Port Phillip Bay Coastal Adaptation Pathways Project

Municipal Association of Victoria

11 September 2012

Adapting to inundation in urbanised areas: supporting decision makers in a changing climate

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Prepared for

Municipal Association of Victoria

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With the assistance of

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Table of Contents

Executive Summary

The combined effects of sea level rise and increased rainfall as a result of climate change will exacerbate flood risk in many coastal areas, exposing areas to more frequent and severe inundation. A growing number of people and properties will be exposed to flooding during this century, resulting in damage to or loss of property and natural assets as well as economic and social disruption unless proactive adaptation is considered.

Identifying cost effective adaptation options, and deciding when to apply those options, presents significant new challenges for both government and the community. Governments will be challenged to demonstrate clear and transparent decision making in responding to changing inundation risks in the face of the diverse range of expectations from the community as well competing pressures for limited financial resources. An adaptation pathways approach can provide a flexible course of action taken over time in response to potential or actual inundation in the short and long term.

The Port Phillip Bay Coastal Adaptation Pathways Project has taken an applied research approach to develop a framework to identify adaptation pathways to support coastal adaptation planning in urbanised areas in response to changing inundation risks as a result of climate change. The framework was applied at five sites around Port Phillip Bay in conjunction with local government authorities to test its practical application.

The framework helps organise complex information to assist the development of an economically feasible adaptation pathway to help manage inundation risk over time. The adaptation pathway is comprised of cost-effective groupings of adaptation options that if taken will help increase the resilience of an area by either reducing the cost of damages from flood events and / or the extent of flooding. The process combines credible technical approaches to both forecasting potential inundation hazards and generating economic analysis, with community involvement, in an orderly investigative sequence. The pathway maps possible actions and their assumptions to better support flexible decision making in the face of uncertainty and to help engage stakeholders.

The pathway is specifically designed for coastal decision-makers at all levels of government. Its approach includes a methodology to assess the value and costs of occupying the hazard zone before identifying and comparing the costs and benefits of different strategic adaptation responses over time using tools such as cost benefit analysis. The pathway will assist all levels of government, the community and the private sector in understanding how to measure and assess the economic costs and benefits of adaptation over time.

Value of this project

Many coastal communities will be affected by changing inundation risk as a result of climate change. This framework provides a useful shared, starting point for coastal decision-makers. Such an approach will help extend limited resources and capacity while also building a better shared understanding of inundation risks and approaches.

Developing a consistent approach will also improve the ability of governments to meaningfully assess and compare coastal adaptation needs across Australia.

The value of this framework is dependent on it producing rational results for different decision makers and being accepted by and useful to stakeholders. To support this objective, the framework was applied in a range of urbanised coastal areas. In doing so, application of the framework has shown that decision-makers can be provided with:

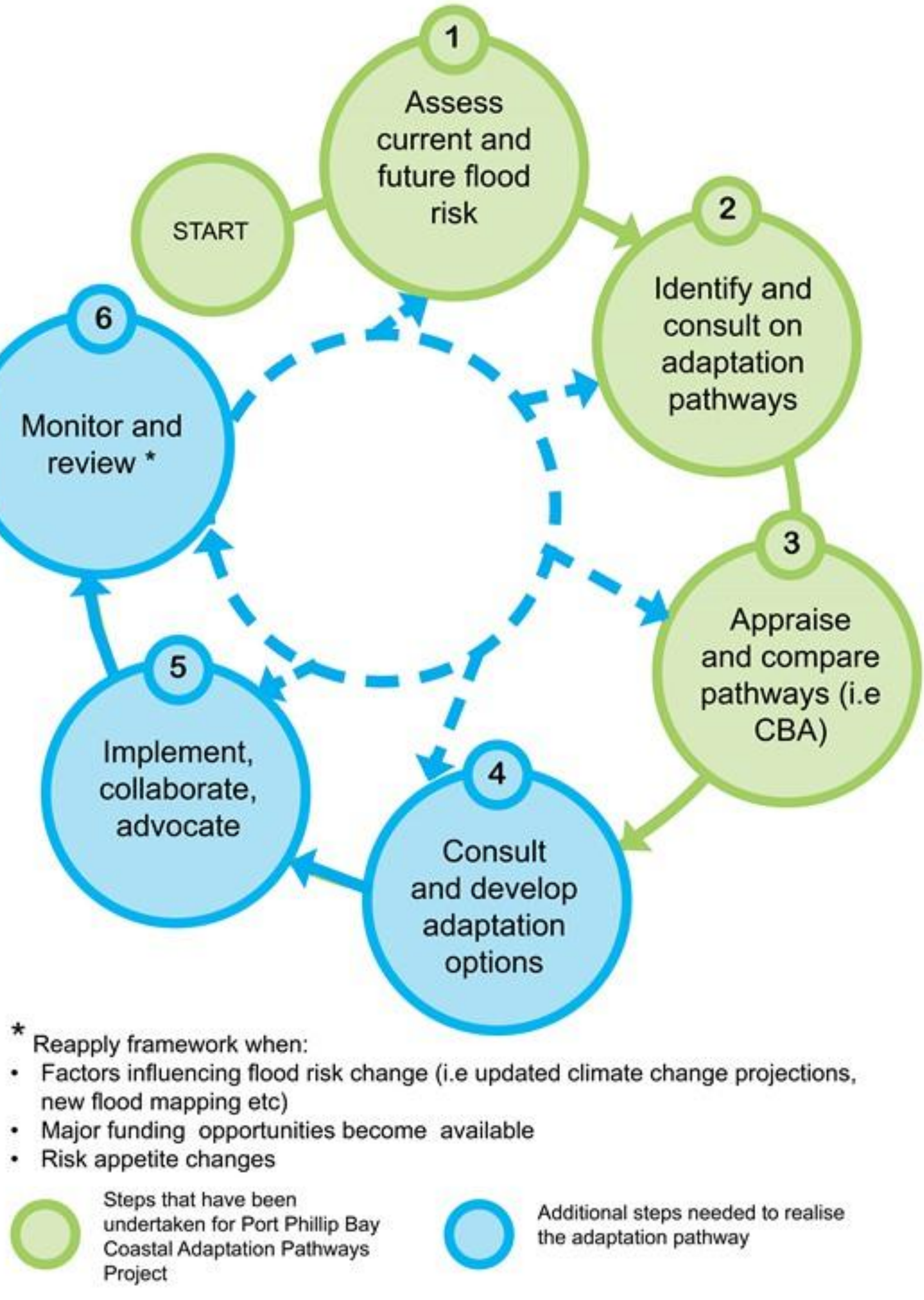
- new data and technical information relating to the future extent and depth of areas of inundation under an assumed climate change scenario
- opportunities for facilitated discussions with other stakeholders, including referral authorities and state government departments
- an initial quantification of the economic value of the hazard zone, the costs of flooding and the potential value of adaptation over time
- opportunities to build internal capacity through knowledge sharing and multi-disciplinary collaboration.

Developing an adaptation pathway for changing flood risk in urbanised coastal areas

The framework is intended to be an iterative process that can be used by coastal decision-makers to inform strategic adaptation decision-making. Six steps have been identified to develop and maintain an adaptation pathway (Figure A):

1) **Assess current and future flood risk** - estimate current and future inundation as a result climate change based on available flood mapping, socio-economic data and climate science.
2) **Identify and consult on initial adaptation pathways -** through engagement with stakeholders, identify individual adaptation options that may contribute to the reduction of flood risk. Options are then grouped into different adaptation pathways with distinctive characteristics to allow comparison between approaches.
3) **Appraise and compare pathways** - using metrics such as the value of occupying the hazard zone, estimated cost of damages and scale of adaptation investment, the application of tools such as cost benefit analysis can identify an economically favourable pathway over time that can be used to guide future adaptation action by a range of stakeholders.
4) **Consult and develop adaptation options** – broader engagement with stakeholders to consider social, environmental and political factors which influence decision-making will be required, including clarification of different roles and responsibilities for managing risks**.** Further analysis or technical investigations on individual adaptation options may also be required**.**
5) **Implement, collaborate and advocate** – Individual organisations will need to consider those adaptation options relevant for their organisation to implement, advocate or collaborate, taking into consideration funding mechanisms, governance arrangements and other factors.
6) **Monitor and review** - an adaptation pathway is likely to evolve over time as a result of changes to flood risk, changes to what risks are acceptable and the emergence of new adaptation opportunities.

Figure A A decision making framework to develop an adaptation pathway for changing flood risk.



A key feature of this process is that finding the optimal pathway may require some changes as new information comes to light. For example, it is conceivable that there might be a step-change in the rate of sea level rise in the future that triggers the introduction of more risk averse adaptation options into the pathway.

Developing adaptation pathways for each case study area has supported the development of a range of tools and approaches which can be applied to a diversity of locations and coastal circumstances. This approach has also helped ensure the findings, recommendations and tools developed through this project are applicable and transferable to other areas.

Testing of the framework

The framework was applied at five sites around Port Phillip Bay in Victoria, Australia. Each area has different characteristics, with a mix of land use types, geographic characteristics and development densities. Section 5.0 outlines the assumptions and approach used to identify and compare potential adaptation pathways at these five locations.

All of these locations already experience some level of flooding, however even under the assumed climate change scenario, the value of occupying the area significantly exceeds estimated increases in the cost of flood damage. Even if no adaptation actions were taken, it would be expected that these areas would continue to be inhabited and used by the community.

Three initial adaptation pathways and options were identified based on the extent to which flood damages would be decreased –

Adaptation options for the Accommodate Pathway were largely similar between all five case studies and focussed on five broad types of responses:

- Increasing council capacity to engage stakeholders and manage inundation risk.
- Increasing community resilience to flood events by increasing awareness, preparedness, response and recovery to flood events informed by social research.
- Adopting or modifying existing planning controls and building regulations to better recognise current and future inundation risks.
- Incorporating future inundation risk into councils' risk register.

Adaptation options under the Moderate and Major Protection pathways were more specific to the individual characteristics of each case study area but included options relating to improved drainage, coastal or estuarine coastal protection works, pumping and establishing retarding basins.

Climate adaptation pathways at three of the five case study sites assessed delivered a favourable economic cost benefit ratio for immediate adaptation action. For two case studies, the maximum benefit was realised by implementing actions to better accommodate existing inundation, such as through the planning process, while preparing to implement a range of moderate protection adaptation actions such as drainage upgrades in the medium term. For a highly urbanised area already facing significant inundation risk, the economic analysis supported greater investment in adaptation options to protect against flooding. In the remaining two areas, the cost benefit analysis did not identify an economically favourable pathway. However, in these areas the economic analysis was constrained by different factors, such as data availability and area of the case study. Taking these factors into account, pursuing an accommodation pathway while seeking information to address data limitations and re-examining identified protective adaptation options for a larger area would likely be economically justified.

Key assumptions used to undertake this work have been noted to help decision-makers better understand the limitations and appropriate application of findings.

Findings from Port Phillip Bay

The testing of the framework through a mix of case studies generated valuable lessons for future adaptation planning. Applying the framework demonstrated different approaches to analysis in response to:

- differing degrees of available data for future flood modelling
- different methods for incorporating uncertainty in the cost benefit analysis
- additional exploration of potential wider bay/catchment solutions that could influence the implementation of adaptation options at a regional level.

This project has also demonstrated that the benefit of occupying the hazard zone in urban areas is significant and the cost of future flooding will be high if preventative adaptation action is not undertaken. However, the economic analysis indicated that a decision to retreat from the *entire* study area is not an economically viable adaptation approach. It is acknowledged that retreat may still be a viable option either at an asset level or for other communities.

Working through the steps to develop an adaptation pathway can provide decision-makers with a better understanding of the hazard zone based on available information and a broad economic analysis which can help narrow down where investment may be best spent – either on adaptation action or on gathering additional information at specific locations which may require the re-assessment of the pathway.

The scale of the area for developing an adaptation pathway is an important factor for climate adaptation planning and applying cost benefit analysis. While a local scale was applied in Port Phillip Bay, a regional scale hazard assessment and adaptation plan would provide a more complete analysis for many inundation protection measures although it is likely to increase the complexity of approach. Data availability is likely to be an issue for either scale.

Adaptation pathways for a catchment or regional scale are likely to offer the greatest value and opportunities. It is not possible to define the optimum size of these regions or catchments quantitatively. Rather it is intended that these scales are defined by the potential needs or benefit of the adaptation options themselves. This may include working across a subsection of a catchment or across catchments, depending on the scale of the flood risk being addressed. For example, an adaptation pathway which includes options to address flooding from a particular river or source should include the entire area which is likely to benefit from the proposed adaptation actions (i.e. all communities along the river). Alternatively, exploring possible efficiencies from larger scale investigations or avoiding the risk of maladaptation in surrounding areas may help define an appropriate scale. For example coastal erosion studies for an entire bay will help reduce the risk of identifying localised adaptation options which may increase erosion and resulting flood risks at other locations along the Bay.

This study has estimated the benefits of the adaptation options using an avoided damages approach. The focus on damage reduction may underestimate both the true cost of flooding and the potential benefit to the community of reducing inundation risks.

Limitations

A series of limitations were identified regarding the use economic analysis tools to support decision making. Cost benefit analysis should be used as supporting information with other decision making criteria due to the following factors:

- many issues are difficult to be address quantitatively in the economic analysis such as safety, quality of life, heritage issues and other social values
- estimates of potential economic impacts and adaptation benefits were limited to within the case study area. In some cases, further consideration of related impacts outside of the case study area should be considered
- the cost benefit analysis is based on indicative costs only and does not accurately cost individual adaptation options

- the economic analysis did not include consideration of who would or should pay for adaptation. The role of this economic analysis is simply to present the net costs and benefits to society.

In addition, there are the inherent limitations associated with modelling a range of future conditions, including changes in climate, socio-economic conditions and flood damages.

Recommendations

This report is intended for a broad range of audiences. As such, the recommendations below are not intended for any one organisation or level of government. The recommendations are also independent of any assumptions or knowledge of different individual roles and responsibilities for managing flood risk. Some organisations will have greater capacity and responsibility than others but the strategic focus is to encourage collaboration and cooperation through improved and shared understanding.

1) Technical standards and supporting data for climate change adaptation planning

Develop a set of technical standards focusing on information and data to support adaptation to current and future inundation. This should include localised climate change projections to support a consistent approach for future inundation and erosion investigations. The second stage of this work should prioritise investigations with respect to inputs and consistent approaches for hydrologic and hydraulic modelling, bathymetric and topographic survey information, extreme sea level computation and coastal erosion. The third stage of this work should provide guidance on consistent approaches to better quantify a broader range of costs and benefits including safety, quality of life, cultural and heritage values and environmental functions.

2) Enhance opportunities for multi-agency collaboration and governance for coastal inundation.

The development of an adaptation pathway is likely to be most effective at a regional or catchment scale in response to sea level rise, catchment flooding and coastal erosion. This will require continued and enhanced collaboration between all levels of government.

3) Prioritise and develop detailed adaptation options at a regional or catchment scale

Undertake more detailed investigations and prioritise adaptation options that provide benefit to the broader region (i.e. greater than the single study area). This may include further technical investigations that underpin broader adaptation planning.

4) Proactive communications and engagement with the community

A proactive communication and engagement program targeted to specific audiences should be developed and shared by coastal decision-makers.

5) Integrating adaptation responses into urban renewal and development planning

Land use and building form will both influence inundation and need to respond to flood risk. Critically, urban renewal and asset replacement will create significant opportunities to develop positive and innovative responses to future inundation, particularly in the longer term (10 to 30+ years).

6) Capacity building for integrating adaptation to climate change into existing systems and processes

How existing information on climate change impacts/future flood risk can be incorporated to support consistent regional responses while recognising local circumstances will be critical. Guidelines and other tools to assist different stakeholders (including local government, developers and the community) to meet new requirements or proactively adapt are required.

Through engagement with stakeholders in testing the framework it was apparent that a skills and capacity building program for managing changing inundation risks is required. A skills audit and needs assessment of key stakeholders would help target the program to specific needs and requirements. A key element of this program would include guidelines and support the incorporation of future coastal risk into existing strategies and mechanisms to better respond to sea level rise and catchment flooding.

7) Funding mechanisms for adaptation options

Funding mechanisms for regional scale adaptation options should be explored. Consideration for private investment should be included, particularly with those likely to benefit from adaptation action.

1.0 Key Terms

1.1 Glossary

The following terms have been defined in relation to their application to this project:

Adaptation - adjustments in natural or human systems in response to actual or expected climatic stimuli or their effects which moderates harm or exploits beneficial opportunities[1]. In the context of this project, this is limited to those adjustments taken in response to inundation.

Adaptation Options - a discrete action or activity taken in response to current or expected inundation**.**

Adaptation Pathways - a flexible course of action taken over time in response to potential or actual inundation. The pathway is comprised of cost-effective groupings of adaptation options that if taken will help increase the resilience of the case study area by either reducing the cost of damages from flood events and / or the extent of flooding. The purpose of the pathway is to map possible actions and their assumptions to better support flexible decision making in the face of uncertainty and help engage stakeholders. In this project three initial adaptation pathways were constructed to allow comparisons using cost benefit analysis:

i) **Accommodate Pathway -** allows flooding to occur but efforts are focussed on minimising impacts when it does occur. Adaptation options are focussed on those which can help communities and individuals prepare for, and recover from, flood events, including behavioural and policy interventions. To estimate the impact of this pathway on average annual damage in the cost benefit model it was assumed that:

- actual damages as a percentage of potential damages are reduced from 80% to 65%
- actual to potential ratios for damage to the contents of commercial buildings are reduced from 44% to 35%.

ii) **Moderate Protection Pathway** - reduces the impact of current flooding by reducing its localised extent via modest or small scale engineering solutions. This pathway also includes behavioural and policy interventions undertaken in the accommodate pathway to help reduce and avoid risks. To assess the benefits of this pathway, it was assumed that the adaptation options included would protect the study area from an existing 100 year ARI event.

iii) **Major Protection Pathway -** eliminates the risk of future flooding through large scale engineering solutions to allow continued use or development of the hazard zone over the longer term. This pathway includes options included in the Accommodate and Moderate Protection pathways. To assess the benefits of this pathway, it was assumed that the adaptation options could protect the study area from a 100 year ARI event under the assumed climate change scenario.

A fourth adaptation pathway was initially identified which would have enabled a retreat out of the hazard zone. This pathway was not considered for any of the five case studies sites in this project based on the estimated value of occupying the hazard zone.

Annual Average Damage (AAD) - an estimation of the average annual damage caused by inundation using a probabilistic estimate of the likely occurrence of different sized events to calculate a total annual figure. Depending on its severity, each inundation event will cause a different amount of damage. The average annual damage is the average damage in dollars per year that would occur in a designated area from inundation over a defined period of time. In many years there may be no flood damage, in some years there may be minor damage (caused by small, relatively frequent floods) and, in a few years, there will be major flood damage. Estimation of the average annual damage provides a basis for comparing the effectiveness of different adaptation pathways across the full timeframes of the study.

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[1] McCarthy, J. J.; Canziani, O. F.; Leary, N. A.; Dokken, D. J.; and White, K. S., ed., *Climate Change 2001: Impacts, Adaptation and Vulnerability,* Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press.

Annual Exceedance Probability (AEP) – the probability associated with a given event being exceeded in any one year. For example, an event with an AEP of 0.1 has a 10% chance of occurring every year.

Assumed Climate Change Scenario - this research relies on a hypothetical climate change scenario which assumes:

- a sea level rise of 0.8m by 2100
- an increase in rainfall intensity of 32% by 2100.

This data has been supplied by Melbourne Water.

Average Recurrence Interval (ARI) - the expected time between the events that exceed a given value (for example rainfall or wave height). Also referred to as the "return period", it is usually expressed in years. For example, the 1 in 100 year rainfall experienced during a storm event will on average only be exceeded once every 100 years. However, it does not mean it cannot happen more, or less, frequently than every 100 years.

Australian Height Datum (AHD) - the datum for altitude measurement in Australia. 0m AHD was mean sea level as determined in 1971 by Geoscience Australia and has been adopted by the National Mapping Council as the datum to which all vertical control for mapping (and other surveying functions) is to be referred.

Benefit Cost Ratio (BCR) - measures the return benefit received per dollar of costs. The Benefit Cost Ratio is calculated by dividing the present value of all benefits by the present value of all costs. The Benefit Cost Ratio is a measure of the *proportional* return on invested funds. A project with a Benefit Cost Ratio greater than one would be considered economically desirable, with the project having the highest Benefit Cost Ratio being most economically desirable.

Catchment – the Victorian *Catchment and Land Protection Act* 1994 defines a catchment as an area of land which, through run-off or percolation, contributes to the water in a stream or stream system. In this project, catchment also refers to where water joins or drains into Port Phillip Bay.

Cost Benefit Analysis - a well-established systematic process that involves the assessment of costs and benefits of an activity over a defined time period. Costs and benefits are always measured as incremental changes relative to a base case (or 'business as usual' case) – for this study, the impacts of coastal inundation without any adaptation. The benefit is therefore the incremental reduction in the expected annual average damages as a result of adaptation. Costs and benefits that occur in different time periods are made comparable in the present time period by converting to Present Value using a process known as discounting.

Coastal Storm Event - a meteorological event that results in elevated tidal heights as a result of high winds and increased wave heights (also referred to as storm surge).

Decision-Making Framework – a framework for organising complex information for the purposes of solving a problem. In this study, the decision making framework was used for identifying a potential adaptation pathway for a defined location.

Decision Making Tools – methods and approaches used in identifying and assessing options and pathways for decision making. The tools utilised in this project include cost benefit analysis, Monte Carlo Analysis, facilitated workshops with stakeholders and hazard mapping.

Discount Rate – the rate used to compare costs and benefits that occur at different points in time to allow comparison of future costs and benefits against today's costs and benefits. Discounting takes into account the time value of costs and benefits as well as opportunity costs such that those accrue further in the future are worth less to society in today's terms. The discount rate allows for future costs to be converted into their present day value so that how much should be spent on climate change adaptation can be determined. A lower discount rate will result in more investment into climate change adaptation. A discount rate of 3% has been used in this study, a middle-ground given the disparity of opinions on the appropriate rate.

Flood (or Hazard) Zone – the area of land that is expected to be inundated during a given flood event. Generally, flood zones are based on a flood event with a 100 year ARI, but can be determined for events with a shorter ARI such as a 10 year ARI.

Inundation Risk - the chance of flooding being experienced in a particular location is known as inundation risk. The level of risk can vary depending on the event being referenced. For example, a location may be at risk of inundation during an event with a 100 year ARI but not a 20 year ARI.

Joint Probability Analysis - the practice of determining the probability of two or more events occurring at the same time. With respect to flooding and inundation, it usually relates to the probability of a downstream water level of high magnitude occurring at the same time as intense rainfall. It could be extended to include the occurrence of periods of sustained rainfall that result in the catchment being saturated, even before the onset of intense rainfall, and, the occurrence of a tsunami at the same time. However, as joint probability analysis is a statistical tool, high quality datasets are required and the analysis is usually limited to events that occur at relatively regular intervals.

Land Parcels–the area of land as defined by the Victorian cadastral system that makes up a property and is a boundary of ownership. One or more parcels can make up a property.

No adaptation – a scenario in which no proactive action is taken to reduce or respond to the risks posed by climate change (i.e. a ‘business as usual’ scenario). This scenario is used as the base case to compare estimates of Annual Average Damages under the various adaptation pathways.

Maladaptation - any changes in natural or *human systems* that inadvertently increase *vulnerability* to climatic *stimuli*; an *adaptation* that does not succeed in reducing vulnerability but increases it instead[2].

Monte Carlo Analysis - a technique which randomly samples values from a pre-determined distribution or range to account for uncertainty with that value. In this study, all input parameters have uncertainty. Monte Carlo simulation samples values for each item, recalculates the costs and benefits, and then repeats the process tens of thousands of times. The results are then aggregated, and a distribution of all sampled results generated.

Net Present Value - measures the difference between benefits and costs, whilst accounting for the timing of benefits and costs. It is equal to the difference between the Present Value of Benefits and the Present Value of Costs. The Net Present Value is a measure of the *absolute* return on invested funds. A project with a Net Present Value greater than zero would be considered economically desirable, with the project having the highest modelled Net Present Value being the most economically desirable. In this project, the present value of benefits is the estimated reduction in AAD, while the present value of costs is the sum of the estimated cost of adaptation options and the residual AAD.

Present Value of Benefits & Present Value of Costs - the sum of all benefits and costs over the appraisal period after application of the discount factor. The benefit of the adaptation pathway for each year is the reduction in average annual damage as a result of the adaptation options undertaken in implementing the pathway. The cost of the adaptation option is any upfront capital cost plus annual operating, maintenance and administration costs.

Storm Surge - a temporary increase in sea level above the level of the predicted tide. It is most severe during extreme weather events such as East Coast Lows. Storm surge occurs when strong winds caused by low-pressure weather systems push along the water’s surface and cause it to accumulate near the coastline. When the slope of the sea bed offshore from the coastline is shallow, storm surge will be higher than if the water was deep (also referred to as ‘coastal storm event’ in this project).

