Demonstrating Climate Change Adaptation of Interconnected Water Infrastructure.

2012

Synthesis Report

Part 4 - Case Studies

SYDNEY COASTAL COUNCILS GROUP

NSW GOVERNMENT Office of Environment & Heritage

Sydney WATER

Coastal Adaptation Decision Pathways Project **(CAP)**

Contents

Introduction

Interconnected water infrastructure is infrastructure where management is shared between agencies or different tiers of government. This can be as a result of physical interconnectedness or shared financial or asset management due to overlapping governance. Climate change will require water infrastructure managers to adapt their asset management and investment programs. This study takes a case study approach to explore this adaptation decision making process through a six stage process.

The report presents a decision making framework for climate change adaptation for interconnected water infrastructure as follows:

Part 1 – Overview: Provides an overview of the study, the general objectives and the issues and challenges facing interconnected water infrastructure managers in the context of climate change. It also provides a summary of key findings.

Part 2 – User Guide: Provides a summary of each stage of the framework including what the stage involves, why it is important and a brief explanation as to how it is to be completed.

Part 3 – The Adaptation Resource Center: The report is also accompanied by an interactive PDF (iPDF) which provides a greater level of detail as to 'how' each stage is to be completed including links to relevant tools. This is an interactive tool available on line at Demonstrating Climate Change Adaptation of Interconnected Water Infrastructure

Part 4 – Case Studies: This section of the report provides details of how the approach was developed from and adopted on each of the five case studies and highlights lessons learnt.

Case study approach

The project has identified five case studies through which climate change impacts on interconnected water infrastructure have been explored and adaptation pathways and responses assessed. The findings and case study process has lead to the development of a framework to guide decision makers with adaptation of interconnected water infrastructure.

Guidance on adapting interconnected water infrastructure to climate change will be relevant to all councils and water infrastructure managers within the Sydney coastal region and beyond. However, the project deliberately adopted a case study approach to develop appropriate guidance through consideration of 'on the ground' in real-world scenarios.

The case studies selected differ in terms of the climate problems faced as well as the governance structures and political and social context through which decision making must occur. The case studies are also in different stages in terms of the progress that has already been made in establishing adaptation pathways.

The study attempts to progress each case study through a framework for adaptation decision making. However, the greater value of the case study approach is in presenting each case study's 'story':

- City of Sydney CBD: Understanding the implications of sea level rise and tidal locking in an existing area of high value assets.
- Green Square: New development accommodating the impact of sea level rise on the drainage network.
- Cooks River: Improving governance arrangements to address existing and future flooding impacts.
- Wollongong: A systems approach for interconnected coastal asset owners to adapt to coastal recession.
- Berry Creek: Valuing community and ecological assets in the adaptation of interconnected water networks under multiple ownership.

The five case study stories communicate the interconnected nature of the problem, the barriers faced, barrier resolution and consideration of long term Flexible Adaptation Pathways. In this way, the project outcomes may be more readily communicated and applied to the wider group of stakeholders.

Selection

The Water Research Laboratory (WRL) was commissioned by Sydney Water (SWC) to undertake a literature review, project plan, and case study selection process prior to the Sydney Coastal Councils Group (SCCG) receiving Coastal Adaptation Pathway (CAP) funding. The aim of the WRL work was to inform the case study selection criteria and provide a more detailed project plan for the project. A workshop was hosted by WRL on 24 August 2011 to discuss the progress of the literature review, and present the draft project plan and draft case study selection criteria. A report was written by WRL combining these three elements.

A call for case studies occurred in October/November 2011 inviting project stakeholders, including all SCCG member councils, to participate in the selection process. Five case studies were selected based on the following criteria:

- Interconnectedness.
- Data availability.
- Barriers to adaptation.
- Diversity of climate change impacts.
- Vulnerability to climate change.

Stakeholder Workshops

Following the selection process, and commencement of this project, an initial workshop (Workshop 1), involving delegates from asset owners, local government and industry bodies, and combining all case studies was undertaken on 28 March 2012 at which:

- Climate change events and consequences to be considered for each case study were selected and agreed.
- Potential adaptation options and barriers to adaptation were selected.

A second workshop for each case study was held between Monday 23 April and Thursday 26 April 2012. The purpose of the Workshop 2 series was to:

- Introduce and discuss the high level 'Flexible Adaptation Pathways Decision Making Framework'.
- Confirm the climate change parameters, events, impacts and adaptation options.
- Discuss and agree on the Flexible Adaptation Pathways for the case study.
- Discuss and agree on the high level economic assessment framework and the specific case study approach.
- Confirm the adaptation barriers and actions to overcome them.
- Agree on the next steps for the case study.

Sydney's CBD: Understanding the implications of sea level rise and tidal locking in an existing area of high value assets

2.1 Overview

The stormwater infrastructure for Sydney CBD is complex and consists of both original brick oviform structures and more recent concrete box culvert and pipe networks. The majority of the stormwater networks discharge into the harbour and as such are at risk from Sea Level Rise (SLR). The majority of the trunk stormwater network in the CBD is owned by SWC, with the remainder of the network being owned by City of Sydney Council (CoS). This creates numerous issues in terms of ownership and future expansion. The network is known to surcharge in large rainfall events and it is generally considered (by CoS Council drainage engineers for example) that the current capacity of the network is between a 2 and 5 year ARI standard. Any climate change impacts, due to SLR or increased storm intensity, will therefore worsen an existing problem, potentially increasing the risk of flooding at key city locations such as the Opera House and Circular Quay.

Key lessons learned from the Sydney CBD Case Study

The results of this case study which focussed on the Sydney CBD showed how the initial climate change variable considered can be less of an impact than imagined. A key factor for this study was to narrow the focus and scope to an individual but significant network, to make the risk assessment process manageable with the limited data available. The team adopted a very simplistic and high level approach within the risk assessment which allowed the team to quantify the risk of sea level rise on this one drainage network. The results were surprising in suggesting that the imagined problem was worse than the modelled results and highlighted the need for the iterative approach and to be prepared to return to the Focus and Scope stage to identify other assets or climate variables to consider. This demonstrates the benefits of using the climate change adaptation framework to scope the problem and then assess the risk before developing adaptation options.

The case study also demonstrated that in the absence of sufficient information, simple approximations can be adopted and used effectively to assist in narrowing the focus and scope of the problem.

2.2 Focus and Scope

The Sydney CBD stormwater network is complex and in parts dates back to the first settlement of the city. Parts of the trunk stormwater mains are brick arch oviform culverts which were originally part of the combined sewer network for the city. As the city grew and pressures on water quality in the harbour increased, additional dedicated sewer networks were constructed leaving the remaining network to provide stormwater drainage for the city. This trunk network is generally owned by SWC, while the additional stormwater networks which have been constructed to drain the buildings and roads tend to be owned by CoS Council.

It is widely acknowledged that the stormwater networks in the CBD are under capacity. The Draft City of Sydney Stormwater Drainage Design Code (City of Sydney Version 1.1 August 2009) suggests that new stormwater networks should be designed to provide a 10 year (residential) or 20 year (commercial) minor storm capacity. In July 1996, SWC completed a study on the capacity of their trunk drainage network. The report prepared following this study titled "Utilities Planning Services City Area SWC 30 – Capacity Assessment" estimates that the current capacity of the network is between a 2 and 5 year ARI standard.

The focus for the case study was agreed during Workshop 1, where the key stakeholders, CoS and SWC, discussed the impacts of climate change on their interconnected water infrastructure assets. The team considered all the different climate change parameters and agreed that the two parameters most likely to impact their assets within the CBD were:

- Increased rainfall intensity.
- Sea level rise.

The case study team discussed the likely events which would occur in the CBD as a result of the climate change parameters above and agreed on the following relevant events:

- Increased surcharging of the stormwater network.
- Increased coastal inundation.
- Tide locking of the stormwater network.

The consequences of these events are shown in Table 1.

Table 1 Sydney CBD – Consequences of climate event

Consequences	
Direct	**Indirect**
Increased blocking of traps Damage to road infrastructure & property Damage and asset failure due to higher flows and sea-water corrosion Reduction in asset life (e.g. maintenance becomes more difficult and expensive) Sewerage overflow – still some combined sewers in the CBD Flooding of Circular Quay area Reduced durability of assets Reduced function of network Pressure on system New governance processes required – due to direct impact	Flooding of transport infrastructure, both within the CBD but also routes passing through (e.g. North Shore and Northern rail lines through Wynyard) Disruption to travel (costs to business – 86% of trips to CBD) Health impacts – location (e.g. streets) and quality of water Increase in insurance costs Potential liability for flooding costs Access to stormwater assets for repair Economic (loss to business & impacts on tourism, Sydney Opera House) New governance processes required – due to new interconnected issues Reputational/public perception issues Increased cost and carbon footprint due to increase in pumping requirement Land value

During the initial workshop the case study participants looked at the consequences of the climate change events and initially agreed that the increase in rainfall intensity would be explored as the critical event. However, later in the workshop and following more discussion around the commonality of the consequences for both increased rainfall intensity and tide locking events the group chose to focus on the tide locking of the stormwater network for this case study. The reason for this was that although it is known that sea level rise will impact every outfall to the stormwater network, it is not fully understood what impact the increased tailwater levels will have further upstream in the networks and thus it is an unknown risk with potentially high consequences. In addition the data was believed to be readily available to allow further analysis of the impact of this event, enhancing the value of studying this parameter.

The NSW Climate Impact Profile, prepared by the Department of Environment, Climate Change and Water, 2010, states that a sea level rise of 400mm by 2050 and 900mm by 2100 is to be adopted as a planning guideline.

As the majority of Sydney's stormwater networks discharge directly into Sydney Harbour the increase in sea levels will increase the downstream (tailwater) level of the networks and will therefore influence the performance of the network. The figure below shows how a 400mm increase in sea level will change the tailwater level at an outlet. This increase in sea levels will increase the number of occasions where the outfall is submerged by a high tide level, a phenomenon which is known as tide locking.

Following Workshop 1, an option to change the location of Case Study 1 from Sydney CBD to the Blackwattle Bay catchment was suggested by CoS Council. The primary driver for this suggested change was the lack of modelled flood data for the CBD drainage networks. In contrast, a Flood Study (including Tuflow model) had recently been completed for the Blackwattle Bay catchment. This potential change in case study location was further discussed at Workshop 2 and Table 2 summarises the pros and cons which were identified for changing the case study from the CBD to Blackwattle Bay.

Table 2 Arguments around changing Case Study 1 location from Sydney CBD to Blackwattle Bay

For	Against
More flooding data available from CoS Known flooding issues (historic and predicted) Lessons learnt at Blackwattle would be more applicable for other councils Residential damages simpler to assess using OEH spreadsheet	How do we justify change in case study? (e.g. just because it is difficult?) Late stage in project for a change would mean rework for research to date CBD is the interesting area for damages estimation CBD is higher profile/'wow' factor Blackwattle Bay is similar to Green Square/Cooks River Case Studies CBD network is approx 50:50 split with SWC and CoS, Blackwattle Bay is more CoS than SWC CBD has historical large stormwater mains – so useful to explore adaptation CBD damages are mainly commercial in nature, is possibly less sensitive than inundation of homes?

Ultimately, it was agreed to retain the CBD as the study area. This decision was based on the following:

- It will not result in duplication of existing work.
- It is consistent with the original intent of the case study submission.
- Alternative modelling approaches are available (i.e. other than Tuflow).
- It presents an opportunity to demonstrate potential ways forward in a scenario of lacking data.
- It will help inform the scope of work for any future CBD flood study.
- The outcomes of Workshop 1 can be utilised.

The case study team agreed that the case study would focus on investigating the impact of a 400mm rise in sea levels by 2050 on the performance of the CBD stormwater network. During Workshop 2, the case study team identified a single network known as Tank Stream – Pitt Street, which contains both SWC and CoS Council assets and which outfalls into Sydney Cove (Circular Quay). The assets related to the Tank Stream are shown in Figure 1, which is an extract from the CoS Geographical Information System (GIS).

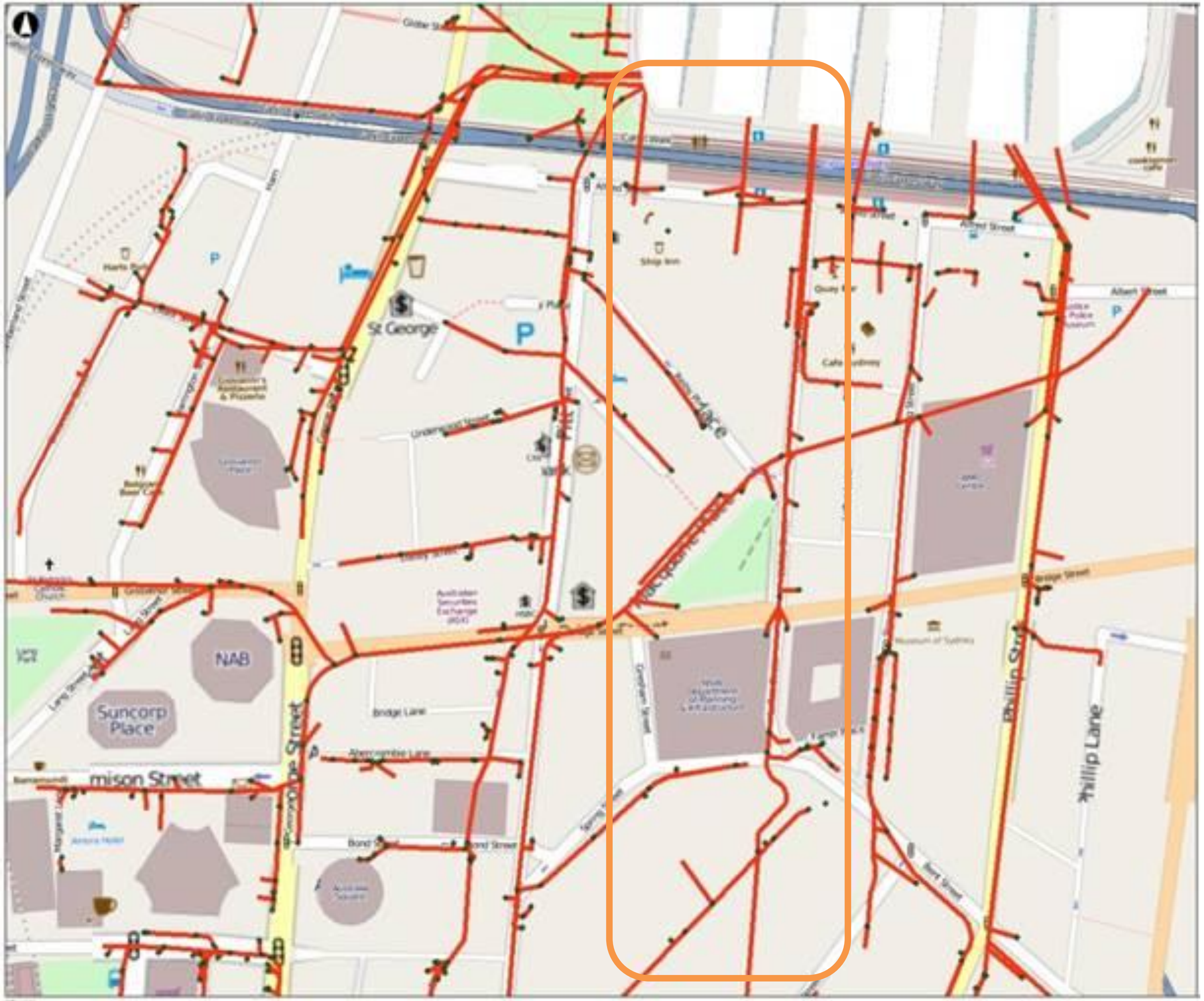


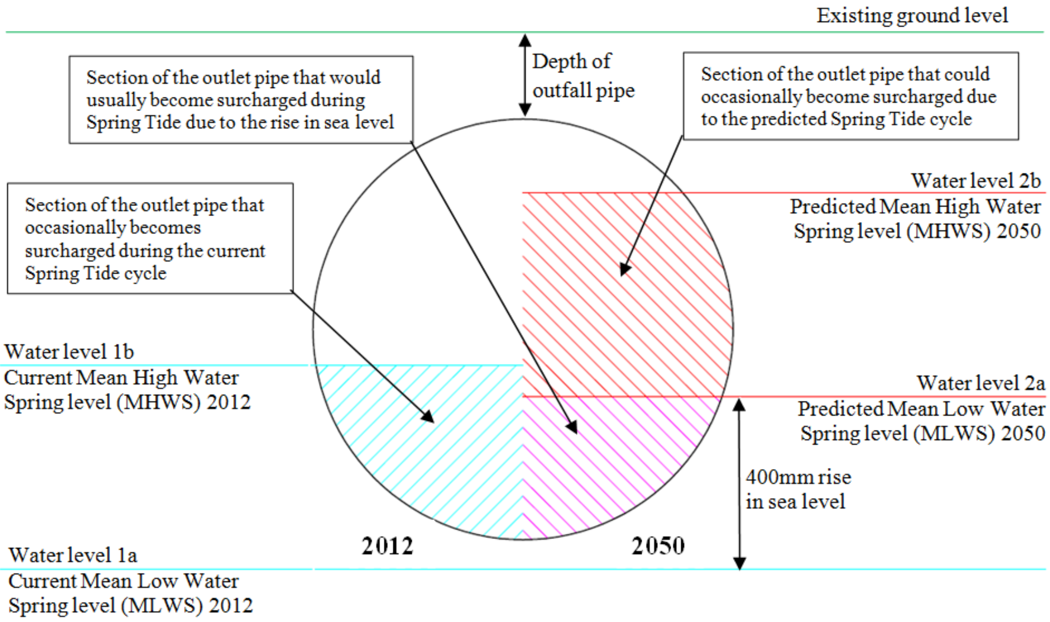
Figure 1 Stormwater drainage network in the vicinity of Tank Stream highlighted within the green boundary (Source: City of Sydney Council)

The NSW Climate Impact Profile, prepared by the Department of Environment, Climate Change and Water, 2010, states that a sea level rise of 400mm by 2050 and 900mm by 2100 is to be adopted as a planning guideline.

As the majority of Sydney's stormwater networks discharge directly into Sydney Harbour the increase in sea levels will increase the downstream (tailwater) level of the networks and will therefore influence the performance of the network. The figure below shows how a 400mm increase in sea level will change the tailwater level at an outlet. This increase in sea levels will increase the number of occasions where the outfall is submerged by a high tide level, a phenomenon which is known as tide locking

Figure 2 is a schematic diagram which illustrates how a stormwater pipe with a given invert level is increasingly submerged by corresponding tide levels.

The focus and scope of this case study was therefore to quantify the additional flooding caused by the increased tailwater in both 2 and 5 year ARI storm events.



Definitions – Spring Tide is the maximum level the tide reaches each month when the gravitational pull from the moon is at its greatest. This monthly maximum is measurable and is given a long term upper and lower average value for design purposes. These values are known as the Mean High Water Spring level (MHWS) and the Mean Low Water Spring level (MLWS).

Figure 2 An illustration of tide locking at an outfall due to sea level rise

2.2.1 Ownership of assets

With joint ownership by SWC and CoS, the interconnectivity issues relating to the CBD stormwater network are complex, especially in relation to investment and maintenance. SWC owns the majority of the trunk network with the remainder being owned by the CoS Council (as indicated in Figure 3). One particular challenge of this situation is that the CoS has control of the planning and development in the CBD, requiring a high level of collaboration to implement adaptation options.

This was a key consideration in the selection of the network during the Focus and Scope stage and the GIS plans were used to select the tank stream network which is jointly owned.

2.3 Risk Assessment

2.3.1 Existing assets and values

The CBD stormwater network is an underground pit and pipe network with very little open channel flow. An extract from the GIS database provided by CoS shows the different ownership of the assets. The blue lines in Figure 3 represent SWC assets and the green lines represent CoS assets.

The existing condition of the assets is documented in various formats, with incomplete information about the condition of the network. SWC has information about the old and sometimes heritage listed culvert structures, but this is not complete.

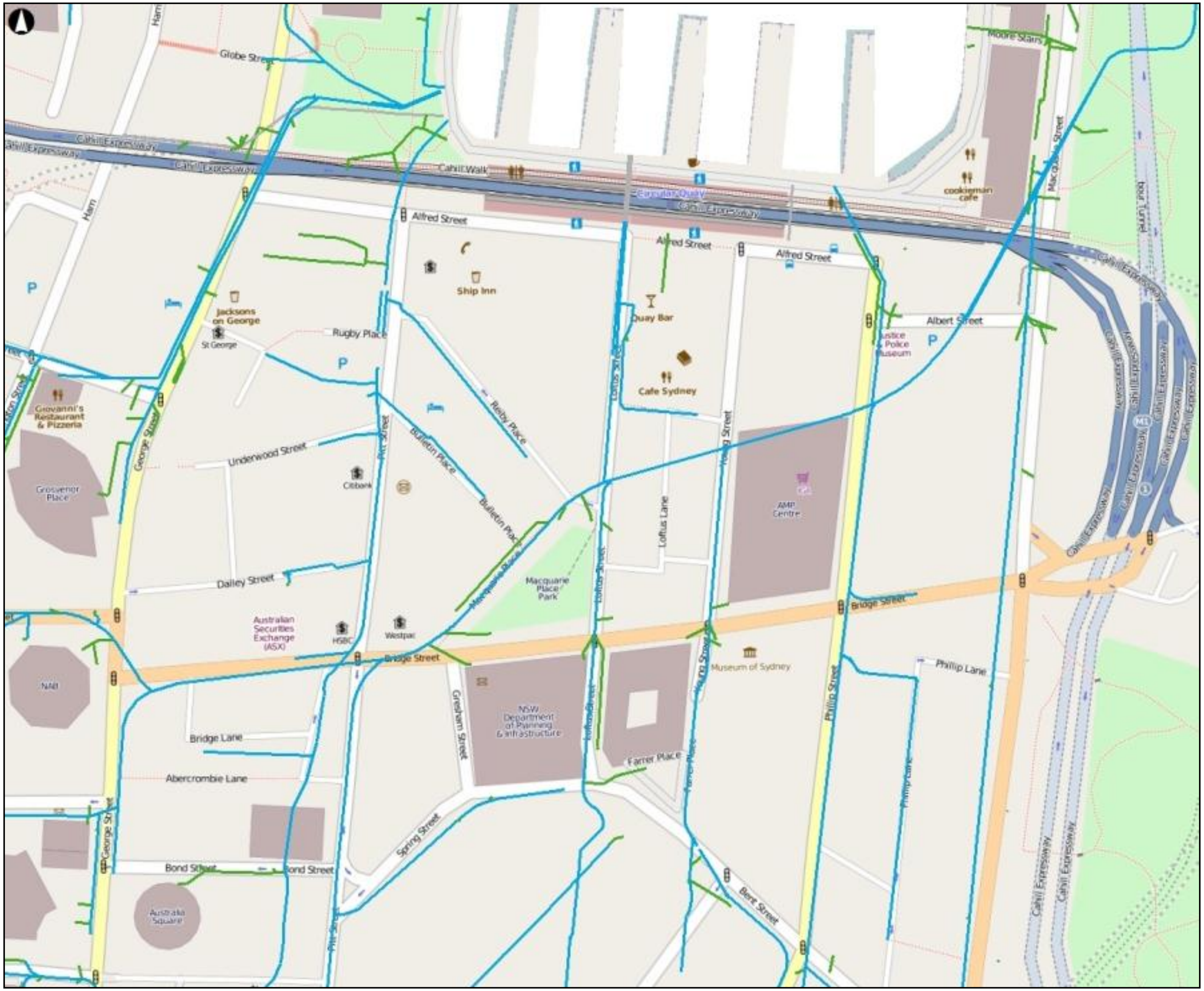


Figure 3 Ownership of the Tank Stream (and part of CBD) drainage network (Source: City of Sydney Council)

2.3.2 Attitudes to risk

CBD stakeholders comprise all residents and businesses and the daily commuting population of over 230,000. The attitudes to risk in this case study were assessed qualitatively.

Whilst it is acknowledged that the current CBD stormwater network does not meet the recommended guidance for minor storm capacity, there appears to be a high level of risk acceptance by most CBD stakeholders in relation to the underperforming drainage networks. This can be demonstrated by both the absence of historical complaints to CoS for flooding in the CBD and by the evidence from the recent rainfall on Thursday 8 March 2012 (see Figure 4 below).

Another qualitative assessment tool used was to review the CoS Council flooding incident reports from 1 January 2007 to present. For the purpose of this review, an incident was classed as an occasion "when the City was notified of where property damage occurred and the City's stormwater system was implicated in some way as being responsible for the damage"[1] (i.e. when drains were blocked or inadequate to cope with the volume of water or were non-existent, etc.). The results reported only 13 incidents for the whole of the CoS administrative area, of which only two or three could be deemed to be in the CBD area.

On the 8 March 2012, Sydney experienced 109.4mm of rain in less than 12 hours. Statistically this was estimated to be less than a 2 year ARI event. The most intense rainfall occurred between 8am and 10am as the majority of Sydney workers were commuting to work and significant disruption occurred as buses were diverted or delayed and train stations inundated. Figure 4 shows the inundation to roads in the CBD while Figure 5 shows flooding of a train station.

Figure 4 Flooding in Sydney streets on 8 March 2012 (Source: Sydney Morning Herald)

[1] City of Sydney Data Records

Figure 5 Flooding at Summer Hill train station on 8 March 2012 (Source: Sydney Morning Herald, 2012)

Interestingly, although the event was widely reported in the news, there was little follow up about the performance of the stormwater network and a seemingly general acceptance that a heavy rainfall event caused flooding. The large number of CBD commuters who regularly walk in thongs or bare foot during rainfall events is perhaps a light hearted indication of the present relaxed attitude to flooding risk.

The issue of risk appetite is important within the context of the risk assessment and this will need to be reviewed over time as the effects of climate change become noticeable. Building on the above, it would be interesting to understand where the threshold lies (e.g. would Sydney commuters be more likely to complain if flooding was occurring every two months rather than every two years?). The concept of flood risk appetite is discussed in Maddocks 2001, "Have we forgotten about flooding on the Georges River? The paper and another similar paper for the Nepean River question whether the lack of recent extreme flooding in Sydney has resulted in reduced community awareness of the potential for extreme flooding in the catchments.

2.3.2 Existing assets and values

The CBD stormwater network is an underground pit and pipe network with very little open channel flow. An extract from the GIS database provided by City of Sydney shows the different ownership of the assets. The blue lines represent Sydney Water assets and the green lines represent City of Sydney assets.

The existing condition of the assets is documented in various formats, with incomplete information about the condition of the network. Sydney Water has information about the old and sometimes heritage listed culvert structures, but this is not complete.

As previously mentioned the existing assets provide between a 2 and 5 year ARI capacity. The aim of this case study was not to improve this level of service but to look at the impact of climate change (in this case sea level rise) on the current level of service and to identify adaptation options to maintain the current level of service. The risk assessment process for this case study requires a flood model to review the impacts of sea level rise on existing stormwater drainage performance. A request was made to both Sydney Water and City of Sydney for existing flooding and drainage models. Although large amounts of asset data are available there is currently no network model in either 1 Dimensional or 2 Dimensional formats available to use.

2.3.3 Ownership and investment models

Funding for the upgrade and maintenance of the stormwater network is the responsibility of the City of Sydney or Sydney Water and is apportioned based on ownership. Funds are generated by Sydney Water through customer network charges and by the City of Sydney through council rates and charges. Developers within the CBD who are altering parts of the drainage network or modifying overland catchment flows are required to fund or contribute to the cost of the works. This is considered within the Development Application process which is managed by City of Sydney and of which Sydney Water is a stakeholder.

Capital intensive projects to be funded by Sydney Water will be subject to a business case and costs will be included as part of Sydney Water's regulatory submission to IPART. IPART ultimately has the responsibility to set the price for stormwater services based on their determination of the submission.

2.3.4 Assess existing risk

There is no recorded evidence of current tide locking of the CBD drainage network, although there is evidence in other locations in Sydney and across Australia where flooding has occurred due to high 'king' tides. The existing risk was therefore qualitatively assessed as low. This was quantified by the modelling of the Tank Stream drainage network in DRAINS which showed that the existing tidal levels included did not impact on the performance of the network.

2.3.5 Assess risk with climate change

As previously discussed the existing stormwater drainage assets in the CDB generally provide between a 2 and 5 year ARI capacity. The aim of this case study was not to improve this level of service but to look at the impact of climate change (in this case sea level rise) on the current level of service and to identify adaptation options to maintain the current level of service. The risk assessment process for this case study requires a flood model to review the impacts of sea level rise on existing stormwater drainage performance. A request was made to both SWC and CoS for existing flooding and drainage models. Although large amounts of asset data are available there is currently no network model in either 1 Dimensional (1D) or 2 Dimensional (2D) formats available to use.

In the absence of a relevant 2D model, the case study proceeded by developing a drainage model using DRAINS for a single network known as the Tank Stream. The trunk main was modelled excluding the smaller branches of the network with the upstream boundary of the model fixed at Bridge Street. This model was then used to estimate the increase in hydraulic grade line due to the increased tailwater level. An extract from the DRAINS model is shown in Figure 6.

It is noted that this method of analysis is overly simplified and the use of a 2D flood model to investigate the impact on flooding extents would be more accurate and informative. However, the simplified method adopted in this case study is an example of how in the absence of sufficient information, simple approximations can be adopted and used effectively.

In this case, the results of the DRAINS modelling show (as expected) that the existing pipe network has insufficient capacity to deal with high volume rainfall events leading to surcharging in two pits.

With a projected 400mm increase in sea level by 2050, there is an increase in the hydraulic grade line (which would increase the amount of water running overland), but no additional pits surcharged as a result. These preliminary results would therefore suggest that for this particular network, the effects of tide locking due to sea level rise would be minimal. A sensitivity analysis was subsequently carried out to extend the results to 2100 with an increase in sea level of 900mm. The results from this analysis showed that an additional pit further downstream of the original surcharging began to inundate the road. In this case the additional surcharge as a result of 2100 sea level rise could pose a greater flood risk and would need to be reviewed again as projections for sea level rise are updated.

2.3.5.1 Evaluation

In this particular case study the use of simplified model data suggests that the susceptibility of the stormwater networks to sea level rise is less than initially thought. This demonstrates the benefits of using the climate change adaptation framework to scope the problem and then assess the risk before developing adaptation options. For this case study and for the Tank Stream network investigated, the results of the risk assessment indicate that the implications of tidal locking on the network are limited and are not particularly sensitive to the climate change parameter of sea level rise.

Using the climate change adaptation framework the next exercise for this case study would be to investigate a second network to compare the results and see if they corroborate. Further investigation of other networks is also recommended as some have lower invert levels and hence may be more susceptible to tide locking.

This approach allows the asset owner to use minimal resources to assist in defining the extents of the risk to their assets. Following the risk assessment for sea level rise the climate change adaptation framework can be used to analyse another climate change parameter such as increased rainfall intensity.

For this case study this represented the point where the project team should return to the Focus and Scope stage in the framework to identify either another network to investigate or another climate change variable to consider. The simple risk assessment results of this case study showed how the initial climate change variable considered can be less of an impact than imagined and why using simple modelling techniques in the risk assessment stage to quantify impacts can be very efficient and assist in narrowing the focus and scope of the problem.

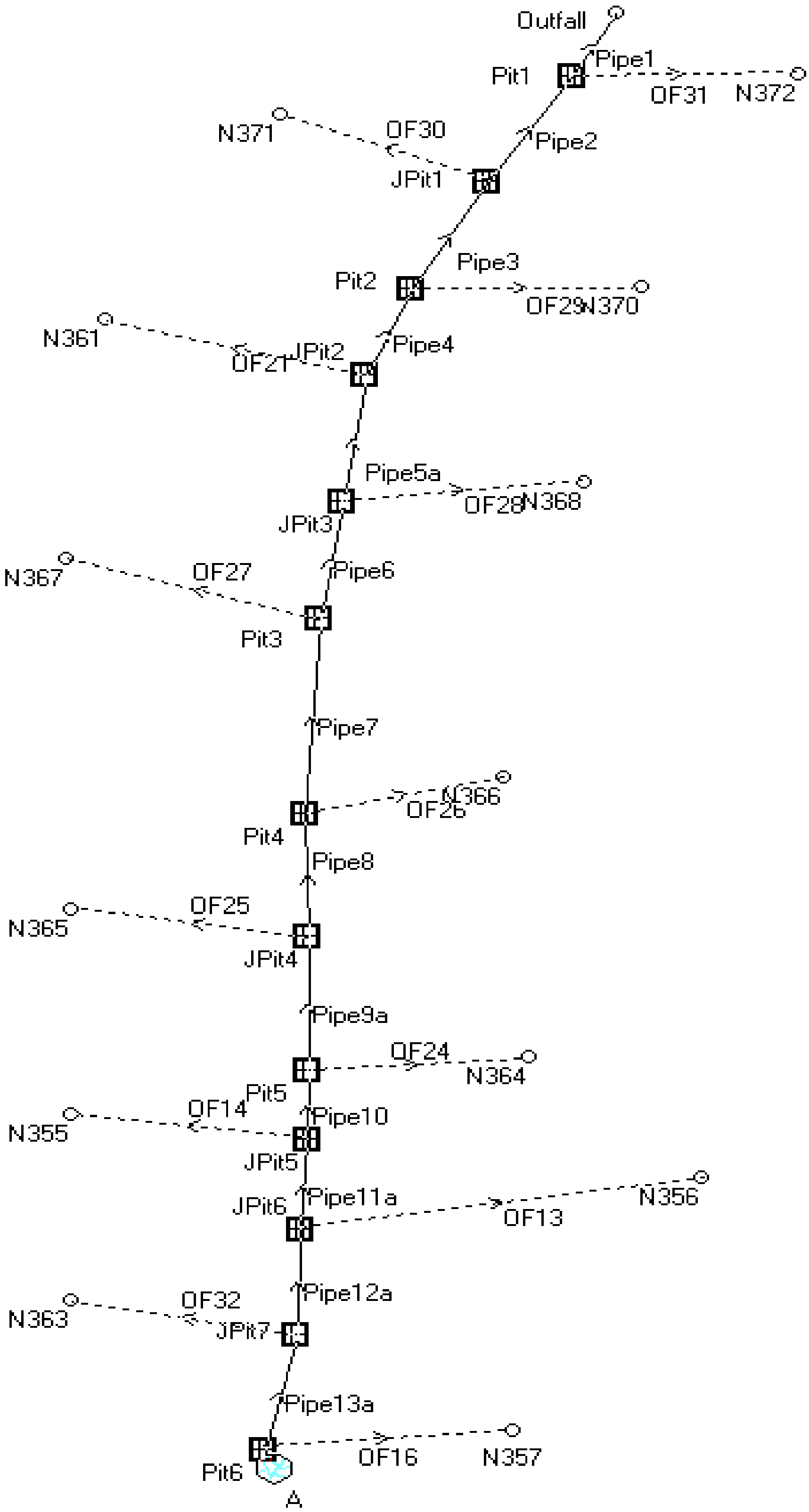


Figure 6 Schematic of the DRAINS Model for Tank Stream

2.4 Adaptation Options

During the two workshops associated with this case study a range of adaptation options were identified under three broad adaptation approaches. The adaptation options were identified as a result of a brainstorming process in the workshops and also expert judgement from those present. These are summarised in Table 3.

Table 3 Adaption options for sea level rise

Adaptation Approach	Adaptation Options	Selected Adaptation Option
Amplification	Overland flow path (increase and define) Raise stormwater outfalls to harbour Larger networks, over design Increasing channel depth (e.g. with walls) Review renewal policy	Larger networks, over design
Storage	Basement Open air Permeable surfaces Decentralised water/reuse/harvesting Aquifer recharge Underground tunnels	Basement storage
Protection	Pumping Raise levels Flood proofing Private flood defences Public flood defences Diversion to another catchment Managed retreat	Private flood defences

Many of these approaches, and their sub-options, may be considered complementary to each other. In fact no one approach is likely to be sufficient on its own and it may require a combination of approaches. It will be important to consider this, and also the timeframes for implementation, within the development of a Flexible Adaptation Pathway.

Of the options listed in Table 3, some options are more viable than others. The three options agreed on to take forward and explore as part of a Flexible Adaptation Pathway by the case study participants in Workshop 2 were:

- Increase capacity in network by augmenting pipe size.
- Provide flood storage capacity within CBD, which would likely involve allowing basement areas to flood to protect property.
- Provide individual flood barriers and defences to property and basements.

Working through the framework process, a decision on what adaptation options to implement is made by comparing the costs of the impact versus the costs of mitigation. Given that for this case study the results of the risk assessment stage, demonstrated that there are minimal impacts of tide locking of the Tank Stream drainage network due to sea level rise, adaptation was not required. The process for implementing the three identified adaption options relies on the need for a detailed flood study to estimate the volumes of additional stormwater which will need to be stored. A strategic plan for flood storage would then need to be developed to identify locations, along with significant stakeholder engagement, and it was envisaged that such a study and plan could take five years to develop.

Funding for the three options would depend on the scale of the adaptation option, with costs for city wide adaptations such as the increasing pipe capacity or directing water to the future Decentralised Water Masterplan being borne jointly by the asset owners. Costs for individual measures such as flood barriers would be borne by the property owners. There was a lot of debate by the case study team regarding the feasibility of convincing building owners of the benefits of allowing basements to flood, or of offering financial incentives for basement owners willing to work with council to provide wider flood storage. For example, a car parking space on a level which could flood would be worth less rental cost than one which was out of the flooding extents.

A key aspect within the discussions was the potential for a change in risk appetite of stakeholders. Currently stakeholders appear to manage with the level of overland stormwater in rainfall events and the risk assessment process undertaken as part of this case study suggests that for the Tank Stream, sea level rise is unlikely to make this significantly worse. It is difficult to imagine at present a scenario where building owners would volunteer to allow their basements to store stormwater rather than increasing overland flood levels.

2.4.1 Barriers and adaptive capacity building options

A key barrier to the adaption options identified for this case study was the different ownership of the CBD stormwater network. During Workshop 1 the case study participants worked through a number of additional barriers and identified opportunities to overcome these barriers, a summary of these key barrier 'themes' can be found in Table 4.

Table 4 Barriers and options to overcome them, from Workshop 1

Key Barriers	Options To Overcome Barriers
Fragmented ownership/ jurisdiction	Legal transfer of stormwater to single owner/manager Change legislation Attach funding base to adaptation solutions and transfer ownership Asset management to look to protection rather that current/historical Collaborative planning on upgrades and protection (SWC and CoS council)
Space constraints between existing use and new infrastructure	New development controls Strategic plan Community education On-site Stormwater Detention (OSD) and stormwater detention – incentives for business
Planning policy/lead time	Develop a vision – consider options Create a strategic plan based on good evidence Community engagement Collective stakeholder input

The discussion focussed on the following points:

- Overcoming barriers is an integral step in implementing the adaptation options. It will be important to consider these steps together.
- Securing buy-in from all stakeholders will be key to enabling effective adaptation. For example, augmenting the stormwater network may be constrained by other services, the owners of which do not have the same adaptation drivers.
- Issues of liability, in the event of no adaptation or maladaptation, are unclear. For example, levels of responsibility between local and state government.
- Uncertainty regarding the actual impact of the climate change event on the stormwater network in this area because of the absence of flood assessment information.

Comments/suggestions on taking these adaptation options and barriers and using them to develop an adaptation pathway included:

- Demonstration of any inter-relationship and/or how complementary options may work in tandem.
- Incorporation of barriers within the pathway.
- Inclusion of discounted/discarded options to demonstrate why they are not practical.

2.4.2 Economic appraisal

The Risk Assessment stage tentatively concluded that there was limited risk exposure to the CBD stormwater network from tidal locking. It was decided therefore that an economic appraisal at this stage in the case study was not appropriate. Instead it was recommended that the case study return the Focus and Scope stage to identify other assets or climate variables to consider.

