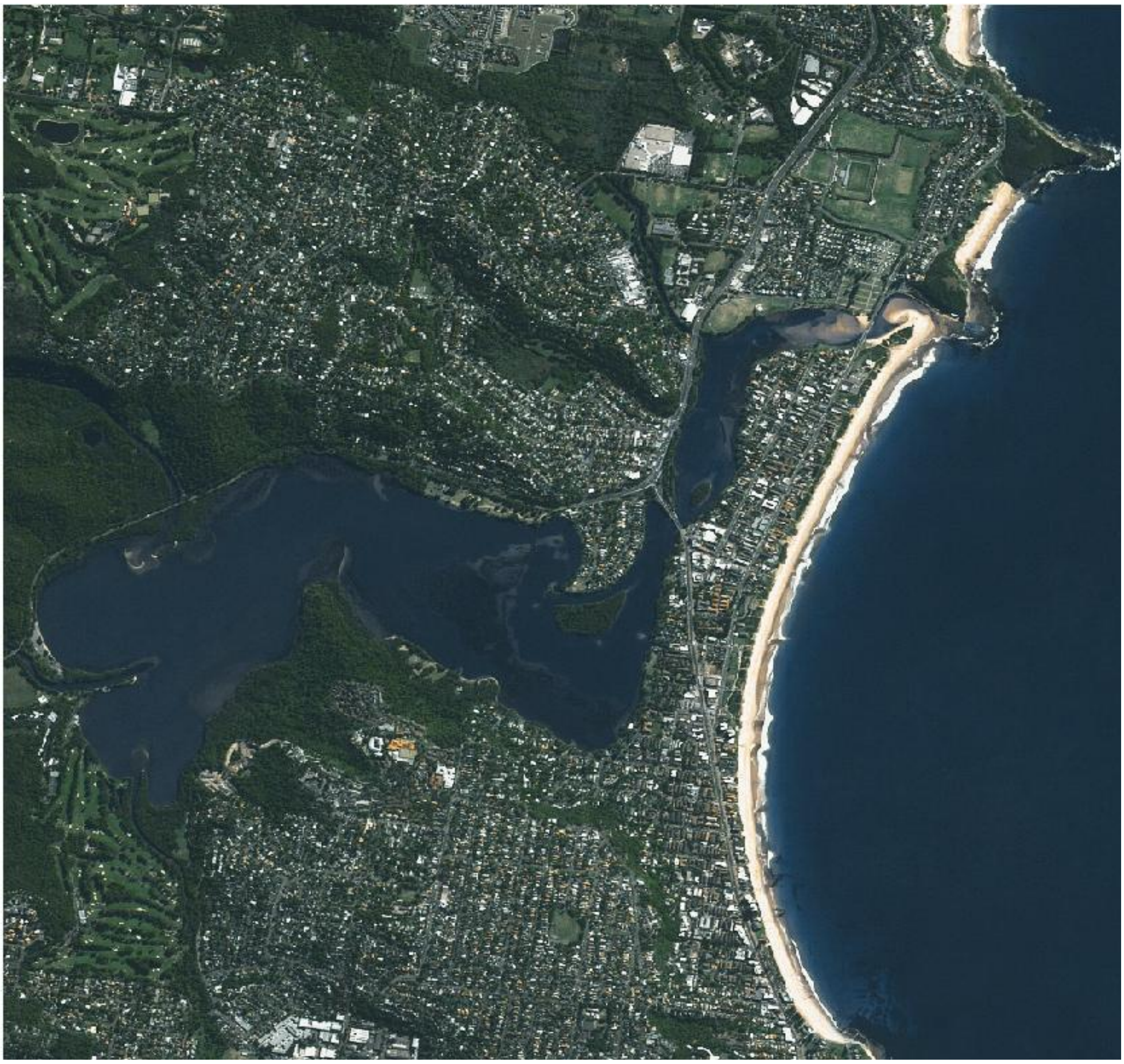
Australian Government

Department of Climate Change

Coastal Inundation at Narrabeen Lagoon

Optimising Adaptation Investment



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This report has been prepared by AECOM based on information from published studies and provided by third parties. The study is intended to demonstrate generally the benefits and costs of adaptation to flooding at Narrabeen Lagoon. The analysis is insufficient to enable any party to rely on findings to makes decisions about any individual adaptation measure.

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Department of Climate Change

Coastal Inundation at Narrabeen Lagoon - Optimising Adaptation Investment

Prepared by

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Glossary of Terms

AADT	Average annual daily traffic
ABS	Australian Bureau of Statistics
ABSLMP	Australian Baseline Sea Level Monitoring Project
AEP	Annual exceedance probability
AHD	Australian height datum
Benefit-cost analysis	A decision-making tool that expresses, as far as possible, all costs and benefits in commensurable monetary units that reflect society's preferences for, and use of resources.
Berm	A narrow ledge or shelf along the edge of a road, slope or canal.
BoM	Bureau of Meteorology
CO_2	Carbon dioxide
COAG	Council of Australian Governments
CPI	Consumer Price Index
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DCC	Department of Climate Change
DECC	NSW Department of Environment and Climate Change (now known as DECCW)
DECCW	NSW Department of Environment, Climate Change and Water (formerly known as DECC)
Discount rate	The rate at which future values are discounted by such that they are comparable to values in the present
ECA	Economics of Climate Adaptation
Flood gate	Adjustable gates used to control water flow
Flood wall	Vertical barrier, often built from concrete, designed to temporarily contain flood waters.
GCI	General construction index
OAGCM	General circulation model
GDP	Gross domestic product
Gumbel distribution	A type of generalised extreme value distribution of the maximum (or the minimum) of a number of samples of various distributions.
ICOLL	Intermittently closed or open lake or lagoon
IPCC	Intergovernmental Panel on Climate Change
Levee	Compacted embankment built to prevent a river overflowing
LGA	Local government area
Linear interpolation	Estimation of a value of a variable between two known values that assumes uniform change between the two known values
Monte Carlo simulation	Typically involves a computer generating random numbers for use in sampling from distributions. This process is repeated many times yielding simulated probability distributions.
Multiple linear regression	Linear relationship between a dependent variable and multiple independent variables plus a stochastic disturbance
Normal distribution	Continuous probability distribution where values are clustered about the mean
NPV	Net present value. The discounted value of a series of benefits and costs over time
NTC	National Tidal Centre
Numeraire	The unit in which prices are measured. This may be a currency, but in real models, such as most trade models, the numeraire is usually one of the goods, whose price is then set at one
OAGCM	Ocean-atmosphere coupled general circulation models
Opportunity cost	The cost of something in terms of opportunity foregone

Probability distribution	The range of values that a random variable can potentially attain
Probability of exceedance, poe	Probability of occurrence of an event that is at least as severe as that specified.
Probable maximum flood	The largest flood that could conceivably occur. Notionally the 0.001% AEP or once in a hundred thousand years flood.
Rainfall intensity	Volume of precipitation over a period of time, such as millimetres per hour (mm/hr)
Revealed preference	A technique whereby an individual's preferences can be determined based on actual behaviour
Revetment	A facing wall designed to sustain an embankment by absorbing energy from incoming water.
RTA	NSW Roads and Traffic Authority
SEIFA	Socio-Economic Indexes for Areas
SLR	Sea level rise
SRES	Special Report on Emissions Scenarios
Stated preference	A technique whereby an individual's preferences can be determined based on their choices under hypothetical situations
Storm surge	A storm surge is a rise above the normal water level along a shore that is the result of strong onshore winds and /or reduced atmospheric pressure
Tidal prism	The amount of water that flows into and out of an estuary or bay with the flood and ebb of the tide, excluding any contribution from freshwater inflows.
UNEP	United Nations Environment Program
Willingness-to-pay	Willingness of an individual or society to give up a given amount of goods and services in exchange for the benefits to be gained from the adaptation measure

At a glance

Knowledge of the physical impacts of climate change is growing but, at this time, it is still insufficient for decision-makers. In addition to developing a better understanding of the physical impacts of climate change, infrastructure owners, investors and governments need advice about adaptation options and their costs and benefits over time.

Infrastructure owners need to know what adaptation options could be taken to optimise their investments and manage risk. Governments need to understand the impediments to infrastructure owners taking efficient adaptation measures to reduce the economic and community impacts of infrastructure failure.

AECOM was engaged by the Australian Department of Climate Change to undertake an economic analysis of climate change impacts on infrastructure through the development of a series of case studies. These studies, which analyse the benefits and costs of adaptation in response to risks of climate change, will be used to inform the Australian Government's discussion on policy responses to the risk that climate change will increase infrastructure investment and maintenance costs.

This case study analyses the impact of climate change on flooding from Narrabeen Lagoon in the northern Sydney local government area of Pittwater. It does not include analysis of impacts from beach erosion.

Narrabeen Lagoon is the smaller body of water to the north and east of Pittwater Road. Narrabeen Lakes is the larger body of water to the south of Pittwater Road and Wakehurst Parkway. Narrabeen Lagoon is one of about 70 intermittently closed and open lakes and lagoons (ICOLLs) spread along the coast of New South Wales. Storms can block ocean entrances to lagoons by depositing sand, but, in combination with flood waters from creeks that feed into a lagoon, they will occasionally also flush away deposits in the entrance.

When its entrance is blocked, rain and floodwaters will generally fill a lagoon like a bathtub, and can therefore flood the land and houses around it. Because climate change is expected to increase the frequency and intensity of storms and rainfall in the Narrabeen catchment over the coming century, as well as raising sea levels, decision makers need a better understanding of the social costs and benefits to their communities of the different adaptation measures that could be implemented to reduce inundation.

This pioneering study estimates the social benefits of adaptation to climate change in terms of willingness to pay, rather than just costs avoided. It also employs Monte Carlo analysis to generate more realistic probabilities of overall costs and benefits, as well as modelling the expected future values of variables such as rainfall using extreme value analysis rather than just taking averages. Six possible measures are analysed in detail. These are:

- Lagoon entrance opening
- Lake Park Road levee
- Progress Park levee
- Nareen Creek levee
- Flood awareness
- Planning control

Opening the ocean entrance to Narrabeen Lagoon permanently by excavating a channel through the headland rock shelf would lower the water level by up to 1 metre. Modelling suggests that a 70-metre wide channel is economically viable now, but the benefits increase if deferred until 2035. However, the study suggests that a 100-metre wide channel would be far more expensive, with little additional benefit, and could therefore not be justified economically.

Construction today of a 3 metre high levee on Lake Park Road along the southern boundary of the Sydney Lakeside Holiday Park would generate net economic benefits of $0.9 million, and is therefore a viable proposition. However, a similar levee at Progress Park is unlikely to generate sufficient social benefit to outweigh the costs involved.

A floodwall and floodgates along Wakehurst Parkway would prevent rising floodwaters in the lagoon from backing up into Nareen Creek, which feeds into it. Although almost 300 houses would be protected, the study suggests that the cost involved outweighs the benefits.

A system to provide Pittwater residents with early warning of floods would be relatively inexpensive, and would allow them to move valuable belongings and business merchandise to higher ground to avoid damage. With net benefits of $12 million in present value terms, it would be worthwhile implementing this strategy immediately.

Amending planning regulations to require an increase in floor height by at least one metre for all new buildings and renovations to existing buildings would reduce flood damage over time. Although an average house is renovated only every 40 years on average, the beneficial net present value from immediate adoption of this measure would be at least $13.8 million.

Overall, a socially and economically justifiable strategy for the Narrabeen community would be to immediately institute an early flood warning system, amend planning regulations, and build the Lake Park Road levee, followed by channel widening in 2035.

The following table shows an appropriate portfolio of measures that, together, have higher benefits than individual actions.

Adaptation Measure	Dimensions (m)	Timing
Lagoon opening: Permanent opening of the lagoon entrance. By controlling the build up of sand, flood waters can flow out quicker reducing the severity of flood events.	70.0 width	2035
Lakeside levee: Increase the level of existing flood protection at Lakeside by increasing the height and lengthening the levee.	2.7 height	2010
Progress Park levee: Construction of a new earth mound levee in Progress Park for flood protection for mainly commercial/industrial properties.	2.5 height	After 2100
Nareen Creek levee: Flood wall and flood gates constructed to protect the lower reaches of the Nareen Creek catchment from backwater flooding from the lagoon.	2.3 height	After 2100
Flood awareness: Early flood warning systems designed to prepare residents and businesses to take steps to minimise damage to property, contents and operations.	Not applicable	2010
Planning control: Planning regulations increasing minimum floor height for all new buildings and building renovations to reduce severity of floods and the number of buildings impacted.	Height not modelled	2010

1.0 Introduction

1.1 Objectives of project

Knowledge of the physical impacts of climate change is often insufficient for decision-makers. Infrastructure investors, owners, managers and governments need to understand the physical impacts of climate change, but just as importantly they need information on adaptation options. Decision making on which adaptation measures to implement and when requires information on: likely future impacts of climate change, a range of adaptation measures, and the costs and benefits of various adaptation measures.

Infrastructure owners need to know about what adaptation measures could be taken to optimise their investments and manage risk. Governments need to understand the community impacts and any impediments to infrastructure owners taking efficient adaptation measures to reduce the economic impact to the community resulting directly and indirectly from the failure of infrastructure.

This project will inform the Australian Government's discussion on policy responses to the risk climate change is likely to increase infrastructure investment and maintenance costs. To achieve this, AECOM has undertaken economic analysis of the climate change impacts on infrastructure of interest for the Australian Government.

AECOM was engaged by the Australian Department of Climate Change to undertake an economic analysis of the climate change impacts on infrastructure through an analysis of the benefits and costs of adaptation in response to risks of climate change. This case study analysed the impact of climate change on coastal flooding around Narrabeen Lagoon in the Pittwater region of Sydney. To limit the scope of the study to manageable and definable dimension, this study only considers the impacts of lagoon-dominated flooding and did not consider the effects of beach erosion.

1.2 Nature of analysis undertaken for Narrabeen Lagoon

Adaptation is one of the three pillars of the Australian Government's climate change strategy. However, a key feature of climate change is the uncertainty that accompanies it. In particular, the timing, severity and frequency of future weather and climate events are not known with any degree of precision at this stage. Even where an ostensibly effective adaptation measure is identified, such as building a levee bank, there is little certainty as to when it should be built, or how high. AECOM has therefore used probabilistic modelling to handle the uncertainty in respect of climate change and adaptation.

Premature construction of a levee bank to protect a road in a coastal area like Pittwater, for example, would involve substantial costs now, but the benefits of avoiding more frequent or higher floods may not be reaped until well into the present century. In such circumstances, the Pittwater community and Australian society as a whole may be better off delaying the construction of the levee bank. Its resources can be used in the meantime for other infrastructure, such as schools or hospitals, which have greater immediate social value. Undue procrastination, on the other hand, could result in significant flood damage that might have been avoided by constructing a levee bank at an appropriate time and to an effective height.

AECOM has therefore used a discounted benefit-cost methodology to rank and select a preferred strategy. Benefit-cost analysis allows assessment of the relative social merits of potential adaptation measures. By incorporating analysis of risk, it can also help determine optimal timing for implementing adaptation measures. Estimating the costs of implementing an adaptation measure such as building a levee bank or raising houses is a fairly straightforward task. Engineering information and the general availability of much commercial data, even if not perfectly suited to the task, can usually be employed to produce fairly robust and reliable estimates.

The estimation of the benefits of adapting to climate change, on the other hand, is more difficult. In principle, economic benefits are estimated in terms of the willingness to pay by consumers or other beneficiaries for a good or service like the result of an adaptation measure. In the absence of markets where it is possible to observe the amount that beneficiaries are willing to pay, it is necessary to resort to so-called 'stated preference' methods, using surveys of potential beneficiaries to state how much they would be willing to pay if offered a specific benefit. Although there is an element of hypothetically in such methods, they have improved significantly in recent years and it is at least arguable that they are sufficiently robust for the purpose.

Because 'stated preference' surveys are relatively expensive, many studies estimate benefits in terms of avoided costs. For example, the benefit of an adaptation measure like raising a house above flood levels might be estimated as the flood damage costs that are avoided as a consequence. This approach can underestimate the true benefits of an adaptation measure because, for example, it does not include the cost of inconvenience to the flooded household. Including only the (market) cost of damaged furniture and fittings, but not the unpaid labour of the household residents in cleaning up, would also underestimate the true economic benefits of avoiding the consequences of a flood.

1.3 Benefits of the modelling approach

Benefit-cost analysis is a decision-making tool that expresses, as far as possible, all costs and benefits in commensurable monetary units that reflect society's preferences for, and use of resources. Its scope therefore encompasses the value placed by society as a whole on the costs and benefits of a proposed course of action, rather than merely financial or commercial values. Costs are measured as implementation and damage costs, and benefits reflect the willingness to pay of those who consume or otherwise benefit from an action or project.

The approach of this study introduces several innovative features and improvements over other studies of the costs and benefits of implementing adaptation measures, as outlined below. The key benefits of this approach are:

- Where possible, benefits have been estimated on the basis of 'willingness to pay' measures, with 'costs avoided' being used only where relevant data were not available;
- Extreme value analysis has been used to better model the likelihood of increasingly frequent and severe climate events;
- Modelling of costs and benefits has been designed to identify the optimal time, over the years 2010 to 2100, to implement the six adaptation measures above so that net benefits are maximised; and
- The modelling allows for estimation of 'real option values', in terms of the difference between costs of acting fully now, or acting partially now and fully later only if necessary.

Studies of adaptation measures have to date focused on estimating the costs of implementing the measures and comparing implementation costs to the damage or costs that would be avoided if the adaptation measure or strategy were implemented. Such studies – a form of cost-effectiveness analysis – typically underestimate the potential benefits of adaptation measures. For example, a sea wall may prevent coastal flooding. However, if only the damage avoided is estimated, then valid social preferences such as the desire to avoid the inconvenience of flooding, or the fear of being drowned, will not have been included.

Consideration of adaptation measures by decision-makers potentially involves a choice between many alternative adaptation strategies. It also involves choices between adaptation strategies and all other potential social projects, such as building roads, schools or hospitals. Because a common money numeraire (which reflects the value of social resources) is used for all costs and benefits, it is possible to compare different projects in order to identify the socially most desirable ones.

This report draws on the scientific advice and modelling as used for *Climate Change Risks to Australia's Coast*. However, this study also used a quantitative risk approach rather than a 'worst case' approach to estimate 90% confidence intervals rather than worst cases. This approach has been discussed in the literature, although rarely applied in practice (Marsden Jacobs Associates, 2004).

1.4 Outline of this report

This report is structured into nine chapters;

- Chapter 1.0 describes the objectives of the project, the nature of the analysis undertaken, and the benefits of the modelling approach adopted.
- Chapter 2.0 describes the area that is the focus of the study, namely Narrabeen Lagoon in the Pittwater region of Sydney. It sets out the current extent and effects of flooding.
- Chapter 3.0 describes the methodology that was used to handle climate and weather uncertainty, within an overarching benefit cost framework.
- Chapter 4.0 describes how the weather impacts might change under a range of equally likely climate scenarios. It is essential to understand that the uncertainty associated with the range of climate scenarios is carried through the modelling.
- Chapter 5.0 presents the approach used in the economic model to predict flood events.
- Chapter 6.0 describes the costs of flood impacts.
- Chapter 7.0 describes adaptation measures that have been assessed, and their benefits and costs.
- Chapter 8.0 presents the preferred adaptation portfolio and draws out lessons about adaptation.

1.5 Acknowledgements

The authors are very grateful to the Pittwater Council for its cooperation during this study and for providing much useful information that has enabled detailed quantitative analysis. We would specifically like to recognise the contribution of Councillor David James, as the former Mayor of Pittwater for his personal assistance in facilitating the study.

The authors would also like to acknowledge the guidance of Dr Leo Dobes, Crawford School of Economics and Government, Australian National University and the assistance of consultants Marsden Jacob Associates as reviewers.

This report has been prepared by AECOM based on information from published studies and provided by third parties. The study is intended to demonstrate generally the benefits and costs of adaptation, but the study has not undertaken sufficient analysis of individual measures to enable any party to rely on findings to make decisions about any individual adaptation measure.

The report has also drawn on previous studies of the impact of flooding in the Pittwater region, including:

- Narrabeen Lagoon Floodplain Management Study (ERM Mitchell McCotter, 1992)
- Nareen Creek (North Narrabeen) Floodplain Risk Management Study & Plan (unpublished Preliminary Draft, final due 2010), (Cardno Lawson Treloar, 2009)
- Manly Lagoon Floodplain Management Plan (Land and Water Conservation, 1997)

These studies were based on historical flood levels and do not take into account risks of climate change.

2.0 Background on flooding at Narrabeen Lagoon

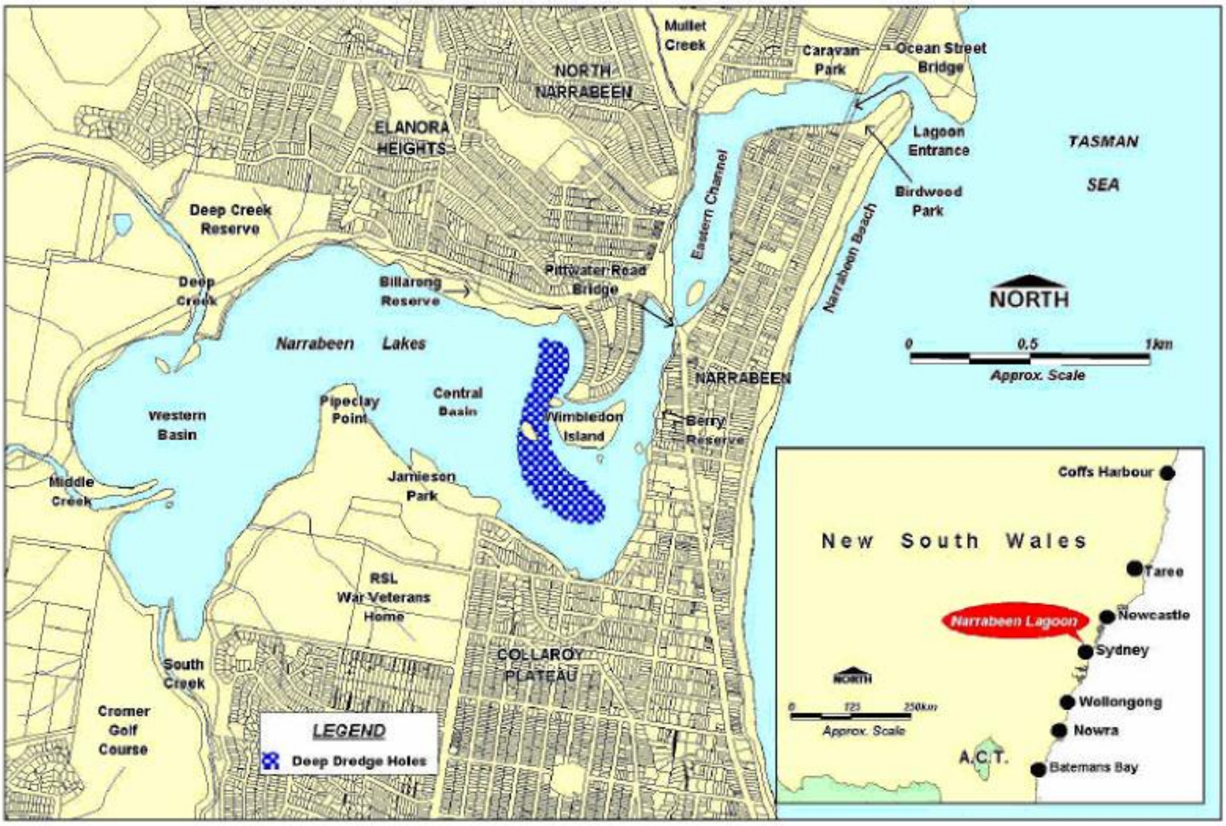
2.1 Description

Narrabeen Lagoon is the largest coastal lagoon in the Sydney Region. The lagoon is used extensively by the community and visitors for a wide range of recreational activities, including kayaking, sailing, rowing, fishing, swimming and less active activities such as walking, picnics and photography. The lagoon also supports an important aquatic ecosystem.

The main body of the lagoon is connected to the ocean by a long narrow channel, two kilometres in length and typically 150 metres wide (Cameron *et al.,* 2007). Narrabeen Lagoon is classified as an intermittently closed or open lake or lagoon (ICOLL). The entrance of Narrabeen Lagoon naturally closes due to the movement of sand into the Lagoon entrance resulting from wave, current and wind processes. The amount of sand that is moved into the lagoon entrance by the incoming tide continually exceeds the amount of sand removed by the outgoing tide resulting in the entrance to Narrabeen Lagoon becoming filled with marine sediment. Over time the entrance closes completely.

Narrabeen Lagoon is located North of Sydney along the NSW coast as can be seen in Figure 1.

Figure 1: Map of Narrabeen Lagoon relative the NSW coast



2.2 Intermittently closed and open lakes or lagoons

Intermittently Closed and Open Lakes or Lagoons (ICOLLs) are a common type of estuary in south-eastern Australia (Everett *et al.*, 2007). Of the 134 estuaries in New South Wales (NSW), 67 (50%) are classified as intermittently open estuaries (Roy *et al.*, 2001). ICOLLs, such as the one at Narrabeen Lagoon, are characterised by low freshwater inflow, leading to sand barriers (berms) forming across the entrance preventing exchange with the ocean (Everett *et. al.*, 2007). Due to the intermittent nature of rainfall, the open/closed cycles of ICOLLs in south-eastern Australia are not seasonal (Environment Protection Authority NSW, 2000). The timing and frequency of the entrance opening relates to factors such as the size of the catchment, rainfall, evaporation, the height of the berm and creek or river inputs (Roy *et al.*, 2001).

As an added complication, 72% of NSW ICOLLs are now artificially opened when they reach a predefined ‘trigger’ height (Dept. of Infrastructure, Planning and Natural Resources, 2004). Reasons for this include flood prevention strategies and flushing in order to minimise pollution (Everett *et al.*, 2007). Due to a lack of flushing, ICOLLs are particularly prone to pollution events such as nutrient or sediment runoff (Everett *et al.*, 2007). Coastal lagoons are typically densely populated. In NSW 75% of the population live near the coast and estuaries and they are popular destinations for local and overseas tourists. An increase in the rate of flooding and the subsequent impacts to these regions poses a significant risk to these coastal communities.

2.3 Extent of flooding

The Narrabeen Lagoon region is a 50 square kilometre catchment area with five creeks (Mullet, Deep, Middle, South, and Narreen) draining into the lagoon. When heavy or sustained rainfall occurs, the lagoon fills up, like a bathtub, and may flood surrounding areas. High sea levels may reduce the ability of rainwater to exit via the narrow channel to the Pacific Ocean, and storm surges may further add to the blockage of egress.

During extreme rainfall events, the ocean outlet of Narrabeen Lagoon often experiences elevated inshore ocean levels as a result of barometric effects of low pressure systems, wind and wave action superimposed on high tide levels (Public Works Department, 1990). These processes are not necessarily independent, as it can be the same low pressure system that causes the heavy precipitation that causes also the storm surge (barometric and wind setup) and wave setup. During extreme events, these processes can last several days, ensuring they occur on high astronomical tides.

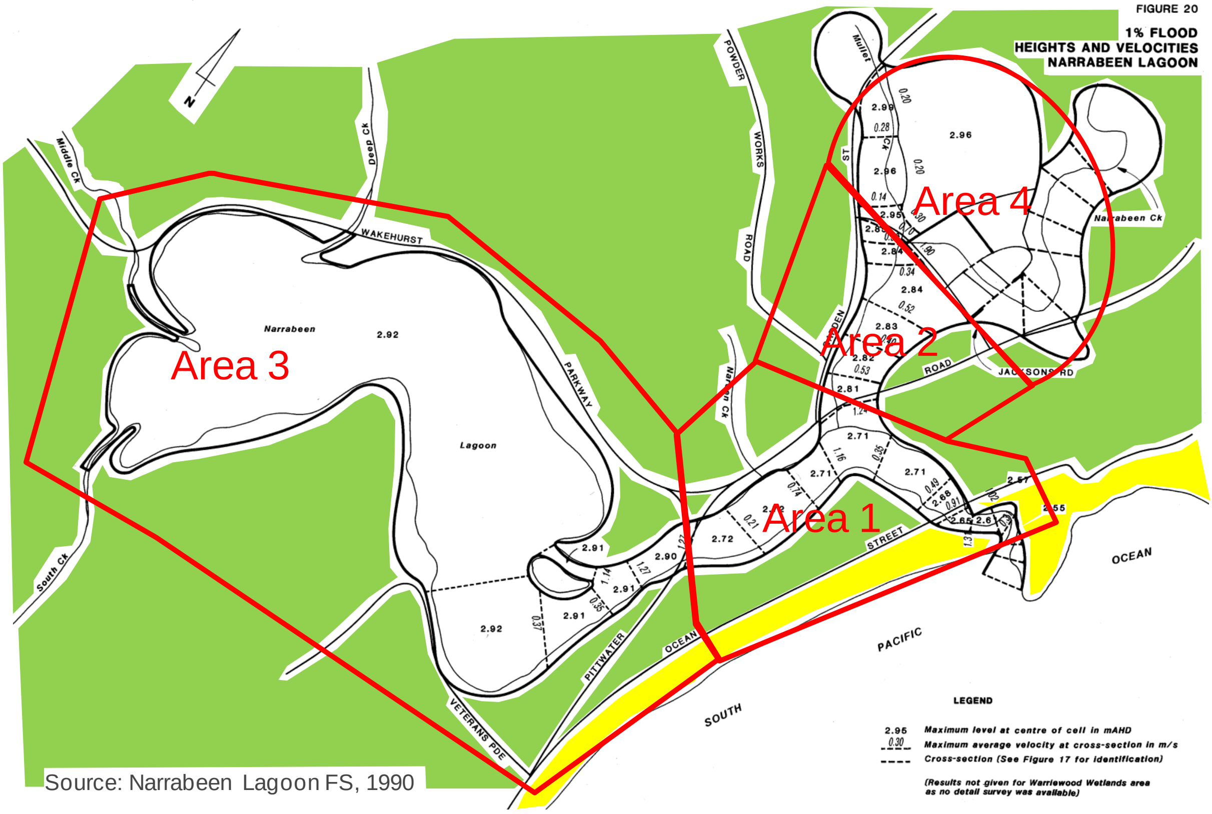
Flooding of the lagoon can be caused by extreme rainfall, extreme ocean water levels or a combination of both. Further, the extent of flooding can be influenced by the entrance conditions at the time these events occur. A closed entrance lagoon combined with significant rainfall will impede floodwaters discharging from the lagoon to the ocean. Conversely, an open entrance will increase the severity of flooding from elevated ocean levels alone (ERM Mitchell McCotter, 1992).

Figure 2: Early photo of flooding at Narrabeen Lagoon

Source: Pittwater Council, date unknown

Flooding varies around the lagoon. Four major areas of flooding are shown in Figure 3. Flooding occurs around the lagoon itself (designated as Area 3) and in Areas 1, 2 and 4 to the north of the lagoon's channel to the ocean. The four areas are affected at different flood heights. The 1992 *Narrabeen Lagoon Floodplain Management Study*, commissioned by Pittwater Council and undertaken by ERM Mitchell McCotter (1992), divided the lagoon into four primary flood affected areas.

Figure 3: Narrabeen Lagoon flood areas



Source: ERM Mitchell McCotter, 1992

The Public Works Department (1990) study identified the critical duration of a storm causing flooding to the lagoon as 36 hours for the 5% and 1% Annual Exceedence Probability (AEP) design rainfall, and 12 hours for the Probable Maximum Flood (PMF). Refer to the text box below for an overview of AEP and PMF.

Box 1: Overview of Annual Exceedance Probability (AEP) and Probable Maximum Flood (PMF)

- The chance of a flood of a given or larger size occurring in any one year is usually expressed as a percentage. For example, if a peak flood discharge of 500 m^3/s has an AEP of 5%, it means that there is a 5% chance (that is one-in-20 chance) of a 500 m^3/s or larger event occurring in any one year (see ARI).
- The PMF is the largest flood that could conceivably occur at a particular location, usually estimated from probable maximum precipitation, and where applicable, snow melt, coupled with the worst flood producing catchment conditions. Generally, it is not physically or economically reasonable to provide complete protection against this event. The PMF defines the extent of flood prone land, that is, the floodplain. The extent, nature and potential consequences of flooding associated with a range of events rarer than the flood used for designing mitigation works and controlling development, up to and including the PMF event should be addressed in a floodplain risk management study.

Source: Department of Infrastructure, Planning and Natural Resources, 2005

While the occurrences of these processes are not independent, their joint probabilities have not been researched thoroughly. While the data in Table 1 suggests that rainfall may have a greater influence on flooding of the lagoon compared with elevated ocean levels, the joint probabilities of the occurrences of these events needs further research. Empirical studies of flooding of ICOLLS in the Gosford area indicated that heavy rainfalls often coincide with large storm surges and high wave conditions.

Table 1: Historical Flood Events at Narrabeen Lagoon

Historical Flood	Main Flooding Mechanism
May 1889	Rainfall Runoff
January 1911	Rainfall Runoff
July 1931	Elevated Ocean Levels and Rainfall Runoff
March 1942	Rainfall Runoff
June 1956	Elevated Ocean Levels
March 1958	Rainfall Runoff
May 1974	Elevated Ocean Levels
1961	Rainfall Runoff
1975	Rainfall Runoff
1986	Elevated Ocean Levels and Rainfall Runoff

Source: Public Works Department, 1990 and ERM Mitchell McCotter, 1992

2.4 Effects of flooding

A large amount of development of the low lying land around Narrabeen Lagoon took place before its flood prone nature was well understood (Manly Hydraulics Laboratory, 1989). As such, there are a significant number of flood affected properties within the Narrabeen Lagoon floodplain. The number of residential and commercial properties in the four flood affected areas is set out in Table 2. This reveals that the main residential areas are Area 1 and 3 (areas are outlined in Figure 3 above).