Sea Level Rise (SLR) - the long term trend of increasing average sea level height that is not caused by seasonal or meteorological factors. The cause of SLR is attributed to thermal expansion and mass exchanges of water between the oceans and land. Global warming from increasing greenhouse gas concentrations is a significant driver of both sources.

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[2] McCarthy, J. J.; Canziani, O. F.; Leary, N. A.; Dokken, D. J.; and White, K. S., ed., *Climate Change 2001: Impacts, Adaptation and Vulnerability,* Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press.

Willingness to pay – the maximum amount a person would be willing to pay or exchange in order to receive a good or to avoid something undesired, such as flooding. If the person receives the good or avoids the undesired outcome for a value lower than their willingness to pay this provides an economic surplus. The avoided cost approach has been used to estimate individuals' willingness to pay due to limitations in the available data. This assumes the individuals would be willing to pay at least the cost of the damages they will incur to prevent flooding. It is understood that this reflects a lower estimate of their willingness to pay.

1.2 Acronyms

AAD – Average Annual Damage

ABM – Association of Bayside Municipalities

AEP – Annual Exceedance Probability

AHD – Australian Height Datum

ARI – Average Recurrence Interval

BCR – Benefit Cost Ratio

CBA – Cost Benefit Analysis

CCB – Central Coastal Board

CoM – City of Melbourne

CoPP – City of Port Phillip

DCCEE – Australian Government Department of Climate Change and Energy Efficiency

DPCD – Victorian Department of Planning and Community Development

DSE – Victorian Department of Sustainability and Environment

KCC – Kingston City Council

LIDAR – Laser Imaging Detection and Ranging

LSIO – Land Subject to Inundation Overlay

MAV – Municipal Association of Victoria

MPSC – Mornington Peninsula Shire Council

NPV – Net Present Value

MW – Melbourne Water

RAM – Rapid Appraisal Methodology

SBO – Special Building Overlay

SLR – Sea Level Rise

UFZ – Urban Floodway Zone

VCCCAR – Victorian Centre for Climate Change Research

VPP – Victoria Planning Provisions

2.0 Background

2.1 Context

In 2007, the Intergovernmental Panel on Climate Change (IPCC) concluded that 'warming of the climate change system is unequivocal' as evident by observed increases in global air and ocean temperatures, widespread melting of snow and ice and increases in the global average sea level'[3].

Coastal communities are particularly vulnerable to climate change due to the potential for inundation associated with increasing mean and extreme sea levels and increasing intensity of rainfall affecting catchment flooding.

These changes will affect the coastal zone through:

- increased tidal or permanent inundation of land by seawater
- increased flooding due to reduced drainage capacity
- altered erosion patterns.

The combined effects of sea level rise and increased rainfall will exacerbate flood risk in low lying coastal areas, making many areas prone to more frequent and severe inundation. A growing number of people and properties will be exposed to flooding during this century, resulting in damage to or loss of property and natural assets as well as economic and social disruption. These changes will affect households, businesses, communities and governments.

The timing and magnitude of future changes to the climate is uncertain and scientific understanding of the how these changes will manifest at the local scale is incomplete and subject to wide ranges. At the same time, how our communities will change between now and the end of the century through changes in population, technology and culture are also a source of uncertainty in planning for the future.

Avoiding or reducing flood risks, and being prepared to take advantage of any opportunities, will require a considered and proactive adaptation response. Adaptation to changes in climate should be considered a risk management process to identify, evaluate and respond to changes in risk by minimising damage and maximising gains from new opportunities.

There is no one solution – adaptation responses will require a diverse range of actions from all levels of government and individuals now and over time. Adaptation will need to reflect both regional and local circumstances, including financial resources, management and governance arrangements and community expectations, further increasing the complexity.

Adaptation responses will range from changes in land use policy and building regulations, catchment and local protective works and other engineering solutions, to behavioural changes. In the coastal zone successful adaptation seeks to:

- reduce risks from current and future flooding
- avoid risks of future flooding in locating and (re) developing new or existing public and private assets
- identify where and how protection of the coast may be possible and appropriate

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

- create opportunities for the re-positioning of natural and infrastructure assets away from inundation zones
- recognise where inundation can be accommodated through minor changes in behaviours
- maintain current environmental values.

Identifying cost effective measures to adapt and deciding when to apply those measures presents significant new challenges for both government and the community. Governments will be challenged to demonstrate clear and transparent decision making in response to inundation risks in the face of the diverse range of values and expectations of the community as well competing pressures for limited financial resources.

2.2 Project description

This project has taken an applied research approach to develop a framework to identify an adaptation pathway to help coastal adaptation planning in urban settlements in response to changing inundation risks as a result of climate change. An adaptation pathway is a flexible course of action taken over time in response to potential or actual inundation.

The framework helps organise complex information to assist in the development of an economically feasible adaptation pathway to better manage inundation risk over the short and long term. The resulting adaptation pathway is comprised of cost-effective groupings of adaptation options that if implemented will help increase the resilience of an area by either reducing the cost of damages from flood events and / or minimise the extent of flooding. The pathway maps possible actions and their assumptions to better support flexible decision making in the face of uncertainty and help engage stakeholders.

The pathway is specifically designed for coastal decision-makers at all levels of government. It includes a methodology to assess the value of coastal assets and to determine the value and costs of occupying identified hazard areas and provides a list of options for managing risks to assets dependent on site context, value and estimates of future risk. The pathway will assist all levels of government, the community and the private sector in understanding how to measure and assess the economic costs and benefits of adaptation over time.

The project has tested the initial steps of the adaptation pathways development process at five sites around Port Phillip Bay in Victoria, Australia in conjunction with the relevant local government.

As a result of the testing, the framework was modified and refined to reflect learning outcomes and to better assist coastal decision-makers seeking to develop an adaptation pathway.

This project was delivered by AECOM with the support of the Municipal Association of Victoria (MAV), Association of Bayside Municipalities (ABM), the Central Coastal Board (CCB), Victorian Department of Planning and Community Development (DPCD) and the Federal Department of Climate Change and Energy Efficiency. The project also involved a broader set of project partners including Melbourne Water, Victorian Department of Sustainability and Environment (DSE), City of Melbourne, City of Port Phillip, City of Kingston, Mornington Peninsula Shire Council and the Victorian Centre for Climate Change Adaptation Research (VCCCAR).

As such, the project has produced information about the:

- usefulness of the decision making framework in producing credible local decisions based on currently available information
- effectiveness of the decision making framework in engaging local stakeholders meaningfully
- potential adaptation options available in coastal areas
- additional value produced by the introduction of more complex analytic tools, relative to the costs of doing so.

2.3 Project purpose

The region surrounding Port Phillip Bay is home to a significant proportion of Victoria's population and includes key economic, social and environmental values. The potential risk to buildings and assets within this region has been identified as a critical concern by all levels of government. Only limited information is currently available to assess the potential costs and benefits of adaptation at a community scale.

The purpose of this project was to create a framework to develop an adaptation pathway to manage changing inundation risk as a result of climate change in the coastal zone. It combines credible technical approaches to both economics and forecasting hazards and risks, with stakeholder involvement, in an orderly sequence of analysis using a variety of tools.

A consistent approach avoids the need for local decision-makers to develop new tools from scratch – thereby improving the efficiency and effectiveness of available resources.

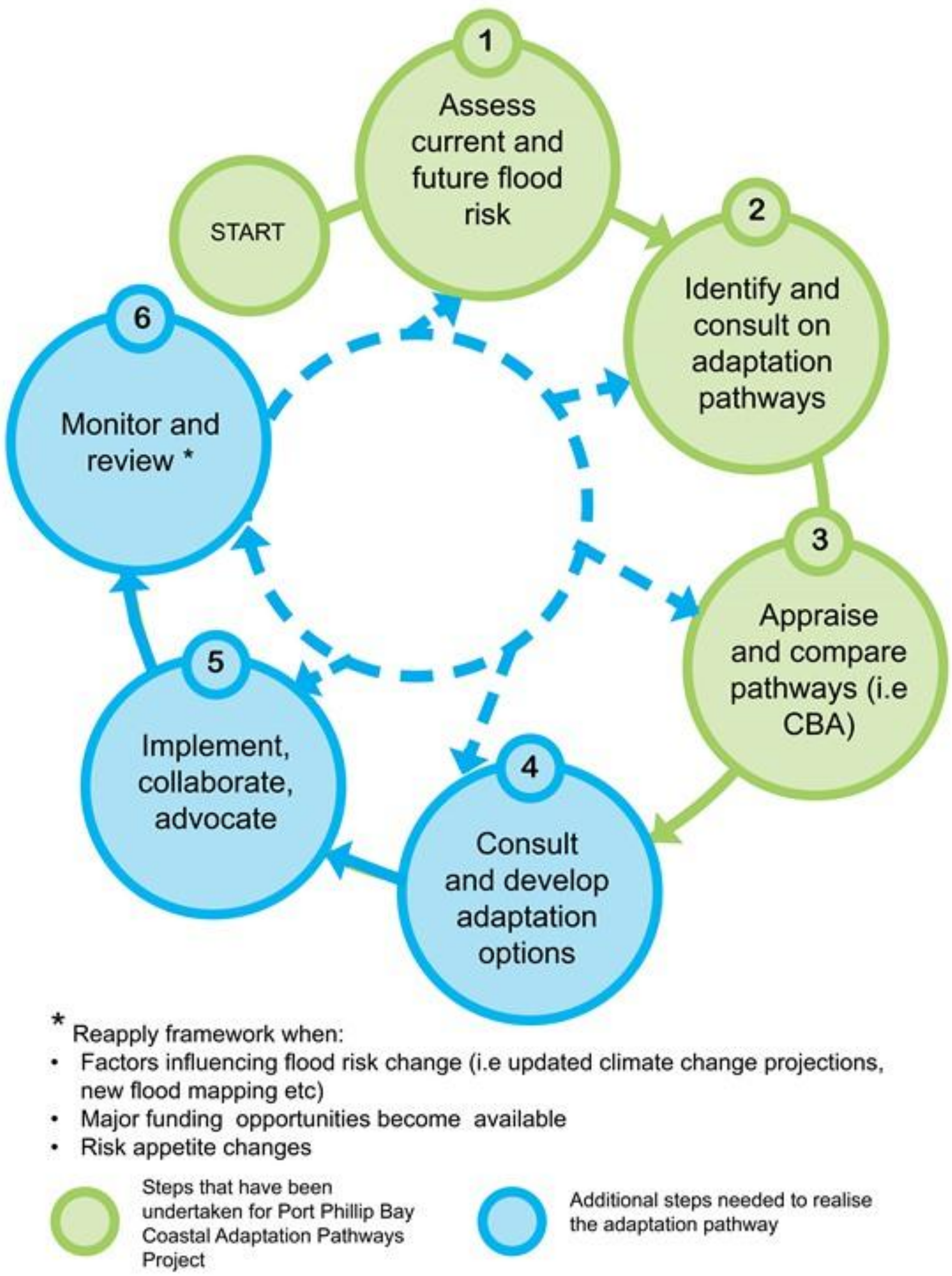
The value of the decision making framework is dependent on it producing rational results in a range of local environments, and being accepted by stakeholders.

Accordingly, this project tests the strengths and weaknesses of the framework by applying it to a range of locations. A range of decision-making tools were also used to better understand current and future inundation hazards in an economic context.

3.0 Developing an Adaptation Pathway for Changing Flood Risk

This project set out to develop and test a framework that helps identify and assess adaptation pathways for urbanised coastal areas. It is focussed on inundation hazards that are expected to increase under climate change as a result of sea level rise and increases in extreme rainfall. The framework is outlined in Figure 1.

Figure 1 A decision making framework to develop an adaptation pathway for changing flood risk.



The framework is intended to be an iterative process that can be used by coastal decision-makers to inform adaptation decision-making by:

- utilising existing data and technical information to consider the potential changes in inundation extent and depths as a result of climate change-induced sea level rise and increases in extreme rainfall
- creating opportunities for facilitated discussions with other responsible flood managers including local government, referral authorities and state government departments
- providing an initial quantification of the economic value of the hazard zone, the costs of flooding and the potential value of adaptation over time
- highlighting opportunities to build internal capacity through knowledge sharing and multi-disciplinary, multi-stakeholder collaboration.

The commencement of an adaptation pathway for inundation in urbanised areas is most likely to be informed by currently known inundation risks and local intelligence. While climate change is expected to introduce new flooding risks in some areas, in many areas climate change will exacerbate existing risks. Six steps have been identified to progress and maintain an adaptation pathway over time:

1) **Assess current and future flood risk** - estimate current and future inundation as a result climate change based on available flood mapping, socio-economic data and climate science.
2) **Identify and consult on initial adaptation pathways** - through engagement with stakeholders, identify individual adaptation options that may contribute to the reduction of flood risk. Options are then grouped into different adaptation pathways with distinctive characteristics to allow comparison between approaches.
3) **Appraise and compare pathways** - using metrics such as the value of occupying the hazard zone, estimated cost of damages and scale of adaptation investment, the application of tools such as cost benefit analysis can identify an economically favourable pathway over time that can be used to guide future adaptation action by a range of stakeholders.
4) **Consult and develop adaptation options** – broader engagement with stakeholders to consider social, environmental and political factors which influence decision-making will be required, including clarification of different roles and responsibilities for managing risks**.** Further analysis or technical investigations on individual adaptation options may also be required**.**
5) **Implement, collaborate and advocate** – Individual organisations will need to consider those adaptation options relevant for their organisation to implement, advocate or collaborate, taking into consideration funding mechanisms, governance arrangements and other factors.
6) **Monitor and review** - an adaptation pathway is likely to evolve over time as a result of changes to flood risk, changes to what risks are acceptable and the emergence of new adaptation opportunities. Depending on which factor triggers the review of the adaptation pathway, users will need to consider where it is most appropriate to re-enter the process.

Guidance on how each of these steps can be undertaken is outlined in Section 4.0.

How steps one, two and three were applied at five Victorian locations and a summary of the findings are outlined in Section 5.0.

The framework recognises that the optimal pathway is likely to evolve over time, as new information becomes available, adaptation options are implemented and other opportunities arise (such as structure plans are updated or funding opportunities emerge). These factors will require the pathway to be reviewed including the inclusion or exclusion of individual adaptation options.

Testing of the framework through a mix of case study settings has ensured an approach that can be applied to a diversity of locations and coastal circumstances across Australia. Lessons learned during the testing of the framework at the five case study locations are provided in Section 5.0.

4.0 Building an Adaptation Pathway

This section provides guidance on how to build an adaptation pathway for an urbanised coastal area. Each of the steps in Figure 1 is outlined in further detail. These steps also include guidance on applying those tools that were tested as part of the five case studies. The inclusion of these tools is not intended to be definitive – other tools, targeted to specific end-user needs may also be considered, however their application to the pathway has not been tested.

4.1 Establish the problem based on existing flood risk

To commence the process, a determination of the boundaries for the assessment area is required. The area for assessment is likely to be based on currently known inundation risk (for example as articulated in existing flood mapping or hazard overlays) or areas of potential hazard under expected climate change conditions.

Additional factors to consider when considering boundaries for the assessment area may include:

- existing governance arrangements where more than one organisation has roles and responsibilities for flood management
- natural processes or other hazards likely to influence inundation, including erosion and catchment drainage
- the desired scale of influence of the adaptation pathway – for example the primary purpose of the pathway may be to assist localised decision-making or to create opportunities for collaboration across multiple organisations to better facilitate regional scale adaptation responses.

The boundary area also represents the area of the community that will share the estimated cost and benefits of the adaptation pathway – thus for regionally significant sites (for example major tourism destinations or economic hubs) limiting the boundary of the assessment area may underestimate how benefits are captured and overestimate costs.

4.2 Assess current and future flood risk

Assessment of current and future flood risk requires collecting and collating a range of relevant information specific to the case study area. This information is likely to include:

- **flood data** - flood modelling for current conditions may already be available from flood managers such as local or state government, catchment management or water authorities. If this does not exist, at a minimum, modelling of marine and local catchment flooding should be undertaken for current 5, 20 and 100 year ARI events. To provide sufficient data for the assessment of changing flood risk over time, inundation modelling should be undertaken for these events for a base year (for example 2012) and future points in time (for example 2030, 2070 and 2100). This will allow a sufficient level of data for the interpolation for intervening events with a greater level of certainty.
- **spatial data** - to understand, assess and communicate flood hazards, a GIS database should be developed. This may include LiDAR data, aerial photography, cadastral information, current planning zones and overlays, building footprint outlines, floor level surveys and locations of critical assets (for example assets related to essential community services or emergency response).
- **socio-economic data** - to estimate the value of occupying the hazard area and the cost of damage from inundation. A range of information relating to land use, development patterns and willingness to pay for different functions or values can be used to estimate the potential economic cost of inundation and the value of occupying the hazard area. Specifically, information relating to population and visitation (current and projected), land values, proposed or adopted structure plans, economic development plans and other sources of data should be collected. Additional information may include quantitative assessments of amenity values relating to occupation, use or access through the hazard zone.

- **climate change data** - relevant to those mechanisms which will affect inundation (including sea level rise, storm surge and extreme rainfall). Modelling should assess the risks of each of these items separately as well as the impact of combined events. Consideration of individual components will allow for the dominant inundation threat to the area to be identified which will assist adaptation planning (see Box 1). Information on climate change projections can be drawn from best available scientific advice (for example from CSIRO), current policy requirements (such as land use planning requirements) or assumptions used in other local assessments of climate change risk. The climate change assumptions used in estimating future flood modelling should be explicitly documented so as to prompt review of estimated future flood risk as new information becomes available.

Box 1. Understanding flood mechanisms to inform adaptation planning

Understanding potential changes to the dominant flood mechanism as a result of climate change is important for effective adaptation planning. For example, in Mordialloc Creek case study, current flooding is predominately the result of catchment flooding from local rainfall. By 2100, under the assumed climate change scenario, it is expected that rainfall will remain the dominant flood mechanism (but there will be an increased contribution from coastal inundation in some areas). Under this scenario, adaptation options to address catchment flooding are likely to provide the greatest benefit (or reduction in flood extent) for most portions of the case study area. Assuming a greater contribution of sea level rise to local flooding would likely result in less efficient adaptation.

With this data, tools such as hazard maps, joint probability analysis and economic valuations can be created to assist with the identification of flood risks. Maps may include:

- flood extent and depths for existing 100 year ARI events and future 100 year ARI events (from rainfall and coastal events as well as combined events) at different points in time
- comparisons of flood extent for existing and future flood events
- changes in permanent future inundation (for example changes in the high tide mark as a result of sea level rise)
- current and future flood extent overlayed by current planning conditions (for example Land Subject to Inundation Overlays) and land use.

In coastal areas the likelihood of extreme sea levels as a result of storm surge and wave setup can combine with extreme rainfall events to produce water levels significantly higher than would result from individual events. This will be particularly important in low lying areas. More sophisticated flood modelling approaches may include joint probability analysis to assess the implications of combined events on flood levels.

Economic valuations include the estimated cost of inundation and the benefits of occupying the hazard zone now and over time. Using average annual damage (AAD) to derive an estimate of inundation costs for each year based on the probability of various flood events occurring is one such approach.

Costs of inundation can be assessed for the following key categories:

- residential impacts (including damage to buildings, contents, cars, and external assets, as well as clean-up costs)
- commercial & industrial impacts (including damage to buildings and contents, and clean-up costs)
- impacts to other assets (including roads, schools and other public assets and infrastructure)
- indirect impacts (including disruptions to transport, commerce, employment, communications or emergency services).

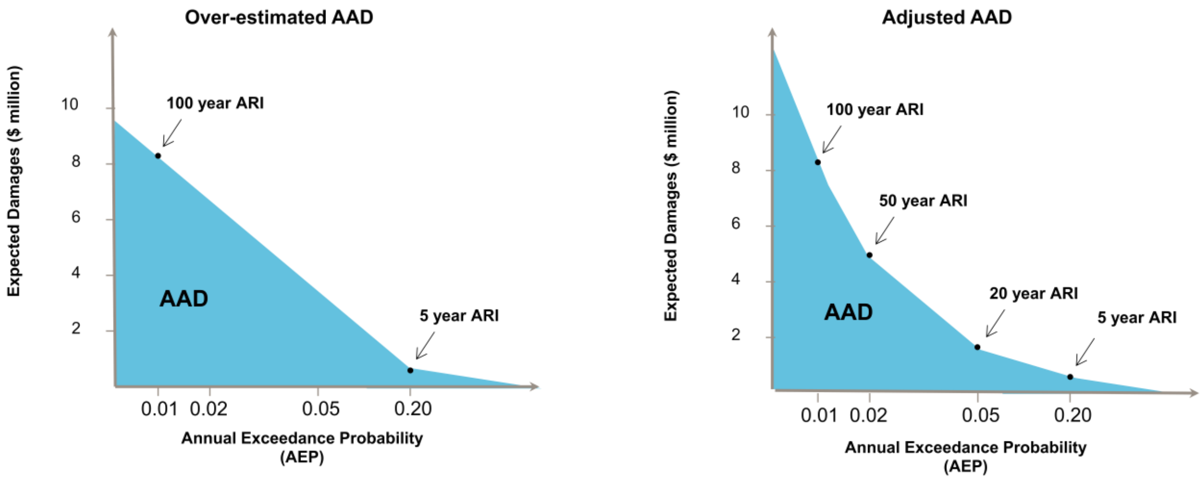
To calculate AAD, the cost of each event needs to be estimated. Inundation costs can be estimated in several ways including from studies of historical events, interviews with affected individuals and interrogation of insurance claims. Due to the large costs involved in collecting and analysing site specific costs, it is likely to be prohibitively expensive to collect past flood cost data for a specific area. Therefore, economic parameters from existing research on inundation events in other areas should be applied alongside any information gathered through local investigations. In Victoria, standard values for flood damages can be sourced from documents such as the Department of Sustainability and Environment's *Review of Flood RAM Standard Values* (2009).

Once the costs of individual flood events are estimated, the AAD can be calculated for each year in which data exists. Recognising that flood events are unlikely to be mapped for every year and therefore costs will not be known for these years, AAD for intermediate years can be interpolated between the known points to allow an estimate of AAD from the current year to the desired end point (for example 2100).

Observing how AAD increases over time creates the ability to contrast the cost of anticipated impacts against the current situation and different adaptation pathways. The present value of inundation costs can then be calculated by discounting forecast AAD to current dollars using chosen discount rates. The present value of costs is useful for gauging the scale of financial impacts expected from future inundation.

If only limited data is available, it is likely that the calculated AAD will be an over-estimate as it will be based on straight interpolations between limited points. To compensate, it can be assumed that the approximate shape of the AAD curve will be similar to the 'no climate change' case, which is likely to have inundation data for a greater number of ARI events. This will allow for damages to be estimated for a larger range of ARI events where damage costs have not been calculated directly. Figure 2 illustrates the difference between assessing AAD from multiple data points compared with limited data points.

Figure 2 Illustration of how AAD is more likely to be overestimated from limited inundation data. The total AAD is represented by the shaded area. As illustrated by the diagram on the right hand side, using only two data points to extrapolate results in an over-estimation of the AAD in comparison to a curve that uses multiple data points.



The estimate of the net value of occupying the hazard zone in which no adaptation measures are expected to occur (or 'business as usual') provides a metric to argue the economic need for adaptation while also creating a useful baseline for comparing different adaptation pathways.

Other useful economic valuations may include estimating the economic benefit of occupying the hazard zone.

Residents, businesses, and visitors value coastal area for different reasons and in different ways. This can be measured through land prices, rents and people's willingness to visit destinations. By estimating these benefits on an annual basis, an estimated value of the benefit of the area can be compared to the AAD. The difference between the two is the net benefit of occupying the hazard zone. Box 2 provides an example of how this information can be presented.