Should the outcomes of the risk assessment have been different and the need for adaptation to mitigate the effects of climate change been identified, then a similar methodology to that adopted for Case Study 2: Green Square, would have been used. The Green Square case study adopted a quantitative approach to assess costs of not adapting versus the costs of adaptation.

A damages assessment was not completed for this case study as the results of the modelling suggest that the problem is not climate change driven but is more related to the existing capacity issues within the stormwater network.

For the CBD it would be important to consider the indirect costs associated with stormwater flooding. The direct costs would include damage to the stormwater infrastructure and flooding to property (commercial and residential). The cost to the asset owner to replace damaged stormwater or road infrastructure is likely to be significantly less than the flood damages incurred by other properties (commercial and residential) and infrastructure. During the discussion an example was given of possible flooding of Wynyard Station and the direct costs (e.g. infrastructure replacement) and indirect costs (e.g. potential disruption to the train network and restriction on train movements to North Sydney, with extent of consequences depending on the time and the worst case being at peak hour).

Economic data on this scale is difficult to estimate but one approach proposed during this case study was to look at the gross domestic product (GDP) for one day in Sydney and to factor a loss to this. The City of Sydney Local Government Area contributes almost 25% of gross state product or approximately $90 billion per year[2]. Flooding may potentially result in loss of access to the CBD or increased travel time and corresponding loss of productivity. For example, the rainfall event on the 8 March 2012 previously discussed, resulted in approximately 4 hours disruption and delay to perhaps 1% of commuters. Assuming there are approximately 265,000 employees within this area working for an average of 30 hours per week, this disruption could have resulted in a loss of $2.3 million.

The capital costs for adaption options would be dependent on the volumes of water required to be stored but are likely to be significant expenditures. As an example a mechanically operated flood gate measuring 10m by 0.8m would currently cost around $80,000 not including GST, to procure and install.

2.5 Flexible Adaptation Pathway

A key benefit of the process is that it allows the asset owner to break the 'messy' problem of climate change into smaller more manageable tasks and work with the information available to them to direct, often limited resources, at larger risks to their assets and organisation.

In this case study the agreed climate change parameter (sea level rise of 400mm by 2050) was found not to pose enough risk to the asset owner to need to implement the adaptation options identified. However, the sensitivity analysis to extend the results to a sea level rise of 900mm by 2100 revealed that greater flood risk could result. On this basis the analysis should be revisited if climate change projections for sea level rise are revised. Further to this, an investigation of the joint probability of tide locking and increased rainfall intensity should be completed before ruling out the current projections out completely. All of this information should be considered in the development of this Flexible Adaptation Pathway.

2.6 Ongoing Monitoring and Evaluation

Ongoing monitoring and evaluation is a critical aspect of the framework. In relation to this case study and the presented outcome that sea level rise is not a significant risk to the performance of the Tank Stream stormwater drainage network, the results of this study would need to be reviewed following changes to the projections used for sea level rise. This is important as increases to the projections may increase the impact of tide locking and result in unacceptable damages that mean adaptation could be required in the future.

[2] http://www.cityofsydney.nsw.gov.au/Council/Elections/Default.asp (accessed 24th September 2012)

What to monitor?

The results of this case study are based on a very simplistic 1D drainage model built as part of the Risk Assessment stage. Monitoring and evaluation of this case study should include a review of the results once more flood information including more detailed 2D modelling of the Tank Stream catchment is available. This should include running the completed 2D model with an additional 400mm tailwater level and comparing the flooding extents to estimate the additional impacts of sea level rise.

How often?

For this case study monitoring of the results would be required following any changes to the predictions for Sea Level Rise.

Who?

As the Sydney CBD stormwater infrastructure is jointly owned by SWC and CoS, it is suggested that both stakeholders are involved in the monitoring and evaluation.

What to do with monitoring information?

Prior to developing adaptation options, this information should be used to determine if the revised climate change projections warrant the development of a Flexible Adaptation Pathway, or if other assets or climate variables need to be considered.

Green Square: New development accommodating the impact of sea level rise on the drainage network

3.1 Overview

The City of Sydney Council is the driving force behind the transformation of the Green Square area into a new retail, residential and employment hub. The $8 billion project will deliver:

- 22,000 jobs.
- 20,000 new homes.
- 40,000 new residents.

The 292 hectare renewal area takes in the suburbs of Alexandria, Beaconsfield, Rosebery and Zetland. Current re-development plans have zoned the south-western portion of the overall area, in the vicinity of the Alexandra Canal, for use as a Business Park and for light industrial uses (see 'Employment Lands Study 2011', City of Sydney Council). This area is shown in Figure 7.

A key consideration of this re-development is adapting to the impacts of climate change by managing excess stormwater flows from intense storms within an urban area that is already prone to flooding. This presents opportunities to incorporate new infrastructure which can readily adapt to the impacts of climate change.

However, such opportunities need to be carefully managed to ensure that all parties have an input to the assessment process. This is particularly the case with respect to water infrastructure as City of Sydney Council owns the existing, and any proposed, drainage network but SWC owns the Alexandra Canal, into which this drainage is likely to flow. It will therefore be important to fully understand and manage the upstream and downstream impacts along this interconnected water network.

Key lessons learned from the Green Square Case Study

The Green Square case study serves as a useful example to demonstrate two key components of the adaptation framework. Firstly, it highlights the importance of the Focus and Scope stage. In particular, identifying and engaging with all the relevant stakeholders and then forming a project team to set clear objectives. This enables a clear methodology to be prepared to move the project through the stages of achieving these objectives.

However, the case study also provides an example of how a project can be progressed through the adaptation framework by maximising use of only readily-available data and resources. In turn, this facilitates future objectives setting by narrowing-down on the range of measures to be addressed and uncertainties.

Further improvements to the example economic appraisal have been identified but this should be undertaken in tandem with an exercise to better define the project objectives. This will avoid any maladaptation associated with pursuing the development of inappropriate options.

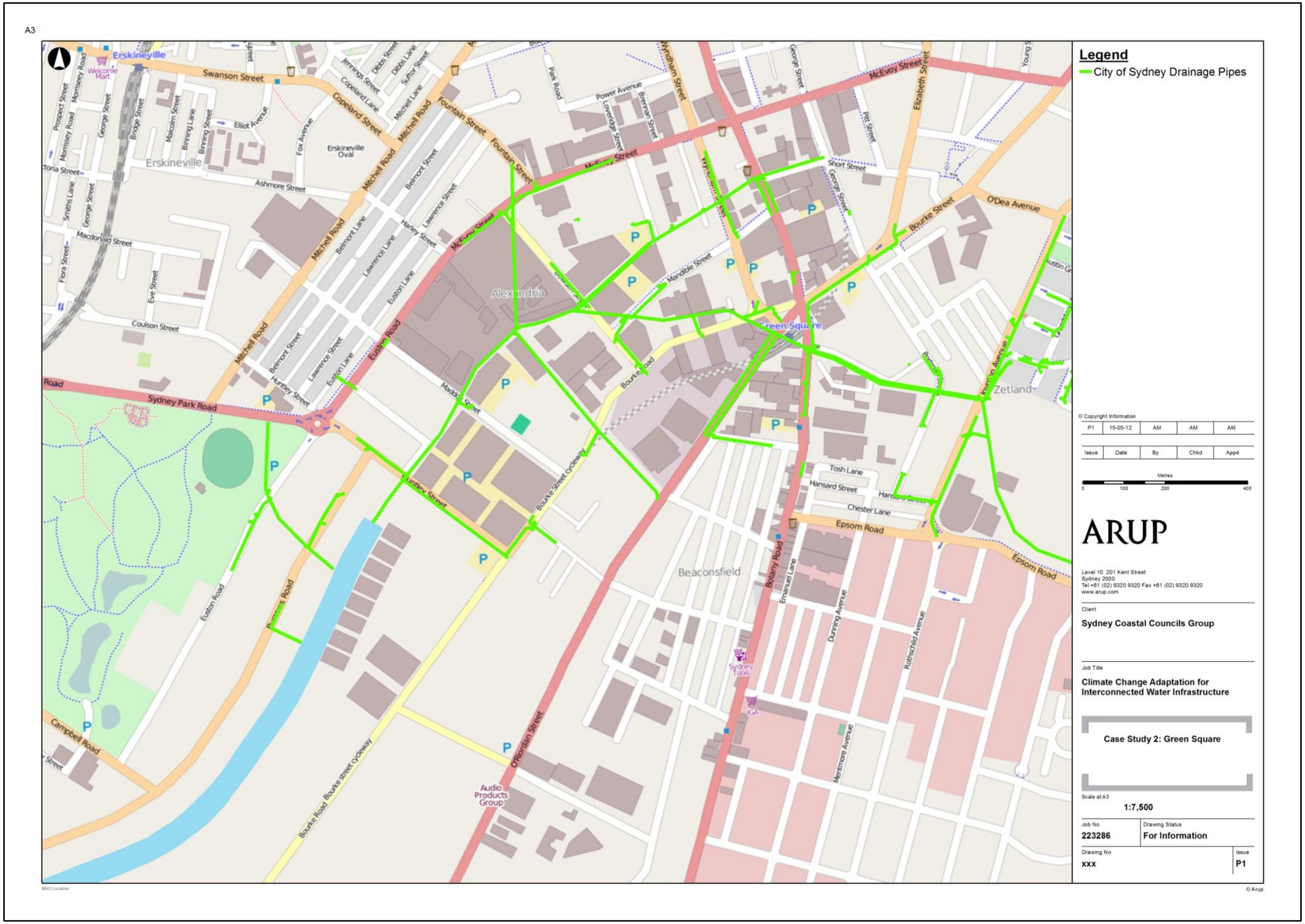


Figure 7 Green Square case study area (Source: Arup, City of Sydney)

3.2 Focus and Scope

3.2.1 Impact screening

During the stakeholder workshops it was acknowledged that various climate change parameters would potentially have an impact upon the Green Square area. An initial screening matrix (see Table 5) was used to identify those climate variables considered most significant for this case study.

Table 5 Green Square: impact screening matrix

Climate Variable	Projection (2050)	Stormwater Network
Average annual rainfall (%)	-20% to +50%	M
Rainfall intensity (%)	+15%	H
Sea level rise (m)	+0.40 m	H
Annual Average temperature (°C)	+1.5°C to +3.0°C	L
Evaporation (%)	+10% to +20%	L
Bushfires (%)	+10% to +50%	L

Legend:

H – High likelihood of this type of asset being impacted

M – Medium likelihood of this type of asset being impacted

L – Low likelihood of this type of asset being impacted

The events resulting from these climate change parameters were considered to be:

- Increased surcharging of the stormwater network.
- Increased groundwater levels as a result of sea level rise.
- Tide locking of the stormwater network.

Further discussion identified a number of direct and indirect consequences arising from the climate change events discussed above. However, it was agreed that the climate event to be considered further with regard to its impact on the Green Square area is tide locking of the stormwater network due to sea level rise.

This would allow the exploration of this particular event and to better understand it's consequences, information on which was currently considered to be lacking, as well as enabling a useful comparison of the same event between existing developments (Case Study 1: Sydney CBD) and a new planned development (Case Study 2: Green Square). The consequences initially identified in relation to this event are summarised in Table 6.

Table 6 Green Square: Climate event consequences

Consequences	
Direct	Indirect
Increased flooding of streets Damage to property and infrastructure Corrosion/reduced life of assets Cost of building adaptation measures (e.g. basement water-proofing, flood resilience) Water-logged parks (inadvertent and/or by design – stormwater detention) Surcharge into sewers Transport issues (e.g. cross city access, airport access)	Liability due to flooding Reputational loss Increased insurance premiums Knock-on costs to business Reduced amenity (loss of public space) Impact on public health Decreased land value Social impacts

3.2.2 Attitudes to risk

3.2.2.1 City of Sydney Council

City of Sydney Council ultimately seeks to deliver a modern and efficient new development which will attract new businesses and residents to a currently run-down area of Sydney. They will aim to provide this re-development within a reasonable budget whilst still ensuring the safety of future occupants and adhering to the principles of the NSW Flood Prone Land Policy.

The primary objective of the NSW Flood Prone Land Policy is "to reduce the impact of flooding and flood liability on individual owners and occupiers of flood prone property, and to reduce private and public losses resulting from floods, utilising ecologically positive methods wherever possible". The management of this flood prone land is, primarily, the responsibility of councils. In addition to requirements under this policy, councils have a duty of care to ensure the safety of their constituents, including during times of flood.

The Policy does not stipulate or define a standard of protection which should be afforded by a particular flood management option. Rather, the focus is on providing the most cost-beneficial option which takes into account technical, environmental and social aspects. The City of Sydney 'Draft Stormwater Drainage Design Code' and the 'Draft Flood Planning Level Requirements' should be adhered to with regard to new development.

3.2.2.2 Sydney Water

SWC is not actively involved in the proposed re-development. Rather, they are a key stakeholder in the process as they are responsible for the management and maintenance of the Alexandra Canal which is one of the watercourses receiving drainage. As such, their primary driver/concern will be to ensure that any amendments to the contributing drainage network do not adversely impact upon the canal, both now and in the future.

3.2.2.3 Existing assets and values

This case study explores adaptation in the context of a new development. Therefore much of the existing asset base, namely commercial warehouses and light industry, will be replaced. The area is to be re-developed as a Business Park and so the proposed property types will predominantly be offices and small-scale industry. City of Sydney Council, in conjunction with the respective developers, will be responsible for the appropriate design of the replacement assets.

One existing asset which will remain in place is the Alexandra Canal, which is likely to receive much of the drainage runoff from the re-development, as per the existing case. This asset is owned by SWC and currently provides a <5 year ARI standard of protection to neighbouring properties (i.e. flood events in excess of this magnitude will overtop the banks of the watercourse).

Current climate change projections will reduce the standard of protection even further. It is important therefore that any upstream developments are appropriately designed to ensure that this standard of protection is not further reduced.

3.2.3 Ownership and investment model

Green Square is a high priority area for the CoS in terms of regeneration strategy. Re-development of the area is a key component of that strategy to help stimulate and drive the regeneration process.

The SWC funding for maintenance or renewal works on the Alexandra Canal is derived from their rates and therefore the proportion allocated to these works is subject to scrutiny by IPART. It is likely to be necessary to demonstrate that any future expenditure on the canal is to adapt to the direct impacts of climate change rather than in response to the consequences of upstream re-development. Even so, the knowledge, or perception, of the value function of these assets by the rates payers will influence the amount of funding that IPART will deem reasonable.

3.3 Risk Assessment

3.3.1 Climate change events

Quantitative information showing the impact of existing and increased (due to climate change) tidal levels on the lower Green Square stormwater network has been provided by Cardno (taken from the Alexandra Canal Catchment Flood Study, 2010). This data (see Figure 8 and Figure 9) shows the existing case 100 year ARI event flood extent and the predicted increase in flood levels, during this same recurrence interval event, with a 20% (500 mm) rise in the level of the lower Alexandra Canal (which broadly corresponds to the 400 mm predicted sea level rise by 2050). The impact is significant in the areas adjacent to the canal but is not predicted to cause additional issues further up the stormwater network.

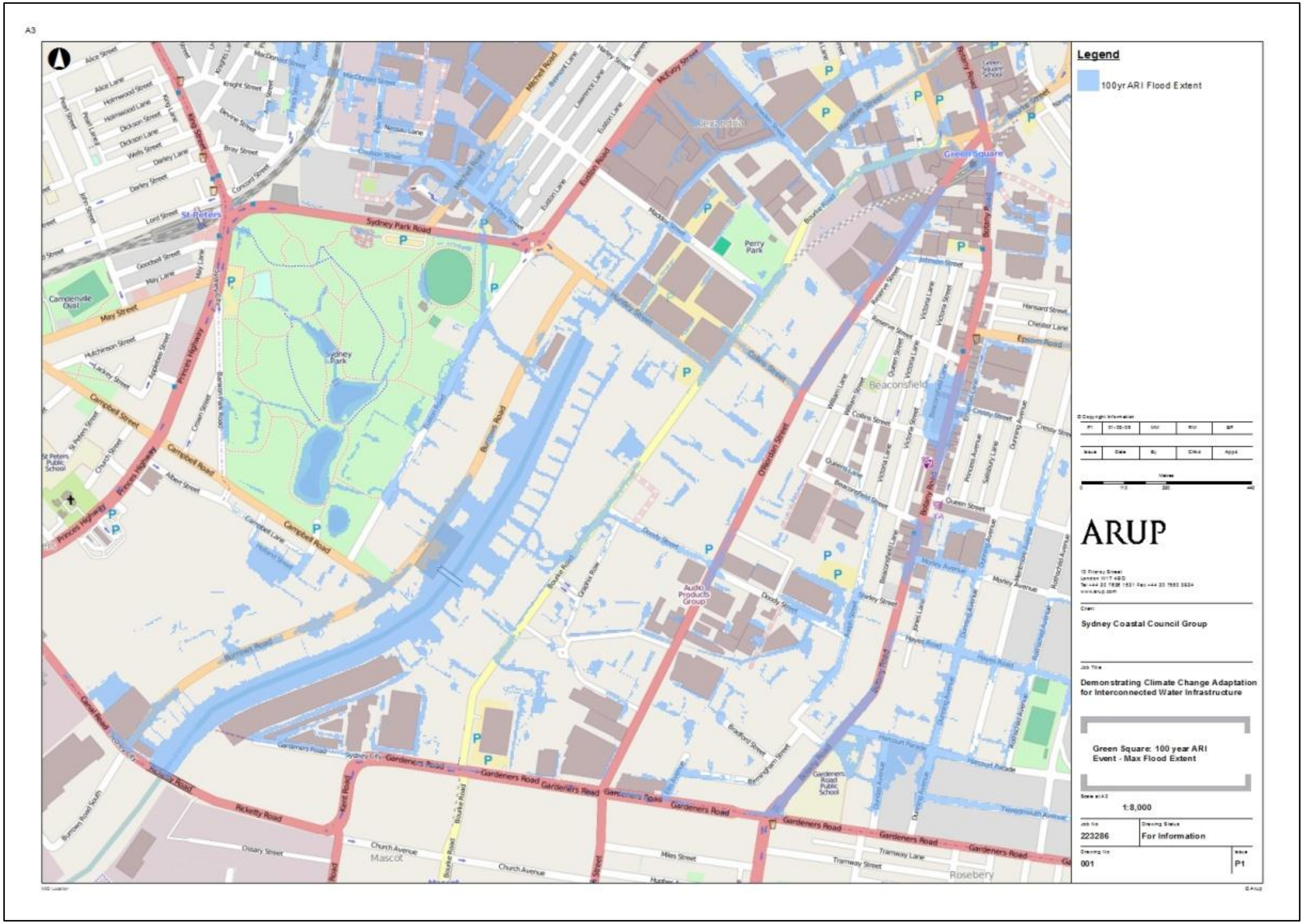


Figure 8 Predicted 100 year ARI flood extent (input data taken from ‘Alexandra Canal Catchment Flood Study’, Cardno, 2010)

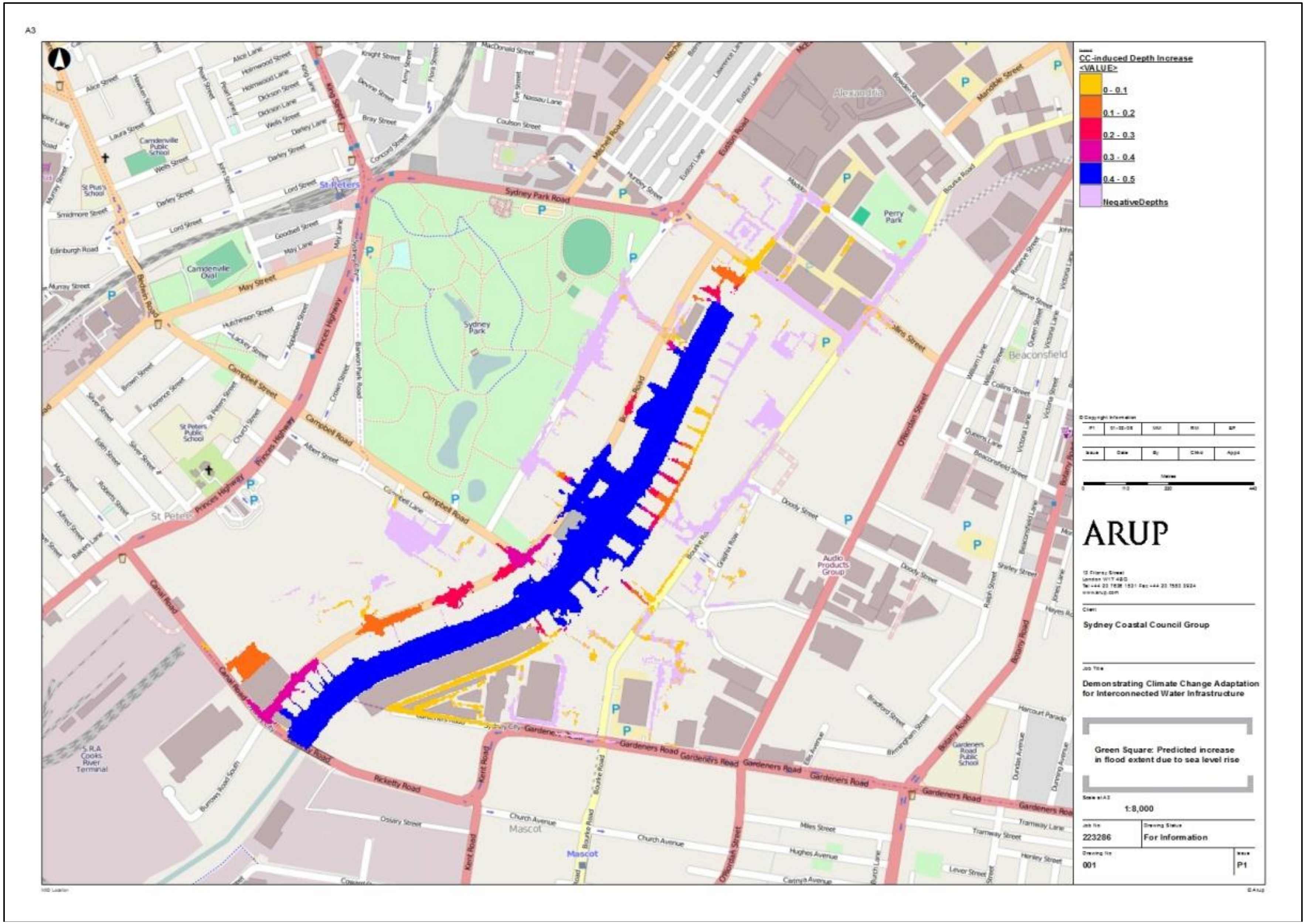


Figure 9 Predicted increase in flood extents due to increased sea level rise (input data taken from ‘Alexandra Canal Catchment Flood Study’, Cardno, 2010)

3.3.3 Flood damages

Initial estimates of the damages which may arise from a range of magnitude flood events in the Green Square area are provided in Table 7. These damages have been estimated for 'with re-development' properties only. The area is to be re-developed as a Business Park and so the property types assessed are an 'Office' and a 'Workshop'.

Currently, there is no suitable Australian-based methodology for the estimation of flood damages to commercial property. To provide an initial indication of the potential quantum of climate change-induced flood damages a methodology from the UK has been adopted. These estimates have therefore been prepared using the 'Multi-Coloured Manual (MCM)'[3]. This method applies observed depth-damage data from relevant property types and assigns a damage value based on the predicted depth of flooding. The results have been converted from Pounds Sterling to Australian Dollars using a currency conversion, but no adjustment has been made for differences in construction techniques or building costs.

It should be highlighted that these values are considered initial estimates only and have been prepared to provide an indication of the order of magnitude of the problem. They are based on a range of calculation data, techniques and assumptions (see Table 8) and should not be used for detailed business case preparation purposes. They are considered relatively conservative estimates as, due to their method of derivation, they may not fully capture the full cost of construction/repair within the central Sydney area.

In summary, the damages use predicted flood depths for differing return periods to produce a probability-weighted annual average damage (AAD) value for a single property (see Figure 10). This AAD is then discounted to produce a Present Value of the damages, and scaled to apply to an assumed 40 properties. The only difference between the 'Present Day' and 'Future Scenario' is the predicted flood depths which are higher in the future. This therefore provides an indication of the estimated increase in flood damages which may arise from climate change.

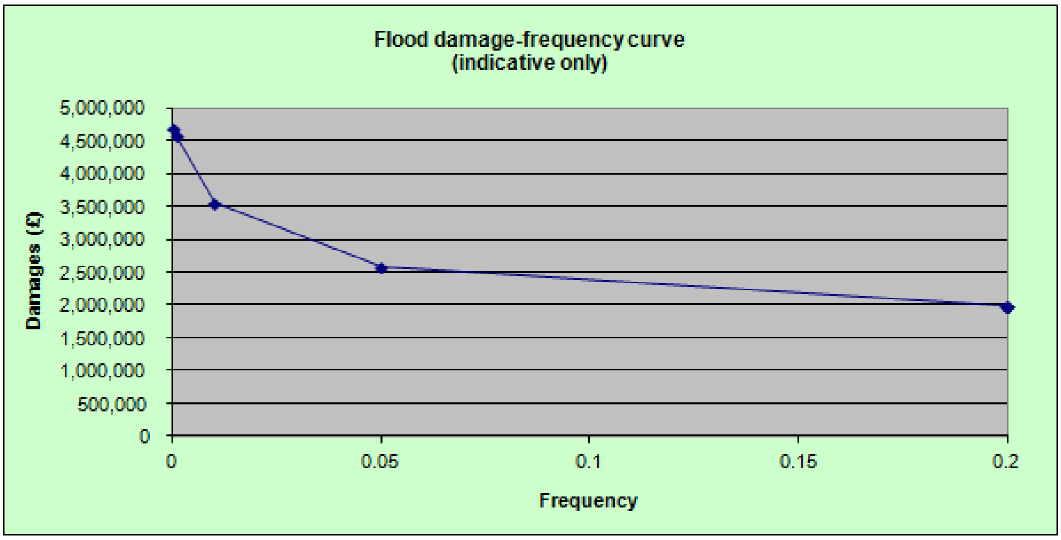


Figure 10 Example flood damage frequency curve for Green Square

[3] 'The Benefits of Flood and Coastal Risk Management: A Handbook of Assessment Techniques', Middlesex University, 2010.

Table 7 Green Square flood damages estimates

Business Park Development Type	**Uncapped Present Value Damages (per property) [AAD] ($ million)**		**Uncapped Present Value Damages (Assume 40 properties) [AAD] ($ million)**		
	2012	2050	2012	2050	Increase
Office	9.1 [0.37]	13.3 [0.54]	364 [14.8]	532 [21.6]	168 [6.8]
Workshop	2.7 [0.11]	4.3 [0.17]	108 [4.4]	172 [6.8]	64 [2.4]

Table 8 Green Square flood damage estimation assumptions

Parameter	**Method**	**Assumptions**
Commercial & Industrial property damages	UK Multi-Coloured Manual with currency conversion to convert to $AUD. Applies a depth-damage value to each m^2 of commercial and industrial property	Uses 'typical' flood depths from Alexandra Canal Catchment Flood Study for: 5, 20, and 100 year ARI events, and 100 year ARI plus climate change allowance event, for a single property Applies a percentage increase to 5 and 20 year ARI event depths, based on ratio of 100 year ARI to 100 year ARI plus climate change Depths estimated for 1000 year ARI events based on depths for lower magnitude events Damages are Present Value 7% discount factor 50 year appraisal period Assumes no capping of damages Assumes each office is $500m^2$, and each workshop is $1000m^2$

3.4 Adaptation Options

3.4.1 Options identified

Discussions during the stakeholder workshops identified a large range of adaptation options which could be applied to the climate change event. Following further discussion, a particular option was then identified within each approach to take evaluate and potentially explore as part of a Flexible Adaptation Pathway. This option selection is summarised in Table 9.

It was agreed that each of these options should be the same as those identified in Case Study 1, where possible and relevant, so that a comparison can be made between 'retro-fit' and 'new development' scenarios. It was also acknowledged that a number of these options are currently being considered/implemented as part of the re-development of the Green Square area, but the key issue is whether potential climate change impacts are being factored into the designs.

Table 9 Adaptation options for Green Square

Adaptation Approach	Adaptation Options	Selected Adaptation Option
Amplification	Overland flow path (Increase and define) Raise outfalls Larger networks, over design Open channels with wall height extended	Larger networks, over design
Storage	Basement Open air Permeable surfaces Decentralised water/reuse/harvesting Aquifer recharge	Basement storage
Protect	Pumping Raise levels Flood proofing Private flood defences Public flood defences	Private flood defences

It was originally envisaged that increased tidal levels in the Alexandra Canal would lead to capacity and surcharge issues further up the piped Green Square stormwater network. The adaptation approaches in Table 9 address this issue.

However, the data obtained from the Draft Alexandra Canal Catchment Flood Study Report has shown this not to be the case, with climate change-related impacts being confined to the area surrounding the Alexandra Canal. Rather than re-visit the adaptation approaches, as these may not specifically address the issue in question, it was decided to incorporate further options, within the overall approach, which would address the increased tidal issue. Therefore, the options which have been subjected to further appraisal are:

- Amplification: increase the conveyance and storage capacity of the Alexandra Canal (i.e. larger open channel network).

- Storage: incorporate storage on the floodplain, through the use of ground floor car-parking and open space areas (basement storage will not provide an effective storage option).
- Protect: provide protection to the source of the increased risk, i.e. increased levels in the Alexandra Canal.

Current flood risk management guidelines do not stipulate or define a standard of protection which should be afforded by an intervention option. Rather, the focus is on providing the most cost-beneficial option which takes into account technical, environmental and social aspects.

Each of the adaptation approaches above offers the flexibility to provide differing standards of protection in response to economic constraints, but also in response to differing social and political aspirations. Therefore, they have been identified and selected on the basis of their flexibility to differing drivers rather than their ability to provide a definitive standard of protection.

3.4.2 Barriers and adaptive capacity building options

The stakeholder workshops also discussed and identified the key barriers to the adaptation options, as well as suggesting options to overcome these barriers (see Table 10).

Table 10 Barriers and opportunities

Key Barriers	Options to Overcome Barriers
Fragmented ownership/jurisdiction	Legal transfer of stormwater assets – owned/managed by a single body Change legislation Attach funding base to adaptation solutions & transfer ownership Asset management to look at protection rather than current/historical approach Collaborative planning on new-builds, upgrades and protection (SWC and CoS Council)
Funding	New development controls Strategic plan Community education On-site Stormwater Detention (OSD) and stormwater detention – incentives for business
Planning policy/lead time	Develop a vision – consider options Create a strategic plan based on good evidence Community engagement Collective stakeholder input

Overall, the key barrier theme for the stakeholders is risk. The assessment, allocation, ownership of, and appetite for, risk is a major barrier. There is nervousness around unknown risk and differing approaches to risk management across stakeholder organisations. A suggestion during the workshops to overcome this barrier was to clarify an approach of 'shared risk and shared reward' from the project outset.

Further consideration has subsequently been given to developing additional guidance to assist in overcoming some of these barriers:

Risk ownership and management

Many adaptation solutions will require additional capital expenditure over and above business as usual and this presents challenges for funding. This challenge can in part be overcome by collaborating on adaptation implementation through effective governance structures. This coordinated approach allows infrastructure providers to share costs and reduce costs through more efficient implementation. Such a collaboration arrangement is likely to raise interesting questions with regard to the apportionment of funding between parties. One possible model is to proportionately allocate responsibility based on quantified benefits each party is deemed to receive as a result of implementing the adaptation option.

Community Engagement

Holding community education sessions on climate change is one option to overcoming this barrier and this is considered to be a no regrets option that helps to build adaptive capacity. The Productivity Commission's Draft Report into the "Barriers to Effective Climate Change Adaptation" supports this, advocating actions which help the community deal with the current climate but which would also enhance the adaptive capacity of the economy, and enable the community to more effectively respond to future climate change.

Investment/funding availability

The impact of climate change of any new development should be accommodated for in the design and funding proposals of the developer. In the case of Green Square this includes the CoS Council although the precise funding arrangements are not known. Further assessment should be undertaken to explore how climate change adaptation, or indeed maladaptation, may impact upon land or property values in the Green Square area.

3.4.3 Economic appraisal

3.4.3.1 Adaptation scenario

An outline economic appraisal has been prepared with the aim of determining the business case behind incorporating climate change adaptation measures now (i.e. in conjunction with overall re-development of the area) or as retro-fit items at a point in the future[4]. This compares the damage estimates in Section 3.3.3 with the cost estimates summarised below.

For each approach two adaptation scenarios have been assessed:

1) Construction and incorporation of adaptation measures in 2012, during development works for overall site re-development.

2) Construction of works to address existing case problem in 2012, followed by further adaptation works to address climate change event at currently undefined point in the future.

[4] The appraisal does not therefore attempt to assess flood damages for the existing (i.e. pre-developed) case.

3.4.3.2 Model and results

Initial cost estimates have been prepared, where possible, for the adaptation approaches identified in Section 3.4.1. Data sources used to prepare the cost estimates included:

- Rawlinsons Manual [Rawlinsons, 2012, Australian construction handbook 2012, 30th Edn, Rawlinsons Publishing Pty. Ltd., Perth].
- Engineering judgement.

A. Adaptation Approach: Protection of receptors:

- Concrete masonry block wall at edge of Alexandra Canal to protect against high canal levels.
- Wall length of 3400m (to run on both sides of Canal from Ricketty Street up to Huntley Street).
- 1.0m high wall required to address current flood levels.
- 1.5m high wall required to address future flood levels.
- 1.0m high wall will be removed to enable construction of higher wall.

B. Adaptation Approach: Network amplification:

- Double width of Alexandra Canal with concrete lining of excavated channel.
- Soft rock excavation for length of 1600m.
- Two-stage adaptation involves widening channel by half of total width in 2012, with remainder of widening in future.
- Direct land acquisition costs have not been included. It is envisaged that adequate space for this adaptation approach could be incorporated at masterplanning stage negating the need for direct purchase of individual blocks.
- Mobilisation costs are included in wider re-development construction activities for 2012. Twenty percent extra mobilisation fees for standalone works in the future.

C. Adaptation Approach: Storage within catchment:

- Forty building units with floor plan of 1000m^2.
- The business case for the re-development requires each office block to have a minimum of four useable floors of office space.
- It is therefore assumed that a four storey office in 2012 will, in the future, require the ground floor to be converted to parking (doubling-up as flood storage) and a further storey added above to retain the minimum of four floors of office space.

Table 11 Adaptation approach (A) : Protection of receptors – cost estimates

	Scenario 1: Adaptation in 2012	**Scenario 2: Adaptation in future**		
Wall Height	Capital costs (2012$ million)	Capital costs (2012$ million)		
		Year: 2012	later#	
1.0m		3.0		
1.5m	3.9		3.9	
Optimism Bias (60%)	2.3	1.8	2.3	
Total:	6.2	4.8	6.2	11.0
Difference:		$4.8 million		

Table 12 Adaptation approach (B): Network amplification – cost estimates

	Scenario 1: Adaptation in 2012	**Scenario 2: Adaptation in future**		
Excavation	Capital costs (2012$ million)	Capital costs (2012$ million)		
		Year: 2012	later#	
Soft Rock	20.0	10.0	12.0	
Optimism Bias (60%)	12.0	6.0	7.2	
Total:	32.0	16.0	19.2	35.2
Difference:		$3.2 million		

Table 13 Adaptation approach (C): Storage within catchment – cost estimates

	Scenario 1: Adaptation in 2012	**Scenario 2: Adaptation in future**		
Building Type	Capital Costs (2012$ million)	Capital Costs (2012$ million)		
		Year: 2012	later#	
5 Storey Office	433			
4 Storey Office		346		
Single Storey Office			59	
Parking (partially underground)			48	
Optimism Bias (60%)	260	208	64	
Total:	693	554	171	725
Difference:		$32 million		

**=** No trigger date has yet been identified for Green Square and therefore it is not possible at this stage to assign a timeframe to any future capital works.

3.4.3.3 Appraisal discussion

Rather than compare flood damages against the current land usage of the lower Green Square area, the appraisal undertaken above highlights that the financial implications of climate change on a **re-developed** Business Park could be significant, with damages of up to **$168 million**.

The costs of adaptation approaches (A) and (B) demonstrate that these measures are strongly cost-beneficial, and there is added economic efficiency in incorporating adaptation now rather than deferring to a point in the future.

Adaptation approach (C) is more intertwined in the overall re-development of the area. Constructing a five storey office in 2012 is $87 to $139 million more expensive (depending on application of optimism bias or not) than a four storey office, but this is still justified when compared to the flood damages of $168 million. Again, there is economic advantage in incorporating adaptation now rather than deferring to a point in the future.

3.4.3.4 Assumptions and limitations

For the purposes of this case study, and in the absence of explicitly modelled/engineered information, it is assumed that each of the adaptation scenarios will provide a 1 in 100 year ARI standard of service. Therefore no flood damages would be incurred up to and including that magnitude flood event. The results of this appraisal highlight that both these scenarios are cost-beneficial and it would therefore be justifiable in pursuing this adaptation further. This would entail more detailed and explicit analysis which may identify that alternative standards of service for each scenario may be the most cost-beneficial.

It should be highlighted that the costs derived are considered initial estimates only and have been prepared to provide an approximate indication of the costing. Therefore, in order that costs are not significantly underestimated, an 'optimism bias' of 60% has been applied to each adaptation approach. This is a common technique to offset somewhat the tendency to produce optimistic cost estimates at the early stages of problem appraisal.

Adaptation scenario (2) clearly involves additional design and the re-mobilisation of contractors in the future whereas Scenario (1) reflects an added efficiency of incorporating a degree of future-proofing in conjunction with the main works. The costs to be incurred in the future have not been discounted, as it is not known at this stage when the expenditure would occur, and are therefore expressed in 2012 terms. The total cost of options which involve future capital expenditure would therefore be lower (due to the discounting) than shown in Table 11 to Table 13 above.

This appraisal does not fully explore the optimum timing of incorporating adaptation. Capital expenditure in the future will be cheaper due to discounting but flood damages will continue to accrue until the adaptation is implemented. The optimal timeframe for future expenditure has not been identified.

Also, there will be other approaches or variations of these approaches which have not been explored as part of this assessment. An example can be applied to approach (A) where a further option would be to construct a 1m high wall in the present day but construct it in such a way that its height can relatively easily be increased at a point in the future.

3.4.3.5 Suggested improvements

Hydraulic modelling of differing adaptation scenarios, and for differing ARI events, would provide qualitative information on the standard of service which could be provided. This could then be factored into the economic appraisal to develop a more detailed assessment, including cost-benefit ratios, identification of any potential trigger points within the flood profile and an optimised timeline of intervention.

Similarly, more detailed cost estimates could be developed which take into account local constraints (e.g. ground conditions, contamination, environmental factors), as well as more accurate quantities of construction materials.

3.5 Flexible Adaptation Pathway

3.5.1 General

Given the high-level nature of the re-development proposals for this particular area of Green Square, including uncertainty over development timescales, it is suggested within this assessment that the case study is still within the Focus and Scope stage, where the nature of the problem to be addressed requires fuller definition.

With this in mind, the economic appraisal above should only be considered an example of a high-level appraisal which could be carried out to assist in the identification of the most appropriate adaptation response. The information and appraisal has been presented above with the aim of progressing this case study through an example Flexible Adaptation Pathway. It has presented both the results of an initial 'risk assessment' and also summarised the identification and assessment of adaptation options. This information should provide the confidence and the framework with which to further advance the assessment of adaptation options.

A key component of the Flexible Adaptation Pathway approach is the incorporation of flexibility to respond to changing drivers and climate projections. However, this economic appraisal also highlights the benefits of effectively 'seizing the opportunity', namely the significantly increased economic efficiency of implementing the adaptation measures at the same time as the re-development of the entire site is taking place. The danger of such an approach is the possibility that the adaptation to be incorporated could actually be considered maladaptation should drivers and/or projections change in the future. The development of a Flexible Adaptation Pathway for Green Square needs to resolve such issues, including the identification of any particular triggers or thresholds which, upon exceedance, may result in maladaptation.