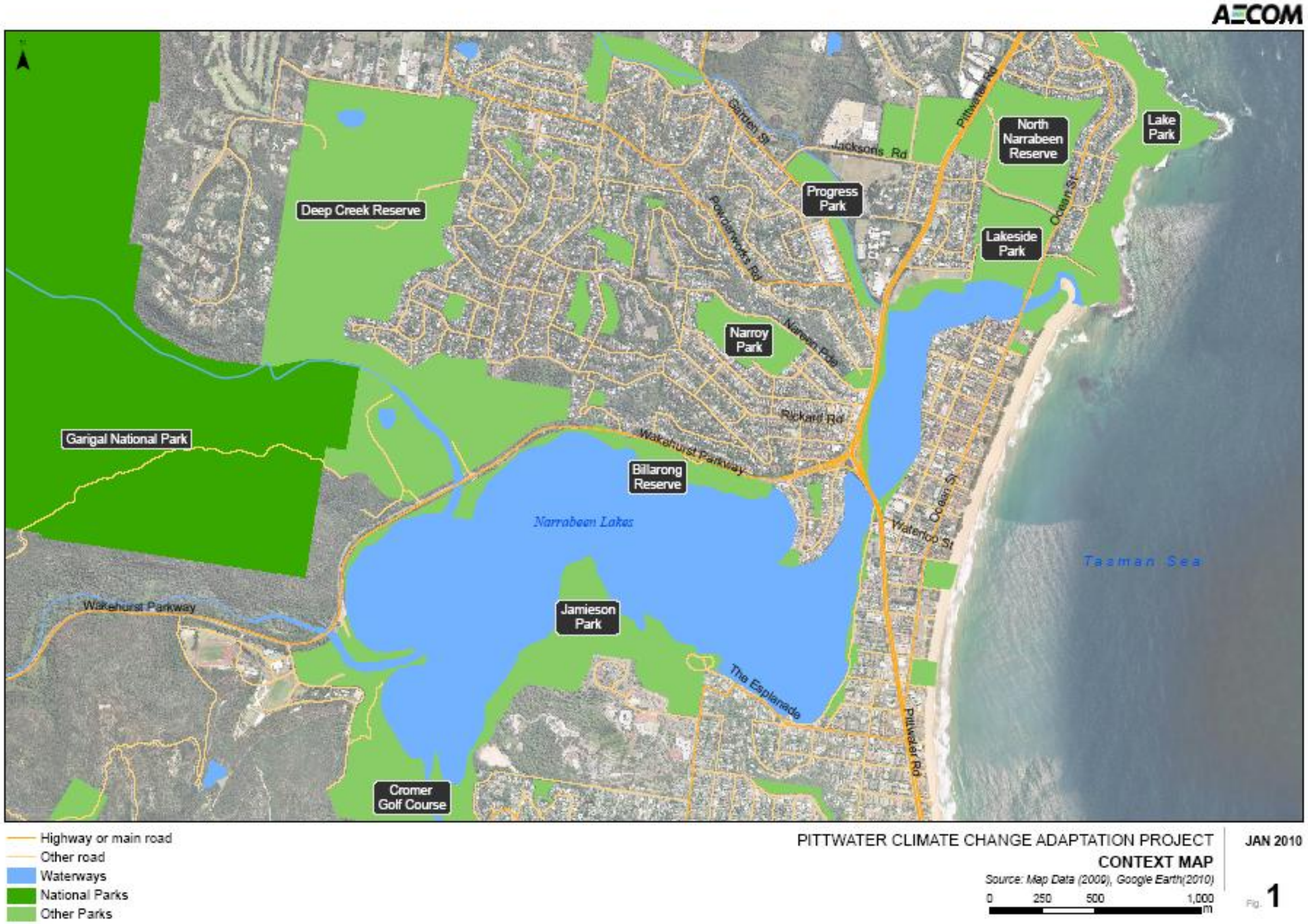
Table 2: Residences and commercial properties in the flood affected areas

Area	Number of residences	Number of commercial properties
Area 1	659	112
Area 2	125	53
Area 3	630	28
Area 4	18	69
Total	1,432	262

Source: ERM Mitchell McCotter, 1992

The effects of flooding are very site specific and depend on the exact location as well as the nature of the flood, height and duration. Flooding in the Narrabeen Lagoon area may submerge some roads, forcing traffic to use alternative routes or trips may be cancelled altogether. The number of roads that are submerged or become unusable will depend on the severity of the flood. At a flood height of 2.5 metres, for example, Garden Street, Waterloo Street, Rickard Road and Jacksons Road would be unusable. Once the flood height reaches 2.8 metres, the major roads around the lagoon, including Pittwater Rd and Wakehurst Parkway, would be closed.

Entry and exit to the Pittwater area would still be possible via Mona Vale Rd, but traffic would face a longer journey. Pittwater residents who use this alternative route incur an additional travel time cost (including additional congestion on the alternative route) and vehicle operating costs due to the longer distance travelled.



PITTWATER CLIMATE CHANGE ADAPTATION PROJECT

JAN 2010

CONTEXT MAP

Source: Map Data (2009), Google Earth(2010)

0 250 500 1,000 m

Fig. 1

2.4.1 Direct impacts

ERM Mitchell McCotter (1992) undertook a detailed assessment which included developing a database of properties and structures, their flood level and how much they would be affected by different flood levels. The following direct impacts were identified:

- Residential property damage – direct damages due to inundation of buildings and structures.
- Commercial property damage – direct damages due to inundation of buildings and structures.
- Damage to roads, bridges and traffic signals – there are five bridges in the study area, three of which would be affected by scour of bridge abutments from a 1% flood. All bridges are submerged under extreme flooding. Traffic signals are also affected by extreme flooding and prolonged inundation of roads could lead to weakened pavements or partial road collapse.
- Damage to water and sewerage infrastructure – eleven sewage pumping stations are in the flood affected area. Pumping units are below ground, however above ground electrical controls and power supply are not flood proof. An extreme flood event would also affect the above ground water main under Pittwater Road Bridge.
- Damage to electricity and gas infrastructure – flood affected assets are transmission infrastructure, substations and underground cables. There are nine substations in the study area that are considered vulnerable to flooding. Gas mains may be affected by water seepage preventing the flow of natural gas.
- Damage to parks and grounds – Lakeside Caravan Park, Cromer Golf Club and the Narrabeen Academy of Sport are each affected by flood inundation. There are also fourteen Council parks and reserves that are potentially flood affected.

The magnitude of direct impacts depends on the combination of flood height, duration and the characteristics of the area affected. Table 3 sets out the estimated direct damage costs from the ERM Mitchell McCotter (1992) study. The magnitude of costs rises significantly for a 1% flood compared to a 5% flood. For the 5% flood the majority of the costs are government infrastructure. However, with a 1% flood, damage to residential property makes up nearly half the costs.

Table 3: Direct damage cost estimates

Direct damage cost	Flood Height AEP 5%	Flood Height AEP 1%
Residential	$0.2m	$2.8m
Commercial	$0.1m	$1.1m
Government infrastructure	$1.6m	$3.2m
Recreational facilities	$0.2m	$0.3m
Total	$2.1m	$7.4m

Source: Based on numbers from ERM Mitchell McCotter, 1992 updated to 2009 using CPI

2.4.2 Indirect impacts

In addition to the direct damage impacts from flooding there are a range of other impacts that arise as a result of the disruption caused by the flood, which include:

- Indirect flood damages for residential properties. As well as the actual damage to property, there are costs associated with cleaning up the property and financial loss. The main costs involve alternative accommodation whilst the property is flooded or damaged and the time involved with cleaning up the property.
- Indirect flood damages for commercial properties. For commercial properties there may be the loss of activity such as sales or production while repairs occur.
- Travel disruption caused by roads flooding around Narrabeen Lagoon. Flooding in Narrabeen Lagoon will cause roads to become submerged forcing traffic to either cancel their trip or to find alternative routes. The number of roads that become submerged and unusable depends on the severity of the flood. Once the flood height reaches 2.8m the major roads around Narrabeen lagoon, including Pittwater Rd and Wakehurst parkway, are closed. Traffic will still be able to enter and exit the area through Mona Vale Road but this will mean longer trips.
- Health impacts: The nature of flooding in and around Narrabeen Lagoon does not directly pose a significant hazard or risk of flood related deaths. Flood velocities are generally low and build up over a long time. This is evidenced by the low number of physical injuries that have occurred during flood events in the Narrabeen Lagoon area. However, a flood can be a traumatic experience for many victims. Flooding often results in loss of memorabilia such as family photographs, loss of pets, living in temporary accommodation, and financial outlays to replace damaged possessions.

3.0 Methodology: measuring the cost and benefits of adaptation

The approach used to measure the cost and benefits of adapting to climate change to reduce the increased impacts of flooding at Narrabeen Lagoon followed seven stages, as illustrated in Figure 4.

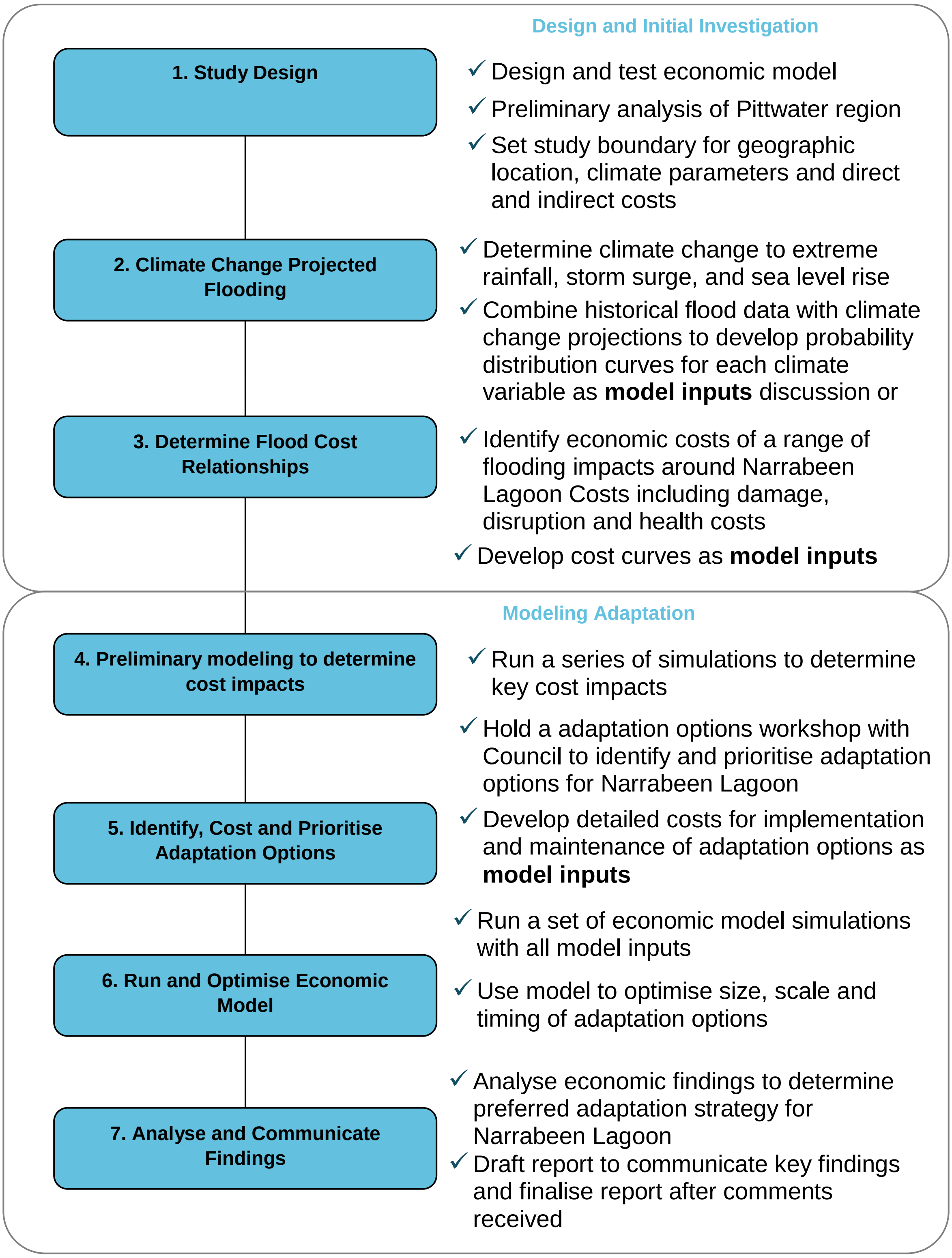


Figure 4: Methodology Overview of project phases

Broadly, our approach involved designing, building and testing the economic model. This progressed to developing inputs that were fed into the model. The inputs included:

- Probability of weather events occurring under different climate scenarios;
- The impacts on infrastructure for randomly simulated climate events;
- The economic costs and benefits of the impact on infrastructure for simulated climate event;
- The reduction in impacts on infrastructure due to adaptation for each possible climate event; and
- The economic costs and benefits of adaptation measures.

The model was run and findings were optimised and communicated. What follows in this section of the report is a discussion on each of the stages undertaken.

3.1 Study design

AECOM undertook a vulnerability assessment to understand the potential impacts of climate change on the Pittwater region. Specifically, a preliminary analysis was undertaken to determine the extent to which climate change may damage or harm existing conditions by researching the current flooding impacts within Narrabeen Lagoon. The boundary of the assessment was then established to set the parameters of the study to be investigated in relation to geographical location, the climate parameters and the direct and indirect impacts.

This initial stage also involved designing, building and testing the economic model that has been used to determine the cost and benefits of adaptation options. This section sets out how the model was constructed to link the weather event with the economic costs and benefits, as illustrated in Figure 5.

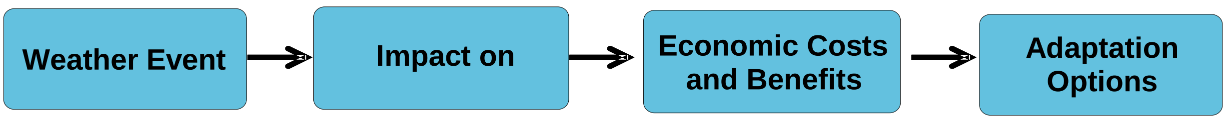


Figure 5: Relationship between weather event, impact on infrastructure and economic costs and benefits

Source: AECOM, 2010

3.1.1 Justification of economic modelling approach

Social benefits are measured as an aggregation of the willingness to pay of affected individuals. Willingness to pay for a particular adaptation measure reflects the amount that an individual or society is willing to pay for the benefits gained from the adaptation measure. Willingness to pay is typically expressed in monetary units.

Society's willingness to pay to obtain a benefit raises a fundamental theoretical issue regarding the comparability of benefits obtained by different individuals. For example, a wealthy individual may value a benefit of one dollar much less than a poorer person. In the absence of information about individuals' utilities it has been assumed here that benefits are valued equally by all individuals; a common assumption in cost-benefit analysis. Given that the socio-economic characteristics of the population of the Pittwater area are reasonably homogeneous, the assumption is reasonable as well as practical.

In practice, measurement of willingness to pay can be problematic. In market situations, it may be possible to estimate a demand function: this approach is preferred because the demand function (willingness to pay) is based on revealed preference and therefore has clear evidence.

In cases such as adaptation to climate change, revealed preference methods cannot be used because there is insufficient history, but stated preference approaches can be applied. These usually take the form of contingent valuation surveys, or choice experiments, where the interviewer elicits the willingness of the individual to pay for a specific good or service such as a levee bank that will protect the individual's house from flooding. Such surveys may involve an element of hypothesis, but their main disadvantage is the expense of conducting them. Unfortunately, no relevant stated preference surveys were available for the current study.

However, it is often possible to obtain information on willingness to pay indirectly. A typical textbook example is the difference in value between a house that is subject to flooding and a comparable one that is not. In the absence of other factors, the difference in value may be attributed to disbenefit of flooding. Because the disbenefit measure in this way encapsulates not only physical damage costs, but also inconvenience, fear of drowning, loss of personal memorabilia, etc., it reflects willingness to pay more closely than damage costs alone.

Although feasible, this study did not directly estimate willingness to pay to avoid flooding on the basis of differences in house prices. Differences in house prices alone would reflect willingness to pay to avoid all aspects of flooding residences, whereas at least one of the adaptation measures that has been analysed below is focused only on the loss of personal effects. A second reason was that anecdotal information indicated that some Pittwater residents preferred houses that are subject to flooding because the disbenefit of periodic flooding was outweighed by the amenity of proximity to water.

In general, this study has necessarily been constrained to the use of damage costs. However, information is available about insurance premiums that may validly be regarded as reflecting different aspects of willingness to pay to avoid flooding. These have been used where appropriate in assessing the adaptation measures in section 7.0.

3.1.2 Design, build and test economic model

AECOM's model enables assessment of different adaptation strategies by varying the level of adaptation and the year in which the adaptation intervention is introduced. The economic parameters, model inputs and required outputs were identified and then the model was built.

The model was built in Microsoft Excel with the Palisade Decision Tools *@Risk Industrial* add-in. The model can be opened on any PC with Microsoft Excel, however a copy of *@Risk* is required in order to run the model. Microsoft Visual Basic for Applications (VBA) has been used to program and automate certain routines within the model.

Economic parameters

Discounting is a standard method to add and compare costs and benefits that occur at different points in time. The method involves summing across future time periods net costs that have been multiplied by a discount rate. If the discount rate is zero then equivalent costs and benefits are valued equally. The rationale behind discounting is that individuals and businesses attach less weight to a cost or benefit occurring in the future as they do to the same cost or benefit occurring now.

The choice of discount rate for environmental project is often contentious. Standard economic appraisal evaluation handbooks for infrastructure projects recommend a pre-tax real discount rate of between 6–7%. NSW State Government generally uses 7% whereas the Victorian State Government uses 6.5%. Infrastructure Australia uses a discount rate of 7%. Where there is an opportunity cost of capital, e.g. for investment in infrastructure projects, a higher discount rate is appropriate. However, when there are intergenerational issues, particularly those involving environmental impacts, it is often argued that society has a duty of care to future generations to avoid these adverse consequences. The Australian Greenhouse Office recommended applying a low or zero discount rate when considering climate change (Australian Greenhouse Office, 2004).

The discount rate used also depends on the purpose of the evaluation. If the economic appraisal is undertaken to assess whether to undertake a project that is competing with other projects for funding, then a higher discount rate may be more suitable. However, in this case where the analysis is trying to identify whether adaptation measures are worthwhile, a discount rate that represents the compensation required for a risk free investment is more suitable. The opportunity cost of investing in adaptation should not be greater than the Government's long term borrowing rate, on the basis that the Government faces the choice of borrowing and investing, or not. As such, this project proposes a discount rate of 3% based on the long term real, risk free, interest rate in September 2009. This was calculated using the indexed yields on 10 year Commonwealth Government Treasury bonds, averaged over a twenty day period (Reserve Bank of Australia, 2009). Indexed rates averaged over the period 25 August 2009 until 16 September 2009, and rounded to one significant figure.

Other economic parameters that have been used in the model are summarised in Table 4.

Table 4: Economic parameters used in cost-benefit analysis

Parameter	Modelled values	Comments
Appraisal period	90 years (2010 to 2100)	To match climate scenario modelling
Time steps	Annual	Only extreme weather events are being modelled, and multiple events in one year have very low probabilities. Also, multiple simulations have been run to model frequencies.
Discount rate (pre tax, real)	3%	Refer to discussion above
Discount year	2010	To match the year that study commences
Base pricing year	2010	To match the year that study commences
Inflation of costs		Costs are based on information from ERM Mitchell McCotter (1992). These have been inflated to 2009 prices using the NSW General Construction Index (GCI) series, which started in 1998. The relationship between CPI and GCI between 1998 and 2009 has been used to estimate the GCI back to 1992 based on CPI. GCI index (ABS, 2006) and CPI (ABS, 2009).

Monte Carlo simulation

@Risk enables Monte Carlo simulation to be undertaken. Monte Carlo simulation performs risk analysis by building models of possible results by substituting a range of values for any of the factors in a model that has inherent uncertainty. It then calculates results over and over, each time using a different set of random values from the probability functions. Depending upon the number of uncertainties and the ranges specified for them, a Monte Carlo simulation could involve thousands or tens of thousands of recalculations before it is complete. Monte Carlo simulation produces a distribution of possible outcomes.

In this model, rainfall level, storm surge and wave setup heights were randomly sampled for each year between 2010 and 2100, and the present value of costs with and without adaptation calculated and recorded. The models were run for 1000 iterations and a distribution of all the recorded results was then created, upon which statistical analysis has been undertaken (to determine the mean, maximum, minimum, standard deviation and 95th percentile of all the recorded results). Based on current best practice modelling of lagoon flooding, the entrance of the Narrabeen lagoon was assumed open for each iteration.

Optimisation and identification of real options

@Risk Industrial also includes a *RiskOptimizer*, which has been used to identify real options in the analysis (i.e. the optimal heights or widths and timings for each of the proposed measures). During an optimisation, *RiskOptimizer* generates a number of trial solutions (heights, widths, timings) and uses genetic algorithms to continually improve results of each trial. For each trial solution, a Monte Carlo simulation is run, sampling rainfall level, storm surge and wave setup heights and generating a new set of costs, from which the mean present value cost (PVC) of adaptation is calculated. The process is repeated until such point that no better trial solutions can be found which result in a lower mean PVC.

Model process

The main model engine undertakes an analysis of each climate change scenario and each adaptation option using the following process, shown in Figure 6.

For each time step in the appraisal period, the model:

1) Randomly generates a weather event for the current time period using Monte Carlo simulation to sample from the appropriate probability function for that time period.
2) Determines the impact on infrastructure due to the generated weather event (with and without adaptation options).
3) Determines the cost of the infrastructure impact (with and without adaptation options).

Once the impacts and costs are generated for each weather event, the model:

1) Discounts event impact costs for each year of appraisal.
2) Discounts adaptation capital costs.
3) Sums all discounted costs across the entire appraisal period and records result.

The process is then repeated using different inputs sampled from the Monte Carlo simulation inputs.

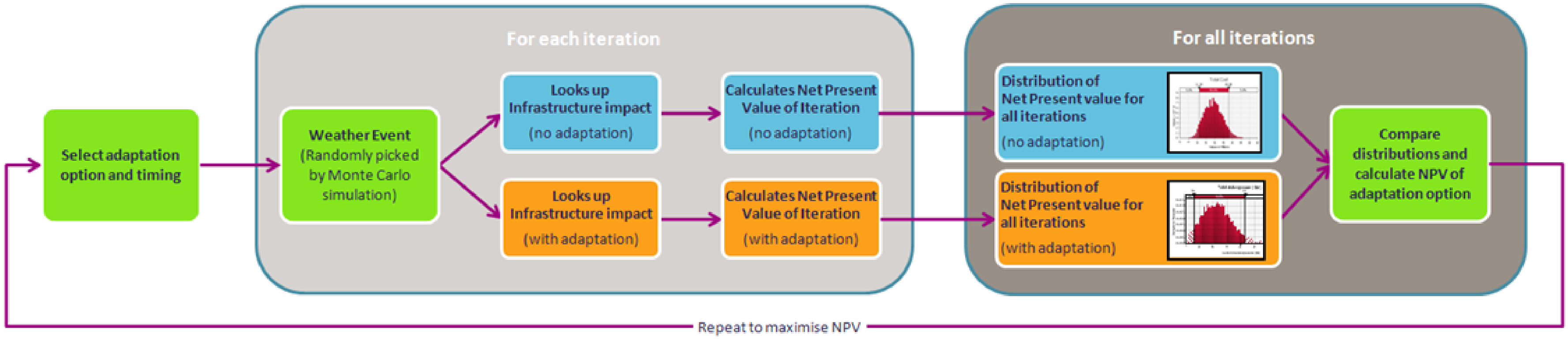


Figure 6: Model Process

3.2 Climate change projected flooding

Projections on the change in key climate variables, extreme rainfall, storm surge, wave setup and sea level rise, were established based on set emission scenarios, data provided by CSIRO, and current publications. The correlation between the climate variables and flooding events was based on an understanding of the climate variables that coincide with flooding. To model the probability and extent of projected flooding, the correlation between climate variables for flooding events and the probability distribution curves for each climate variable was established.

Probability distributions

Weather event probability distribution curves were established with and without climate change, as illustrated in Figure 7 and Figure 8 respectively. For ease of understanding, the vertical axis curves shows probability of exceedance, that is, the probability of the severity of an event. For example, there is a higher probability of exceedance for a moderate weather event (see point A on Figure 1.2) than for an extreme weather event (See point B in Figure 7).

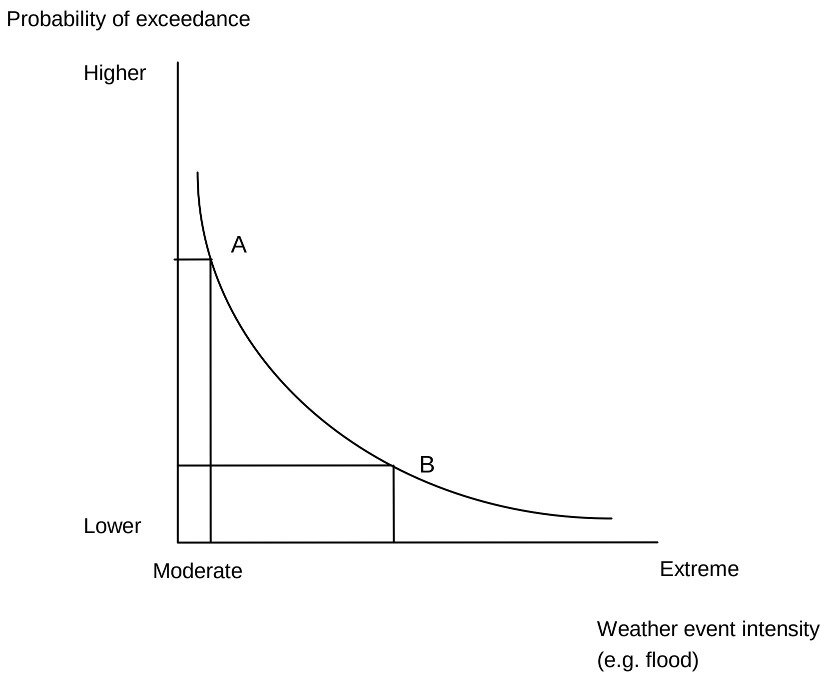


Figure 7: Weather event probability distribution curve (no climate change)

Note: illustrative only

The second step involved identifying the climate change impacts on weather. Due to the uncertainty surrounding climate change, scientists have developed a number of climate models, which are Ocean-Atmosphere coupled General Circulation Models (OAOAGCM), of what could happen under climate change for particular emission scenarios and selected climate variables. This allows for the uncertainty of climate change to be captured in the model and allow for the assessment of real option values. However, more climate models make the modelling more complex, so a balance must be struck between the number of models and breadth of uncertainty. As such, 10 OAOAGCMS for extreme rainfall have been modelled for this study, which are understood to be equally likely, enabling calculation of an expected net present value.

A (parametric) weather event probability distribution curve has been developed for each climate change variable. Assumptions have been made that the parametric forms of the curves will not change under climate change, although the shape may change. Figure 8 illustrates what these distributions look like under a nominal climate scenario and how the probability of exceedance of the same weather event (point A on the figure) changes.

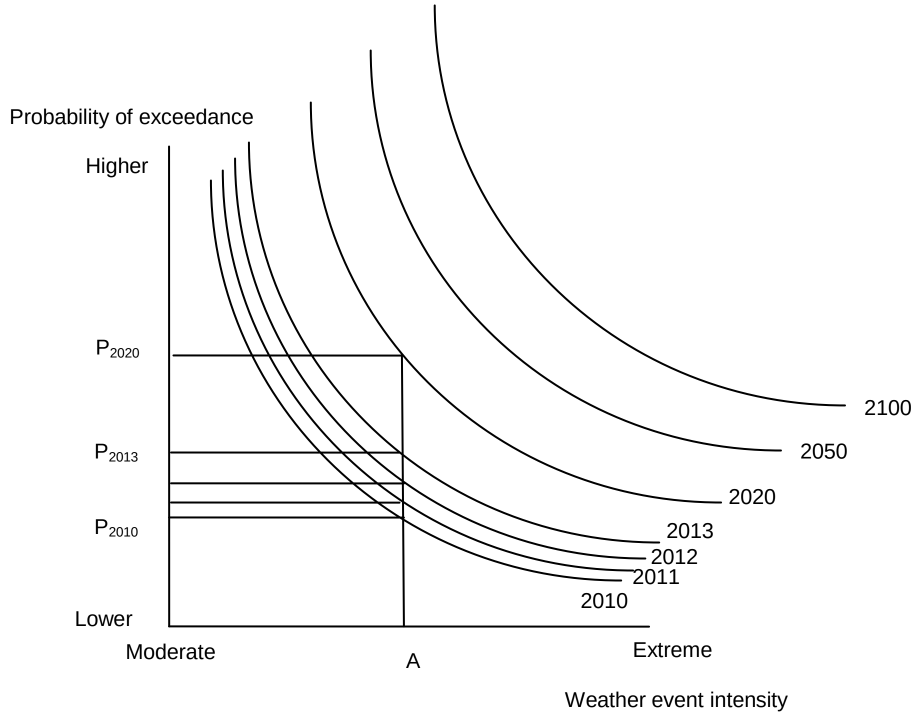


Figure 8: Weather event probability distribution curves with climate change

Note: illustrative only. In general the shape of the extreme value curve will change rather than just shift. Also, under some climate scenarios, extreme events may become less likely rather than more likely.

In summary, there are two steps in determining the weather event model inputs

- Weather event probability distributions without climate change
- Weather event probability distributions with climate change under different climate models (OAGCMS)

3.3 Determine the flood cost relationship

The economic costs of a range of flooding impacts around Narrabeen Lagoon were identified and the costs curves developed as model inputs. The economic costs of flooding impacts around the Narrabeen Lagoon catchment have been categorised as damage, disruption and health costs. Where possible costs have been taken from published sources, such as a study undertaken by ERM Mitchell McCotter (1992). The cost and benefits have been estimated for a number of sub-areas that have been defined by ERM Mitchell McCotter (1992).

The direct costs for each infrastructure type have been extracted from published data and added together to determine the flood damage curves for residential, commercial and infrastructure assets for particular flood heights. AECOM has also modelled indirect flood damage, which includes labour hours for cleaning up and costs relating to travel disruption requiring people to cancel or find alternative routes.

The next step involved establishing the relationship between a weather event occurring and the impact to infrastructure (see Figure 9), covering both damage to infrastructure and duration of loss of service, where applicable. This was done using historic data, past climate damage and industry guidelines.

The relationship between impact on infrastructure and weather event intensity will depend on a number of factors including the age of the infrastructure, the level of exposure and the design standards to which it was built (see Figure 9).

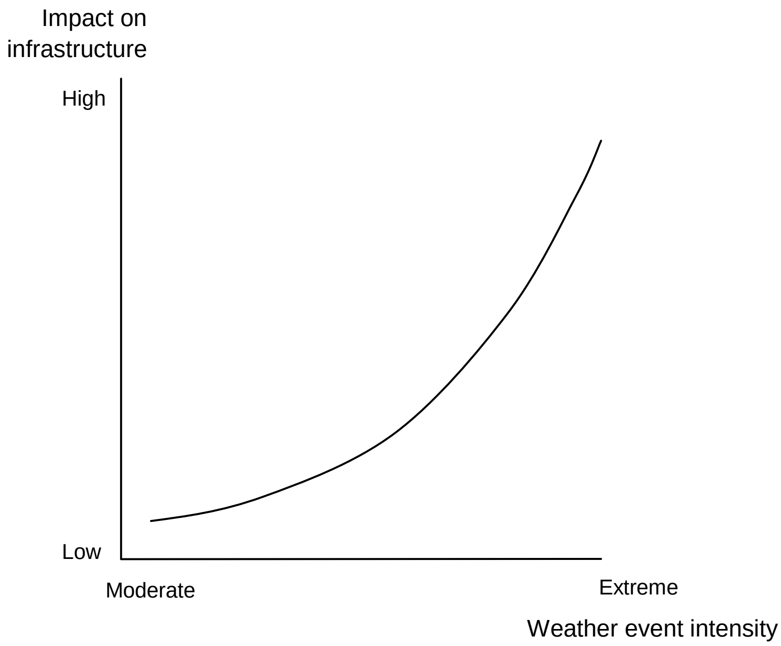


Figure 9: Weather event versus infrastructure impact curve

Note: illustrative only

3.4 Preliminary modelling of the base case to determine cost impacts

This step involved determining the relationship between the impact on infrastructure and the economic costs and benefits without adaptation. As with any economic analysis, it is important to document the base case against which the adaptation has been compared. The base case assumed no changes in population because the affected region is fully developed.

The economic costs from flooding have been split into three types:

- Damage to infrastructure: This comprises the cost to repair infrastructure, for example the cost of repairing damage to roads.
- Loss of infrastructure service: For example, closure of the road. The value of loss of service may vary by time such as closures in the peak period cost more than closures in off peak. The loss of service cost will depend on a number of factors including the duration of the impact, the location and availability of alternative infrastructure and frequency of use.
- Flow on economic and social impacts: For example, the road closure significantly reduces access to business and community amenities.

The damage to infrastructure cost has been estimated based on standard engineering costs. The cost of infrastructure loss and flow-on economic and social impacts have also been measured, where possible, using estimates of the price people are prepared to pay to avoid the impacts of flooding.

The relationship between duration of impact and the cost in terms of loss of service and the flow on economic and social impacts is represented in Figure 10 and Figure 11.

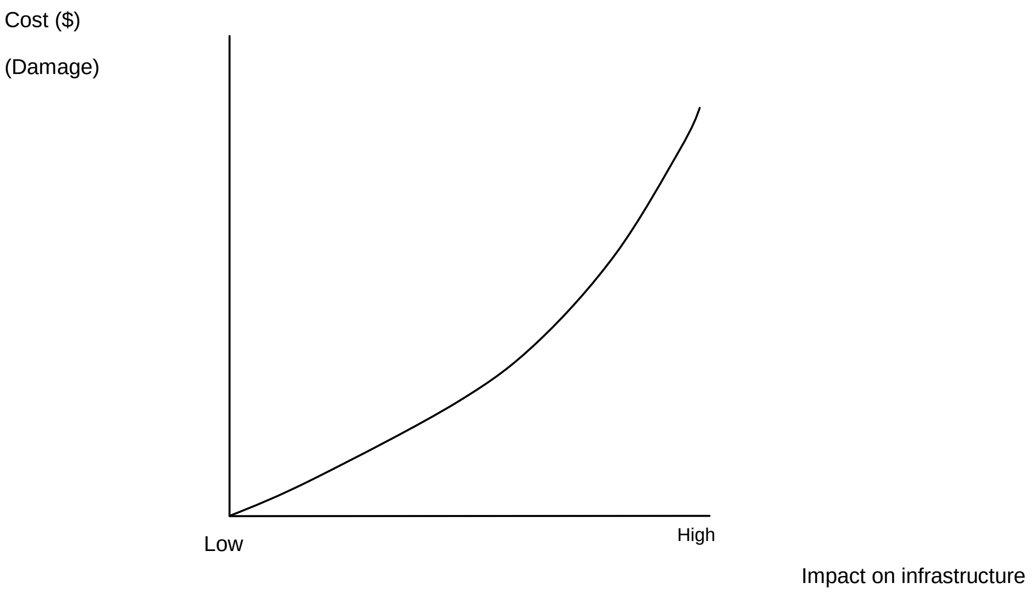


Figure 10: Infrastructure impact versus damage cost curve

Note: illustrative only

Figure 11: Loss of service cost curve

Note: illustrative only

3.5 Identify, prioritise and cost the preferred adaptation strategies

Adaptation strategies are characterised by their scale, cost and timing. AECOM's modelling incorporated an optimisation process to seek combinations of adaptation solutions that increased the net benefit of adaptation. However, as with most optimisation modelling, there is not complete certainty that the identified combination maximises benefits across the entire range of strategies.