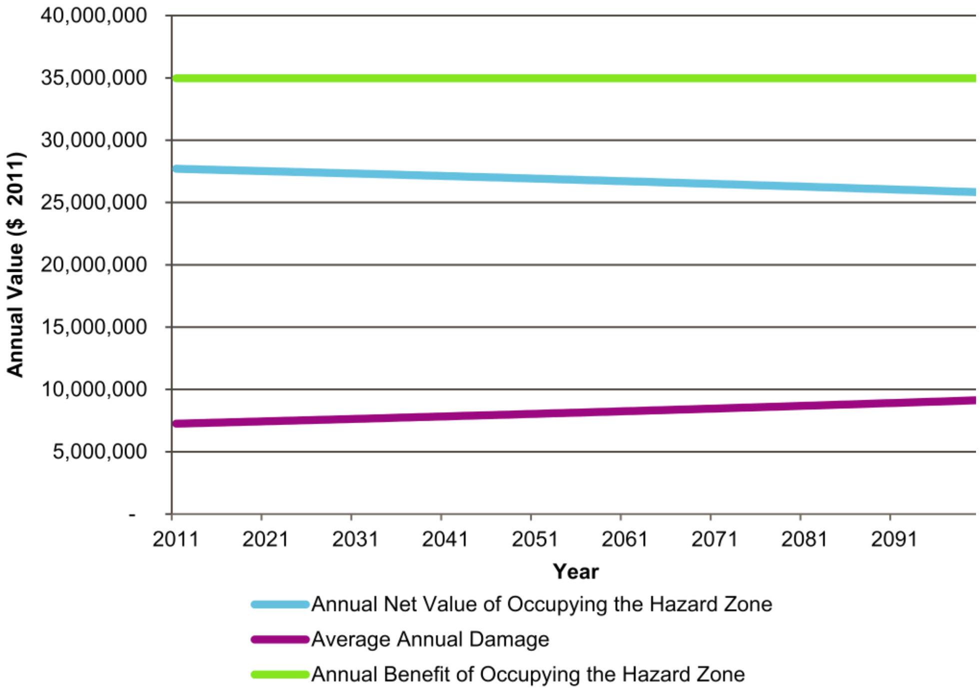
Box 2. The net benefit of occupying a hazard zone with changing flood risks.

Graphs combining the different economic valuations used to assess changing flood risk can be a useful communication tool.

The example below is for a hypothetical location where flooding already occurs but is expected to worsen as sea levels rise and rainfall is more extreme. No major changes in land use or new development is expected to occur between now and 2100.

The green line indicates the estimated annual net benefit of occupying the hazard zone will be constant between now and 2100 as no growth is expected. The red line shows that AAD from inundation is expected to grow as flooding caused by increases in sea levels and extreme rainfall increases (assuming no adaptation occurs). In areas where increases in development are planned, it would be expected that the slope of this line would increase as a greater number of assets would be at risk, however the slope of the green line would also increase. The blue line indicates the 'net' benefit of occupying this area. It represents the difference between the annual benefit of occupying the area and the expected AAD. This example also points out the importance of including appropriate contextual information to allow for more meaningful interpretation.

***Figure A** Estimated net value of occupying the hazard zone for a hypothetical coastal location where no change in land use is expected and no major re-development is currently planned, but where flooding is expected to increase over time as a result of climate change.*



Due to the high value of many coastal areas, the benefit of occupying any coastal area is likely to be much higher than the AAD. Thus occupying the hazard zone is likely to continue to be economically favourable despite increasing flood costs. Although this suggests retreating from the *entire* hazard zone would not be a suitable response, it does not imply that retreat is not the optimal economic solution for individual assets or activities. This project did not consider the potential cost of retreat from of the hazard zone.

This tool is best used for smaller areas or individual assets located in high risk locations. For example, a residential property at risk inundation may face expected future damages well above the economic value of occupying the site. If there are no solutions to protect the property from the inundation (which cost less than the cost of retreating) then retreating would represent the lowest cost option. The benefit of occupying sites within the hazard zone is a useful calculation when assessing possible adaptation options for high risk assets. However, only using the net benefit of occupying the entire hazard zone to test the economic viability of retreating ignores the possibility of other lower cost adaptation options.

The key objective in assessing current and future flood risk is ultimately to determine if intervention (adaptation) is required.

Once the average annual damage has been calculated it is important to consider how these will change over time and if increases are economically significant enough to warrant active intervention. This economic information will also assist in identifying the appropriate scale of adaptation investment.

For example, an urbanised area with limited development planned and a relatively low estimated cost of inundation would have to consider if the cost of protection measures are warranted (although other social or environmental factors may also need to be considered). If current flood risks are acceptable to the community and these risks are not expected to increase dramatically in the future, an economically prudent approach would be to continue monitoring flood risks and local circumstances.

If it is determined that intervention is not required at this time, then application of the framework may pause at this point.

Alternatively, for areas where the cost of inundation is expected to be significant or the community has limited capacity to bear these costs, continuing to develop an adaptation pathway is recommended.

4.3 Identify and consult on initial adaptation pathways

An adaptation pathway describes a flexible course of action to be taken over time in response to potential or actual inundation. The pathway is likely to comprise of cost-effective groupings of adaptation options that if taken will help increase the resilience of an area by reducing the cost of damages from flood events and / or the extent of flooding.

The first step in developing a pathway is identifying potential adaptation options in response to the identified inundation risks. A ‘blue sky’ approach to brainstorm options can help identify more creative adaptation options which may have win-win benefits and can help avoid constrained thinking where responsibilities for flood management are unclear. Options can be considered across the following themes:

- **Policy** - changes to existing, or the development of new, policy, standards or guidelines (for example changes in zoning or building regulations)
- **Physical/engineered** - physical changes or engineered solutions to existing assets, or creation of new assets (for example improved drainage works or the construction of flood barriers)
- **Research** - specialist technical investigations and feasibility assessments of a site, asset or solution to address the identified risks (for example research into the effectiveness of upstream retarding basins to help minimise the risk of flooding)
- **Behavioural** - adjustments to existing processes or procedures as well as awareness raising and education (for example emergency management procedures, flood alert systems or information sessions for residents in flood prone areas).

Adaptation options will vary in scale and scope – some options will only reduce inundation risk within the physical boundaries of the assessment area while others may help reduce risk to a wider area (i.e.

an entire catchment). Options may also be outside of a single organisation's responsibilities or capacity. Regardless, all potential adaptation options should be captured. A range of non-site specific adaptation options relevant to managing flood risk are outlined in Table 1.

To assist with the selection of adaptation options in Step 4, it can also be useful to capture additional detail for each identified option, including:

- **Lead agency** - which organisation would be most effective in leading the implementation of the action (e.g. local government, the private sector, state government)?
- **Supporting Agencies** - would support be required from other agencies to develop or implement the option? What type of role would these agencies have (for example changes to existing legislation or regulation, provision of data or public support)?
- **Organisation's role** - what role would the organisation leading this process take in implementing or supporting the implementation of the adaptation option (for example active collaboration, advocacy or provision of data)?
- **Trigger or timing** - what would trigger the development or implementation of the adaptation option (for example a major flood event or a broader review of current policy)?
- **Enabling mechanism** - what actions or processes would ensure the effective implementation of this option (for example political or community support, removal of a policy barrier, redevelopment or funding opportunity)?
- **Barriers** - what issues would prevent the effective implementation of this action (for example lack of data)?

The process for developing options may be conducted internally within an organisation, in conjunction with stakeholders. Broader engagement may lead to a greater pool of options and provide other benefits (such as building awareness of risks or identifying areas where responsibilities are not clear). However, it may raise stakeholders expectations, require additional resourcing or extend project timeframes. Therefore engagement around adaptation options should be considered as a part of a broader communication and stakeholder engagement process. Appendix A provides a potential model for stakeholder engagement.

Table 1 Potential adaptation options to manage flood risk.

Policy	Physical/engineered	Research	Behavioural
- New or extended flood overlays to inform land use planning - New or extended special building overlays - Update state and municipal emergency management plans - Incorporate changing inundation risks into corporate risk registers - Re zoning of land subject to inundation - Mandatory disclosure of flood risk at time of purchase and leasing - Update drainage asset management plans - Incorporate consideration of inundation issues in relevant planning checklists - Review heritage policies to minimise potential barriers to flood protection measures	- Upgrade of local drainage assets - Increase height or extent of current flood levees - Upstream retarding basins to improve flood storage capacity - Floodgates for creeks and rivers - Modify stormwater diversions and storages - Restore natural floodplains and swamps - Elevate critical assets above the flood level - Relocate critical assets	- Develop climate resilient design standards for developments and assets in flood prone areas - Undertake erosion assessments - Detailed risk assessments to determine risk of flood protection failure - Technical feasibility studies for proposed flood protection measures	- Increased training to enhance organisational capacity to prepare for and respond to flood events - Community awareness and education campaigns to increase resilience to flood events - Targeted information resources for flood protection measures for builders and renovators - Increased maintenance of key assets such as stormwater drains - Review insurance arrangements - Clarify roles and responsibilities for flood mitigation, response and recovery

The second stage of this step is to group adaptation option into different potential adaptation pathways.

The purpose of these potential adaptation pathways is to allow transparent comparisons between different groups of adaptation options to assist strategic decision-making by estimating the economic value of different strategic approaches to adaptation. Box 3 describes the adaptation pathways that were used in the Port Phillip Bay case studies. This approach also allows consideration of when it is economically favourable to transition between pathways based on the level of adaptation.

Box 3. The adaptation pathways used in the Port Phillip Bay Coastal Adaptation Pathways project

For the five case studies in Port Phillip Bay three initial adaptation pathways were constructed to allow comparisons using cost benefit analysis. Each pathway illustrates a potential scenario for the overall intent or purpose of the adaptation response.

***Accommodate Pathway** - allows flooding to occur but efforts are focussed on minimising impacts when it does occur. Adaptation options are focussed on those which can help communities and individuals prepare for, and recover from, flood events, including behavioural and policy interventions. To estimate the impact of this pathway on average annual damage in the cost benefit model it was assumed that:*

- *actual damages as a percentage of potential damages are reduced from 80% to 65%*
- *actual to potential ratios for damage to the contents of commercial buildings are reduced from 44% to 35%.*

***Moderate Protection Pathway** - reduces the impact of current flooding by reducing its localised extent via modest or small scale engineering solutions. This pathway also includes behavioural and policy interventions undertaken in the Accommodate Pathway to help reduce and avoid risks. To assess the benefits of this pathway, it was assumed that the adaptation options included would protect the study area from a current (2011) 100 year ARI event.*

***Major Protection Pathway** - eliminates the risk of future flooding through large scale engineering solutions to allow continued use or development of the hazard zone over the longer term. This pathway includes options included in the Accommodate and Moderate Protection pathways. To assess the benefits of this pathway, it was assumed that the adaptation options could protect the study area from a 100 year ARI event in 2100 under the assumed climate change scenario.*

A fourth adaptation pathway was initially identified which would have enabled retreat from the hazard zone. This pathway was not considered for any of the five case studies sites in this project based on the estimated value of occupying the hazard zone.

Adaptation options will need to be assigned to a particular pathway. The grouping of actions into the pathways can include a mix of actions that are the sole responsibility of the organisation, actions that require multiple owners or actions where the owner is yet to be defined. This approach supports a broad cost benefit assessment where the costs or benefits are not assigned.

The final stage of this step is to estimate the cost of developing and delivering each adaptation pathway. This should include an estimate of both the upfront or capital costs as well as any required operating costs. Costs can be estimated based on experiential evidence, recent comparable works or activities or available funding envelopes. To simplify this process, an initial short listing of the identified adaptation options may be helpful.

The process of shaping and costing the potential adaptation pathways may benefit from engagement with technical specialists.

4.4 Appraise and compare adaptation pathways

Numerous tools or approaches can be used to appraise and compare different adaptation pathways. Cost benefit analysis (CBA) is a well-established, systematic process that involves the assessment of costs and benefits of a project over a defined time period.

The economic benefit of each pathway can be calculated as the reduction in average annual damage from implementing adaptation options. An example of how this can be shown graphically using the pathways developed for Port Phillip Bay is shown in Box 4. The cost component of the analysis can include the estimated cost to develop, implement and operate adaptation options within the pathway combined with any residual AAD.

Costs and benefits are always measured as incremental changes relative to a base case (or ‘business as usual’ case). For example, when measuring the benefits of an adaptation option, an incremental benefit of the option is the reduction in average annual damage – that is, the average annual damage in the base case without any adaptation minus the average annual damage with the adaptation option. This benefit of reduced damages is then assessed against the incremental change in cost – that is, the cost of implementing and maintaining the adaptation option.

Costs and benefits that occur in different time periods are made comparable in the present time period by converting to present value using a process known as discounting. The basic premise is that society has a preference for benefits to be achieved sooner rather than later (known as a ‘social time preference’) and that delays in receiving these benefits impose an opportunity cost. Therefore, $100 in benefits received today is worth more than $100 received in ten years. Similarly, the occurrence of costs is preferred later rather than earlier. Therefore, $100 in costs today is a greater burden than $100 to be paid in 10 years.

The degree to which future costs and benefits are reduced to convert them to present value is determined by the discount rate. Higher discount rates reduce future streams of costs and benefits more relative to lower ones, and indicate a relatively higher social preference for more immediate net benefits.

Annual benefits will need to be discounted back to present dollars and compared to the present value of the adaptation costs estimated for each adaptation pathway. If the present value of the benefits is larger than the present value of the costs, the adaptation pathway is expected to provide a positive economic return to the area as a whole.

The difference between the present value of costs and the present value of benefits is known as the net present value (NPV). The NPV is the present value of all benefits less the present value of all costs and is a measure of the absolute return on invested funds. The Benefit Cost Ratio (BCR) represents the present value of all benefits divided by the present value of costs and is a measure of the proportional return on invested funds.

Pathways with a positive NPV would be considered economically favourable and should be considered for implementation within the context of other options available and the allowable budget. Projects with a negative NPV are uneconomic and should not proceed unless there are considerable external benefits that are not quantified within the CBA. Pathways with a BCR greater than 1 would generally be considered economically viable investment choices.

An economically favourable pathway will always result in a positive NPV and a BCR greater than 1, and an uneconomic project will always result in a negative NPV and a BCR less than 1. However, the NPV can sometimes give conflicting results – sometimes a pathway may have a lower BCR but a higher NPV than another pathway.

Which is more important depends on the circumstances. The goal is to get the maximum value from the available funds to be invested, with the assumption that any unused dollars can be invested elsewhere and achieve an expected return equal to the discount rate. If projects are mutually exclusive, then choosing the pathway with the highest positive NPV within budget constraints is always economically preferred. For example if there is a given amount of funding available for adaptation in a certain area, the pathway with the highest NPV would be economically preferred.

Choosing a combination of options for a pathway to get the greatest total NPV within the available budget is preferred. This may not mean always choosing the pathway with the largest NPV first, since there are likely to be many combinations of options that use the available budget more effectively. This could be the case when looking at a range of adaptation pathways over a region. For example, if you have a maximum budget of $100,000, then choosing two options that cost $50,000 each and both have NPVs of $20,000 is preferable to choosing a $70,000 project with an NPV of $30,000 (despite it being more highly ranked on the NPV scale).

However, if the aim is to achieve the greatest return on investment funds without reference to a budget constraint, and projects are not mutually exclusive, then choosing projects based on BCR provides the best economic outcome.

The economic analysis will be useful to help decision-makers assess the relationship between the costs and benefits of different adaptation approaches. If a pathway involves large scale protection measures, the costs may be significantly higher than the estimated accrued benefits. This may provide decision-makers with an opportunity to proceed with an improved understanding of the economic impacts of inundation and consider alternative adaptation approaches which may help increase the expected level of benefit.

4.4.1 Additional tools to help manage uncertainty

It is expected that a number of assumptions have been made to get to this step. These assumptions are likely to include variables relating to damage costs, flood heights, discount rates, adaptation costs etc.

Monte Carlo analysis is a tool that quantifies the uncertainty of individual inputs (i.e. distributions between upper and lower estimates) to be used to feed into an overall assessment of uncertainty of the findings.

The outputs of the Monte Carlo Analysis are a distribution around the expected value of these economic indicators so that a confidence interval can be estimated. This analysis provides a useful indication of the extent of uncertainty and risks posed by the incomplete nature of different data inputs. The range of possible results and their associated probabilities helps quantify and measure uncertainty to better inform decision-making.

Application of Monte Carlo analysis is best considered in relation to high cost adaptation pathways or options. It does not add enough value to warrant its application to all cost benefit analyses undertaken as part of Step 3. Further explanation how Monte Carlo Analysis was used at one case study location is included in Section 5.5.

Box 4. The net benefit of occupying a hazard zone with changing flood risks.

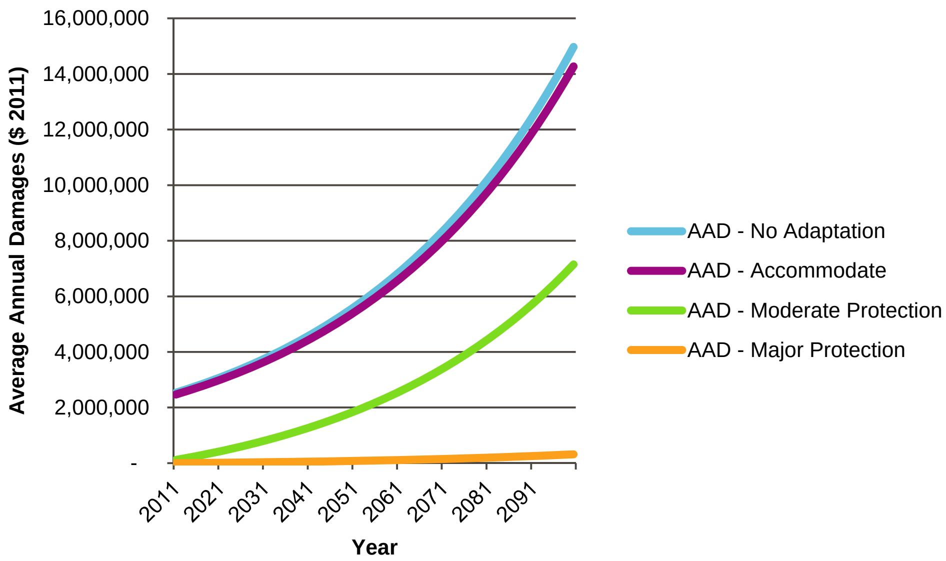
The example below is for a hypothetical location where flooding already occurs but is expected to worsen as sea levels rise and rainfall is more extreme. No major changes in land use are expected to occur between now and 2100, but it was assumed that development will intensify.

Each line indicates the expected change to estimated flood damages for each adaptation pathway. For the purposes of comparison, a business as usual case (where no planned adaptation occurs) has been included.

In this example, pathways involving physical protection are assumed to reduce either current or future inundation levels. This may be through stopping water entering areas using levees and sea walls or by removing water through improved drainage systems. In many cases, a combination of both approaches may be appropriate.

For both the Moderate and Major Protection pathways, new flood heights have been estimated to recalculate flood costs and associated changes to AAD. If the resources are available this should be done by including the effect of protection assets such as levees or improved drainage into the flood models. Alternatively, new flood heights can be estimated based on the engineering knowledge of the local area and the assumed capacity of the protection measures. Once the new inundation heights are entered into the model, revised average annual damage figures can be calculated and used to estimate the annual benefit of the adaptation pathway.

Figure B Example of how different adaptation pathways are expected to affect AAD over time under the assumed climate change scenario. Results are for a hypothetical location.



4.5 Consult and develop adaptation options

The results from the previous steps are expected to provide initial guidance to decision-makers about the scale of adaptation required and indicative timing of when to adapt based on the scale of flooding and potential economic benefits.

If decision-makers have a clear objective to keep damages below a certain threshold, they can plan an adaptation pathway based on the expected AAD. Alternatively, other trigger points could be identified such as when inundation levels threaten critical infrastructure.

Although important, results of economic analyses will be just one input for decision-makers – stakeholder views and expectations, feasibility, impacts on local amenity as well as other social or environmental impacts will also need to be considered for individual adaptation options and groupings of options. If a protection option is popular with the community but has much higher costs than benefits, this can be used to start a dialogue regarding possible alternative approaches including changes to design or additional funding mechanisms. Sensitivity tests can be undertaken to investigate how benefits can be maximised at minimum cost.

It will also be critical for decision-makers to explore the potential social, environmental and economic implications of individual adaptation options for both the community, their organisation and other stakeholders. Further investigations and consultation with the community are likely to be required. Tools such as multi-criteria assessments may be useful to ensure a transparent process.

4.6 Implement, collaborate and advocate

The adaptation pathway is likely to include actions within and outside the current responsibility of a single organisation. More detailed consideration by individual actors will be required, including how adaptation options will be progressed.

It will be important for individual organisations to prioritise specific adaptation actions within the pathway and to collaborate with other organisations undertaking supporting adaptation options. For many, this process is likely to involve a multi-criteria assessment to help prioritise based on which actions:

- there is direct control of or where a leading role has been identified
- are of low cost and high benefit to both the organisation and the community
- require further research or technical investigation to reduce uncertainty or assess individual adaptation options
- can be expected to have a long lead time.

The process of prioritising adaptation options may also benefit from external stakeholder engagement, including consultation with the community.

The different actors involved in managing flood risk can now consider how to best prioritise and implement adaptation options in both the short and long term. Ideally, this should be done in collaboration and conjunction with other stakeholders to allow a more coordinated and efficient adaptation response. Ideally, prioritised options should be integrated into existing strategies, plans and activities, such as strategic plans, structure plans, adaptation strategies or maintenance plans.

4.7 Monitor and review

Similar to a risk management process, the development and implementation of an adaptation pathway is not a linear process with a static beginning and end point. Reviewing and re-assessing the adaptation pathway chosen will be required as:

- **Flood risk changes**. Between now and 2100, flood risks will change as a result of:
    - new information or improved data becoming available. This information may be in relation to climate change projections, physical conditions or economic data for example. Flood modelling forms the basis of the economic assessment undertaken using this framework.

The generation of new flood models or reductions in uncertainty of assumptions made to inform the initial adaptation pathway would assist in reducing the uncertainty relating to this fundamental component of the assessment. Similarly, the generation or release of updated or locally specific climate change projections would generate the need to revisit the flood modeling which forms the basis of the economic assessment.

- a major flood event occurring which leads to the generation of new flood extents. This would require revisiting Step 1 of the framework. Major flood events may also generate locally specific cost (damage) information that could reduce uncertainties associated with damage estimates.
- unexpected or non-linear changes in climate occur (for example an acceleration in the rate of sea level rise). The IPCC recognises that non-linear changes in climate may occur as a result of positive and negative feedback loops in the climate system. Such changes may significantly alter the rate of change or the amount of change expected in climate variables such as sea level.
- social, environmental or physical factors influencing vulnerability or adaptive capacity. Demographic, social, economic, technological and environmental change will occur between now and 2100. These factors will positively and negatively influence vulnerability and adaptive capacity to inundation risk. These factors will need to be monitored over time and considered when reviewing the current adaptation pathway.
- the implementation of adaptation options. As adaptation options are implemented, the need for and effectiveness of other adaptation options will should be re-considered, particularly across scales. For example, changes in policy may direct activities or assets out of the hazard zone over time, thereby potentially negating the need for some adaptation options. Alternatively, investment in significant protection options may eliminate the need for behavioural adaptation options.

- **Funding opportunities become available**. Changes in access to funding, either through grant programs or internal budget processes may influence the viability of some adaptation actions. In this situation the framework can be reapplied from Step 2. Alternatively, significant adaptation options not previously considered due to lack of funding may be re-incorporated into the adaptation pathways at Step 2 or Step 4.
- **Risk appetite changes**. The willingness of a community, organisation or individual to accept inundation risk is unlikely to change. Repeated flood events, or a significant flood event will likely result in changes to what is considered tolerable. Alternatively changes which affect the ability of risk to be managed or transferred (such as access to finance or insurance) may also affect risk appetite and therefore the value of occupying the hazard zone or the perceived benefits of adaptation.

Depending on which factor triggers the review of the adaptation pathway, users will need to consider where it is most appropriate to re-enter the process. Continued collaboration and consultation with all relevant stakeholders and the community will be essential for effective monitoring and review.

5.0 Testing of the framework

Testing of the framework in different case study settings has supported the development of a more robust framework, including supporting tools which can be applied to other locations.

The framework was tested and informed through:

- its application at five different locations with four different local government authorities
- regular engagement and feedback from the Project Steering Committee which included representatives from key state government departments, as well as peak body associations and the local coastal committee of management
- application of additional tools (joint probability analysis, Monte Carlo analysis and additional future flood modelling) at different locations to assess their value for incorporation into the final framework.

The framework was applied at five sites around Port Phillip Bay in Victoria, Australia. Each area has different characteristics, with a mix of land use types, geographic characteristics and development densities (Table 2). Maps of each case study boundary are shown in Figures 3 to 7. This mix of case study settings and application of different tools was taken to help ensure that recommendations and lessons are both practical and transferrable to other Australian coastal communities.

Table 2 Summary of the five case study areas where the framework was tested.