In the case of Green Square, the added benefits of adaptation approach (B) is that it can be considered a 'no regrets' option. Should future sea level rise projections decrease in magnitude then this approach will still provide protection against an existing problem and afford this protection to a higher standard. Should future projections increase it will not prevent other approaches being incorporated. Approach (B) may also provide the opportunity to re-vitalise the environmental, ecological and aesthetic amenity of the Alexandra Canal by giving consideration to alternative forms of channel protection other than concrete-lining.

Should future projections increase, approach (A) may preclude, or complicate, other adaptation approaches and therefore risks being classified as maladaptation. If projections decrease however then this approach will provide protection to a higher standard.

The overall concept of adaptation approach (C), namely providing space and storage within the catchment, can also be considered a 'no regrets' approach as the space will be a benefit to the amenity value of the development and the storage may help manage the impacts of flooding elsewhere. However, the particular option used within this case study, provision of ground-floor car-parking, could potentially be classified as excessive and/or overly expensive (and therefore maladaptation) should future climate projections reduce in the scale of change. Should climate change projections increase the inverse will be true and this particular approach would be able to accommodate additional storage.

Options (B) and (C) have the potential to be complimentary options so that a combination of both could result in efficiencies of scale and cost for the other.

3.5.2 Implementation

It is recommended that the overall next step for this case study is to fully define the scope and nature of the problem to be assessed. The analysis above is presented as an example of how to move a particular problem forward rather than being a solution to a key problem to which all parties have bought into.

A key element of this scope definition will be to ensure that all stakeholders have been identified and are involved in setting the objectives and limitations of the study. This will include the geographical boundaries of the area to be considered as well as the type of re-development proposals to be assessed.

A useful pre-cursor to the scope definition above would be to undertake the initial risk assessment and adaptation options assessment for other potential climate change impacts (e.g. increased rainfall intensity). This could follow similar lines to the example presented within this case study but will fundamentally be driven by the available data. Such an initial assessment would help inform the overall scope definition exercise and help identify priorities.

The economic appraisal undertaken as part of this case study has been presented as an example of the type of analysis which could inform adaptation. There are a number of assumptions and weaknesses within the approach adopted. However, no recommendation is made for refinements to this economic appraisal until the scope and nature of the problem has been much more clearly defined.

3.6 Ongoing Monitoring and Evaluation

3.6.1 Monitoring and review

The development of an adaptation pathway for Green Square is an ongoing process. Therefore, as this pathway develops it will be crucial to constantly monitor, and factor in, any changes in drivers, projections and uncertainty factors.

What to monitor?

Climate change projections are clearly a key area of uncertainty but other drivers which may influence adaptation and should be tracked to ensure they are incorporated into future decision-making include:

- Extent and nature of land-use proposals, including re-development but also any abandonment of re-development proposals.
- Political influences.
- Future operations/plans of interconnected water infrastructure owners such as SWC.

How often?

It is not possible at this stage to prepare a precise schedule or time interval to which monitoring should be undertaken. However, should there be changes in any of the key drivers above then this would form a useful point at which to re-assess adaptation approaches.

Who?

City of Sydney Council have a sound overview of the current developments and future proposals within the Green Square area and, as such, it is suggested that they undertake a monitoring role.

What to do with monitoring information?

It will be key to the ongoing review of the overall Flexible Adaptation Pathway to evaluate the effectiveness and/or efficiency of any adaptation measures adopted. The Implementation section above has identified some achievable next steps, and the means by which these could be evaluated are:

- Scope definition – has the scope been better defined such that a set of problem/project objectives have been defined and agreed upon by all parties?

Cooks River: Improving governance arrangements to address existing and future flooding impacts

4.1 Overview

The Cooks River catchment is located in south-western Sydney with the spatial extent of the catchment shown in Figure 11. Within the catchment itself there are thirteen local councils, eight of which have foreshore management responsibilities. Furthermore, the Cooks River Alliance was launched in September 2011 by eight councils in the catchment. The aim of the Alliance is to address the complex problems of the Cooks River in the long term, whilst maximising the efficient use of member councils' limited resources.

There are also several state government agencies with management responsibilities (e.g. OEH, NSW Department of Primary Industries), as well as SWC who own approximately half of the Cooks River main channel. In addition, there are several major transport-related organisations who, although not having direct Cooks River management responsibilities, do own and/or operate major links or hubs within the catchment. Examples include Sydney Airport, Sydney Ports Corporation, RailCorp and NSW Roads and Maritime Services.

Mitigating and adapting to climate change is one of the issues underpinning the management strategies of each of the organisations above. Particular issues within the catchment include an existing flood risk problem which will increase with any climate change-induced rise in sea level and/or increase in rainfall intensity. At present, there are an estimated 709 residential and 156 commercial and industrial properties at risk of flooding during a 100 year ARI flood event. This is predicted to increase to 1003 and 229 properties, respectively by the year 2050.

Key lessons learned from the Cooks River Case Study

One of the major barriers within the Cooks River case study is the issue surrounding governance across the catchment, and the lack of an organisation with the particular legislative powers and funding to undertake a lead role. There is enthusiasm and desire amongst the stakeholders to more effectively manage issues on a catchment wide basis. Guidance and improvements have been suggested with a view to facilitate this scale of management.

The complexity and scale of existing and future flood risk across the catchment may also be a barrier to identifying the most appropriate course of adaptation, particularly in the context of the governance issues. The case study has shown that, by combining economic damages from a number of receptors, there is a strongly positive financial argument for implementing additional adaptation measures, even allowing for the cost of such measures across a large and densely-populated catchment. This should help provide greater confidence to enable decision-makers to approve further assessment of adaptation studies.

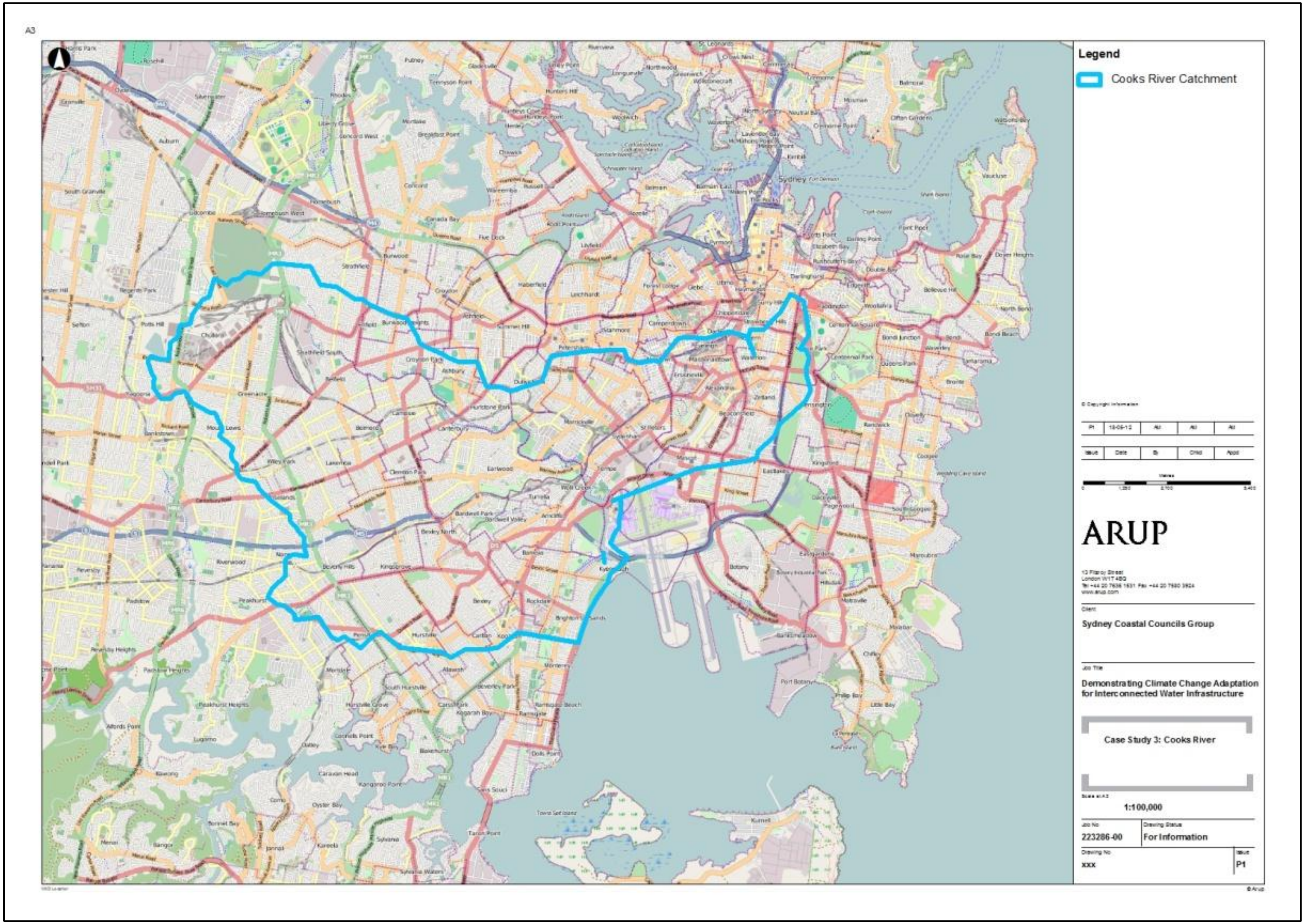


Figure 11 Cooks River catchment

Figure 12 Images of the Cooks River flooding. Clockwise from top left: flooding at Strathfield in 1959 (Source: www.strathfieldimages.com); flooding at Canterbury, March 2012 (Source: www.au.news.yahoo.com); flooding at Marrickville (bottom right and left), March 2012 (Source: www.inner-west-courier.whereilive.com.au).

The images in Figure 12 provide examples of the problems faced by the Cooks River. These highlight that this is not a new problem, as the 1959 photo shows, but also that recent events have ensured that flooding is a prominent issue.

There are currently significant sections of the Cooks River channel which are concrete-lined. The flood risk problem may become further exacerbated by the continued deterioration of sections of river channel (see Figure 13). This may lead to increased erosion and greater sinuosity in the river's course.

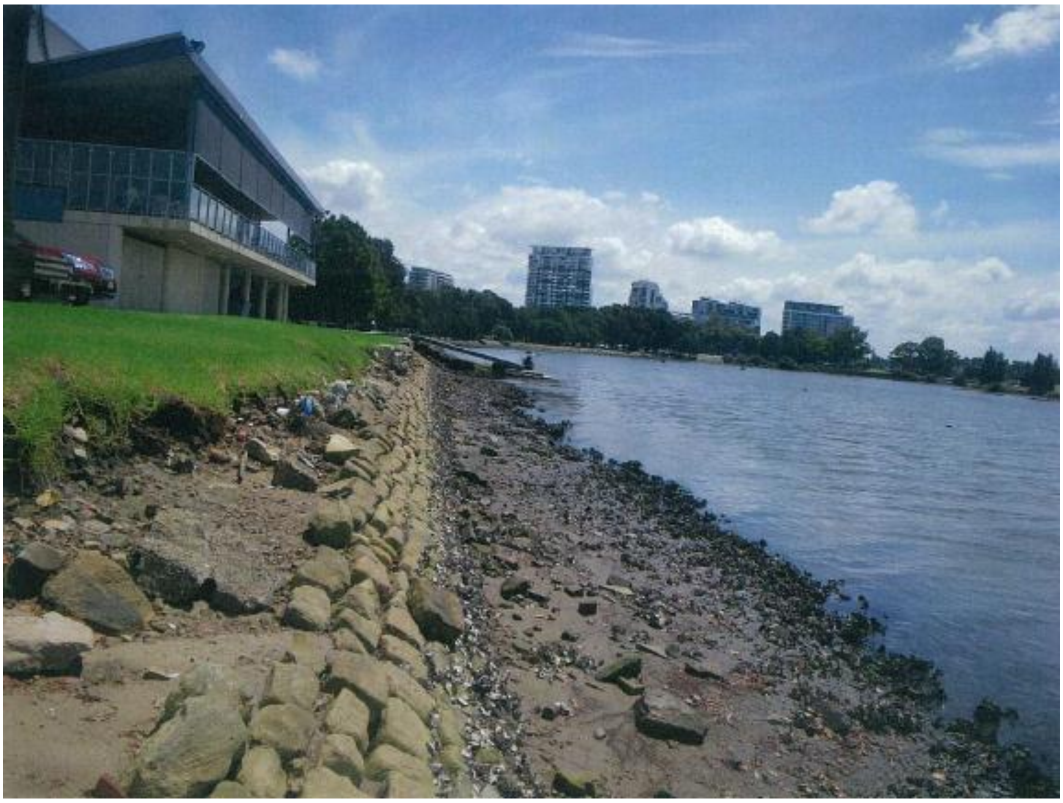


Figure 13 Example of deteriorated channel on the Cooks River (Source: Rockdale Council)

SWC has recently undertaken river bank renewal work to ensure a greater asset lifespan for some sections of the river, as well as maintaining the hydraulic capacity and increasing the ecological and visual appeal of these sections. A recommendation of the SWC work is that implementation of similar technology/methods in other parts of the river should be explored. The SCCG project “Assessment and Decision Frameworks for Seawall Structures” will provide support for local government staff investigating these options.

4.2 Focus and Scope

4.2.1 Interconnected problem

One of the key issues surrounding any form of management intervention within the Cooks River catchment is the degree of interconnectivity, both in the sense of physical processes but also across differing organisations with management responsibilities.

For example, SWC are able to undertake improvements to the sections of river channel within their ownership but these works may be rendered ineffective should similar upgrades not be undertaken to adjoining sections not within SWC ownership. In addition, these channel improvement works may indirectly provide a significant degree of flood risk protection to nearby properties for which no financial contribution or recognition may be provided.

A further example relates to the implementation of flood risk management works. Flood management works undertaken within one local authority will generally either provide benefit or detriment to neighbouring authorities within the catchment. Within present management and appraisal systems the extent of this benefit/detriment is not typically fully captured.

There is presently no one body with over-arching management responsibilities to take the lead and provide strategic direction and coordination across the catchment.

4.2.2 Climate change problem

During the stakeholder workshops to discuss this case study it was acknowledged that various climate change parameters would potentially have an impact upon the Cooks River. An initial screening matrix (see Table 14) was used to identify those climate variables considered most significant for this case study.

Table 14 Cooks River: impact screening matrix

Climate Variable	Projection (2050)	Stormwater Network
Average annual rainfall (%)	-20% to +50%	M
Rainfall intensity (%)	+15%	H
Sea level rise (m)	+0.40 m	H
Annual Average temperature (°C)	+1.5°C to +3.0°C	L
Evaporation (%)	+10% to +20%	L
Bushfires (%)	+10% to +50%	L

Legend:

H – High likelihood of this type of asset being impacted

M – Medium likelihood of this type of asset being impacted

L – Low likelihood of this type of asset being impacted

It was agreed that the two most significant parameters would be increased rainfall intensity and sea level rise. The key events resulting from these parameters were considered to be:

- Increased surcharging of stormwater network.
- Increased coastal inundation.
- Sewer surcharging.
- Increases in groundwater level.

Of these events, the stakeholders then agreed that **increased surcharging of the stormwater network** due to increases in rainfall intensity is of the most significance for all parties and should be taken forward for further consideration in the context of this case study. The consequences of this event are summarised in Table 15.

Table 15 Cooks River – Consequences of climate event

Consequences	
Direct	Indirect
Property flooding Infrastructure flooding (road, rail, stormwater) Existing stormwater pumping stations may be overwhelmed Stormwater pumping stations required Water treatment impacts Water quality Mobilisation of existing contaminants (acid sulphate soils, river sediment, groundwater, flood plain sediment) Increased erosion (loss of public land) Mobile river bank Residential and commercial property loss	Commuter/travel impacts (road/rail network) Health impacts (low flows – mosquitoes) Increased insurance Airport flooding – protection will impact elsewhere Recreational land loss (temporary due to water logging) Loss of salt marsh – endangered ecological community Conflict with community

4.2.3 Legislative requirements and risk attitudes

4.2.3.1 Local Councils

The management of this flood prone land is, primarily, the responsibility of councils. The primary objective of the NSW Flood Prone Land Policy is "*to reduce the impact of flooding and flood liability on individual owners and occupiers of flood prone property, and to reduce private and public losses resulting from floods, utilising ecologically positive methods wherever possible*". In addition to requirements under this policy, councils have a duty of care to ensure the safety of their constituents, including during times of flood.

Therefore whilst councils have an obligation under the Flood Prone Land Policy this becomes more critical in those locations where safety of residents is an issue and even more so where there is a risk to life aspect.

4.2.3.2 Sydney Water

Riverbank naturalisation would significantly improve the environmental and social values of the riverbank and foreshore area. This aligns with SWC's driver of Ecologically Sustainable Development (ESD), contained in the Environment Policy. The project would also contribute to the following corporate objectives:

- Contributing to clean beaches, oceans, rivers and harbours.
- Optimising resource use.
- Serving customers.
- Developing a safe, capable, committed workforce.
- Delivering an economically efficient business.

Renewal of the riverbanks along the Cooks River would fulfil requirements under the Sydney Water Act to ensure the structural stability of the riverbanks and maintain the hydraulic capacity of the channel, as well as ensuring that public safety hazards are not increased.

4.2.4 Existing assets – ownership and information

4.2.4.1 General

Within the context of this case study, the assets in question are:

- The Cooks River itself.
- The concrete-lined banks and inverts of the Cooks River.
- The numerous assets (property, transport, recreation, etc.) which lie within the Cooks River catchment and are at risk from the river.

These are clearly quite varied assets, in terms of ownership, maintenance and management of future risk. The final set of assets (i.e. those within the catchment) may alternatively be termed receptors as they will bear the consequence of any maladaptation of the other two assets.

4.2.4.2 Ownership and investment model

SWC owns roughly half of the Cooks River, from Strathfield down to the old Sugar Mill footbridge at Campsie, and undertakes an ongoing inspection program to determine the condition of its stormwater assets. These inspections may recommend maintenance works to rectify minor deterioration. When assets reach the end of their lifespan, there comes a point where replacement becomes more cost effective than continued repair work. The decision to renew assets is also based on the type and location of the asset and what risks are associated with the asset failing.

The funding for such maintenance or renewal works is derived from SWC rates which are subject to scrutiny by IPART. Under the current regime rates are set based on IPART's determination of SWC's submission which includes estimates for future capital and operational costs.

The remainder of the Cooks River falls under the responsibility of the local authority in which that section of the river is located. Funding for any maintenance, upgrade or renewal works is derived from council rates and is therefore prioritised in the same way as all other council services.

4.2.4.3 Local community

Consultation with local council staff has identified that the community within the Cooks River are well informed with regard to both flood risk management and the value of the existing Cooks River asset. There is a strong desire to increase the biodiversity and recreational values of the river and its corridor whilst also providing effective flood risk management.

This public viewpoint is borne out by SWC customer research which has consistently demonstrated poor community perception of its stormwater management (Sydney Water 2009, Sydney Water 2000). Bank naturalisation offers a significant opportunity to rectify this poor community perception of SWC by applying industry best practice in water sensitive urban design, where there is demonstrated strong stakeholder support.

4.2.4.4 Existing information and strategies

SWC has prepared a Flood Study for the catchment (Cooks River Flood Study, February 2009) which provides a useful tool in the quantification of the degree of current and future flood risk.

Some local councils have prepared Flood Studies or Flood Risk Management Plans for smaller sub-catchments within their jurisdiction (e.g. Coxs Creek Flood Study by Strathfield Council). However, there is no over-arching or comprehensive study or strategy which seeks to provide a management or adaptation strategy for the catchment as a whole.

4.3 Risk Assessment

4.3.1 Risk attitude

Local Councils are willing to take less risk in those scenarios where risk to life is a distinct possibility as compared to situations where this may not be so prevalent.

Similar to the local Councils, SWC's attitude to risk becomes more focussed in those instances where public safety may be an issue. An example of such a pro-active approach is provided by the riverbank naturalisation works.

4.3.2 Current risk

Information on the existing degree of flood risk within the catchment has been provided by SWC (Cooks River Flood Study, February 2009) which shows the onset of flooding in a 2 year ARI event. Such a recurrence interval may be classified as high risk due to the relatively frequent occurrence coupled with likely deep floodwaters, particularly in the greater magnitude events.

The frequency of this flooding will increase with the predicted impacts of climate change, although the amount by which it increases is not currently available. Also, comparing the predicted flooding information with property level data show there to be an estimated 709 residential and 156 commercial and industrial properties at risk of flooding during a 100 year ARI flood event (see Figure 14). Therefore, the consequences in Table 15 may be realised on a relatively frequent basis and the impacts of these consequences are likely to be severe. This is highlighted by the flood damages estimates in Table 16 which show the scale of the potential financial impact.

The concrete-lined sections of the Cooks River are in various states of repair, with some sections having already reached the end of their useful life. These sections of bank protection perform a useful function in controlling erosion and potential movement in the course of the river across the floodplain. There are approximately 160 properties (residential and commercial) which would be at risk should the river channel vary in its lateral extent by 40m. This impact is not linked to a particular magnitude event, rather it is provided to highlight the number of properties in relatively close proximity to the current watercourse channel.

4.3.3 Risk with climate change

Both the frequency of flooding, and the number of receptors impacted, will increase with the predicted impacts of climate change. Information on the degree of the change in frequency is not currently available but predicted flood extent information, provided by the Sydney Water Flood Study, show that the number of properties at risk in a 100 year ARI flood event will increase to 1003 residential and 229 commercial and industrial (see Figure 14).

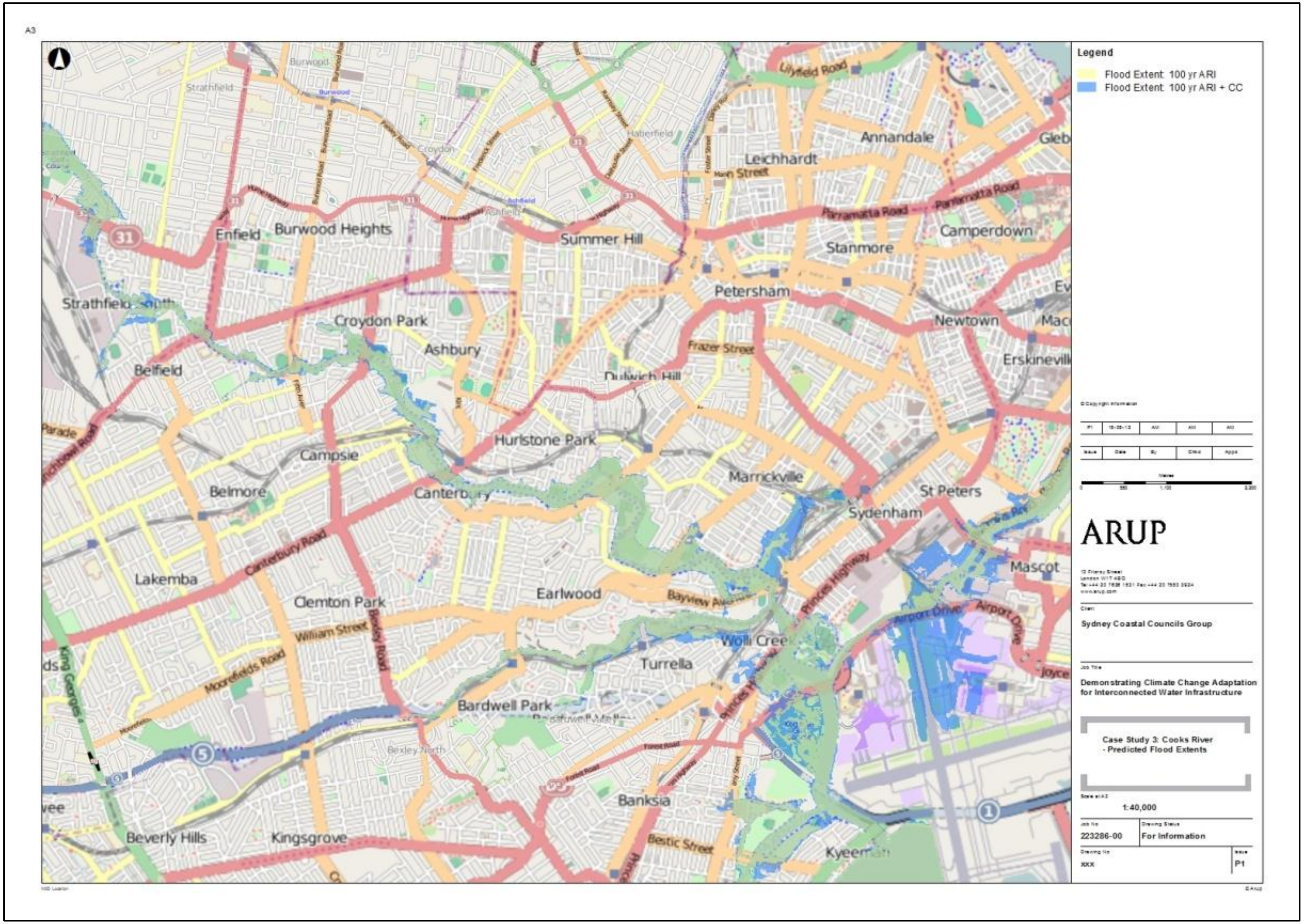


Figure 14 Predicted flood extents for the Cooks River catchment (data adapted from Sydney Water – Cooks River Flood Study)

4.4 Adaptation Options

4.4.1 Options identified

Discussions during the stakeholder workshops identified a large range of adaptation options which could be applied to the climate change event. Further qualitative screening during the workshops focussed in on those options considered to be the most effective on a catchment-wide basis.

The stakeholders agreed to take the following adaptation approaches forward, to be explored more fully:

A. Adopting a catchment-wide approach, with options such as:
   - Bio-retention, storm-water harvesting, coupled with
   - Removal of bridge constrictions.
B. Creation of a water compatible zone, including measures such as:
   - DCP amendments.
   - Masterplanning.
   - Property resilience.
C. Formal flood detention/attenuation, likely to include:
   - Large scale flood storage reservoirs/basins

Current flood risk management guidelines do not stipulate or define a standard of protection which should be afforded by an intervention option. Rather, the focus is on providing the most cost-beneficial option which takes into account technical, environmental and social aspects.

Each of the adaptation approaches above offers the flexibility to provide differing standards of protection in response to economic constraints, but also in response to differing social and political aspirations. Therefore, they have been identified and selected on the basis of their flexibility to differing drivers rather than their ability to provide a definitive standard of protection.

4.4.2 Barriers and adaptive capacity building options

The scale and extent of the problem is such that there are a myriad of potential barriers. The stakeholder workshops identified some key barriers which would effectively form the most obvious early 'hurdles' within an adaptation pathway (see Table 16). They also then agreed on some suggested options to overcome these barriers.

Table 16 Key barriers and options to overcome them

Key Barriers	Options to Overcome Barriers
Lack of collaboration/ownership of problem. Each council working by itself.	Cooks River Alliance (as an umbrella organisation) to investigate feasibility of developing a catchment strategy. This may need to be taken forward as a flood management strategy rather than a climate change adaption strategy in order to encounter fewer 'obstacles' within the local councils.
Lack of community interest/engagement. May stem from a reluctance to accept climate change.	Create and empower floodplain committee representatives so that message can be distributed more effectively, and key decisions can be made in collaboration (rather than dictated to). Investigate appointment of influential figureheads within the community (e.g. sporting, celebrity, achievers) who would be willing to spread message of flooding/water inundation (avoid issues over 'climate change').
Investment/funding required to incorporate measures.	Increase Sydney Water River Management Levy. Implement/increase local council flood mitigation/management levy. Both of these measures will require support of the local community as the local council levy would be added to rates, and the SWC levy will require the approval of IPART (who in turn will be influenced by the local community). An option would be for the Cooks River Alliance to coordinate responses from all local councils with a view to increasing rates and making a case to IPART. However, this is likely to require progress to be made on the second barrier above.

Further consideration has subsequently been given to developing additional guidance to assist in overcoming each of these barriers:

Collaboration/ownership of problem

- There is considerable enthusiasm within the local councils and the Cooks River Alliance to more effectively and efficiently manage issues within and across the catchment as a whole. This enthusiasm extends to driving forward flood management issues on a catchment basis. However, liaison with the Cooks River Alliance has identified that additional funding input to the functioning of the Alliance would be required to enable them to undertake such an umbrella organisation role.
- The Georges River Combined Councils' Committee (GRCCC) may provide an example of how further funding can be secured for a catchment-scale umbrella organisation. The GRCCC, with funding support from the Sydney Catchment Management Authority (CMA), engaged a consultant to recommend an organisational structure and operational plan to better position the GRCCC to meet current and future demands. As a result, the GRCCC is now able to align its program of works to meet National Resource Management (NRM) objectives, as well as the objectives of the State Plan and the Georges River Catchment Management Plan. Current State and Federal funding is directed to meeting these objectives. As this funding is more generally granted to partnership organisations with a

regional focus, the GRCCC provides an excellent organisational structure by which member councils can derive financial benefits for their commitment to the Georges River catchment.

- At present, the Cooks River Alliance are not an incorporated organisation and currently require a member Council to act in the lead role when applying for grants or commissioning studies. Should the funding barrier be overcome it may become more efficient for the Alliance to become incorporated, as is the case for the GRCCC or indeed the SCCG.

Community Engagement

- Holding community education sessions on climate change is one option to overcoming this barrier and this is considered to be a no regrets option that helps to build adaptive capacity. The Productivity Commission's Draft Report into the "Barriers to Effective Climate Change Adaptation" supports this, advocating actions which help the community deal with the current climate but which would also enhance the adaptive capacity of the economy, and enable the community to more effectively respond to future climate change.

Investment/funding availability

- Councils do have the opportunity to request 'Special Variations' which allow a temporary increase in rates above the peg in order to fund shortfalls in infrastructure expenditure. Further to this, the Local Government Amendment Stormwater Act 2005 allows councils to make or levy an annual charge for stormwater management services only in respect of urban land that is categorised for rating purposes as residential or business. Under the act the maximum annual charge for stormwater management services that may be levied is $25 for residential rated land and $25 for business rated land plus an additional $25 for each 350 square metres.

4.4.3 Economic appraisal

4.4.3.1 General

Discussions during the stakeholder workshops identified that due to the lack of 'ownership' of the problem for the Cooks River catchment as a whole, there is also a gap in the understanding of the scale of the total problem in economic terms. This, in turn, results in there being a lack of information on the scale of intervention which can be economically justified.

As outlined in Section 4.4.1, the adaptation options identified for this case study are not at a stage of development for which detailed costs can be prepared. Rather, this economic appraisal seeks to prepare order of magnitude costings to compare against initial calculations of the damages which may occur due to the climate event, both now and in the future.

4.4.3.2 Flood damages

Initial estimates of the damages which may arise from a range of flood events in the Cooks River catchment are provided in

Table 17. These damages include direct impacts on properties as well as an estimate of the indirect disruption which would be caused by flooding. The transport-related damages focus on three main forms of transport infrastructure which all traverse the catchment and would be impacted during a flood event. These transport networks are:

- Major highways, all of which carry large commuter volumes.
- All passenger rail lines.
- The freight rail line which connects the Sydney Ports terminal at Botany Bay to the mainline rail network.

It should be highlighted that these values are considered initial, relatively conservative estimates only and have been prepared to provide an indication of the order of magnitude of the problem[5]. They are based on a range of calculation data, techniques and assumptions (see Table 18) and should not be used for detailed business case preparation purposes. Links to some of the tools applied are included in the interactive PDF document (Part 3), with other assessment methodologies undertaken by experienced flood and transport management practitioners. It is recommended that the preparation of economic assessments to a similar, or greater, level of detail be undertaken by experienced practitioners.

In summary, the damages use predicted flood extents for differing return periods to produce a probability-weighted AAD value. This AAD is then discounted to produce a Present Value of the damages. The only difference between the 'Present Day' and 'Future Scenario' is the predicted flood depths which are higher in the future. This therefore provides an indication of the estimated increase in flood damages which may arise from climate change.

[5] Due to the high-level nature of the assessment it is not possible to provide an indication of the level of confidence attributable to the estimates.

Table 17 Cooks River flood damages estimates

Parameter	Flood Damages	
	Present Day	Future Scenario
Residential property damages	- 'Low' flood depths: $172.3 million (AAD = $11.6 million) - 'High' flood depths: $217.1 million (AAD = 14.7 million)	Year 2050: - 'Low' flood depths: $231.8 million (AAD = $15.7 million) - 'High' flood depths: $286.7 million (AAD = $19.4 million)
Commercial property damages	- 'Low' flood depths: $81.8 million (AAD = $5.6 million) - 'High' flood depths: $139.7 million (AAD = $9.5 million)	Year 2050: - 'Low' flood depths: $98.9 million (AAD = $6.7 million) - 'High' flood depths: $169.5 million (AAD = $11.5 million)
Industrial property damages	- 'Low' flood depths: $50.4 million (AAD = $3.4 million) - 'High' flood depths: $90.4 million (AAD = $6.1 million)	Year 2050: - 'Low' flood depths: $83.3 million (AAD = $6.7 million) - 'High' flood depths: $156.1 million (AAD = $10.6 million)
Traffic impacts	$108.25 million	At least same as present day
Passenger rail impacts	$65.25 million	At least same as present day
Freight rail impacts	- Flood event only: $67.6 million - Flood event + repair period: $405.5 million	Year 2031: - Flood event only: $281.9 million - Flood event + repair period: $845.7 million
Totals	- Lower estimate: $545.6 million - Higher estimate: $1,026.2 million	- Lower estimate: $869.4 million - Higher estimate: $1,631.5 million

Table 18 Cooks River flood damage estimation assumptions

Parameter	Method	Assumptions
Residential property damages	OEH Flood damages spreadsheet	- Uses flood extents from Sydney Water Flood Study for: 2, 20, 100 year ARI + PMF events to calculate property numbers - Uses flood extent from Sydney Water Flood Study for 100 year ARI plus climate change allowance to calculate property numbers. Applies percentage increase in property numbers to other events - Assumes two differing flood depth scenarios for each event. 'Low': 2 year = 0.1m; 20 year = 0.3m; 100 year = 0.5m; PMF = 2m. 'High': 2 year = 0.2m; 20 year = 0.7m; 100 year = 1.0m; PMF = 4m - All properties assumed to be two storey - Damages are Present Value - 7% discount factor - Assumes no capping of damages
Commercial & Industrial property damages	UK Multi-Coloured Manual with currency conversion to convert to $AUD	- Uses flood extents from Sydney Water Flood Study for: 2, 20, 100 year ARI + PMF events to calculate property numbers - Uses flood extent from Sydney Water Flood Study for 100 year ARI plus climate change allowance to calculate

Parameter	Method	Assumptions
		property numbers. Applies percentage increase in property numbers to other events - Assumes flood depths for each event of 2 year = 0.1m; 20 year = 0.5m; 100 year = 0.8m; PMF = 3m. - Damages are Present Value - 7% discount factor - Assumes no capping of damages
Traffic impacts	Road counter location information BTS Household Travel Survey RMS Economic Analysis Manual	- Major road crossings of Cooks River analysed only: Hume Highway, Georges River Road, Canterbury Road, Princes Highway. - Vehicle occupancy = 1.45 passengers per vehicle - Value of time = $11.89 per hour - Roads are predicted to flood in a 20 year ARI event, so approx. 2.5 times over a 50 year appraisal period - Does not account for any actual physical damage to road infrastructure - Does not account for increased frequency of flooding due to climate change - Assumes network ‘shut-down’ for 12 hours covering morning and afternoon rush hours
Passenger rail impacts	Origin-Destination Matrix – passenger numbers RailCorp Compendium – rail value of time	- Following rail crossings of Cooks River analysed: Illawarra Line, East Hills Line, Bankstown Line, South Coast Line - Value of time = $11.90 per hour - Rail lines are predicted to flood in a 20 year ARI event, so approx. 2.5 times over a 50 year appraisal period - Does not account for any actual physical damage to rail infrastructure - Does not account for increased frequency of flooding due to climate change - Assumes network ‘shut-down’ for 12 hours covering morning and afternoon rush hours
Freight rail impacts	Sydney Ports Annual Report Sydney Ports Freight Logistics Plan NSW Long Term Masterplan	- Percentage of train movements disrupted by: 8 hour flood event only; 48 hour time period for flood event plus subsequent repair of flood damage - Percentage applied to total 2011 Sydney Ports revenue as estimated loss - Port revenue, and total freight movements, predicted to increase significantly over next 20 years. Losses estimated for future scenarios also. - Does not account for increased frequency of flooding due to climate change - Damages are for one-off flood event only and do not take account of multiple floods over an appraisal period

4.4.3.3 Adaptation option cost estimates

Initial cost estimates have been prepared, where possible, for the adaptation approaches identified in Section 4.4.1. Data sources used to prepare the cost estimates included:

- Rawlinsons Manual [Rawlinsons, 2012, *Australian construction handbook 2012*, 30th Edn, Rawlinsons Publishing Pty. Ltd., Perth].
- Georges River report [Maddocks, J., 2001, 'Have we forgotten about flooding on the Georges River?', *Floodplain Management Authorities Conference*].
- WSUD report [Water by Design, 2010, A Business Case for Best practice Urban Stormwater Management (Version 1.1), South East Queensland Healthy Waterways Partnership, Brisbane, Queensland.].
- Proxy examples.
- Engineering judgement.

It should also be highlighted that these values are considered initial estimates only and have been prepared to provide an indication of the order of magnitude of the costing. Therefore, in order that costs are not significantly underestimated, an 'optimism bias' of 60% has been applied to each adaptation approach. This is a common technique to offset somewhat the tendency to produce optimistic cost estimates at the early stages of problem appraisal. It is assumed that these costs would be incurred at the start of any appraisal period and so they have not been discounted.

Amendments to the relevant DCPs and any future appropriate masterplanning of re-development areas will not incur any direct expenditure specifically related to adaptation within the Cooks River.

Table 19 Cooks River: adaptation options cost estimates

Adaptation Approach	Costing Assumptions	Cost Estimate
Bio-retention, storm-water harvesting	High density residential development, including: life cycle costs and annual maintenance Applied to quarter of total catchment area	$149 million
Removal of bridge constrictions	4 no. new bridge crossings Composite, six lanes, 27m wide	$44 million
	Optimism bias (60%):	$116 million
	Sub-total:	$309 million
DCP amendments	No direct cost	
Masterplanning	No direct cost	
Property resilience	709 residential properties within 100 year ARI flood extent Assume 25% to be raised Apply 50% inflation adjustment to Georges River report cost estimate	$11.8 million
	Optimism bias (60%):	$7.1 million
	Sub-total:	$18.9 million
Formal flood storage reservoirs	Land will be most significant cost. Assume mix of open-space ($135 per m^2) and commercial (327 perm^2) land. Area of 180,000m^2 – based on area of Canterbury Racecourse. Catchment gradient will dictate relatively low-level, but extensive reservoir embankments. Assume cost $1 million per reservoir. Assume 3 no. flood storage reservoirs	$125 million $3 million
	Optimism bias (60%):	$77 million
	Sub-total:	$205 million

4.4.3.4 Appraisal discussion

The flood damages summarised in Table 17 highlight the potential scale of the impact should there be a major flood event in the Cooks River catchment. Applying relatively conservative assumptions to a selection of key damage sources produces a minimum flood damages estimate in excess of $500 million over a 50 year appraisal period. This can potentially increase three-fold with the predicted impacts of climate change.

The option costs show that, while there are no inexpensive options, the costs are far out-weighed by the flood damages (see Table 20). Any flood management, or climate change adaptation, expenditure within the Cooks River catchment will therefore be a sound investment. This appraisal does not explore adaptation at a given year in the future, rather it assumes that measures would be undertaken in the present day. Therefore no discounting of the costs, or accumulation of damages prior to adaptation, has been undertaken.