A range of adaptation solutions, from an engineering perspective to non-technical solutions, such as changes in zoning or planning laws, have been considered where appropriate. A key part of identifying the preferred adaptation combination has been achieved by considering where the biggest economic impacts occur, as identified in Section 3.4.

A workshop was held with Pittwater Council, the Department of Climate Change and AECOM's adaptation experts to identify and prioritise adaptation options for Narrabeen Lagoon.

3.5.1 Identifying economic costs and benefits of adaptation solutions

The costs of adaptation options were then identified. This involved:

- Determining the cost for each adaptation solution (capital and operating), and
- Identifying how the adaptation option will affect the impact of the weather event on infrastructure and the resulting economic benefits.

The economic costs and benefits for each adaptation solutions were calculated based on the capital and operating expenditure. The benefits included:

- Reduction in damage to infrastructure;
- Reduction in loss of infrastructure service;
- Inferred consumer welfare, estimated as willingness to pay to avoid impacts.

3.6 Run the economic model to optimise adaptation solutions

A series of simulations of the economic model were run with all model inputs to determine the optimal adaptation options. Optimisation was employed to determine the preferred set of adaptation solutions by comparing the net benefits under different combinations.

AECOM extended its probabilistic modelling to seek combinations that **maximise** the net benefits of combined adaptation by:

- using the optimisation feature of @*Risk* modelling environment to seek to maximise expected net present value of benefits; and
- searching through the 12 dimensional space of possible adaptation scope and timing to search for combinations with higher benefits.

The maximising model was used to analyse different combinations of adaptation measures and to search for portfolios with higher benefits. It must be understood that the modelling may not have settled on the portfolio that completely maximises net benefit, due to the limitations of the modelling.

The model has an iteration loop to identify better adaptation solutions (in terms of combination of options, scale of each and timing) that improve the net present value. Some of the adaptation options were designed to reduce the impact on infrastructure due to a particular weather event, while others reduced the cost (or increase in the benefits from adaptation) associated with a particular infrastructure impact, and some performed both functions. The framework of the model enabled the maxima or minima of the 'objective' function, to be identified and the maximum net benefit of adaptation to be identified compared to a base case of no adaptation. Refer to section 3.1.2 for further information on the model.

Timing is a key issue to optimising value –to delay the expensive capital cost of implementing adaptation solutions until it is essential. The risk of flooding may not become a significant issue for twenty years. A levee of specified height may be sufficient for the current flood risk but after twenty years it may no longer be an effective adaptation measure. In this case, the optimal strategy may be to implement a levy immediately and raise houses after twenty years.

Box 2: Combining strategies

For example, the cost of raising properties will vary with the scale (height) that the properties are raised. Assume for illustrative purposes that the cost of raising properties consists of a high upfront capital cost. In this case, implementing this strategy is likely to result in higher net benefits the sooner the strategy is implemented because the relatively high cost requires a longer time period over which to accrue the benefits. Consider then a second strategy of a levee to protect properties. As with property raising, the levee also serves to protect houses from flood damage.

Weather event versus infrastructure impact curve

Figure 12 illustrates adaptation solutions that are designed to reduce the impact associated with a weather event. The same event causes a lower impact on infrastructure with adaptation. Examples of this include building levees so that fewer houses are affected or damaged by inundation.

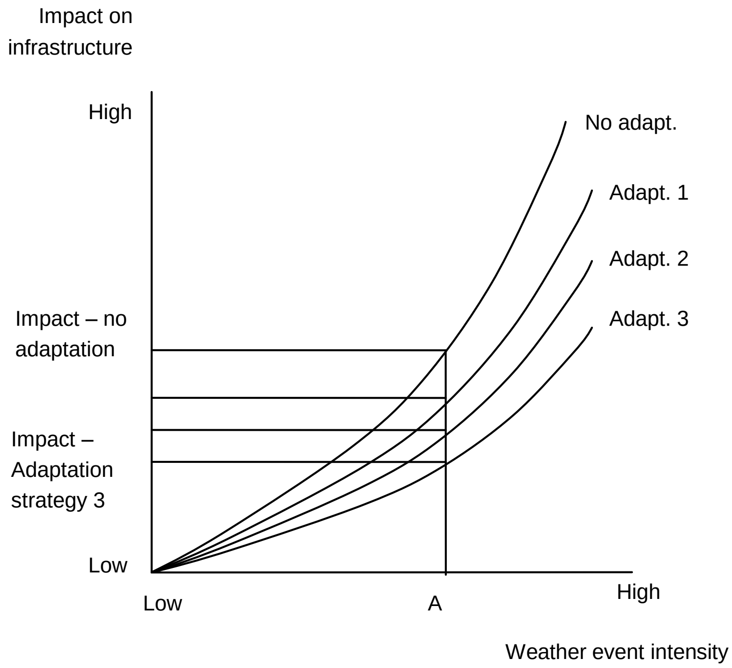


Figure 12: Weather event versus infrastructure impact curve

Note: illustrative only

Figure 13 illustrates adaptation solutions designed to reduce the economic costs associated with a particular infrastructure impact. The same impact on infrastructure causes less damage with adaptation. An example of this is building a new road so that when the vulnerable road floods there is an alternative route and less people are affected.

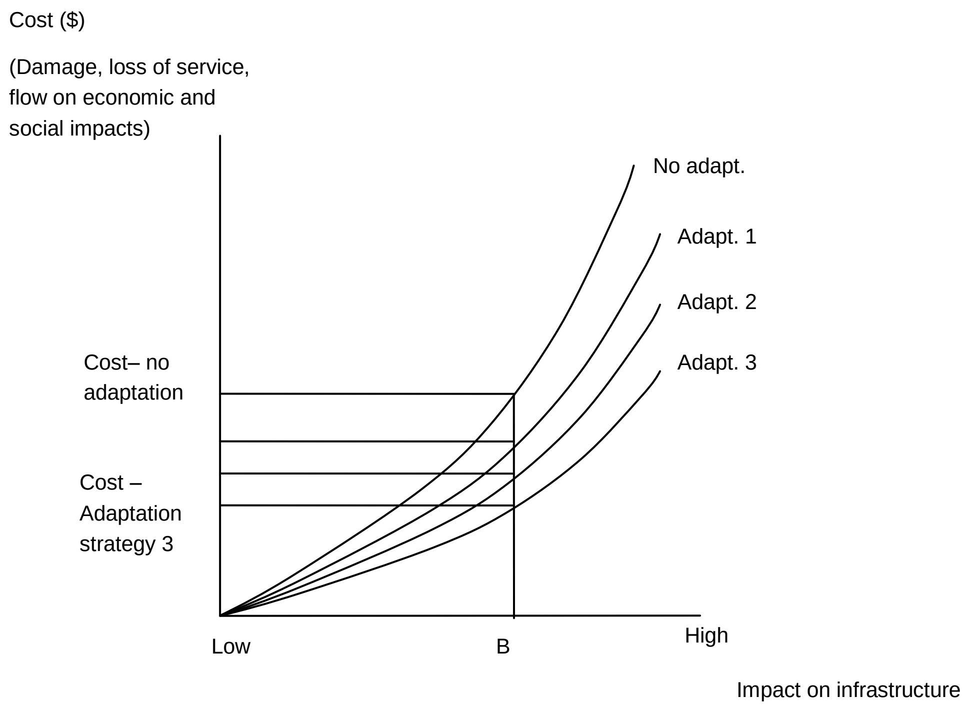


Figure 13: Weather event versus infrastructure impact curve

Note: illustrative only

Model outputs

The model produced distributions of results (total discounted costs over the appraisal period) with and without adaptation. Model outputs included:

- Distribution of present value of costs with/without adaptation under modelled climate change scenarios, and
- Distribution of net present value of adaptation benefits (present value of benefits with adaptation minus present value of benefits without adaptation).

3.7 Analyse and communicate findings

The economic modelling results for each adaptation measure were analysed to determine a preferred combination of adaptation options for Narrabeen Lagoon, with the objective of improving the expected (mean) net present value of adaptation. The probability distribution of the modelling results was analysed to determine the minimum cost, maximum cost, at the 90% confidence interval, and the mean and standard deviation. The result of the preferred adaptation strategy was compared to full adaptation now to assess the real option value in adapting later rather than now.

4.0 Climate Change Influencing Flooding

The increase in atmospheric concentrations of greenhouse gas emissions is projected to change the nature of climate variables. The key climate variables that will affect the extent and risk of flooding at Narrabeen Lagoon are rainfall intensity, wave climate, storm surge and sea level rise, as set out in Section 2.3. A schematic diagram representing the way these climate variables will impact rainfall runoff and the lagoon entrance conditions leading to flooding in Narrabeen Lagoon is shown in Figure 14.

Secondary effects of changes to climate variables may also have significant effects on the flooding characteristics of Narrabeen Lagoon. In the first instance, the tidal hydraulics of the Lagoon are controlled, *inter alia*, by a shallow rock shelf at the ocean entrance. Located at around mid-tide level, this shelf constricts the ebb tide discharge of the Lagoon, which in turn constricts the tidal prism. A sea level rise of around 1 m would reduce this constriction significantly, increasing the tidal discharge of the Lagoon. Further, the higher levels of the high tide planes may also result in increasing the tidal prism further. These changes to tidal estuaries have the potential to trip ICOLLs into unstable scouring modes (Nielsen & Gordon, 2008). This could lead to further increases in tidal range and high water levels in the Lagoon.

Another secondary effect has the potential for even greater changes to the flooding characteristics of the Lagoon. A sea level rise of 1 m has the potential to cause significant erosion of the entire Collaroy-Narrabeen Beach, causing recession of the unconsolidated foreshores. Without revetment protection, the entire sand spit at the ocean entrance is likely to be eroded, causing the loss of Birdwood Park and allowing the Lake to enter the ocean at the Ocean Street Bridge. This could reduce greatly the impedance to tidal flow, which would have a significant impact on the tidal hydraulics of the Lagoon. The increased tidal prism would be reflected in higher tidal planes, which would result in increased flooding around the foreshores of the Lagoon.

It is beyond the scope of this study to predict or model these secondary effects.

Future flood heights have been estimated based on projected:

- Elevated ocean water levels, which have been determined by adding sea level rise projections based on the climate change scenario, A1FI (DECC 2009) to storm surge and wave setup values derived from existing data and projected changes (McInnes 2007); and
- Extreme rainfall intensity which has been determined by multiplying current extreme rainfall values by the projected percentage change in extreme rainfall values based on 10 climate models (scenario A2), refer to Table 4.

An overview on climate change scenarios (refer to Box 3) and the potential changes in extreme rainfall, sea level rise, wave climate and storm surge follow.

Box 3: Emission Scenarios

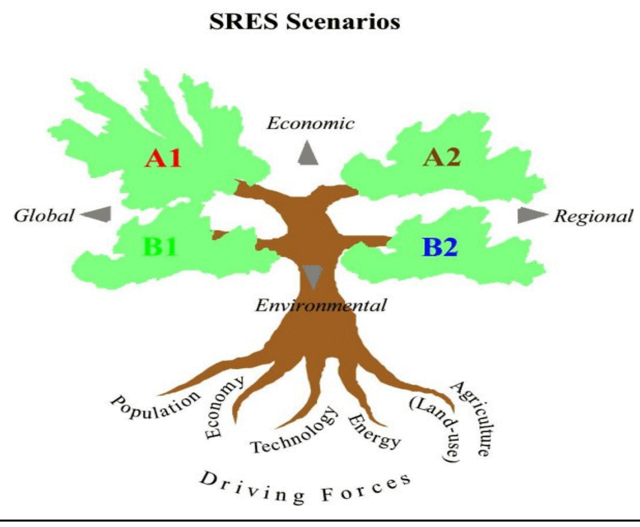
Emission scenarios are estimations of the future quantity of greenhouse gases that may be released into the atmosphere. They are based on assumptions about future demographic evolution, and the implementation and efficiency of energy policies. The scenarios are just assumptions and they are a primary source of uncertainties and are usually grouped into families.

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

The IPCC emission scenarios are divided into four families (A1, A2, B1 and B2). A description of each scenario is given in Table 5.

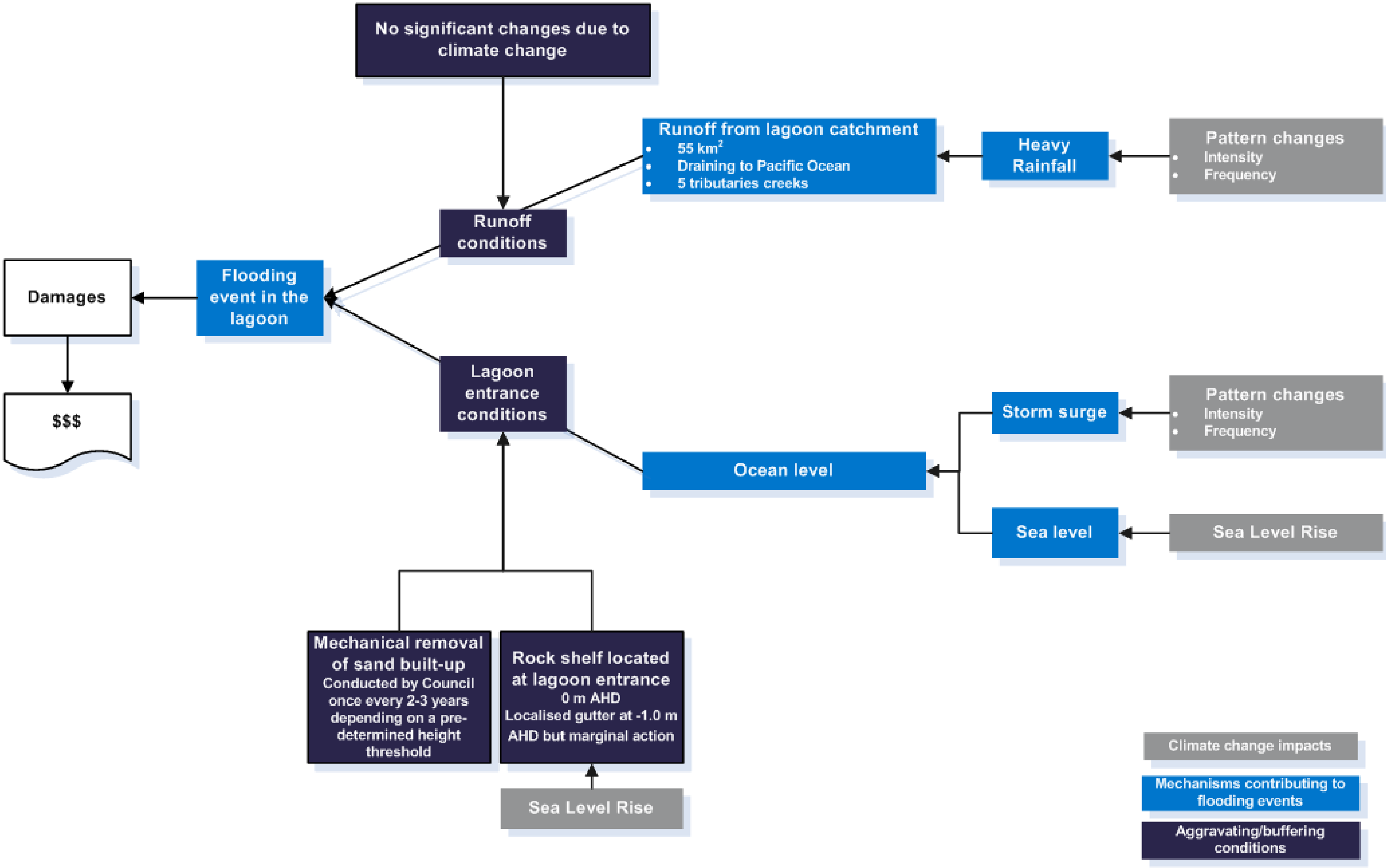
Table 5 – SRES Scenarios

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



Source: IPCC, 2000

Figure 14: Schematic diagram of the climate variables causing floods to occur in the Narrabeen Lagoon



4.1 Extreme rainfall

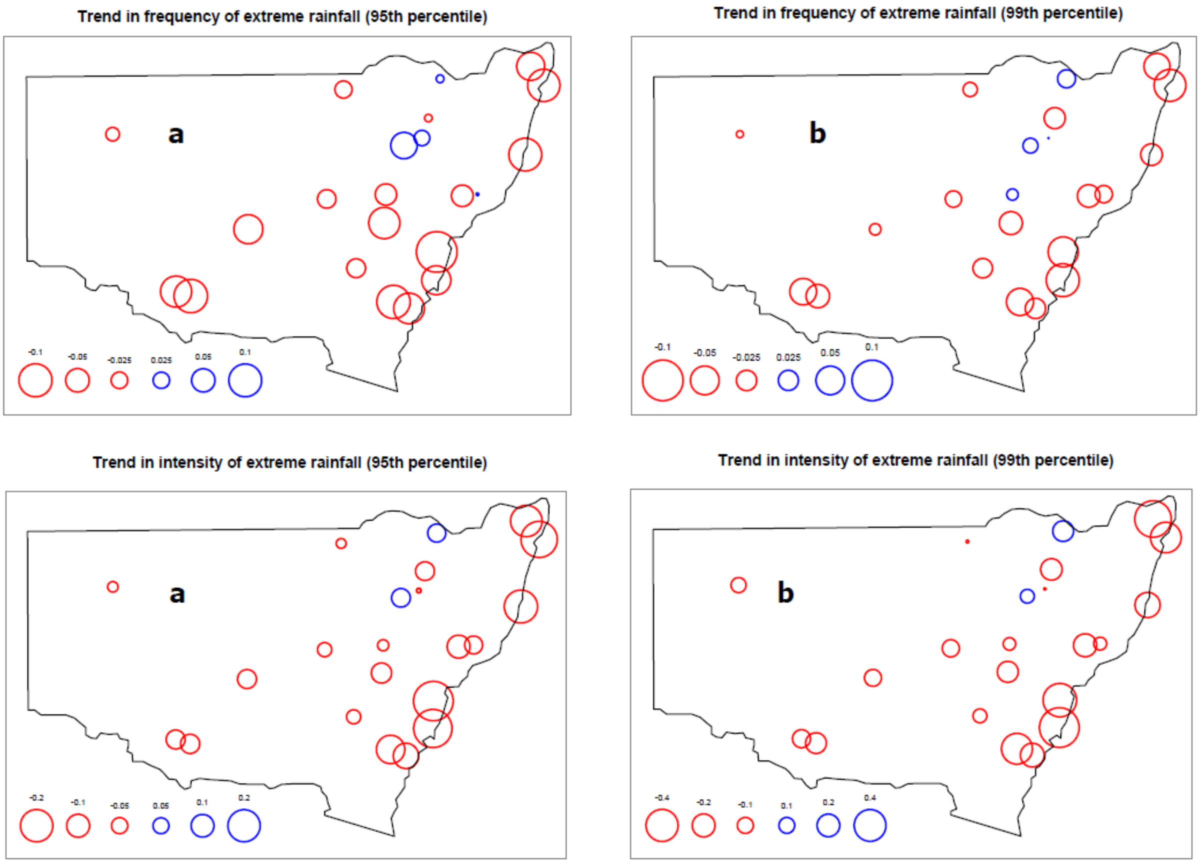
Extreme rainfall observation in NSW

Extreme daily rainfall observations from high quality stations in New South Wales have been analysed by CSIRO (2004) in terms of frequency (number of daily totals above the 1961-1990 mean 95th and 99th percentile levels) and intensity (average of daily totals above or equal to the 95th and 99th percentile levels). Both frequency and intensity of extreme rainfall events exhibit decreasing trends.

These trends are consistent with the mean precipitation decrease observed over NSW since 1950. These decreasing trends have been found to be stronger at coastal locations including in the vicinity of Pittwater.

In contracts to observation of the past 50 years, climate change models used to project future extreme rainfall suggests that the intensity of events will increase in the future.

Table 6: Trends in annual frequency (days/year) of extreme daily rainfall and intensity (mm/year) of extreme rainfall from 1950-2003.



Source: CSIRO, 2004

Extreme rainfall projections in the Pittwater region, NSW

CSIRO provided projections of future heavy rainfall events generated by ten Ocean-Atmosphere coupled General Circulation Models (OAGCM) for a grid of 1 degree by 1 degree around the latitude-longitude point of Pittwater, as defined by Geoscience Australia as 33.5485°S 151.3512°E. The A2 emissions scenario was used in this modelling as presently it is the only emission scenario available for the extreme rainfall variable. The characteristics of the OAGCM are provided in Table 7.

Table 7: OAGCM model used in this study

Model	Name in tables	Current	Mid-century	Late-century
CNRM-CM3	CNRM3	1961-2000	2046-2065	2081-2100
CSIRO-Mk3.0	MK3.0	1961-2000	2046-2065	2081-2100
CSIRO-Mk3.5	MK3.5	1961-2000	2046-2065	2081-2100
GFDL-CM2.0	CM2.0	1961-2000	2046-2065	2081-2100
GFDL-CM2.1	CM2.1	1961-2000	2046-2065	2081-2100
MIROC3.2 (medres)	MIROCm	1961-2000	2046-2065	2081-2100
MIUB Echo G	Echo-G	1961-2000	2046-2065	2081-2100
MPI ECHAM5	ECHAM5	1961-2000	2046-2065	2081-2100
MRI CGCM 2.3.2A	CGCM	1961-2000	2046-2065	2081-2100
NCAR CCSM3 (x2 runs)	CCSM3	1960-1999	2050-2069	2080-2099

Source: provided by CSIRO, 2009

These ten OAGCMs have been selected by CSIRO out of a group of 23 available models as they are the models that most accurately represent projected rainfall and heavy rainfall patterns over this region of Australia. For more information on the models technical specifications and scoring, please see *Climate Change in Australia, Technical Report 2007* (CSIRO, 2007, p. 40).

The projected changes in rainfall were subsequently estimated for the ten equally probable climate change models provided by the CSIRO. Projections are provided as a percentage change in rainfall compared to current value (1961-2000) for 1 day duration and 3 day duration events and for the following return period: 1 in 5 years; 1 in 10 years; 1 in 20 years and 1 in 40 years. Projected changes are provided over two periods, (2046-2065) and (2081-2100) for floods with a 1 in 40 year recurrence interval or less. The results of rainfall projections in the Pittwater area are provided in Table 8 and Table 9. Results show significant differences exist in the direction and magnitude of projected rainfall changes, a result of the uncertainty associated with rainfall projections. The results have not been averaged to avoid masking the wide range of increasing and decreasing rainfall trends. Rather, the implied uncertainty has been carried through to the economic modelling.

Table 8: Heavy rainfall projections as a percentage change for 1 day duration events

2055 (2046-2065)										
RP	**CNRM 3**	**Echo-G**	**CGCM**	**MK3.0**	**MK3.5**	**CM2.0**	**CM2.1**	**MIROC m**	**ECHA M5**	**CCSM 3 (1)**	**CCSM 3 (3)**
5	12.2	8.6	-8.3	4.5	-6.2	-6.8	1.0	17.6	4.1	1.3	-6.7
10	15.9	7.9	-7.3	3.9	-5.0	-9.7	3.2	13.2	4.5	-1.6	-7.4
20	16.2	9.5	-4.1	2.6	-3.5	-13.0	7.8	7.1	1.9	-5.6	-8.8
40	14.7	11.9	-0.4	1.6	-2.3	-15.2	12.1	2.7	-1.0	-8.6	-9.9
2090 (2081-2100)											
RP	**CNRM 3**	**Echo-G**	**CGCM**	**MK3.0**	**MK3.5**	**CM2.0**	**CM2.1**	**MIROC m**	**ECHA M5**	**CCSM 3 (1)**	**CCSM 3 (3)**
5	0.3	20.1	10.5	10.2	1.1	-6.5	-0.1	27.9	8.5	-4.2	6.1
10	9.0	20.4	9.7	10.4	0.2	-5.4	2.4	26.3	16.6	-4.0	9.3
20	21.9	21.5	9.0	12.5	-1.3	-3.4	12.9	25.0	25.0	-1.7	15.0
40	32.9	22.5	9.0	15.2	-2.5	-1.8	25.8	24.4	30.5	1.4	20.3

Table 9: Heavy rainfall projections as a percentage change for 3 day duration events

2055 (2046-2065)											
RP	**CNRM 3**	**Echo-G**	**CGCM**	**MK3.0**	**MK3.5**	**CM2.0**	**CM2.1**	**MIROC m**	**ECHA M5**	**CCSM 3 (1)**	**CCSM 3 (3)**
5	2.6	11.7	-8.2	0.1	-1.9	-4.7	2.3	10.8	2.9	5.5	-9.2
10	6.1	11.5	-3.9	0.1	-2.5	-7.8	4.0	6.6	1.5	5.7	-10.5
20	9.8	15.2	6.4	0.2	-4.2	-10.9	4.6	0.6	-3.3	5.6	-11.2
40	12.2	20.3	18.2	0.5	-5.9	-12.8	4.4	-4.0	-7.6	5.6	-11.2
2090 (2081-2100)											
RP	**CNRM 3**	**Echo-G**	**CGCM**	**MK3.0**	**MK3.5**	**CM2.0**	**CM2.1**	**MIROC m**	**ECHA M5**	**CCSM 3 (1)**	**CCSM 3 (3)**
5	-7.9	31.0	7.5	9.8	-1.2	3.0	-2.2	26.5	5.6	2.1	2.6
10	-4.2	32.7	8.8	11.6	-3.5	4.3	0.2	27.0	14.7	0.9	4.8
20	2.5	35.3	12.5	15.2	-7.2	5.7	6.6	27.3	24.8	-2.5	10.5
40	8.8	37.3	16.3	18.6	-10.1	6.5	13.2	27.5	31.6	-5.8	16.4

Source: provided by CSIRO, 2009

Note: RP denotes return periods

Further data manipulation was undertaken to estimate finer rainfall changes. For the purposes of interpolation, it has been assumed that 2055 is the reference year for the first set of rainfall change predictions whilst 2090 has been nominated as the reference year for the second set of rainfall changes. For the years between 2009, 2055 and 2090, linear interpolation of the projected percentage changes in rainfall was undertaken to estimate the change in rainfall relative to 2009. It was also necessary to project a 1 in 100 year rainfall change for each of the 10 model runs as this probability point is used to calculate probability distributions of flood events and was not available in the data set provided by CSIRO. Projected changes in rainfall were then used to estimate parameters for each climate change scenario, year and area. The analysis is described in section 5.0 and the results of rainfall projections are provided in Table 10.

Table 10: Changes in Rainfall by Period by Climate Change Scenario

Current Relative Probability of Flood (Years)	Probability	CNRM3	Echo-G	CGCM	MK3.0	MK3.5	CM2.0	CM2.1	MIROCm	ECHAM5	CCSM3 (1)	CCSM3 (3)
2046-2065 (mid point 2055)												
5	20.0%	12.2	8.6	-8.3	4.5	-6.2	-6.8	1.0	17.6	4.1	1.3	-6.7
10	10.0%	15.9	7.9	-7.3	3.9	-5.0	-9.7	3.2	13.2	4.5	-1.6	-7.4
20	5.0 %	16.2	9.5	-4.1	2.6	-3.5	-13.0	7.8	7.1	1.9	-5.6	-8.8
40	2.5 %	14.7	11.9	-0.4	1.6	-2.3	-15.2	12.1	2.7	-1.0	-8.6	-9.9
100	1.0 %	14.3	12.9	1.3	1.0	-1.6	-16.6	14.4	-0.1	-2.5	-10.4	-10.6
2081-2100 (mid point 2090)												
5	20.0%	0.3	20.1	10.5	10.2	1.1	-6.5	-0.1	27.9	8.5	-4.2	6.1
10	10.0%	9.0	20.4	9.7	10.4	0.2	-5.4	2.4	26.3	16.6	-4.0	9.3
20	5.0 %	21.9	21.5	9.0	12.5	-1.3	-3.4	12.9	25.0	25.0	-1.7	15.0
40	2.5 %	32.9	22.5	9.0	15.2	-2.5	-1.8	25.8	24.4	30.5	1.4	20.3
100	1.0 %	39.0	23.1	8.8	16.4	-3.2	-0.8	31.6	23.9	34.0	2.7	23.1

Source: CSIRO, 2009

4.2 Sea level rise (SLR)

Observed SLR in New South Wales

Since 1991, the Australian Baseline Sea Level Monitoring Project (ABSLMP) managed by the National Tidal Centre (NTC) of the Bureau of Meteorology (BoM) (National Tidal Centre, 2009) has been monitoring sea level rise at 14 points of the Australian coast line, 12 stations in mainland Australia, one in Tasmania and one in Cocos (Keeling) Islands. From the ABSLMP the sea level monitoring station closest to Pittwater is located in Port Kembla (NSW).

From the observations at the Port Kembla monitoring station, there is a SLR trend of +1.9mm per year since 1991. This value has been corrected to take into account the effects of local inverse barometric pressure and vertical movement of the observation platform. As highlighted in *The Australian Baseline Sea Level Monitoring Project, Annual Sea Level Data Summary Report July 2008-June 2009* (National Tidal Centre, 2009), the length of the date series is relatively short from a climate perspective; however it demonstrates a clear trend of sea level rise in the region which is consistent with satellite altimetry observation.

A map of the net relative trend in sea level rise for the Australian coastline from the ABSLMP in mm per year, less the effects of the vertical movement of the platform and the inverse barometric pressure, is provided in Figure 15.

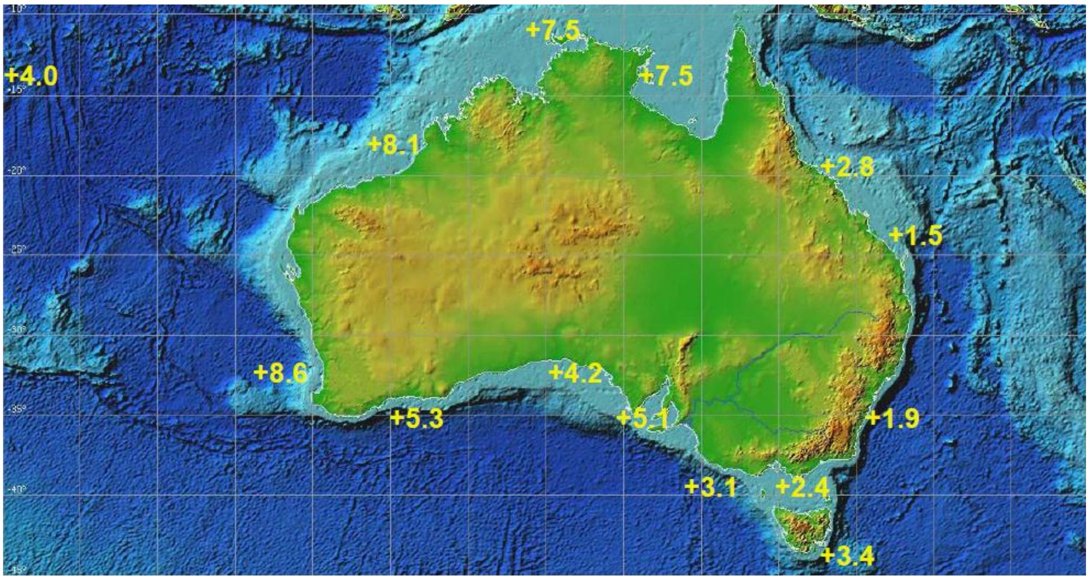


Figure 15: Net relative sea level rise for the Australian coastline less effects (mm/year)

Source: National Tidal Centre, 2009

SLR Projections in New South Wales

Sea levels are projected to increase under climate change, to 0.4 m by 2050 and 0.9 m by 2100. Under the A1FI scenario they are not treated as stochastic variables. These SLR values are the results of global multi-model mean run (when the global models are run together and averaged) and integrate accelerated ice melt and local variation along the NSW coast. They have been sourced from the recently released NSW Sea Level Rise Policy Statement (NSW Government, 2009) and the Derivation of the NSW Government's sea level rise planning benchmarks Technical Note (Dept. of Environment Climate Change, 2009). Comparisons of observed and projected CO_2 emissions have shown that CO_2 emissions have been higher than the highest projected IPCC emission scenario; the A1FI scenario. Therefore the A1FI scenario has been chosen by the NSW DECC for their technical note on sea level rise. A summary of the sea level rise projections for NSW is provided in Table 11, rounding was adopted as the projections have a degree of uncertainty, and adopting values to the nearest centimetre would imply a high degree of accuracy in the projections.