Local government authority	Characteristics	Size	Land use		Additional analysis undertaken
			Now	2100	
Mornington Peninsula Shire Council	Residential/peri-urban area in steep upper catchment	274 ha 2605 land parcels	Predominately residential with mixed use on the foreshore	No change	-
Kingston City Council	Low lying suburban business district situated close to coastal foreshore unprotected by levies or structures	66 ha 503 land parcels	Predominately residential	No change	Joint probability analysis of inundation
City of Port Phillip	Former coastal swamp now highly modified and urbanised	205 ha 2634 land parcels	Predominately residential	No change	Monte Carlo analysis
City of Melbourne (A)	Low lying urban renewal precinct situated along a creek	147 ha 1146 land parcels	Residential and industrial	Mixed use	-
City of Melbourne (B)	Low lying central business district situated along the tidal zone of the Yarra River	158 ha 581 land parcels	Residential and commercial	No change	Flood modelling for 2040, 2070 and 2100

Figure 3 Boundaries for the Mornington Peninsula Shire Council case study site (Murray Anderson Catchment)

Figure 4 Boundaries for Kingston City Council's case study site (Mordialloc Creek)

Figure 5 Boundaries for the City of Port Phillip case study site (Elwood Canal)

Figure 6 Boundaries for the City of Melbourne case study site (Southbank)

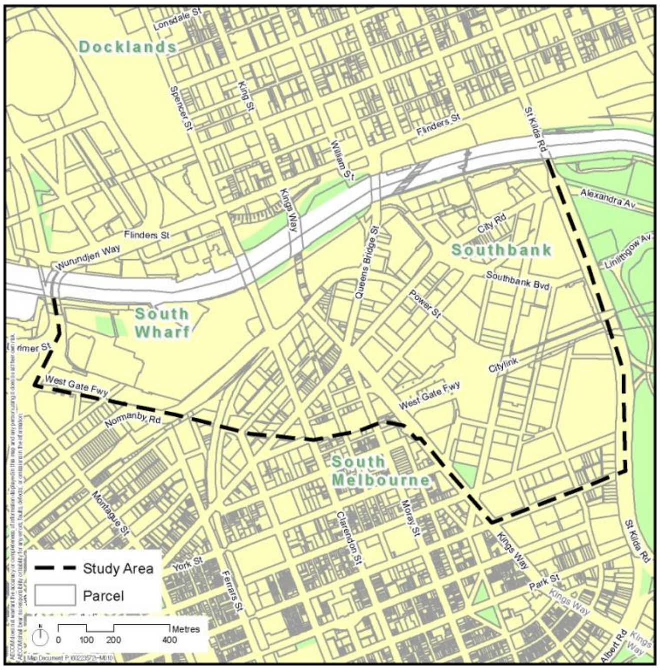
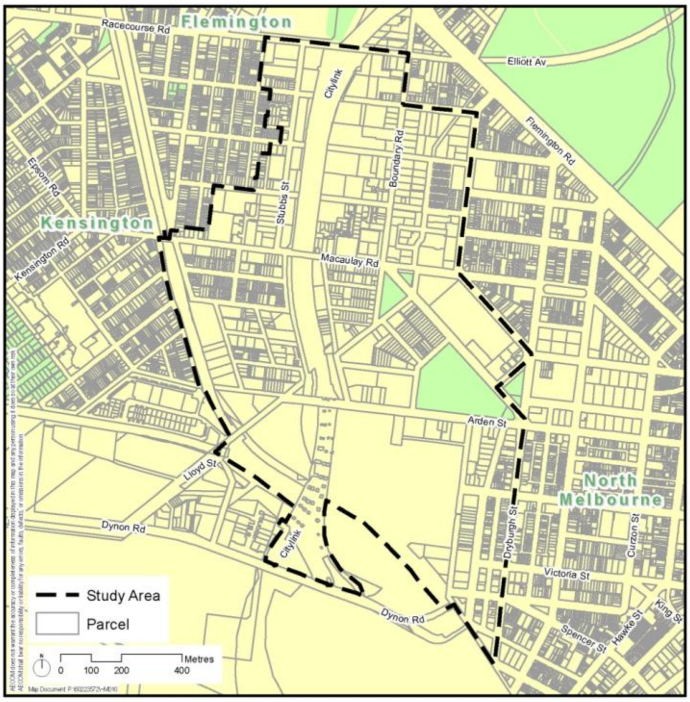


Figure 7 Boundaries for the City of Melbourne case study site (Arden Macaulay)



Engagement with local government focussed on the application of the framework through a series of workshops. Workshops typically involved representatives from across each council including planners, drainage engineers, environmental officers and elected councillors as well as a representative from the local water authority.

Testing has demonstrated:

- different approaches to analysis in response to available data
- different methods for considering uncertainty
- the value of improved collaboration between organisations responsible for different aspects of managing flood risk
- the implications of different geographical scales in applying the framework.

The following section presents a discussion of some of the assumptions used, key findings, limitations and the lessons gained from applying the framework.

A summary of data sources used in developing this report is included in Appendix B. Detail regarding the approach used to undertake the flood modelling in this study is included in Appendix C.

5.1 Assumptions applied in testing the framework

This section sets out the assumptions and resulting limitations that were adopted to develop adaptation pathways for each of the five case study locations.

5.1.1 Assumptions about future climate change

The impacts of climate change on both extreme rainfall and sea level rise have been incorporated into the modelling and flood mapping[4]. Localised climate change projections for changes in extreme rainfall, both in relation to its intensity and frequency, are not currently available. As such, this study has applied an allowance for future extreme rainfall which is used by other relevant planning authorities. This data was provided by Melbourne Water and is based on the following assumptions:

- Sea-level rise of 0.8m by 2100.
- Increase in rainfall intensity of 32% by 2100.

5.1.2 Assumptions about flood extent

This study has used existing flood modelling at three of the five case study sites. Communication with the City of Melbourne and Melbourne Water indicated that there was no existing flood modelling or mapping results for the Southbank Case Study. For this reason, AECOM were commissioned to undertake additional flood modelling and mapping of the study area. Details of this investigation can be found in AECOM's *Southbank Flood Modelling and Report* (2012) which was undertaken for the study area in accordance with Melbourne Water's *Technical Specifications and Guidelines for Flood Modelling and Mapping* (2010). Similarly, there was no appropriate flood mapping for key segments of the Arden Macaulay Case Study. However, a one-dimensional HEC-RAS (flood) model was available from Melbourne Water for Moonee Ponds Creek which was used to generate flood extents.

All inundation extents for existing ARI events and 2100 ARI events came from data supplied by Melbourne Water. As the economic analysis is derived directly from this data, all assumptions that have gone into inundation modelling will be reflected in the economic outputs.

This study has not analysed the costs and benefits of changes to coastal erosion caused by sea level rise. Inundation modelling indicates that most of the flooding in the case studies is due to intense rainfall events and not inundation from Port Phillip Bay storm events. However, over time, significant coastal erosion could take place potentially causing large impacts to the local area. While this issue is related to coastal inundation it is a complex issue requiring dedicated investigations.

As flood events in those case studies caused large areas of low level flooding, the results of the economic analysis are very sensitive to the floor heights of buildings. Floor levels were provided by Melbourne Water for the modelled flood extents only. Where a floor level elevation was not available it was estimated based on the ground elevation from the LiDAR data for each land parcel and an onsite visual assessment of the estimated height of the floor level above the ground level.

Mapping of future inundation at four of the five case study sites did not include joint probability analysis for co-events (such as a king tide coinciding with catchment flooding).

Flood information is based on theoretical storm events, and may not reflect actual flooding behaviour.

[4] Sea level rise was not considered for the Arden Macaulay Case Study. Due to the site being an inland location, immediate coastal inundation effects are not represented explicitly. They are represented as an increase in the downstream boundary water level (which is the Yarra River water level). This incorporates sea level rise, but not directly.

5.1.3 Assumptions about economic costs

Costs of inundation are limited to damage to residential, commercial and public assets, clean-up costs and indirect costs (e.g. disruption to business, transport and communication). There are various other issues not addressed quantitatively in the economic modelling such as safety, quality of life, heritage issues and other social values. For this reason cost benefit analysis should be used as a piece of information to be used alongside other decision making criteria.

A discount rate of 3% was chosen as a mid-range estimate of other published discount rates used for assessing long term environmental and social impacts. A different discount rate would affect the results as would changes to a number of other data inputs.

Due to the long time frames associated with adaptation planning, land prices were assumed to increase at the same rate as inflation (i.e. remaining constant in real terms). Although Australia has seen large increases in real estate prices in the past 20 years, most long term trends (50 to 100 years) indicate that real estate prices tend to show mostly constant real prices. For areas expecting urban renewal, it has been assumed that the current low value, low density land uses are replaced with higher value land uses based on council structure plans.

For the Murray-Anderson Catchment case study, costs of inundation for foreshore camping areas were estimated by assuming a relationship between flood depth and length of closure of campsite. The direct loss of this flooding was determined to be the lost revenue to operators with the indirect losses represented by the lost revenue to local business for money not spent in the local area. This was estimated based on data received from Tourism Victoria relating to average spend per tourist.

The cost of adaptation options included in the adaptation pathways for the CBA were derived based on recent comparable works in consultation with AECOM’s technical areas. These costs are provided to indicate the magnitude of expenditure required at each location and can be used for initial planning purposes. For more detailed estimates, a further costing exercise would need to be undertaken.

5.1.4 Assumptions related to future socio economic changes

Changes in land use and population were factored into the analysis as indicated by Council plans and structure plans. No major changes to planning provisions have been assumed.

The estimate for the base case in 2100 assumes that climate change occurs but no planned adaptation is undertaken.

5.2 Summary of findings from the Port Phillip Bay case studies

A summary of the findings for Steps1 to 3 of the decision-making framework generated from the case studies are presented below. The purpose of including these findings is to present example outputs for establishing an adaptation pathway. It is not intended that either the methodology or the findings below are used to compare adaptation needs between areas.

5.2.1 Current and future flood risk

As noted previously, flood modelling for current conditions was available for three of the five case study areas from the local water authority (Melbourne Water). For the Mordialloc Creek Case Study, an alternative approach was developed with Melbourne Water using a one-dimensional HEC-RAS model. Detailed modelling was conducted by AECOM for the Southbank Case Study as no appropriate flood modelling was available at the time. Appendix C provides technical information on how the 100 year ARI sea level rise was determined for each of the five sites.

Extreme rainfall causes flooding in the upper reaches of catchments. In some of the lower reaches, flooding extent is dominated by water levels in Port Phillip Bay and the Yarra River.

The results of this flood modelling were used to identify and compare current inundation with potential inundation under the assumed climate change scenario which incorporates sea level rise and extreme rainfall[5].

[5] Sea level rise was not considered to be a relevant flood mechanism for Arden Macaulay Case Study and was therefore not considered at this site.

The extent of inundation for the 100 year ARI flood event was considered to be any area inundated by either a 100 year ARI local rainfall event or a 100 year ARI coastal flooding event.

The expected increase in flood extent by 2100 is outlined in Table 3.

Table 3 Current and future flood extent as a result of sea level rise and increased extreme rainfall. Inundation extents for 2100 are based on the assumed climate change scenario.

Case study	Inundation extent (% of land parcels flooded within the case study area)	
	2011	2100 (assumed climate change scenario)
Murray-Anderson Catchment	74	76
Mordialloc Creek	43	73
Elwood Canal	60	80
Arden Macaulay	55	65
Southbank	79	90

5.2.2 Cost of flooding

Cost of flooding (AAD) was estimated using the following key categories:

- residential impacts (including damage to buildings, building contents, cars and external assets as well as clean-up costs associated with flooding)
- commercial and industrial impacts (including damage to buildings, building contents and clean-up costs associated with flooding)
- impacts to other assets (including roads, schools and other public assets and infrastructure)
- indirect impacts (including disruptions to transport, commerce, employment, communications and emergency services).

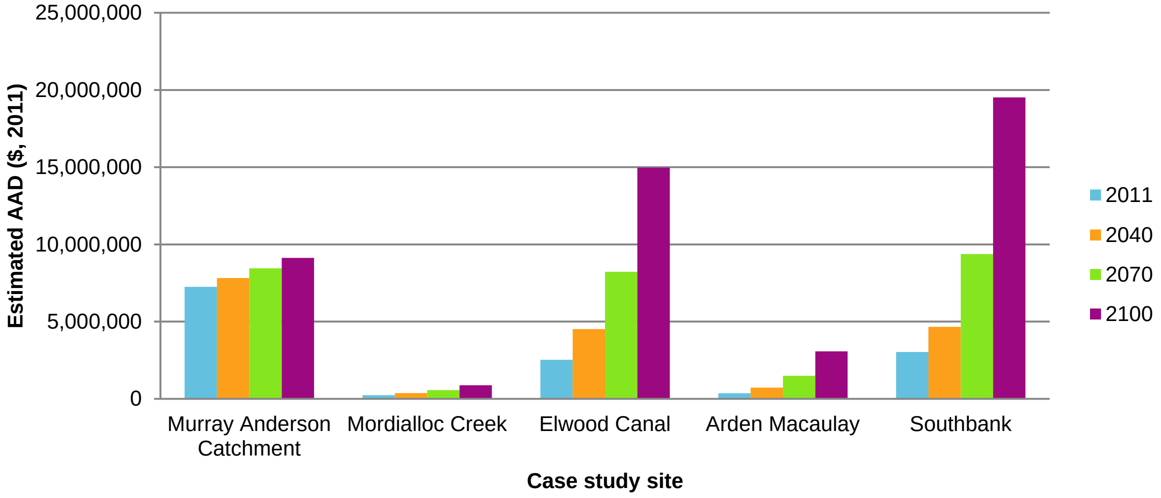
For 2100, inundation data was only available for a limited number of flood events (100, 20 and 5 year ARI) at four of the five sites. A straight-line interpolation at these sites would have likely overestimated AAD. To avoid this, the approximate shape of the AAD curve generated for the 'no adaptation' scenario was used to interpolate estimates of AAD for 10 and 50 year ARI events. However less confidence should be placed in these results.

Without adaptation, all case study areas indicated an increase in AAD between 2011 and 2100 (Figure 8). The differences between the scale of changes in AAD in each of the case study areas is a result of the physical properties of the case study area, the planned development scenario and the level of flooding. For instance, the high AAD for Murray Anderson Catchment Case Study under current conditions is a result of this area having a large number of properties being inundated by relatively small events (10 and 20 year ARI events) under current conditions.

Expected increases in AAD for each site are a function of increased flood extent and depth as well as planned changes in development which was based on information provided by each council.

Appendix E includes a summary of the economic assumptions used for estimating AAD at each of the five sites.

Figure 8 Estimated changes to AAD for each case study area under the assumed climate change scenario. Estimates assume no adaptation occurs. All costs are in 2011 dollars.



5.2.3 Benefit of occupying the hazard zone

The benefits of occupying the hazard zone include residing, conducting business, and recreational opportunities in the area. To calculate the annual net value of occupying the hazard zone, the AAD was subtracted from the estimated annual benefit of occupying the hazard zone.

Benefits were quantitatively assessed by estimating individuals and society's willingness to pay to receive them. This willingness to pay is most obviously reflected in the rental price that residents and businesses pay for real estate within the case study area. Alternatively, if the property is owned and not rented, the rental revenue foregone can be taken as an indication of willingness to pay.

For residents of the area, the decision to rent or buy property in an area involves consideration of not only the property itself but the available amenities and recreational opportunities that the area provides. Such opportunities are therefore factored into the decision about how much to pay (either in rent or to purchase) for property in the area. For this reason property values were used as a proxy for the benefit of occupying the land.

Similarly for businesses, the benefit of renting or owning property within an area is largely a function of the potential of the business to generate profits. The larger this potential, the greater the price that a business is willing to pay to locate their business in the area. The benefit of locating the business in the area is therefore largely captured in the price to rent or buy the occupied space.

Where specific rental prices were not available for a case study area, rental prices were estimated based on capital improved values of land as provided by each council. Annual rental yields were sourced from publically available real estate databases.

Public assets such as schools and halls were assessed based on the opportunity cost of using this land, with the assumption that this land could be rented for either commercial or industrial use, depending on the area. By using this land for public purposes, society is expressing a willingness to pay that is at least as great as this opportunity cost.

The estimated annual benefits of occupying the hazard zone for each case study are shown in Table 4. The annual net value of occupying the hazard zone was calculated by subtracting the AAD from the annual benefit of occupying the hazard zone.

Table 4 The estimated annual benefit of occupying the hazard zone for each case study area. Estimates for 2100 are in 2011 dollars. The estimated benefit in 2100 does not consider the affects of climate, but does consider potential changes in land use and development based on information supplied by councils.

Case study	Estimated annual benefit of occupying the hazard zone in 2011	Estimated annual benefit of occupying the hazard zone in 2100
Murray-Anderson Catchment	$34,965,000	No change
Mordialloc Creek	$11,866,000	No change
Elwood Canal	$103,601,000	$130,843,000
Arden Macaulay	$34,130,000	$60,577,000
Southbank	$276,908,000	$768,151,000

All case study areas indicated a positive annual value of occupying the hazard zone ranging from 2.5 to 10 times the estimated AAD in 2100. This indicates that if no adaptation actions were taken, it would be expected that each study area would continue to be inhabited and used by the community. This analysis supported the decision by each council that retreating from the entire study area is not a viable adaptation approach.

The benefits of occupying the hazard zone are not directly relevant to the cost benefit assessment. It is the benefits of the adaptation options themselves (i.e. the reductions in damage or flood extend) that are of importance to the CBA.

5.3 Identification of adaptation pathways

Workshops with individual councils (and invited key stakeholders such as Melbourne Water) were held to identify potential adaptation options for each case study site. Representatives from different areas of each council were encouraged to attend – particularly from planning, engineering and environment branches.

Hazard maps along with the identification of significant assets located within flood zones, initial estimates of AAD and the value of occupying the hazard zone were used to facilitate a brainstorming approach to both current and future flood risks. Potential adaptation options were not limited to any one organisation’s responsibilities (for example workshop participants identified options which could be implemented by another level of government or behavioural changes by local residents). Many of these identified options have already been included in Table 1.

Identified adaptation options for each case study were initially grouped into one of three categories:

- policy responses
- physical or engineered responses
- behavioural responses.

In addition to these categories, options that would have benefits for the wider Port Phillip Bay or a whole of catchment scale (i.e. well beyond individual case study areas) were segregated. Table 5 provides an overview of these wider adaptation options for Port Phillip Bay / the Port Phillip and Westernport Catchment. While there was no formal criteria for the classification of these options, there was general agreement the scale of these options (in relation to cost, implementation consideration or effectiveness) excluded them for further consideration given the scale of the case study areas.

Table 5 Wider bay/catchment adaptation options identified during workshops with individual councils.

Policy	Physical	Behavioural
- Amend the Victoria Planning Provisions to account for increased flood risk - Create a new coastal flood zone overlay to guide future zoning changes - Update the National Construction Code to increase floor heights and incorporate additional flood resilience requirements such as footings and materials - Develop a '5 star' type standard for flood resilient residential and commercial buildings - Amend heritage overlays to allow flood proofing measures - Develop state or national coastal zones / overlays to help prioritise flood risk responses - Ensure consideration of coastal biodiversity protection principles - Review insurance mechanisms - Review investment in critical infrastructure in 'at risk' coastal areas - Requirement for development to follow local planning requirements based on local flood risks - Create a state-managed insurance pool for significant flood events - Review existing legislation to help ensure clear allocation of roles and responsibilities for managing flood risk (including coastal and catchment asset management as well as between levels of government and individual agencies).	- Build tide gates at the heads of Port Phillip Bay to restrict tidal flow - Build sea walls and artificial reefs to reduce flooding and erosion at vulnerable sections of the coastline - Upgrade all sewage infrastructure to prevent backflow - Reestablishment of The Great Sand – a natural sand barriers along the southern section of the Bay - Flood gates for the Yarra River - Undertake an erosion and sand deposition budget analysis for Port Phillip Bay to identify where opportunities for natural accretion can be explored.	- Establish a state or national flood emergency warning system - Consistency in messaging (including providing accessible information regarding the area at risk) - Ensure flood recovery plans are consistent with adaptation policy in the short and long term - Sustained education and resources to help better prepare communities to prepare for and manage the impacts of flooding - Education for improved / consistent planning and for decision makers within councils, planning authorities and tribunals - Establish/improve mechanisms for whole of bay collaboration between councils, CMAs, water authorities and state government.

Typical adaptation pathways were developed to illustrate the overall intent or purpose of the adaptation. These are described in Table 6. The options in each pathway include a mix of actions that may be the sole responsibility of a single organisation or actions that require multiple owners. The owner of these actions has not been defined in this project.

Common descriptions of four different adaptation pathways were proposed to facilitate a cost benefit analysis for each case study. The use of common pathway descriptions also allowed the project to consider the validity of this approach across all five case studies.

Table 6 Characteristics of initial adaptation pathways used to inform the cost benefit analysis at each case study site.

Accommodate	Moderate protection	Major protection	Retreat
Allow flooding to occur but efforts are focussed on minimising impacts when it does occur. Focus on adaptation options which can help communities and individuals prepare for, and recover from, flood events.	Reduce the impact of *current* flooding by reducing its localised extent via modest or small scale engineering solutions. This is supported by behavioural and policy interventions to help reduce and avoid risks.	Eliminate the risk of *future* flooding through large scale engineering solutions to allow continued use or development of the hazard zone over the longer term.	Allow flooding to occur but adaptation efforts are focussed on transitioning assets out of, or away from, the hazard zone. (Not considered for this project due to the estimated net benefits of occupying the hazard zone).

Adaptation options for the Accommodate Pathway were largely similar between all five case studies and focussed on five broad types of responses:

- Increasing council capacity to engage stakeholders and manage inundation risk.
- Increasing community resilience to flood events by increasing awareness, preparedness, response and recovery to flood events informed by social research.
- Adopting or modifying existing planning controls and building regulations to better recognise current and future inundation risks.
- Incorporating future inundation risk into councils' risk register.

Adaptation options under the Moderate and Major Protection pathways were more specific to the individual characteristics of each case study area. However, all generally considered options relating to improved drainage, coastal or estuarine coastal protection works, pumping and establishing retarding basins.

The estimated cost of adaptation options was based on experiential evidence and recent comparable works or activities in consultation with AECOM's technical areas. A summary of the estimated adaptation costs assumed for each case study area is included in Table 7. The range in cost reflects both the differences in size of the case study areas and the scale of the adaptation options included in each pathway.

Table 7 Estimated cost of adaptation pathway cost (implementation and annual operating costs) assumed each case study area.

Case study	Accommodate Pathway	Moderate Protection Pathway	Major Protection Pathway
Murray Anderson Catchment	$2,000,000 + $50,000 p.a.	$100,000,000 + $200,000 p.a.	$350,000,000 + $600,000 p.a.
Mordialloc Creek	$1,000,000 + 50,000 p.a.	$9,500,000 + $100,000 p.a.	$64,500,000 +$300,000 p.a.
Elwood Canal	$2,000,000 + $50,000 p.a.	$70,000,000 + $200,000 p.a.	$190,000,000 + $200,000 p.a.
Arden Macaulay	$2,000,000 + $50,000 p.a.	$12,800,000 + $100,000 p.a.	$40,000,000 + $100,000 p.a.
Southbank	$2,000,000 + $50,000 p.a.	$44,000,000 + $200,000	$244,000,000 + $600,000 p.a.

5.4 Appraising and comparing adaptation pathways

5.4.1 Cost Benefit Analysis

Cost benefit analysis was used to compare the economic feasibility between the different adaptation pathways for each case study. The benefit of each adaptation pathway was measured by the reduction in average annual damage between now and 2100 (discounted to current dollars) to provide an estimate of the present value of benefits.

The economic cost of each pathway was the estimated costs associated with implementation and operating costs of the adaptation options within each pathway (as identified in the previous step). A cost benefit analysis (CBA) was then used to appraise and compare different adaptation pathways within each case study area.

How changes in AAD as a result of adaptation were estimated depended on the type of adaptation options included in each pathway. For an Accommodate Pathway which aimed to minimise damages but did not reduce the level of inundation, a reduction in the cost per asset was made in the AAD model. For example, if one of the initiatives in the pathway is to improve early warning systems for catchment flooding, the damage per building will be reduced as it is assumed that individuals will have longer to prepare for the flood event. The model then produced new AAD estimates based on the lower expected damages to these assets.