Table 20 Cooks River adaptation approaches cost-benefit ratio summary

Adaptation Approaches		**Present Day**		**Future Scenario**	
Approach	Cost	Flood Damage	Benefit-Cost Ratio	Flood Damage	Benefit-Cost Ratio
A) Catchment wide approach	$309 million	'Low' = $545.6 million	'Low' = 1.8 'High' = 3.3	'Low' = 869.4 million	'Low' = 2.8 'High' = 5.3
B) Water compatible zone	$18.9 million	'High' = 1026.2 million	'Low' = 28.9 'High' = 54.3	'High' = 1631.5 million	'Low' = 2.8 'High' = 86.3
C) Flood storage	$205 million		'Low' = 2.7 'High' = 5.0		'Low' = 4.2 'High' = 8.0

4.5 Flexible Adaptation Pathway

4.5.1 General

There is an existing problem, with regard to surcharging of the stormwater network, in the Cooks River catchment. The predicted impacts of climate change will therefore exacerbate this existing problem rather than instigate a new problem.

4.5.2 'No regrets' options

Adaptation approaches (A) and (B) may be considered 'no regrets' options. Although approach (A) would result in significant expenditure the measures in question would have benefits for local-scale flood risk management and re-instatement of a more 'natural' regime for the river (by removal of the bridge constrictions) that are not dependent upon a particular scale of climate impact.

Approach (B) is a much lower capital cost option and the particular measures within this approach (e.g. masterplanning and DCP amendments) would produce added benefits beyond flood risk management. For example, appropriate masterplanning is likely to set aside open space areas adjacent to the river which would increase the public amenity value of the area.

Approach (C) may form the option which is able to provide a defined standard of protection across the catchment but this is likely to cost a significant sum. Should climate change projections reduce in the future then this option may have resulted in the construction of excessively large storage areas. Should climate change projections increase further in the future then this approach would still provide some degree of attenuation against these higher flows. This approach can therefore not be classified as a ‘no regrets’ option but is does provide a measure of contingency should climate projections increase.

4.5.3 Complementarity of options

It was acknowledged in the stakeholder workshops that, due to the scale and extent of the problem (i.e. volume and spatial extent of flood water) and the complexity of the catchment, with regard to the physical and built characteristics and the convoluted governance arrangements, no one adaptation option is likely to provide a solution. A range or collection of complimentary options will be required to address the current extent of the problem and also provide flexibility to respond to future changes.

For this reason the measures contained within adaptation approaches (A) and (B) are all complimentary to one another. Each of these measures forms current best practice with regard to catchment management and therefore no measures are in direct contradiction of each other.

Approach (C) will be complimentary to (B) and may actually help reduce the size of the storage areas due to more efficient channels downstream. However, (C) may not be complimentary to (A) as the construction of large flood storage reservoirs may utilise valuable space within an overall masterplanning exercise.

4.5.4 Decision points

The assessment and appraisal undertaken as part of this case study has sought to help reduce some of the complexity surrounding the problem and reduce some of the uncertainty to enable decisions to be made regarding further adaptation.

The economic appraisal has made use of existing data (i.e. flood extents provided by SWC) to prepare initial calculations of the order of magnitude of flood damages. In conjunction with the stakeholders, adaptation options have been identified and initial cost estimates have been prepared. A large number of assumptions have been made with regard to both these sets of calculations however, the overall results highlight that the scale of the flood damages is likely to far outweigh the cost of viable adaptation options.

This also provides a measure of resilience against any future changes in climate change projections. Should these increase in magnitude then the business case will become stronger. Should the projections decrease in magnitude the business case is likely to be robust enough (given the strong benefit cost ratio) to remain positive towards adaptation.

As this is an existing problem, which is predicted to increase in frequency and impact with climate change, there is no decision or trigger point related to flood inundation or frequency. Other potential trigger points may relate to legislative, funding or social drivers and these should be identified with further development of a FAP.

4.5.5 FAP preparation

The information and guidance has been presented above with the aim of progressing this case study through an initial Flexible Adaptation Pathway. It has presented both the results of an initial ‘risk assessment’ and also summarised the identification and assessment of adaptation options. This information should provide the confidence and the framework with which to further advance the assessment of adaptation options.

It is suggested that the overall next step for this case study is to commence a second iteration of the decision-making framework. The information presented in this assessment can be used to help refine the scope and identify the next steps and required inputs, so that a more refined and informed FAP can ultimately be produced.

In order to further advance the understanding of the impacts and requirements of potential adaptation options it is recommended that a quantitative assessment be undertaken, which is likely to include hydraulic and hydrological modelling. This will help with the initial design, and hence costing, of the options and also determine any upstream or downstream impacts.

In parallel to such a quantitative study, it is also recommended that the local councils instigate the process of increasing their rates to cover such a capital expenditure. Also, planning system amendments, to both development control and forward planning (masterplanning), should be progressed so that these policies include robust mechanisms to deal with current and future flood risk.

Each of these measures represent ‘no regrets’ options as they will not result in significant expenditure and will not be rendered ineffective by any future change in climate projections or other external influence. Similarly, none of these measures are in direct contradiction of each other, they are complimentary so that progression or implementation of all together will not result in abortive work.

Governance issues within the catchment are considered a primary barrier to effective climate change adaptation. The Cooks River catchment is in an advantageous position in that there is presently an umbrella organisation (the Cooks River Alliance) across the local councils which could act as a focal point to drive forward adaptation on a catchment, rather than local council scale. However, the Cooks River Alliance would require additional funding to undertake such a role, which further highlights the importance of the funding aspects summarised above. Further guidance on potentially overcoming such governance issues is provided in Section 4.4.2 above.

4.6 Ongoing Monitoring and Evaluation

What to monitor?

As this is an existing, rather than future, problem it is not necessarily particularly sensitive to changes in climate projections. However, any such changes should be borne in mind during further assessment of the most appropriate options, particularly if they result in significant alteration to the scale or rate of the impact.

Other drivers which may influence adaptation and should be tracked to ensure they are incorporated into future decision-making include:

- Community perceptions of flood risk, climate change and environmental issues.

- Political influences.
- Future operations/plans of major transport system operators (e.g. RMS, RailCorp, Sydney Ports).
- Any major commercial or residential developments proposed within the catchment.

How often?

It is not possible at this stage to prepare a precise schedule or time interval to which monitoring should be undertaken. However, should there be changes in any of the key drivers above then this would form a useful point at which to re-assess adaptation approaches.

Who?

Given the issues surrounding governance and management responsibility within the Cooks River catchment the responsibility for monitoring and evaluating is a key question. The presence of the Cooks River Alliance as an umbrella organisation would point towards this organisation as the most appropriate to undertake this monitoring. However, further resolution would be required on funding aspects (see Section 4.4.2) to enable this to happen.

What to do with monitoring information?

It will be key to the ongoing review of the overall Flexible Adaptation Pathway to evaluate the effectiveness and/or efficiency of any adaptation measures adopted. The FAP section above has identified some achievable next steps and the means by which these could be evaluated are:

- Quantitative modelling study:
    - Has this study identified viable adaptation options?
    - Has this study increased the knowledge base and enabled further adaptation pathway decisions to be made?
- Planning system amendments:
    - Has the rate or number of properties being exposed to flood risk within the catchment reduced?

Wollongong: A systems approach for interconnected coastal asset owners to adapt to coastal recession

5.1 Overview

The broader Wollongong case study area consists of the coastal zone within the Wollongong City Council (WCC) Local Government Area (LGA), refer Figure 15. This coastal zone consists of 23 discrete sites/beaches from Stanwell Park Beach in the north to Perkins Beach in the south.

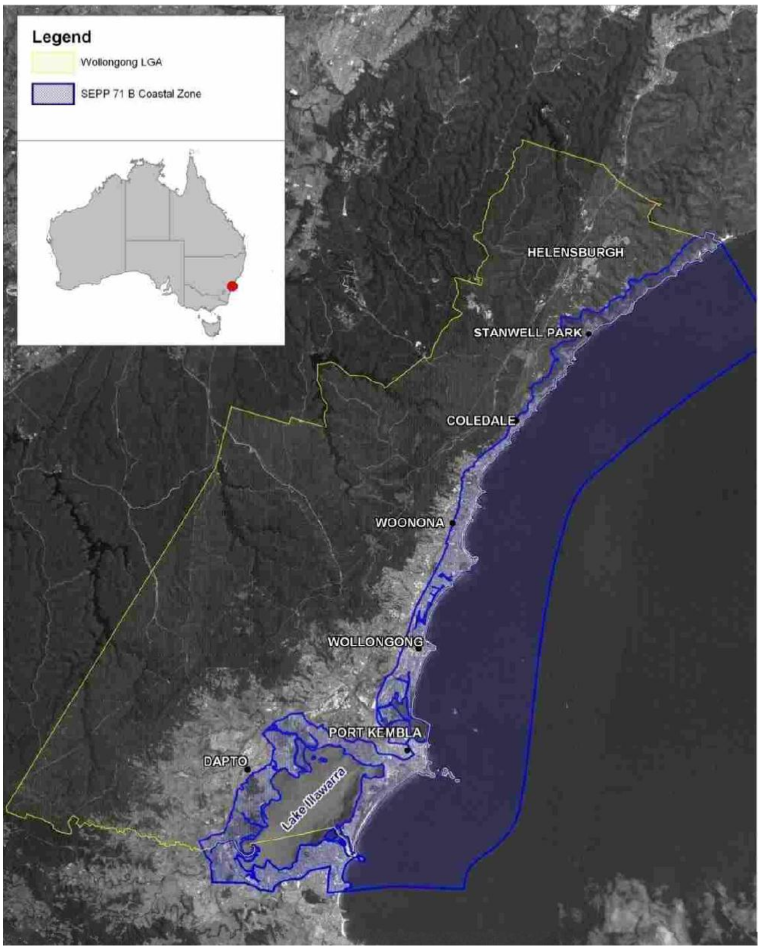


Figure 15 Wollongong Case Study Zone (Source: BMT WBM, 2012)

Previous studies have identified that a number of interconnected water infrastructure assets, and other infrastructure assets types, are at risk from erosion, recession and coastal inundation now and in the future, accounting for climate change.

There are two key stakeholders associated with this case study area, namely WCC and SWC. Other stakeholders include OEH, Roads and Maritime Services (RMS), other utilities providers and the local residents. Currently, coordinated decision-making between stakeholders for the managed adaptation of the coast's interconnected water infrastructure to climate change events is limited due to various barriers including the lack of a clear and agreed approach for knowledge and responsibility sharing.

Key lessons learned from the Wollongong Case Study

The Wollongong LGA case study identified that the key stakeholders of WCC and SWC had each collated a good amount of data on their at-risk coastal assets. This includes information on the location and condition of assets, risk zones associated with different coastal zone hazards (erosion, recession and inundation) and preliminary adaptation option assessment. However to date this cross-stakeholder information had not been considered collectively to obtain an overall understanding of the combined asset risk from climate change effects and the applicability of different adaptation options to provide protection to each stakeholder's assets.

It was found beneficial to firstly prioritise the beaches within the Wollongong LGA in terms of vulnerability of the assets along and behind the beach through a first pass assessment to narrow the focus of the assessment to make it more 'solvable'.

The economic analysis undertaken of a vulnerable beach demonstrated that the value attributed to societal amenity assets (e.g. beach area, back of beach parkland) and loss of service costs (e.g. loss of sewerage and stormwater provision) can have a strong influence on the outcome of the results. As such, these non-tangible cost assumptions should be agreed by all stakeholders prior to undertaking any economic assessment work. This analysis stage also showed that different adaptation options may be more economically advantageous to different stakeholders, dependant on the location, value and risk profile of their assets. As such a holistic economic analysis could be a useful tool to form the basis for apportioning funding for implementing a chosen adaptive measure, based on the relative benefit to each stakeholder. To pursue this approach there needs to be strong buy-in to the economic appraisal approach and input data by all relevant stakeholders.

5.2 Focus and Scope

A Coastal Zone Study commissioned by WCC identifies coastal areas at risk from erosion and coastal inundation from a 100 year ARI storm event in 2010 (assumed as the present day). This storm event consists of the short-term combination of extreme waves and sea water levels occurring at the coastline. The spatial extent of the 'at risk' coastal land from this event for a number of discrete sites within the study area is defined by the study through hazard lines/zones.

Various interconnected water infrastructure assets along the coastline have been identified to be located within the 'at risk' present-day hazard lines/zone including stormwater and sewerage pipelines, wastewater treatment plants and outfall structures. Commercial, residential, community and other infrastructure assets have also been identified as being vulnerable.

The present-day hazard lines/zones for this particular storm event may be exacerbated in the future due to the effects of various climate change parameters. Within the stakeholder workshops the following climate change parameters were identified to apply to the Wollongong case study area:

- Sea level rise.

- Increased rainfall intensity.
- Increased storm surge.
- Increased magnitude of wave climate.

The primary events resulting from these climate change parameters were discussed within the workshop and determined to be:

- Increased coastal erosion/recession and associated geotechnical instability.
- Increased coastal inundation.
- Increased surcharging of the stormwater network.

The following direct and indirect consequences of these climate change-induced events on potentially affected assets were identified:

Table 21 Wollongong Coastline – Consequences of climate change

Direct Consequence	Indirect Consequence
Increased damage to: Pipelines Pumping stations Outlets Waste water treatment plants Water distribution networks (SWC to community) Loss of sand dune acting as buffer Sand filling of outlets (from wind and wave action) Road network/cycleway damage Damage to other assets (e.g. properties)	Redirects funding and resources away from water infrastructure provision Health and Safety (H&S) issues More exposure to assets (public liability and physical vulnerability) Loss of beach/cliff amenity areas Flood upstream exacerbated from tidal locking Increase in stormwater drains 'popping' Debris deposited along coast

The workshop participants agreed that time constraints meant that only one of these events should be considered further in this study, and this was selected to be increased erosion/recession and associated geotechnical instability. This event was chosen as it was considered by WCC and SWC to represent the primary threat to interconnected water infrastructure assets owned by the two parties.

A future increase in coastal erosion/recession and associated geotechnical instability along the coastline would occur from the following physical processes:

- An increase in the mean sea water level from sea level rise would move the average coastline landwards (long-term recession).
- An increase in storm magnitude or duration (waves and storm surge) would lead to more intense short-term erosion events.
- The increased erosion/recession will lead to lowering of beach levels closer to the location of assets sited at the back of the beach. Lower levels will result in larger waves being able to propagate inshore, exposing the assets to increased wave attack.

- As well as the direct physical impact of assets from erosion/recession, assets further inland may also become damaged through the weakening of nearby soils, resulting in the ground on which they are sited no longer being able to provide an adequate foundation.

It was generally agreed in the workshops that this case study is relatively well progressed in the decision making framework process. The studies commissioned by WCC have essentially taken the process up to the to the Adaptation Options stage including a quantitative appraisal of adaptation options in the form of economic modelling for Thirroul Beach. However, the main gap in the process undertaken to date is that the detailed WWC planning studies do not consider SWC's assets.

The case study is informed by the following studies/documents provided by WCC:

- Wollongong City Council Coastal Zone Study, Wollongong City Council, June 2010.
- Wollongong Coastal Zone Management Plan (Draft), Wollongong City Council, January 2012.
- Wollongong Development Control Plan, Wollongong City Council, 2009.
- GIS data on WCC's stormwater assets within the study area.

Notably, the Coastal Zone Study and Management Plan commissioned by WCC does not consider SWC's wastewater assets along the coastline.

SWC has provided Arup with the following information on their assets:

- GIS data on SWC's waste water assets within the study area.
- Information on typical replacement costs for SWC's wastewater assets.
- Sydney Water Operating Licence 2010-2015.
- SWC risk criteria.

5.3 Risk Assessment

5.3.1 Attitudes to risk

The NSW Coastal Protection Act (1979) is the main legislation relating to the coastal zone and its management in NSW. The Act contains provisions relating to the use and occupation of the coastal zone, the carrying out of coastal protection works, the preparation of coastal zone management plans and other ancillary matters relating to the coastal zone. There is no strict legislative requirement for local or regional coastal government bodies to prepare a Coastline Management Plan. However, many coastal councils in NSW have prepared one in accordance with established guidelines, and regularly maintain it to manage risks to their assets.

Nb. Recent coastal management reforms enacted since the completion of the assessment stages of this project have removed the uniform NSW Sea Level Rise

Benchmarks for coastal hazard assessment. Councils will now be required to establish individual sea level rise benchmarks appropriate to their locality.

Before undertaking a vulnerability assessment of existing interconnected water infrastructure assets, stakeholders should ideally first consider collectively what level of risk they are willing to accept in terms of preventing damage. This risk level may vary for different asset types. For example, major critical assets such as wastewater treatment plants where the consequence of damage would be very high (i.e. high replacement and loss-of service costs), may mean that SWC may decide it should be protected from a less frequent storm event than for its other assets.

Both WCC and SWC acknowledge that the risk of climate change events increasing the vulnerability of their respective assets is real and worth acting upon.

As mentioned previously, WCC recently commissioned a Coastal Zone Study and Management Plan. These essentially define 'at risk' assets to be those affected by a 100 year ARI storm event (i.e. an event that on average occurs every 100 years). This is a common return period storm event used within the industry for defining vulnerable coastal assets. This is not to say that assets located further landward of the 100 year ARI hazard zones are not at risk of damage, but it does imply that WCC has taken the view that the likelihood of more intense events (e.g. a 500 year ARI storm event) is considered low enough not to require mitigating against. These studies considered sea level rise as the only climate change parameter, with an allowance made as recommended by the NSW Government's Sea Level Rise Policy (2009).

It is understood that WCC has recently established an Assets Management Plan for the LGA (2011) which ideally would be informed by the Coastal Zone Management Plan and vice versa.

SWC is undertaking an exercise to map the exposure of their assets to climate change. They are currently at a qualitative screening stage to determine which assets are likely to be exposed. The first two stages have been completed involving the telecommunications and energy sector. The final stage is about to commence to assess vulnerability to the exposed assets. There is currently no WCC involvement with this project.

SWC has also published a Climate Change Strategy document detailing their corporate approach to dealing with climate change. This includes an allowance for quantifying climate change risk to infrastructure and acting to mitigate those risks.

It is worth considering the potential for non-monetary damage costs that could be incurred should damage be sustained as a result of climate change events. These are most commonly associated with reputational costs borne by the body that the community feel is responsible. Local communities may not differentiate between bodies that have legal responsibility and those they assume to have responsibility for providing protective adaptation measures.

Local communities may have an expectation that WCC have a duty to protect their property from coastal damage associated with climate change, which should WCC fail to do so may incur political reputational costs. In some instances councils along Sydney's Northern Beaches have purchased private properties for demolition as a cheaper alternative to funding protective adaptive measures. SWC may suffer from reputational damages as a result of failure of the wastewater infrastructure. As a quasi-governmental entity, there may be the expectation that SWC should act more in the public interest than the local community may expect from a private organisation.

The political and social context, and any costs associated with failing to meet societal expectations should be included either quantitatively or qualitatively in any assessment for undertaking adaptive measures to consider climate change.

Ongoing collaboration between WCC and SWC is needed to collectively agree the levels of risk each is willing to accept when considering the extent of adaptation measures. This issue of risk appetite should be reviewed over time as the effects of climate change become noticeable.

5.3.2 Existing assets and values

5.3.2.1 General

A wide range of water infrastructure assets, as well as other asset types, are located within the case study area. The water infrastructure assets include:

- Storm water pipelines and outfalls.
- Wastewater pipelines, outfalls and vent structures and treatment plants.

Other asset types include:

- Roads, car parks, non-water related utilities.
- Residential and commercial properties.
- Community facilities (e.g. public baths, kiosks, surf clubs).

The condition of the existing water infrastructure assets is not recorded in the GIS information received from either WCC or SWC. Information on the construction date for the wastewater network is available and can be used to determine an assumed condition based on the expected working life for the given pipe type/material in the environment under consideration including consideration of pipe depth. The GIS information received from WCC does not include information on the pipe size, level, construction date or material. As only limited information is available for the existing condition of the assets within the hazard zone simplified methods have been adopted in assuming how they will be damaged due to climate change related events.

The wastewater pipe network lying within the coastal zone consists of a range of different pipe uses, materials and sizes from small 150mm diameter gravity reticulation sewers to 1200mm diameter trunk gravity sewers and a large diameter pressure main network. The level and hence importance of service can be related to the pipe diameter and type; with smaller gravity reticulation pipes providing local community connectivity into larger trunk and pressure main systems which service many reticulation networks and carry waste water to treatment works.

General details on the pipe type used within the stormwater network are not known across the study area.

The assets most exposed to climate change events are generally those located most seawards. The structural integrity of the asset will determine how susceptible it is to both foundation erosion and increased wave attack. It may be that some more robust assets can resist these affects and retain their integrity beyond those located landwards. Where assets are buried beneath the beach their vulnerability is also dependent on the depth to which they are buried and the type of material they are buried in. A detailed investigation of the structural condition of any potentially affected assets would need to be undertaken to determine their behaviour and response to this climate change event.

5.3.2.2 Asset vulnerability assessment

There are a number of beaches within the Wollongong study area, each which have a different number and type of assets to consider within the potential ‘at risk’ zones from coastal recession and associated geotechnical instability. In the second Stakeholder Workshop, it was decided that a systematic, semi-quantitative assessment of the vulnerability of SWC’s assets in the study area should be undertaken to identify the high risk sites within the study area. The results of this vulnerability assessment, considered within the context of the hazard study undertaken by WCC, would allow a decision to be made on which site within the study area to take forward for further analysis.

Details of the vulnerability assessment completed by Arup is contained within Section 5.8.1. A summary is provided below.

The following methodology was adopted:

1. For each of the 23 discrete sites/beaches in the study area, determine the type and extent of SWC assets within the 100 year ARI coastal recession hazard zone. SWC assets in the hazard zone were identified by overlaying SWC GIS asset information with WCC hazard zone GIS mapping data.

2. For those sites which have assets within the hazard zone, rate the asset (1- low, 2- medium and 3- high) for the following attributes. The value adopted was determined through judgement informed by the available information, consisting of the overlain SWC and WCC GIS data, for the site:
   a. Network (system) importance: i.e. What extent of impact on the serviceable network would occur with the asset being damaged/taken out of service.
   b. Vulnerability: i.e. How probable is it the asset will be damaged/taken out of service (probability of asset being physically impacted by event, and probability if this occurs that the asset will be damaged).
   c. Adaptive capacity: i.e. How easy is it to implement measures to make the asset less vulnerable.

3. Determine a risk value for each asset (A x B x C), and sum the ‘at risk’ assets up within each site. The higher the number for a site indicates a higher risk/vulnerability.

4. Rank each site according to the overall risk of its vulnerable assets.

Four sites were identified as containing the most overall ‘at risk’ SWC assets:

- Bellambi Beach.
- Austinmer Beach.
- Thirroul Beach.
- McCauleys Beach.

Out of the four highly ranked sites for SWC asset vulnerability, it is only for Austinmer Beach that a WCC adaptation measure (e.g. seawall) would also provide protection to all SWC’s vulnerable assets. For the other beaches, WCC would need to extend their hard defences significantly to also protect all of SWC’s assets.

While ranked highly for having a number of vulnerable SWC assets, Bellambi Beach only has a very limited number of other assets within the hazard zone to consider (e.g. SWC, properties, roads). Adopting this option would therefore not meet the project objective of considering interconnectivity between water infrastructure types. McCauleys Beach is similar to Bellambi Beach in terms of this.

The sites of Thirroul Beach and Austinmer Beach are similar in terms of vulnerability of SWC assets but also include a number of other assets in the hazard zone (e.g. SWC, properties, roads). It is acknowledged that WCC have previously indicated their interest in sites with properties at risk. Thirroul Beach contains a handful of properties/building in its hazard zone, more-so than Austinmer Beach. In addition, Thirroul Beach is more interesting because WCC have already completed an economic appraisal for this site. It would therefore be advantageous to build on this initial appraisal by incorporating SWC’s assets and adopting a more sophisticated economic model. A useful comparison can then be made between the preliminary and more-comprehensive economic appraisal outputs.

<u>It was therefore recommended that the Thirroul Beach site be taken forward for further appraisal</u>.

This exercise has proven to be a useful starting point for narrowing down which beaches/sites within the case study are most vulnerable to climate change and therefore which to focus on when prioritising managed adaptation.

5.3.2.3 Storm events considered

Building on work previously undertaken in WCC’s Coastal Zone Study where damage extents were calculated for a 100 year ARI event now and in the future, Arup first undertook a high level sensitivity analysis of how the incident wave height at the coastline varied with event ARI for the chosen site of Thirroul Beach.

This analysis was completed using the beach erosion prediction software SBEACH with the input beach profile and metocean conditions derived from those provided in the Coastal Zone Study. Arup found that the incoming waves are generally depth limited (meaning water depths are shallow enough to break the wave before reaching the shoreline) for events more extreme than between about a 5-20 year ARI. As such, all storm events with an ARI of greater than approximately 5-20 years result in a similar wave height, and with only small differences in water level between different ARI events the resulting damage to coastal assets is also similar.

This led Arup to choose the1year, 5 year and 100 year ARI storm events for further analysis (refer Section 5.4.3).

5.3.3 Ownership and investment model

The two main types of interconnected waters assets under consideration within the study area are wastewater and stormwater infrastructure. WCC has ownership of and responsibility for the stormwater network and associated assets, and also has ownership/stewardship of various community assets located along the coastline including public baths, kiosks and lifesaving clubs. SWC has ownership of and responsibility for the sewerage network and associated assets.

Investment in capital projects and maintenance for the stormwater network is funded by WCC. Their main source of funding is through council rates and charges; other funding comes through sources including government grants and revenue from investments. Residential and business rates include a Stormwater Charge to manage water quality and quantity, introduced in accordance with the Local Government Amendment (Stormwater) Act 2005. The Act allows for annual charges to be made and levied towards the cost of providing stormwater management services.

Investment in capital projects and maintenance for the wastewater network is funded by SWC. SWC source funding through the rates and charges levied for the supply of water and wastewater services to residential and commercial consumers. IPART determines the prices that customers pay for water, wastewater, stormwater and other services in Sydney, the Blue Mountains and the Illawarra through periodic reviews.

Within the chosen specific study site of Thirroul Beach, there also exist a number of non-water related assets at risk from climate change events, whose owners have a vested interest in the asset being maintained. The owners of these non-water related assets include different departments within WCC who manage and maintain the varied assets under WCC ownership/stewardship (e.g. carparks), RMS (e.g. roads), and private owners (e.g. residential and commercial properties). However, WCC as the local government body may also have some duty of care to protect these private assets.

It is worth considering how funding could be leveraged from different stakeholders, with the value of their contribution to Opex (operational /maintenance expenditure) and Capex (capital expenditure) costs being proportionate to the benefit value they derive from the implementation of the project. Within the economic analysis stage of this appraisal Arup has looked at the Benefit Cost Ratio (BCR) of both the project as a whole, and the isolated value to SWC of implementing one of the considered adaptation options against the implementation costs.

5.4 Adaptation Options

5.4.1 Options Identified

Considering the whole Wollongong study area, the following main potential climate change adaptation options were identified within the workshops:

- Relocation of assets landwards.
- Construction of coastal structures (seawalls, breakwaters, etc.).
- Dune management/beach nourishment.
- Introduce planning measures to provide a buffer zone to allow for asset relocation, access routes, easements.
- Increase the resilience of existing assets against the direct climate change consequences.

In Workshop 2, the adaptation options participants specifically agreed to consider the following adaptation options for the economic appraisal:

- Moving the infrastructure out of the hazard zone.
- Maintaining the infrastructure on an ongoing basis (i.e. repairing faults and failures, increased pumping, etc.).
- Protecting the infrastructure (i.e. seawall).

Since Workshop 2, Thirroul Beach was chosen as the site to progress to the detailed economic appraisal. Arup considered four specific adaptation measures, partially informed from the measures considered within the WCC Coastal Zone Study. These are listed below and described in more detail in the following sections:

- 1a: Full length seawall with beach nourishment.
- 1b: Full length seawall without beach nourishment.
- 2: Partial length seawall with beach nourishment.
- 3: Planned retreat.

These adaptation options were considered along with the Business As Usual (BAU) scenario which involves reactive insitu maintenance/repair of existing assets damaged from coastal storm events only.

5.4.1.1 1a, 1b: Full seawall with/without nourishment

This option is illustrated in Figure 16. A sea wall extending the full length of the beach protects all at-risk assets located within the hazard zone. The seawall with beach nourishment maintains the beach amenity in front of the wall whereas without nourishment the beach will recede landwards over time gradually reducing the available beach amenity area.

Figure 16 Adaptation Option 1a and 1b (Source: Arup, WCC and SWC, 2012)

5.4.1.2 2: Partial seawall with nourishment & partial planned retreat

This option is illustrated in Figure 17. The partial length seawall option protects all but a single private property and the SWC assets which run along the northern end of the beach for which a planned retreat would be implemented. There appears to be sufficient space to relocate these northerly assets to landwards of their existing locations beyond the 100 year ARI hazard line. Under this option beach nourishment is undertaken and beach amenity is therefore maintained.

Figure 17 Adaptation Option 2 (Source: Arup, WCC and SWC, 2012)

5.4.1.3 3: Full planned retreat

This option is illustrated in Figure 18. Planned retreat of all assets considers the relocation of all affected assets outside of the 100 year ARI hazard zone and allows the natural erosion and recession of the beach. Under this option beach amenity is maintained. This option assumes there are no land-side constraints to relocation.

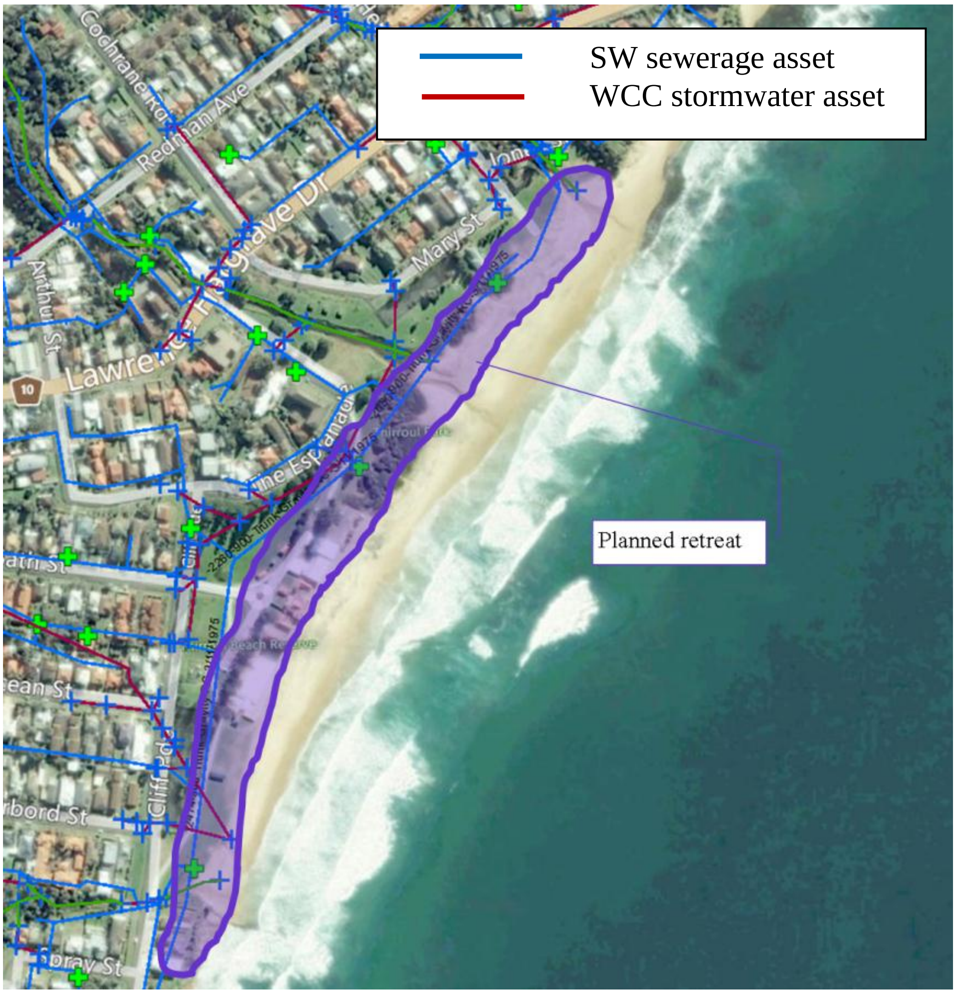


Figure 18 Adaptation Option 3 (Source: Arup, WCC and SWC, 2012)

The assumed capital and maintenance costs associated with each of these options adopted within the economic appraisal are detailed in Table 22.

Table 22 Assumed costs associated with adaptation options[6]

Option	Capital Cost	Maintenance Cost
1a: Full length seawall with beach nourishment	Seawall $9,000,000 Beach nourishment $450,000 Protect outfalls $10,000	Seawall $450,000 per annum Beach nourishment $225,000 every 10 years

[6] Refer to the Economic Appraisal in Section 5.8.2 for a build up of the costs summarised in this table.

1b: Full length seawall without beach nourishment	Seawall $9,000,000 Protect outfalls $10,000	Seawall $450,000 per annum
2:Partial length seawall with beach nourishment and partial planned retreat	Seawall $5,300,000 Beach nourishment $225,000 Relocation of SWC assets along the northern length $1,314,445 (assumed same cost as replacing assets **insitu**) Relocation of private property assets along northern length $2,000,000 (assumed same cost as replacing assets insitu)	Seawall $265,000 per annum Beach nourishment $75,000 every 10 years
3: Full planned retreat	Relocation of all assets $30,862,786 (assumed same cost as replacing all assets insitu)	None

Note that costs associated with ongoing maintenance and operating costs of assets would be the same for all options including the BAU scenario, and therefore are not considered in this relative analysis.

In addition to these more obvious costs associated with each adaptation option, there are also less tangible costs that would ideally be considered:

- Societal costs associated with the loss of amenity space which would result if a hard defence structure is installed to hold the line whilst beach recession causes narrowing of the beach in front of the defence. This can be avoided by undertaking beach nourishment, although the exercise would need to be periodically maintained to avoid future loss of beach area.
- Lost opportunity costs associated with the loss of land development potential for new development if it is required for the relocation of assets under a planned retreat adaptation option.
- The value of coastal land, especially on highly prized beachside sites, may become more volatile if there is uncertainty as to whether the land is protected from damage resulting from climate change events, and the legal responsibilities for providing protection. This price volatility may also feed into the rental market.

The economic appraisal undertaken for this study has only attempted to quantify the first of the above less tangible costs.

For each of the four considered adaptation options to be realised, prior steps as listed below would need to be undertaken in advance of implementation. This is not an exhaustive list and the timescales for each of these depend on numerous factors.

All Options:

- Agreement between stakeholders on choice of adaptation option.
- Secure funding for the scheme.
- Environmental impact assessment for the scheme.
- Obtaining planning approvals.
- Construction licences.

Option 1a: Full length seawall with beach nourishment

- Engineering design of the seawall and nourishment.
- Obtaining dredging approvals and licence for the source of the beach nourishment material.

Option 1b: Full length seawall without beach nourishment

- Engineering design of seawall.

Option 2: Partial length seawall with beach nourishment and partial planned retreat

- Engineering design of seawall and nourishment
- Obtaining dredging approvals and licence for the source of the beach nourishment material.
- Design of relocation of SWC assets.
- Compulsory purchase of the affected private property and planned relocation options.

Option 3: Full planned retreat

- Development control planning to allow for relocation of assets.
- Design of relocation of all assets.
- Compulsory purchase of the affected properties and planned relocation options.

5.4.2 Barriers and adaptive capacity building options

5.4.2.1 Barriers to implementation of adaptive measures

In Workshop 2, the key barriers to implementation of the adaptation options listed in Table 23 were identified for the different broad forms of adaptive option.

Table 23 Barriers to implementation of adaption options

Adaptation Option	Barrier
Dune/beach nourishment management (soft engineered measures)	Sourcing of sand NSW Government prohibits offshore dredging for sourcing sand for nourishment (moratorium) Ownership & responsibility Assumes a benefits based approach Responsibility is more clear for hard rather than soft options Community opposition Compromise on beach amenity Climate change scepticism Some decision makers are unwilling to invest in managing projected future risks now with the current uncertainties
Seawall (hard engineered structural measures)	Funding Capital & ongoing maintenance levy Argument over extent of benefits & distribution/contribution to capital costs Ownership/responsibility Unclear for future long-term plan Currently emergency protection responsibility is clear Community acceptance Willingness to accept beach loss/loss of amenity area Mismatch in benefit and amenity loss Potential risk to tourism Climate change scepticism Some decision makers are unwilling to invest in managing projected future risks now with the current uncertainties
Retreat Options (Property)	Community Time-frame & where to retreat to Litigation Duty of care to protect Council exempt if due process is followed Council is liable if the Development Control Plan (DCP) allows construction where/when a known problem exists Funding Land acquisition costs Spatial Land availability Access to infrastructure Easements Climate change scepticism Some decision makers are unwilling to invest in managing projected future risks now with the current uncertainties

5.4.2.2 Overcoming barriers to adaptation

Some high level means to overcome the key barriers to the implementation of adaptation options for this case study have been identified in Table 24.

Table 24 Means to overcome barriers to adaptation

Barrier	Means to overcome barrier
Sourcing of sand Moratorium on offshore dredging	The Australian states and federal government have different legislative approaches to offshore dredging. Some states such as NSW do not permit dredging within their territorial waters whereas other states do permit this activity, as does the federal government. The political and legislative environment for the site location should be investigated early on in the project if beach nourishment is being proposed. If required sediment could be sourced from port and harbour dredging programs, or from further afield where dredging is permitted, although any additional costs should be considered within the economic appraisal.
Ownership & responsibility Assumes a benefits based approach Responsibility is more clear for hard rather than soft options	Undertake early stakeholder engagement to determine their attitude to risk and willingness to fund protective measures. Clearly define the legal responsibilities different parties have for providing and funding protective measures against climate change events before such measures need to be implemented. For adaptive measures that incur significant maintenance liabilities agree how the funding of these liabilities will be met during the planning stage of the adaptive measures project, prior to construction. (See funding barrier for how these costs could be apportioned.)
Community acceptance & opposition Compromise on beach amenity	Undertake early community consultation on proposed adaptive options and identify the opportunity cost of spending on protection of certain assets (i.e. preservation of beach amenity in the existing case will cost x amount, that will not be available for other community projects).
Funding Capital & ongoing maintenance levy Argument over extent of benefits & distribution/contribution to capital costs	Undertake an economic appraisal that can determine the cost of the benefit that each stakeholder will realise from the implementation of the project. The results of this can be used to apportion the capital and maintenance costs associated with the scheme. Secure agreement on how costs are to be apportioned before the scheme is commenced to avoid dispute and risk to the project.

Barrier	Means to overcome barrier
Litigation	Ensure all stakeholders are aware of who has the legal responsibility to provide protection to which assets. Develop a clear road-map for how adaptation to climate change events is to be implemented. Include within work undertaken to develop coastal zone management plan 'trigger' events that require further stages of work for adaptation for climate change events to be considered.
Spatial	Include allowances for land that will be required for relocated properties and assets in DCPs early to avoid conflicting land use. Use DCPs to zone land appropriately to avoid further development occurring on land that is intended to be lost should a planned retreat option be implemented.
Climate change scepticism	Undertake quantitative assessments with sensitivity testing to demonstrate to decision makers the potential economic consequences for delaying adaptation management planning.

5.4.3 Economic appraisal

5.4.3.1 General

Compared to the other case studies considered for this project, sufficient information exists to perform a preliminary, relatively-detailed quantitative economic appraisal. This appraisal can be used to determine which adaptation option may be the most favourable based on the available information and the assumed climate change projections.

As discussed previously, in agreement with SWC and WCC, Thirroul Beach was selected by Arup as the study beach for Arup's economic appraisal. The economic appraisal investigated the costs associated with implementing different adaptive options against the costs of damages to assets within the hazard zone.