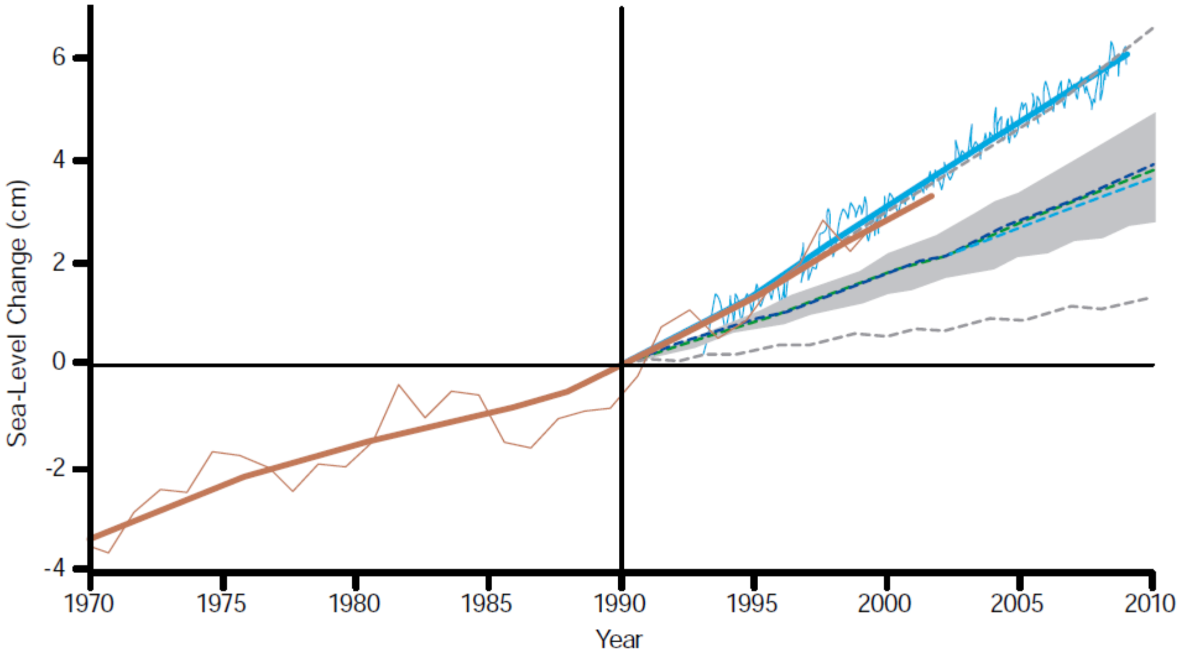
Table 11: Sea level rise projection for NSW

Component	Year 2050 (A1F1)	Year 2100 (A1F1)
Sea level rise	30 cm	59 cm
Accelerated ice melt	(included in above value)	20 cm
Regional sea level rise variation	10 cm	14 cm
Rounding	0	-3 cm
Total	+ 40 cm	+ 90 cm

Source: NSW Government, 2009 and Department of Environment and Climate Change, 2009

While larger values of sea level rise cannot be excluded (notably if the behaviour of large polar ice sheets in Greenland and Antarctica are taken into account), the A1FI scenario of a 0.9 m sea level rise by 2100 has been used for the purpose of this study. The "High End" scenario considers the possible high-end risk identified in the IPCC Fourth Assessment Report (AR4) and includes some new evidence on icesheet dynamics published since 2006 and after AR4. This value, of a 1.1 m sea level rise by 2100, was first proposed in the Netherlands Delta Committee, has been agreed by CSIRO and was selected by DCC as the value used in the Climate Change Risks to Australia's Coast released in November 2009.

Comparisons between SLR observations and projections are showing that current SLR values are tracking well above the upper limit of the IPCC SLR projections (see Figure 18).



The envelope of IPCC projections are shown for comparison. (Source: After Rahmstorf et al. 2007, based on data from Cazenave and Narem (2004); Cazenave (2006) and A. Cazenave for 2006–2008 data)

Figure 16: Sea level change from 1970 to 2008, Source: DCC 2009a

There is a discrepancy between recent observations which suggests a 1.1 m sea level rise by 2100 (DCC, 2009a) and the NSW government sea level rise policy statement which refers to a 0.9 m sea level rise by 2100 (NSW, 2009). For the purpose of this study a value of 0.9 m has been used with an assumed linear increase in sea level rise overtime, meaning the values have not been treated as stochastic variables.

4.3 Elevated ocean water levels

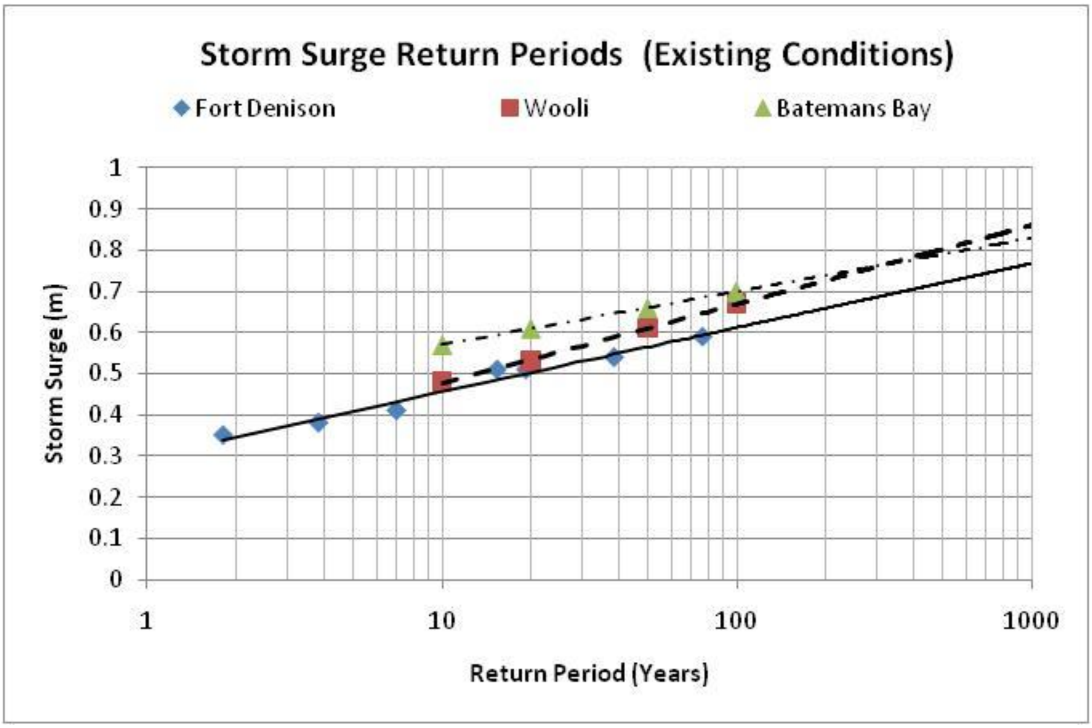
4.3.1 Introduction

Elevated ocean water levels will be coincident with flooding at the ocean entrance to Narrabeen Lagoon. The components that lead to elevated ocean water levels at the ocean entrance to Narrabeen Lagoon include storm surge (barometric setup and wind setup) and wave setup, the latter resulting from the shallowness of the ocean entrance. The duration of storm surge during extreme events, typically, is several days, thereby ensuring occurrence with high tides. However, as the degree of wave setup is directly dependent upon the *significant* wave height, occurrences of 12 hour duration wave heights have been taken to ensure that the storm surge and wave setup combine to occur on high tides.

4.3.2 Storm surge

Figure 17 presents occurrences of storm surge that have been quantified by comparing projected tidal elevations with measured ocean water levels at Fort Denison for a 77 years period from 1914 to 1991 (AWACS 1991) as well as for the far north coast of NSW at Yamba and the south coast at Batemans Bay (CSIRO, 2007). CSIRO's results of climate change modelling for the NSW east coast at Batemans Bay and Wooli, for the CCM3 climate model run for the A2 emission scenario, indicated an increase in 1 in 100 years storm surges heights of up to 1% for 2030 and 4% for 2070. Under the same climate model run, the frequency of storms is projected to increase up to 13% by 2030 and 48% by 2070.

Figure 17: Current Storm Surge Occurrences for the NSW Coast



Source: AECOM, 2009

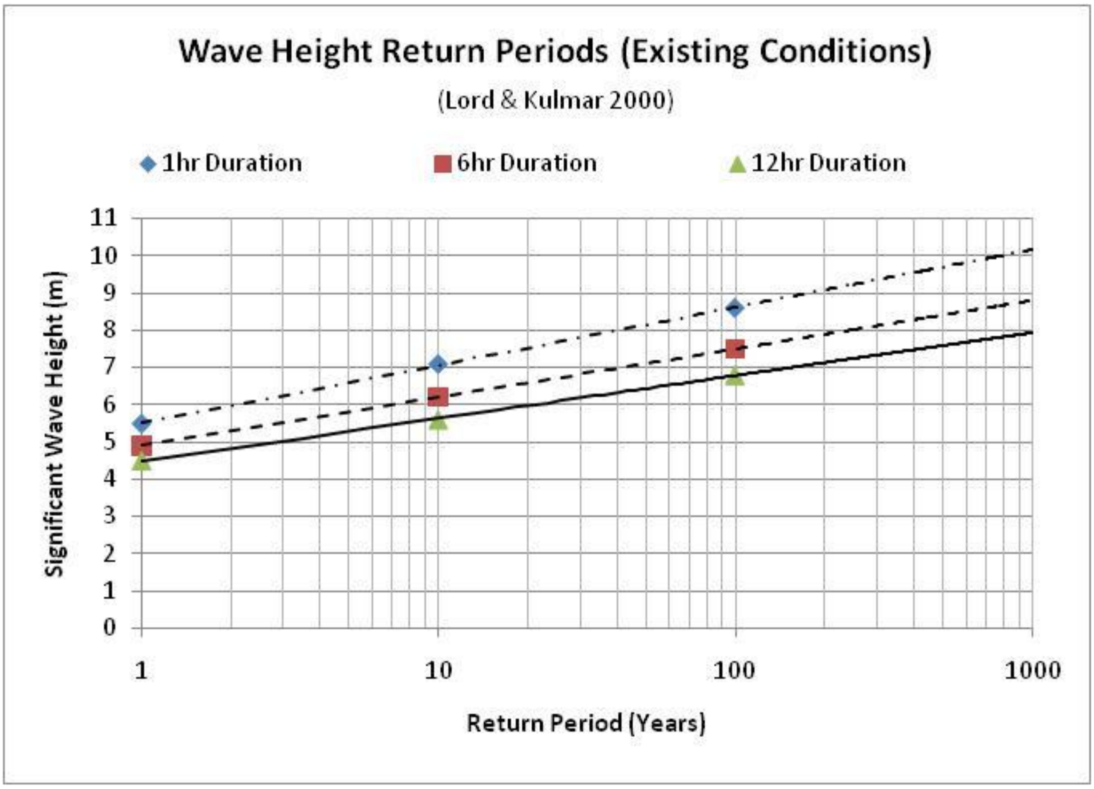
4.3.3 Nearshore wave setup

Super-elevated water levels are generated on the beach face as a result of wave setup. The maximum value of wave setup is at the shoreline where the water depth is zero. At this location, the super-elevation of the water level, generally, is around an additional 15% of the offshore *significant* wave height (see SPM 1984).

The increase in water level at the ocean entrance to Narrabeen Lagoon resulting from wave setup will be less than the maximum that occurs at the shoreline because there will be some 2 to 3 m of water depth. In this case, the extent of wave setup at the ocean entrance to Narrabeen lagoon has been taken as an additional 10% of the offshore *significant* wave height. Specifically, the modelling has used 0.6 m wave height at the shore for 20 year return period (5% probability of exceedance or poe) and 0.68 m wave height at the shore for 100 year return period (1% poe).

Figure 18 presents occurrences of various wave height durations that have been estimated from the Sydney Waverider buoy (Lord & Kulmar 2000). Modelling by McInnes *et al*. (2007) for the A2 emission scenario indicated that the higher order values project an increase in the *significant* wave height during extreme storms by some 10% for 2030 and some 30% by 2070. To ensure that the wave setup would occur on a high tide, 12 hour duration wave heights have been adopted.

Figure 18: Current Offshore Storm Significant Wave Height Occurrences



Source: Lord & Kulmar 2000, adapted by AECOM, 2009

4.3.4 Design ocean water level

Elevated ocean tail water levels used for flood modelling comprise the addition of storm surge and wave setup to the astronomical tidal elevation. The storm surge durations are such that they would occur on high tides. The wave durations adopted were 12 hrs, which ensures coincidence on a high tide. The values adopted for storm surge and wave setup corresponded to the occurrence interval adopted for the rainfall event.

The tidal elevation adopted for the modelling was that which occurred in the 1974 storms, being 0.9 m AHD, which, while close to the highest astronomical tide, is exceeded every month. The levels adopted for the modelling are in Table 12.

Table 12: Tidal heights adopted for modelling

Time Horizon	Sea Level Rise	Design Ocean Tidal Level (m AHD)
Current	-	0.9 m
Year 2050 (A1F1)	+ 0.4 m	1.3 m
Year 2100 (A1F1)	+ 0.9 m	1.8 m

5.0 Predicting flood events for the model

Even under normal circumstances, predicting flooding events at Narrabeen lagoon is no more certain than predicting the weather. At best, possible flooding can be forecast, albeit with uncertainty, only a few days in advance. The problem becomes even more complex with the added uncertainty about the degree, timing and intensity of future climate change. Modelling flood events and consequential damage and cost therefore requires the application of probabilities.

Under 'normal' circumstances, we might expect that the intensity of rainfall could be adequately modelled as mean rainfall with variations that reflect a parametric distribution, perhaps a bell-shaped Normal Distribution. Given sufficient historical records, the parameters of the distribution such as the mean and variance can be estimated. It is then possible to specify, the probability of a rainfall level over, say, a 36 hour period in July of any year. Alternatively, it is possible to say with 90 per cent certainty that rainfall will exceed that level. Provided we know the relationship between rainfall over a specified period like 36hours and flood levels in the Narrabeen lagoon, it is possible to forecast the likelihood of a flood in July of any given year.

However, circumstances under expected climate change are unlikely to be 'normal' in either the sense of resembling past patterns or following a bell-shaped distribution. If rainfall events are expected to become more extreme due to climate change, the parametric distribution would shift to the right, so that the probability of any particular level of rainfall would be associated with a higher probability than before the shift. Estimation of the extent of such a shift is explored in section 5.2 below. Note that the probability of extreme rainfall events would increase, similarly to the probability of all other levels of rainfall.

A further analytical complication is that the overall pattern of rainfall is of only secondary interest. In terms of adaptation to flooding, the key items of interest are the levels in extreme rainfall events. Because lower levels of rainfall will not cause flooding, or perhaps only minor flooding, the focus is on the high rainfall events at the upper extreme end of the distribution. In other words, modelling of flood events requires the modelling of only extreme rainfall, storm surge, wave set up and sea level rise that may bottle up the rainwater in the lagoon. The modelling of extreme events is further explored in section 5.1.

5.1 Current flooding

Flood levels depend on the combined impacts of weather events of storm surge, wave set up, extreme rainfall and flood heights. One might expected that there is some correlation between these weather events, although there is no published analysis. AECOM is currently modelling complete correlation between the events, so that the impacts of the climate variables on flood levels have been estimated together. However, AECOM's modelling methodology has been designed to handle less than complete correlation.

Flood level data for varying ocean level with 1% AEP rainfall and in Areas 1 and 3 has been sourced from Public Works Department (1990). In the absence of available information for other rainfall events and areas, the relative change in 1% AEP flood level with varying ocean level for Areas 1 and 3 has been used to estimate the variation in flood levels for other events (5% AEP and extreme) and areas (Areas 2 and 4). The actual and estimated flood heights for combinations of sea levels and rainfall intensities and duration across the four areas has been sourced from the Public Works Department (1990). The values are provided in Table 13, where estimated values are provided in bold italics.

Table 13 also shows the level of floods for each of the four areas in Pittwater that would result from combinations of storm surge, wave set up and AEPs. Information about actual flood heights was only available for some combinations: shown in black. Values in red have been interpolated linearly from the available data. It is likely that a study to update flood level data proposed for 2010 will provide more accurate information.

The intensity of rainfall (mm per hour) and its duration (hours) is categorised in terms of AEP of flooding. For example, an AEP of 5 per cent indicates that there is a 1 in 20 chance (5 per cent) of an event of this type occurring: in other words, a flood that would, on average, occur once every twenty years, or 5 times in a century. Table 13 shows that a rainfall intensity of 8 mm per hour over a period of 36 hours has an AEP of 5 per cent.

Table 13: Current Flood Experience (values in mAHD)

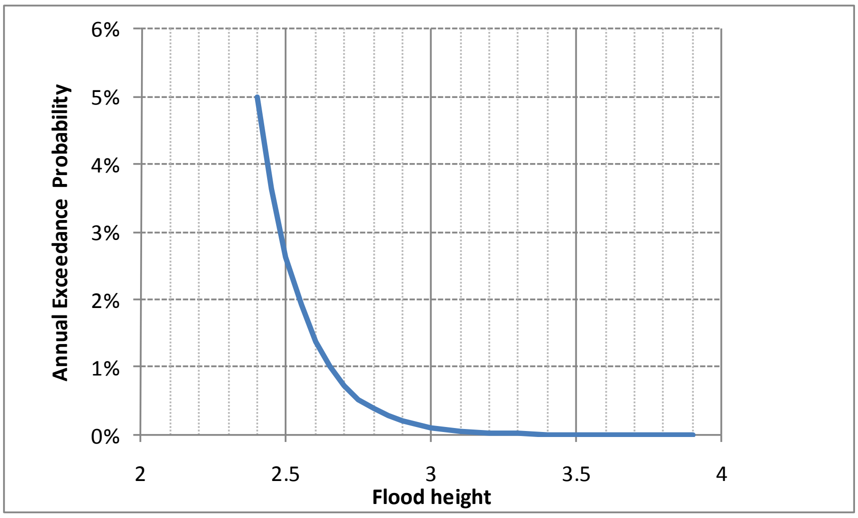
AEP	Rainfall Intensity (mm/h)	Storm surge and wave setup level (mAHD)				
		0.0	0.9	1.2	1.4	2.1
			Area 1			
5%	8	***2.30***	***2.35***	2.40	***2.45***	***2.75***
1%	11	2.55	2.60	***2.65***	2.70	3.00
0.001%	66	***3.35***	***3.40***	***3.45***	***3.50***	3.80
			Area 2			
5%	8	***2.40***	***2.45***	2.50	***2.55***	***2.85***
1%	11	2.65	2.70	***2.75***	2.80	3.10
0.001%	66	***3.65***	***3.70***	***3.75***	***3.80***	4.10
			Area 3			
5%	8	***2.50***	***2.55***	2.60	***2.65***	***2.95***
1%	11	2.75	2.80	***2.85***	2.90	3.20
0.001%	66	***4.05***	***4.10***	***4.15***	***4.20***	4.50
			Area 4			
5%	8	***2.60***	***2.65***	2.70	***2.75***	***3.05***
1%	11	2.75	2.80	***2.85***	2.90	3.20
0.001%	66	***4.15***	***4.20***	***4.25***	***4.30***	4.60

Source: Public Works Department (1990)

The AEP values of 5 per cent (1 in 20 years flood), 1 per cent (once in a hundred years flood) and 'Probable Maximum Flood (notionally 0.001% AEP or once in a hundred thousand years flood) in Table 13 are extreme events. The extreme hydrology literature typically uses extreme value distributions such as the Gumbel distribution (WolframMathWorld, 2009 & Wapedia, 2009). For instance, Booij (2004) used the Gumbel distribution when measuring the impact of climate change on river flooding over a 30 year period.

The Gumbel distribution is skewed to the right to focus on maximum events such as flood levels, as shown in Figure 19 below. The distribution shows probability of exceedance of a specified flood height per year, that is, AEP. For example, a flood of height 2.4m has AEP of 5% — a 1 in 20 year flood. A flood of height 2.9m has AEP of 0.2% % — a 1 in 500 year flood. It is important to understand that this model allows for very large floods, albeit with very low probabilities.

Figure 19: Extreme value distribution (Area 1)



Source: curve fitted to data from Table 13

Historical data for maximum flood levels for the Narrabeen Lagoon were used to determine the parameters [mu] and [beta] for the Equation 1 below.

Equation 1 $F = e^{-e^{\frac{(\mu - h)}{b}}}$, where F is cumulative probability of event of size h, that is, 1-AEP.

Four Gumbel distributions, one for each area of flooding, were estimated for flood distributions based on historical records. The parameters (mu and beta) were calculated using heights corresponding to 5% AEP and 1% AEP, which comprise two simultaneous equations in two unknowns.

Under current year conditions, four distributions were estimated, one for each area. For current year flood distributions, a Gumbel distribution was fitted to the 95% and 99% flood levels at a 1.8m AHD, which is usually associated with extreme rainfall events. The estimated parameters μ and β, as shown in Table 14, apply to both 5% and 1% AEP flood levels and provide a good fit to historical flood data.

Table 14: Current Flood Heights and Estimated Gumbel Parameters

Area	Flood Height AEP (at a 1.8 mAHD)		Gumbel Parameters	
AEP	**5.0%**	**1.0%**	**μ**	**β**
Area 1	2.40	2.65	1.9444	0.1534
Area 2	2.50	2.75	2.0444	0.1534
Area 3	2.60	2.85	2.1444	0.1534
Area 4	2.70	2.85	2.4267	0.0920

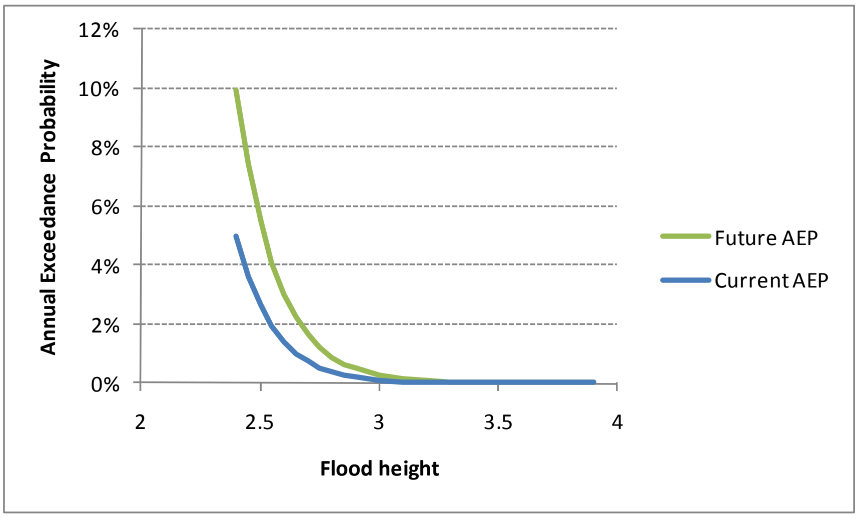
Source: flood heights from Table 13, Gumbel parameters from AECOM modelling, 2100

5.2 Additional flooding due to anticipated climate change

In order to be able to predict the frequency of extreme flood events over the remainder of the century, it is necessary to take into account the effects of expected climate change. In general, it is expected that the frequency of extreme rainfall events will increase, that sea levels will rise, and that storm surges may also increase in frequency.

Individually, or in combination, these climate change effects would change the flood height for given AEP. For example, a 5% AEP, 2.40 m flood may become a 2.52 m flood. Equivalently, this would shift any historical Gumbel distribution (section 5.1) to the right. Figure 20 illustrates how this rightward shift in the distribution would increase the probability of a given flood event, producing an augmented distribution — for example, a flood height of 2.4 m could change from AEP 5% (1 in 20 years) to AEP 10% (1 in 10 years). As previously discussed, the parametric distribution is assumed to remain the same, although the shape has clearly changed.

Figure 20: Shift in Gumbel distributions



Source: parameters from AECOM modelling, 2100

Extreme flood events predicted up to the year 2100 are based on these augmented distributions, rather than the distribution estimated from historical flood data. The shift factors for each of the 10 different OAGCMs were estimated on the basis of data provided by CSIRO, as set out in section 4.0.

As discussed in section 4.1, CSIRO actually provided shifts in rainfall for each climate scenario for 5 year, 10 year, 20 year and 40 year recurrence intervals, as shown in Table 4. AECOM estimated a rainfall shift for 100 year recurrence interval using quadratic polynomial extrapolation. In the absence of better data, the values for rainfall derived for the mid-point years 2055 and 2090 were extrapolated linearly between the periods 2009-2055 and 2056-2090.

As discussed in section 4.2, sea levels have been modelled as rising at a constant linear rate to reach an additional 0.4 m by 2050 and 0.9 m by 2100. . Unlike rainfall, sea level changes were not considered to be stochastic in nature.

As discussed in section 4.3, elevated ocean water levels have been modelled as a combination of storm surge and wave set-up, both of which are stochastic but the same across all climate model runs.

5.3 Predicted flooding events to 2100

Flood levels are due to the combined impact of rainfall, sea level rise and elevated ocean water levels. AECOM used linear regression to estimate the combined effect of changes in rainfall, storm surge, wave set up and sea levels have on flood levels. Analysis of the data revealed that rainfall, storm surge, wave set up, sea levels and flood levels are reasonably linearly related in the range of heights of interest. Therefore, a linear model between flood levels (dependent variable) and flood level at 1.2 m AHD, storm surge, wave set up, and sea levels was estimated. The functional form is shown in Equation 2.

Equation 2: Linear Regression Framework

$$flood\ height = \beta_1(flood\ height\ at\ 1.2m\ AHD) + \beta_2 \quad (storm\ surge + and\ wave\ setup\ ) + \beta_3(sea\ level\ rise)$$

The analysis included testing other functional forms to investigate whether flood levels were different between areas and whether sea levels and rainfall intensity had area specific effects on flood levels. No significant area specific effects were found.

Table 15 contains the result of the multiple linear regression, with distinct results for each of the four areas subject to flooding. The below model enabled a good fit (adjusted R-squared of 0.96 with standard error of regression 0.098, F-statistic of 6690.

Table 15: Regression coefficients

Variable Name	Coefficient (β_i)	Standard Error
Dependent Variable: Flood Height		
Flood height Area 1	0.922	0.016
Storm surge + wave setup + tide	0.192	0.036
Sea level rise	1**	0
Flood height Area 2	0.928	0.014
Storm surge + wave setup	0.188	0.034
Sea level rise	1**	0
Flood height Area 3	0.935	0.013
Storm surge + wave setup	0.182	0.033
Sea level rise	1**	0
Flood height Area 4	0.937	0.014
Storm surge + wave setup	0.182	0.036
Sea level rise	1**	0

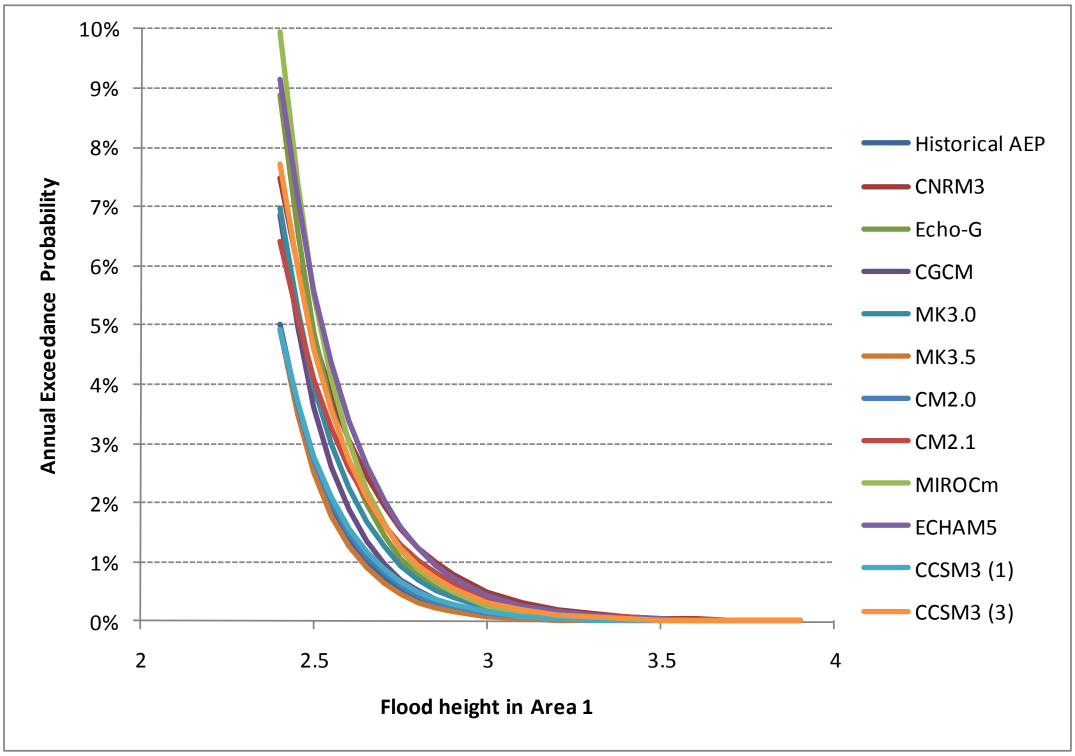
Source: AECOM, 2010

Note: ** assumed all sea level rise affects lagoon

The shifts in probability distributions of rainfall and sea were converted to shifts in flood height distributions using regression estimated from Table 15.

Although the results of each scenario are considered by CSIRO to be equally probable, the results of the models vary widely, both in direction and magnitude, as shown in Figure 21 (for rainfall only, assuming 1.8m AHD). For example, a 2.5m flood height has a 10% annual exceedance probability in the Echo-G climate scenario and a 5% annual exceedance probability in the CCSM3 (3) model. This result reflects the considerable degree of uncertainty that exists regarding future climate change. It is important to understand that flood heights are not averaged, but are carried through the modelling to produce cost impacts that are then averaged.

Figure 21: Shifts in extreme value distributions for floods in Area 1, for 10 OAOAGCM under the A1FI scenario



Note; changes due to rainfall, assuming rainfall 1.2m AHD.

6.0 Flood cost curves

Damage costs vary with flood height. The model therefore includes 'damage functions' that calculate the costs associated with floods of different heights. This section details the costs of flood impacts around the Narrabeen Lagoon catchment. Costs can be categorised as damage costs, disruption costs and health costs.

The nature of flooding in and around Narrabeen Lagoon does not pose a significant risk of injury or flood-related deaths. Flood velocities are generally low and build up over a period of time. However, a flood can be a traumatic experience for many victims. Family memorabilia such as photographs or pets may be lost, temporary accommodation may be required and unforeseen financial outlays may be necessary. However, little reliable data are available concerning such costs, so they have not been included in the modelling undertaken in this study.

Damage costs are site specific and require a detailed assessment of properties and structures in each of the four flood-prone areas, as well as their floor levels. Direct damage costs were therefore taken from ERM Mitchell McCotter (1992) and cost data were updated to 2009 prices using the New South Wales General Construction Price index (ABS, 2006a) and Consumer Price Index (ABS, 2009).

6.1 Direct damage costs

Direct damages include the actual effects of flood inundation on buildings and structures. Damage costs are site specific and require a detailed assessment of properties and structures in the area as well as their floor levels. This study therefore uses the direct damage costs from ERM Mitchell McCotter (1992). ERM Mitchell McCotter undertook a detailed assessment which included developing a detailed database of properties and structures, their flood level and how much they would be affected by different flood levels.

Direct damages include the effects of flood inundation on buildings and structures for the following:

- Residential property damage – direct damages due to inundation of buildings and structures.
- Commercial property damage – direct damages due to inundation of buildings and structures.
- Damage to roads, bridges and traffic signals – there are five bridges in the study area, three of which would be affected by scour of bridge abutments from a 1% flood. All bridges are submerged under extreme flooding. Traffic signals are also affected by extreme flooding and prolonged inundation of roads could load to weakened pavements or generate partial road collapse.
- Damage to water and sewerage infrastructure – eleven sewage pumping stations are in the flood affected area. Pumping units are below ground, however above ground electrical controls and power supply are not flood proof. An extreme flood event would also affect the above ground water main under Pittwater Road Bridge. Contamination of freshwater supply was not considered as lagoon flooding has minimal impact on upstream supply infrastructure.
- Damage to electricity and gas infrastructure – flood affected assets are transmission infrastructure, substations and underground cables. There are nine substations in the study area that are considered vulnerable to flooding. Gas mains maybe affected by water seepage preventing the flow of natural gas.
- Damage to parks and grounds – Lakeside Caravan Park, Cromer Golf Club and the Narrabeen Academy of Sport are each affected by flood inundation. There are also fourteen Council parks and reserves that are potentially flood affected.

Whilst there has been some development in the Narrabeen area over the past fifteen years, the properties and structures of the four affected areas have not significantly changed. This information has been used to derive damage cost curves for residential property, commercial property and infrastructure. Each of these is discussed in more detail below:

6.1.1 Residential property

Direct damage to property is generally categorised as contents damage (e.g. damage to carpets and furniture), structural damage (e.g. damage to the fixed part of the building) and external damage (e.g. damage to parked vehicles).

ERM Mitchell McCotter found a total of 1,432 dwellings in the study area, with 659 within Area 1, 125 within Area 2, 630 within Area 3 and 18 within Area 4. The majority of the residences were single storey small/medium sized dwellings located in Areas 1 and 2 (downstream of Pittwater Road Bridge). In Area 3 over half the dwellings are flats/units. **Figure 22** sets out the residential buildings flood damage curve for each of the areas. Area 4 has the least impact due to the small number of residential properties in the area, a total of 18. These have been inflated to 2009 prices using the NSW General Construction price index (ABS, 2006a) and CPI (ABS, 2009). As the NSW General Construction Index (GCI) series started in 1998, the trend between CPI and GPI between 1998 and 2009 has been used to estimate the GCI back to 1992.

Damage is limited until the flood height exceeds 2.5 m. The analysis shows that the cost is not linear with flood height and there is a shift in the curve at around 3.7 to 3.8 m. This suggests the area has fewer properties affected by flood above 3.7 to 3.8 m and likely reflects the changes in terrain. . This highlights the importance of site specific analysis.

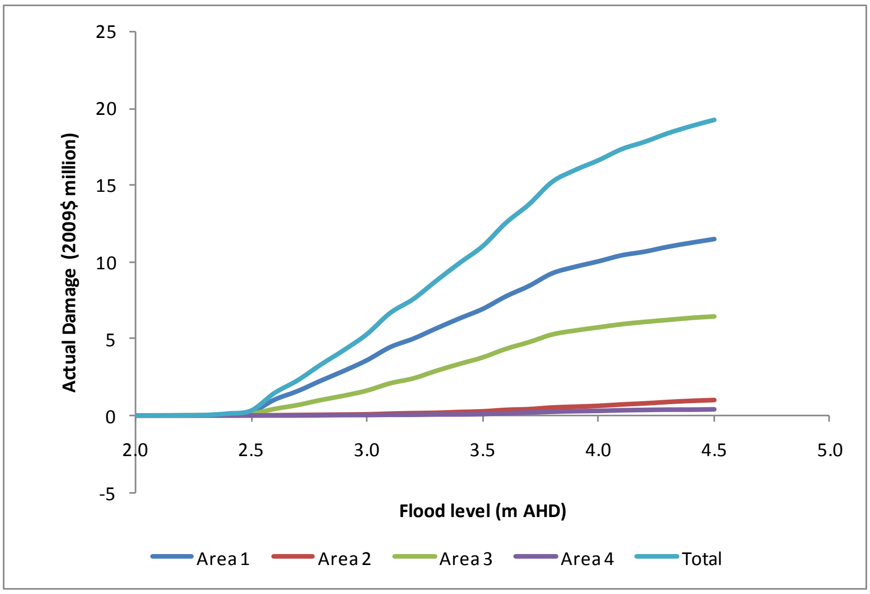


Figure 22: Residential buildings flood damage curve

Source: AECOM based on data in the 1992 flood management study

It is important to note that these represent actual flood damage costs and assume some property protection measures are undertaken. Depending on the nature of flooding, the degree of warning and the level of community understanding of flooding, significant savings in the level of damages are possible. ERM Mitchell McCotter (1992) uses actual to potential damage ratios of 0.3 and 0.6 for the 5% and 1% flood damages respectively. These have been adopted in this study.