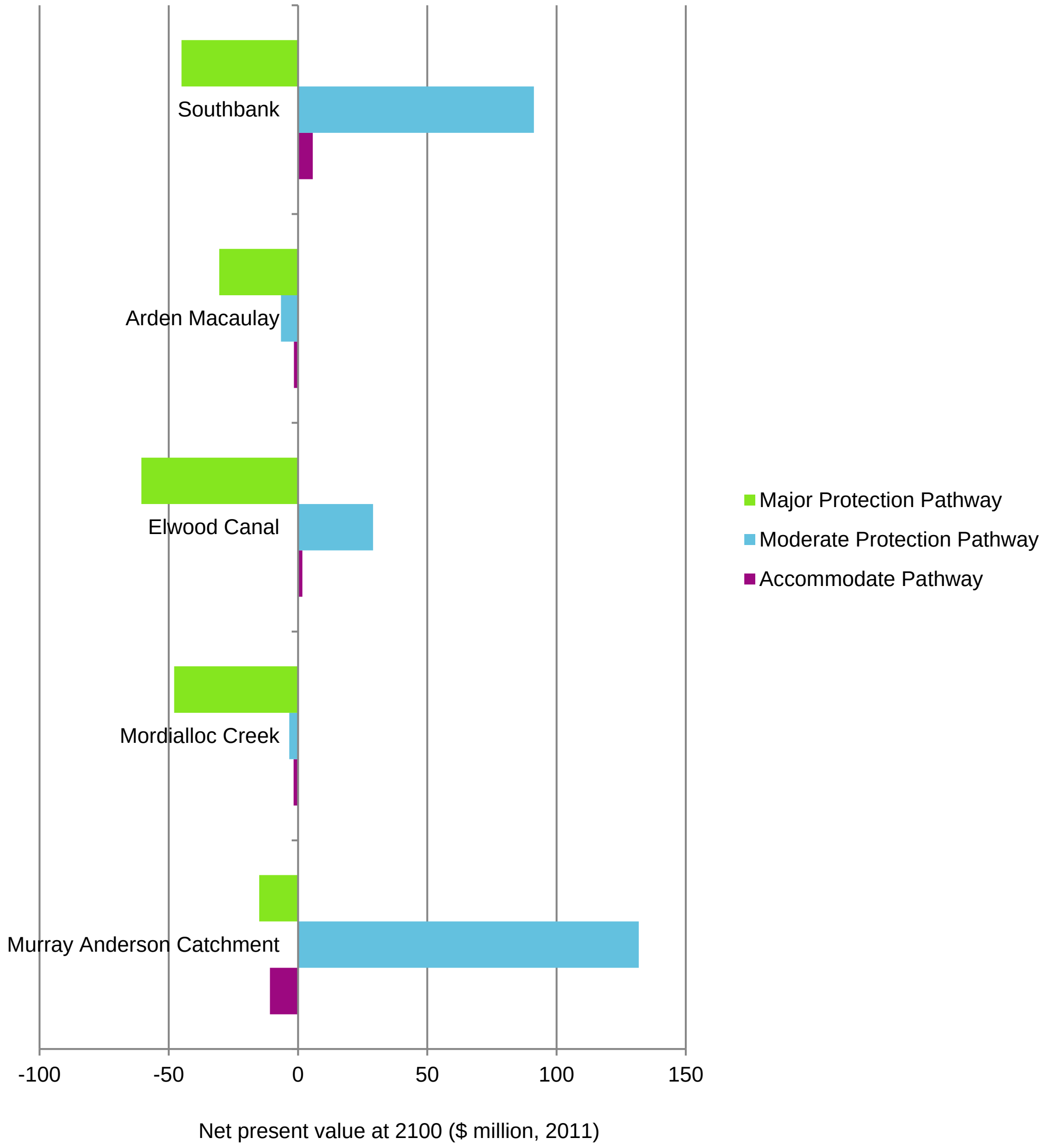
The same approach was used to calculate the benefits for options involving changes to building design and planning regulations which did not reduce inundation heights but instead increased the resilience of the assets.

The economic analysis presented both net present value and benefit cost ratios as outputs for all pathways.

A comparison of the net present values between pathways for each case study location is shown in Figure 9. By implementing the Accommodation Pathway immediately, a positive cost benefit ratio was achieved for all but two locations. A third location had a relatively low NPV for the Accommodation Pathway, largely as a result of the limited value of adaptation in the longer term as a resulting of increasing flood risk under climate change.

Due to the current level of flooding experienced in three of the case study areas (Murray-Anderson Catchment, Elwood Canal and Southbank), the largest NPV was achieved by immediately implementing a Moderate Protection Pathway. This is indicative of the value of early action where current flood extents are significant.

Figure 9 Comparison of adaptation pathways by net present value in 2100 under the assumed climate change scenario. NPV estimates assume that adaptation pathway is implemented immediately. Values are in 2011 dollars and assume a 3% discount rate. NPV estimates are limited by the assumptions associated with the calculated adaptation benefits and the estimated cost of implementing the adaptation pathway.



The BCRs calculated for all adaptation pathways are shown in Table 8. This shows the proportional return on invested funds and provides contrasting results compared to the NPV for some pathways for each site.

For example the Murray-Anderson Catchment Case Study has a larger BCR for the Accommodate Pathway (4.07) than for the Moderate Protection Pathway (2.24) while the NPV for the Moderate Protection Pathway ($132 million) is substantially higher than that of the Accommodate Pathway ($10 million). This indicates that the Accommodate Pathway provides a greater return for each dollar invested while the Moderate Protection Pathway provides a far greater net return. Which pathway is better depends on the goal of decision makers and the availability of funding for adaptation. If the funds are available, the Moderate Protection Pathway would be preferred as the net return is larger. If funding for adaptation is limited, choosing the lower cost but higher BCR pathways may prove a better use of funds.

Additional adaptation pathways were created for each case study area to consider the economic implications of staged implementation of adaptation pathways between now and 2100. This approach helped to identify potential transitional times between pathways for a given area.

Implementing the Accommodate Pathway before implementing either of the protection-focussed pathways at a later date reduces the present value of costs as it delays the outlay of large capital costs. However, this also reduces the value of benefits as the possible savings in the early years are foregone by delaying action. In some cases this provides a higher BCR than by early implementation of options to reduce flooding. For example, Elwood Canal has a higher BCR when the Accommodation Pathway is implemented between and 2040, when implementation of the Moderate Protection Pathway would commence. The BCR of 1.59 is higher than immediate implementation of the Accommodate Pathway (1.47) or the Moderate Protection (1.36) pathways.

Further details of a cost benefit approach can be found in Appendix E.

Table 8 Comparison between adaptation pathways using the calculated benefit cost ratios for 2100 under the assumed climate change scenario. These figures estimate the proportional return on invested funds. Values greater than 1 indicate a positive return on investment. The estimate of the BCR is limited by the assumptions associated with both the benefit of adaptation and the cost of adaptation. This information is not intended to be used to compare the value of adaptation between locations.

Pathway	Murray-Anderson Catchment	Mordialloc Creek	Elwood Canal	Arden Macaulay	Southbank
Accommodate	4.07	0.33	1.47	0.54	2.6
Moderate Protection	2.24	0.73	1.36	0.58	2.82
Major protection	0.94	0.20	0.71	0.34	0.79
Accommodate till 2040, then moderate protection	2.16	0.63	1.59	0.9	3.41
Accommodate till 2070, then moderate protection	1.93	0.47	1.53	0.92	3.63
Accommodate till 2040, then moderate protection until 2070, then major protection	1.14	0.31	1.26	0.49	0.66
Accommodate till 2040, then major protection	0.71	0.21	0.98	0.33	1.39

5.5 Monte Carlo Analysis (Elwood Canal Case Study)

For the Elwood Canal Case Study, Monte Carlo simulations were used to generate probabilistic distributions of the range of possible AAD results as well as the cost benefits of each adaptation pathway using the simulation software @Risk.

Key inputs were assigned ranges of possible values (Table 9). This table shows the large range of some variables, especially the hydrology in 2100, as this represents the large uncertainty in climate change projections.

Table 9 Estimated range of key inputs used to assess potential inundation and associated AAD that were tested using Monte Carlo analysis. These potential ranges are estimates only, based in assumed levels of potential uncertainty for key variables relevant to assessing the economic potential of different adaptation pathways.

Category	Input Variable	Range
Technical	Floor height	-0.3m to +0.3m on floor height
	Hydrology (2011)*	-10% to +10% on flood height
	Hydrology (2100)*	-40% to +60% on flood height
	Hydraulics*	-10% to +10% on flood height
Damage Estimation	Building & Content Damage Values	-20% to +20% on unit values
	Indirect Damage %	20% to 60%
Cost of adaptation	Pathway costs	- 40 % to +40% on estimated costs

**Hydrology refers to the amount of water entering a catchment area in terms of rainfall while hydraulics relates to how the water acts once in the catchment in terms of waterway and overland flow, ground filtration etc.*

The results of the Monte Carlo analysis for the average annual damage estimates are shown in Table 10. The gap between the lower and upper bounds show the range of possible results within the 90% confidence interval while also providing a 'most likely' estimate (the mean value).

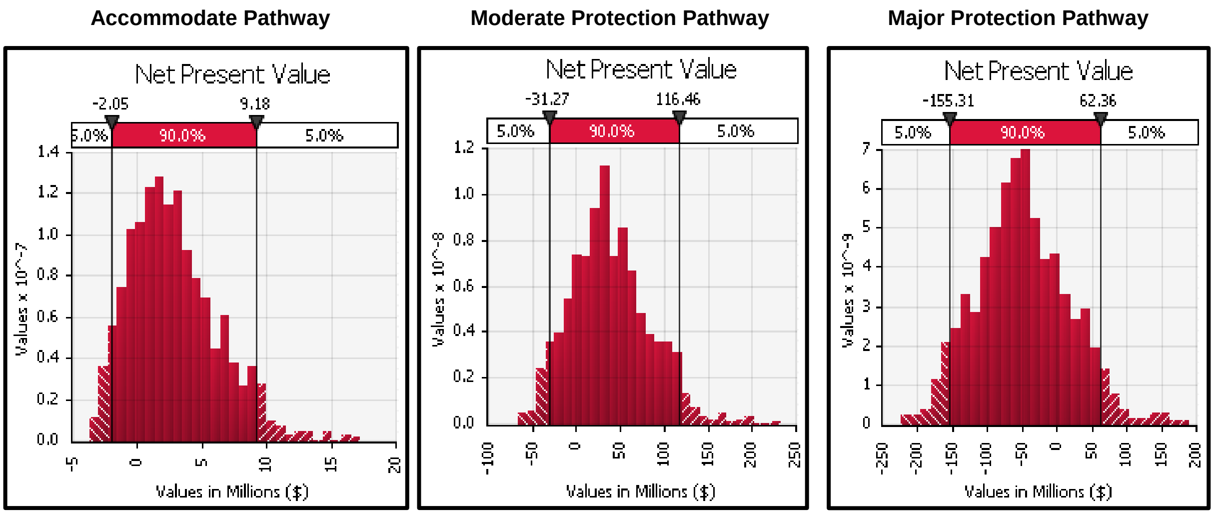
Table 10 Results of Monte Carlo analysis on average annual damage showing 90% confidence intervals.

Output	Mean value ($ 2011)	90% confidence interval ($ 2011)	
		Lower bound	Upper bound
AAD in 2011	$2,700,000	$1,250,000	$5,000,000
AAD in 2100 under the assumed climate scenario, assuming no adaptation	$16,100,000	$2,600,000	$30,200,000
Total Value of Damages between 2011 and 2100	$164,000,000	$71,700,000	$272,000,000

The results of the Monte Carlo analysis for each adaptation pathway are shown as distributions in Figure 10. The results show the outcome of 1000 simulations which randomly select each of the variables based on the range detailed in Table 9. The results for the Accommodate and Moderate Protection pathways show that the majority of values indicate a positive net present value. This provides greater confidence that these are economically viable pathways even with the identified uncertainties. Only a small percentage of results for these two pathways have a net present value below zero. These results at the lower end of the distribution represent unlikely scenarios where future benefits of adaptation are lower than expected and costs are higher. The Major Protection Pathway has a different shaped distribution with the majority of the results below zero. This implies that there is a low likelihood of this pathway being economically viable, given the assumptions used in this study.

The large range of values within the 90% confidence interval highlights the level of uncertainty associated with estimating AAD and the impact of different adaptation responses.

Figure 10 Distribution of results for Monte Carlo simulations on the NPV for different adaptation pathways for the Elwood Canal Case Study. It is assumed that the adaptation pathways are implemented now.



5.6 Limitations

As with any modelling attempting to capture future changes, there are the inherent limitations associated with modelling a range of future conditions, including changes in climate, socio-economic conditions and flood damages. In addition to these, a number of other limitations associated with methodology were identified through the application of the framework at the five case study sites in Port Phillip Bay.

The application of the framework at the case study locations did not address broader climate risks to the coastal zone which may need to be considered as part of adaptation planning, including changes to:

- coastal erosion and deposition and resulting changes to the form and shape of the coastline and estuaries
- extreme wind and the predominate wind direction which will affect wave set up and wave run up
- changes in the temperature and acidity of the ocean which may affect the expected life span of coastal protection assets
- extreme temperatures which, as well as directly impacting asset condition, may also increase population pressures in coastal locations
- average and total annual rainfall
- salt water intrusion into groundwater and estuaries.

Consideration of the impact of coastal erosion is generally considered an important element of coastal inundation assessments. Coastal erosion is likely to change ground levels in the immediate area and thus those areas would become at increased risk of inundation. However, these areas are small and located directly on the coastline so while erosion may change inundation extents, it was considered a minor impact for these case study locations.

These remaining additional variables are likely to interact and potentially increase climate change impacts (and associated costs) for a location. However, consideration of these additional impacts was outside the scope of this study.

While the focus of the framework is on inundation risk, consideration of other climate change variables may be critical for local and state governments seeking to develop a more holistic adaptation strategy or pathway and to ensure appropriate targeting of specific adaptation options. For example, options to increase community resilience may benefit from including a range of climate change hazards beyond inundation, such as heatwave or bushfire information.

It is common practice in planning for climate change impacts and risk assessments to consider a range of change for any one variable, to help recognise the uncertainty associated with climate change. To test this framework and reduce the complexity associated with modelling multiple variables, a simplified approach was taken, assessing a single value for each climate variable.

In testing the framework, costs of inundation were limited to damage to residential, commercial and public assets, clean-up costs and indirect costs (including disruption to business, transport and communication). Other issues such as safety, quality of life, heritage issues and other social values were not addressed quantitatively.

The focus on damage reduction may underestimate the true benefit of offering flood protection to the community. The actual benefit to these parties is measured by their willingness to pay to avoid them, which is typically larger than the actual cost of damages when flood events do occur. This is partly reflected in the fact that people are generally willing to pay insurance premiums that may be (at least cumulatively) in excess of expected damages to their property. Floods can also cause emotional and psychological distress that is not measured by the methodology employed here. Similarly, broader disruptions to economic activity associated with a central business district or tourist destinations have not been fully included. Reductions in average annual damage are therefore likely to represent an underestimate of the full benefit to the community from flood protection. A range of indirect impacts were not quantified due to data availability issues, including health and safety and social impacts.

Many of the benefits of flood protection are intangible or ‘non-market’ benefits. These are benefits that arise due to the absence of markets in which to buy or sell certain goods and services, and are therefore considered ‘public goods’. These include, for example, the benefits of accessible roads, recreation in public open spaces and the visual amenity of the area. It is the presence of these types of public benefits which governments must also consider when funding public infrastructure and services. There may be considerable benefits from offering flood protection that have not been assessed, and that may further justify the case for adaptation investment.

There is a risk of underestimating the costs of inundation due to limitations in available data as well as data relevant to relatively small physical portion of a community. A second inherent risk arises as the result of the artificial nature of the boundaries of the study area. While there is a practical need to construct boundaries, it limits the ability to consider broader costs and benefits beyond the boundary. This inherent limitation will be greatest in areas of regional, state or national significance for example for areas containing tourism assets or economic hubs.

The economic analysis does not address the issue of who would or should pay for adaptation. The economic modelling assumes a standard neo-classical economic theory perspective (e.g. those benefiting from the adaptation actions should bear the costs). However, there are also social equity and political issues that will influence how and if adaptation actions are funded. The role of this economic analysis is to present the net costs and benefits to society from different approaches to adaptation.

The CBA analysis is based on indicative costs only and does not accurately cost individual adaptation options. Similarly, the value or benefit of some adaptation options identified will have variable lead times based on external factors (e.g. the rate of development and asset renewal resulting from policy changes) and internal factors (e.g. the amount of time required to undertake a major drainage upgrade).

A number of inherent risks in the approach have also been identified which may reduce the robustness of the findings. The economic analysis is based on the modelling of current and future inundation risk which has its own inherent limitations and assessments. As the economic analysis is derived directly from this data, all assumptions that have gone into inundation modelling will be reflected in the economic outputs.

6.0 Findings

This project has produced two primary outcomes –

- a tested approach to developing a strategic adaptation pathway to help manage flood risks in a time of climate change in urbanised coastal areas using available information as inputs into different decision-making tools
- initial adaptation pathways for five locations along Port Phillip Bay informed by a cost benefit approach.

Success will be determined in the long term by these locations continuing to develop and implement their adaptation pathways and others localities commencing their own pathways building on the approach developed here.

While this framework outlines consistent steps for others to follow, the tools and approaches will vary depending on local circumstances and scale. The testing of the methodology at various locations around Port Phillip Bay does not mean that the process does not need to be carried out at other coastal locations. However, it is recognised that the level of input data, analysis and financial modelling required may be inhibitive to smaller locations or specific communities. Smaller scale applications may also miss or underestimate broader potential benefits arising from adaptation.

The sections below attempt to capture the key learning from starting the process to develop adaptation pathways with five different communities, synthesising these lessons for other communities and making suggestions to build on the adaptation pathways approach.

6.1 Key findings from applying the framework

There are many uncertainties associated with estimating changing inundation risks in a time of climate change. Further complications will be encountered when looking at these changes over long time horizons where a range of socio-economic, technological and political changes will occur and interact. To best manage these uncertainties maintaining flexibility within the adaptation pathway is critical. To help maintain flexibility, all assumptions need to be transparent so as to best allow new information and broader adaptation responses to be incorporated. The use of adaptation pathways was intended to demonstrate and compare the value and implications of different approaches to managing risk. It was not intended to 'lock out' adaptation options either now or in the future.

Effective adaptation planning will require a systems thinking approach. Complex interactions between hazard, impacts and responses will continuously occur. Decision-makers will need to ensure that limited adaptation resources are invested both effectively and efficiently despite these challenges. Development of a highly localised adaptation pathway is likely to be both expensive and inefficient as many of the more effective adaptations options to reduce flooding will realise benefits for the wider area. Estimates of potential economic impacts and adaptation benefits were limited to within the case study area. In some cases, further consideration of related impacts outside of the case study area may have significantly influenced the outcome of the comparisons of pathways. This was particularly important for key transport routes and assets of regional significance – for example a state museum or a tourist attraction which is a key visitor drawcard.

As such adaptation pathways for a catchment or regional scale are likely to offer the greatest value and opportunities. It is not possible to define the optimum size of these regions or catchments quantitatively. Rather it is intended that these scales are defined by the potential needs or benefit of the adaptation option itself. For example an adaptation option which is likely to benefit all downstream communities. Alternatively, exploring possible efficiencies from larger scale investigations or avoiding the risk of maladaptation in surrounding areas may also help define the most appropriate scale. For example coastal erosion studies for an entire bay or system will help reduce the risk of identifying localised adaptation options which increase risk for surrounding areas.

Mapped outputs from the hazard modelling can be an effective engagement tool for adaptation planning. These maps show the change in extent of the future hazard zone and distinguish the source of the hazard (coastal versus catchment flooding) which can enable more robust and specific adaptation discussions. In the majority of the case studies, catchment inundation was likely to be the primary flood source over the medium (up to 10 years) to long term based on the climate change assumptions used in this project. As such catchment-based solutions are likely to be more important and provide greater benefit for more regionally-based adaptation approaches, and further reduce the possibility of localised adaptation action increasing risk to surrounding areas.

Using best available data has enabled generation of quantitative and visual estimates of future inundation that would not otherwise be available to local decision-makers. However, allowing for contingencies and information gaps is also important. For example a number of the case studies required a specific methodology to be applied to the CBA. In addition, the need to develop tailored communication tools for each council was also identified. Communication of potential hazards to the community needs early consideration for effective stakeholder engagement for adaptation planning.

Hazard modelling can be used to identify information gaps or where additional analytical approaches may need to be considered. For example, coastal erosion assessments at three of the five case studies would have resulted in more robust inundation mapping and adaptation options. Specific data limitations (related to specific drainage assets and their condition) were also identified within this process thereby helping inform project partners understand their own gaps information.

Framing of adaptation pathways using adaptation characteristics (accommodate, protect and retreat) was useful to commence discussions with stakeholders about the strategic intent of risk management and adaptation investment. While this approach helped group adaptation options, stakeholders raised concerns about how such descriptions would be communicated to and perceived by wider audiences. Additional concerns raised included the scale of resources to implement pathways, lack of synergy with existing strategic or development plans and community sensitivity. However, pathways were useful in consistently comparing adaptation costs and benefits within each of the case studies.

Opportunities to introduce large scale innovation need further consideration, especially in those areas where large scale retreat has been excluded as a pathway. A creative approach to adaptation that encourages bold solutions may be the best approach to help turn a potentially negative situation into a positive, especially if broader social or environmental objectives can be included. Maintaining the viability of the hazard zone in the long term may benefit from a visionary approach in the short term.

The economic analysis has allowed initial quantification of the value of the hazard zone, the costs associated of occupying the hazard zone and the potential benefits of adaptation actions. The purpose of this analysis was to help identify the relative costs and benefits between approaches rather than select a preferred pathway based solely on the identified adaptation options. Costs of inundation were limited to damage to residential, commercial and public assets, clean-up costs and indirect costs (including disruption to business, transport, communication). It is acknowledged that there are other issues not addressed quantitatively such as safety, quality of life, heritage issues and other social values.

This study and application of the framework will help facilitate broader engagement with additional stakeholders and the community which will assist continued collaboration for adaptation planning and implementation.

6.2 Recommendations

This report is intended for a broad range of audiences. As such, the recommendations below are not intended for any one individual, organisation or level of government. The recommendations are also independent of any assumptions or knowledge of different individual roles and responsibilities for managing flood risk. Some organisations will have greater capacity and responsibility than others but the strategic focus is to encourage collaboration and cooperation through improved and shared understandings.

1) Technical standards and supporting data for climate change adaptation planning

Develop a set of technical standards focusing on information and data to support adaptation to current and future inundation. This should include localised climate change projections to support a consistent approach for future inundation and erosion investigations. The second stage of this work should prioritise investigations with respect to inputs and consistent approaches for hydrologic and hydraulic modelling, bathymetric and topographic survey information, extreme sea level computation and coastal erosion. The third stage of this work should provide guidance on consistent approaches to better quantify a broader range of costs and benefits including safety, quality of life, cultural and heritage values and environmental functions.

One of the biggest gaps for coastal climate change adaptation is the limited information available for modelling flooding and erosion. Detailed modelling will ensure that adaptation options are based on the best available science and technical information. A clearly identified need from this study is for detailed technical investigations to a set standard. This would be a valuable input into this framework but other adaptation investigations.

A set of standards would ensure that all technical investigations by relevant organisations are consistent in their inputs, methodology and assessment. These standards could cover the following areas:

- *Climate science*. Recommendations on the appropriate timescales for investigation (for example 2040, 2070 and 2100). Guidance on regionally specific projections for key climate change variables such as sea-levels, rainfall intensity and wind speed should be included.
- *Hydrologic and hydraulic modelling*. Recommendations on the type of modelling to be undertaken and the appropriate range of factors that should be used as inputs to this modelling.
- *Bathymetric and topographic survey information*. Recommendations on the extent and accuracy of any survey information used in these investigations.
- *Extreme sea-level computation*. Recommendations on the methodology and factors to be used in the computation of extreme sea levels and joint probability analyses for any investigations.
- *Coastal erosion*. Recommendation that coastal erosion be included in all technical investigations. This should include the computation of storm erosion rates, longshore transport rates and recession rates due to sea-level rise.
- *Socioeconomic projections*. Recommendation for consistent and shared approach for estimating potential costs and benefits and the level of inherent adaptation that may occur over the longer term (10-30+ years) may help reduce the overestimation of risk.

Where possible, this information should be integrated into existing mechanisms and processes, such as Australian Rainfall and Runoff Standards and the Draft Australian Standard for Settlements and Infrastructure, or in consultation with organisations such as Standards Australia.

Standards or guidance in relation to long term socio-economic scenarios would also benefit adaptation planning. Such guidance should focus on information relating to future socio-economic changes as well as consistent approaches to better quantify a broader range of costs and benefits including safety, quality of life, cultural and heritage values and environmental functions.

2) Enhance opportunities for multi-agency collaboration and governance for coastal inundation.

The development of adaptation pathways is likely to be most effective at a regional or catchment scale in response to sea level rise, catchment flooding and coastal erosion. This will facilitate continued and enhanced collaboration between all levels of government.

There are a range of authorities with different responsibilities involved with the planning, development and functioning of coastal areas. Responsibilities may be differentiated, or complementary, in relation to coastal adaptation, but will likely need to be redefined to best coordinate a response to climate change. While the role of government for adaptation is increasingly being clarified through National Climate Change Adaptation Framework (2007)[6] and the Productivity Commission's Draft Report on Barriers to Effective Adaptation (2012), application of these concepts remains a work in progress.

In many cases, a combined adaptation response by several governments or tiers of governments was identified as being the most effective approach for broader scale impact investigations that underpin adaptation and further development and delivery of adaptation responses. Multi agency governance arrangements exist but are not fit for purpose to support the delivery of the climate change adaptation decision making framework for urbanised coastal areas. Improvements to existing multi agency governance arrangements are required to:

- help clarify local roles and responsibilities
- coordinate more effective and efficient adaptation responses, including the integration of inundation risk into existing strategies, policies and regulation
- harness local capacity, knowledge and expertise
- identify adaptation barriers arising service obligations and arrangements between state government, its agencies and local government
- identify opportunities for catchment scale or wider bay responses
- provide a forum for cross-agency collaboration and discussion on broader strategic issues.