Arup's appraisal builds on a previous economic appraisal undertaken at Thirroul Beach as part of the Wollongong Coastal Zone Management Plan, the main differences being:

- Arup's appraisal considers WCC and SWC assets, whereas the previous appraisal considered WCC assets only.
- The previous appraisal considered damages for a 100 year ARI event only, whereas Arup's appraisal estimates damages for the full range of return period events based on the extrapolation and interpolation of damages for three ARIs.
- Arup's appraisal forecast period is present day until 2050, whereas the previous appraisal was until 2100.

All water infrastructure and non-water assets were considered in this economic appraisal.

A summary of the economic appraisal is provided below, to be read with accompanying information and data provided in Section 5.8.2.

5.4.3.2 Methodology

Cost Data

The input cost data for undertaking the appraisal has been sourced from a number of locations, primarily:

- Existing WCC economic appraisal for Thirroul Beach (2011).
- Rawlinson's Australian Construction Handbook (2012).
- Sydney Water costing spreadsheet for typical SWC assets (incomplete) and Sydney Water compensation policy.
- Arup in-house cost information.

Note that all cost data has been adjusted to 2012 costs for the appraisal.

Appraisal period

Present day (2012) until 2050.

Storm Events Considered

The economic appraisal has been completed using damage costs calculated for the 1 year, 5 year and 100 year ARI storm events as previously discussed in Section 5.3.2.2.

The figure below shows how damage costs vary with ARI, and as discussed previously it can be seen that above an approximately 5-20 year ARI event the damage costs remain broadly constant. Due to limits on the time and budget available for this appraisal only the three ARI events have been considered. Increasing the number of ARI events considered would improve the definition of the trend line.

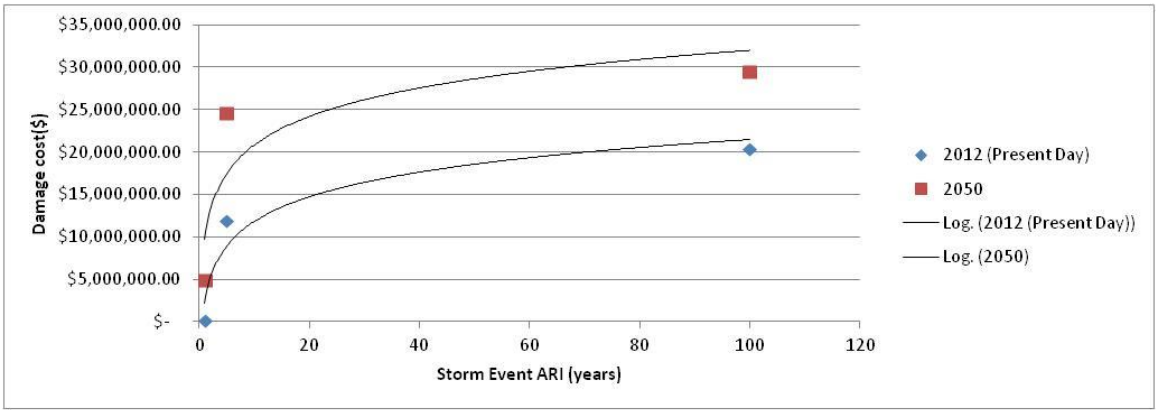


Figure 19 Estimated total asset damage costs at Thirroul Beach for various return periods (ARIs) at year 2012 and 2050.

This limitation on wave height due to water depth will be common across most Wollongong beaches with a shallow sloped bed profile which forces waves over a certain height to break before reaching the shore.

Expected Damage Cost

The damage costs associated with each storm event ARI have been weighted by the probability of exceedance of that event occurring in any one year. Weighting the damage costs allows the full range of storm event ARI periods to be included within the analysis giving an expected damage cost.

Total damage costs (direct and indirect) over the appraisal period for each adaptation option (including the BAU scenario) were calculated as being the area under the damage vs. probability of annual exceedance curve developed.

Net Present Value (NPV)

The Net Present Value (NPV) for each option was calculated over the appraisal period as the difference between the expected total damage costs of the BAU scenario and the damage costs following implementation of the adaptation option, subtracting the costs of implementing the adaptive measure (Capex and Opex), as shown in the formula below.

The NPV figures have been determined considering a range of discount rates, 0%, 4%, 7% and 10%. Including a discount factor accounts for the financial benefits associated with deferring investment into the future.

$$NPV = \overbrace{[BAU\ damage\ cost - Adaptation\ Option\ damage\ cost]}^{\text{Benefit of implementing adaptive measure}} - \underbrace{Adaptation\ Option\ CAPEX + OPEX}_{\text{Cost of implementing adaptive measure}}$$

Benefit Cost Ratio

The Benefit Cost Ratio (BCR) was calculated for each adaptation option. It attempts to describe the value of implementing a particular option in terms of the ratio of the benefit of implementation against the cost of implementation, as shown in the formula below.

$$BCR = BAU\ damage\ cost - \frac{Adaptation\ Option\ damage\ cost}{Adaptation\ Option\ implementation\ cost}$$

5.4.3.3 Limitations and assumptions

The economic appraisal undertaken for this study as part of the overall project has been undertaken as an example based on incomplete data and some basic assumptions and should not be used for decision making at Thirroul Beach or any other site until key assumptions can be more properly verified.

A number of assumptions were required to be made by Arup in undertaking this economic appraisal as follows:

- Storm hazard lines and therefore asset damage determined for 2010 will be the same for 2012 (i.e. negligible difference).
- It was assumed that assets seaward of the hazard lines would be completely damaged from the storm event. In reality, some assets may only be partially damaged, or not at all (e.g. where pipelines or buildings are placed on robust foundations).
- Where planned retreat has been proposed sufficient space exists for relocation of retreating properties.
- The cost of repairing total damage to an asset/property is equal to the cost of relocating that asset/property.
- The appraisal does not consider the societal non-monetary costs associated with damage, such as public health costs as a result of failure of the wastewater network.
- It has been assumed that a complete property will be damaged if any part of it is within the zone of reduced foundation capacity, all other assets are assumed to be damaged if they are located within the erosion hazard zone.
- A cost of $50 per affected household has been assumed for the loss of service compensation costs for the loss of wastewater and stormwater service should these networks be damaged.

The economic model used within this appraisal aims to capture the costs of losing amenity space, in particular lost beach amenity. Our findings indicate that the appraisal can be especially sensitive to the value attributed to beach amenity. To increase confidence in the cost associated with this a ‘willingness to pay’ approach could be considered.

5.4.3.4 Results

The tables and figures below summarise the results of the economic appraisal. Both the costs of adaptation for all the assets, and for SWC assets only, have been considered. Results provided below assume a discount rate of 7%. For the full results with a range of discount rates please refer to Section 5.8.2.

Figure 20 and Figure 21 show how the NPV varies depending on the year in which the adaptation option is implemented. Depending on how the value of costs and benefits change with time and respond to the implementation of the adaptation measure this can vary when it is economically optimal to implement the option.

Table 25 and Table 26 display the results of the economic analysis including the NPV and BCR. Descriptions of the key terms used in the analysis are provided in the tables.

Table 25 Net Present Value (NPV) for each adaptation option (including the 'business as usual (BAU) scenario) implemented in year 2015 for all assets

Adaptation option	Expenditure		Damage costs			Analysis of adaptation option		
	CAPEX [2]	OPEX [3]	Sydney Water Assets	Other Assets [4]	Loss of beach amenity	Total Cost [5]	NPV [6]	BCR [7]
BAU [1]	n/a	n/a	$4,123,913	$111,039,295	n/a	$115,163,209	$-	n/a
Adaptation Option 1a	$7,209,360	$4,599,139	$684,153	$21,317,954	n/a	$33,810,605	$81,352,603	7.89
Adaptation Option 1b	$6,866,057	$4,444,973	$684,153	$21,317,954	$16,315,701	$49,628,837	$65,534,372	6.79
Adaptation Option 2	$6,743,571	$2,668,984	$684,153	$22,843,744	n/a	$32,940,452	$82,222,757	9.74
Adaptation Option 3	$23,545,059	n/a	$684,153	$21,317,954	n/a	$45,547,165	$69,616,043	3.96

Notes:

[1] Costs if no action was taken over the entire 38 year appraisal period except for reactive repair/replacement to storm events

[2] CAPEX = Capital expenditure

[3] OPEX = Operational/maintenance expenditure

[4] Assets not owned by SWC (e.g. WCC, private property)

[5] Total Cost = The total cost of implementing the option, being the sum of expenditure and damage costs allowing for the benefits derived from the option being implemented

[6] NPV = Relates the differences in costs in implementing adaptation against the BAU scenario, a greater than unitary value represents a net benefit to implementation

[7] The ratio of investment in CAPEX and OPEX required for each option related to the savings in damage costs. A higher value for BCR represents a higher return on investment for a given option.

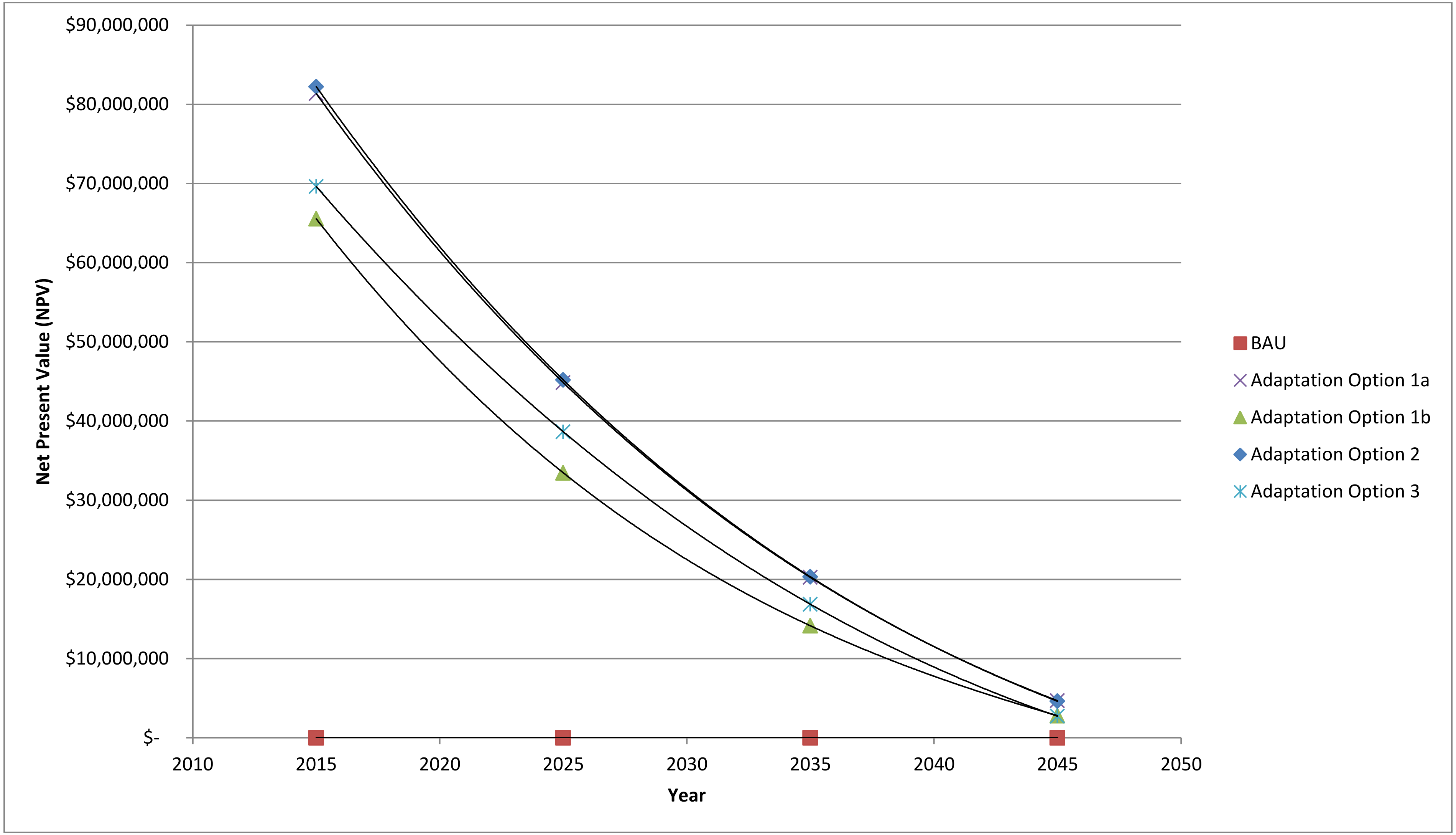


Figure 20 NPV for each adaptation option (including the BAU scenario) for **all assets** depending on the year of implementation of the adaptation measure. The figure shows that the greatest NPV is achieved if all options are implemented as soon as possible. The option providing the overall greatest benefit is Option 2 (Partial seawall with beach nourishment), closely followed by Option 1a (Full seawall with beach nourishment).

Table 26 NPV for each adaptation option (including the BAU scenario) implemented in year 2015 for SWC assets only

Adaptation option	Expenditure		Damage costs			Analysis of adaptation option		
	CAPEX [2]	OPEX [3]	Sydney Water Assets	Other Assets [4]	Loss of beach amenity	Total Cost	NPV [6]	BCR [7]
BAU [1]	n/a	n/a	$4,123,913	n/a	n/a	$4,123,913	$-	n/a
Adaptation Option 1a	$7,209,360	$4,599,139	$684,153	n/a	n/a	$12,492,651	-$8,368,738	0.29
Adaptation Option 1b	$6,866,057	$4,444,973	$684,153	n/a	n/a	$11,995,182	-$7,871,269	0.30
Adaptation Option 2	$6,743,571	$2,668,984	$684,153	n/a	n/a	$10,096,707	-$5,972,794	0.37
Adaptation Option 3	$1,002,784	n/a	$684,153	n/a	n/a	$1,686,937	$2,436,976	3.43

Notes

[1] Costs if no action was taken over the entire 38 year appraisal period except for reactive repair/replacement to storm events.

[2] CAPEX = Capital expenditure.

[3] OPEX = Operational/maintenance expenditure.

[4] Assets not owned by SWC (e.g. WCC, private property).

[5] Total Cost = The total cost of implementing the option, being the sum of expenditure and damage costs allowing for the benefits derived from the option being implemented.

[6] NPV = Relates the differences in costs in implementing adaptation against the BAU scenario, a greater than unitary value represents a net benefit to implementation.

[7] The ratio of investment in CAPEX and OPEX required for each option related to the savings in damage costs. A higher value for BCR represents a higher return on investment for a given option.

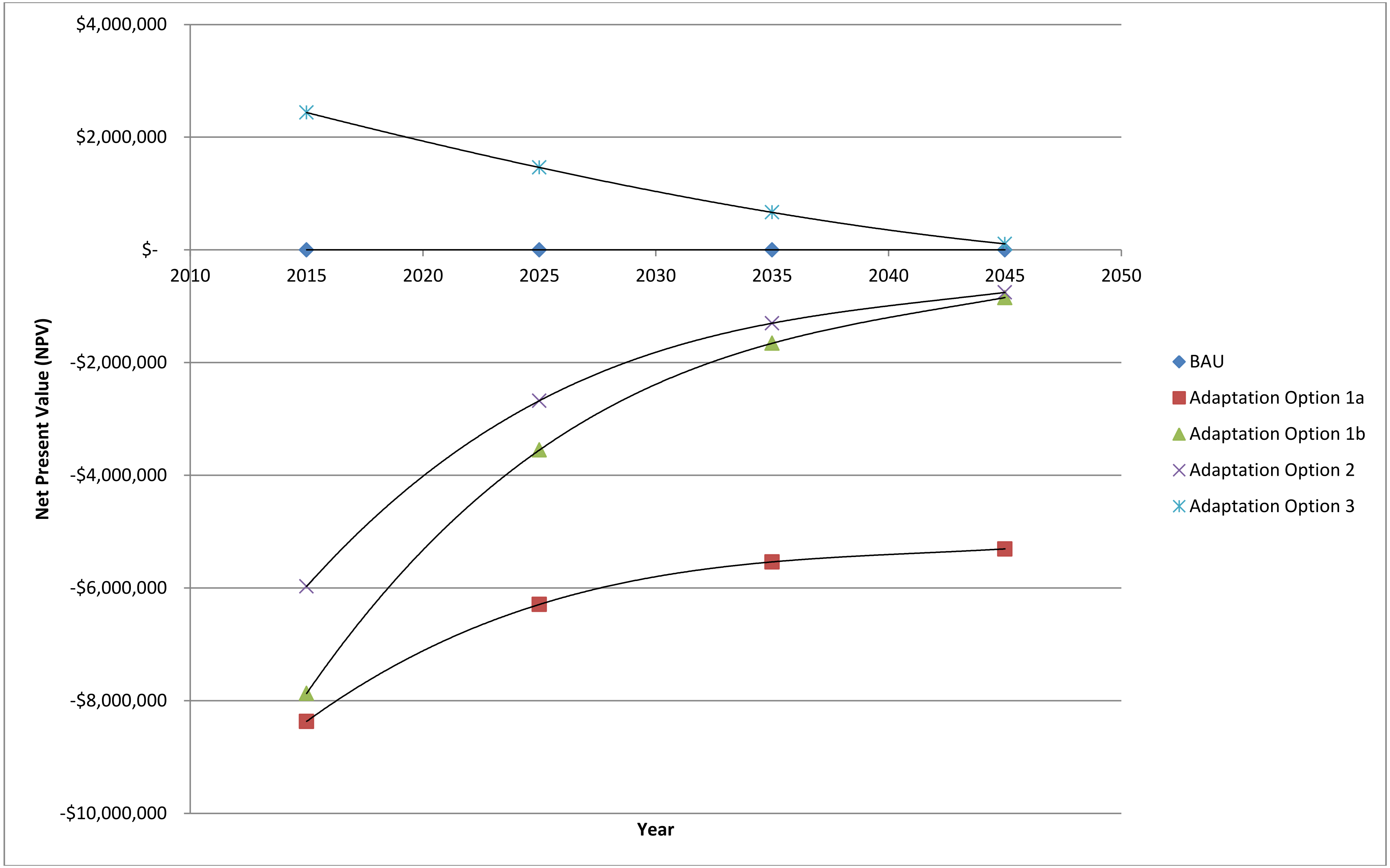


Figure 21 NPV for each adaptation option (including the BAU scenario) for **SWC assets only** depending on the year of implementation of the adaptation measure. The figure shows that only Option 3 (Full retreat) would be economically beneficial to adopt compared to the BAU scenario when considering SWC's assets in isolation.

5.4.3.5 Discussion

The following conclusions can be drawn from the results of the appraisal.

All assets considered

- For all assets considered, all adaptation options are much more favourable compared to the BAU scenario. This is shown both in Table 25 where all adaptation options have a BCR of greater than 1, and in Figure 20 where it can be seen that all the options present a positive NPV.
- Option 2, the partial sea wall and planned retreat option with beach nourishment, has the highest BCR of all the options and would therefore be the preferred adaptation option for this scenario.
- It can be seen in Figure 20 and Table 25 that whilst there is only a small benefit when considering NPV in implementing Option 2 over Option 1a, there is a more significant benefit when considering the BCR between the two options. This shows that whilst both options result in a similar reduction in the value of damage, Option 2 does so for a lower Capex and Opex.
- Option 1b, the full length seawall without beach nourishment, is the least favourable of the adaptation options as it has the lowest BCR.
- The results are highly sensitive to the assumed cost of maintaining beach and reserve amenity.
- Figure 20 shows that it appears to be more cost effective to enact adaptive options sooner as opposed to later. This is likely because the selected study area, Thirroul Beach, was selected on the basis that assets were already at threat of damage from climate change events. For other beaches with assets generally set back further the same analysis might show it to be more beneficial to defer implementing adaptive measures.
- Depending on the discount factor used the relative difference between the benefits of implementing the different adaptation measures does vary. Whilst the relative difference between the BCR of the different options varies with discount factor, Option 2 is still always the preferred option with the highest BCR.

Sydney Water Assets only considered

- Option 3, planned retreat of SWC's assets, would appear to be the only cost effective option from SWC's perspective if considering their assets in isolation compared to the BAU scenario, and would therefore be the preferred option. Option 3 is the only adaptation option with a positive NPV and BCR above 1, showing there is a positive return on investment.
- Figure 21 shows that it appears SWC would also benefit from implementing the preferred adaptive option sooner as opposed to later, with the NPV of implementing adaption Option 3 reducing with implementation time into the future. However, the profile of the curve is far less steep suggesting the change in BCR with time is not as pronounced. SWC should therefore consider the benefits and costs of the timing of funding this option with respect to their overall asset

management strategy and where their limited funding can be most effectively deployed.

General conclusions

- Economically, the most favourable adaptation option for considering just SWC's assets (planned retreat) changes if all assets are considered (seawall with beach nourishment). This means that if SWC considers the adaptive management of their assets in isolation, they might take steps for planned retreat, however this may not be necessary (i.e. wasted costs) depending on the adaptive measure that WCC implement. If WCC implement the preferred option resulting from this appraisal, Option 2, this option proposes planned retreat for SWC's assets which is compatible with the preferred option for when SWC's assets are considered in isolation.
- In terms of NPV damage costs over the appraisal period until 2050 without adaptation measures (i.e. BAU scenario), SWC's costs are less than 5% of the total assets (SWC and WCC). When considering jointly funding an adaptation measure such as a seawall, this distribution of costs avoided might be considered in terms of assigning proportion of funding and making a business case in this respect. Before agreeing funding responsibilities both parties should be satisfied the costs and benefits have been appropriately determined such that the value each party derives from the implementation of the project is best represented.
- With this form of economic assessment the scale of magnitude of the cost avoided through early implementation of the adaption option tends to distort the implementation date optimisation. For this case study the results show it is always ideal to implement any of the considered adaptive measures sooner rather than later. In different scenarios, and considering different discount factors, this may not always be the case. The adaptive measure implementation date should be optimised by assessing the changes in NPV with time, not BCR. The BCR should only be used to assess the benefit cost ratio across different options for a given year of implementation.
- The assessment has been undertaken assuming that the costs of relocating assets are equal to the cost of in-situ replacement, and there are no obstructions to relocation including planning approvals, operational constraints or availability of land. The validity of these assumptions should be confirmed in more detailed investigation.
- The range of options considered within this assessment is not exhaustive and there may be barriers to their implementation that have not been identified. As such any option identified as most cost effective, is the most cost effective of the options considered.

5.5 Flexible Adaptation Pathway

For the Thirroul Beach example considered by Arup, the conclusions of the preliminary economic appraisal suggest that adaptation options are available which are more economically favourable than the status quo in terms of comparative expected damage costs until 2050, and in this case there is actually no economic benefit in delaying their implementation (although there may be barriers preventing this).

However, it may be that other beaches along Wollongong's coastline with assets that are currently not as vulnerable to damage from storm events as Thirroul Beach would show through economic appraisal that implementation of measures can be delayed until a point further into the future, and this would provide some flexibility in the choice of measures available to eventually adopt (if any at all).

Where the economic appraisal shows it is beneficial to implement adaptive measures at a time in the future, this point in time can be considered a 'trigger' point. The stakeholders will need to have undertaken a number of planning steps prior to this 'trigger' in order for the adaptation option to be implemented at the identified point in time. These cross-stakeholder planning stages include, identification of a preferred adaptation option, obtaining any necessary planning approvals and funding agreements between stakeholders.

In addition, this study did not specifically consider more flexible/modular or 'real' options such as implementing a seawall designed for present-day100 year ARI conditions with measures in place to allow augmenting the structure in the future (e.g. crest raising) to account for differences between forecast and actual climate change should this be necessary.

5.6 Implementation

The vulnerability assessment for the Wollongong study area, and specific economic appraisal of Thirroul Beach undertaken as part of this project by Arup provide examples of how WCC and SWC could work collaboratively to pool their knowledge and data to assist in identifying the sites within the study area to focus on, and undertake a quantitative economic appraisal of a range of possible adaptation measures to inform decision making.

It is recommended that WCC and SWC work collaboratively to close information gaps and further develop the preliminary work undertaken as part of this project. Specifically, recommended steps include:

- Of the 23 beaches/sites along Wollongong's coastline, as a screening exercise prioritise those for further consideration by identifying the most vulnerable to climate change. An approach for determining the most vulnerable beaches should be agreed by all stakeholders. This screening process may be similar to that already undertaken by Arup, but perhaps include agreed criteria for when a beach is vulnerable enough to warrant more detailed assessment.

- Carry out an economic appraisal of the most vulnerable beaches along the Wollongong coastline which considers erosion/recession as well as coastal inundation events with the best available input data. In particular, a better understanding of actual damage, relocation and replacement costs of assets, and the more intangible costs such as loss of beach amenity, is needed. The detailed appraisal should identify the optimal commencement of adaptation options for the highest economic benefit, and the trigger points in time for when decisions need to be made, taking account of planning and design periods. Ideally the analysis should also consider a range of climate change parameter projections to understand sensitivities.

- If the economic appraisal for a beach concludes that there is no benefit to implementing adaptation options at any time at the beach in the planning period, continue the business as usual approach and reassess again if critical new input information is made available in the future.
- If the economic appraisal for a beach concludes there is benefit in implementing one or more adaptation options, combine the results of the appraisal in a more overarching assessment to consider non-economic metrics such as the ability to overcome key barriers to implementing adaptation options including funding. Where identified barriers are found to have a reasonable chance of being overcome, commence planning for the preferred adaptation option by preparing a business case for obtaining funding and undertake the required planning and design studies leading up to the previously-identified optimum implementation date.

5.7 Ongoing Monitoring and Evaluation

What to monitor?

Climate change projections are clearly a key area of uncertainty and should be monitored for deviations away from the forecast levels. However there are other factors that will influence the need and ability to implement adaptation that should be monitored along the sites deemed ‘at risk’, including:

- The space available behind the hazard area for asset relocation.
- The space available behind the hazard area for asset relocation.
- Cliff failure and geotechnical instability, which would influence the hazard areas.
- Network system importance, where changes in population may increase the significance of system failure.
- Installation of new assets and repairs/modifications made to existing ones.

How often?

It is not possible to specify a precise timeframe for the monitoring except that it should be done to a reasonable timetable, such that deviations from assumptions made can be recorded and assessed in sufficient time that the implementation of an adaptation option can be flexibly managed so it is installed at a revised opportune time.

Who?

The monitoring information identified above would likely be collected on an on-going basis by all the key stakeholders as extensions of their existing asset management. It should be noted that the data has maximum value when it is shared and collated to provide a detailed overview of the interconnected systems.

What to do with the monitoring information?

The process described in Section 5.6 should be revisited over time when critical changes to previous inputs and assumptions become apparent (e.g. sea level rise projections or the risk appetite at the time), or when an adaptation measure has been implemented at a beach.

5.8 Attachments

5.8.1 Vulnerability Assessment

Climate Change Climate Change Adaptation for Interconnected Water Infrastructure - Case Study 4 (Wollongong)

Vulnerability Assessment of Sydney Water Assets

Data Sources: GIS data of Sydney Water Assets for Wollongong LGA
WCC Coastal Zone Study (Cardno, 2010)

Location	Sydney Water Asset Type[1]	Asset Details	Level (mmAHD)	Date Laid	Extent of asset vulnerable to 100yr ARI event: Present Day	Extent of asset vulnerable to 100yr ARI event: 2050 (+ PD)	Notes	A. Network Importance L (1) / M (2) / H (3)	B. Vulnerability L (1) / M (2) / H (3)	C. Adaptive Capacity L (1) / M (2) / H (3)	Risk A x B x C	Risk Sum	Rank	WCC Proposed Adaptation Measures	Comments
Stanwell Park Beach	*None within 100yr ARI hazard zone*														
Coalcliff Beach Reserve	*None within 100yr ARI hazard zone*														
Scarborough/Wombarra Beach	*None within 100yr ARI hazard zone*														
Coledale Beach	*None within 100yr ARI hazard zone*														
Sharkies Beach	Branch Gravity Sewer	525mm dia VC	800	1980	n/a	60m		2	2	2	8	9	9		
	Gravity Overflow Sewer	525mm dia VC	2800	1980	n/a	5m		1	1	1	1				
Austinmer North Beach (Little Austinmer)	Brranch Gravity Sewer	600mm dia VC	1300 / 3290 /	1977	360m	130m		2	2	3	12	15	7		
	Reticulation Gravity Sewer	150mm dia VC	4920	1977	n/a	5m		1	1	1	1				
	Reticulation Gravity Sewer	150mm dia VC	2270	1977	8m	8m		1	1	1	1				
	Reticulation Gravity Sewer	150mm dia VC	2650	1977	n/a	8m		1	1	1	1				
	Ventshaft										n				
Austinmer Beach	Trunk gravity sewer	750mm dia RC	-370 / -600	1977	150m	300m		3	2	3	18	30	3	Seawall Option Should provide protection to all SW assets depending on final alignment.	- Site has a variety of WCC assets at risk: Property, car park, community baths, extensive stormwater network, roads
	Reticulation Gravity Sewer	225mm dia VC	2450	1977	n/a	10m		1	1	2	2			Planned Retreat Option Beach management and dune revitalisation may afford some protection to SW assets.	- Hard defence (seawall) and managed retreat options identified
	Reticulation Gravity Sewer	300mm dia VC	N	1977	n/a	20m		1	1	2	2				- Sydney Water pipe network appears to be at levels near to AHD/MSL which would indicate high vulnerability.
	Reticulation Gravity Sewer	225mm dia VC	1120 / 2510	1977	n/a	15m		1	2	2	4				
	Reticulation Gravity Sewer	150mm dia VC	1240	1977	n/a	20m		1	2	2	4				
	Ventshaft										n				
	Ventshaft										n				
Thirroul Beach	Trunk Gravity Sewer	900mm dia RC	-1977 / 1437	1975	320m	70m		3	3	3	27	32	2	Seawall Option 1 SW assets not within seawall protected length. Beach management and dune revitalisation along length of beach may provide some protection.	- Site has a variety of WCC assets at risk: Private and commercial properties, car park, baths, stormwater network (much less extent than Austinmer Beach)
	Reticulation Gravity Sewer	150mm dia VC	810	1978	n/a	2m		1	1	1	1			Seawall Option 2 SW assets not within seawall protected length. Beach management and dune revitalisation along length of beach may provide some protection.	- Hard defence (seawall) and managed retreat options identified by WCC
	Reticulation Gravity Sewer	225mm dia VC	2000	1978	55m	n/a		1	2	1	2			Planned Retreat Option Beach management and dune revitalisation along length of beach may provide some protection.	- Sydney Water pipe network appears to be at levels near to AHD/MSL which would indicate high vulnerability.
	Ventshaft	Free standing fibreglass									n				-WCC have already completed an economic assessment for this site - could be interesting to build on this by incorporating Sydney Water assets and adopting a more sophisticated economic model.
	Branch Gravity Sewer	400mm dia VC	-250	1976	3m	10m		1	1	1	1				
	Gravity Ventline	225mm dia SGW	N	1975	n/a	6m		1	1	1	1				
	Ventshaft	Free standing - taper	N								n				
McCauley's Beach	Trunk gravity sewer	900mm dia RC	-3156 / -3236	1975	125m	170m		3	1	3	9	23	4	Seawall Option Very short length of seawall proposed to protect one property. Would only provide protection to a very short length of SW's assets. Dune revitalisation (no beach management) may provide some protection.	- Limited number of WCC assets within this area within the at risk zone.
	Reticulation Gravity Sewer	225mm dia VC	350	1975	5m	25m		1	2	1	2			Planned Retreat Option Dune revitalisation (no beach management) proposed for entire beach length may provide some protection.	- Beach generally backs onto parkland rather than constrained by development like Austinmer and Thirroul favouring managed retreat options
	Pressure Main Sewer	600mm dia CICL	N	1975	170m	150m	Bored tunnel?	3	2	2	12				- Managed retreat options generally proposed by WCC with only a short length of sea wall to protect a discrete length of beach at one end
Sandon Point Beach	Trunk gravity sewer	1200mm dia Conc	-816 / -947	1973	265m	75m		3	3	3	27	14.5	8		
	Reticulation Gravity Sewer	225mm dia VC	2918	1973	10m	15m		1	2	1	2				
	Ventshaft	Free standing fibreglass tube									n				
Bulli Beach	Trunk gravity sewer	1200mm dia Conc	-1175 / -1236 / -1459	1973	610m	50m		3	3	2	18	19	5		
	Branch Gravity Sewer	525mm dia VC	-489	1973	n/a	5m		1	1	1	1				
	Ventshaft	Free standing fibreglass tube									n				
	Ventshaft										n				
	Ventshaft										n				
Woonoona Beach	Trunk gravity sewer	1350mm dia RC	-2897 / -2792 / -2628	1972	580m	250m		3	1	3	9	9	9		
	Ventshaft			1972	Y	Y					n				
	Ventshaft			1970	n/a	Y					n				

Bellambi Beach	*None within 100yr ARI hazard zone*														
Bellambi Point	Overflow gravity sewer	1050mm dia Conc	-580	1967	15m	15m		3	2	3	18	87	1	Dune revitalisation proposed but may have limited protective potential in this area due to rock foreshore. A short sea wall proposed to protect a stormwater outflow may depending on the exact alignment protect one of the SW overflow pipes.	- Limited number of WCC assets within this area and the at risk zone: one short section of stormwater network.
	Overflow gravity sewer	750mm dia Conc	-586	1964	70m	n/a		3	2	3	18				- Potentially very highly vulnerable site (STW), with space contraints and other challenges to designing protective measures. - Outlet structures unknown - Sydney Water pipe network appears to be at levels near to AHD/MSL which would indicate high vulnerability.
	Maintenance hole	Overflow weir		2010				2	3	2	12				
	Maintenance hole	Overflow weir		1967				2	3	2	12				
	Outfall gravity sewer	900mm dia Conc	N	1973	80m	20m		3	3	3	27				
Corrimal Beach	*None within 100yr ARI hazard zone*														
Towradgi Beach	Pressure main effluent sewer	750mm dia MSCL	5260 / 5270	2004	n/a	130m		2	2	2	8	9	9		
	Reticulation Gravity Sewer	225mm dia VC	4796	1967	n/a	40m		1	1	1	1				
Fairy Meadows Beach	*None within 100yr ARI hazard zone*														
North Wollongong Beach	Pressure main effluent sewer	710mm dia PE	N	2005	128m	25m	Pipe loops under the bay - tunneled pipe?	3	1	3	9	9	9		
Wollongong City Beach	*None within 100yr ARI hazard zone*														
Coniston Beach	Outfall gravity sewer	900mm dia MS	N	1963	95m	10m	discharges out to sea - assume well buried	3	1	2	6	18	6		
	Overflow gravity sewer	1350mm dia Conc	N	1963	20m	10m	discharges out to sea - assume well buried	3	1	2	6				
	Outfall gravity sewer	1050mm dia PE	-9626 / -6826 / -3762	2006	70m	15m	discharges out to sea - assume well buried	3	1	2	6				
North Beach	*None within 100yr ARI hazard zone*														
Fishermans Beach	*None within 100yr ARI hazard zone*														
Perkins Beach	*None within 100yr ARI hazard zone*														

Notes
1. Only assets within the Coastal Hazard Study 100yr ARI 'at risk' zones


Austinmer Beach
Legend
environmentdata_ENVIRONMENT_CZS_RFC_2050
environmentdata_ENVIRONMENT_CZS_RFC_2010
SewerMain_Centreline_polyline
assetdata_MAPPING_Assets_Stormwater_Line
Lawrence Hargrave Dr
Austinmer St
Austinmer Park
Tuckerman Park
Tasman Sea
9630-150-Reticulation-Gravity-VC-7/12/1977
0-225-Reticulation-Gravity-VC-7/12/1977
7010-150-Reticulation-Gravity-VC-7/12/1977
-300-750-Trunk-Gravity-RC-25/11/1977
-370-750-Trunk-Gravity-RC-25/11/1977
-600-750-Trunk-Gravity-RC-25/11/1977
4580-225-Reticulation-Gravity-VC-7/12/1977
1240-150-Reticulation-Gravity-VC-7/12/1977
-710-750-Trunk-Gravity-RC-25/11/1977
-1190-900-Trunk-Gravity-RC-25/11/1977
10

Thirroul Beach
Legend
environmentdata_ENVIRONMENT_CZS_RFC_2050
environmentdata_ENVIRONMENT_CZS_RFC_2010
SewerMain_Centreline_polyline
assetdata_MAPPING_Assets_Stormwater_Line
Cochrane Rd
Redman Ave
Lawrence Hargrave Dr
Henley Rd
Mary St
Arthur St
Bath St
Ocean St
Cliff Pde
Spray St
Surfers Pde
Craig St
Tasman Sea
Tuckerman Park
Thirroul Park
Thirroul Beach Reserve
4100-150-Reticulation-Gravity-VC-28/05/1992
0-225-Reticulation-Gravity-VC-28/05/1992
2080-900-Trunk-Gravity-RC-3/11/1975
-2260-900-Trunk-Gravity-RC-3/11/1975
2474-900-Trunk-Gravity-RC-3/11/1975
-2855-1050-Trunk-Gravity-RC-3/11/1975

Tasman Pde
Craig St
Surfers Pde
Woodland Ave
Hamilton Rd
Corbett Ave
Tuckerman Park
Tasman Sea
8310-150-Reticulation-Gravity-VC-31/10/1975
-2874-1050-Trunk-Gravity-RC-3/11/1975
-3156-1050-Trunk-Gravity-RC-3/11/1975
-3382-900-Trunk-Gravity-RC-3/11/1975
-3531-900-Trunk-Gravity-RC-3/11/1975
0-600-Pressure Main-Effluent-CICL-10/10/1975
9270-225-Reticulation-Gravity-VC-17/11/1975
Somerville St
McCauleys Beach
Legend
environmentdata_ENVIRONMENT_CZS_RFC_2050
environmentdata_ENVIRONMENT_CZS_RFC_2010
SewerMain_Centreline_polyline
assetdata_MAPPING_Assets_Stormwater_Line

Tasman Sea
-586-750-Overflow-Gravity-CONC-1/01/1964
0-600-Pressure Main-Effluent-DICL-1/01/2005
Armour St
Bellambi Park
0-900-Outfall-Gravity-CONC-30/06/1973
Tasman Sea
Bellambi Point
Legend
environmentdata_ENVIRONMENT_CZS_RFC_2050
environmentdata_ENVIRONMENT_CZS_RFC_2010
SewerMain_Centreline_polyline
assetdata_MAPPING_Assets_Stormwater_Line