6.1.2 Commercial property

ERM Mitchell McCotter (1992) found a total of 262 commercial properties within the four areas – 112 within Area 1, 53 within Area 2, 28 within Area 3 and 69 within Area 4. Of these, 68 were categorised as low value, 119 as medium value and 75 as high value (in 1992). No site visit was undertaken to update this assessment.

Figure 22 sets out the commercial buildings flood damage curve for each of the areas. These have been inflated to 2009 prices using the NSW General Construction price index (ABS, 2006a) and CPI (ABS, 2009). There are shifts in the shape of the curve at around 3m and 3.7m. Area 2 is the area that will have the biggest costs to commercial property.

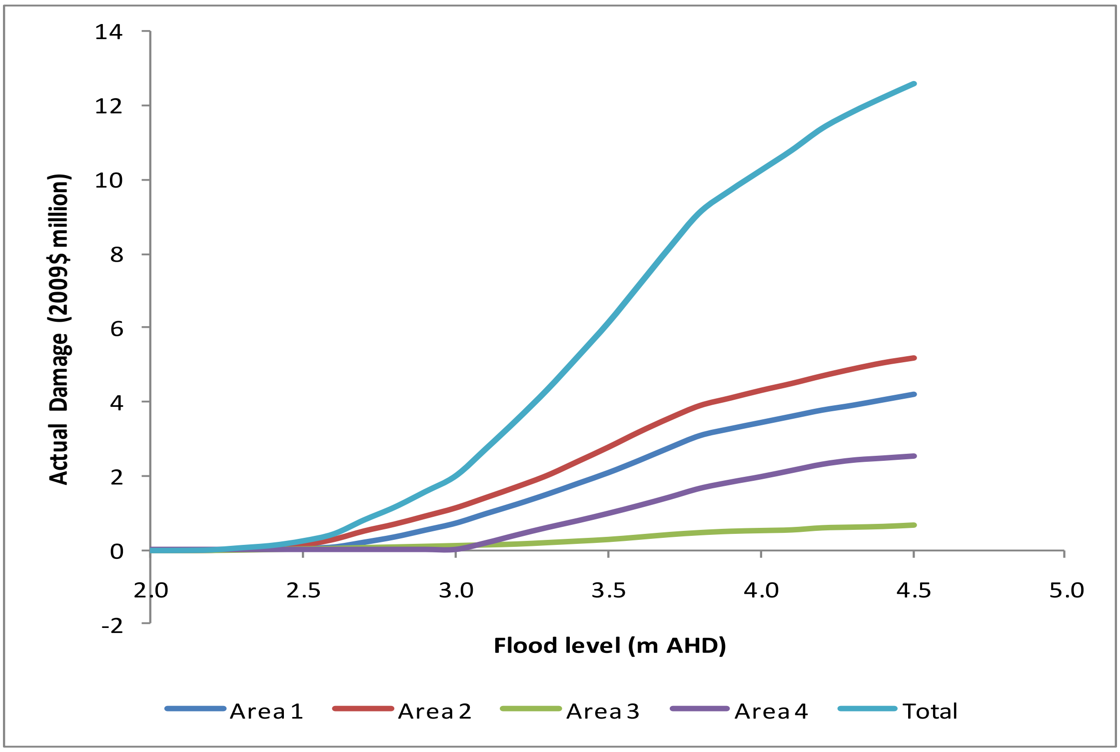


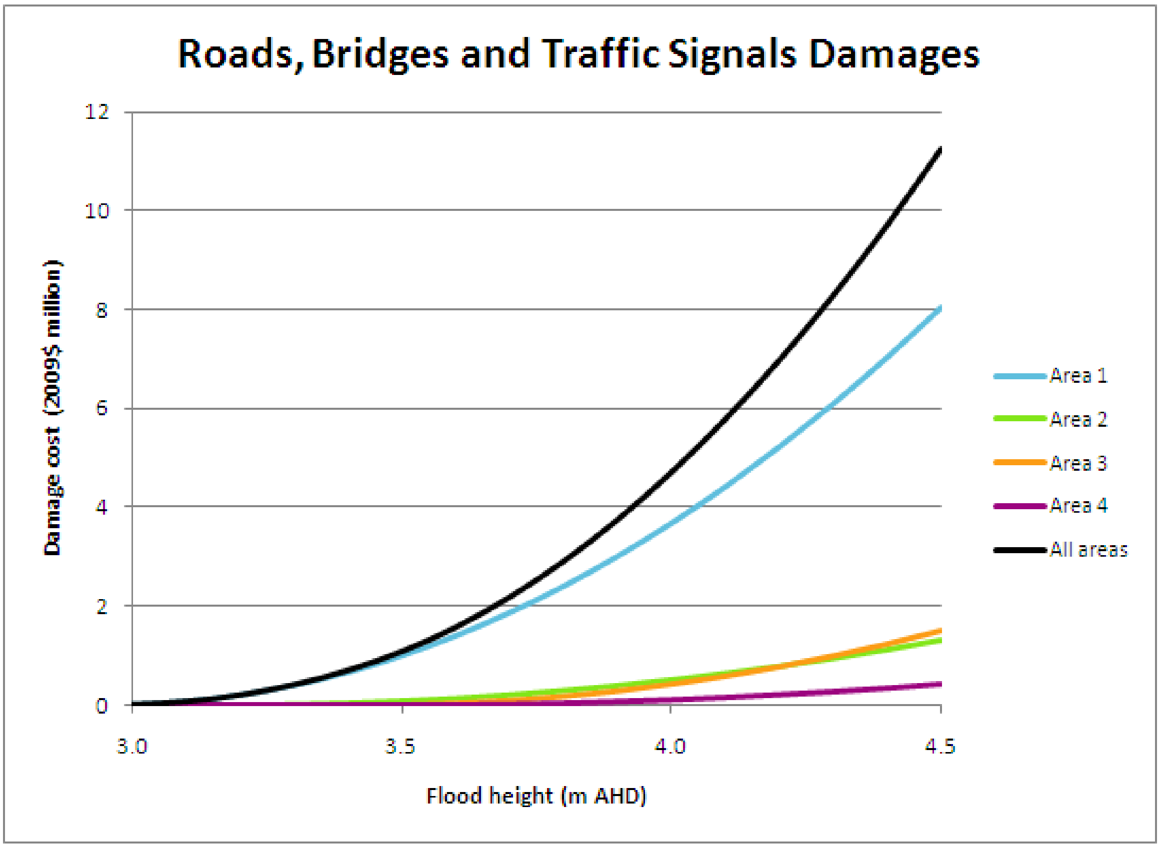
Figure 23: Commercial buildings flood damage curve

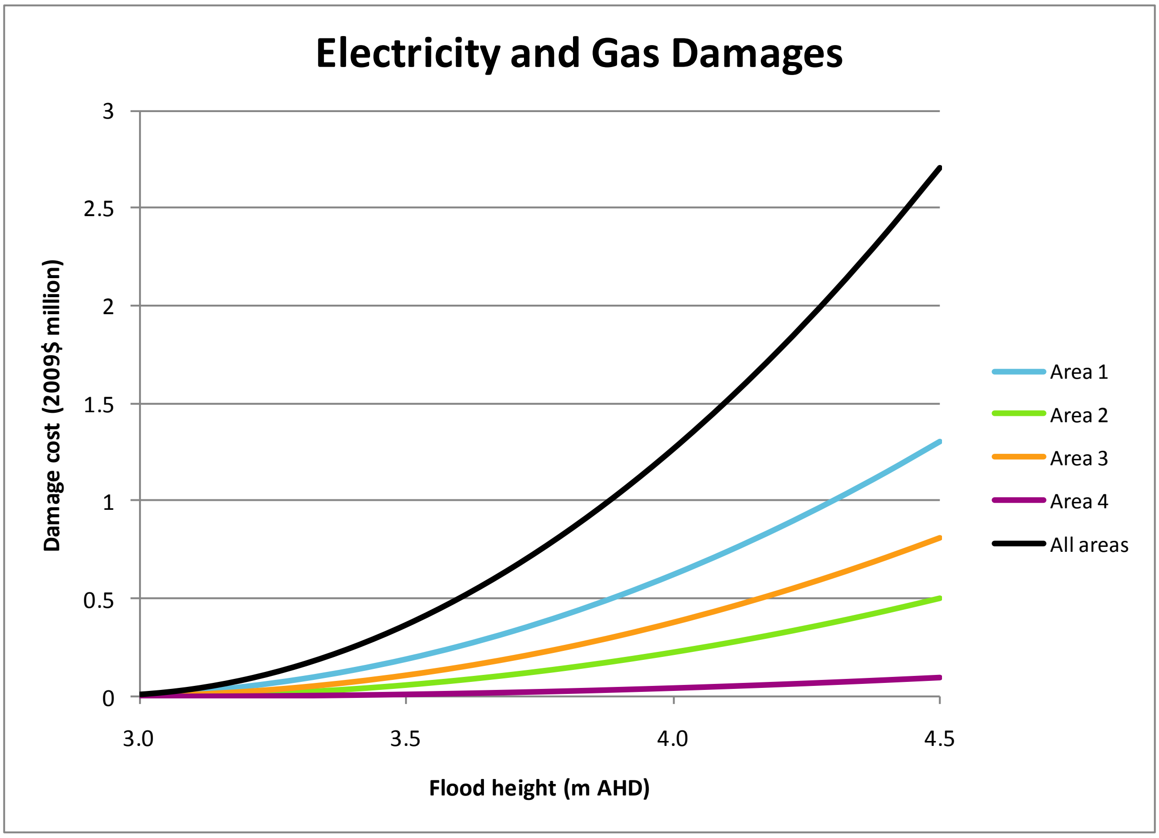
Source: AECOM based on data in the 1992 flood management study

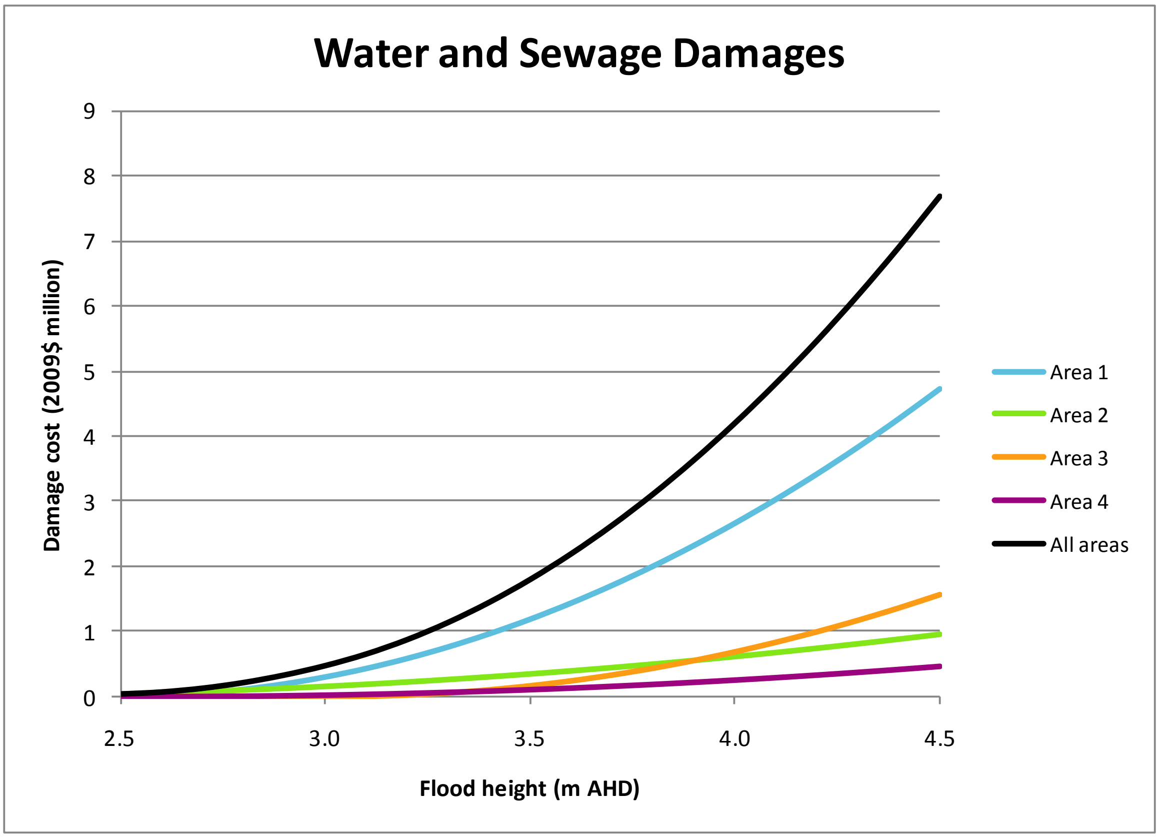
6.1.3 Infrastructure

ERM Mitchell McCotter (1992) identified a range of other damage costs including damage to roads, bridges and traffic signals; damage to water and sewerage infrastructure; damage to electricity and gas infrastructure and damage to parks and grounds. ERM Mitchell McCotter (1992) provided damage costs for the 1% AEP 1% and AEP 5% flood levels. These values were updated to 2009 prices and a quadratic function was used to fit the damage curve. The quadratic function was used because it showed a good fit to the empirically based residential and commercial buildings flood damage curves. Figure 24 shows the cost curves.

The biggest costs occur from damage to roads, bridges and traffic signals, followed by damage to water and sewerage infrastructure. Areas 1 and 3 have the biggest costs of flooding.


Roads, Bridges and Traffic Signals Damages
Damage cost (2009$ million)
12
10
8
6
4
2
0
3.0
3.5
4.0
4.5
Flood height (m AHD)
Area 1
Area 2
Area 3
Area 4
All areas


Electricity and Gas Damages
Damage cost (2009$ million)
3
2.5
2
1.5
1
0.5
0
3.0
3.5
4.0
4.5
Flood height (m AHD)
Area 1
Area 2
Area 3
Area 4
All areas



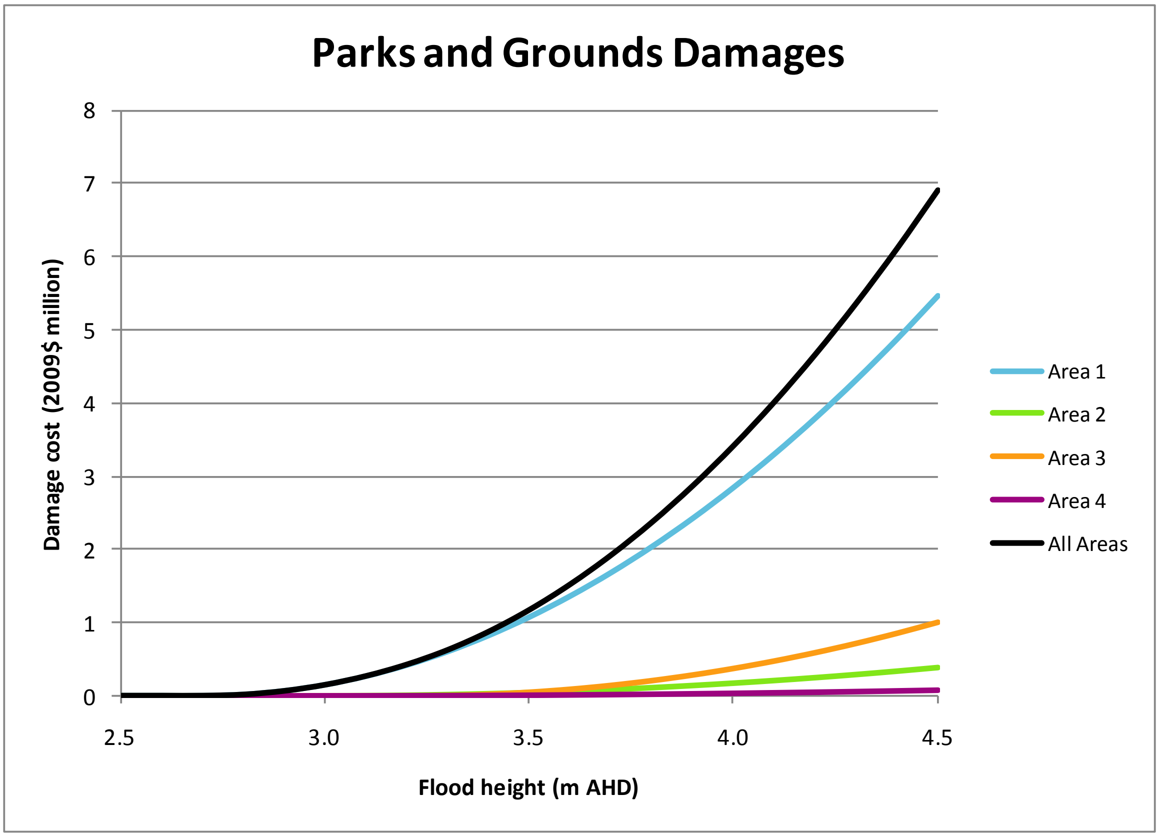


Figure 24: **Other Damage cost curves**

Source: AECOM based on data in ERM Mitchell McCotter (1992)

6.1.4 Direct damage cost curves

All of the above cost curves have been added together to get a total flood damage curve as set out in Figure 25.

As can be seen damage to residential buildings is the main component of costs from flooding in Narrabeen Lagoon. This is followed by damage to commercial buildings. This suggests any adaptation options should focus on reducing the costs for residential and commercial properties.

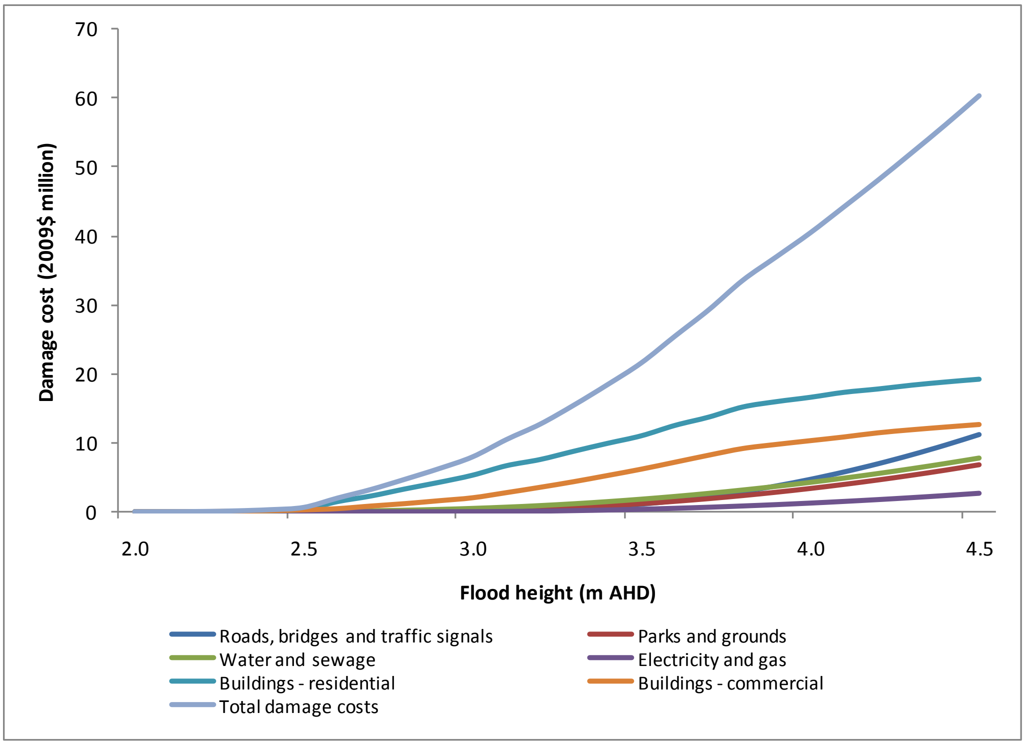


Figure 25: Total flood damage cost curve for the Narrabeen Lagoon area

Source: AECOM, 2009

6.2 Indirect costs

In addition to the direct damage impacts from flooding, there are a range of other impacts that arise as a result of the disruption caused by the flood. These have been categorised as travel disruption, and physical and emotional health damages. These are discussed below.

6.2.1 Indirect flood damages for residential and commercial properties

As well as the actual damage to property there are costs associated with cleaning up the property (usually in terms of people's time) and financial loss. This will be different for residential and commercial buildings. It has been assumed that two days of labour would be required to clean up a flooded residential property after a flood event involving removal of debris and mud.

For residential buildings, there may be costs of alternative accommodation and loss of wages.

For commercial properties, there may be the loss of sales and production as a result of flood events. The majority of commercial property likely to be affected is small retail, which is assumed to open within a couple of days with lost profit used to value costs (Australian Taxation Office, 2009). The average profit of businesses in the Narrabeen Lagoon area is $215,771 per annum (in 2009 prices), which accounted for the current composition of business types within the local area. 2007 values were indexed to 2009 values using CPI (ABS, 2009).

6.2.2 Travel disruption

Flooding in Narrabeen Lagoon will cause roads to become submerged, forcing road users to either cancel their trip or to find alternative routes. The number of roads that become submerged and unusable depends on the severity of the flood. With a flood height of 2.5m, Garden Street, Waterloo Street, Rickard Road and Jacksons Road are unusable (ERM Mitchell McCotter, 1992). Once the flood height reaches 2.8m the major roads around Narrabeen lagoon, including Pittwater Rd and Wakehurst parkway, are closed as shown in Figure 26. Traffic will still be able to enter and exit the area through Mona Vale Road but this will result in longer trips. Additional travel time and vehicle operating costs have been used as a proxy for people's willingness to pay to avoid travel disruption.

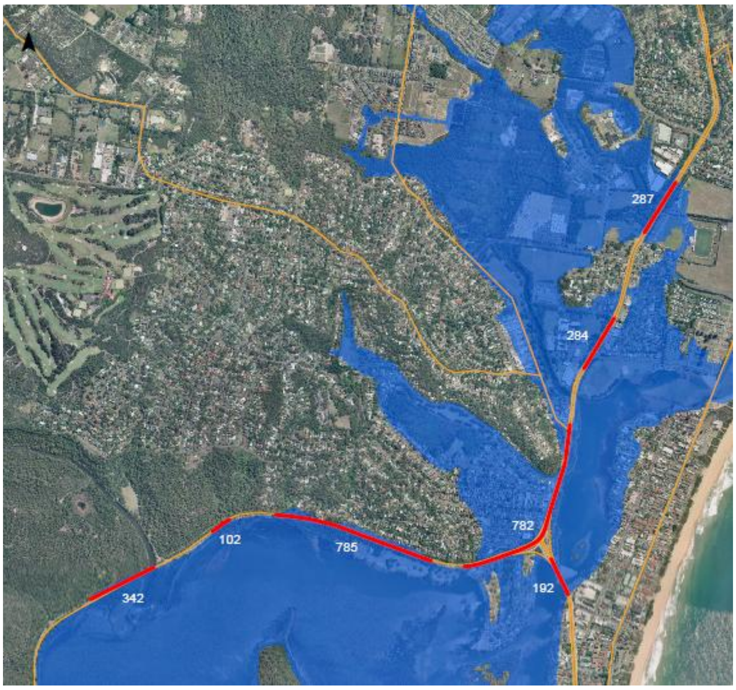


Figure 26: Road Closures with a 2.8m flood

Source: AECOM, 2009

Figure 27 sets out the cost curve for traffic disruption. In summary, ERM Mitchell McCotter (1992) identifies that Garden Street Waterloo Street, Rickard Road and Jacksons Road are unusable once the flood height reaches 2.5m, which is shown by the first step increase in costs. As the major arterial roads such as Pittwater Road and Wakehurst Parkway are still open, the traffic disruption cost of a 2.5 m flood is expected to be minimal. The second step in the distribution is associated with the closure of all major roads in the area, including Pittwater Rd and Wakehurst parkway, this occurs once the flood height reaches 2.8 m (ERM Mitchell McCotter, 1992). Once flooding exceeds 2.8 m, all the main roads are closed except Mona Vale Road, as it has a steeper gradient and runs west away from the flood affected area.

Details of the calculation follow.

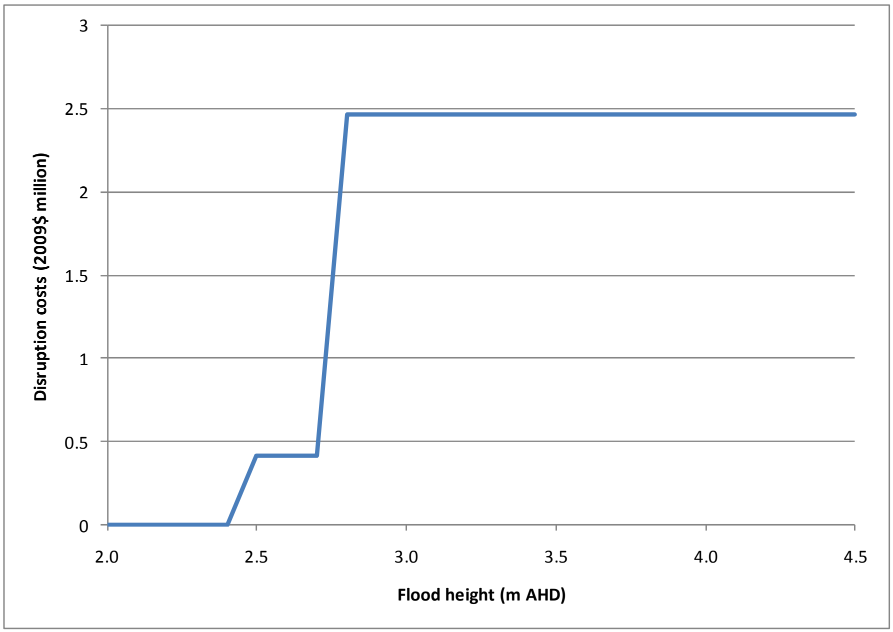


Figure 27: Distribution of Disruption Costs

Source: AECOM analysis

Table 16 contains the average annual daily trips (AADT) along Wakehurst Parkway, west of Pittwater Road, Pittwater Road, Garden Street and Ocean Street. These numbers have been calculated using RTA counts from 2005 and accelerating them to 2009 volumes based on historical growth rates. As stated in ERM Mitchell McCotter (1992) trips diverted from Pittwater Rd are extended by 15km (26min) and those diverted from Wakehurst Parkway are extended by 10km (19 min).

Table 16 Number of Trips by Road

Location	AADT (2009)	Through Traffic
Wakehurst Parkway, west of Pittwater Road	21,847	10,923
Pittwater Road Bridge	48,221	24,110
Pittwater Road (at Nareen Pde)	58,092	29,046
Garden Street (west of Pittwater Road)	16,723	8,362
Ocean Street	8,004	4,002

Source: AECOM analysis

Through traffic represents all those trips that are required to be taken and will occur regardless of route choice, which is assumed to be 50% of AADT, this assumption is consistent with that of ERM Mitchell McCotter (1992).

The additional costs include vehicle operating costs (VOC) and travel time. VOC measures the costs per kilometre associated with travelling further to reach their destination, these include fuel costs, wear and tear, depreciation, oil and maintenance. The vehicle operating costs have been calculated at 89.7cents per kilometre based on economic parameters published by the RTA. The value of time represents the cost to the occupants of each vehicle for every extra hour travelled to avoid the flood affected area, this has been calculated at $46.61/car/hour, this is added to the VOC to obtain the total cost of traffic disruption. The value of time has been weighted by car type and passengers per car (which is weighted by time of day).

Table 17: Disruption Costs

Location	Vehicle Operating Costs/Day	Value of Time/ Day	Total/Day
Wakehurst Parkway, west of Pittwater Road	$98,032	$161,223	$259,255
Pittwater Road Bridge	$324,566	$486,957	$811,524
Pittwater Road (at Nareen Pde)	$391,011	$586,646	$977,658
Garden Street (west of Pittwater Road)	$112,561	$168,879	$281,440
Ocean Street	$53,875	$80,830	$134,705
Total	**$980,047**	**$1,484,537**	**$2,464,584**

Source: AECOM, 2009

6.2.3 Health damages

Physical health

Loss of life during flooding may result from accidents, drowning or stress. Most flood related deaths in Australia are a result of flooded roads sweeping cars off the road or people being swept away. The nature of flooding in and around Narrabeen Lagoon does not pose a significant hazard or risk of such an accident. Flood velocities are generally of a low build up over a long time. This is evidenced by the low number of physical injuries that have occurred during flood events in the Narrabeen Lagoon area.

Emotional health

A flood can be a traumatic experience for many victims. Flooding often results in loss of memorabilia such as family photographs, loss of pets, living in temporary accommodation, large financial outlays to replace damaged possessions.

The actual cost is difficult to quantify and depends on the severity of the flood and the degree of resulting hardship which is affected by age and socio-economic status (Chamberlain *et al*., 1981). A study of the 1974 Brisbane flood found that 25% of victims had not recovered from the emotional trauma 15 months after the flood. The study also found elderly people on low incomes whose houses were deeply flooded were the most ill affected.

Socio-Economic Indexes for Areas (SEIFA) is a product developed by the Australian Bureau of Statistics (ABS) for those interested in the assessment of the welfare of Australian communities (ABS, 2006b). The ABS developed four indexes to allow ranking of regions/areas, providing a method of determining the level of social and economic well-being in regions. Each index summarises different aspects of the socio-economic conditions; based on information from the 2006 Census. Pittwater is ranked as the as the 8th most advantageous LGA in Sydney, with a SEFIA rating of 1,107 (ABS, 2006b).

Pittwater is generally characterized by an older population, higher incomes, and larger houses (ABS, 2007). There is a potential that 1,432 residential properties may be flood affected, it is not expected that this will cause significant financial stress. However some of the older population, on fixed incomes may be more affected by the flood. Given a large proportion of the area is flood prone and yet people choose to live there it has been assumed that people have already internalised these benefits and costs. No additional impact has been modelled.

7.0 Potential measures for adapting to the flooding of Narrabeen Lagoon

7.1 Introduction

This chapter describes a range of adaptation measures suitable for Narrabeen Lagoon and analyses their costs and benefits compared to a base case of no adaptation. The Intergovernmental Panel on Climate Change (IPCC) defines adaptation to climate change as “any adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploit beneficial opportunities”.

The British Government commissioned the Stern Report in 2006 which estimated the costs of worldwide adaptation measures under a “Business As Usual” scenario would result in annual costs between 5 and 20% of the Global Domestic Product (GDP).

Based on the experience of developing numerous adaptation plans for all levels of the Australian Government, private sector and local communities, AECOM has identified the Six Steps for being Resilient, Prepared and Prosperous in response to climate change effects as indicated in Table 18. This guide emphasises the need to make informed decisions regarding adaptation solutions to suit the scale, timing and cost implications of a specific climate change threat.

There is a need to establish a “Standard of Practice” to assess and respond to the impacts of climate change that can be more easily integrated into current decision making processes. Good decision making usually includes considerations of capital or operating cost, value for money, impacts to performance of critical functions, community expectations and governance implications. The adaptation measures considered in this study for Narrabeen Lagoon have been selected and analysed to assess benefits and costs of adaptation response from a community perspective. Local governments will need to consult further with stakeholders to make their own decisions on the best adaptation solution for their communities.

Table 18: Six Steps for being Resilient, Prepared and Prosperous in response to Climate Change Effects

Steps		Key Considerations
1.	Identifying the current and potential future impacts	Exploring local impacts from a full range of changing climatic effects such as extreme events (flooding, wind, heatwaves, storm surge etc), annual climate (rainfall, evaporation, temperature etc) and correlated impacts (sea level rise, increased storm surge and extreme rainfall).
2.	Prioritising the vulnerabilities and understanding likely future costs	Use a criteria (such as a risk rating) to prioritise vulnerable communities, natural systems, assets or locations. Further analyse priorities using cost (and value) estimations of current or past impacts to inform future implications based on climate model simulations.
3.	Identifying specific and relevant adaptation options	Consult with stakeholders relevant to priority impacts to explore specific and relevant adaptation options. Important to understand strengths and weaknesses of current or future preventive measures. Clarify barriers and benefits to adaptation options.
4.	Determining scale, cost and optimum timing of implementation	Assess the optimum size or scale of adaptation measures bearing in mind transitions in magnitude of impacts over time. It is necessary to understand the costs and best timing of implementation to achieve a well planned, equitable and valuable solution for a community.
5.	Communicating and implementing adaptation strategies	Communicating with relevant stakeholders the mix and timing of adaptation solutions is vital to support implementation. Implementation should be integrated and link to existing or emerging strategies for planning, development and management.
6.	Monitoring, review and adjust to changes	To review the effectiveness of adaptation over time it is necessary to monitor changes as they occur such as sea level rise. If the rate of change increases faster than expected then the adaptation measures may require adjustment to scale and timing of implementation.

Source: AECOM, 2010

The potential measures for adapting Narrabeen Lagoon to climate change can be classified into three categories, namely: protection, accommodation and retreat.

Protection refers generally to the construction of hard infrastructure such as sea walls and levee banks that protect coastal zones from the effects of extreme weather events. It can also include so-called ‘soft’ measures such as revegetating sand dunes or sand nourishment. Protection is usually seen as a first defence against the expected effects of climate change. However, the effectiveness of the protection strategy in ameliorating the effects of climate change may be only temporary because coastal erosion and flooding often tend to continue despite any defensive infrastructure.

Because of the generally temporary nature of the ‘protection’ strategy, a fallback strategy is ‘accommodation’ to the effects of climate change. Accommodation involves an acceptance of effects such as flooding. Examples include raising residential buildings and accepting that lower levels such as basements or ground floors will suffer from flooding, or instituting warning systems to provide more time for residents to prepare for floods.