The framework would best be delivered through coordinated multi governance arrangements for example collaboration between State, Local Governments and Non-Government Organisations to develop and deliver community education campaigns aimed at increasing community resilience to flooding and climate change. This requires multi agency governance arrangements to coordinate and monitor the roll out efficiently, consistently and effectively.

3) Prioritise and develop detailed adaptation options at a regional or catchment scale

Undertake more detailed investigations and prioritise adaptation options that provide benefit to the broader region (i.e. greater than the single study area). This may include further technical investigations that underpin broader adaptation planning.

Assets of state and national significance, particularly tourism, cultural and national heritage, provide significant economic and social benefit to local communities but also to the broader region. Because of their significant value and benefit a local or regional adaptation pathway may be significantly influenced by:

- the additional benefit the asset provides to the community as measured through the cost benefit analysis
- the viability of the asset remaining in its current form or location over the long term
- the adaptation response for the asset itself.

Adaptation pathways for a catchment or regional scale are likely to offer the greatest value and opportunities. It is not possible to define the optimum size of these regions or catchments quantitatively. Rather it is intended that these scales are defined by the potential needs or benefit of

[6] http://www.coag.gov.au/coag_meeting_outcomes/2007-04-13/docs/national_climate_change_adaption_framework.pdf

the adaptation option itself. This approach to scale would also allow for the consideration of assets or areas of state and national significance.

Importantly the economic analysis did not include consideration of who would or should pay for adaptation. From an economic theory perspective, those benefiting from the adaptation actions should bear the costs. However, there are broader social equity and political issues that will influence how and if adaptation actions are funded. Cost benefit analysis should be used as a piece of information to be used alongside other decision making criteria to determine priorities for funding.

As many regions are facing limited resources and capacity to respond to climate change impacts, consideration should be given to the costs associated with investigating protection options to be shared. Financial incentives to promote early action should be considered, including to land owners.

The cost benefit analysis tested in the framework was based on indicative costs only and does not accurately cost individual adaptation options. Similarly, the value or benefit of some adaptation options identified will have variable lead times based on:

- external factors (such as the rate of development and asset renewal in relation to policy changes); and
- internal factors (such as the amount of time required to undertake a major drainage upgrade).

In many cases more detailed investigations will be required to test the potential effectiveness of more specific designs of the individual adaptation options.

While economic considerations are a key factor in decision-making, they are not the only factor, particularly for government who need to balance diverse issues such as safety, economic development, heritage and environmental sustainability.

4) Proactive communications and engagement with the community

A proactive communication and engagement program targeted to specific audiences should be developed and shared by coastal decision-makers.

The communication of information to a diverse range of stakeholders that is complex, technical and potentially sensitive requires a considered specialist response that is informed by local conditions and issues. A number of specific communication and engagement needs were identified during the testing of the framework, including:

- Stakeholder segmentation to target key messages to specific audiences
- Development of shared key messages between the different responsible authorities
- Proactive media engagement, including the support of media to convey information accurately and appropriately to the community and non-technical audiences
- Exploration of different communication tools to engage stakeholders, including visualisation of adaptation options and pathways.

Project stakeholders identified concerns about the sensitivity associated with the public release of hazard mapping including possible misinterpretation, inappropriate use of information taken from maps and communication of the information by media. Use of appropriate disclaimers and statements about key assumptions as well as other guidance materials for the communication of this information can help address these concerns.

5) Integrating adaptation responses into urban renewal and development planning

Land use and building form will both influence inundation and need to respond to flood risk. Critically, urban renewal and asset replacement will create significant opportunities to develop positive and innovative responses to future inundation, particularly in the longer term (10-30+ years).

Opportunities to integrate adaptation responses which support the adaptation pathway into urban renewal and development should be proactively explored. Improved understanding of a location's current and potential flood risk with climate change will be a useful starting point to consider developments which are specifically designed to mitigate or eliminate the impacts of flooding at either the asset level or for a larger precinct

6) Capacity building for integrating adaptation to climate change into existing systems and processes

Current planning and building controls can support response to future inundation risks with consideration of broader objectives (such as community safety, heritage protection, environmental sustainability).

How existing information on climate change impacts/future flood risk can be incorporated to support consistent regional responses while recognising local circumstances will be critical. Guidelines and other tools to assist different stakeholders (including local government, developers and the community) to meet new requirements or proactively adapt are required.

Through engagement with stakeholders in testing the framework it was apparent that a skills and capacity building program for local government specific to inundation is required. A skills audit and needs assessment of coastal councils would help target the program to specific needs and requirements. A key element of this program would include guidelines and support the incorporation of future coastal risk into existing strategies and mechanisms to better respond to sea level rise and catchment flooding.

All Councils and some agencies showed signs of trying to implement some accommodate adaptation actions due to existing flood issues. They should be supported to more effectively deliver or support this function.

Moderate protection could be justified for all case study sites now or within the next 10 years based on existing data assessed while acknowledging the limitations of the data available. The additional value produced by conducting further cost benefit analysis for components of catchment areas with existing high level flooding risk to properties, public activity areas and services is likely to yield little additional value for the cost of doing further assessments. This is because it is clear that regional scale assessments will better capture and attribute costs and benefits. Cost benefit analysis should be used to support decision making at a detailed adaptation assessment level to yield most value.

The scale of the assessment of costs and benefits was an important factor in assessing moderate and major protection adaptation options. This was particularly the case for constrained benefits of major and protection adaptation options for other areas that would also benefit (i.e. catchment scale).

7) Funding mechanisms for regional scale adaptation

Funding mechanism for regional and local scale adaptation should be established with emphasis on private investment for moderate protection measures.

Both public and private interests will benefit from adaptation to reduce flood risk. The mix of who will benefit will be dependent on the location and activities in the area being investigated.

It is generally expected that those who directly benefit, should ultimately pay more towards adaptation. Specific targeting may be possible through existing mechanisms for sourcing funding for inundation adaptation measures including:

- Local Government – (rates, levies, development contribution, rental income, parking)
- State and Federal government revenue (taxes, stamp duties, regulated agency service fees – water, power and transport)
- Private investment (industry and business interests including developer contributions and insurance).

The sourcing of funding and application into adaptation implementation at a local level is possible under existing mechanisms where the investment cost is low, linked to opportunistic grants or is integrated into new developments.

The issue of funding becomes more challenging for more expensive adaptation options where the benefits are shared over a large number of parties. The cost of large infrastructure items is generally too large for Council to fund through their regular income channels (property rates and commercial charges). For example, increasing the height of a levee bank through an urban area may protect a range of residential and commercial properties as well as state and local government assets such as roads and water infrastructure. A fundamental problem remains in how inundation risks and adaptation costs are determined and shared within the economy. While the roles of government and the public are the subject of recent discussion in forums such as Council of Australian Governments (COAG) and The Productivity Commission, a black and white approach to risk allocation and funding for adaptation will not be necessarily straight forward or effective for the community as a whole.

Currently there is no or limited consideration of the preferred funding mechanisms to efficiently and equitably invest in climate adaptation responses at a regional scale. Funding mechanisms should focus on shared investment by multiple stakeholders and the potential to accrue funding over a 20 year time period to implement larger investments that to meet a future threat such as permanent inundation of an area through rising sea level.

Appendix A

Model Stakeholder Engagement Plan

Appendix A Model Stakeholder Engagement Plan

The purpose of this outline is to ensure the agreed framework has the required components to deliver effective, targeted and meaningful engagement with communities and other stakeholders relating to the Port Phillip Bay Coastal Adaptation Pathways Project. The final stakeholder engagement framework is intended to guide councils to develop individual community engagement programs for exploring adaptation pathways with key government and community stakeholders.

The following outline has been developed after reviewing community engagement documentation from state and local government as well as CSIRO. A draft framework will be developed following a workshop with project partners to review this outline, determine missing elements and provide inputs through collaborative discussion to assist in populating the various sections.

Once a draft framework is developed, the project Steering Committee, including workshop participants, will be asked to review the document before a final document is delivered as part of the project.

Purpose of the Framework

This section will outline the purpose of the framework which is primarily:

- guide councils to develop individual community engagement programs for exploring adaptation pathways with key government and community stakeholders
- to complement existing communication and consultation tools that exist within local communities
- to assist in developing effective, and engaging consultative mechanisms.

Benefits of Effective Engagement

The benefits below have been developed after considering other community engagement frameworks, they will be discussed and modified after discussions at the coming workshop.

- Engaging local communities builds capacity, knowledge and results in more sustainable outcomes as stakeholders take ownership of projects and initiatives.
- Working with stakeholders builds greater awareness of potential issues and opportunities leading to more informed decision making and better project outcomes.

Engaging with stakeholders can enhance organisational reputation, build strong relationships and ultimately provide return on investment by understanding and identifying potential issues and constraints early.

Key Principles for Effective Engagement

A key feature of the workshop will be defining the principles that will drive all engagement. The principles are essentially the building blocks from which all engagement activities should flow. By establishing agreed principles, project partners will help to develop a consistent approach to adaptation planning engagement. This will encourage social equity and increase trust in the community.

The recommended principles below are provided as prompts only and will be clarified following consultation with project partners. Importantly, once the principles have been agreed, workshop participants will also establish definitions to ensure everyone has the same understanding of what the principle implies.

Suggested principles include:

- ensure clarity
- create trust
- build capacity
- deliver responsively
- encourage feedback

- evaluate and continuously improve.

Assign Responsibilities

This section will outline what internal stakeholders are required to ensure the engagement activities are carried out on time and to budget.

This section will highlight the importance of understanding:

- articulating the resources and budget required
- ensuring there is a project sponsor within the organisation
- providing details of who are the important project stakeholders.

Define Objectives

The workshop will include a brainstorm of what type of objectives should support an effective engagement program. This section could also include the type of engagement intended to be carried out (i.e. inform, consult, involve, collaborate, empower etc).

The IAP2 Spectrum will be discussed to outline the different levels of engagement.

Emphasis will be given to the importance of spending time clarifying what you want to achieve from the engagement process.

Understanding Stakeholders

This section will include discussion of stakeholder groups that need to be considered including an analysis of their interest, influence and/or impact on the project.

Stakeholders may include:

- schools and students
- local action/interest groups
- coastal management committees
- small and medium businesses
- residents (which can be further divided into different cohorts)
- friends of groups
- politicians
- media
- emergency services
- state government
- community organisations.

Assess Challenges

At the workshop a session titled “lay it on the table” will help to understand possible challenges and opportunities regarding adaptation planning. This is an important situation analysis that will help in the delivery of reasoned and informed engagement. Workshop participants will be encouraged to discuss how these opportunities may be realised and challenges mitigated.

The following challenges and opportunities are presented as a starting point for discussion only.

- Local challenges
  - manage expectations
- Climate change adaptation challenges
  - misinformation, uncertainty and scepticism
  - lack of resources
  - expectation that a solution will be provided
  - negative emotional reactions
  - address gaps in knowledge
  - acknowledge uncertainty

Leverage opportunities

- Local opportunities
  - build on work already undertaken
  - use networks and channels
- Climate change adaptation opportunities

Choosing engagement tools

This section will outline available communication and engagement tools and when they are preferred.

For example:

- use group discussions for emotional issues
- provide information in different formats to increase communication reach
- have face to face discussions for hard to understand information.

Follow up and evaluation

Effective engagement activities are based on continuous improvement. This section will propose different evaluation techniques to ensure engagement practices are responsive and meet the required outcomes.

Information to be detailed in this section includes:

- maintain contact and feedback
- evaluate process and outcomes.

Appendix B

Data sources

Appendix B Data sources

This appendix outlines the data and formats delivered as part of the Port Phillip Bay Coastal Adaptation Pathways Project.

Data supply includes all layers that were created for use in the externally submitted final report figures. These include the following datasets:

Content	Format	Data type	Sources
Study areas	Shapefile	Polygon / Polyline	City of Melbourne, City of Kingston, City of Port Phillip and Mornington Peninsula Shire Council
Flood extents	Shapefile	Polygon	Original inundation surface heights for Arden Macaulay, Elwood, and Murray-Anderson Catchment provided by Melbourne Water
			Original inundation heights for Mordialloc modelled by GHD and provided by Melbourne Water
			Southbank data modelled by AECOM
Flood depths	ESRI Geodatabase	Rasters	Original inundation surface heights for Arden Macaulay, Elwood, and Murray-Anderson Catchment provided by Melbourne Water
			Original inundation heights for Mordialloc modelled by GHD and provided by Melbourne Water
			Southbank data modelled by AECOM
			Southbank modelled by AECOM
DEM (Digital Elevation Model)	ESRI Geodatabase	Rasters	Department of Sustainability and Environment
Tidal Inundation extents	Shapefile	Polygon	AECOM
Asset Property Database	Shapefile	Polygon	Original parcel layer provided by Department of Sustainability and Environment
Asset Property Database	Spreadsheet with field metadata	MS Excel	AECOM

1. Field attributes

Content	Fields	Field type	Example
Study areas	Site Name	Text	Elwood Canal
	Council	Text	City of Port Phillip
	Area	Double	
Flood extents	Site Name	Text	Elwood Canal
	ARI	Integer	100
	Scenario	Text	2100

Content	Fields	Field type	Example
	Source	Text	CoPP
	Area	Double	1.530772 (sq km)
	Source Type	Text	Melbourne Water Flood Extent
	Council		City of Port Phillip
Flood depths	Depth of flooding	Float	1.54 (metres)
DEM (Digital Elevation Model)	Terrain height	Float	(mAHD)
Tidal Inundation extents	Site Name	Text	Elwood Canal
	Scenario	Text	Existing / 2100
	Area	Text	0.36 (sq km)
Asset Property Databases (Includes the following but not limited to)	Site Name	Text	Elwood Canal
	Parcel number	Text	Existing / 2100
	Area	Text	125.7 (sq m)
	Zone Code	Text	MUZ
	Generic Zone	Text	Mixed Use
	Overlays	Text	DDO, SBO
	Construction Types (Residential, Industrial and Retail)	Many attributes included in metadata spreadsheet	
	Number of Stories	Integer	2
	Utilities	Text	Power Substation
	Comments	Text	Night club / Bridge
	Public Facility	Text	Other
	Flood Data (Water Surface Elevation values for each scenario)	Many attributes included in metadata spreadsheet	1.4431
	Address	Text	90 QUEENS BRIDGE STREET
	Other fields specific to each site	N/A	

2. Notes

Datasets provided by 3rd parties to AECOM have been obtained under licence arrangements for the Port Phillip Bay Coastal Adaptation Pathways Project. Use of this data for any other purpose is subject to these licence conditions and permission should be sought from the data owner before use or publication outside of this project.

AECOM acknowledges the use under licence of the LiDAR imagery/DEM produced by the Department of Sustainability and Environment's Future Coasts Program. The vertical accuracy for the DEM is +/- 10cm @ 1 sigma (68% Conf. Level) in bare ground. Depths have been calculated and processed using surface water flood levels and terrain heights.

The data and information provided must be used in conjunction with the report for “Port Phillip Bay Coastal Adaptation Pathways Project” for each catchment area.

Flood information has been provided by Melbourne Water and is indicative only. This information is not to be used for design purposes.

This flood information is based on theoretical storm events, and may not reflect actual flooding behaviour. The information is based on hypothetical climate change scenarios which rely on assumptions (including in relation to storm events) which are not endorsed by any local, state or federal government agency.

Care has been taken to use appropriate assumptions in developing the scenarios but they cannot be relied on as accurate. Over time the climate change scenarios and the assumptions on which they are based are likely to change and alter the resulting flood information.

Due consideration must be given to any decisions made utilising this flood information.

All data is correct when used in its native projection and formats.Reprojecting, changing format or re-sampling may cause changes in the data therefore the data may not remain as accurate as stated in this document.

All data are available only in their native projection of GDA 94 MGA Zone 55.

All data is available only in their native file formats as stated in this document.

3. Reference Systems

The datum used in the construction and maintenance of this data is the Geocentric Datum of Australia. Data is held in MGA Zone 55 (eastings/northings) computed in terms of the GDA at 01 January 1994 (GDA94).

Appendix C

Determination of 100 Year ARI Sea Level

Appendix C Determination of 100 Year ARI Sea Level

This appendix outlines the analysis performed to determine the extreme sea levels at Elwood, Mordialloc and Murray Anderson for the Port Phillip Bay Climate Change Adaptation Project. When assessing an area for coastal flooding, it is essential to obtain sea level values to predict the extent of inundation. The sea level we have computed is inclusive of the following:

- astronomical tide
- storm surge
- wave setup.

The sea levels have been determined for this project by modelling wind conditions in Port Phillip Bay to determine the wave height experienced in a storm with a 100 year average recurrence interval (ARI). The wave height was then incorporated into a model containing tidal and storm surge information relating to an event with a 100 year ARI, and bathymetry for the locations of interest. This model calculated the maximum sea level inclusive of astronomical tide, storm surge and wave setup, the effect of breaking waves on the shoreline, at each of the locations. More details of the methodology, and the results, follow.

Methodology

1.0 Run an existing SWAN model of Port Phillip Bay

The waves in the body of Port Phillip Bay are generated by the winds blowing over the water in the Bay. Swell waves from the open ocean are dampened by the Sands area and do not penetrate further into the Bay. Wind generated waves are sensitive to the fetch, i.e. the distance over which the wind blows over water. Thus the waves in Port Phillip Bay are generally fetch-limited. The industry standard and the widely used SWAN model has been used to compute the wind-generated waves at the study sites.

The SWAN model is a third-generation phase-averaged wave model for the simulation of waves in waters of deep, intermediate and finite depth (Booij, 1999). It is also suitable for use as a wave hindcast model. The model is based on the wave action balance equation with sources and sinks.

SWAN simulates the following physical phenomena:

- wave propagation in time and space, shoaling, refraction due to current and depth, frequency shifting due to currents and non stationary depth
- wave generation by wind
- nonlinear wave-wave interactions (both quadruplets and triads)
- whitecapping, bottom friction, and depth-induced breaking
- blocking of waves by currents.

A grid covering the entire Port Phillip Bay has been set-up for a previous project (Point Wilson Waterside Infrastructure Remediation, 2011). The bathymetry has been updated using the LiDAR data from the study sites. The model has been forced by applying uniform winds all over the model domain. The modelled wave parameters (significant wave height, Hs and peak wave period, Tp) have been extracted in the vicinity of the study sites.

The model inputs were the 100 year ARI winds from AS/NZS1170.2 for all directions that were used to determine the maximum wave height. The model output the 100 year ARI wave parameters (significant wave height and peak wave period) in approximately 10-15 m depth of water. Graphical representation of the output is shown in Figure 11 for the modelled scenario with winds coming from the North East.

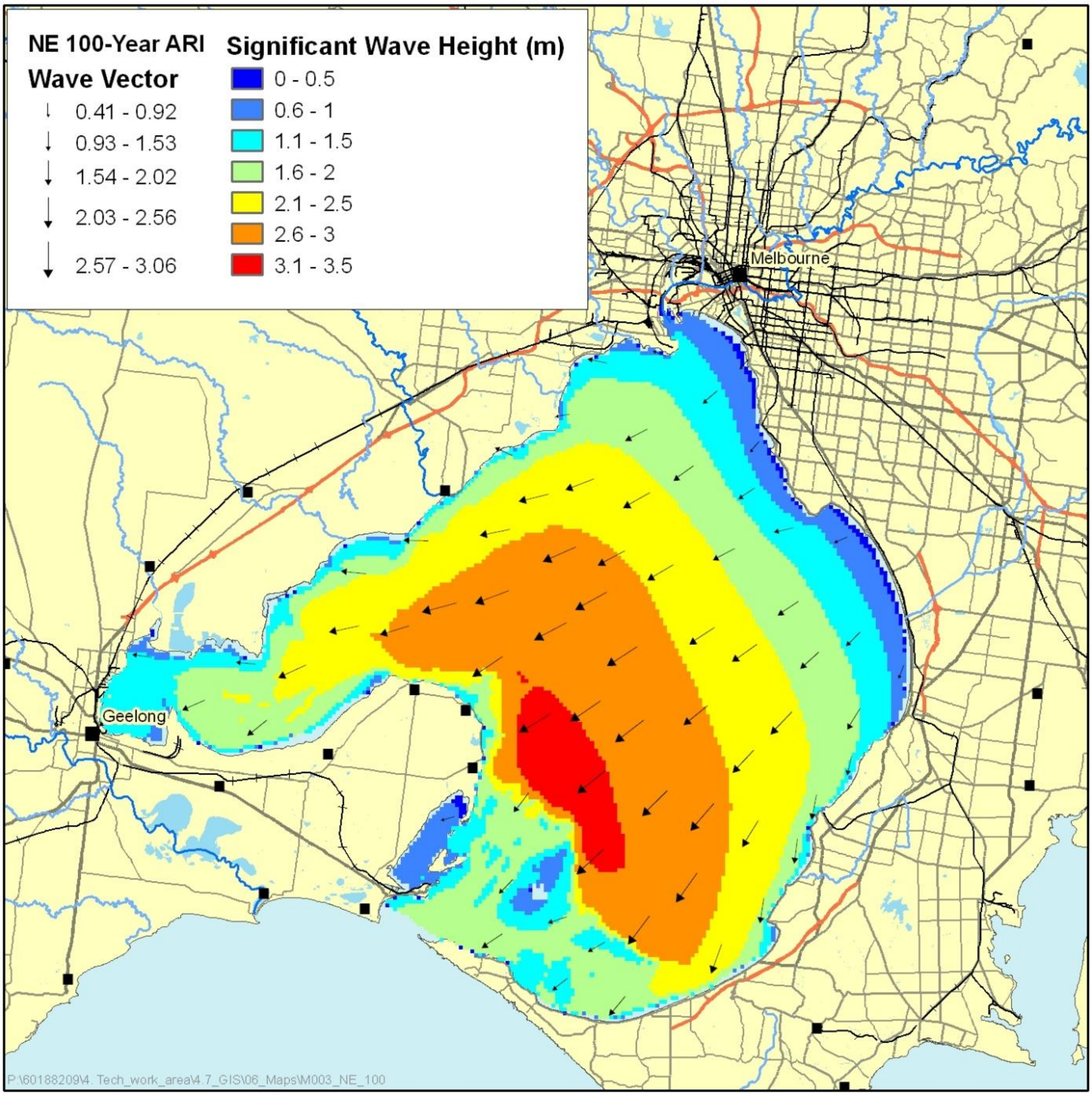


Figure 11 SWAN model output for north east winds scenario in Port Phillip Bay.

After modelling for three different direction scenarios, the extreme waves for Port Phillip Bay were generated as shown in Table 11.

Table 11 Extreme wave conditions for 100 year ARI event.

Parameter	100 year ARI
Significant Wave Height	3 m
Wave Period[7]	7 seconds

[7] Wave period – Wave period is the amount of time taken for a complete cycle of a wave to pass a fixed reference point. This is most easily measured as the time between arrival of wave crests (peaks).

2.0 SBEACH modelling of coastal profiles to determine water elevation

SBEACH has been used to determine the wave set-up and the resulting water surface elevation along each beach profile due to extreme storm events. SBEACH, an acronym for Storm induced Beach Change was developed at the US Army Engineer Waterways Experiment Station, Coastal and Hydraulics Laboratory (Larson et al, 1990) to calculate beach and dune erosion under storm water levels and wave action. SBEACH is an empirical based program that calculates the net cross-shore sand transport rate in four zones from the dune or beach face, through the surf zone and into the offshore past the deepest break-point bar produced by short period incident waves. The wave model is relatively sophisticated and computes shoaling, refraction, breaking, breaking wave re-formation, wave and wind induced set-up and set-down and run-up.

The design storm was developed from the outputs of a SWAN model created for Port Phillip Bay. The estimated values relate to a storm event with an average recurrence interval (ARI) of 100 years for significant wave height (the average height of the largest one third of waves) and the peak wave period (wave period associated with the most energetic waves in the total wave spectrum). These values were then used in the setup of a design storm with a duration of 48 hours. The wave height was assumed to increase linearly from 0.3 m to a peak equal to the 100 year ARI wave height. The peak wave height lasted for 6 hours before decreasing linearly to 0.3 m. The water elevation applied during modelling was a predicted spring tide translated so a 100 year ARI storm surge persisted throughout modelling. A peak storm tide level (which includes astronomical tide and storm surge) of 1.18 m AHD was used to represent the 100 year ARI storm event. This is derived from the following CSIRO reports:

Kathleen L. McInnes, Ian Macadam and Julian O'Grady, 2009. "The Effect of Climate Change on Extreme Sea Levels along Victoria's Coast". A Project Undertaken for the Department of Sustainability and Environment, Victoria as part of the 'Future Coasts' Program, National Research Flagships Climate Adaption, CSIRO, November 2009.