5.8.2 Economic Appraisal

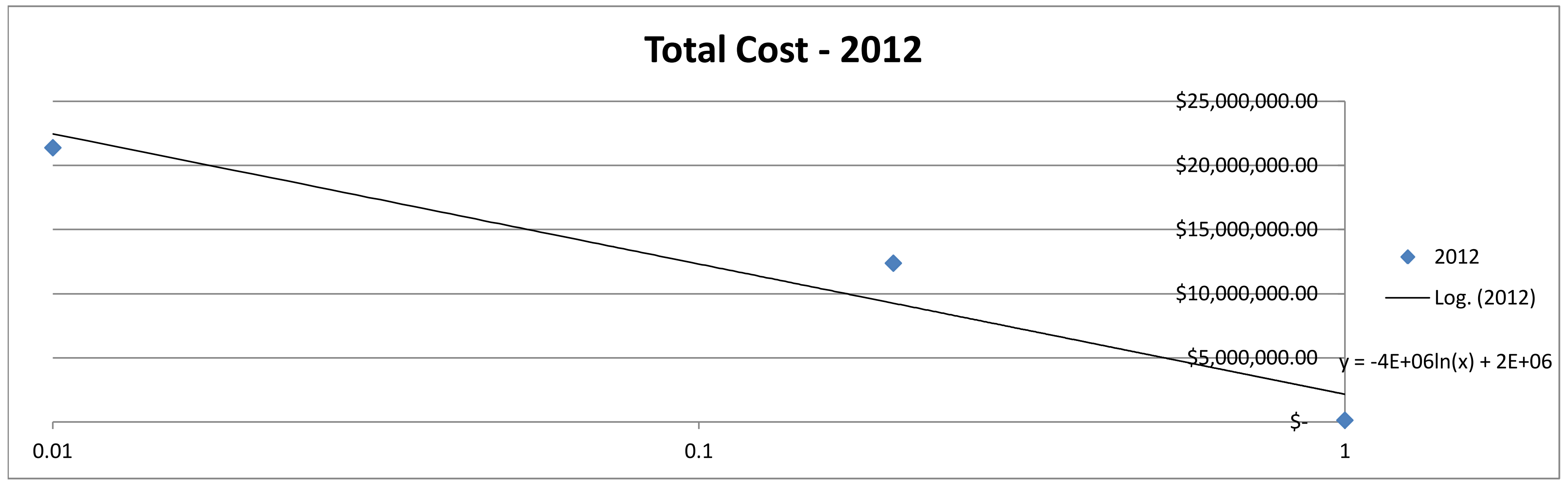
Thirroul Beach

Economic Assessment - Costs

Timeframe 2012

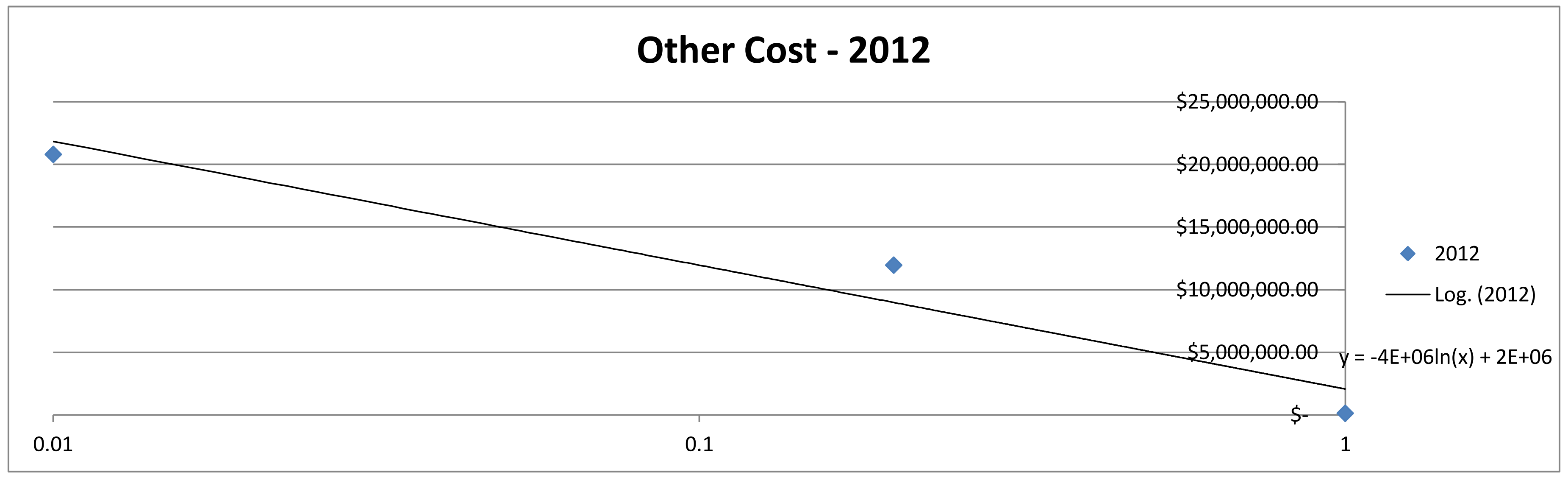
				Storm Event ARI (yr)											
				1				5				100			
Assets				Damage	Unit	Rate	Value	Damage	Unit	Rate	Value	Damage	Unit	Rate	Value
Asset Owner	**Asset Class**	**Asset**	**Cost type**	[quantity]		[$]	[$]	[quantity]		[$]	[$]	[quantity]		[$]	[$]
Sydney Water	Sewer Infastructure	Reticulation sewer network (225mm dia, VC)	Damage and replacement	-	m	$ 528.70	$ -	0	m	$ 528.70	$ -	2	m	$ 528.70	$ 1,057.39
			Other costs												
			Loss of service	-	m^2	$ 0.06	$ -	0	m^2	$ 0.06	$ -	2000	m^2	$ 0.06	$ 124.00
		Trunk gravity sewer (900mm dia, RC)	Damage and replacement	-	m	$ 4,297.38	$ -	55	m	$ 4,297.38	$ 236,355.96	90	m	$ 4,297.38	$ 386,764.30
			Other costs												
			Loss of service	-	m^2	$ 0.06	$ -	3,000,000	m^2	$ 0.06	$ 186,000.00	3,000,000	m^2	$ 0.06	$ 186,000.00
		Branch gravity sewer (400mm dia, VC)	Damage and replacement	-	m	$ 1,275.08	$ -	0	m	$ 1,275.08	$ -	0	m	$ 1,275.08	$ -
			Other costs												
			Loss of service	-	m^2	$ 0.06	$ -	0	m^2	$ 0.06	$ -	0	m^2	$ 0.06	$ -
		Gravity ventline	Damage and replacement	-	m		$ -	0	m		$ -	0	m		$ -
			Loss of service	-	m^2	$ 0.06	$ -	0	m^2	$ 0.06	$ -	0	m^2	$ 0.06	$ -
		Ventshaft structures	Damage and replacement	-	No.	$ 10,000.00	$ -	0	No.	$ 10,000.00	$ -	1	No.	$ 10,000.00	$ 10,000.00
			Loss of service	-		$ 0.06	$ -	0		$ 0.06	$ -			$ 0.06	$ -
WCC	Stormwater Infrastructure	Stormwater network	Damage and replacement	-	m		$ -	15	m		$ -	25	m		$ -
			Loss of service	-			$ -			As for outfall				As for outfall	
		Outfall structures	Damage and replacement	-	No.	$ 10,000.00	$ -	1	No.	$ 10,000.00	$ 10,000.00	1	No.	$ 10,000.00	$ 10,000.00
			Loss of service	-	m^2	$ 0.06	$ -	500,000	m^2	$ 0.06	$ 31,000.00	500,000	m^2	$ 0.06	$ 31,000.00
	Community Assets	Swimming pool (olympic and wading) - free	Damage and replacement	-	No.	$ 2,256,000.00	$ -	1	No.	$ 2,256,000.00	$ 2,256,000.00	1	No.	$ 2,256,000.00	$ 2,256,000.00
			Loss of service	-	Visitors	$ 10.50	$ -	500000	Visitors	$ 10.50	$ 5,247,640.00	500,000	Visitors	$ 10.50	$ 5,247,640.00
		Thirroul Surf Lifesaving Club	Damage and replacement	-	No.	$ 1,756,800.00	$ -	1	No.	$ 1,756,800.00	$ 1,756,800.00	1	No.	$ 1,756,800.00	$ 1,756,800.00
			Loss of service	-	Visitors	$ 10.50	$ -	5000	Visitors	$ 10.50	$ 52,476.40	5,000	Visitors	$ 10.50	$ 52,476.40
		Thirroul Pavillion - restaurant	Damage and replacement	-	No.	$ 1,756,800.00	$ -	1	No.	$ 1,756,800.00	$ 1,756,800.00	1	No.	$ 1,756,800.00	$ 1,756,800.00
			Loss of service	-	No.	$ 629,716.80	$ -	1	No.	$ 629,716.80	$ 629,716.80	1	No.	$ 629,716.80	$ 629,716.80
		Thirroul Pavillion - residences	Damage and replacement			As for restaurant				As for restaurant				As for restaurant	
			Loss of service	-		$ 31,485.84	$ -			$ 31,485.84	$ -			$ 31,485.84	$ -
		Thirroul Pavillion - herritage	Loss of herritage	-	No.		$ -	1	No.		$ -	1	No.		$ -
		Thirroul Reserve - ammenity	Damage and replacement	200	m^2		$ -	825	m^2		$ -	1,285	m^2		$ -
			Loss of service		Visitors	$ 10.50	$ -		Visitors	$ 10.50	$ -	200,000	Visitors	$ 10.50	$ 2,099,056.00
		Public toilet by southern carpark	Damage and replacement	-	No.	$ 226,350.00	$ -	0	No.	$ 226,350.00	$ -	1	No.	$ 226,350.00	$ 226,350.00
			Loss of service	-	Visitors		$ -	0	Visitors		$ -		Visitors		$ -
	Highway	Roads	Damage and replacement	0	m	$ 360.00	$ -	5	m	$ 360.00	$ 1,800.00	10	m	$ 360.00	$ 3,600.00
			Loss of service	0			$ -				$ -				$ -
		Northern car park	Damage and replacement	370	m^2	$ 85.00	$ 31,450.00	500	m^2	$ 85.00	$ 42,500.00	730	m^2	$ 85.00	$ 62,050.00
			Loss of service	4,052	vehicles pa	$ 10.00	$ 40,515.00	5,475	vehicles pa	$ 10.00	$ 54,750.00	7,994	vehicles pa	$ 10.00	$ 79,935.00
	Beach	Beach ammenity	Recession	-	Visitors	$ 20.99	$ -	-	Visitors	$ 20.99	$ -	-	Visitors	$ 20.99	$ -
			Erosion	2	Days	$ 28,754.19	$ 57,508.38	4.00	Days	$ 28,754.19	$ 115,016.77	10.00	Days	$ 28,754.19	$ 287,541.92
Private ownership	Property	Private properties	Damage and replacement	-	/ property	$ 2,099,056.00	$ -	0	/ property	$ 2,099,056.00	$ -	3	/ property	$ 2,099,056.00	$ 6,297,168.00

	1	5	100
TOTAL	$ 129,473.38	$ 12,376,855.93	$ 21,380,079.81
SW	$ -	$ 422,355.96	$ 583,945.69
Other	$ 129,473.38	$ 11,954,499.97	$ 20,796,134.12

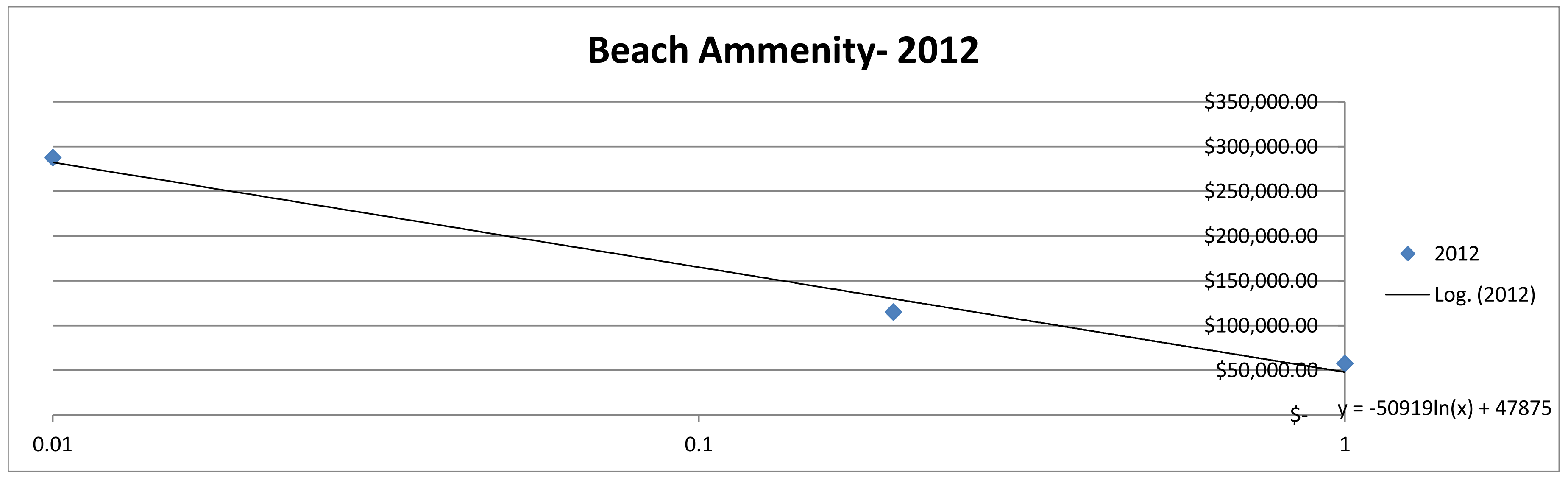


Weighted Costs - ARI events up to 10,000yrs				Weighted Costs - ARI events up to 100yrs			
Weighted average				**Weighted average**			
a		1	1yr	a		1	1yr
b		0.0001	10,000yr	b		0.01	100yr
A		6000000		A		6000000	
B		4284		B		244207	
Area	**$**	**5,995,716**		**Area**	**$**	**5,755,793**	

Weighted average				**Weighted average**			
a		1	1yr	a		1	1yr
b		0.0001	10,000yr	b		0.01	100yr
A		186471		A		186471	
B		111		B		6470	
Area	**$**	**186,360**		**Area**	**$**	**180,001**	



Weighted average				**Weighted average**			
a		1	1yr	a		1	1yr
b		0.0001	10,000yr	b		0.01	100yr
A		6000000		A		6000000	
B		4284		B		244207	
Area	**$**	**5,995,716**		**Area**	**$**	**5,755,793**	



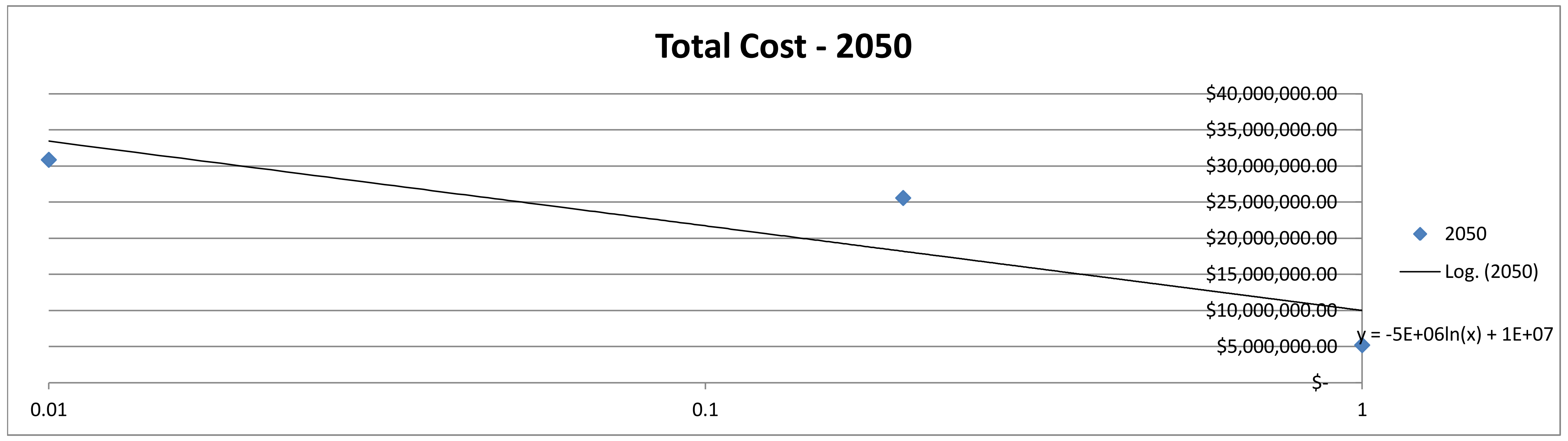
Weighted average				**Weighted average**			
a		1	1yr	a		1	1yr
b		0.0001	10,000yr	b		0.0001	10,000yr
A		94131		A		94131	
B		54		B		54	
Area	**$**	**94,077**		**Area**	**$**	**94,077**	

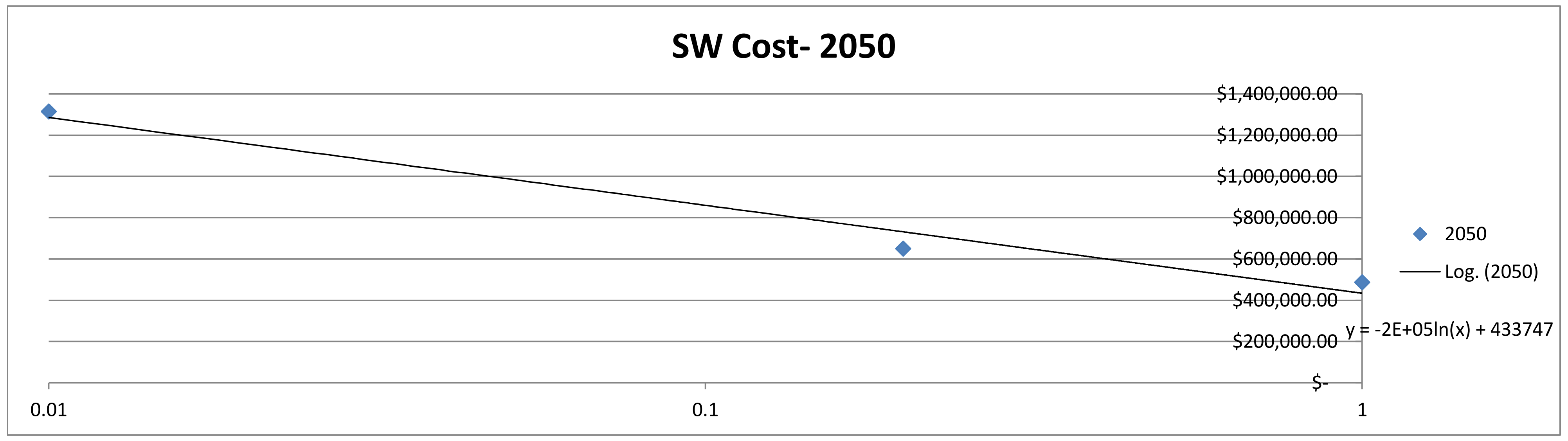
Thirroul Beach

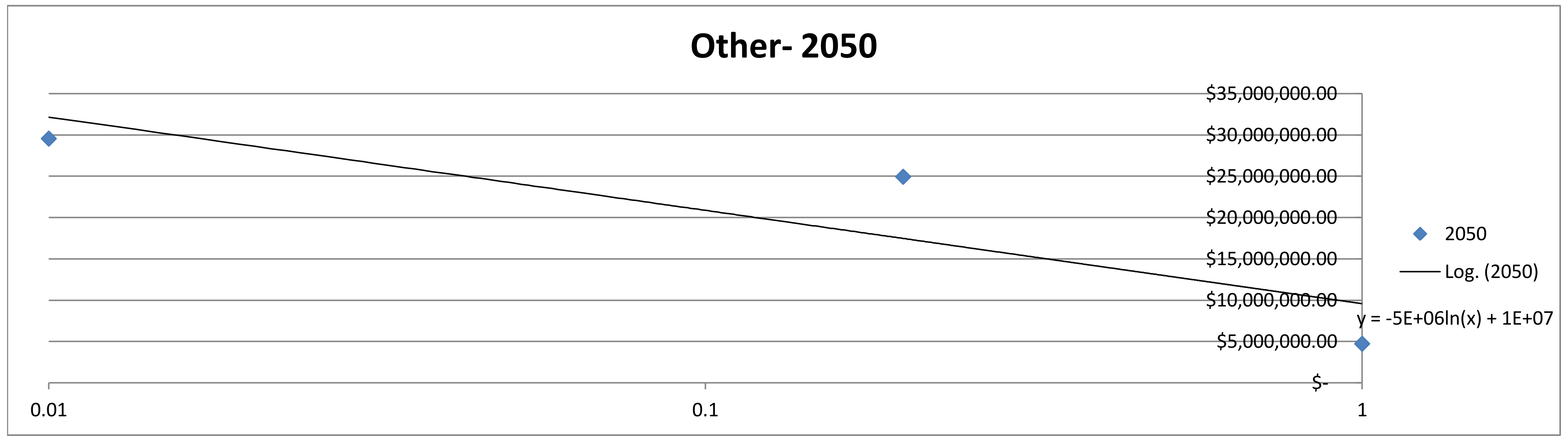
Economic Assessment - Costs

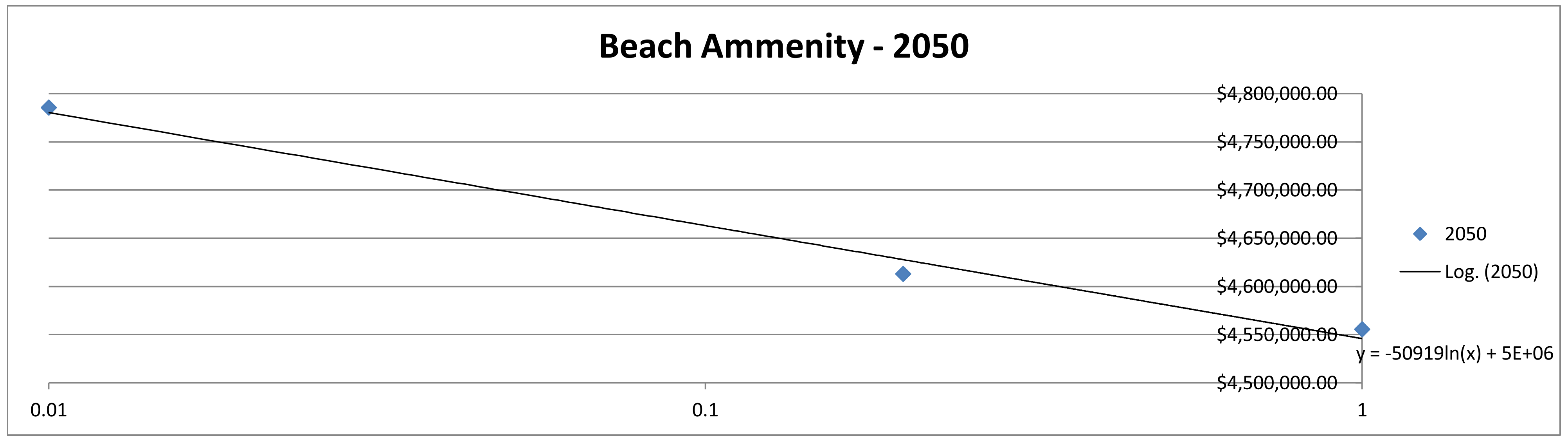
Timeframe 2050

				Storm Event ARI (yr)											
				1				5				100			
Assets				Damage	Unit	Rate	Value	Damage	Unit	Rate	Value	Damage	Unit	Rate	Value
Asset Owner	Asset Class	Asset	Cost type	[quantity]		[$]	[$]	[quantity]		[$]	[$]	[quantity]		[$]	[$]
Sydney Water	Sewer Infastructure	Reticulation sewer network (225mm dia, VC)	Damage and replacement	-	m	$ 528.70	$ -	5	m	$ 528.70	$ 2,643.48	45	m	$ 528.70	$ 23,791.30
			Other costs												
			Loss of service	-	m^2	$ 0.06	$ -	2000	m^2	$ 0.06	$ 124.00	2,000	m^2	$ 0.06	$ 124.00
		Trunk gravity sewer (900mm dia, RC)	Damage and replacement	70	m	$ 4,297.38	$ 300,816.68	105	m	$ 4,297.38	$ 451,225.02	250	m	$ 4,297.38	$ 1,074,345.28
			Other costs												
			Loss of service	3,000,000	m^2	$ 0.06	$ 186,000.00	3,000,000	m^2	$ 0.06	$ 186,000.00	3,000,000	m^2	$ 0.06	$ 186,000.00
		Branch gravity sewer (400mm dia, VC)	Damage and replacement	-	m	$ 1,275.08	$ -	-	m	$ 1,275.08	$ -	1	m	$ 1,275.08	$ 1,275.08
			Other costs												
			Loss of service	-	m^2	$ 0.06	$ -	-	m^2	$ 0.06	$ -	305,000	m^2	$ 0.06	$ 18,910.00
		Gravity ventline	Damage and replacement	-	m		$ -	-	m		$ -	-	m		$ -
			Loss of service	-	m^2	$ 0.06	$ -	-	m^2	$ 0.06	$ -	-	m^2	$ 0.06	$ -
		Ventshaft structures	Damage and replacement	-	No.	$ 10,000.00	$ -	1	No.	$ 10,000.00	$ 10,000.00	1	No.	$ 10,000.00	$ 10,000.00
			Loss of service	-		$ 0.06	$ -			$ 0.06	$ -			$ 0.06	$ -
WCC	Stormwater Infrastructure	Stormwater network	Damage and replacement	20	m		$ -	30	m		$ -	45	m		$ -
			Loss of service			As for outfall				As for outfall				As for outfall	
		Outfall structures	Damage and replacement	1	No.	$ 10,000.00	$ 10,000.00	1	No.	$ 10,000.00	$ 10,000.00	1	No.	$ 10,000.00	$ 10,000.00
			Loss of service	500,000	m^2	$ 0.06	$ 31,000.00	500,000	m^2	$ 0.06	$ 31,000.00	500,000	m^2	$ 0.06	$ 31,000.00
	Community Assets	Swimming pool (olympic and wading) - free	Damage and replacement	-	No.	$ 2,256,000.00	$ -	1	No.	$ 2,256,000.00	$ 2,256,000.00	1	No.	$ 2,256,000.00	$ 2,256,000.00
			Loss of service	-	Visitors	$ 10.50	$ -	500000	Visitors	$ 10.50	$ 5,247,640.00	500,000	Visitors	$ 10.50	$ 5,247,640.00
		Thirroul Surf Lifesaving Club	Damage and replacement	-	No.	$ 1,756,800.00	$ -	1	No.	$ 1,756,800.00	$ 1,756,800.00	1	No.	$ 1,756,800.00	$ 1,756,800.00
			Loss of service	-	Visitors	$ 10.50	$ -	5,000	Visitors	$ 10.50	$ 52,476.40	5,000	Visitors	$ 10.50	$ 52,476.40
		Thirroul Pavillion - restaurant	Damage and replacement	-	No.	$ 1,756,800.00	$ -	1	No.	$ 1,756,800.00	$ 1,756,800.00	1	No.	$ 1,756,800.00	$ 1,756,800.00
			Loss of service	-	No.	$ 629,716.80	$ -	1	No.	$ 629,716.80	$ 629,716.80	1	No.	$ 629,716.80	$ 629,716.80
		Thirroul Pavillion - residences	Damage and replacement			As for restaurant				As for restaurant				As for restaurant	
			Loss of service		No.	$ 31,485.84	$ -			$ 31,485.84	$ -			$ 31,485.84	$ -
		Thirroul Pavillion - heritage	Loss of herritage	-	No.		$ -	1	No.		$ -	1	No.		$ -
		Thirroul Reserve - ammenity	Damage and replacement	1,100	m^2		$ -	1,980	m^2		$ -	2,650	m^2		$ -
			Loss of service		Visitors	$ 10.50	$ -	200,000	Visitors	$ 10.50	$ 2,099,056.00	200,000	Visitors	$ 10.50	$ 2,099,056.00
		Public toilet by southern carpark	Damage and replacement	-	No.	$ 226,350.00	$ -	0	No.	$ 226,350.00	$ -	1	No.	$ 226,350.00	$ 226,350.00
			Loss of service	-			$ -	0			$ -				$ -
	Highway	Roads	Damage and replacement	8	m	$ 360.00	$ 2,880.00	12	m	$ 360.00	$ 4,320.00	20	m	$ 360.00	$ 7,200.00
			Loss of service				$ -				$ -				$ -
		Northern car park	Damage and replacement	625	m^2	$ 85.00	$ 53,125.00	900	m^2	$ 85.00	$ 76,500.00	1000	m^2	$ 85.00	$ 85,000.00
			Loss of service	6,844	vehicles pa	$ 10.00	$ 68,437.50	9,855	vehicles pa	$ 10.00	$ 98,550.00	10,950	vehicles pa	$ 10.00	$ 109,500.00
	Beach	Beach ammenity	Recession	214,285	Visitors	$ 20.99	$ 4,497,962.15	214,285	Visitors	$ 20.99	$ 4,497,962.15	214,285	Visitors	$ 20.99	$ 4,497,962.15
			Erosion	2	Days	$ 28,754.19	$ 57,508.38	4.00	Days	$ 28,754.19	$ 115,016.77	10.00	Days	$ 28,754.19	$ 287,541.92
Private ownership	Property	Private properties	Damage and replacement	-	/ property	$ 2,099,056.00	$ -	3	/ property	$ 2,099,056.00	$ 6,297,168.00	5	/ property	$ 2,099,056.00	$ 10,495,280.00
			TOTAL				$ 5,207,729.71				$ 25,578,998.61				$ 30,862,768.92
			SW				$ 486,816.68				$ 649,992.50				$ 1,314,445.65
			Other				$ 4,720,913.03				$ 24,929,006.12				$ 29,548,323.27









Weighted Costs - ARI events up to 10,000yrs

Weighted average			
a		1	1yr
b		0.0001	10,000yr
A		15000000	
B		6105	
Area	**$**	**14,993,895**	

Weighted average			
a		1	1yr
b		0.0001	10,000yr
A		605947	
B		245	
Area	**$**	**605,702**	

Weighted average			
a		1	1yr
b		0.0001	10,000yr
A		14000000	
B		6005	
Area	**$**	**13,993,995**	

Weighted average			
a		1	1yr
b		0.0001	10,000yr
A		4048516	
B		450	
Area	**$**	**4,048,066**	

Weighted Costs - ARI events up to 100yrs

Weighted average			
a		1	1yr
b		0.01	100yr
A		15000000	
B		380259	
Area	**$**	**14,619,741**	

Weighted average			
a		1	1yr
b		0.01	100yr
A		605947	
B		15270	
Area	**$**	**590,677**	

Weighted average			
a		1	1yr
b		0.01	100yr
A		14000000	
B		370259	
Area	**$**	**13,629,741**	

Weighted average			
a		1	1yr
b		0.01	100yr
A		4048516	
B		42719	
Area	**$**	**4,005,797**	

Notes

Increase in construction prices from 2010 to 2012 rates

2005-2006	2.9%
2006-2007	2.4%
2007-2008	4.2%
2008-2009	2.5%
2009-2010	2.9%
2010-2011	3.3%
2011-2012	1.6%

Housing density - determine avg housing density to determine loss of service costs

Sample area	25000	m^2	measured on plot bounded by ocean st/Harbord St/Cliff parade/MacCaulley St
No of houses	31	No.	
Density	0.00124	houses/m^2	

Loss of sewerage compensation - based on avg housing density

Sewerage service charge	$	50.00	per house	Owners would get rebate for entire service charge if more than 1 event per year
Sewerage service charge	$	0.06	$ /m^2	

Bellambi is the only STW in WCC LGA to the south of Thirroul - therefore all wastewater north of the site up to Scarborough must travel through Thirroul

Loss of parking

north car park total area	1000	m^2	
total capacity	30	vehicles	
total capacity per year	10950	vehicles pa	assuming 1 vehicle a day
density	0.03	vehicles / m^2	

Beach Closure (due to erosion post storm event)

total no of visitors pa		500,000.00	visitors pa
visitors per day		1,369.86	visitors per day
consumer surplus	$	20.99	$
cost per day closure		28,754.19	$

Beach Loss (due to recession)

2050 shoreline recession	8.1	m
2100 shore line recession	18.9	m
2100 lost visit days due to recession	500,000.00	from WCC Economic Assessment
Lost days in 2050	214,286	visit days

Costs

	Item	Price year	Cost	Cost (2012 prices)	Unit	Source	Notes
1	Car parking	2012	$ 85.00	$ 85.00	m^2	Rawlinsons p51/63	Open air retail/office parking - upper bound
2	Roads	2012	$ 360.00	$ 360.00	m	Rawlinsons p681	Surburban road 6.0m wide with kerbs - upper bound
3	Sewerage service charge	2012 (assumed)	$ 0.06	$ 0.06	m^2	Sydney Water compensation guidelines	
4	Swimming pool	2012	$ 1,496,500.00	$ 1,496,500.00	No.	Rawlinsons p54	Olympic pool (50m x 21m)
5	Wading pool	2012	$ 35,500.00	$ 35,500.00	No.	Rawlinsons p54	Domestic (9m x 4.5m) - closest in size to wading pool dims
6	Swimming pool changing facilities	2012	$ 2,550.00	$ 2,550.00	m^2	Rawlinsons p53	270m^2 facility - simple change room/toilet
7	Total pools cost	2012	$ 2,256,000.00	$ 2,256,000.00	No.	Items 4, 5, 6	1.No. Olympic Pool + 2.No. Wading Pools + change room
8	Thirroul Pavillion Residence	2010	$ 30,000.00	$ 31,485.84	No.	WCC Economics Rp	Rent pa
9	Thirroul Pavillion Restaurant	2010	$ 600,000.00	$ 629,716.80	No.	WCC Economics Rp	Restaurant producer surplus
10	900mm dia RC ww pipe	2005	$ 3,914.00	$ 4,297.38	m	Sydney Water costs	For a 1050mm dia RC pipe burried up to 4.5m, closest info
11	400mm dia VC ww pipe	2005	$ 1,133.00	$ 1,275.08	m	Sydney Water costs	For a 450mm dia MSCL water pipe, 05-06 prices, below ground suburban areas
12	Public toilet	2012	$ 2,515.00	$ 2,515.00	m^2	Rawlinsons p52	90m^2 public toilet attached building at rear - closest approximation
13	Public toilet cost	2012	$ 226,350.00	$ 226,350.00	No.	Item 12 @ 90m^2	
14	250mm dia VC ww pipe	2005	$ 435.00	$ 528.70	m	Sydney Water costs	250mm dia DICL water pipe, 05-06 prices, suburban areas
15	SLSC	2012	$ 2,345.00	$ 2,345.00	m^s	Rawlinsons p53	Clubhouse and change room
16	SLSC cost	2012	$ 1,758,750.00	$ 1,758,750.00	No.	Item 15	for a 750m^2 building
17	Thirroul Pavillion	2012	$ 2,160.00	$ 2,160.00	m^2	Rawlinsons p44	Country motel - standard, overall cost (Rawlinsons proposes use of hotel for restaurant costs)
18	Thirroul Pavillion	2012	$ 28,800.00	$ 28,800.00	No.	Rawlinsons p44	Country motel - standard, fit out cost
19	Thirroul Pavillion	2012	$ 1,756,800.00	$ 1,756,800.00	No.	Item 17, 18	800m^2 restaurant
20	Car parking CS	assumed (2012)	$ 10.00	$ 10.00	per car/day		Price estimate
22	Beach erosion	2010	$ 20.00	$ 20.99	per person/day	WCC Economics Rp	
23	Private properties	2010	$ 2,000,000.00	$ 2,099,056.00	No.	WCC Economics Rp	
24	Seawall - capital cost	2010	$ 10,000.00	$ 10,495.28	m	WCC Economics Rp	
25	Seawall - maintenence cost	2010	$ 500.00	$ 524.76	m/pa	WCC Economics Rp	
26	Beach nourishment	2010	$ 25.00	$ 26.24	m^3	WCC Economics Rp	
27	Swimming pool consumer surplus	2010	$ 10.00	$ 10.50	No.	WCC Economics Rp	
28	Thirroul SLSC consumer surplus	2010	$ 10.00	$ 10.50	No.	WCC Economics Rp	
29	Thirroul Reserve ammenity value	2010	$ 10.00	$ 10.50	No.	WCC Economics Rp	
30	Beach closure	2012	$ 28,754.19	$ 28,754.19	per day	WCC Economics Rp & ammended as described above	

Adaptation Options

Costs & Benefits

	Option				
	Base Case	1a) Full seawall with nourishment	1b) Full seawall without nourishment (900m)	2) Partial seawall (530m)	3) Planned Retreat with beach nourishment
Costs					
Thirroul SLSC - relocation	x				x
Thirroul Pool - relocation	x				x
Thirroul Pavilion - relocation	x				x
Thirroul Pavillion - loss of herritage	x				x
Thirroul Beach Reserve - loss of use value	x				x
Beach - loss of use value			x		
Private proprties - relocation	x			1	x
Wastewater assets - repair cost	x			x	x
Wastewater assets - associated damage cost	x			x	x
Stormwater assets - repair cost	x				x
Stormwater assets - associated damage cost	x				x
Seawall capital cost		x	x		
Seawall maintenance cost		x	x		
Beach nourishment cost		x		x	x
Beach nourishment maintenance cost		x		x	x
Benefits					
Thirroul SLSC - avoid loss		x	x	x	
Thirroul Pool - avoid loss		x	x	x	
Thirroul Pavilion - avoid loss		x	x	x	
Thirroul Pavillion - avoid loss of herritage		x	x	x	
Thirroul Beach Reserve - avoid loss of use value		x	x	x	
Beach - avoid loss of use value	x	x		x	x
Private proprties - avoid relocation		x	x	x some	
Wastewater assets - avoid repair cost		x	x		
Wastewater assets - avoid associated damage cost		x	x		
Stormwater assets - avoid repair cost		x	x	x	
Stormwater assets - avoid associated damage cost		x	x	x	

Adaptation Option Costs

Seawall	Quantity	Unit	Rate	Total
Full Seawall capital cost	900	m	$ 10,000.00	$ 9,000,000.00
Full Seawall maintenance costs	900	m	$ 500.00	$ 450,000.00
Partial Seawall capital cost	530	m	$ 10,000.00	$ 5,300,000.00
Partial Seawall maintenance costs	530	m	$ 500.00	$ 265,000.00
Beach nourishment				
Full - Initial volume	18000	m^3	$ 25.00	$ 450,000.00
Full - On-going volume	9000	m^3	$ 25.00	$ 225,000.00
Partial - Initial volume	9000	m^3	$ 25.00	$ 225,000.00
Partial - On-going volume	3000	m^3	$ 25.00	$ 75,000.00

Adaptation Option Works Costs

	1a	1b	2	3
Seawall capital cost	$ 9,000,000.00	$ 9,000,000.00	$ 5,300,000.00	$ -
Seawall maintenance cost	$ 450,000.00	$ 450,000.00	$ 265,000.00	$ -
Beach nourishment capital cost	$ 450,000.00	$ 450,000.00	$ 225,000.00	$ -
Beach nourishment maintenance cost	$ 225,000.00	$ 225,000.00	$ 75,000.00	$ -
Protect outfall	$ 10,000.00	$ 10,000.00	$ 10,000.00	$ 10,000.00
Dune revitalisation capital cost(assume as for partial nourishment)	$ 225,000.00	$ 225,000.00	$ 225,000.00	$ 225,000.00
Dune revitalisation maintenance cost (assume as for partial nourishment)	$ 75,000.00	$ 75,000.00	$ 75,000.00	$ 75,000.00

Adaptation Option 1a

Full seawall with beach nourishment

Seawall		
CAPEX year	2015	
CAPEX value	$ 9,000,000.00	
OPEX start year	2016	
OPEX value	$ 450,000.00	pa
Beach Nourishment		
CAPEX year	2015	
CAPEX value	$ 450,000.00	
OPEX start year	2025	2025 2035 2045 BEYOND 2050 BEYOND 2050 BEYOND 2050 BEYOND 2050 BEYOND 2050 BEYOND 2050 BEYOND 2050 BEYOND 2050 BEYOND 2050 BEYOND 2050 BEYOND 2050 BEYOND 2050 BEYOND 2050 BEYOND 2050 BEYOND 2050
OPEX value	$ 225,000.00	per nourishment
OPEX frequency	10	yrs (whole yrs only)