At some stage, when protective measures and accommodation are considered to be no longer effective, a final strategy is to abandon the coastal zone and to retreat further inland. Retreat would in principle occur once the benefits of accommodation and protection were outweighed by the costs: for example, houses would need to be raised significantly higher as well as alternative access to properties required at considerable expense because of rising sea levels.

In the case study of Narrabeen lagoon, the effects of climate change are at an early stage. Of the six potential adaptation measures that have been assessed, the first four in the list below are protection measures, and the last two fall into the category of accommodation measures:

1) Widening the entrance to the lagoon.
2) A levee bank to protect the Lake Park Road and allow continued accessibility.
3) A levee bank to protect Progress Park and allow continued accessibility.
4) A flood wall and flood gates to protect the lower reaches of the Nareen Creek catchment from backwater flooding from the lagoon.
5) A warning system that would provide residents and businesses with more time to prepare for a flood event, so that damage is reduced.
6) Introduction of planning regulations that will gradually reduce damage from flooding to existing residences in flood-prone areas.

Each of these is discussed in more detail below. The analysis undertaken below also considers combinations of these measures.

A range of other adaptation responses were also considered such as rainwater tanks, upgrading of bridges and drainage infrastructure but when assessed were not deemed to viable adaptation measures for the nature of flooding in Narrabeen lagoon.

7.2 Adaptation measure 1 - widening the entrance to the Lagoon

7.2.1 Description of adaptation measure

As discussed in Section 2.1, Narrabeen Lagoon naturally closes over time, limiting the outflow of water from the lagoon. The closure of the lagoon increases the severity of flooding of low lying residential/commercial areas surrounding the lagoon, as well as creeks discharging into it. Pittwater and Warringah Councils operate a lagoon entrance management strategy to control the build up of sand at the entrance to the lagoon. Since 1975, the clearance operations have been undertaken approximately every three years (Warringah Council, 2009). By controlling the build up of sand, flood waters can flow out quicker than would otherwise be the case, reducing the severity of flood events. Ongoing management is required to ensure that the build up of sand is not excessive.

Adaptation measure 1 considers a permanent opening of the lagoon entrance. This measure involves the excavation of a 70m or 100m channel through the Narrabeen headland rock shelf and the construction of training walls along the north and south banks of the channel to aid in the removal of sand.

7.2.2 Costs of adaptation measure

Capital and annual operating costs for implementing the widening of the entrance to the lagoon were updated to 2009 prices using ABS NSW General Construction Price Index implement Adaptation for Measure 1 as shown in Table 19.

Table 19: Costs of Adaptation Measure 1

Width of Entrance Opening	Capital Costs($m)	Operating Costs($m/annum)
70m	6.8	0.4
100m	7.1	0.4

Source: ERM Mitchell McCotter, 1992

In addition to these quantified capital and operating costs, the opening of the lagoon will also have the following impacts:

- Lowering the average lagoon water level. The difference in average water levels between the ocean entrance being open to that when it is closed is around 0.5 m to 1.0 m (Gordon, 2006). This increases the exposure of sea grasses and may impact on recreational use of the lagoon;
- Increase the incidence of oceanic flooding; and
- Loss of visual amenity due to the training walls.

7.2.3 Benefits of adaptation measure

Implementation of this adaptation measure will increase the outflow of floodwaters resulting in reduced flood levels. The 1992 flood management study anticipates a reduction in flood levels of 11cm to 16cm for the 70 metre opening and 11cm to 17cm for the 100 metre opening.

Section 2.0 sets out a range of direct and indirect cost associated with flooding including damage to residential property, commercial property, other infrastructure such as roads and utilities, inconvenience to households, businesses and road users. Through the general reduction of flood heights, Adaptation Measure 1 will be expected to reduce these costs. The value attached by the general community to flood mitigation strategies that prevent damage generally exceeds the value of avoided costs and, where possible, this study uses a willingness to pay approach to measure the benefits of adaptation.

Improved household welfare

This study has adopted the willingness to pay estimates from the Hawkesbury-Nepean Floodplain Management Steering Committee's (2006) study which estimated the value of flood mitigation for residents living on the Hawkesbury-Nepean flood plain. This study found that residents would be willing to pay an average of 10 percent of their property value to avoid structural damage caused by floods and approximately $200 per annum to avoid contents damage caused by floods. It has been assumed that together these represent residents' willingness to pay to avoid damage to their property as well as any inconvenience associated with this such as stress and uncertainty.

This willingness to pay has been included as a benefit to 127 residences that are currently affected by the 1 in 100 year flood event but will be protected under the adaptation measure. This is a conservative estimate of benefits as other properties may still experience a benefit from less flooding. Average property prices around Narrabeen Lagoon vary between $642,000 and $690,000 as set out in Box 5 below.

Box 4: Average property prices around Narrabeen Lagoon

The area affected by Narrabeen Lagoon is split between North Narrabeen and Narrabeen. Generally, Narrabeen covers Areas 1 and 3 and North Narrabeen covers areas 2 and 4. The types of properties and average prices vary between the two regions.

Average property prices in Narrabeen

The median price of a house in Narrabeen in the 12 months to October 2009 was $907,500 with a long term trend increase of 6%. The median price of a unit in Narrabeen in the 12 months to October 2009 was $486,750 (Australian Property Monitor, 2009) with a long term trend increase of 3.0%. In the 2006 Census there were 2,972 occupied private dwellings counted in Narrabeen, of which 19.3% were separate houses, 17.1% were semi-detached, row or terrace houses, townhouses etc, 63.1% were flats, units or apartments and 0.5% were other dwellings. Using the proportion of dwelling types provides a weighted average price of $642,000 per property in Areas 1 and 3.

Average property prices in North Narrabeen

The median price of a house in North Narrabeen in the 12 months to October 2009 was $751,000 with a long term trend increase of 6.1%. The median price of a unit in North Narrabeen in the 12 months to October 2009 was not available so has been assumed to be the same as for Narrabeen. In the 2006 Census there were 1,876 occupied private dwellings counted in North Narrabeen of which 85.9% were separate houses, 2.2% were semi-detached, row or terrace houses, townhouses etc, 4.4% were flats, units or apartments and 7.2% were other dwellings. Using the proportion of dwelling types provides a weighted average price of $689,879 per property in Areas 2 and 4.

Reduced road travel disruptions[1]

Flooding in Narrabeen Lagoon will cause roads to become submerged, forcing road users to either cancel their trip or to find alternative routes. The number of roads that become submerged and unusable depends on the severity of the flood. With a flood height of 2.5m, Garden Street, Waterloo Street, Rickard Road and Jacksons Road are unusable (ERM Mitchell McCotter, 1992). Once the flood height reaches 2.8m the major roads around Narrabeen lagoon, including Pittwater Rd and Wakehurst parkway, are closed as shown in Figure 28. Traffic will still be able to enter and exit the area through Mona Vale Road but this will result in longer trips. Additional travel time and vehicle operating costs has been used as a proxy for people's willingness to pay to avoid travel disruption.

[1] There may be some minor double counting as the willingness to pay is assumed to cover travel disruption. However as there are only 127 properties that have a willingness to pay benefit this is likely to be minimal.

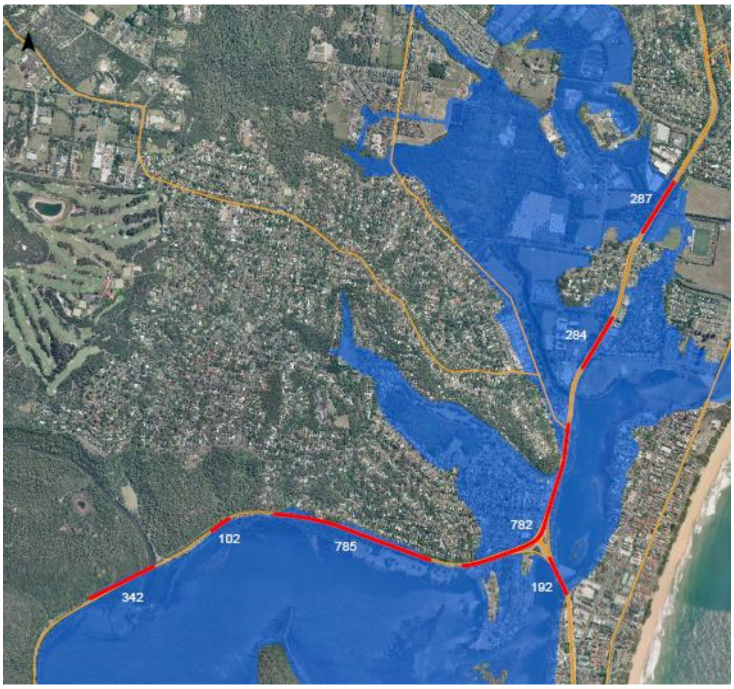


Figure 28: Road Closures with a 2.8m flood

Source: AECOM, 2009

Avoided damage costs

The following damage costs will also be avoided:

- Commercial property damage including structural and contents damage
- Damage to roads, bridges and traffic signals
- Damage to water and sewerage infrastructure
- Damage to electricity and gas infrastructure
- Damage to parks and grounds

Damage costs are site specific and require a detailed assessment of properties and structures in the area as well as their floor levels. This study therefore uses the direct damage costs from the 1992 Narrabeen Lagoon floodplain management study with costs updated to 2009 prices using the NSW General Construction Price index (ABS, 2006a) and CPI (ABS, 2009)[2]. Damage costs vary by flood height, so damage cost curves were developed to chart the damage cost against the flood height[3]. Figure 29 sets out an example of the damage flood curves developed. It shows that, for a flood height of 3.5m, the total damage cost to commercial buildings is expected to be around $5m. When the flood height falls to 3.0m the total damage cost to commercial buildings falls to around $2m.

[2] Whilst there has been some development in the Narrabeen area over the past fifteen years, the properties and structures of the four areas considered have not significantly changed

[3] For commercial property there were enough data points for the damage curve. For other damage costs a quadratic function was used to fit the damage curve

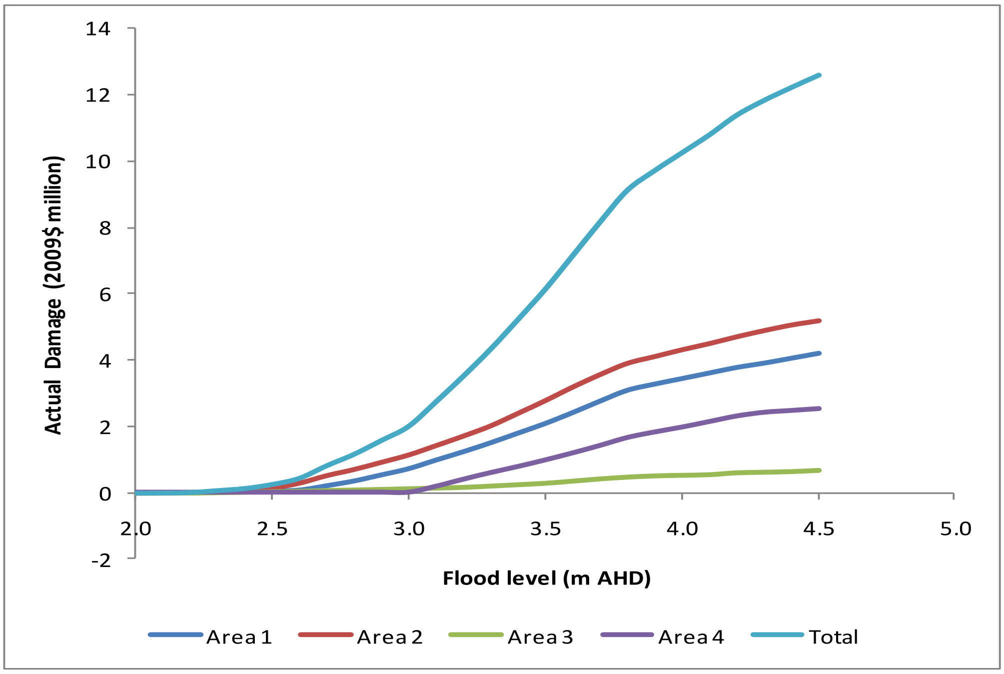


Figure 29: Commercial buildings flood damage curve

Source: AECOM based on data in ERM Mitchell McCotter, 1992

Avoided inconvenience costs for Commercial Properties

For commercial properties there may be the loss of activity such as sales or production whilst repairs occur. The majority of commercial property affected is small retail and is assumed to open within a couple of days with lost profit used to value this (Australian Taxation Office, 2009)[4].

Non quantified benefits

The permanent opening of the lagoon will change the ecology of the lagoon. It may improve the water quality due to increased tidal flushing and may increase the biodiversity of the lagoon. These benefits have not been quantified.

[4] The average profit of businesses in the Narrabeen lagoon area is $215,771 (per annum in 2009 prices), which accounted for the current composition of business types within the local area. 2007 values were indexed up to 2009 values using CPI.

7.2.4 Results

Figure 30 and Figure 31 set out the Net Present Value (NPV) of Adaptation Measure 1 compared to the base case of no adaptation for the following possible measures: permanently opening the lagoon entrance at 70 metres in 2010, 2035 or 2050 or permanently opening the lagoon entrance at 100 metres in 2010, 2035 or 2050, or not at all (2101).

Permanently opening the lagoon at 70 metres in 2010 has a mean NPV of $0.6m. Delaying this measure until 2035 increases the mean NPV to $3.9 m, since the probability of flooding increases over time under most of the changing climate scenarios. However, beyond 2035, the benefits begin to decrease. Permanently opening the lagoon at 100m is not a cost-effective option. This is because the costs are more than the 70m opening for little additional benefit.

Outputs from the Monte Carlo simulation showing the distribution of modelled results are shown in Figure 32 to Figure 37.

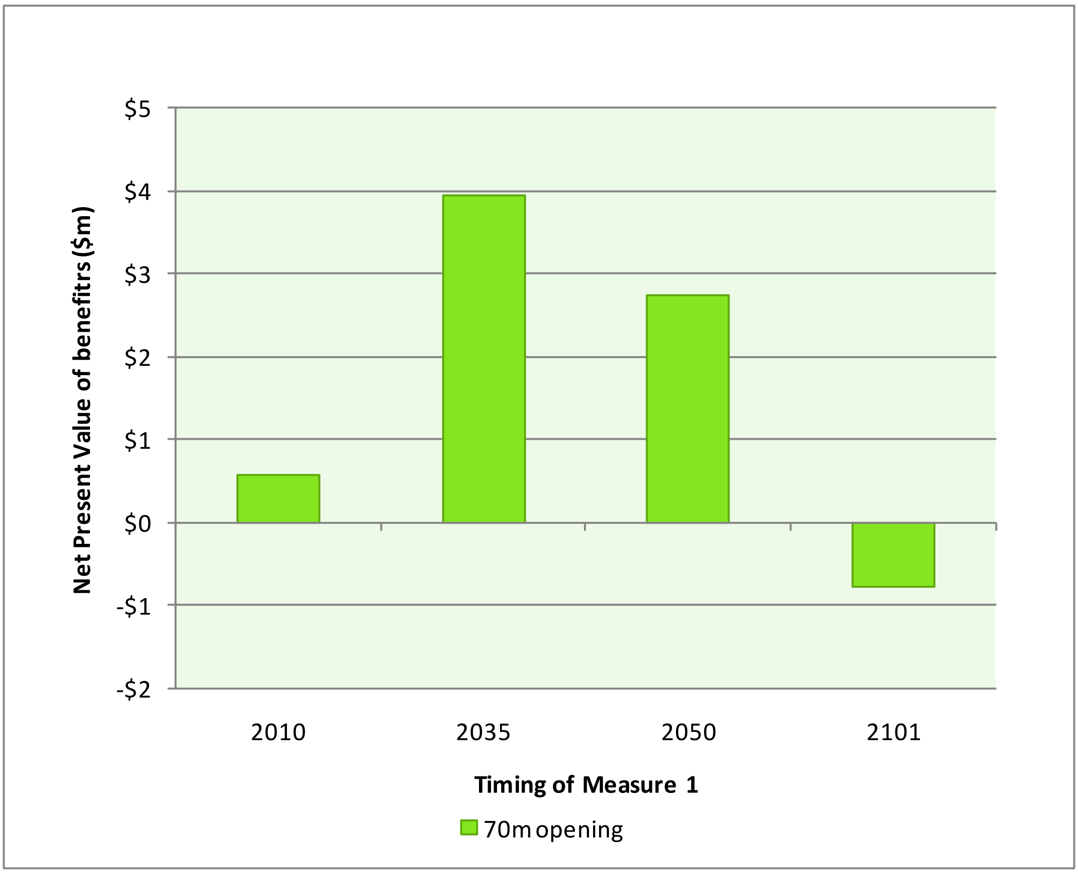


Figure 30: Mean Net Present Value of Adaptation Measure 1 (70m opening) compared with the Base Case of no adaptation

Source: AECOM, 2009

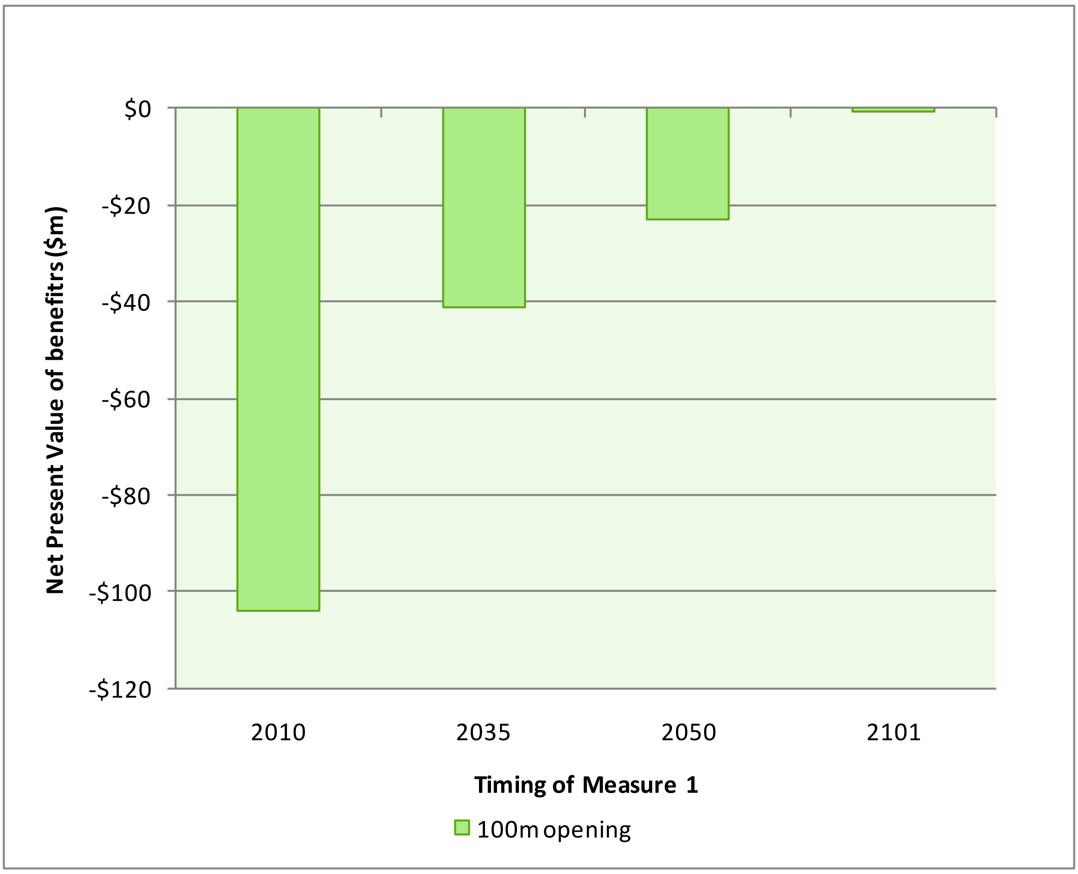


Figure 31: Mean Net Present Value of Adaptation Measure 1 (100m opening) compared with the Base Case of no adaptation

Source: AECOM, 2009

Figure 32: Measure 1 in 2010, with 70m opening (values in $m, discounted to 2009 at 3%)

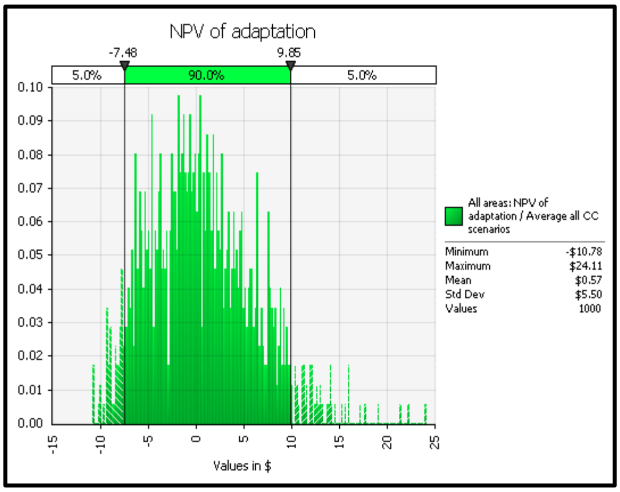


Figure 33: Measure 1 in 2010, with 100m opening (values in $m, discounted to 2009 at 3%)

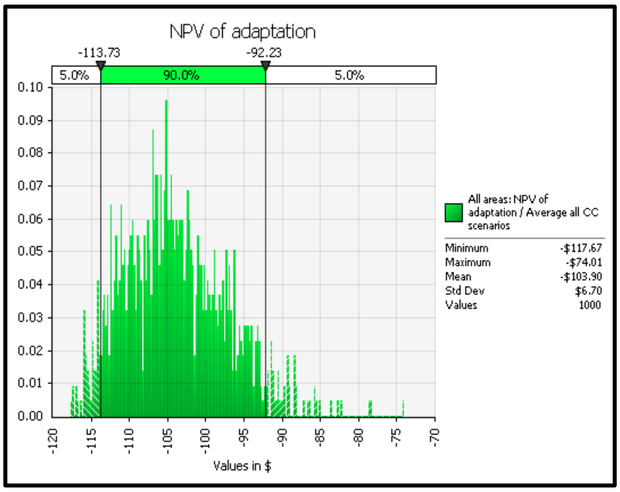


Figure 34: Strategy 1 in 2035, with 70m opening (values in $m, discounted to 2009 at 3%)

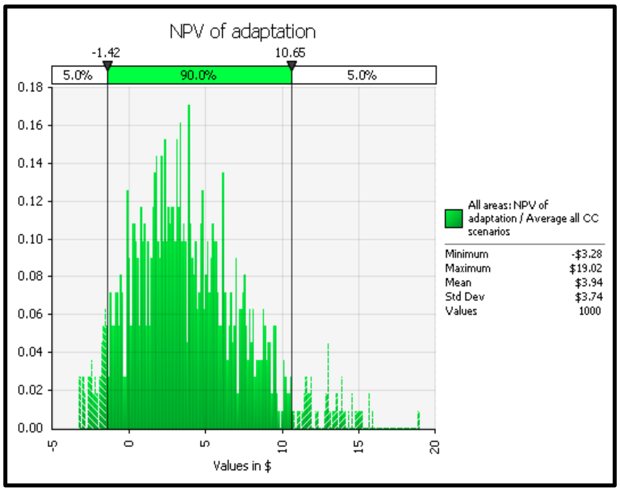


Figure 35: Strategy 1 in 2035, with 100m opening (values in $m, discounted to 2009 at 3%)

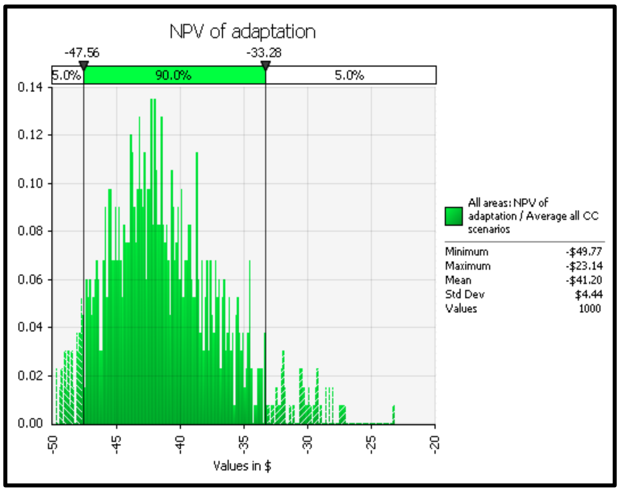


Figure 36: Strategy 1 in 2050, with 70m opening (values in $m, discounted to 2009 at 3%)

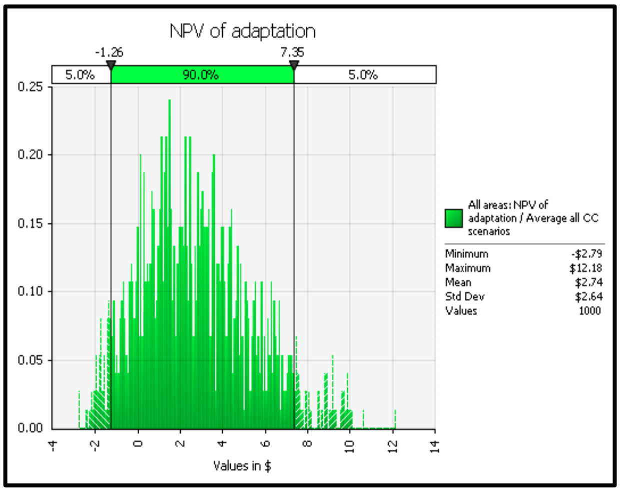
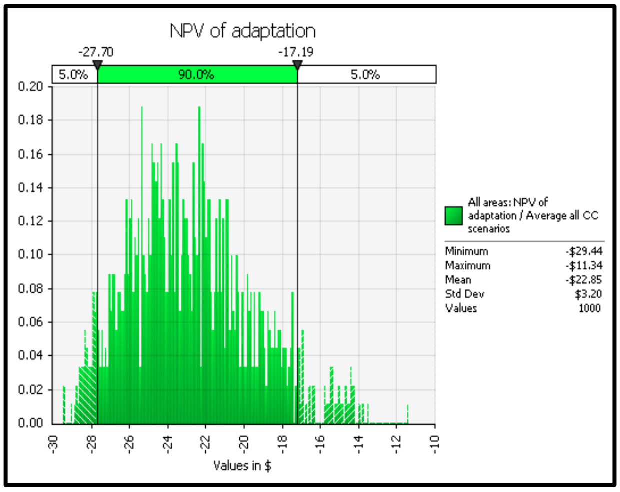


Figure 37: Strategy 1 in 2050, with 100m opening (values in $m, discounted to 2009 at 3%)



7.3 Adaptation measure 2 - Lake Park Road levee

7.3.1 Description of adaptation measure

Currently there are levees constructed around parts of Narrabeen Lagoon which provide some protection such as the levee along the southern boundary of the Sydney Lakeside Holiday Park at North Narrabeen.

Adaptation Measure 2 will increase the level of existing protection by increasing the height and lengthening the levee. The height of the existing earth mound levee would be increased from 2.4m AHD to 2.7m AHD. The levee would then be extended westwards to Pittwater Road by 340m. In addition to providing enhanced protection to the Lakeside Holiday Park, the levee would provide flood protection for up to 113 residential properties in an area bounded by Pittwater Road, Lake Park Road, Collins Street and Berry Avenue. Figure 38 sets out the location of the proposed levee and the area it protects from flooding.

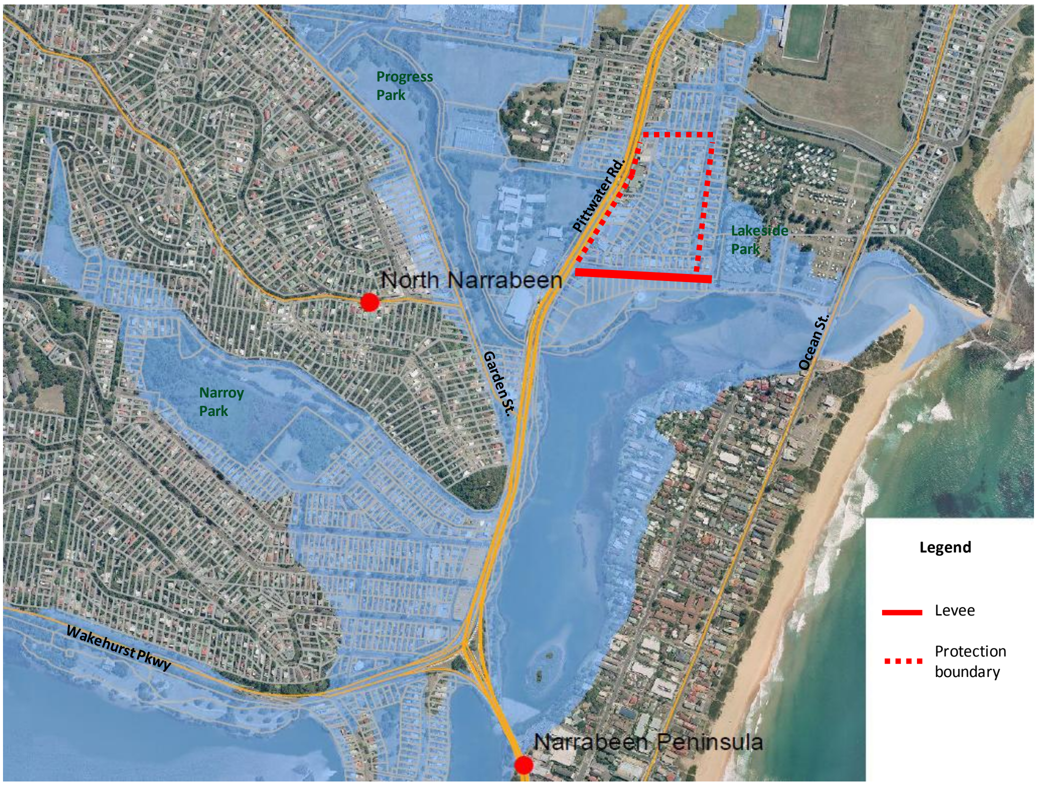


Figure 38: Location of Lake Park Road Levee

Source: AECOM, 2009

7.3.2 Costs of adaptation measure

The upfront capital costs associated with enhancing the Lake Park Road levee up to a height of 2.7m AHD are estimated to be $148,000 with recurrent costs of approximately $2,000 per annum[5].

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[5] Costs are based on information from ERM Mitchell McCotter (1992). These have been inflated to 2009 prices using the NSW General Construction price index (ABS, 2006) and CPI (ABS, 2009). The NSW General Construction Index (GCI) series started in 1998. The trend between CPI and GPI between 1998 and 2009 has been used to estimate the GCI back to 1992.

There is a potential for increased flood impacts on other areas of the lagoon due to the removal of overland flood storage. The evaluation of these impacts is beyond the scope of this study but it is considered that the flood liable areas that would be protected by the levee have little capacity for flood storage, so the impact is likely to be negligible. It can also be expected that the enhancement of the levee will affect visual aesthetics and reduce available usable land.

7.3.3 Benefits of adaptation measure

The primary benefit from the enhancement of the Lake Park Road levee will be protection to residential properties from flood heights up to the levee height. Through this protection, Adaptation Measure 2 will generate improved household welfare from avoided residential damage and the inconvenience associated with a flood event.

As for Adaptation Measure 1, it has been assumed that households are willing to pay an average of 10 percent of their property value to avoid structural damage caused by floods and approximately $200 per annum to avoid contents damage caused by floods and together these represent residents' willingness to pay to avoid damage to their property as well as any inconvenience associated with this such as stress and uncertainty. These benefits will start the year in which the levee is built.

7.3.4 Results

Figure 39 sets out the Net Present Value (NPV) of Adaption Measure 2 compared to the base case of no adaptation for building a 2.7m levee or a 3.0m levee in 2010 or 2050.

The mean NPV of these scenarios is positive in 2010 suggesting it is worthwhile to build a levee at Lake Park Road. However, the NPV decreases over time and is negative in 2050. Since the benefits accrue straight away, the sooner the levee is built the bigger the benefits are. The 2.7m levee results in a higher NPV as the additional costs involved with a higher levee do not yield significantly different benefits. The 2.7m levee also reduces the amenity impacts on local residences.

Outputs from the Monte Carlo simulation showing the distribution of modelled results are shown in Figure 40 to Figure 43.