Kathleen L. McInnes, Ian Macadam and Julian O'Grady, 2009. "Extreme sea levels and coastal vulnerability in a changing climate - a state-wide assessment for Victoria", Centre for Australian Weather and Climate Research: A partnership between CSIRO and the Bureau of Meteorology.

The design storm is represented graphically in Figure 12. Wind was not included in this part of the analysis as its effect is adequately captured in the generation of the waves in the SWAN model. Wave directions were modelled as arriving perpendicular to the shoreline.

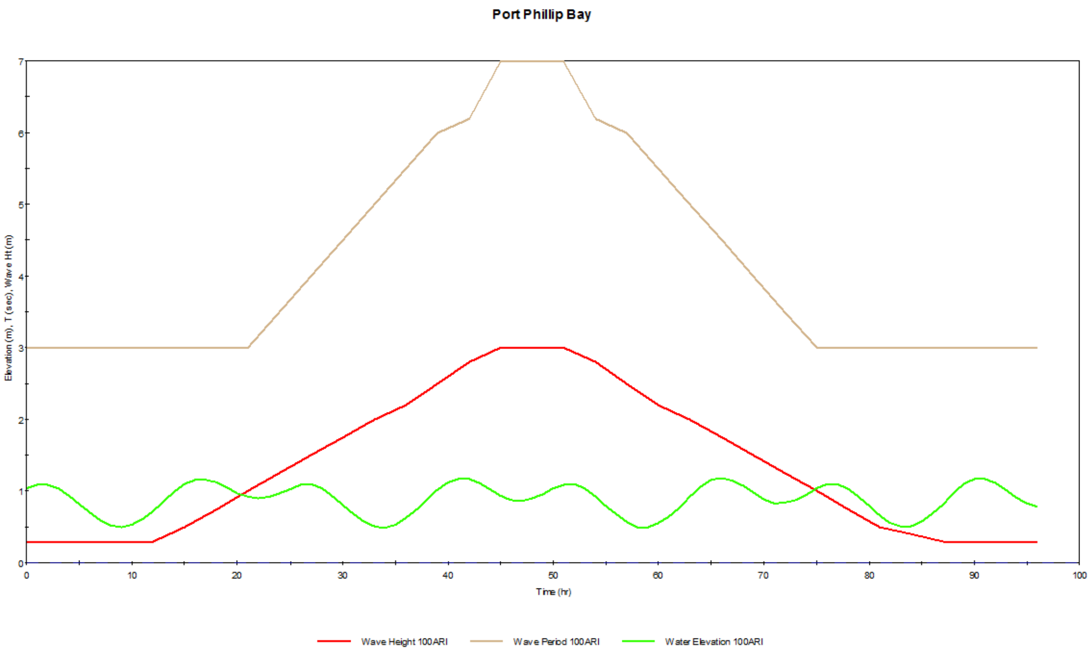


Figure 12 Design storm using during modelling.

Ground elevation profiles were extracted for assessment at the following locations from Future Coasts LiDAR data provided by the Department of Sustainability and Environment (2011)[8]:

- Elwood – 2 profiles
- Mordialloc
- Murray-Anderson (Rosebud/Mornington) – 2 profiles

The locations of the profiles are shown in Figure 13 and Figure 14, respectively.

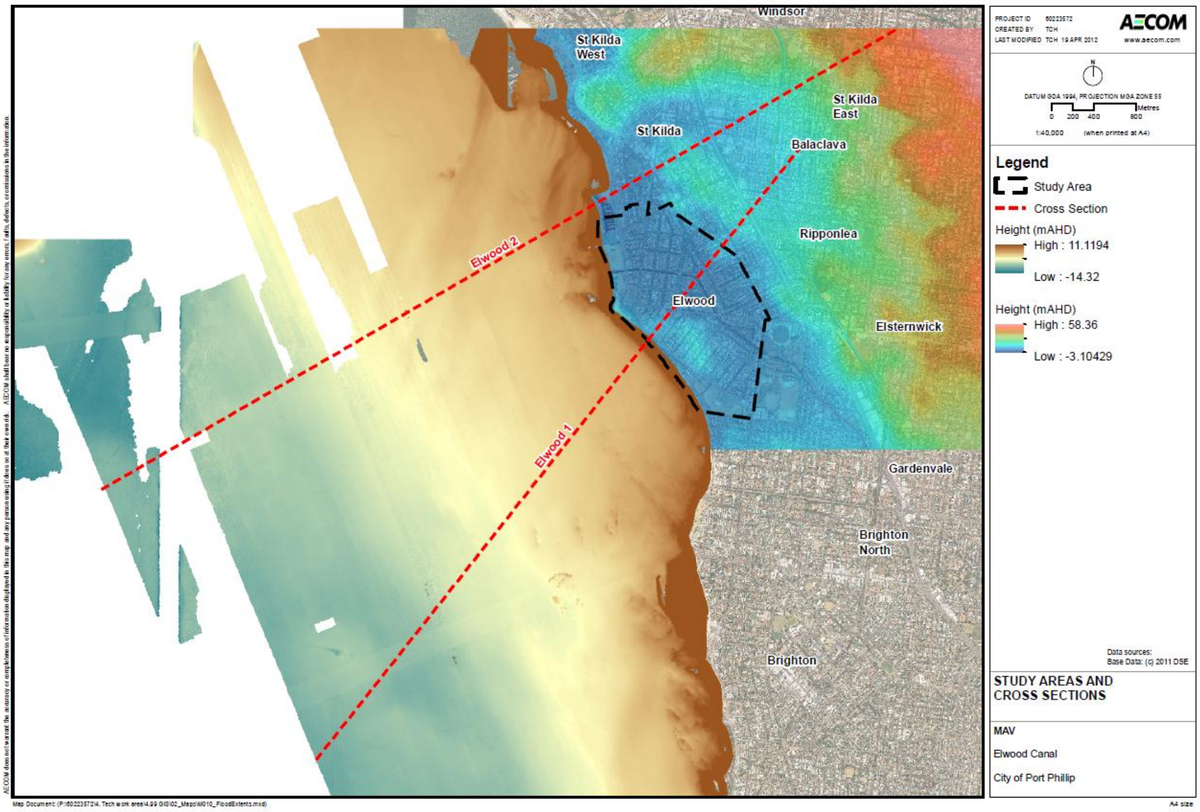


Figure 13 Location of extracted elevation profiles in Elwood.

[8] AECOM acknowledges the use under licence of the LiDAR imagery/DEM produced by the Department of Sustainability and Environment's Future Coasts Program.

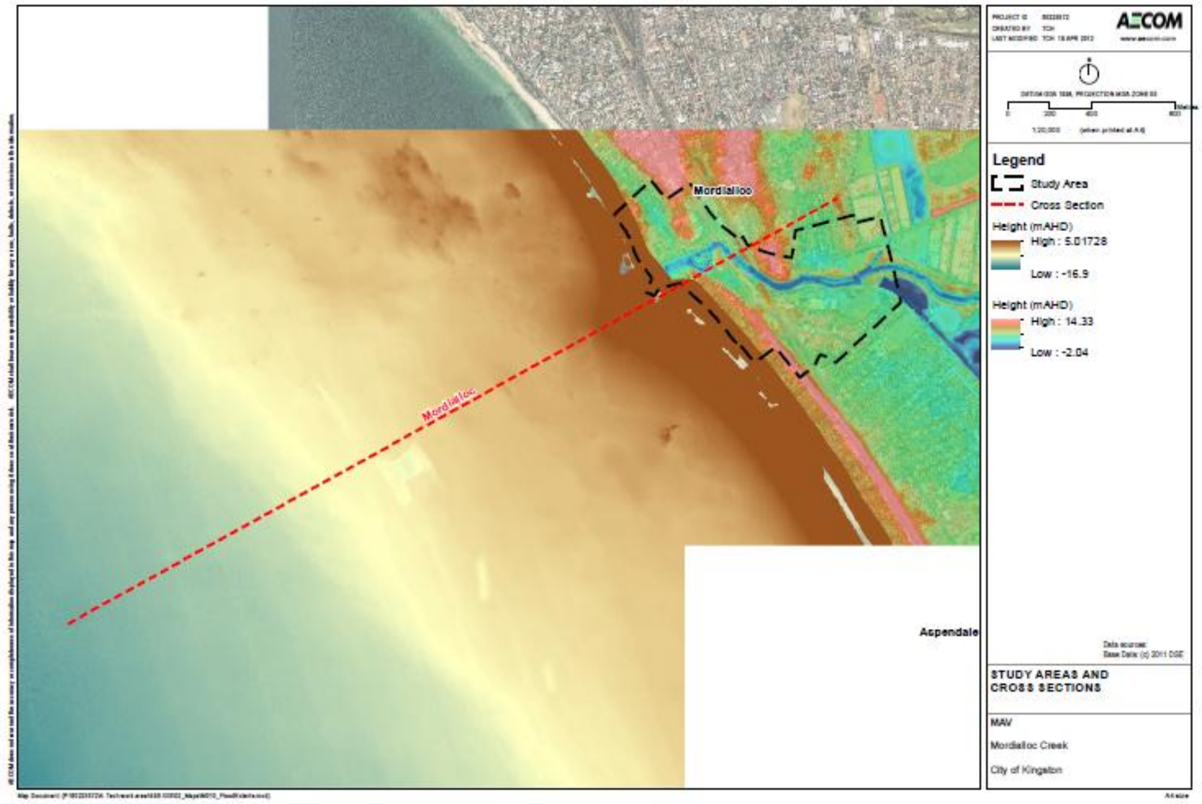


Figure 14   Location of extracted elevation profile at Mordialloc.

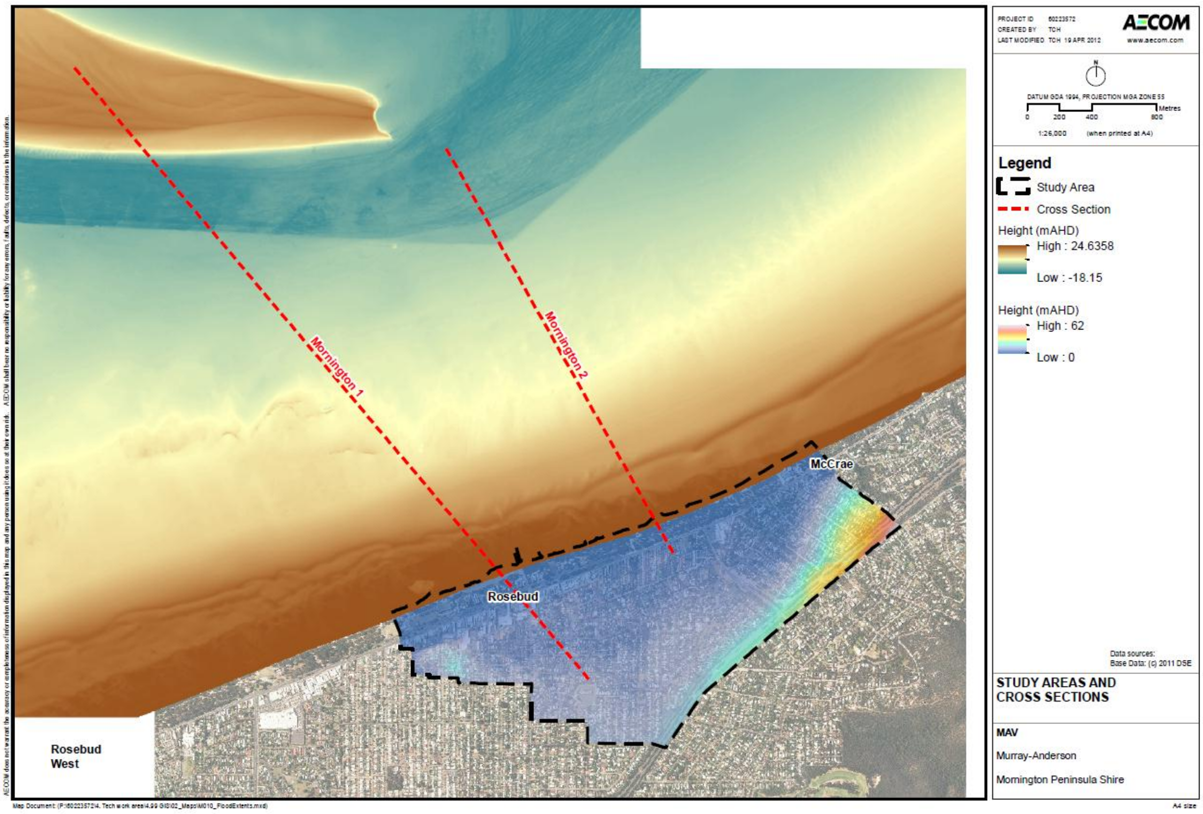


Figure 15 Location of extracted profiles at Murray-Anderson.

The SBEACH model was then setup using the coastal profiles extracted from the LiDAR data and the wave parameters from the wave model. A scenario of a 100 year ARI wave height coinciding with a 100 year ARI water level has been modelled. The resultant maximum sea level inclusive of tide, storm surge and wave setup was extracted and is shown in .

Table 12 Maximum values for tide + storm surge, wave setup and sea level during modelling for 100 year ARI event.

Location	Max Tide + Storm Surge	Max Wave Setup	Max Sea Level
Elwood	1.18 m AHD	0.66 m	1.78 m AHD
Mordialloc	1.18 m AHD	0.48 m	1.65 m AHD
Murray Anderson (Rosebud / Mornington)	1.18 m AHD	0.52 m	1.69 m AHD

The results of the SBEACH analysis have been provided and show the ground elevation profile (red line), maximum sea level (green line) and maximum wave height (brown line).

Elwood

Two elevation profiles were extracted at Elwood. As shown in Figure 16 and Figure 17, the bathymetry (underwater profile) decreases to depth relatively close to shoreline, before continuing at a more gradual slope. The maximum water elevation during simulation is indicated by the green line. The maximum sea level for this location is taken as an average of the two simulations and is 1.78 m AHD.

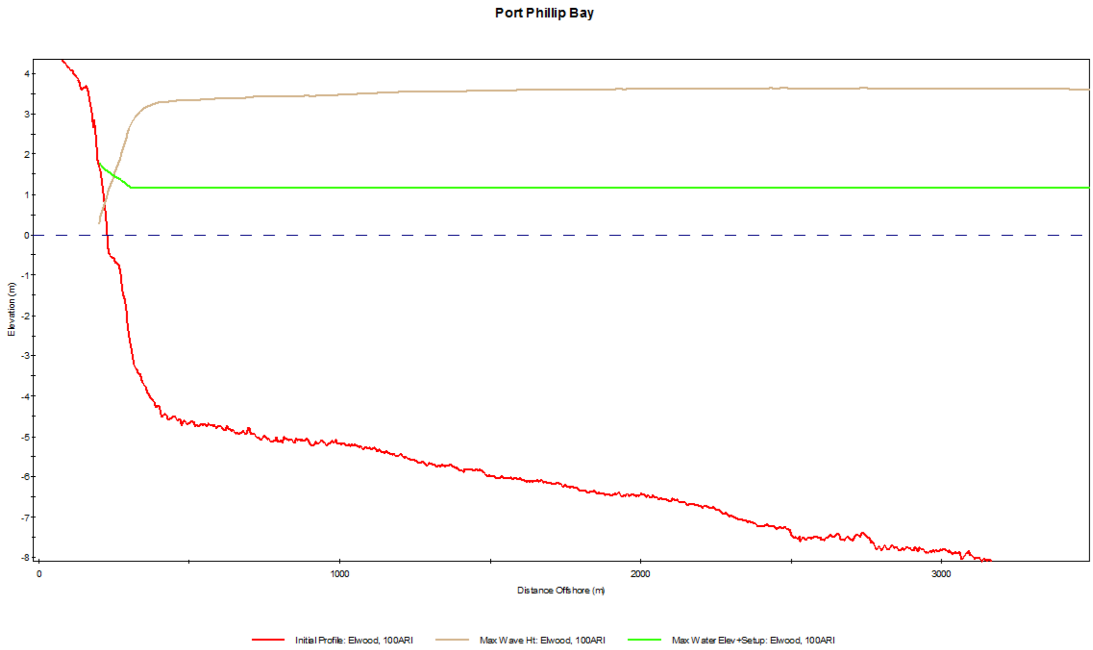


Figure 16 SBEACH model for elevation profile at Elwood (1).

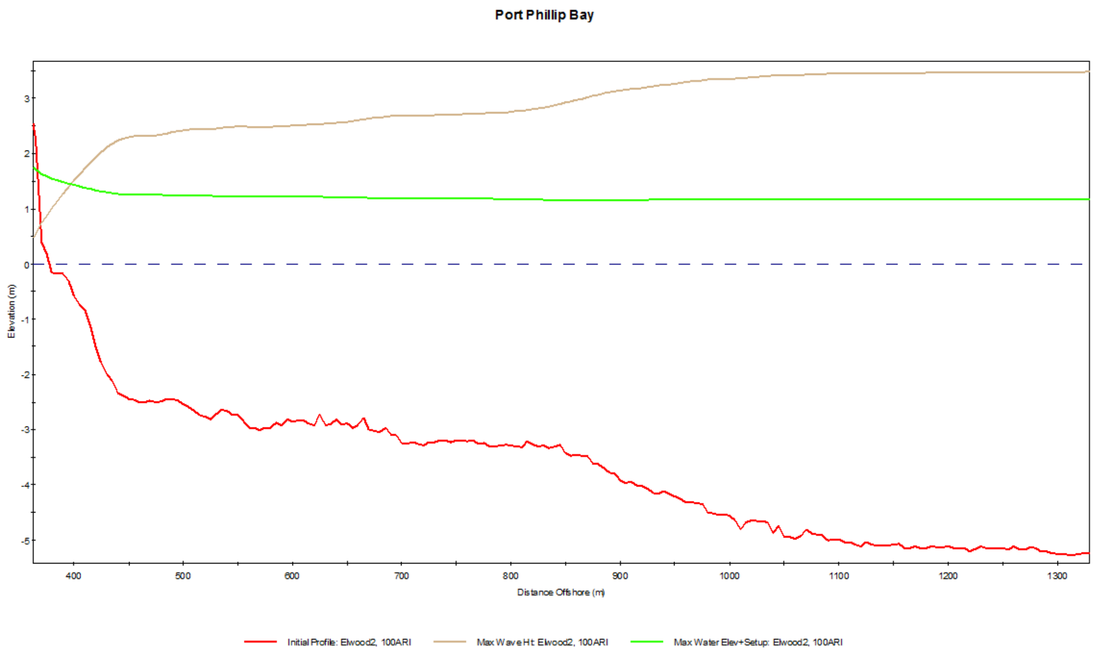


Figure 17 SBEACH model for elevation profile at Elwood (2).

Mordialloc

At Mordialloc only one elevation profile was extracted, as shown in Figure 18. At this location, the bathymetry retrieved from the LiDAR indicates the presence of an underwater sand bar approximately 125 m from 0 m AHD. As indicated by the green line, the simulation showed the max sea level to be 1.65 m AHD.

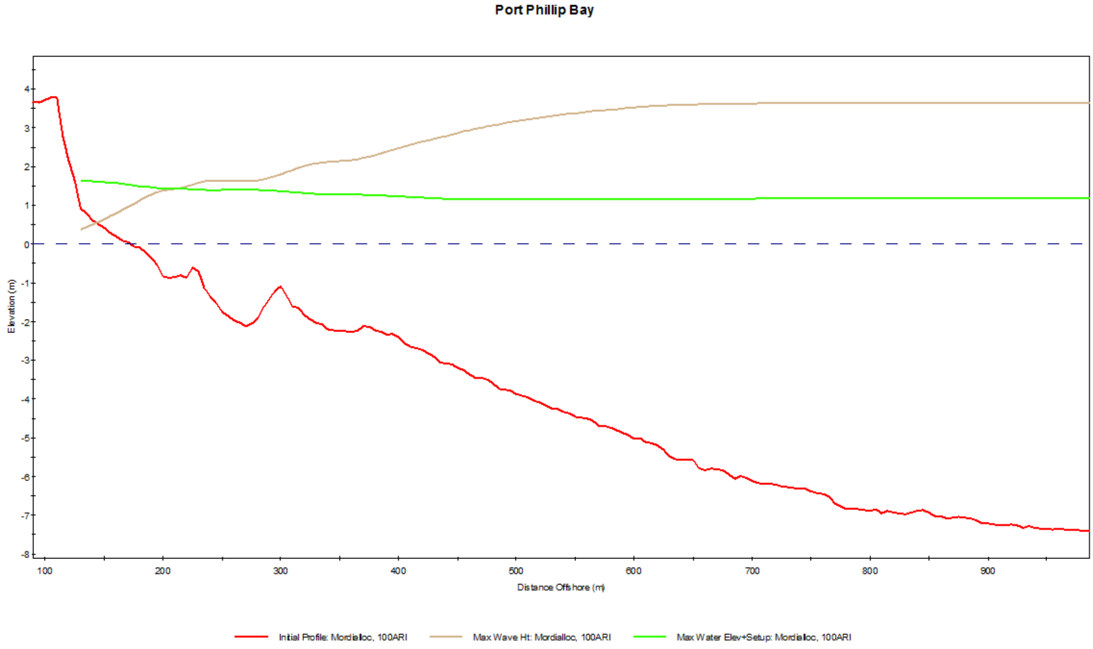


Figure 18 SBEACH model for elevation profile at Mordialloc.

Murray-Anderson

At Murray-Anderson two elevation profiles were extracted for input into SBEACH modelling. As shown in Figure 19 and Figure 20, the bathymetry is very shallow near the shoreline in this region. Additionally, there is an underwater sand bar approximately 300 metres from the shoreline. At this location, the simulation showed a maximum sea level of 1.69 m AHD.

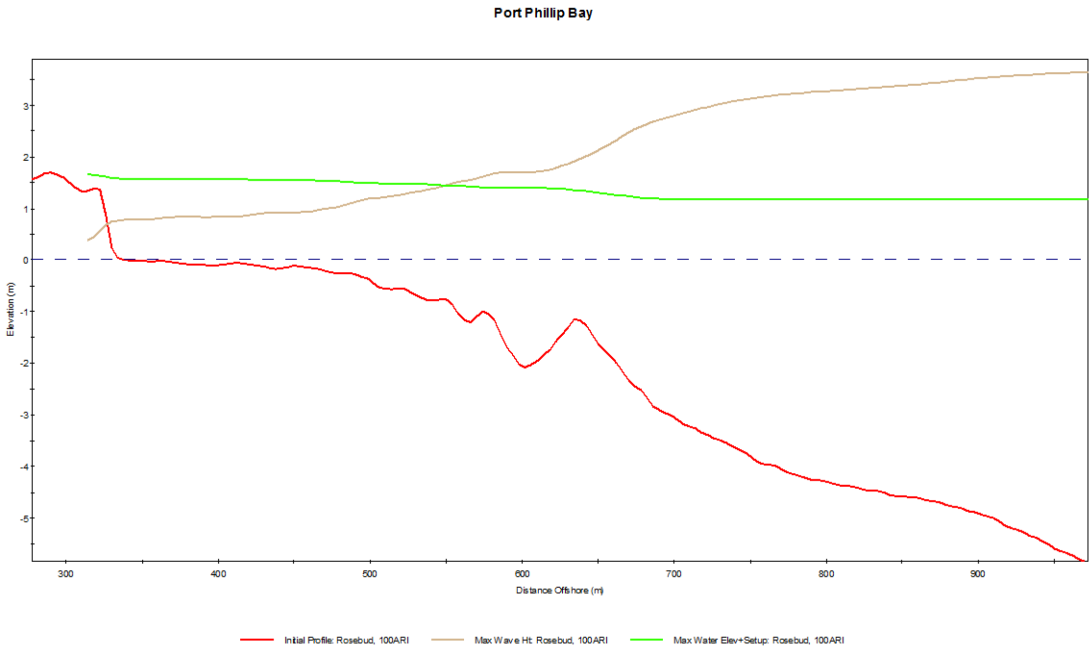


Figure 19 SBEACH model for elevation profile at Murray-Anderson (1).