(orange)	Data entry
(grey)	Interpolate

Assets		Year																	
Asset	**Notes**	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029
Base Case Costs	Sydney Water	$ 186,360	$ 197,396	$ 208,431	$ 219,466	$ 230,502	$ 241,537	$ 252,572	$ 263,607	$ 274,643	$ 285,678	$ 296,713	$ 307,749	$ 318,784	$ 329,819	$ 340,855	$ 351,890	$ 362,925	$ 373,961
	Other	$ 5,995,716	$ 6,206,197	$ 6,416,678	$ 6,627,159	$ 6,837,640	$ 7,048,121	$ 7,258,602	$ 7,469,083	$ 7,679,564	$ 7,890,045	$ 8,100,526	$ 8,311,007	$ 8,521,488	$ 8,731,969	$ 8,942,450	$ 9,152,931	$ 9,363,412	$ 9,573,893
Adaptation Option Costs	Seawall CAPEX	$ -	$ -	$ -	$ 9,000,000	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
	Seawall OPEX	$ -	$ -	$ -	$ -	$ 450,000	$ 450,000	$ 450,000	$ 450,000	$ 450,000	$ 450,000	$ 450,000	$ 450,000	$ 450,000	$ 450,000	$ 450,000	$ 450,000	$ 450,000	$ 450,000
	Beach nourishment CAPEX	$ -	$ -	$ -	$ 450,000	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
	Beach nourishment OPEX	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 225,000	$ -	$ -	$ -	$ -
Benefits Costs	Sydney Water	$ -	$ -	$ -	$ -	-$ 230,502	-$ 241,537	-$ 252,572	-$ 263,607	-$ 274,643	-$ 285,678	-$ 296,713	-$ 307,749	-$ 318,784	-$ 329,819	-$ 340,855	-$ 351,890	-$ 362,925	-$ 373,961
	Base Case	$ -	$ -	$ -	$ -	-$ 6,837,640	-$ 7,048,121	-$ 7,258,602	-$ 7,469,083	-$ 7,679,564	-$ 7,890,045	-$ 8,100,526	-$ 8,311,007	-$ 8,521,488	-$ 8,731,969	-$ 8,942,450	-$ 9,152,931	-$ 9,363,412	-$ 9,573,893
Incurred Costs																			

BEYOND 2050	BEYOND 2050	BEYOND 2050	BEYOND 2050	BEYOND 2050	BEYOND 2050	BEYOND 2050	BEYOND 2050	BEYOND 2050	BEYOND 2050	BEYOND 2050
2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040
$ 384,996	$ 396,031	$ 407,067	$ 418,102	$ 429,137	$ 440,172	$ 451,208	$ 462,243	$ 473,278	$ 484,314	$ 495,349
$ 9,784,374	$ 9,994,855	$ 10,205,336	$ 10,415,817	$ 10,626,298	$ 10,836,779	$ 11,047,260	$ 11,257,741	$ 11,468,223	$ 11,678,704	$ 11,889,185
$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
$ 450,000	$ 450,000	$ 450,000	$ 450,000	$ 450,000	$ 450,000	$ 450,000	$ 450,000	$ 450,000	$ 450,000	$ 450,000
$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
$ -	$ -	$ -	$ -	$ -	$ 225,000	$ -	$ -	$ -	$ -	$ -
-$ 384,996	-$ 396,031	-$ 407,067	-$ 418,102	-$ 429,137	-$ 440,172	-$ 451,208	-$ 462,243	-$ 473,278	-$ 484,314	-$ 495,349
-$ 9,784,374	-$ 9,994,855	-$ 10,205,336	-$ 10,415,817	-$ 10,626,298	-$ 10,836,779	-$ 11,047,260	-$ 11,257,741	-$ 11,468,223	-$ 11,678,704	-$ 11,889,185

BEYOND 2050	BEYOND 2050	BEYOND 2050	BEYOND 2050	BEYOND 2050	BEYOND 2050	BEYOND 2050	BEYOND 2050	BEYOND 2050	BEYOND 2050
2041	2042	2043	2044	2045	2046	2047	2048	2049	2050
$ 506,384	$ 517,420	$ 528,455	$ 539,490	$ 550,526	$ 561,561	$ 572,596	$ 583,632	$ 594,667	$ 605,702
$ 12,099,666	$ 12,310,147	$ 12,520,628	$ 12,731,109	$ 12,941,590	$ 13,152,071	$ 13,362,552	$ 13,573,033	$ 13,783,514	$ 13,993,995
$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
$ 450,000	$ 450,000	$ 450,000	$ 450,000	$ 450,000	$ 450,000	$ 450,000	$ 450,000	$ 450,000	$ 450,000
$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
$ -	$ -	$ -	$ -	$ 225,000	$ -	$ -	$ -	$ -	$ -
-$ 506,384	-$ 517,420	-$ 528,455	-$ 539,490	-$ 550,526	-$ 561,561	-$ 572,596	-$ 583,632	-$ 594,667	-$ 605,702
-$ 12,099,666	-$ 12,310,147	-$ 12,520,628	-$ 12,731,109	-$ 12,941,590	-$ 13,152,071	-$ 13,362,552	-$ 13,573,033	-$ 13,783,514	-$ 13,993,995

SUM			
Discount Rate			
0%	4%	7%	10%
$ 15,445,218	$ 6,722,079	$ 4,123,913	$ 2,790,419
$ 389,799,359	$ 176,022,404	$ 111,039,295	$ 77,041,384
$ -	$ -	$ -	$ -
$ -	$ -	$ -	$ -
$ 9,000,000	$ 7,693,238	$ 6,866,057	$ 6,147,121
$ 15,750,000	$ 7,179,565	$ 4,444,973	$ 2,964,191
$ 450,000	$ 384,662	$ 343,303	$ 307,356
$ 675,000	$ 277,008	$ 154,166	$ 90,900
-$ 14,633,565	-$ 5,987,488	-$ 3,439,760	-$ 2,151,368
-$ 364,553,609	-$ 153,149,988	-$ 89,721,342	-$ 57,114,261
$ -	$ -	$ -	$ -
$ -	$ -	$ -	$ -
$ -	$ -	$ -	$ -
$ -	$ -	$ -	$ -
$ -	$ -	$ -	$ -

Adaptation Option 1b

Full seawall without beach nourishment

Seawall

CAPEX year	2015
CAPEX value	$ 9,000,000.00
OPEX start year	2016
OPEX value	$ 450,000.00 pa

	Data entry
	Interpolate

Assets		Year																				
Asset	**Notes**	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032
Base Case Costs	Sydney Water	$ 186,360	$ 197,396	$ 208,431	$ 219,466	$ 230,502	$ 241,537	$ 252,572	$ 263,607	$ 274,643	$ 285,678	$ 296,713	$ 307,749	$ 318,784	$ 329,819	$ 340,855	$ 351,890	$ 362,925	$ 373,961	$ 384,996	$ 396,031	$ 407,067
	Other	$ 5,995,716	$ 6,206,197	$ 6,416,678	$ 6,627,159	$ 6,837,640	$ 7,048,121	$ 7,258,602	$ 7,469,083	$ 7,679,564	$ 7,890,045	$ 8,100,526	$ 8,311,007	$ 8,521,488	$ 8,731,969	$ 8,942,450	$ 9,152,931	$ 9,363,412	$ 9,573,893	$ 9,784,374	$ 9,994,855	$ 10,205,336
Adaptation Option Costs	Seawall CAPEX	$ -	$ -	$ -	$ 9,000,000	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
	Seawall OPEX	$ -	$ -	$ -	$ -	$ 450,000	$ 450,000	$ 450,000	$ 450,000	$ 450,000	$ 450,000	$ 450,000	$ 450,000	$ 450,000	$ 450,000	$ 450,000	$ 450,000	$ 450,000	$ 450,000	$ 450,000	$ 450,000	$ 450,000
Benefits Costs	Sydney Water	$ -	$ -	$ -	$ -	$ 230,502	$ 241,537	$ 252,572	$ 263,607	$ 274,643	$ 285,678	$ 296,713	$ 307,749	$ 318,784	$ 329,819	$ 340,855	$ 351,890	$ 362,925	$ 373,961	$ 384,996	$ 396,031	$ 407,067
	Base Case	$ -	$ -	$ -	$ -	$ 6,837,640	$ 7,048,121	$ 7,258,602	$ 7,469,083	$ 7,679,564	$ 7,890,045	$ 8,100,526	$ 8,311,007	$ 8,521,488	$ 8,731,969	$ 8,942,450	$ 9,152,931	$ 9,363,412	$ 9,573,893	$ 9,784,374	$ 9,994,855	$ 10,205,336
Incurred Costs	Loss of beach ammenity	$ -	$ -	$ -	$ 406,234	$ 510,286	$ 614,339	$ 718,391	$ 822,443	$ 926,496	$ 1,030,548	$ 1,134,600	$ 1,238,653	$ 1,342,705	$ 1,446,758	$ 1,550,810	$ 1,654,862	$ 1,758,915	$ 1,862,967	$ 1,967,019	$ 2,071,072	$ 2,175,124

2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050	SUM Discount Rate 0%	4%	7%	10%
$ 418,102	$ 429,137	$ 440,172	$ 451,208	$ 462,243	$ 473,278	$ 484,314	$ 495,349	$ 506,384	$ 517,420	$ 528,455	$ 539,490	$ 550,526	$ 561,561	$ 572,596	$ 583,632	$ 594,667	$ 605,702	$ 15,445,218	$ 6,722,079	$ 4,123,913	$ 2,790,419
$ 10,415,817	$ 10,626,298	$ 10,836,779	$ 11,047,260	$ 11,257,741	$ 11,468,223	$ 11,678,704	$ 11,889,185	$ 12,099,666	$ 12,310,147	$ 12,520,628	$ 12,731,109	$ 12,941,590	$ 13,152,071	$ 13,362,552	$ 13,573,033	$ 13,783,514	$ 13,993,995	$ 389,799,359	$ 176,022,404	$ 111,039,295	$ 77,041,384
																		$ -	$ -	$ -	$ -
																		$ -	$ -	$ -	$ -
$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 9,000,000	$ 7,693,238	$ 6,866,057	$ 6,147,121
$ 450,000	$ 450,000	$ 450,000	$ 450,000	$ 450,000	$ 450,000	$ 450,000	$ 450,000	$ 450,000	$ 450,000	$ 450,000	$ 450,000	$ 450,000	$ 450,000	$ 450,000	$ 450,000	$ 450,000	$ 450,000	$ 15,750,000	$ 7,179,565	$ 4,444,973	$ 2,964,191
																		$ -	$ -	$ -	$ -
																		$ -	$ -	$ -	$ -
-$ 418,102	-$ 429,137	-$ 440,172	-$ 451,208	-$ 462,243	-$ 473,278	-$ 484,314	-$ 495,349	-$ 506,384	-$ 517,420	-$ 528,455	-$ 539,490	-$ 550,526	-$ 561,561	-$ 572,596	-$ 583,632	-$ 594,667	-$ 605,702	-$ 14,633,565	-$ 5,987,488	-$ 3,439,760	-$ 2,151,368
-$ 10,415,817	-$ 10,626,298	-$ 10,836,779	-$ 11,047,260	-$ 11,257,741	-$ 11,468,223	-$ 11,678,704	-$ 11,889,185	-$ 12,099,666	-$ 12,310,147	-$ 12,520,628	-$ 12,731,109	-$ 12,941,590	-$ 13,152,071	-$ 13,362,552	-$ 13,573,033	-$ 13,783,514	-$ 13,993,995	-$ 364,553,609	-$ 153,149,988	-$ 89,721,342	-$ 57,114,261
																		$ -	$ -	$ -	$ -
																		$ -	$ -	$ -	$ -
$ 2,279,176	$ 2,383,229	$ 2,487,281	$ 2,591,333	$ 2,695,386	$ 2,799,438	$ 2,903,491	$ 3,007,543	$ 3,111,595	$ 3,215,648	$ 3,319,700	$ 3,423,752	$ 3,527,805	$ 3,631,857	$ 3,735,909	$ 3,839,962	$ 3,944,014	$ 4,048,066	$ 80,177,408	$ 30,269,077	$ 16,315,701	$ 9,607,662
																		$ -	$ -	$ -	$ -
																		$ -	$ -	$ -	$ -

Adaptation Option 2

Partial seawall with beach nourishment

Seawall					
CAPEX year	2015		Data entry		
CAPEX value	$ 5,300,000.00		Interpolate		1314445.654
OPEX start year	2016				
OPEX value	$ 265,000.00 pa				

Beach Nourishment																					
CAPEX year	2015																				
CAPEX value	$ 225,000.00																				
OPEX start year	2025	2025	2035	2045	BEYOND 2050	BEYOND 2050	BEYOND 2050	BEYOND 2050	BEYOND 2050	BEYOND 2050	BEYOND 2050	BEYOND 2050	BEYOND 2050	BEYOND 2050	BEYOND 2050	BEYOND 2050	BEYOND 2050	BEYOND 2050	BEYOND 2050	BEYOND 2050	BEYOND 2050
OPEX value	$ 75,000.00	per nourishment																			
OPEX frequency	10	yrs (whole yrs only)																			

Relocation Costs	
CAPEX year	2015
CAPEX Cost	$ 1,314,445.65

Assets		Year									
Asset	**Notes**	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Base Case Costs	Sydney Water	$ 186,360	$ 197,396	$ 208,431	$ 219,466	$ 230,502	$ 241,537	$ 252,572	$ 263,607	$ 274,643	$ 285,678
	Other	$ 5,995,716	$ 6,206,197	$ 6,416,678	$ 6,627,159	$ 6,837,640	$ 7,048,121	$ 7,258,602	$ 7,469,083	$ 7,679,564	$ 7,890,045
Adaptation Option Costs	Seawall CAPEX	$ -	$ -	$ -	$ 5,300,000	$ -	$ -	$ -	$ -	$ -	$ -
	Seawall OPEX	$ -	$ -	$ -	$ -	$ 265,000	$ 265,000	$ 265,000	$ 265,000	$ 265,000	$ 265,000
	Beach nourishment CAPEX	$ -	$ -	$ -	$ 225,000	$ -	$ -	$ -	$ -	$ -	$ -
	Beach nourishment OPEX	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Benefits Costs	Sydney Water	$ -	$ -	$ -	$ -	-$ 230,502	-$ 241,537	-$ 252,572	-$ 263,607	-$ 274,643	-$ 285,678
	Base Case	$ -	$ -	$ -	$ -	-$ 6,837,640	-$ 7,048,121	-$ 7,258,602	-$ 7,469,083	-$ 7,679,564	-$ 7,890,045
Relocation Costs	Loss of 1.No. private property	$ -	$ -	$ -	$ 2,000,000.00	$ -	$ -	$ -	$ -	$ -	$ -
	Relocation of SW assets	$ -	$ -	$ -	$ 1,314,445.65	$ -	$ -	$ -	$ -	$ -	$ -

Assets		Year									
Asset	**Notes**	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031
Base Case Costs	Sydney Water	$ 296,713	$ 307,749	$ 318,784	$ 329,819	$ 340,855	$ 351,890	$ 362,925	$ 373,961	$ 384,996	$ 396,031
	Other	$ 8,100,526	$ 8,311,007	$ 8,521,488	$ 8,731,969	$ 8,942,450	$ 9,152,931	$ 9,363,412	$ 9,573,893	$ 9,784,374	$ 9,994,855
Adaptation Option Costs	Seawall CAPEX	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
	Seawall OPEX	$ 265,000	$ 265,000	$ 265,000	$ 265,000	$ 265,000	$ 265,000	$ 265,000	$ 265,000	$ 265,000	$ 265,000
	Beach nourishment CAPEX	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
	Beach nourishment OPEX	$ -	$ -	$ -	$ 75,000	$ -	$ -	$ -	$ -	$ -	$ -
Benefits Costs	Sydney Water	-$ 296,713	-$ 307,749	-$ 318,784	-$ 329,819	-$ 340,855	-$ 351,890	-$ 362,925	-$ 373,961	-$ 384,996	-$ 396,031
	Base Case	-$ 8,100,526	-$ 8,311,007	-$ 8,521,488	-$ 8,731,969	-$ 8,942,450	-$ 9,152,931	-$ 9,363,412	-$ 9,573,893	-$ 9,784,374	-$ 9,994,855
Relocation Costs	Loss of 1.No. private property	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
	Relocation of SW assets	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -

2015	$ 32,023,457
2020	$ 52,474,411
2025	$ 69,482,977
2030	$ 83,347,040
2035	$ 94,463,972
2045	$ 110,181,864

BEYOND 2050 BEYOND 2050 BEYOND 2050 BEYOND 2050 BEYOND 2050 BEYOND 2050 BEYOND 2050 BEYOND 2050 BEYOND 2050 BEYOND 2050 BEYOND 2050 BEYOND 2050 BEYOND 2050 BEYOND 2050 BEYOND 2050 BEYOND 2050 BEYOND 2050 BEYOND 2050 BEYOND 2050

2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050
$ 407,067	$ 418,102	$ 429,137	$ 440,172	$ 451,208	$ 462,243	$ 473,278	$ 484,314	$ 495,349	$ 506,384	$ 517,420	$ 528,455	$ 539,490	$ 550,526	$ 561,561	$ 572,596	$ 583,632	$ 594,667	$ 605,702
$ 10,205,336	$ 10,415,817	$ 10,626,298	$ 10,836,779	$ 11,047,260	$ 11,257,741	$ 11,468,223	$ 11,678,704	$ 11,889,185	$ 12,099,666	$ 12,310,147	$ 12,520,628	$ 12,731,109	$ 12,941,590	$ 13,152,071	$ 13,362,552	$ 13,573,033	$ 13,783,514	$ 13,993,995
$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
$ 265,000	$ 265,000	$ 265,000	$ 265,000	$ 265,000	$ 265,000	$ 265,000	$ 265,000	$ 265,000	$ 265,000	$ 265,000	$ 265,000	$ 265,000	$ 265,000	$ 265,000	$ 265,000	$ 265,000	$ 265,000	$ 265,000
$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
$ -	$ -	$ -	$ 75,000	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 75,000	$ -	$ -	$ -	$ -	$ -
-$ 407,067	-$ 418,102	-$ 429,137	-$ 440,172	-$ 451,208	-$ 462,243	-$ 473,278	-$ 484,314	-$ 495,349	-$ 506,384	-$ 517,420	-$ 528,455	-$ 539,490	-$ 550,526	-$ 561,561	-$ 572,596	-$ 583,632	-$ 594,667	-$ 605,702
-$ 10,205,336	-$ 10,415,817	-$ 10,626,298	-$ 10,836,779	-$ 11,047,260	-$ 11,257,741	-$ 11,468,223	-$ 11,678,704	-$ 11,889,185	-$ 12,099,666	-$ 12,310,147	-$ 12,520,628	-$ 12,731,109	-$ 12,941,590	-$ 13,152,071	-$ 13,362,552	-$ 13,573,033	-$ 13,783,514	-$ 13,993,995
$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -

SUM			
Discount Rate			
0%	4%	7%	10%
$ 15,445,218	$ 6,722,079	$ 4,123,913	$ 2,790,419
$ 389,799,359	$ 176,022,404	$ 111,039,295	$ 77,041,384
$ -	$ -	$ -	$ -
$ -	$ -	$ -	$ -
$ 5,300,000	$ 4,530,462	$ 4,043,345	$ 3,619,971
$ 9,275,000	$ 4,227,966	$ 2,617,595	$ 1,745,579
$ 225,000	$ 192,331	$ 171,651	$ 153,678
$ 225,000	$ 92,336	$ 51,389	$ 30,300
-$ 14,633,565	-$ 5,987,488	-$ 3,439,760	-$ 2,151,368
-$ 364,553,609	-$ 153,149,988	-$ 89,721,342	-$ 57,114,261
$ -	$ -	$ -	$ -
$ -	$ -	$ -	$ -
$ 2,000,000	$ 1,709,608	$ 1,525,790	$ 1,366,027
$ 1,314,446	$ 1,123,594	$ 1,002,784	$ 897,784
$ -	$ -	$ -	$ -

Adaptation Option 3

Planned retreat

Relocation Cost

CAPEX year	2015
CAPEX value	$ 30,862,768.92

	Data entry
	Interpolate

Assets		Year										
Asset	**Notes**	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Base Case Costs	Sydney Water	$ 186,360	$ 197,396	$ 208,431	$ 219,466	$ 230,502	$ 241,537	$ 252,572	$ 263,607	$ 274,643	$ 285,678	$ 296,713
	Other	$ 5,995,716	$ 6,206,197	$ 6,416,678	$ 6,627,159	$ 6,837,640	$ 7,048,121	$ 7,258,602	$ 7,469,083	$ 7,679,564	$ 7,890,045	$ 8,100,526
Adaptation Option Costs	Relocation cost	$ -	$ -	$ -	$ 30,862,769	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Benefits Costs	Sydney Water	$ -	$ -	$ -	$ -	-$ 230,502	-$ 241,537	-$ 252,572	-$ 263,607	-$ 274,643	-$ 285,678	-$ 296,713
	Base Cost	$ -	$ -	$ -	$ -	-$ 6,837,640	-$ 7,048,121	-$ 7,258,602	-$ 7,469,083	-$ 7,679,564	-$ 7,890,045	-$ 8,100,526
Incurred Costs												

Assets		Year									
Asset	**Notes**	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032
Base Case Costs	Sydney Water	$ 307,749	$ 318,784	$ 329,819	$ 340,855	$ 351,890	$ 362,925	$ 373,961	$ 384,996	$ 396,031	$ 407,067
	Other	$ 8,311,007	$ 8,521,488	$ 8,731,969	$ 8,942,450	$ 9,152,931	$ 9,363,412	$ 9,573,893	$ 9,784,374	$ 9,994,855	$ 10,205,336
Adaptation Option Costs	Relocation cost	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Benefits Costs	Sydney Water	-$ 307,749	-$ 318,784	-$ 329,819	-$ 340,855	-$ 351,890	-$ 362,925	-$ 373,961	-$ 384,996	-$ 396,031	-$ 407,067
	Base Cost	-$ 8,311,007	-$ 8,521,488	-$ 8,731,969	-$ 8,942,450	-$ 9,152,931	-$ 9,363,412	-$ 9,573,893	-$ 9,784,374	-$ 9,994,855	-$ 10,205,336
Incurred Costs											

2033	2034	2035	2036	2037	2038	2039	2040	2041
$ 418,102	$ 429,137	$ 440,172	$ 451,208	$ 462,243	$ 473,278	$ 484,314	$ 495,349	$ 506,384
$ 10,415,817	$ 10,626,298	$ 10,836,779	$ 11,047,260	$ 11,257,741	$ 11,468,223	$ 11,678,704	$ 11,889,185	$ 12,099,666
$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
-$ 418,102	-$ 429,137	-$ 440,172	-$ 451,208	-$ 462,243	-$ 473,278	-$ 484,314	-$ 495,349	-$ 506,384
-$ 10,415,817	-$ 10,626,298	-$ 10,836,779	-$ 11,047,260	-$ 11,257,741	-$ 11,468,223	-$ 11,678,704	-$ 11,889,185	-$ 12,099,666

2042	2043	2044	2045	2046	2047	2048	2049	2050
$ 517,420	$ 528,455	$ 539,490	$ 550,526	$ 561,561	$ 572,596	$ 583,632	$ 594,667	$ 605,702
$ 12,310,147	$ 12,520,628	$ 12,731,109	$ 12,941,590	$ 13,152,071	$ 13,362,552	$ 13,573,033	$ 13,783,514	$ 13,993,995
$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
-$ 517,420	-$ 528,455	-$ 539,490	-$ 550,526	-$ 561,561	-$ 572,596	-$ 583,632	-$ 594,667	-$ 605,702
-$ 12,310,147	-$ 12,520,628	-$ 12,731,109	-$ 12,941,590	-$ 13,152,071	-$ 13,362,552	-$ 13,573,033	-$ 13,783,514	-$ 13,993,995

SUM			
Discount Rate			
0%	4%	7%	10%
$ 15,445,218	$ 6,722,079	$ 4,123,913	$ 2,790,419
$ 389,799,359	$ 176,022,404	$ 111,039,295	$ 77,041,384
$ -	$ -	$ -	$ -
$ -	$ -	$ -	$ -
$ 30,862,769	$ 26,381,624	$ 23,545,059	$ 21,079,686
$ -	$ -	$ -	$ -
$ -	$ -	$ -	$ -
$ -	$ -	$ -	$ -
-$ 14,633,565	$ 5,987,488	$ 3,439,760	$ 2,151,368
-$ 364,553,609	$ 153,149,988	$ 89,721,342	$ 57,114,261
$ -	$ -	$ -	$ -
$ -	$ -	$ -	$ -
$ -	$ -	$ -	$ -
$ -	$ -	$ -	$ -
$ -	$ -	$ -	$ -

Adaptation Option BASE CASE

	Data entry
	Interpolate

Assets		Year										
Asset	**Notes**	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Base Case Costs	Sydney Water	$ 186,360	$ 197,396	$ 208,431	$ 219,466	$ 230,502	$ 241,537	$ 252,572	$ 263,607	$ 274,643	$ 285,678	$ 296,713
	Other	$ 5,995,716	$ 6,206,197	$ 6,416,678	$ 6,627,159	$ 6,837,640	$ 7,048,121	$ 7,258,602	$ 7,469,083	$ 7,679,564	$ 7,890,045	$ 8,100,526
Adaptation Option Costs												
Benefits Costs												
Incurred Costs												

Assets		Year									
Asset	**Notes**	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032
Base Case Costs	Sydney Water	$ 307,749	$ 318,784	$ 329,819	$ 340,855	$ 351,890	$ 362,925	$ 373,961	$ 384,996	$ 396,031	$ 407,067
	Other	$ 8,311,007	$ 8,521,488	$ 8,731,969	$ 8,942,450	$ 9,152,931	$ 9,363,412	$ 9,573,893	$ 9,784,374	$ 9,994,855	$ 10,205,336
Adaptation Option Costs											
Benefits Costs											
Incurred Costs											

2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050
$ 418,102	$ 429,137	$ 440,172	$ 451,208	$ 462,243	$ 473,278	$ 484,314	$ 495,349	$ 506,384	$ 517,420	$ 528,455	$ 539,490	$ 550,526	$ 561,561	$ 572,596	$ 583,632	$ 594,667	$ 605,702
$ 10,415,817	$ 10,626,298	$ 10,836,779	$ 11,047,260	$ 11,257,741	$ 11,468,223	$ 11,678,704	$ 11,889,185	$ 12,099,666	$ 12,310,147	$ 12,520,628	$ 12,731,109	$ 12,941,590	$ 13,152,071	$ 13,362,552	$ 13,573,033	$ 13,783,514	$ 13,993,995

SUM			
Discount Rate			
0%	4%	7%	10%
$ 15,445,218	$ 6,722,079	$ 4,123,913	$ 2,790,419
$ 389,799,359	$ 176,022,404	$ 111,039,295	$ 77,041,384
$ -	$ -	$ -	$ -
$ -	$ -	$ -	$ -
$ -	$ -	$ -	$ -
$ -	$ -	$ -	$ -
$ -	$ -	$ -	$ -
$ -	$ -	$ -	$ -
$ -	$ -	$ -	$ -
$ -	$ -	$ -	$ -
$ -	$ -	$ -	$ -
$ -	$ -	$ -	$ -
$ -	$ -	$ -	$ -
$ -	$ -	$ -	$ -
$ -	$ -	$ -	$ -

Adaptation Option 1aS
Sydney Water Assets Only — Full seawall with beach nourishment

Seawall

CAPEX year	2045	
CAPEX value	$ 9,000,000.00	
OPEX start year	2046	
OPEX value	$ 450,000.00	pa

(orange)	Data entry
(grey)	Interpolate

Beach Nourishment

CAPEX year	2045	
CAPEX value	$ 450,000.00	
OPEX start year	2055	BEYOND 2050
OPEX value	$ 225,000.00	per nourishment
OPEX frequency	10	yrs (whole yrs only)

Assets		Year																			
		BEYOND 2050	BEYOND 2050	BEYOND 2050	BEYOND 2050	BEYOND 2050	BEYOND 2050	BEYOND 2050	BEYOND 2050	BEYOND 2050	BEYOND 2050	BEYOND 2050	BEYOND 2050	BEYOND 2050	BEYOND 2050	BEYOND 2050	BEYOND 2050	BEYOND 2050	BEYOND 2050	BEYOND 2050	BEYOND 2050
Asset	**Notes**	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031
Base Case Costs	Sydney Water	$ 186,360	$ 197,396	$ 208,431	$ 219,466	$ 230,502	$ 241,537	$ 252,572	$ 263,607	$ 274,643	$ 285,678	$ 296,713	$ 307,749	$ 318,784	$ 329,819	$ 340,855	$ 351,890	$ 362,925	$ 373,961	$ 384,996	$ 396,031
Adaptation Option Costs	Seawall CAPEX	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
	Seawall OPEX	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
	Beach nourishment CAPEX	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
	Beach nourishment OPEX	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Benefits Costs	Sydney Water	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Incurred Costs																					

BEYOND 2050	BEYOND 2050	BEYOND 2050	BEYOND 2050	BEYOND 2050	BEYOND 2050	BEYOND 2050	BEYOND 2050	BEYOND 2050	BEYOND 2050	BEYOND 2050	BEYOND 2050	BEYOND 2050	BEYOND 2050	BEYOND 2050	BEYOND 2050	BEYOND 2050	BEYOND 2050	BEYOND 2050
2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050
$ 407,067	$ 418,102	$ 429,137	$ 440,172	$ 451,208	$ 462,243	$ 473,278	$ 484,314	$ 495,349	$ 506,384	$ 517,420	$ 528,455	$ 539,490	$ 550,526	$ 561,561	$ 572,596	$ 583,632	$ 594,667	$ 605,702
$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 9,000,000	$ -	$ -	$ -	$ -	$ -
$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 450,000	$ 450,000	$ 450,000	$ 450,000	$ 450,000
$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 450,000	$ -	$ -	$ -	$ -	$ -
$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	-$ 561,561	-$ 572,596	-$ 583,632	-$ 594,667	-$ 605,702

SUM			
Discount Rate			
0%	4%	7%	10%
$ 15,445,218	$ 6,722,079	$ 4,123,913	$ 2,790,419
$ -	$ -	$ -	$ -
$ -	$ -	$ -	$ -
$ -	$ -	$ -	$ -
$ 9,000,000	$ 2,371,969	$ 901,974	$ 352,283
$ 2,250,000	$ 527,979	$ 184,914	$ 66,771
$ 450,000	$ 118,598	$ 45,099	$ 17,614
$ -	$ -	$ -	$ -
-$ 2,918,158	-$ 683,752	-$ 239,213	-$ 86,289
$ -	$ -	$ -	$ -
$ -	$ -	$ -	$ -
$ -	$ -	$ -	$ -
$ -	$ -	$ -	$ -
$ -	$ -	$ -	$ -
$ -	$ -	$ -	$ -

Adaptation Option 1bS
Sydney Water Assets Only Full seawall without beach nourishment

Seawall

CAPEX year	2045	Data entry
CAPEX value	$ 9,000,000.00	Interpolate
OPEX start year	2046	
OPEX value	$ 450,000.00 pa	

Assets		Year																			
Asset	**Notes**	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031
Base Case Costs	Sydney Water	$ 186,360	$ 197,396	$ 208,431	$ 219,466	$ 230,502	$ 241,537	$ 252,572	$ 263,607	$ 274,643	$ 285,678	$ 296,713	$ 307,749	$ 318,784	$ 329,819	$ 340,855	$ 351,890	$ 362,925	$ 373,961	$ 384,996	$ 396,031
Adaptation Option Costs	Seawall CAPEX	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
	Seawall OPEX	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Benefits Costs	Sydney Water	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Incurred Costs																					

2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050
$ 407,067	$ 418,102	$ 429,137	$ 440,172	$ 451,208	$ 462,243	$ 473,278	$ 484,314	$ 495,349	$ 506,384	$ 517,420	$ 528,455	$ 539,490	$ 550,526	$ 561,561	$ 572,596	$ 583,632	$ 594,667	$ 605,702
$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 9,000,000	$ -	$ -	$ -	$ -	$ -
$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 450,000	$ 450,000	$ 450,000	$ 450,000	$ 450,000
$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	-$ 561,561	-$ 572,596	-$ 583,632	-$ 594,667	-$ 605,702

SUM			
Discount Rate			
0%	4%	7%	10%
$ 15,445,218	$ 6,722,079	$ 4,123,913	$ 2,790,419
$ -	$ -	$ -	$ -
$ -	$ -	$ -	$ -
$ -	$ -	$ -	$ -
$ 9,000,000	$ 2,371,969	$ 901,974	$ 352,283
$ 2,250,000	$ 527,979	$ 184,914	$ 66,771
$ -	$ -	$ -	$ -
$ -	$ -	$ -	$ -
-$ 2,918,158	-$ 683,752	-$ 239,213	-$ 86,289
$ -	$ -	$ -	$ -
$ -	$ -	$ -	$ -
$ -	$ -	$ -	$ -
$ -	$ -	$ -	$ -
$ -	$ -	$ -	$ -
$ -	$ -	$ -	$ -

Adaptation Option 2S
Sydney Water Assets Only Partial seawall with beach nourishment

Seawall		
CAPEX year	2045	
CAPEX value	$ 5,300,000.00	
OPEX start year	2046	
OPEX value	$ 265,000.00	pa
Beach Nourishment		
CAPEX year	2045	
CAPEX value	$ 225,000.00	
OPEX start year	2055	BEYOND 2050 BEYOND 2050 BEYOND 2050 BEYOND 2050 BEYOND 2050 BEYOND 2050 BEYOND 2050 BEYOND 2050 BEYOND 2050 BEYOND 2050 BEYOND 2050 BEYOND 2050 BEYOND 2050 BEYOND 2050 BEYOND 2050 BEYOND 2050 BEYOND 2050 BEYOND 2050 BEYOND 2050 BEYOND 2050
OPEX value	$ 75,000.00	per nourishment
OPEX frequency	10	yrs (whole yrs only)
Relocation Costs		
CAPEX year	2045	
CAPEX Cost	$ 1,314,445.65	

(Data entry)	Data entry
(Interpolate)	Interpolate

Assets		Year																			
Asset	**Notes**	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031
Base Case Costs	Sydney Water	$ 186,360	$ 197,396	$ 208,431	$ 219,466	$ 230,502	$ 241,537	$ 252,572	$ 263,607	$ 274,643	$ 285,678	$ 296,713	$ 307,749	$ 318,784	$ 329,819	$ 340,855	$ 351,890	$ 362,925	$ 373,961	$ 384,996	$ 396,031
Adaptation Option Costs	Seawall CAPEX	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
	Seawall OPEX	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
	Beach nourishment CAPEX	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
	Beach nourishment OPEX	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Benefits Costs	Sydney Water	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Incurred Costs	Loss of 1.No. private property	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
	Relocation of SW assets	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -

BEYOND 2050 BEYOND 2050 BEYOND 2050 BEYOND 2050 BEYOND 2050 BEYOND 2050 BEYOND 2050 BEYOND 2050 BEYOND 2050 BEYOND 2050 BEYOND 2050 BEYOND 2050 BEYOND 2050 BEYOND 2050 BEYOND 2050 BEYOND 2050 BEYOND 2050 BEYOND 2050 BEYOND 2050

2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050
$ 407,067	$ 418,102	$ 429,137	$ 440,172	$ 451,208	$ 462,243	$ 473,278	$ 484,314	$ 495,349	$ 506,384	$ 517,420	$ 528,455	$ 539,490	$ 550,526	$ 561,561	$ 572,596	$ 583,632	$ 594,667	$ 605,702
$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 5,300,000	$ -	$ -	$ -	$ -	$ -
$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 265,000	$ 265,000	$ 265,000	$ 265,000	$ 265,000
$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 225,000	$ -	$ -	$ -	$ -	$ -
$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	-$ 561,561	-$ 572,596	-$ 583,632	-$ 594,667	-$ 605,702
$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 2,000,000	$ -	$ -	$ -	$ -	$ -
$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 1,314,445.65	$ -	$ -	$ -	$ -	$ -

SUM			
Discount Rate			
0%	4%	7%	10%
$ 15,445,218	$ 6,722,079	$ 4,123,913	$ 2,790,419
$ -	$ -	$ -	$ -
$ -	$ -	$ -	$ -
$ -	$ -	$ -	$ -
$ 5,300,000	$ 1,396,826	$ 531,163	$ 207,455
$ 1,325,000	$ 310,921	$ 108,894	$ 39,321
$ 225,000	$ 59,299	$ 22,549	$ 8,807
$ -	$ -	$ -	$ -
-$ 2,918,158	-$ 683,752	-$ 239,213	-$ 86,289
$ -	$ -	$ -	$ -
$ -	$ -	$ -	$ -
$ -	$ -	$ -	$ -
$ 2,000,000	$ 527,104	$ 200,439	$ 78,285
$ 1,314,446	$ 346,425	$ 131,733	$ 51,451
$ -	$ -	$ -	$ -

Adaptation Option 3S
Sydney Water Assets Only Planned retreat

Relocation Cost
CAPEX year 2045
CAPEX value $ 1,314,445.65

Data entry
Interpolate

Asset	Notes	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Base Case Costs	Sydney Water	$ 186,360	$ 197,396	$ 208,431	$ 219,466	$ 230,502	$ 241,537	$ 252,572	$ 263,607	$ 274,643	$ 285,678
Adaptation Option Costs	Relocation cost	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Benefits Costs	Sydney Water	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Incurred Costs											

Asset	Notes	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031
Base Case Costs	Sydney Water	$ 296,713	$ 307,749	$ 318,784	$ 329,819	$ 340,855	$ 351,890	$ 362,925	$ 373,961	$ 384,996	$ 396,031
Adaptation Option Costs	Relocation cost	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Benefits Costs	Sydney Water	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Incurred Costs											

2032	2033	2034	2035	2036	2037	2038	2039	2040	2041
$ 407,067	$ 418,102	$ 429,137	$ 440,172	$ 451,208	$ 462,243	$ 473,278	$ 484,314	$ 495,349	$ 506,384
$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -

2042	2043	2044	2045	2046	2047	2048	2049	2050
$ 517,420	$ 528,455	$ 539,490	$ 550,526	$ 561,561	$ 572,596	$ 583,632	$ 594,667	$ 605,702
$ -	$ -	$ -	$ 1,314,446	$ -	$ -	$ -	$ -	$ -
$ -	$ -	$ -	$ -	$ 561,561	$ 572,596	$ 583,632	$ 594,667	$ 605,702

SUM			
Discount Rate			
0%	4%	7%	10%
$ 15,445,218	$ 6,722,079	$ 4,123,913	$ 2,790,419
$ -	$ -	$ -	$ -
$ -	$ -	$ -	$ -
$ -	$ -	$ -	$ -
$ 1,314,446	$ 346,425	$ 131,733	$ 51,451
$ -	$ -	$ -	$ -
$ -	$ -	$ -	$ -
$ -	$ -	$ -	$ -
$ 2,918,158	$ 683,752	$ 239,213	$ 86,289
$ -	$ -	$ -	$ -
$ -	$ -	$ -	$ -
$ -	$ -	$ -	$ -
$ -	$ -	$ -	$ -
$ -	$ -	$ -	$ -
$ -	$ -	$ -	$ -

Adaptation Option BASE CASE S

Sydney Water Assets Only

	Data entry
	Interpolate

Assets		Year									
Asset	**Notes**	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Base Case Costs	Sydney Water	$ 186,360	$ 197,396	$ 208,431	$ 219,466	$ 230,502	$ 241,537	$ 252,572	$ 263,607	$ 274,643	$ 285,678
Adaptation Option Costs											
Benefits Costs											
Incurred Costs											

Assets		Year									
Asset	**Notes**	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031
Base Case Costs	Sydney Water	$ 296,713	$ 307,749	$ 318,784	$ 329,819	$ 340,855	$ 351,890	$ 362,925	$ 373,961	$ 384,996	$ 396,031
Adaptation Option Costs											
Benefits Costs											
Incurred Costs											

2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050
$ 407,067	$ 418,102	$ 429,137	$ 440,172	$ 451,208	$ 462,243	$ 473,278	$ 484,314	$ 495,349	$ 506,384	$ 517,420	$ 528,455	$ 539,490	$ 550,526	$ 561,561	$ 572,596	$ 583,632	$ 594,667	$ 605,702

SUM			
Discount Rate			
0%	4%	7%	10%
$ 15,445,218	$ 6,722,079	$ 4,123,913	$ 2,790,419
$ -	$ -	$ -	$ -
$ -	$ -	$ -	$ -
$ -	$ -	$ -	$ -
$ -	$ -	$ -	$ -
$ -	$ -	$ -	$ -
$ -	$ -	$ -	$ -
$ -	$ -	$ -	$ -
$ -	$ -	$ -	$ -
$ -	$ -	$ -	$ -
$ -	$ -	$ -	$ -
$ -	$ -	$ -	$ -
$ -	$ -	$ -	$ -
$ -	$ -	$ -	$ -
$ -	$ -	$ -	$ -