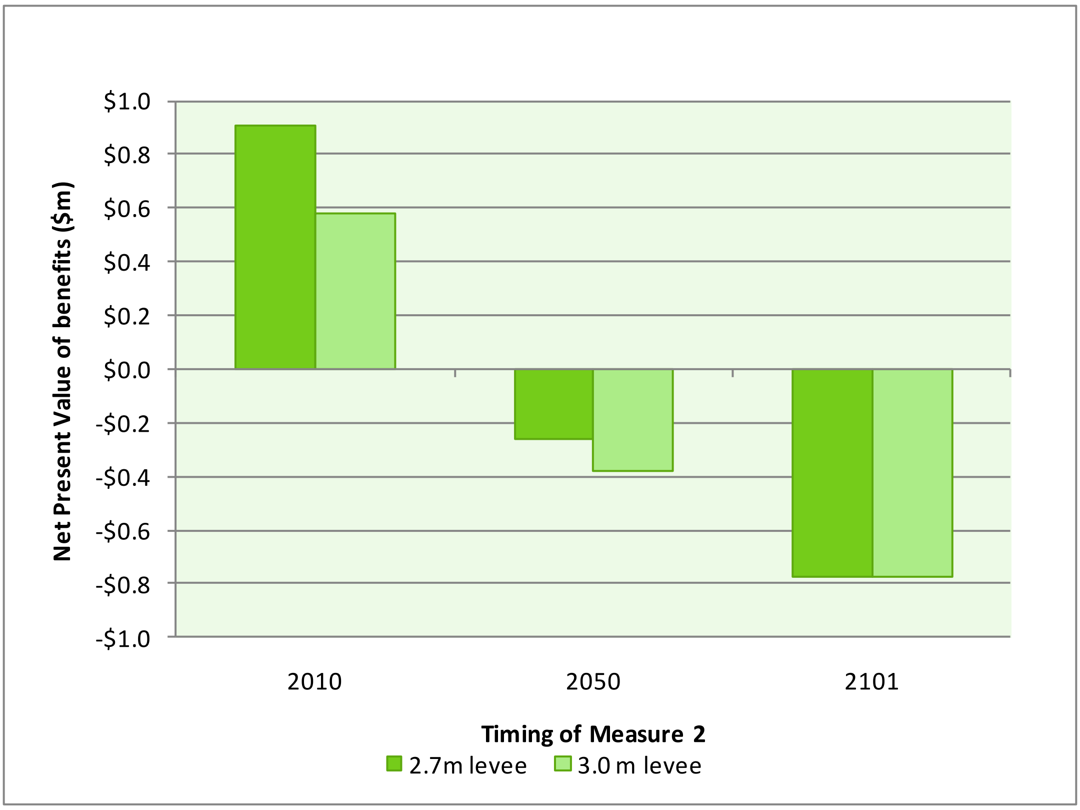


Figure 39: Mean Net Present Value of Adaptation Measure 2 compared with the Base Case of no adaptation

Source: AECOM, 2009

Figure 40: Measure 2 in 2010, with 2.7m levee (values in $m, discounted to 2009 at 3%)

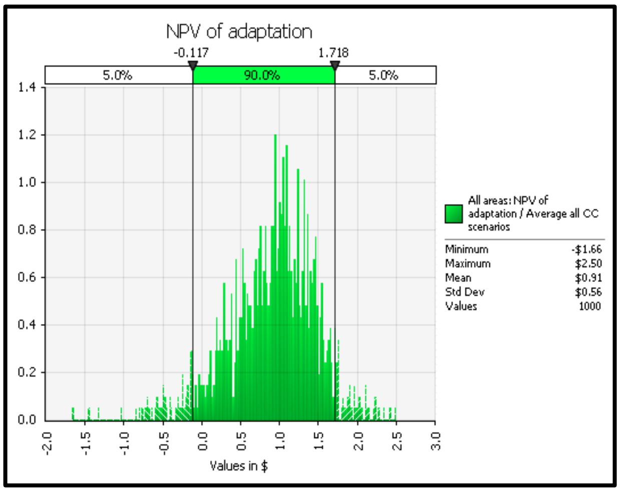


Figure 41: Measure 2 in 2010, with 3.0m levee (values in $m, discounted to 2009 at 3%)

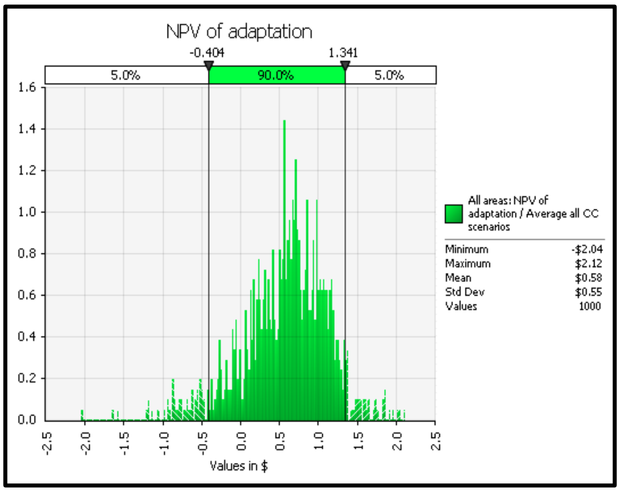


Figure 42: Measure 2 in 2050, with 2.7m levee (values in $m, discounted to 2009 at 3%)

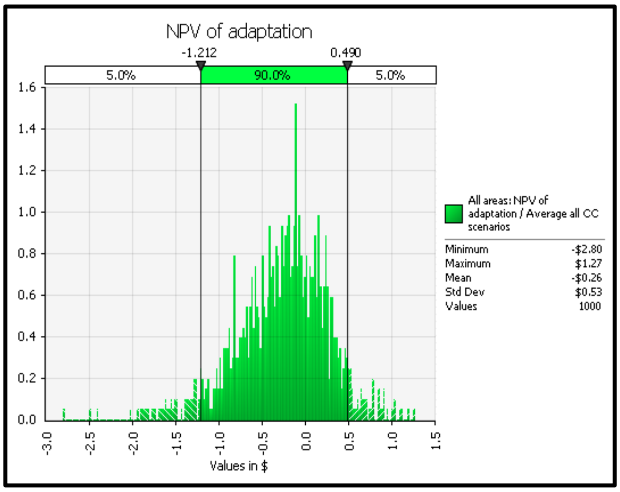
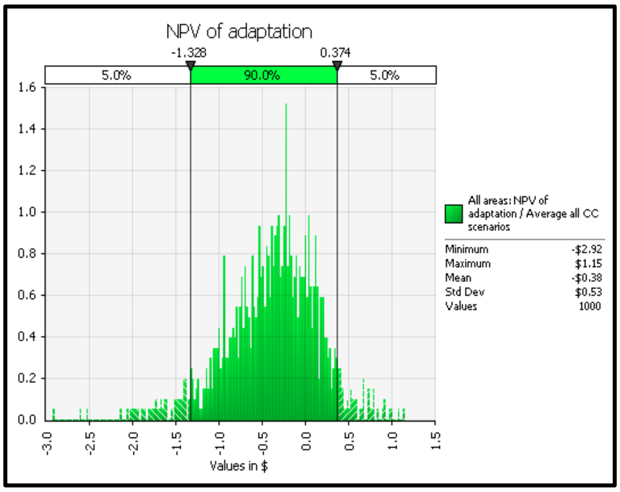


Figure 43: Measure 2 in 2050, with 3.0m levee (values in $m, discounted to 2009 at 3%)



7.4 Adaptation measure 3 - Progress Park levee

7.4.1 Description of adaptation measure

Adaptation Measure 3 will involve the construction of a new earth mound levee in Progress Park. The length of the new levee is approximately 850m and runs along Garden Street as set out in Figure 44. The levee would offer flood protection for up to 50 mainly commercial/industrial properties in the block fronting Garden Street. There is very little protection for residential properties.

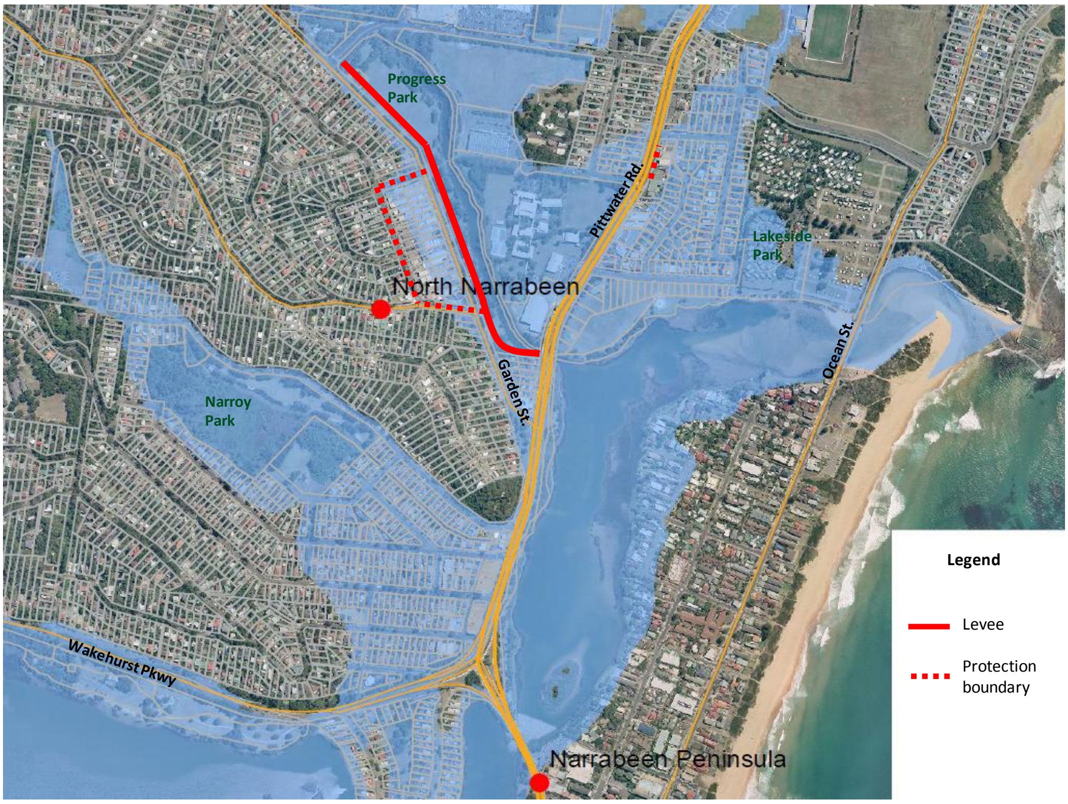


Figure 44: Location of Progress Park Levee

Source: AECOM, 2009

7.4.2 Costs of adaptation measure

The upfront capital costs associated with developing the Progress Park levee to a height of 2.8m AHD are estimated to be $241,000 with recurrent costs of approximately $2,000 per annum[6].

There is a potential for increased flood impacts on other areas of the lagoon due to the removal of overland flood storage. The evaluation of these impacts is beyond the scope of this study, but it is considered that the flood liable areas that would be protected by the levee have little capacity for flood storage, so the impact is likely to be negligible. It can also be expected that the enhancement of the levee will affect visual aesthetics and reduce available usable land.

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6 Costs are based on information from ERM Mitchell McCotter (1992). These have been inflated to 2009 prices using the NSW General Construction price index (ABS, 2006) and CPI (ABS, 2009). The NSW General Construction Index (GCI) series started in 1998. The trend between CPI and GPI between 1998 and 2009 has been used to estimate the GCI back to 1992.

7.4.3 Benefits of adaptation measure

The primary benefit from developing the Progress Park levee will be for the protection of commercial properties from flood heights up to the levee height. Through this protection, Adaptation Measure 3 will generate improved welfare from avoided damage and the inconvenience associated with a flood event.

7.4.4 Results

Figure 45 sets out the Net Present Value (NPV) of Adaption Measure 3 compared to the base case of no adaptation for building a 2.5m levee or a 2.8m levee in 2010 or 2050.

The 2.5m levee has a negative NPV, increasing over time, suggesting the Progress Park Levee is not worthwhile building at this height. Interestingly the 2.8m levee has a higher NPV than 2.5m, still negative but decreasing over time. This suggests that a higher levee may be worth building at some time but not before 2101.

Modelling has not yet revealed when a levee might be worthwhile. All NPVs are small, so decisions about this measure are not clear-cut.

Outputs from the Monte Carlo simulation showing the distribution of modelled results are shown in Figure 46 to Figure 51Figure 40.

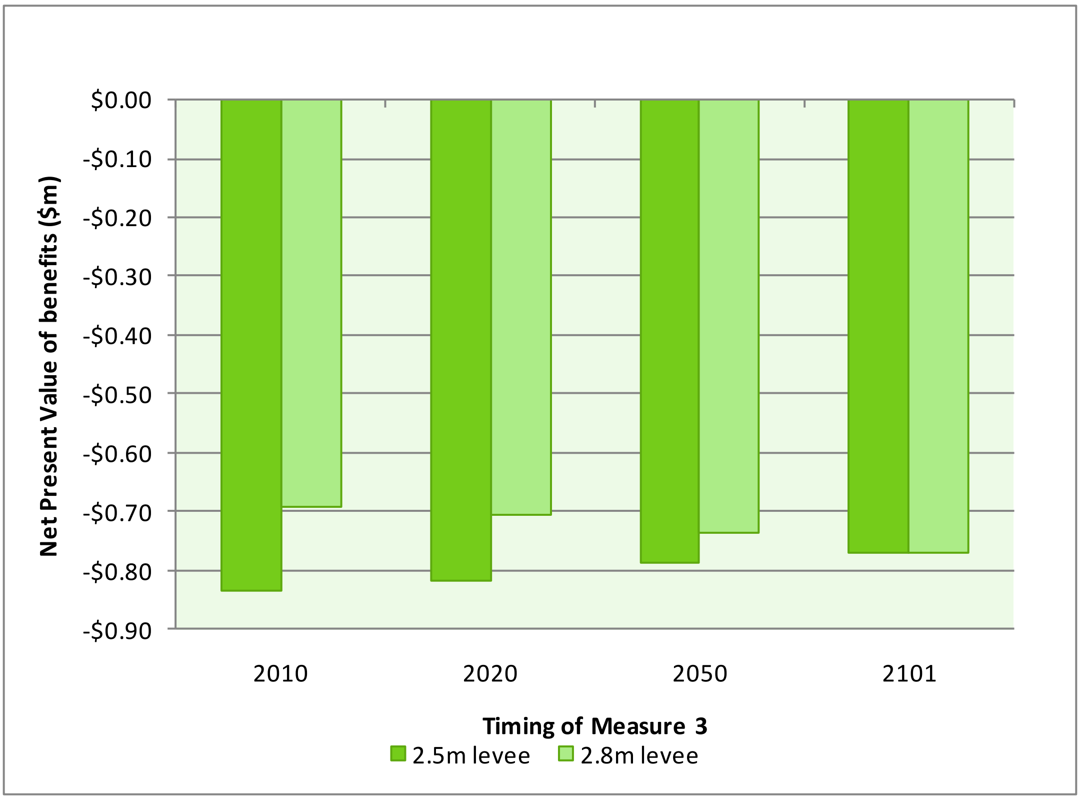


Figure 45: Mean Net Present Value of Adaptation Measure 3 compared with the Base Case of no adaptation

Source: AECOM, 2009

Figure 46: Measure 3 in 2010, with 2.5m levee (values in $m, discounted to 2009 at 3%)

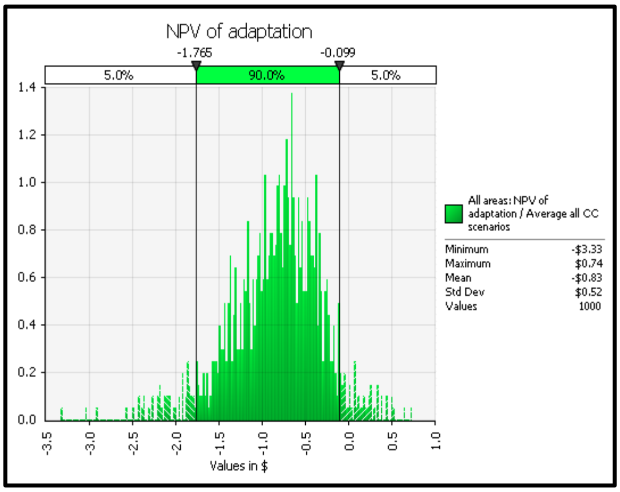


Figure 47: Measure 3 in 2010, with 2.8m levee (values in $m, discounted to 2009 at 3%)

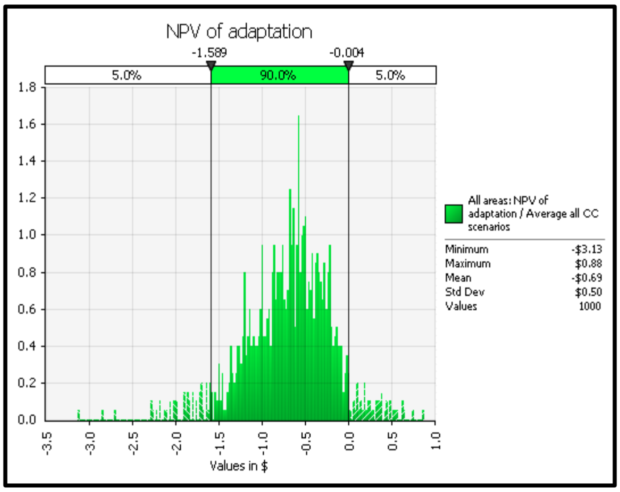


Figure 48: Measure 3 in 2020, with 2.5m levee (values in $m, discounted to 2009 at 3%)

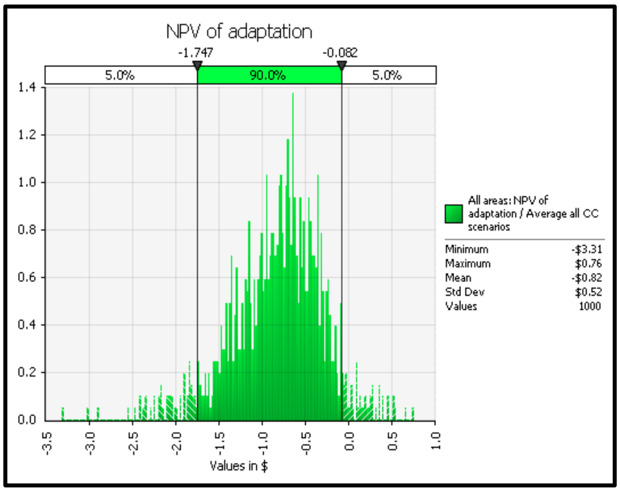


Figure 49: Measure 3 in 2020, with 2.8m levee (values in $m, discounted to 2009 at 3%)

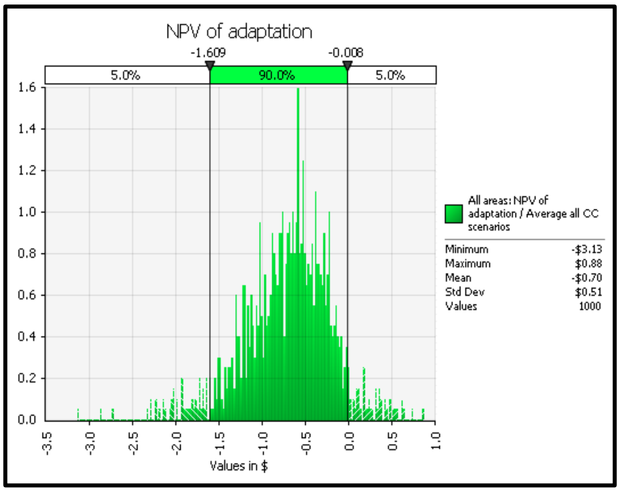


Figure 50: Measure 3 in 2050, with 2.5m levee (values in $m, discounted to 2009 at 3%)

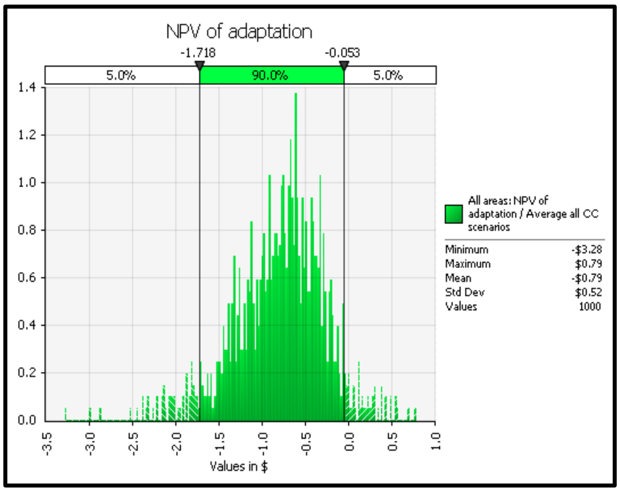
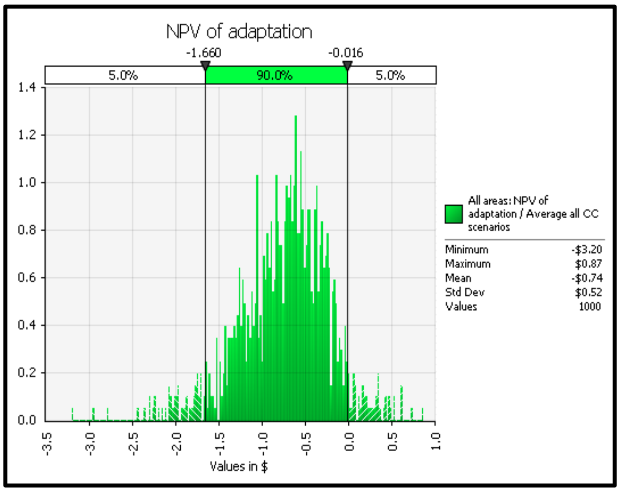


Figure 51: Measure 3 in 2050, with 2.8m levee (values in $m, discounted to 2009 at 3%)



7.5 Adaptation measure 4 - Nareen Creek floodwall and floodgates

7.5.1 Description of adaptation measure

Adaptation Measure 4 involves a small flood wall constructed along Wakehurst Parkway to protect the lower reaches of the Nareen Creek catchment from backwater flooding from the lagoon, as shown in Figure 52. In addition to the flood wall, flood gates would also be installed on the culvert outlets discharging into the lagoon at Pittwater Road and Wakehurst Parkway. These flood gates would prevent flows from Narrabeen Lagoon backing up the culverts into Nareen Creek. These flood gates can also be opened to reduce local catchment flooding in Nareen Creek providing the lagoon is not also flooded.

The floodwall and floodgates would provide protection for up to 299 residential properties in an area bounded at the northern end by Nareen Parade, Rickard Road, and Gondola Road and by Pittwater Road and Wakehurst Parkway at the southern end.

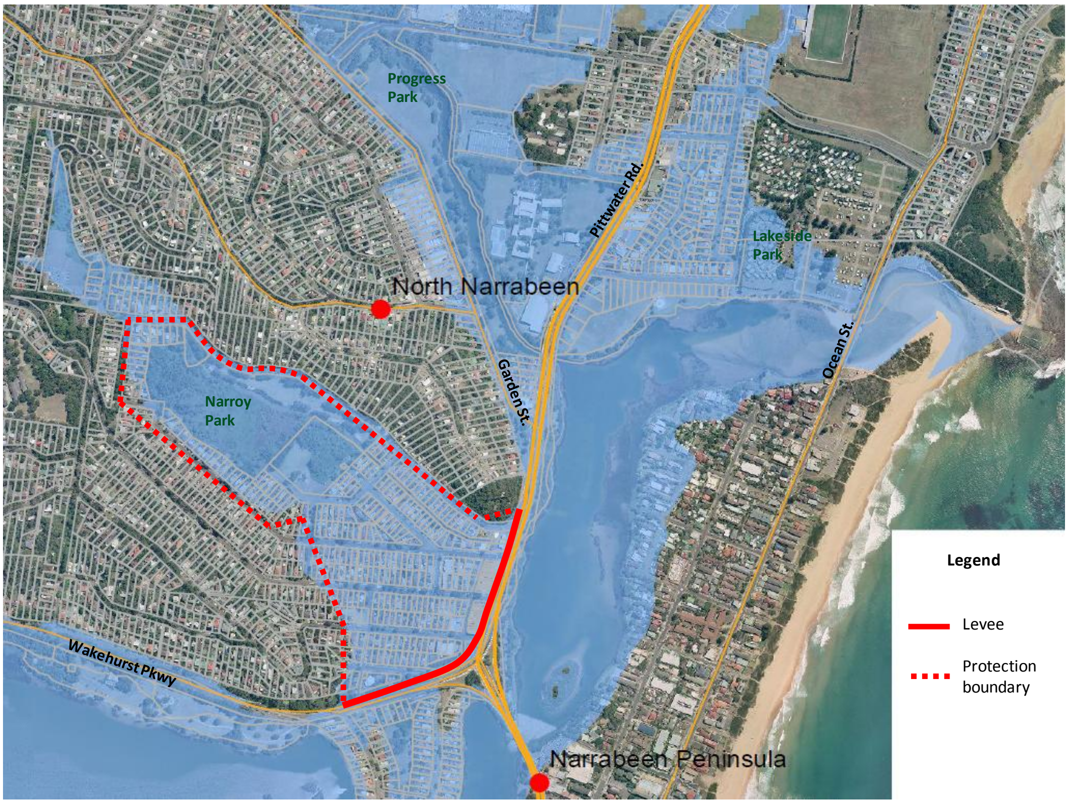


Figure 52: Location of Nareen Creek floodwall and floodgates

Source: AECOM, 2009

7.5.2 Costs of adaptation measure

The upfront capital costs associated with developing the Nareen Creek floodwall and floodgates to a height of 2.4m AHD are estimated to be $340,000 with recurrent costs of approximately $2,000 per annum. Note: the Nareen Creek flood study is currently considering this option and has included cost estimates (PDW, 2010).

There is a potential for increased flood impacts on other areas of the lagoon due to the removal of overland flood storage. The evaluation of these impacts is beyond the scope of this study. However, it is considered that the flood liable areas that would be protected by the levee have little capacity for flood storage, so the impact is likely to be negligible. It can also be expected that the enhancement of the levee will have impacts on visual aesthetics and reduce available usable land.

7.5.3 Benefits of adaptation measure

The primary benefit from the construction of the Nareen Creek floodwall and floodgates will be from the protection to residential properties from flood heights up to the levee height. Through this protection, Adaptation Measure 4 will generate improved household welfare from avoided residential damage and the inconvenience associated with a flood event.

As for Adaptation Measure 1, it has been assumed that households are willing to pay an average of 10 percent of their property value to avoid structural damage caused by floods and approximately $200 per annum to avoid contents damage caused by floods and together these represent residents' willingness to pay to avoid damage to their property as well as any inconvenience associated with this such as stress and uncertainty. These benefits will start the year in which the floodwall is built.

7.5.4 Results

Figure 53 sets out the Net Present Value (NPV) of Adaption Measure 4 compared to the base case of no adaptation for building a 2.3m flood or a 2.4m flood wall in 2010 or 2050.

All of the scenarios provide a negative NPV suggesting it is not worthwhile building a flood wall at the lower reaches of the Nareen Creek. The NPV becomes more viable over time suggesting the benefits from this option accrue much further into the future.

Outputs from the Monte Carlo simulation showing the distribution of modelled results are shown in Figure 54 to Figure 59.

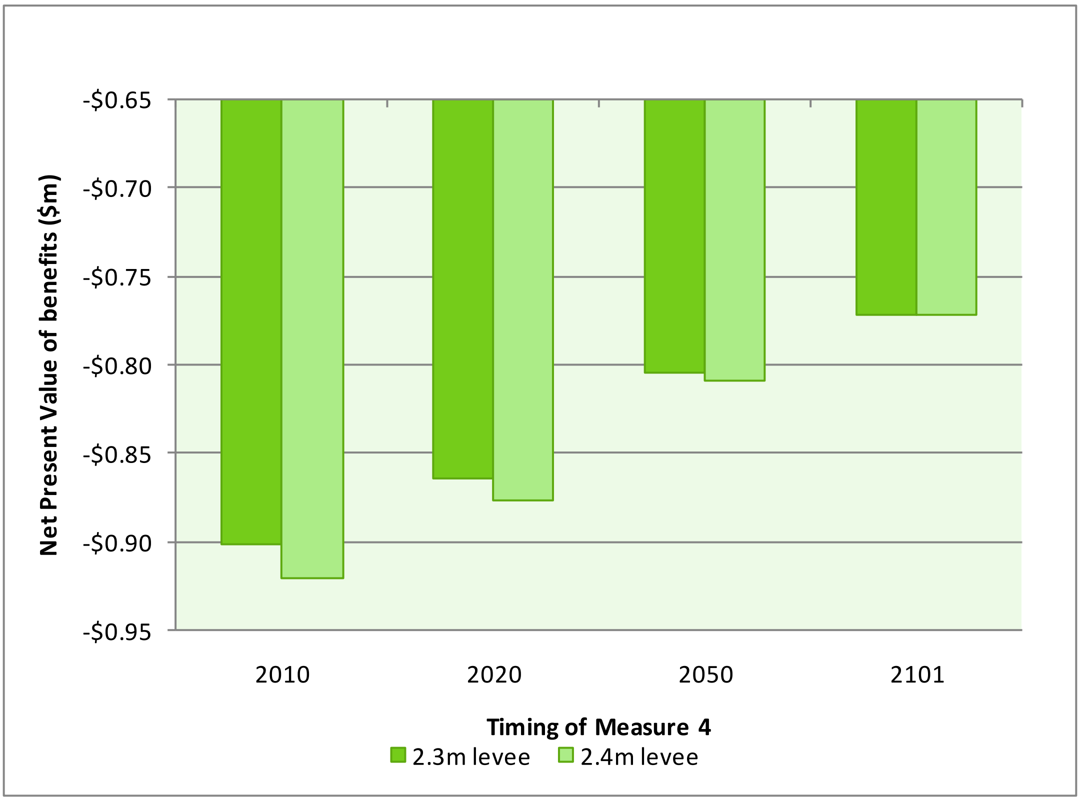


Figure 53: Mean Net Present Value of Adaptation Measure 4 compared with the Base Case of no adaptation

Source: AECOM, 2009

Figure 54: Measure 4 in 2010, with 2.3m levee (values in $m, discounted to 2009 at 3%)

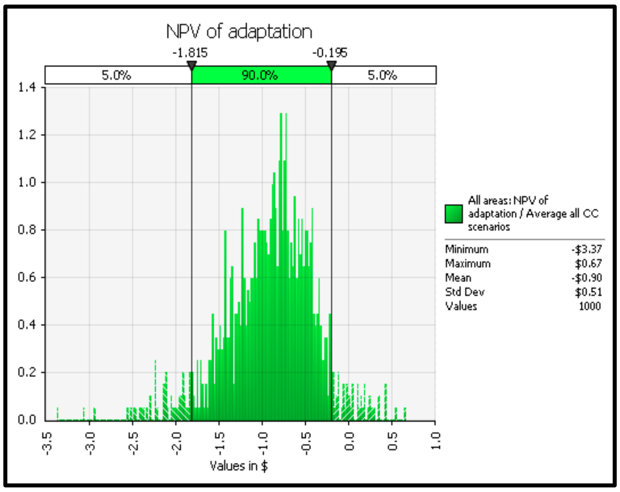


Figure 55: Measure 4 in 2010, with 2.4m levee (values in $m, discounted to 2009 at 3%)

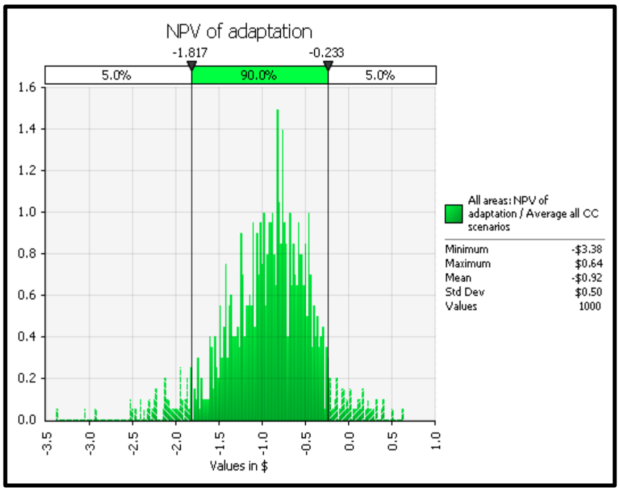


Figure 56: Measure 4 in 2050, with 2.3m levee (values in $m, discounted to 2009 at 3%)

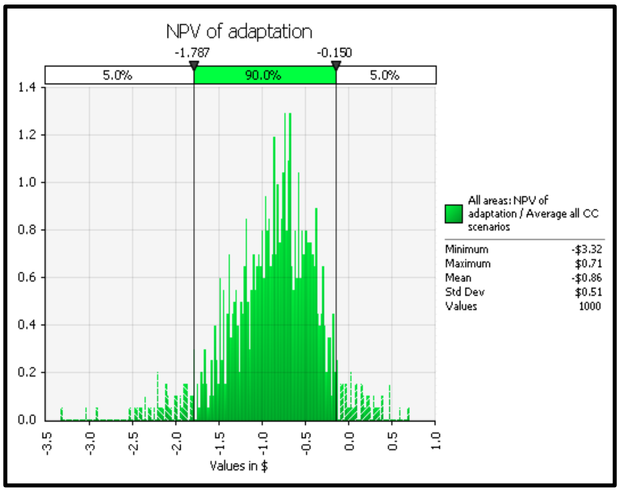


Figure 57: Measure 4 in 2050, with 2.4m levee (values in $m, discounted to 2009 at 3%)

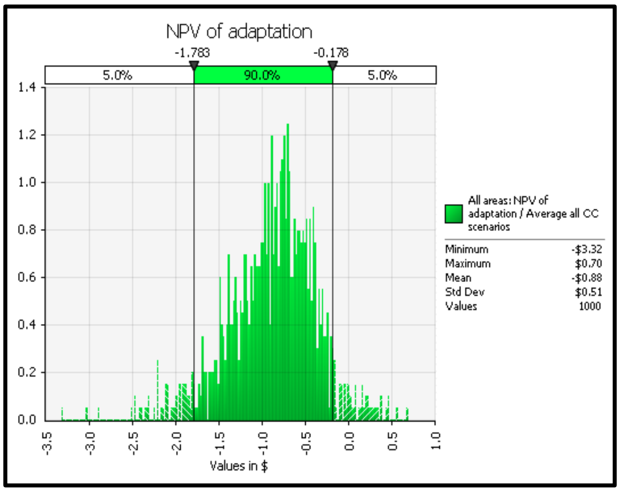


Figure 58: Measure 4 in 2050, with 2.3m levee (values in $m, discounted to 2009 at 3%)

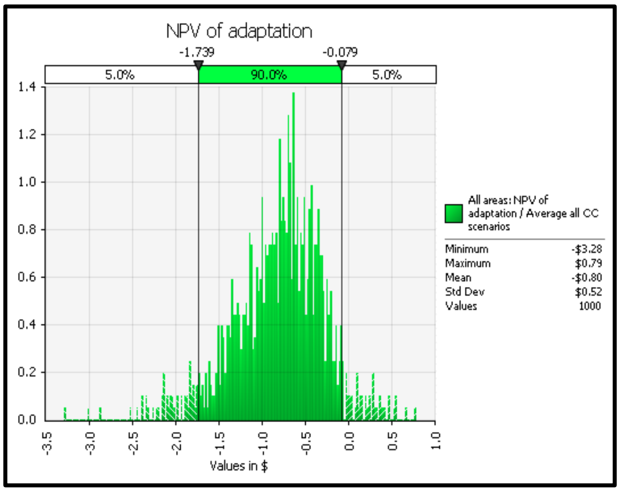
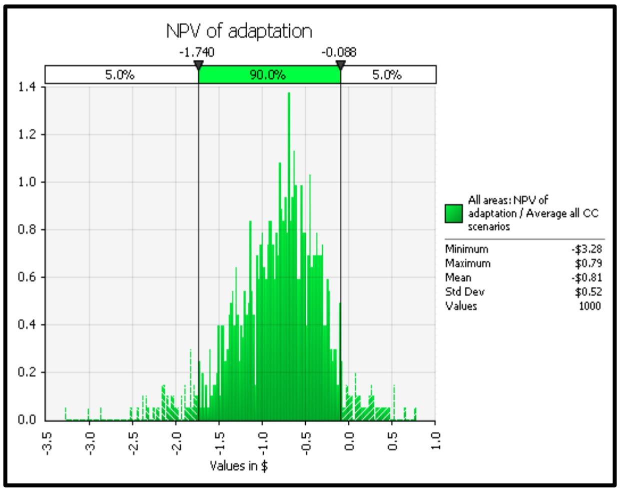


Figure 59: Measure 4 in 2050, with 2.4m levee (values in $m, discounted to 2009 at 3%)



7.6 Adaptation measure 5 – early flood warning system

7.6.1 Description of adaptation measure

A large proportion of the costs of flooding are attributable to damage to residential and commercial premises and the subsequent inconvenience. Early flood warning systems designed to warn residents and businesses to prepare for a potential flood event can allow residents and businesses to take steps to minimise damage to their contents. For instance, valuables and inventory could be moved to higher ground prior to a flood arriving.