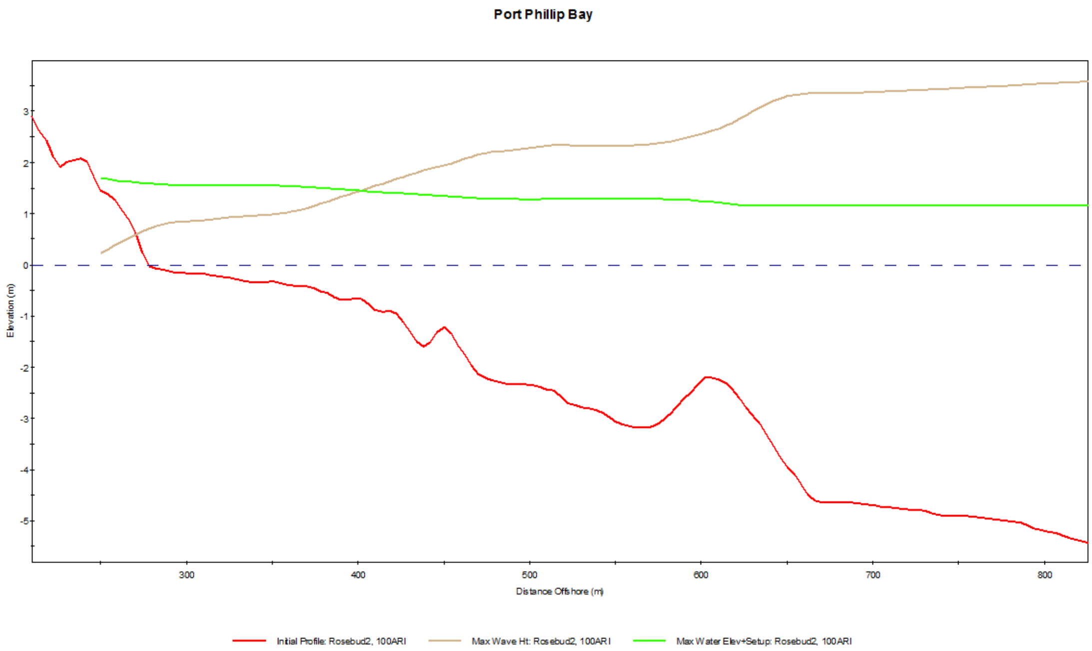


Figure 20 SBEACH model for elevation profile at Murray-Anderson (2).

Appendix D

Economic assumptions for estimating Annual Average Damages

Appendix D Economic assumptions for estimating Annual Average Damages

1. Discount Rate

Discounting is a standard method to add and compare costs and benefits that occur at different points in time, allowing a comparison of future costs and benefits against today's costs and benefits (Garnaut, 2010). Discounting takes into account the time value of costs and benefits and opportunity costs such that those accrue further in the future are worth less to society in today's terms.

The choice of discount rate for environmental projects is contentious. Standard infrastructure projects use a discount rate between 6% and 7%, the Victorian State Government typically uses 6.5%, while Infrastructure Australia uses a 7% discosunt rate. However, it is common for projects with long term social and environmental impacts, such as those relating to climate change, to adopt a much lower discount rate. For example, in the Garnaut Climate Change review, Garnaut argues for adoption of a social discount rate between 1.4% and 2.7%. The Stern Review on the Economics of Climate Change (2006) adopted a discount rate of between 1.4% and 1.7%. Given the disparity of opinions on the appropriate rate of discounting, this study has utilised a 'middle-ground' discount rate of 3%.

2. Change in land use, population and employment

The case study areas used in the analysis have very different characteristics in terms of future growth capability. The change in land uses, population and employment were assumed to be in line with each council forecasts.

3. Damage Cost Parameters

Table 13 shows a list of the cost parameters that were applied to assets in the study area to calculate inundation damages.

Table 13 Details of economic parameters used and source

Cost Item	Method	Source
Residential Building and Content Damage	Costs relationship used for different house types. Depth damage relationships used to assign costs.	Department of Sustainability and Environment, *Review of Flood RAM Standard Values.*(2009)
Residential clean up costs	Fixed cost per building.	
External property damage costs	Fixed cost per building.	
Commercial, industrial and public building damage	Depth damage relationships used to assign costs per square metre of floor space.	
Commercial and industrial content damage	Depth damage relationships used to assign costs. Different values applied for low, medium and high value contents.	
Commercial clean up costs	40% of direct damages	
Motor Vehicles	Cost per vehicle once flood height is greater than 40cm.	
Road damage	Cost per square metre of road space for different road types and for 'major' and 'minor' floods.	Department of Sustainability and Environment, *Review of Flood RAM Standard Values.*(2009)
Bridge damage	Cost per bridge for 2 and 4 lane bridges for 'major' and 'minor' floods.	
Parkland damage	Costs calculated per hectare of parkland flooded. Costs assumed at 40 hours of work per hectare @ $60 per hectare plus $2000 of materials per hectare.	AECOM calculation
Damage to boats in marinas	Market rate for boats sought from resale sites. Damage to boats estimated to begin when flood waters reach top of marina edge. Damage to depth ratio applied.	www.boatsales.com.au AECOM calculation
Electricity distribution station and substations	Damages to both electrical distribution stations and substations for different flooding levels estimated based on engineering experience and knowledge of local sites.	AECOM electrical engineering group
Transport Impacts	Impact to rail and road transport assessed using traffic count data, published rail patronage data and AustRoads value of time parameters used in transport appraisal.	AustRoads value of travel time Traffic counts from VicRoads Metro Rail Patronage
Foreshore camping impacts	The daily economic impact to the region from campers was calculated based on camping fees and estimated daily spend. Different size flood events were assumed to close the camping ground for a number of days, resulting in a loss of economic activity to the region.	AECOM calculation

4. Economic Modelling Parameters

The following tables provide the economic parameters used to calculate the economic cost of inundation events.

Residential building damages

Building type	Fixed cost per building	Variable cost per building per square metre under water
Single storey	$15,906	$5,886
High set	$20,041	$9,007
Two-storey	$11,135	$4,041
Average	$15,694	$6,311

Residential content damages Climate Adaptation Decision Making Framework for Urbanised Coastal Areas Adapting to inundation in urbanised areas: supporting decision makers in a changing climate

Building type	Overflow depth range (metre)	Fixed cost per building	Variable cost per building per metre under water
Single storey	[-∞, 0]	-	-
	(0, 2]	$10,634	$10,634
	(2, ∞]	$31,903	-
High set	[-∞, 0]	-	-
	(0, 2]	$10,634	$10,634
	(2, ∞]	$31,903	-
Two-storey	[-∞, 0]	-	-
	(0, 2]	$7,435	$7,435
	(2, ∞]	$22,349	-

Residential Clean up and External Costs

Residential	Fixed cost per building
Clean up cost	$4,323
External cost	$5,404

Commercial and Industrial Building Damages

Depth of over floor inundation	Actual damage per sq. m	Potential damage per sq. m
3	$255	$580
2.7	$255	$580
2.4	$255	$580
2.1	$255	$580
1.8	$204	$465
1.5	$191	$434
1.2	$153	$348
1	$128	$290
0.9	$121	$276
0.6	$102	$232
0.5	$96	$217
0.3	$72	$165
0.2	$64	$146
0.1	$49	$109
0.05	$35	$78
0	$19	$43
-0.01	-	-

Commercial content damages

Content damage per square metre			
Depth of over floor inundation	**Low value contents**	**Medium value contents**	**High value contents**
2.7	$128	$255	$378
2.4	$128	$255	$378
2.1	$128	$255	$378
1.8	$102	$204	$306
1.5	$96	$191	$287
1.2	$77	$153	$230
1	$64	$127	$191
0.9	$60	$121	$182
0.6	$51	$102	$153
0.5	$48	$96	$143
0.3	$37	$73	$109
0.2	$32	$64	$96
0.1	$24	$48	$72
0.05	$18	$34	$52
0	$10	$19	$29
-0.01	-	-	-

Road damages per km

	Major Flooding			Minor Flooding		
Road type	**Initial road repair**	**Subsequent accelerated deterioration**	**Total cost**	**Initial road repair**	**Subsequent accelerated deterioration**	**Total cost**
Major highway (4 lane)	$237,759	$118,880	$356,639	$118,880	$59,440	$178,319
Major sealed road	$59,440	$29,720	$89,160	$29,720	$14,860	$44,580
Minor sealed road	$32,422	$16,211	$48,633	$16,211	$8,105	$24,316
Unsealed road	$9,727	$4,863	$14,590	$4,863	$2,432	$7,295

Bridge Damage Costs

Bridge damage	Major flooding	Minor flooding
Major (4-lane) bridge	$540,361	$108,072
Minor (2-lane) bridge	$143,736	$35,664

Repair cost for parkland and foreshore

Cost to council of employees ($/hr)	$60
Hours of work per flooded hectare	$40
Materials required per hectare	$2,000

Depth to damage ratio for boats in wet berths

Depth above eastern dock	Proportion of boats damaged
0	10.00%
0.1	15.00%
0.2	20.00%
0.3	22.50%
0.4	25.00%
0.5	27.50%
0.6	30.00%
0.7	32.50%
0.8	35.00%
0.9	37.50%
1	40.00%

Depth to damage ratio for boats on sea wall

Depth above sea wall	Proportion of boats damaged on sea wall
0	0.00%
0.1	10.00%
0.2	20.00%
0.3	30.00%
0.4	40.00%
0.5	50.00%
0.6	60.00%
0.7	70.00%
0.8	80.00%
0.9	90.00%
1	100.00%

Cost of electricity distribution station

Flood class	Inundation level (cm)	Man hours to repair	Time out of service (hours)	Cost of lost load per hour	Direct cost	Indirect cost
Minor	≤50	16	0	$3,400,000	$2,000	$0
Medium	>50	80	8		$70,000	$27,200,000
Major	>150	400	48		$900,000	$163,200,000

Impact of flooding on retail and food & beverage outlets

Height of flood over ground floor	Reduction in daily revenue	Duration of impact (days)	Number of days revenue lost
0	60.00%	1	0.6
0.1	60.00%	1	0.6
0.2	80.00%	1	0.8
0.3	80.00%	1	0.8
0.4	80.00%	1	0.8
0.5	100.00%	1	1
0.6	100.00%	1.5	1.5
0.7	100.00%	1.5	1.5
0.8	100.00%	1.5	1.5
0.9	100.00%	2	2
1	100.00%	2	2
1.1	100.00%	2	2
1.2	100.00%	2	2
1.3	100.00%	3	3
1.4	100.00%	3	3
1.5	100.00%	3	3

Appendix E

Cost Benefit Approach

Appendix E Cost Benefit Approach

Overview

The focus of the economic assessment of the case study sites is twofold:

- To assess the direct economic impacts of climate change expected within each site over the next century; and
- To assess the economic value of adaptation options aimed at reducing the impacts of climate change over the next century.

The scope of climate change impacts is limited to increases in flooding from intensified rainfall events and tidal surges.

The assessment of climate change impacts with and without adaptation options provides the means with which to assess the benefits of these options; the reduction in impacts is the primary benefit of the option.

The benefits of different adaptation options are compared against the cost of implementing the options in a Cost Benefit Analysis (CBA) to assess whether the options are economic, and the options to be ranked on their relative ability to provide value-for-money.

Assessment of damages

The assessment of damages (and associated impacts) for each assessed flood event have, where appropriate, draw on the standard values for flood damages provided in the 2009 Department of Sustainability and Environment report entitled “Review of Flood RAM Standard Values”.

The following damages have been assessed for each flood event modelled (depending on data availability and the relevance to each case study):

- residential, commercial, and industrial buildings
- building contents
- clean up costs
- external property damage
- motor vehicles
- indirect damages (disruption to business, communications, transport)
- roads and transport infrastructure
- damage to utilities
- damage to public parkland
- damage to boats and marinas
- damage to public infrastructure such as electricity and gas.

Assessing Economic Impacts

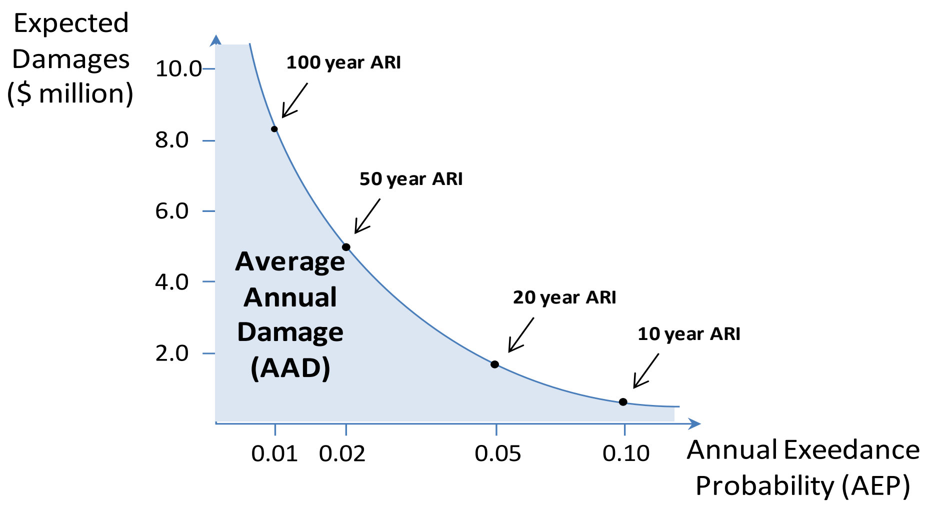
The economic impacts of weather related events over time are uncertain, due in part to the inherent difficulty in predicting such events. As a result, a probabilistic method is required that deals with the likelihood of events occurring in any one year. The Average Annual Damage (AAD) is the probabilistic approach that has been used to estimate impacts in the study. This approach is consistent with the Rapid Appraisal Methodology (RAM) for Floodplain Management, developed by Read Sturgess and Associates for the Department of Sustainability and Environment (2000).

The AAD approach involves an assessment of the area flooded in a particular event. For example, a flood with an Average Return Interval (ARI) of 100 years (i.e. a 'one-in-a-hundred year event') is modelled allowing the expected footprint and depth of the flood to be estimated. Based on these outputs, an assessment of the damage to infrastructure (and other inundation impacts) can be estimated.

The 100 year ARI is said to have an Annual Exceedance Probability (AEP) of 0.01 – that is, a flood is expected to have a 1% chance of being equal to or greater than the 100 year ARI event in any one year. The consequential damages from this event are therefore also expected to have a 1 % chance of being equal to or greater than the expected damages of the modelled 100 year ARI event.

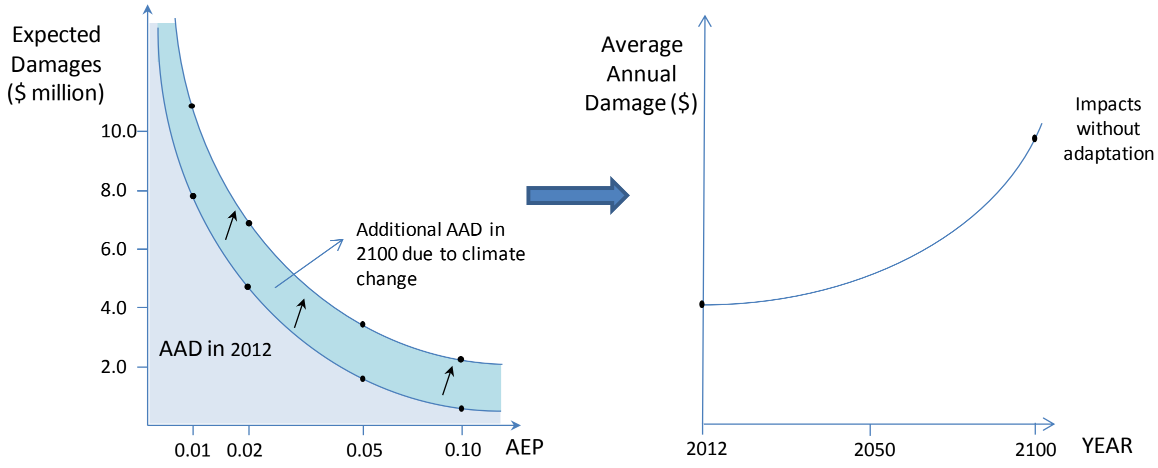
By modelling the extent of flooding and estimating the damages expected for a number of different ARI events, an Average Annual Damage curve can be plotted (see Figure 23). The area under the curve is the Average Annual Damage (AAD). This represents the level of damage that can, on average, be expected in any one year.

Figure 21 An example of an Average Annual Damage (AAD) curve.



To assess the impacts of climate change, similar assessment are made using hydrological modelling of the area at 2100. With increasing climate change impacts, the AAD curve will shift out (i.e. each event will result in greater levels of damage), and thus AAD will increase over time. This is depicted in Figure 22. Observing how the AAD increases from the current level allows council to contrast the anticipated impacts against the current situation.

Figure 22 An example of an increase in AAD due to climate change.



Economic assessment of adaptation options

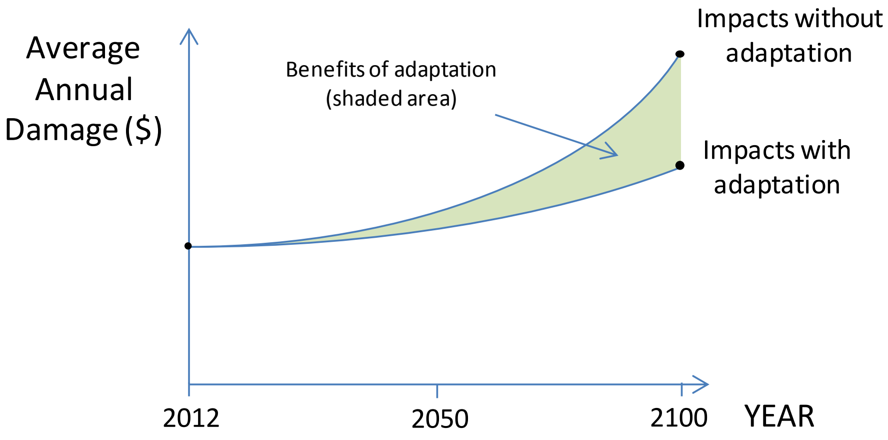
Once adaptation options have been identified, an economic assessment can be made about each option's effectiveness in reducing the impacts of climate change on the elements assessed in the previous exercise. This will be used to produce an alternative AAD assessment for each option out to 2100.

How the AAD with adaptation is estimated depends on the type of adaptation pathway. For 'accommodate' pathways which aim to minimise damages without reducing level of inundation, a reduction in the cost per asset can be made in the AAD model. For example, if one of the initiatives in the pathway is to improve early warning systems for river flooding the damage per building will be reduced as individuals have longer to prepare for the flood events. The model will then produce new AAD figures based on the lower expected damages for these assets. The same approach can be used to calculate the benefits for options involving changes to building design and planning regulations which don't aim to reduce inundation heights but increase the resilience of the assets.

Pathways involving physical protection aim to reduce the inundation level. This may be through stopping the water entering the sensitive areas using levees and sea walls or by removing water already in sensitive areas such as via improved drainage systems. In many cases it may be a combination of both. For these pathways new flood heights need to be estimated in order to recalculate flood costs and AAD. If the resources are available this should be done by including the protection assets such as levees or drainage into the flood models. Alternatively, the new flood heights can be estimated based on engineering knowledge of the local area and the capacity of the protection measures. Once the new inundation heights are entered into the model the new AAD figures and therefore the benefits of the adaptation can be calculated.

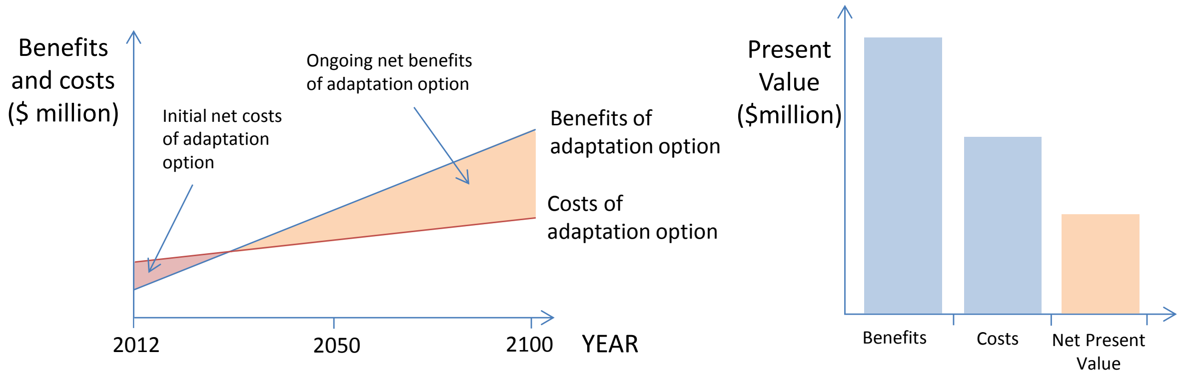
The reduction in AAD represents the annual benefits of adaptation, as illustrated in Figure 23

Figure 23 An example of estimating the annual benefits of adaptation.



This projection of annual benefits out to 2100 will then be assessed against the costs of implementing these options in a Cost Benefit Analysis (refer to Figure 23). All costs and benefits will be discounted to the present time period using an appropriate discount rate.

Figure 24 An example of estimating the ongoing net benefits of adaptation.



The outputs of the economic assessment will include:

- Net Present Value of each option
- Benefit Cost Ratio of each option
- Break-even analysis to assess the benefits that are required for each option to be considered economic
- Ranking of adaptation options

An example of the cost benefit calculations for an adaptation option is shown in Figure 24.

Table 14 Example cost benefit calculation

Year	2011	2012	2013	2014
Estimated Average Annual Damage without adaptation	$1,000,000	$1,100,000	$1,200,000	$1,300,000
Estimated Average Annual Damage with adaptation	$900,000	$950,000	$1,000,000	$1,050,000
Reduction in Average Annual Damage due to adaptation	$100,000	$150,000	$200,000	$250,000
Present Value of Benefits (discounted at 3%)	$100,000 ÷ $(1.03)^0$ = $100,000	$150,000 ÷ $(1.03)^1$ = $145,631	$200,000 ÷ $(1.03)^2$ = $188,519	$250,000 ÷ $(1.03)^3$ = $228,785
Total Present Value of Benefits (2011-2014)	**$662,936**			
Capital Cost of Adaptation Option	$500,000			
Operating and Maintenance cost of adaptation option		$30,000	$30,000	$30,000
Reduction in Average Annual Damage due to adaptation	$500,000	$30,000	$300,00	$30,000
Present Value of Benefits (discounted at 3%)	$500,000 ÷ $(1.03)^0$ = $500,000	$30,000 ÷ $(1.03)^1$ = $29,126	$30,000 ÷ $(1.03)^2$ = $28,278	$30,000 ÷ $(1.03)^3$ = $27,454
Total Present Value of Benefits (2011-2014)	**$584,858**			
Net Present Value	**$662,936 - $584,858 = $78,078**			
Benefit Cost Ratio	**$662,936 ÷ $584,858 = 1.13**			

The economic modelling of climate change impacts and cost benefit analysis of adaptation options inevitably involves assumptions and levels of uncertainty. These would exist in elements including the designated flood levels, the magnitude of monetized flood damages, individual benefits of adaptation (e.g. recreational value of public spaces), and costs of adaptation. In general, these limitations and levels of confidence will be discussed in a qualitative manner, for example noting the areas of uncertainty (e.g. the source or potential accuracy of inundation levels).

Benefit of occupying the hazard zone

Another piece of analysis that has been used for assessment is the benefit of occupying the hazard zone. Residents, businesses, and visitors value coastal area for different reasons and in different ways. This can be measures through land prices, rents and people willingness to travel to destinations. By estimating these benefits on an annual basis we get an estimated value of the area to society and can compare this to the AAD. The difference between the two is the net benefit of occupying the hazard zone. This is useful comparison to see the scale of expected damages compared to the value of the area; however, it should not be used a measure to test the economic merit of retreating from the hazard zone.

Even if average annual damage are larger than the benefit of occupying the hazard zone (negative net value of occupying), retreat is an expensive adaptation option and therefore may not be optimal. Small changes to existing assets as well as physical protection measures could greatly reduce the expected damages at a low cost while still allowing the entire area to continue to be occupied. In this way, retreat is simply another adaptation option that should be assessed in a cost benefit approach in the same way as other adaptation options.

Due to the high value of many coastal areas the benefit of occupying any coastal area is likely to be much higher than the average annual damage. This would produce a positive net value of occupying the hazard zone. Although this suggests retreating from the *entire* hazard zone would not be a suitable response, it does not imply that retreat is not the optimal economic solution for individual sites within this larger area. This measure can be used for small land areas or assets that are in a high risk area. For example, a residential property at risk from sea level rise and storm surge may face expected future damages well above the value of occupying the site. If there are no solutions to protect from the inundation which have a lower cost than the cost of retreating (losing the benefit of occupying the site) then retreating represents the lowest cost option.

Monte Carlo Analysis

Monte Carlo simulations are used to generate a probabilistic distribution for the range of possible average annual damage results and costs and benefits of each adaptation pathway. It provides a useful indication of the extent of uncertainty and risks posed by the incomplete nature of some information. The range of possible results and their associated probabilities helps quantify and measure uncertainty to better inform decision-making. For example, some large scale protection measures may have a large expected net present value but also the possibility of a large negative net present value if the predicted flooding extent does not eventuate.

The simulation software used (@Risk) samples from the input distributions and recalculates economic indicators such as the net present value and benefit cost ratio. This is then repeated thousands of times so that a statistical distribution of all possible outcomes can be generated. From this distribution, the probability of the pathway being economically viable can be determined. This also allows uncertainty associated with individual inputs to be tested to see a range of possible results. The software also indicates the key inputs which have the greatest influence on variation to the net present value and benefit cost ratio.