The adoption of Adaptation Measure 5 would require an early flood warning system, usually carried out in co-ordination with the State Emergency Services which would be able to:

- Predict approximate height and timing of flood levels;
- Efficiently and effectively disseminate these predictions to affected individuals promptly;
- Inform the community how to respond; and
- Set evacuation thresholds and procedures.

In addition to the flood warning system a flood awareness campaign would be implemented to ensure local residents and business know how to respond to a warning system. This would include the distribution of flood information toolkits to flood affected residents and businesses, providing education on the nature of flooding, how to obtain information on the onset of a flood and what to do during a flood. Information toolkits have already been distributed to parts of Warringah and Pittwater Council areas.

7.6.2 Costs of adaptation measure

The upfront capital costs associated with setting up an early flood warning system and an awareness campaign are assumed to cost around $100,000 with recurrent costs of approximately $5,000 per annum[7].

In the event of a pending flood, households and businesses are expected to incur some loss of productive time in order to prepare for a flood. An additional day per person per household and a day of lost trade for businesses have been counted as an inconvenience cost[8].

7.6.3 Benefits of adaptation measure

Previous studies have shown that a community with high flood awareness will suffer less damage and disruption during and after a flood (Dept. of Environment and Climate Change, 2005). People are aware of the potential of the situation and listen to official warnings on the radio and television. It is common for residents in flood liable areas, particularly those who have experienced flooding in the past, to develop flood compatible storage facilities and buildings. Whilst their property may still be damaged, they can move their contents to higher levels and non-replaceable items such as photographs can be put in safe places reducing the stress associated with flood events. It is also likely that households that are prepared and able to move possessions to high levels will need less time to clear up after the flood event.

Improved household welfare

As set out in Section 7.2.3, the Hawkesbury-Nepean Floodplain Management Steering Committee's study (2006) shows households are willing to pay around $200 per annum to avoid contents damage caused by flood. It has been assumed that all 1432 households within the floodplain area receive a benefit of $200 per annum from this Adaptation Measure. These benefits start the year in which Adaptation Measure 5 is implemented.

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[7] ERM Mitchell McCotter (1992) estimates a Lagoon watch monitoring program will cost in the region of $40,000 and a community awareness program will cost around $40,000. The Manly flood study has similar costs.

[8] Average wages have been used as a proxy for a lost day for residences and average profit as a proxy for a lost day for commercial businesses.

Avoided inconvenience costs for commercial properties

Raising flood awareness and preparedness to flooding has the ability to reduce flood related damages. To provide an indication on the quantum of reduction, ERM Mitchell McCotter (1992) study noted that flood damage to residential and commercial buildings could be reduced by the following proportions if people were prepared for the flood:

Table 20: Potential Reduction in Damages Due to an Early Warning System

Flood Event	Reduction in Damage Due to Warning System
1 in 20 year flood	70%
1 in 100 year flood	40%
Extreme flood event	0%

Source: workshop with Pittwater Council

As a conservative measure, AECOM has assumed that increased awareness and preparedness could reduce the actual to potential damages ratio by 20% for commercial businesses. These benefits start the year in which Adaptation Measure 5 is implemented.

7.6.4 Results

Figure 60 sets out the Net Present Value (NPV) of Adaption Measure 5 compared to the base case of no adaptation if this measure was implemented in 2010 and 2050.

The early flood warning system provides a NPV of $12.0 million if it is implemented in 2010 and this reduces to $2.5 million if this is delayed until 2050. Given this is a low cost option, it is worthwhile implementing straight away.

Outputs from the Monte Carlo simulation showing the distribution of modelled results are shown in Figure 61 and Figure 62.

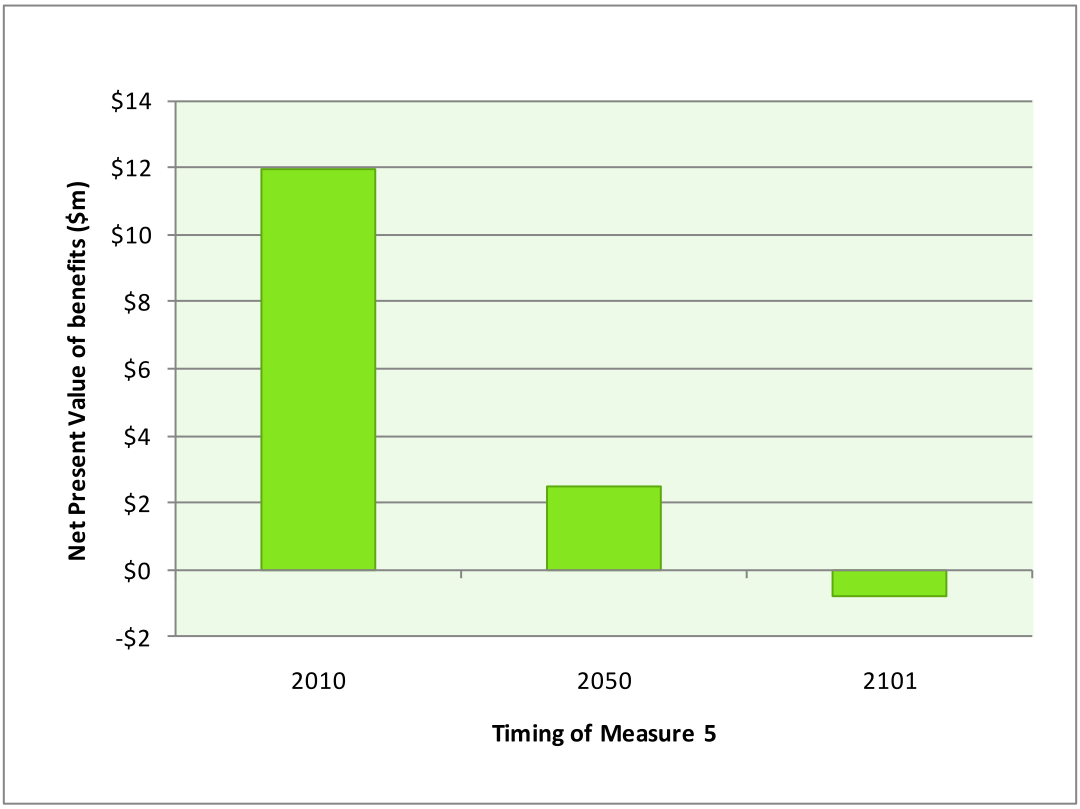


Figure 60: Mean Net Present Value of Adaptation Measure 5 compared with the Base Case of no adaptation
Source: AECOM, 2009

Figure 61: Measure 5 in 2010 (values in $m, discounted to 2009 at 3%)

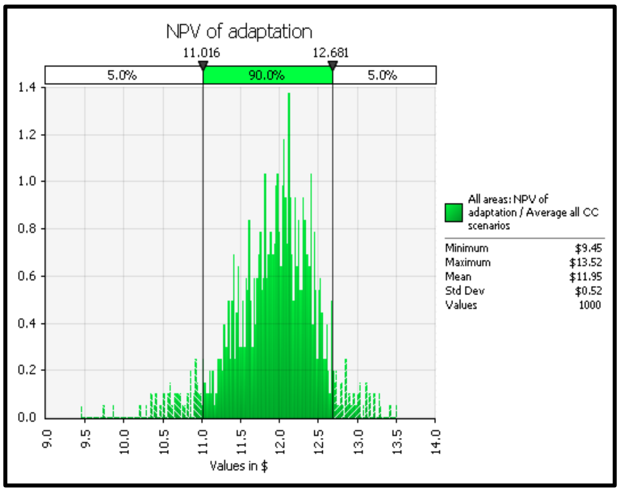
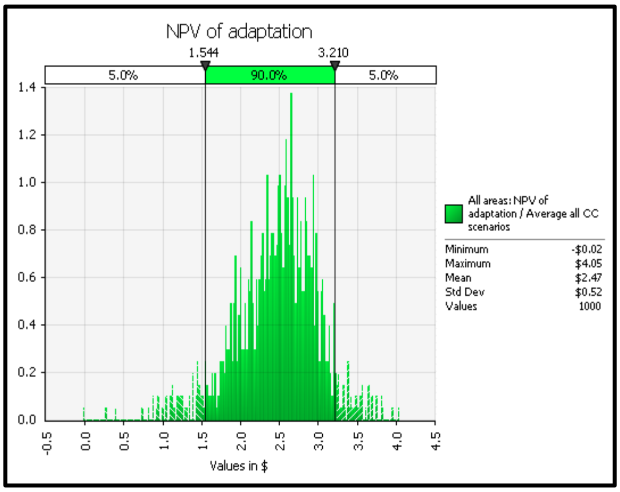


Figure 62: Measure 5 in 2050 (values in $m, discounted to 2009 at 3%)



7.7 Adaptation measure 6 – introduction of flood planning controls

7.7.1 Description of adaptation measure

Adaptation Measure 6 involves the introduction of planning regulations that will increase the minimum floor height by one metre for all new buildings and building renovations that require planning permission. In raising minimum floor heights, the severity of future floods will be reduced by increasing the number of properties above future flood levels.

It should be noted that this study does not consider what the optimal minimum floor height should be. However, it is assumed that an increase in the minimum floor height by one metre should be sufficient to protect properties from potential structural and contents damage caused by future 100 year ARI floods under the 10 OAGCMs until 2100.

7.7.2 Costs of adaptation measure

The one-off cost of raising a residential dwelling by one metre has been estimated to be $20,000[9]. No recurrent costs are expected to be incurred from the raising of dwellings.

With minimal increase in the number of dwellings expected to be constructed within the study area, the additional cost of complying with new flood planning controls was applied only to existing dwellings. It has been assumed that on average a house is renovated every 40 years, so 2.5 percent of the existing housing stock in the study area will be renovated and raised each year subsequent to the introduction of Adaptation Measure 6. It is worth noting that not every property can be raised in which case an additional level is added to the property at a higher cost. In summary, a one-off raising cost of $20,000 was applied to 2.5 percent of the housing stock every year.

7.7.3 Benefits of adaptation measure

The primary benefit from the adoption of stricter minimum flood height levels will be from the protection to the raised residential properties. Through this protection, Adaptation Measure 6 will generate improved household welfare from avoided residential damage and the inconvenience associated with a flood event.

[9] These costs have been based on ERM Mitchell McCotter (1992) which estimated that the cost incurred to raise floor levels by one metre was $10,000 These have been inflated to 2009 prices using the NSW General Construction price index (ABS, 2006) and CPI (ABS, 2009). The NSW General Construction Index (GCI) series started in 1998. The trend between CPI and GPI between 1998 and 2009 has been used to estimate the GCI back to 1992.

As for Adaptation Measure 1, it has been assumed that households are willing to pay an average of 10 percent of their property value to avoid structural damage caused by floods and approximately $200 per annum to avoid contents damage caused by floods and together these represent residents' willingness to pay to avoid damage to their property as well as any inconvenience associated with this such as stress and uncertainty. These benefits will start to accrue proportionally from the year in which the controls are first introduced.

7.7.4 Results

Figure 63 sets out the Net Present Value (NPV) of Adaptation Measure 6 compared to the base case of no adaptation if this measure was implemented in 2010 and 2050.

The introduction of flood planning controls provides a NPV of $13.8 million if it is implemented in 2010 and this reduces to $3.8 million if this is delayed until 2050, suggesting that consideration should be given to its immediate implementation.

Outputs from the Monte Carlo simulation showing the distribution of modelled results are shown in Figure 64 and Figure 65.

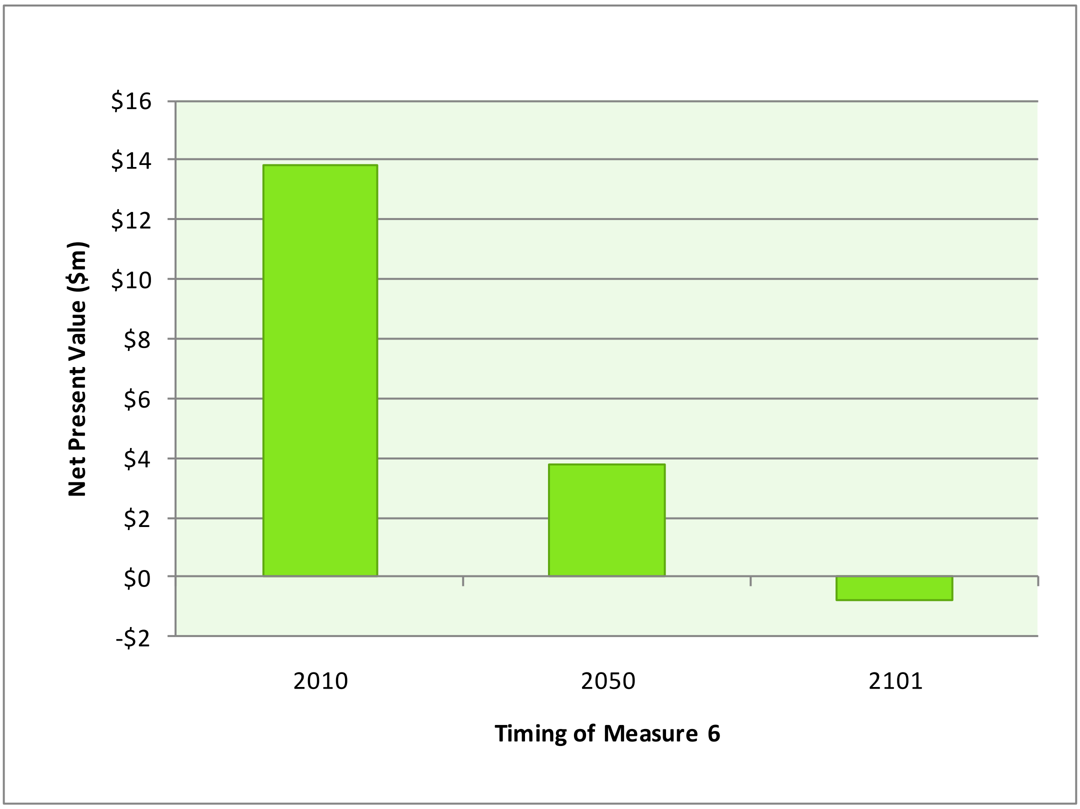


Figure 63: Mean Net Present Value of Adaptation Measure 6 compared with the Base Case of no adaptation

Source: AECOM, 2009

Figure 64: Measure 6 in 2010 (values in $m, discounted to 2009 at 3%)

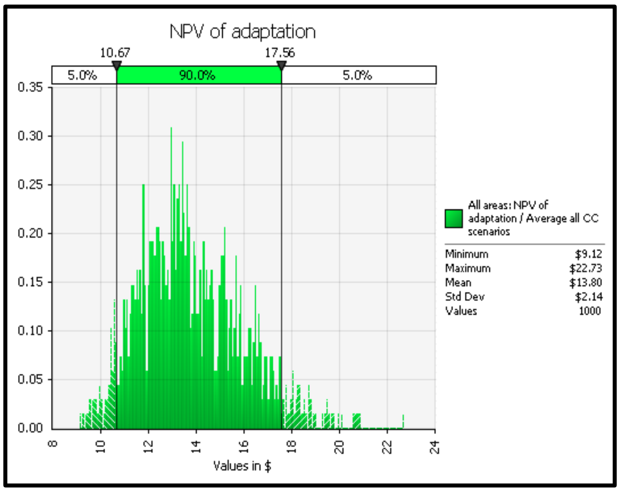
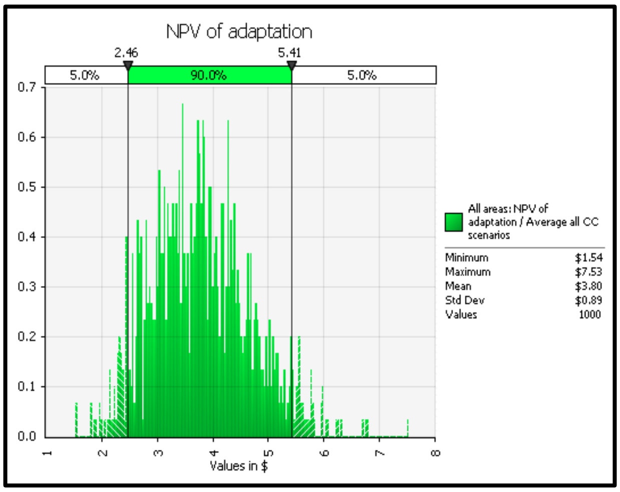


Figure 65: Measure 6 in 2050 (values in $m, discounted to 2009 at 3%)



8.0 Findings and lessons

8.1 Preferred portfolio

The preferred portfolio of adaptation measures should be chosen as the best response for the present (now) given the expected impacts of climate change under a range of climate scenarios considered until 2100.

AECOM proposes that the 'best' response is that which maximises net economic benefits of adaptation compared to no adaptation, that is, strategies are ranked in terms of their expected[10] net present value of benefits. This method of ranking is better than the following alternatives:

- Net benefits for 'worst case' climate scenario — this method of ranking would place too much weight on a single climate scenario rather than take account of the uncertainty in climate forecasts;
- Net benefits with 10% probability of exceedance across all climate scenarios — this method of ranking would place too much weight on higher risk outcomes;
- Risk, for example measured as variance in net benefits across climate scenarios — this method of ranking would place too little weight on the costs of adaptation.

AECOM has therefore extended its probabilistic modelling to seek to **maximise** the net benefits of combined adaptation by:

- using the optimisation feature of @Risk modelling environment with the objective of maximising expected net present value of benefits; and
- searching through the 12 dimensional space of possible adaptation scope and timing to search for combinations with higher benefits.

The maximising model was run to analyse different combinations of adaptation measures and to search for portfolios with higher benefits. It must be understood that the modelling may not have settled on the portfolio that completely maximises net benefit, due to the limitations of the modelling.

The most appropriate strategy for adaptation will be a portfolio of responses, that is, a combination of various measures for adaptation at different times. AECOM has therefore extended its probabilistic modelling to combine the costs of adaptation but counting additional benefits once only. To date, the search has found that highest value seems to come from Measures 2, 5 and 6 being implemented in 2010, Measure 1 being implemented later in the period (2035) and Measures 3 and 4 deferred until after 2100. The sizes and timing of measures within the overall portfolio are shown in Table 22.

[10] Expected net present value of benefits means the probability weighted average across all climate scenarios of net present value of benefits for each scenario.

Table 21: Strategies in preferred portfolio

Adaptation Measure	Dimensions (m)	Timing
Lagoon Opening (measure 1) Permanent opening of the lagoon entrance. By controlling the build up of sand, flood waters can flow out quicker reducing the severity of flood events.	70.0 width	2035[1]
Lakeside Levee (measure 2) Increase the level of existing flood protection at Lakeside by increasing the height and lengthening the levee.	2.7 height	2010
Progress Park Levee (measure 3) Construction of a new earth mound levee in Progress Park for flood protection for mainly commercial/industrial properties.	2.5 height	2101[2]
Nareen Creek Levee (measure 4) Flood wall and flood gates constructed to protect the lower reaches of the Nareen Creek catchment from backwater flooding from the lagoon.	2.3 height	2101[2]
Flood Awareness (measure 5) Early flood warning systems designed to prepare residents and businesses to take steps to minimise damage to property, contents and operations.	Not Applicable	2010
Planning Control (measure 6) Planning regulations increasing minimum floor height for all new buildings and building renovations to reduce severity of floods and the number of buildings impacted.	Height not modelled[3]	2010

1. Measure 1 is best deferred until later in the period when probability of flooding increases
2. Modelling suggests that Measures 3 and 4 are not yet worthwhile but may become so in long-term future
3. Not modelled for optimum minimum floor height, this needs to be explored by Pittwater Council in development of any planning controls. Several arbitrary heights up to 1 metre were utilised for this assessment.

The following figure shows that it is 90% likely that net present value of benefits will be between $23.8m and $42.5m. The mean expected net present value of benefits is $32.0 million, with a standard deviation of $5.69 million benefits.

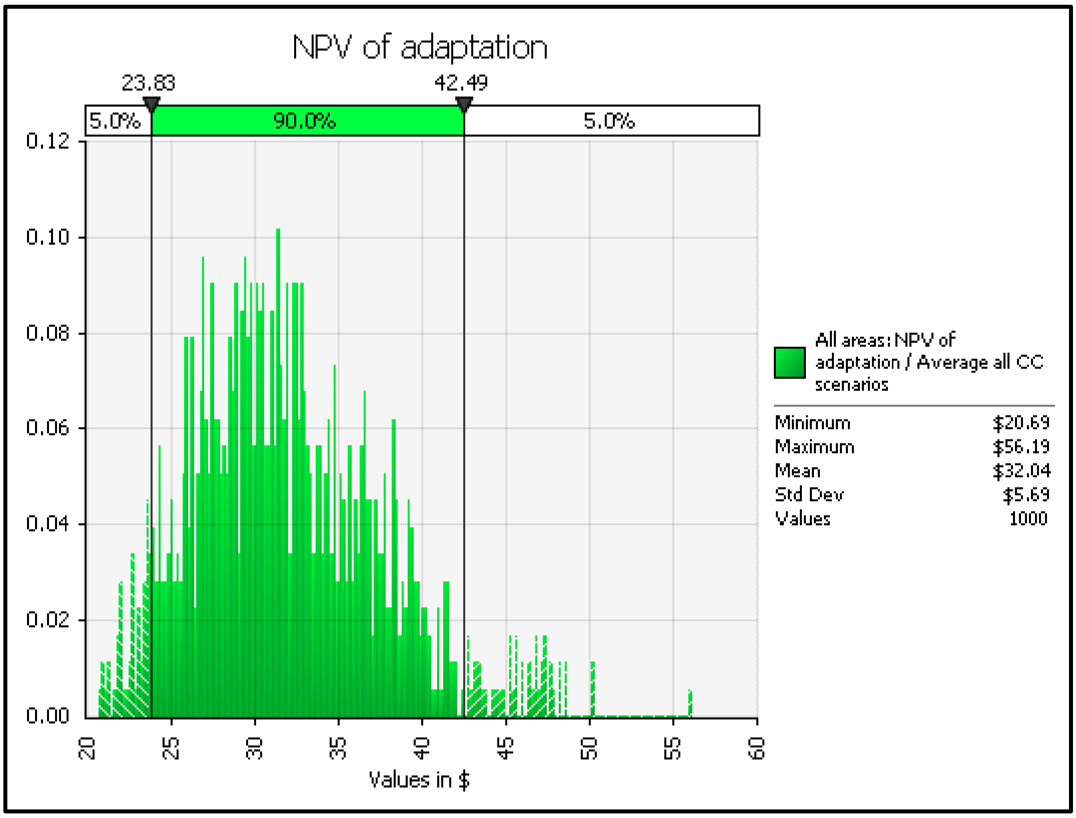


Figure 66: NPV of adaptation (values in $m, discounted to 2009 at 3%)

8.2 Lessons for other areas

In NSW there are around 70 major estuaries classified as intermittently closed or open lake or lagoon (ICOLLs). Most of these are located near Sydney, which also contains the greatest density of ICOLLs in Australia, due to the high wave activity, low rainfall and close proximity of the Great Dividing Range to the coast (Haines *et al.*, 2006). Coastal lagoons typically have large populations living around them. In NSW 75% of the population live near the coast and estuaries. In addition, coastal lagoons are a popular destination for both domestic and international tourists.

The benefits and costs of adaptation strategies analysed in this case study are specific to Narrabeen Lagoon. However there are some lessons that can be drawn for other ICOLLs.

- Residents are willing to pay to receive greater protection against property structural damage and contents damage. There are few avenues to capture this willingness to pay, for example, limited availability of flood insurance, so benefits arises from any measures that could reduce flood impacts.
- Few of the preferred adaptation measures involve changes to physical infrastructure in the short term.
- Flood awareness measures appear to have high net benefits and to be immediately worthwhile. However consultation suggests that such programs are not rated highly – perhaps because flooding is infrequent.
- Changes to flood planning levels provide benefits from long term warnings about risks of flooding but further work would be needed to specify an appropriate change in planning heights.

The following lessons apply to adaptation generally.

- Many adaptation measures have net benefits even in the absence of climate change, that is, are ‘no regrets’ measures. The risk of climate change may focus attention on the measures and could be a benefit in encouraging their adoption.
- There is value in having options to implement climate adaptation measures in the future, even though the measures may not have immediate value.

9.0 References

Australian Bureau of Statistics, 2006a, *Producer Price Indexes*, "Tables 15 and 16. Output of the General Construction Industry", Cat. no. 6427.0.55.001, Australian Bureau of Statistics, Canberra.

Australian Bureau of Statistics, 2006b, *Census of Population and Housing: Socio-Economic Indexes for Areas (SEIFA), Australia*, Cat. no. 2033.0.55.001, Australian Bureau of Statistics, Canberra.

Australian Bureau of Statistics, 2007. *2006 Census of Population and Housing*, Australian Bureau of Statistics, Canberra.

Australian Bureau of Statistics, 2009, *Consumer Price Index*, "Tables 1 and 2. CPI: All Groups, Index Numbers and Percentage Changes", Cat. no. 6401.0, Australian Bureau of Statistics, Canberra.

Australian Greenhouse Office, 2004. *Economic issues relevant to costing climate change impacts*, Australian Greenhouse Office, Canberra.

Australian Property Monitor, 2009. Accessed 4 November 2009, <www.apm.com.au>.

Australian Taxation Office, 2009. *Taxation statistics 2006-07*, Australian Taxation Office, Canberra.

AWACS (1991). Design Guidelines for Water Level and Wave Climate at Pittwater. Australian Water And Coastal Studies Report 89/23, March 1991.

Bureau of Meteorology (BoM) / National Tidal Centre (NTC) (2009). *The Australian Baseline Sea Level Monitoring Project, Annual Sea Level Data Summary Report July 2008-June 2009*, Kent Town: BoM, 41 pages.

Booij, M.J., 2004. "Impact of climate change on river flooding assessed with different spatial model resolutions", *Journal of Hydrology*, 303(1-4):176-198.

Cardno Lawson Treloar, 2009. Nareen Creek (North Narrabeen) Floodplain Risk Management Study & Plan (unpublished Preliminary Draft), Pittwater Council, Pittwater.

Cameron, D.W., Morris, B.D., Collier, L., and Mackenzie, T., 2007. "Management and monitoring of an ICOLL entrance clearance", *17th NSW Coastal Conference*, 4-7 November 2008, Wollongong.

Chamberlain, E.R., Hartshorn, A.E., Muggleston, H., Short, P., Svensson, H. and Western, J.S., 1981. *Queensland Flood Report – Australia Day 1974*. Australian Government Publishing Service, Canberra.

Commonwealth Scientific and Industrial Research Organisation (CSIRO) (2004). *Climate change in New South Wales. Part 2: Projected changes in climate extremes*. Consultancy report for the NSW Greenhouse Office, 79 pages.

CSIRO, 2004. *Climate change in New South Wales. Part 2: Projected changes in climate extremes*. Consultancy report for the NSW Greenhouse Office.

CSIRO, 2007. *Climate Change in Australia: Technical Report 2007*, CSIRO, Clayton South.

CSIRO/BoM (2007). *Climate change in Australia, technical report 2007*. Canberra: CSIRO, 148 pages.

CISRO, 2007. *Projected changes in climatological forcing for coastal erosion in NSW*. Consulting report for the NSW DECC, 38 pages

Department of Climate Change (DCC), 2009a, *Climate Change 2009, Faster and More Serious Risks*. Canberra: DCC, 60 pages.

Department of Climate Change (DCC), 2009b. *Climate Change Risks to Australia's Coast: A First Pass National Assessment*, Department of Climate Change, Canberra.

Department of Environment and Climate Change, 2005. *Floodplain Development Manual*, Department of Environment and Climate Change, Sydney.

Department of Environment and Climate Change, 2009. *Scientific Basis of the 2009 Sea Level Rise Benchmark: Draft Technical Note*, Department of Environment and Climate Change, Sydney South.

Department of Infrastructure, Planning and Natural Resources (DIPNR), 2005: *Floodplain development manual: the management of flood liable land / New South Wales Government*, accessed 15 January 2010, <http://www.dipnr.nsw.gov.au/floodplain.html>.

Department of Infrastructure, Planning and Natural Resources (DIPNR), 2004. *Discussion Paper: ICOLL Management Guidelines*, Department of Infrastructure, Planning and Natural Resources, NSW.

Economics of Climate Adaptation Working Group, 2009. *Shaping Climate-Resilient Development: A Framework for Decision Making,* accessed 18 November 2009, <http://www.swissre.com/pws/media%20centre/news/news_releases_2009/eca_pr.html>.

Environment Protection Authority (EPA) NSW, 2000. *NSW State of the Environment 2000*, Environment Protection Authority, NSW.

ERM Mitchell McCotter, 1992. *Narrabeen Lagoon Floodplain Management Study*, Waringah Shire Council in association with Pittwater Municipal Council, Waringah.

Everett, J.D., Baird, M.E. and Suthers, I.M., 2007. "Nutrient and plankton dynamics in an intermittently closed/open lagoon, Smiths Lake, south-eastern Australia: An ecological model". *Estuarine, Coastal and Shelf Science*, 72(4):690–702.

Gordon, A.D. 2006. *Narrabeen Lagoon Restoration Project − Concept*. Paper prepared for the Steering Committee of the Narrabeen Lagoon Restoration Project Advisory Board, Waringah.

Haines, P.E., Tomlinson, R.B. and Thom, B.G., 2006. "Morphometric assessment of intermittently open/closed coastal lagoons in New South Wales, Australia". *Estuarine, Coastal and Shelf Science*, 67(1-2):321-332.

Hawkesbury-Nepean Floodplain Management Steering Committee, 2006. *Managing Flood Risk Through Planning Opportunities - Guidance on Land Use Planning in Flood Prone Areas*, Hawkesbury-Nepean Floodplain Management Steering Committee, Parramatta.

Land and Water Conservation (1997): Land and Water Conservation, 1997. *Manly Lagoon Floodplain Management Plan*, Manly Council and Warringah Council, Manly.

Lord, D.B. & M. Kulmar (2000). The 1974 Storms Revisited: 25 Years Experience in Ocean Wave Measurement Along the South-East Australian Coast. ASCE, Proc. Coastal Engineering 2000, Sydney, Australia, pp 559-572.

Intergovernmental Panel on Climate Change (IPCC), 2000. Special Report on Emission Scenarios, Intergovernmental Panel on Climate Change, accessed 2 November 2009, <http://www.grida.no/publications/other/ipcc_sr/?src=/climate/ipcc/emission/>.

Marsden Jacobs Associates 2004, *Economic Issues Relevant to Costing Climate Change Impacts*, Australian Greenhouse Office, Canberra.

Manly Hydraulics Laboratory, 1989. *Narrabeen Lagoon Entrance Study (MHL552)*, Public Works Department, NSW.

McInnes, KL., DJ. Abbs, SP O'Farrell, I Macadam, J O'Grady & R Ranasinghe, 2007. Projected Changes in Climatological Forcing for Coastal Erosion in NSW. A CSIRO Project Undertaken for the NSW Department of Environment and Climate Change. August 2007

National Tidal Centre (NTC), 2009. *The Australian Baseline Sea Level Monitoring Project, Annual Sea Level Data Summary Report July 2008-June 2009*, Bureau of Meteorology, Kent Town.

Nielsen, A.F. & A.D. Gordon (2008). The hydraulic stability of some large NSW estuaries. Aust. Jnl. Civ. Eng., IEAust., (2008).

Palisade Corporation, 2009, *@RISK*, accessed 4 November 2009, <http://www.palisade.com/risk/default.asp>.

Public Works Department (PWD), 1990. *Narrabeen Lagoon Flood Study,* Public Works Department (Report No. PWD 86009), NSW.

NSW Government, 2009. *NSW Sea Level Rise Policy Statement*, Department of Environment, Climate Change and Water, Sydney South.

Pittwater Council & Department of Land and Water Conservation, 2002. *Narrabeen Lagoon Floodplain Risk Management Plan Volume 1 – Pittwater*, Pittwater Council, Pittwater.

Pittwater Council, date unknown. *Photo of flooding at Narrabeen Lagoon*, accessed 12 November 2009, <http://www.pittwater.nsw.gov.au/environment/natural_hazards/flood_risk/where_does_it_flood/narrabeen_lagoon >

Reserve Bank of Australia, 2009. *Treasury Indexed Capital Bonds*, accessed 10 November 2009, <http://www.rba.gov.au/statistics/tables/xls/e07hist.xls>.

Roy, P.S., Williams, R., Jones, A.R., Yassini, I., Gibbs, P.J., Coates, B., West, R.J., Scanes, P.R., Hudson, J.P., and Nichol, S., 2001. *Structure and function of south-east Australian estuaries*, *Estuarine, Coastal and Shelf Science*, 53(3),351-384.

SPM (1984). Shore Protection Manual. US Army Corps of Engineers, Coastal Engineering Research Centre, Vicksburg, Miss.

Wapedia, 2009. *Gumble distribution*, accessed 2 November 2009, <http://wapedia.mobi/en/Gumbel_distribution>.

WBM Oceanics Australia, 2001. *Narrabeen Lagoon Estuary Processes Study*, WBM Oceanics, Newcastle.

Warringah Council, 2009. *Entrance management*, accessed 16 November 2009, <http://www.warringah.nsw.gov.au/community/EntranceManagement.aspx>.

WolframMathWorld, 2009. *Gumbel Distribution*, accessed 2 November 2009, <http://mathworld.wolfram.com/GumbelDistribution.html>.