TOTAL COSTS

Table 1. Cost per Option ($M, 2012 Prices)

Adaptation implementation year 2015
Discount rate 7%

Adaptation option	Capex	Opex	Damages: Sydney Water	Damages: Other	Damages: Loss of beach ammenity	Total Cost	NPV	BCR
BAU [a]	n/a	n/a	$ 4,123,913	$ 111,039,295	n/a	$ 115,163,209	$ -	n/a
Adaptation Option 1a	$ 7,209,360	$ 4,599,139	$ 684,153	$ 21,317,954	n/a	$ 33,810,605	$ 81,352,603	7.89
Adaptation Option 1b	$ 6,866,057	$ 4,444,973	$ 684,153	$ 21,317,954	$ 16,315,701	$ 49,628,837	$ 65,534,372	6.79
Adaptation Option 2	$ 6,743,571	$ 2,668,984	$ 684,153	$ 22,843,744	n/a	$ 32,940,452	$ 82,222,757	9.74
Adaptation Option 3	$ 23,545,059	n/a	$ 684,153	$ 21,317,954	n/a	$ 45,547,165	$ 69,616,043	3.96

Note: 38 year Assessment period
[a] Costs if no action was taken over the entire assessment period

Adaptation implementation year 2015
Discount rate 0%

Adaptation option	Capex	Opex	Damages: Sydney Water	Damages: Other	Damages: Loss of beach ammenity	Total Cost	NPV	BCR
BAU [a]	n/a	n/a	$ 15,445,218	$ 389,799,359	n/a	$ 405,244,576	$ -	n/a
Adaptation Option 1a	$ 9,450,000	$ 16,425,000	$ 811,653	$ 25,245,750	n/a	$ 51,932,402	$ 353,312,174	14.65
Adaptation Option 1b	$ 9,000,000	$ 15,750,000	$ 811,653	$ 25,245,750	$ 80,177,408	$ 130,984,810	$ 274,259,766	12.08
Adaptation Option 2	$ 8,839,446	$ 9,500,000	$ 811,653	$ 27,245,750	n/a	$ 46,396,848	$ 358,847,728	20.57
Adaptation Option 3	$ 30,862,769	n/a	$ 811,653	$ 25,245,750	n/a	$ 56,920,171	$ 348,324,405	12.29

Note: 38 year Assessment period
[a] Costs if no action was taken over the entire assessment period

Adaptation implementation year 2015
Discount rate 4%

Adaptation option	Capex	Opex	Damages: Sydney Water	Damages: Other	Damages: Loss of beach ammenity	Total Cost	NPV	BCR
BAU [a]	n/a	n/a	$ 6,722,079	$ 176,022,404	n/a	$ 182,744,482	$ -	n/a
Adaptation Option 1a	$ 8,077,900	$ 7,456,574	$ 734,591	$ 22,872,416	n/a	$ 39,141,480	$ 143,603,002	10.24
Adaptation Option 1b	$ 7,693,238	$ 7,179,565	$ 734,591	$ 22,872,416	$ 30,269,077	$ 68,748,886	$ 113,995,596	8.66
Adaptation Option 2	$ 7,555,995	$ 4,320,302	$ 734,591	$ 24,582,024	n/a	$ 37,192,913	$ 145,551,570	13.26
Adaptation Option 3	$ 26,381,624	n/a	$ 734,591	$ 22,872,416	n/a	$ 49,988,631	$ 132,755,851	6.03

Note: 38 year Assessment period
[a] Costs if no action was taken over the entire assessment period

Adaptation implementation year 2015
Discount rate 10%

Adaptation option	Capex	Opex	Damages: Sydney Water	Damages: Other	Damages: Loss of beach ammenity	Total Cost	NPV	BCR
BAU [a]	n/a	n/a	$ 2,790,419	$ 77,041,384	n/a	$ 79,831,802	$ -	n/a
Adaptation Option 1a	$ 6,454,477	$ 3,055,091	$ 639,051	$ 19,927,123	n/a	$ 30,075,741	$ 49,756,061	6.23
Adaptation Option 1b	$ 6,147,121	$ 2,964,191	$ 639,051	$ 19,927,123	$ 9,607,662	$ 39,285,147	$ 40,546,655	5.45
Adaptation Option 2	$ 6,037,460	$ 1,775,879	$ 639,051	$ 21,293,150	n/a	$ 29,745,540	$ 50,086,263	7.41
Adaptation Option 3	$ 21,079,686	n/a	$ 639,051	$ 19,927,123	n/a	$ 41,645,860	$ 38,185,942	2.81

Note: 38 year Assessment period
[a] Costs if no action was taken over the entire assessment period

Table 2 - Option Evaluation Summary Table

Adaptation option	BCR 0%	BCR 4%	BCR 7%	BCR 10%
BAU [a]	n/a	n/a	n/a	n/a
Adaptation Option 1a	14.7	10.2	7.9	6.2
Adaptation Option 1b	12.1	8.7	6.8	5.5
Adaptation Option 2	20.6	13.3	9.7	7.4
Adaptation Option 3	12.3	6.0	4.0	2.8

SYDNEY WATER COSTS

Table 1. Cost per Option ($M, 2012 Prices)

Adaptation implementation year 2045
Discount rate 7%

Adaptation option	Capex	Opex	Damages: Sydney Water	Damages: Other	Damages: Loss of beach ammenity	Total Cost	NPV	BCR
BAU [a]	n/a	n/a	$ 4,123,913	n/a	n/a	$ 4,123,913	$ -	n/a
Adaptation Option 1a	$ 947,073	$ 4,599,139	$ 3,884,700	n/a	n/a	$ 9,430,912	-$ 5,306,999	0.04
Adaptation Option 1b	$ 901,974	$ 184,914	$ 3,884,700	n/a	n/a	$ 4,971,588	-$ 847,675	0.22
Adaptation Option 2	$ 885,883	$ 108,894	$ 3,884,700	n/a	n/a	$ 4,879,477	-$ 755,564	0.24
Adaptation Option 3	$ 131,733	n/a	$ 3,884,700	n/a	n/a	$ 4,016,433	$ 107,480	1.82

Note: 38 year Assessment period
[a] Costs if no action was taken over the entire assessment period

Sensitivity analysis for adaptation implementation date

Undertaken for 7% discount rate and
Values are copies taken for each implementation year - not active cells

Adaptation implementation year 2015
Discount rate 7%

Adaptation option	Capex	Opex	Damages: Sydney Water	Damages: Other	Damages: Loss of beach ammenity	Total Cost	NPV	BCR
BAU [a]	n/a	n/a	$ 4,123,913	$ 111,039,295	n/a	$ 115,163,209	$ -	n/a
Adaptation Option 1a	$ 7,209,360	$ 4,599,139	$ 684,153	$ 21,317,954	n/a	$ 33,810,605	$ 81,352,603	7.89
Adaptation Option 1b	$ 6,866,057	$ 4,444,973	$ 684,153	$ 21,317,954	$ 16,315,701	$ 49,628,837	$ 65,534,372	6.79
Adaptation Option 2	$ 6,743,571	$ 2,668,984	$ 684,153	$ 22,843,744	n/a	$ 32,940,452	$ 82,222,757	9.74
Adaptation Option 3	$ 23,545,059	n/a	$ 684,153	$ 21,317,954	n/a	$ 45,547,165	$ 69,616,043	3.96

Adaptation implementation year 2025
Discount rate 7%

Adaptation option	Capex	Opex	Damages: Sydney Water	Damages: Other	Damages: Loss of beach ammenity	Total Cost	NPV	BCR
BAU [a]	n/a	n/a	$ 4,123,913	$ 111,039,295	n/a	$ 115,163,209	$ -	n/a
Adaptation Option 1a	$ 3,664,873	$ 2,100,665	$ 2,152,570	$ 62,406,208	n/a	$ 70,324,316	$ 44,838,893	8.78
Adaptation Option 1b	$ 3,490,355	$ 2,033,757	$ 2,152,570	$ 62,406,208	$ 11,632,530	$ 81,715,420	$ 33,447,788	7.05
Adaptation Option 2	$ 3,428,089	$ 1,219,959	$ 2,152,570	$ 63,181,842	n/a	$ 69,982,462	$ 45,180,747	10.72
Adaptation Option 3	$ 11,969,114	n/a	$ 2,152,570	$ 62,406,208	n/a	$ 76,527,892	$ 38,635,316	4.23

Adaptation implementation year 2035
Discount rate 7%

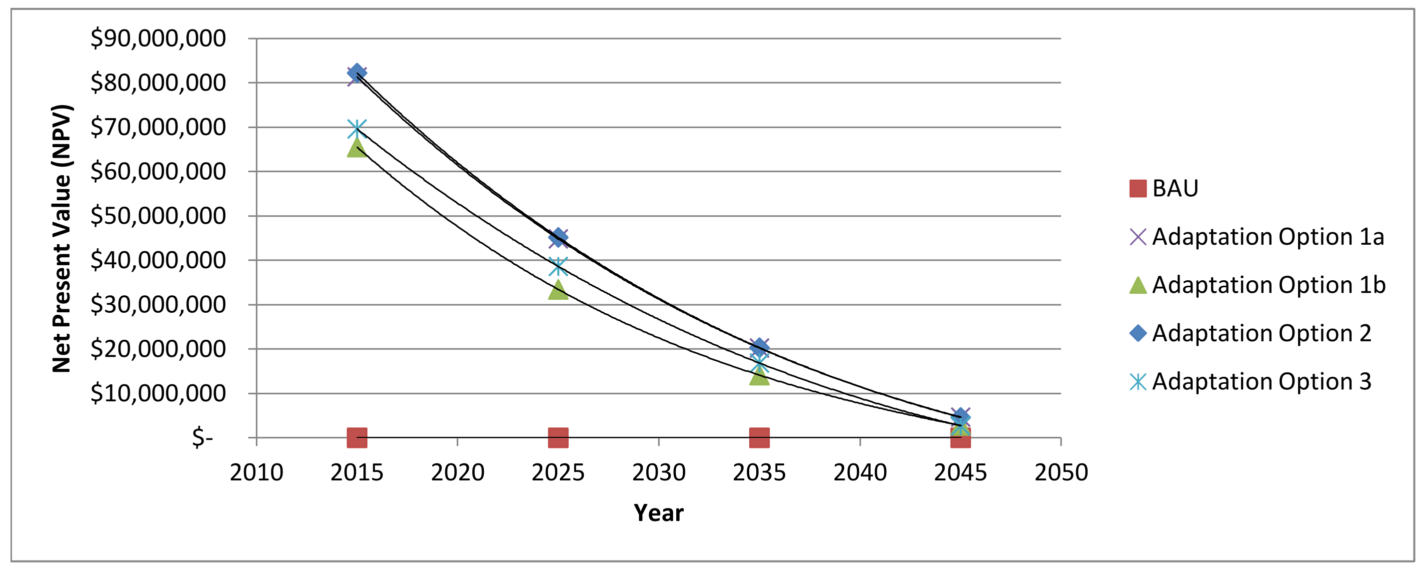
Adaptation option	Capex	Opex	Damages: Sydney Water	Damages: Other	Damages: Loss of beach ammenity	Total Cost	NPV	BCR
BAU [a]	n/a	n/a	$ 4,123,913	$ 111,039,295	n/a	$ 115,163,209	$ -	n/a
Adaptation Option 1a	$ 1,863,036	$ 830,567	$ 3,199,627	$ 89,026,614	n/a	$ 94,919,843	$ 20,243,365	8.52
Adaptation Option 1b	$ 1,774,320	$ 808,018	$ 3,199,627	$ 89,026,614	$ 6,219,199	$ 101,027,777	$ 14,135,432	6.47
Adaptation Option 2	$ 1,742,667	$ 483,349	$ 3,199,627	$ 89,420,907	n/a	$ 94,846,550	$ 20,316,659	10.13
Adaptation Option 3	$ 6,084,491	n/a	$ 3,199,627	$ 89,026,614	n/a	$ 98,310,731	$ 16,852,477	3.77

Adaptation implementation year 2045
Discount rate 7%

Adaptation option	Capex	Opex	Damages: Sydney Water	Damages: Other	Damages: Loss of beach ammenity	Total Cost	NPV	BCR
BAU [a]	n/a	n/a	$ 4,123,913	$ 111,039,295	n/a	$ 115,163,209	$ -	n/a
Adaptation Option 1a	$ 947,073	$ 184,914	$ 3,884,700	$ 105,473,558	n/a	$ 110,490,244	$ 4,672,964	5.13
Adaptation Option 1b	$ 901,974	$ 184,914	$ 3,884,700	$ 105,473,558	$ 1,925,694	$ 112,370,839	$ 2,792,370	3.57
Adaptation Option 2	$ 885,883	$ 108,894	$ 3,884,700	$ 105,673,996	n/a	$ 110,553,473	$ 4,609,735	5.63
Adaptation Option 3	$ 3,093,046	n/a	$ 3,884,700	$ 105,473,558	n/a	$ 112,451,304	$ 2,711,904	1.88

NPV

Adaptation option	2015	2025	2035	2045
BAU	$ -	$ -	$ -	$ -
Adaptation Option 1a	$ 81,352,603	$ 44,838,893	$ 20,243,365	$ 4,672,964
Adaptation Option 1b	$ 65,534,372	$ 33,447,788	$ 14,135,432	$ 2,792,370
Adaptation Option 2	$ 82,222,757	$ 45,180,747	$ 20,316,659	$ 4,609,735
Adaptation Option 3	$ 69,616,043	$ 38,635,316	$ 16,852,477	$ 2,711,904



Adaptation implementation year 2015
Discount rate 7%

Adaptation option	Capex	Opex	Damages: Sydney Water	Damages: Other	Damages: Loss of beach ammenity	Total Cost	NPV	BCR
BAU [a]	n/a	n/a	$ 4,123,913	n/a	n/a	$ 4,123,913	$ -	n/a
Adaptation Option 1a	$ 7,209,360	$ 4,599,139	$ 684,153	n/a	n/a	$ 12,492,651	-$ 8,368,738	0.29
Adaptation Option 1b	$ 6,866,057	$ 4,444,973	$ 684,153	n/a	n/a	$ 11,995,182	-$ 7,871,269	0.30
Adaptation Option 2	$ 6,743,571	$ 2,668,984	$ 684,153	n/a	n/a	$ 10,096,707	-$ 5,972,794	0.37
Adaptation Option 3	$ 1,002,784	n/a	$ 684,153	n/a	n/a	$ 1,686,937	$ 2,436,976	3.43

Adaptation implementation year 2025
Discount rate 7%

Adaptation option	Capex	Opex	Damages: Sydney Water	Damages: Other	Damages: Loss of beach ammenity	Total Cost	NPV	BCR
BAU [a]	n/a	n/a	$ 4,123,913	n/a	n/a	$ 4,123,913	$ -	n/a
Adaptation Option 1a	$ 3,664,873	$ 4,599,139	$ 2,152,570	n/a	n/a	$ 10,416,582	-$ 6,292,669	0.24
Adaptation Option 1b	$ 3,490,355	$ 2,033,757	$ 2,152,570	n/a	n/a	$ 7,676,683	-$ 3,552,770	0.36
Adaptation Option 2	$ 3,428,089	$ 1,219,959	$ 2,152,570	n/a	n/a	$ 6,800,619	-$ 2,676,706	0.42
Adaptation Option 3	$ 509,765	n/a	$ 2,152,570	n/a	n/a	$ 2,662,335	$ 1,461,578	3.87

Adaptation implementation year 2035
Discount rate 7%

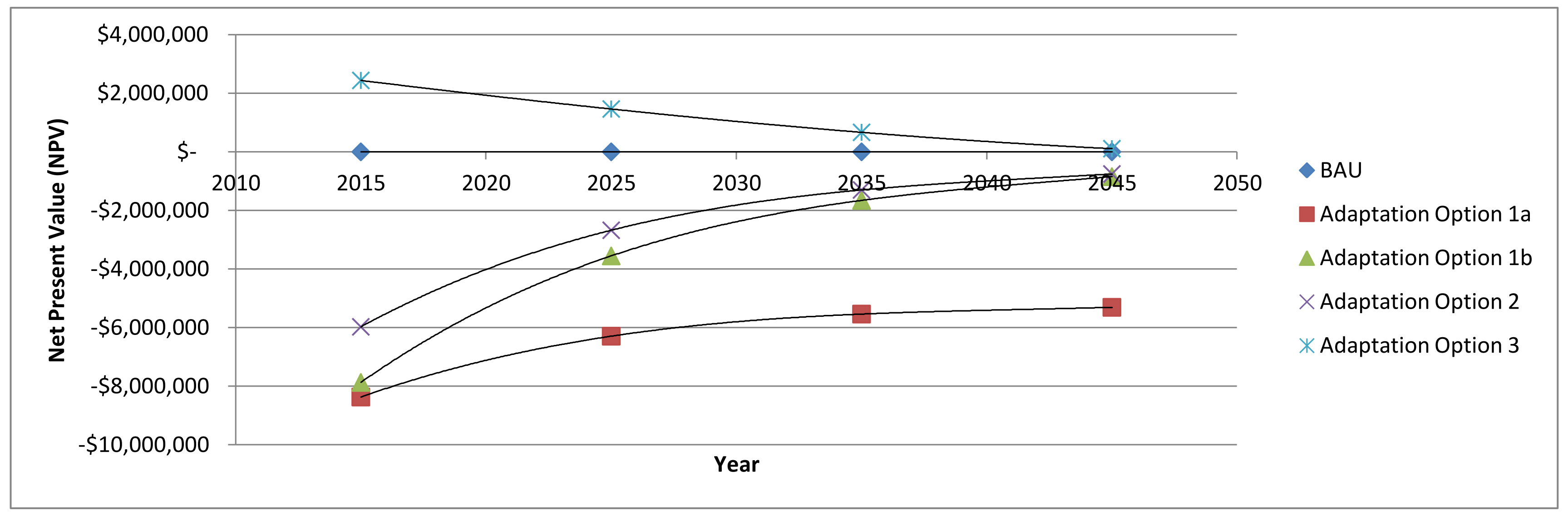
Adaptation option	Capex	Opex	Damages: Sydney Water	Damages: Other	Damages: Loss of beach ammenity	Total Cost	NPV	BCR
BAU [a]	n/a	n/a	$ 4,123,913	n/a	n/a	$ 4,123,913	$ -	n/a
Adaptation Option 1a	$ 1,863,036	$ 4,599,139	$ 3,199,627	n/a	n/a	$ 9,661,801	-$ 5,537,888	0.14
Adaptation Option 1b	$ 1,774,320	$ 808,018	$ 3,199,627	n/a	n/a	$ 5,781,964	-$ 1,658,051	0.36
Adaptation Option 2	$ 1,742,667	$ 483,349	$ 3,199,627	n/a	n/a	$ 5,425,642	-$ 1,301,729	0.42
Adaptation Option 3	$ 259,139	n/a	$ 3,199,627	n/a	n/a	$ 3,458,765	$ 665,148	3.57

Adaptation implementation year 2045
Discount rate 7%

Adaptation option	Capex	Opex	Damages: Sydney Water	Damages: Other	Damages: Loss of beach ammenity	Total Cost	NPV	BCR
BAU [a]	n/a	n/a	$ 4,123,913	n/a	n/a	$ 4,123,913	$ -	n/a
Adaptation Option 1a	$ 947,073	$ 4,599,139	$ 3,884,700	n/a	n/a	$ 9,430,912	-$ 5,306,999	0.04
Adaptation Option 1b	$ 901,974	$ 184,914	$ 3,884,700	n/a	n/a	$ 4,971,588	-$ 847,675	0.22
Adaptation Option 2	$ 885,883	$ 108,894	$ 3,884,700	n/a	n/a	$ 4,879,477	-$ 755,564	0.24
Adaptation Option 3	$ 131,733	n/a	$ 3,884,700	n/a	n/a	$ 4,016,433	$ 107,480	1.82

NPV

Adaptation option	2015	2025	2035	2045
BAU	$ -	$ -	$ -	$ -
Adaptation Option 1a	-$ 8,368,738	-$ 6,292,669	-$ 5,537,888	-$ 5,306,999
Adaptation Option 1b	-$ 7,871,269	-$ 3,552,770	-$ 1,658,051	-$ 847,675
Adaptation Option 2	-$ 5,972,794	-$ 2,676,706	-$ 1,301,729	-$ 755,564
Adaptation Option 3	$ 2,436,976	$ 1,461,578	$ 665,148	$ 107,480



Berry Creek: Valuing community and ecological assets in the adaptation of interconnected water networks under multiple ownership

6.1 Overview

Berry Creek bushland supports a number of important ecological habitats including Coastal Littoral Rainforest (recognised by the State Government as critically endangered), salt marsh and sea grass. The bushland faces pressures from changes to water quality and runoff, weed and feral animal invasion, urban encroachment, altered bushfire regimen, tree vandalism and the uncertain impacts of climate change.

Berry Creek is an important community asset. There are a number of bush care groups established in the area, as well as a creek restoration group who dedicate time and resources to regenerating the creek.

The location of Berry Creek is shown in Figure 22. Berry Creek bushland is on the border between North Sydney Council and Lane Cove Council. A number of water infrastructure assets run through or adjacent to the bushland, including stormwater and wastewater infrastructure. Stormwater discharges into the creek close to Russel Street while a SWC sewer line runs the length of the creek buried beneath the creek line.

In addition to the main wastewater infrastructure owned by SWC, there are a number of connections from private households on either side of the creek.

Berry Creek bushland is already under pressure. The case study relates to the potential for climate change, in particular, its impact on creek water quality, to exacerbate impacts on an important ecological and community asset. Climate change has the potential to change the water quality entering Berry Creek; increasing the amount of runoff, changing the sediment and nutrient loads, and increasing weed and feral animal invasion, increasing the stress on the biodiversity of the area.

The adaptation responses are complicated by the range of land and asset ownership in the creek and the difficulties in clearly identifying the source and defining the problems. Additionally, difficulties lie in defining the water quality issues currently occurring in the creek, how this would change under climate change scenarios, and the relationship between water quality and biodiversity of the creek.

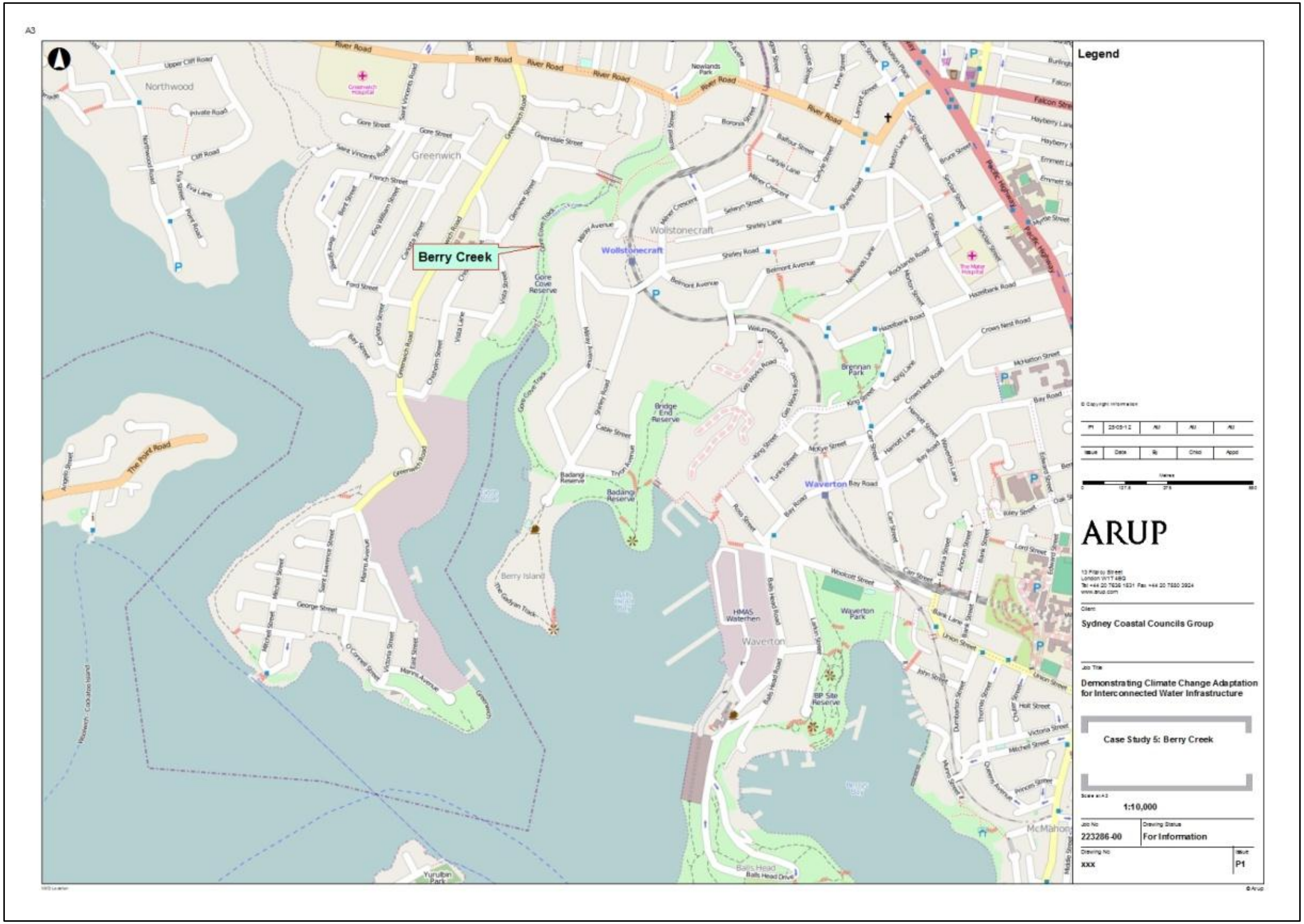


Figure 22 Berry Creek site plan

Key lessons learned from the Berry Creek Case Study

The Berry Creek case study demonstrates the difficulty in accurately defining the scope of the adaptation problem to be addressed. Part of the difficulty with this case study was highlighted by the need to gather additional data, specific to the study. The case study also showed the importance of drawing on the expertise that exists within stakeholder groups to make informed judgements about the potential scope of the problem. Involving the right people early in the process is important.

The inability to accurately define the scope of the problem runs the risk of inappropriate adaptation options emerging. To avoid maladaptation, caution is required in identifying adaptation options prior to the scope of the problem being properly understood.

However, lack of evidence should not inhibit efforts to address the problem. The case study demonstrates the need for better data to underpin problem definition but identifies a number of 'no regret' adaptation options which should proceed in the absence of such data.

6.2 Focus and Scope

The Berry Creek case study links intangible concepts, such as ecological and community value, to observable characteristics, such as infrastructure performance and water quality. These case study attributes make it difficult to define the problem focus and scope. This already complex problem, becomes even more difficult to define when climate change is considered. The challenge in decision making under current and future uncertainty is to enable progress to be made in resolving a problem, while in parallel gathering further information to better define the problem. This should also ensure the avoidance of maladaptation, or the implementation of adaptation options which are not effective at addressing the problem.

Due to the issues discussed above this case study concentrated on defining the problem focus and scope. In particular, the workshops and site visit for this case study highlighted the importance of fully understanding the problem and the inter-relationship to climate change impacts to avoid maladaptation.

6.2.1 Current water quality

The water quality of Berry Creek is currently under pressure from contaminants, including nutrients and faecal coliforms. North Sydney Council water quality monitoring data indicates an increase in faecal coliforms in Berry Creek associated with wet weather events, refer to Figure 23 and Figure 24. This contributes excess moisture/nutrients into bushland, facilitating weed growth and directly affecting water quality. North Sydney Council water quality monitoring data also indicates an increase in contaminants associated with urban water runoff during wet weather events, refer to Figure 25 and Figure 26).

Under future climate scenarios of increased rainfall, the water quality issues of Berry Creek have the potential to increase. However, due to difficulties in defining the source of contaminants and defining the links between water quality and the biodiversity of the creek, uncertainty surrounds the impacts of future climate change scenarios.

An increase in rainfall intensity may result in a dilution of contaminants, if the source is further up the catchment, or contribute to making the problem worse if the source of faecal coliforms is immediate sewer overflows.

When considering increased rainfall intensity under climate change scenarios, the impacts of prolonged periods of drought must also be considered. Increased rainfall intensity may decrease the frequency of rainfall events, while increasing the intensity of rain throughout the event, contributing to increased periods of intermittent drought. Such drought periods are likely to complicate the impacts of climate change further.

The source of this faecal coliform is not known, but discussions with stakeholders have identified three potential possibilities. Table 27 contains the potential faecal coliform sources, identified by the stakeholders, and the likely impacts with increased rainfall intensity and prolonged drought periods.

Table 27 Potential sources of faecal coliform contamination and impacts of climate change.

Source of contaminants	**Impact of increased rainfall**	**Impact of prolonged drought**
Urban stormwater runoff transporting faecal coliform into the creek during wet weather events.	Dilution of contaminants being transported to creek.	Build up of contaminants which will be washed to creek.
Stormwater surcharge of the sewer network leading to wastewater overflow into the creek (North Sydney Council refer to 'pop-top' valves designed to allow wastewater overflow during wet weather events).	Increased water volume within the sewerage system. This could result in both an increase in contaminants directly entering the creek and a dilution effect due to the increased water volume.	Increased tree root penetration and pipe rupture and the potential for dry weather sewer overflows.
Leakage of wastewater from private connections either side of the creek.	Potential increase in runoff entering private connections, resulting in both an increase in contaminants directly entering the creek and a dilution effect due to the increased water volume.	Increased tree root penetration and pipe rupture and the potential for dry weather sewer overflows.

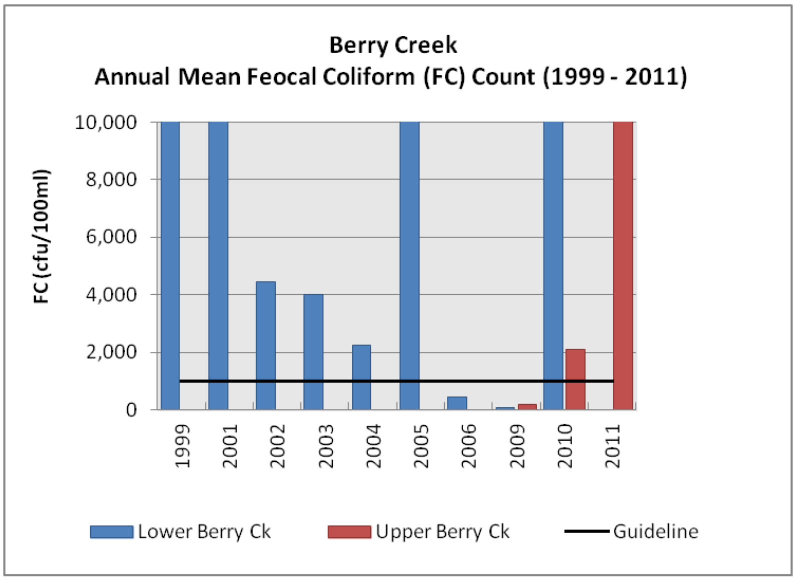


Figure 23 Berry Creek annual mean faecal coliform count (1999-2011) (Source: North Sydney Council)

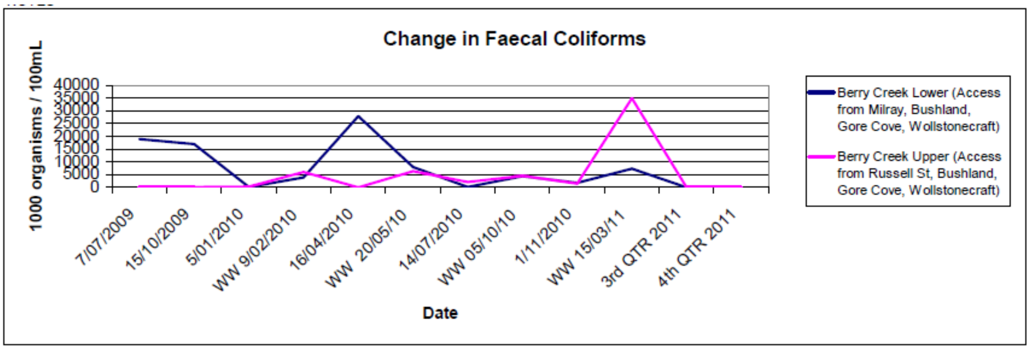


Figure 24 Berry Creek changes in faecal coliform levels associated with weather events

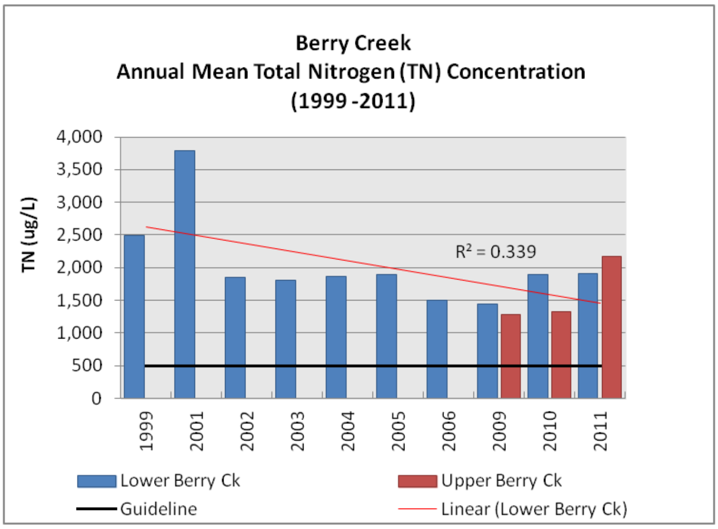


Figure 25 Berry Creek Annual Mean Total Nitrogen Concentration (1999-2011) (Source: North Sydney Council)

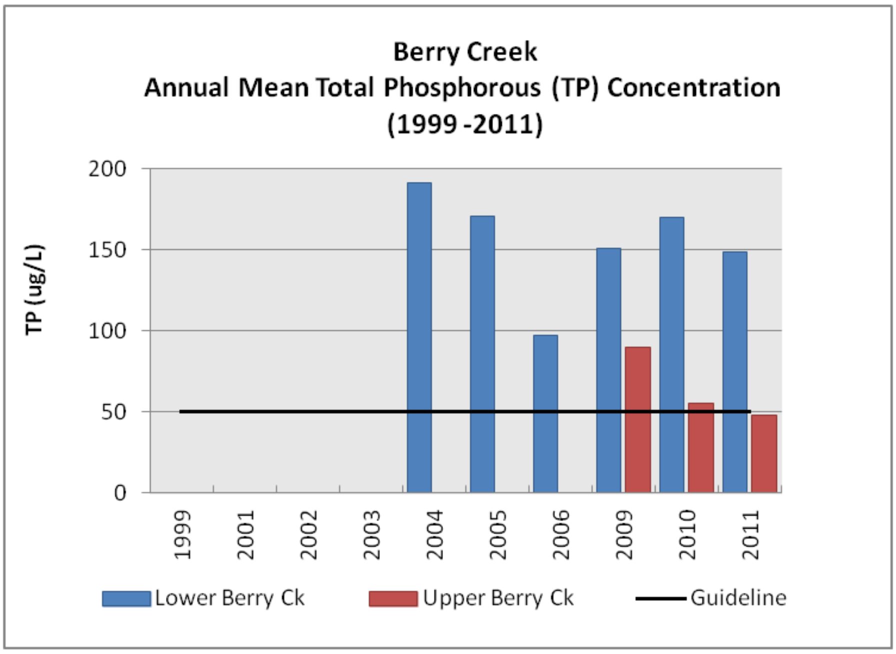


Figure 26 Berry Creek Annual Mean Total Phosphorous Concentration (1999-2011) (Source: North Sydney Council)

6.2.2 Climate change parameters

During the stakeholder workshops various climate change parameters were considered for this case study. Those climate change parameters considered include:

- Rainfall intensity.
- Sea level rise.
- Drought.

The events resulting from these climate change parameters were considered in the workshops by stakeholders to include the following:

- Increased rainfall runoff and erosion.
- Increased contaminant loading to Sydney Harbour.
- Drought followed by flooding.
- Coastal inundation.

From workshop discussions it was agreed that the climate event to be considered further with regard to its impact on Berry Creek was increased rainfall runoff and contamination due to increased rainfall intensity. Workshop discussions identified a number of direct and indirect consequences arising from the climate change events discussed above. The consequences initially identified in relation to this event are summarised in Table 28.

Table 28 Direct and indirect consequences of sewer network surcharge on Berry Creek

Consequences	
Direct	Indirect
SWC infrastructure overflowing Sedimentation from stormwater runoff Failure of bio-retention basin Failure of sea wall infrastructure Bush regeneration contracts (i.e. cost of contracts between local authorities and bush regeneration contractors)	Reduced recreational value Health impacts Mobilisation of contaminants Mobilise failure of old mining infrastructure Loss of endangered species Loss of heritage items Loss of biodiversity corridor (mangroves, salt marsh, littoral rainforest, sea grass, cork tree) Reduction in water quality Cessation of bush regeneration contracts

Discussions in both workshops focussed on surcharge from the sewer infrastructure as well as the potential for contamination from urban stormwater runoff, due to the increase in rainfall intensity. However, the link between increased rainfall intensity and increased contaminant loadings from upstream urban runoff was questioned due to the likely dilution of contamination rather than an increase which would be observed for an increase in rainfall events.

During Workshop 2 it was agreed between the stakeholders to concentrate on surcharge from the sewer network and associated contamination which does have the potential to occur in intense rainfall events.

It was therefore concluded that wastewater overflow into the creek should be taken forward as the main consequence of increased rainfall intensity. The reasons for this were:

- Wastewater overflow allowed clearer definition of the problem compared to erosion, sedimentation, and contamination.
- It required engagement with SWC to identify the problem and adaptation options, and could therefore take advantage of SWC's existing involvement in the project.
- It raised issues of how to deal with private sewer infrastructure ownership in developing adaptation options, highlighting the issue of interconnectedness (private infrastructure connected to SWC infrastructure).

There was also discussion about the role of drought periods in contributing to sewer overflow issues. For the Sydney region, short-term hydrological droughts are projected to become more severe, while medium and long-term droughts are projected to become less severe. Prolonged periods of drought would lead to increased drying of soil, penetration of tree roots into pipes, causing blockage and cracking.

According to SWC (Sewer Main Chokes – Draft Paper[7]), choke occurrence is dependent on season, climate and management. Chokes for cities in Southeast

[7] Sydney Water, 2010. Sydney Water Corporation Board, Sewer Main Chokes (Draft Paper)

Australia show a strong seasonality with a maximum in winter (~August) and a minimum in summer (~January). This effect is thought to be due to higher tree root growth rates during winter compared to summer. In winter energy and nutrients captured during summer are directed to root growth. In summer root growth slows as energy and nutrient are directed to foliage growth. Chokes for cities in Southeast Australia also vary across years and this is thought to be a climatic effect with maxima during dry years and minima during wet years. This effect is thought to be due to higher tree root growth in sewers (where moisture is available) when root growth is the surrounding soil has slowed due to low water availability.

This focus area allows the concept of interconnected water infrastructure to be assessed as it looks at the relationship between stormwater and wastewater infrastructure as well the associated ownership and organisational arrangements. However, it should be emphasised that there is no data to support the link between wet weather events and sewer network overflow, i.e. the source of faecal coliform is not known.

6.3 Risk assessment

6.3.1 Attitudes to risk

Various stakeholders are interested and affected by the water quality of Berry Creek including SWC, North Sydney and Lane Cove Councils, bush care volunteers and the local community.

Attitudes to risk for the corporate stakeholders is largely determined by the potential for their role in Berry Creek to translate into:

- Reputational damage: not meeting with its stated corporate objectives or not meeting minimum compliance standards.
- Regulatory non-compliance: not meeting minimum compliance standards translating into financial penalties, delays, disruption to operations, and impact on reputation.
- Cost: ability to meet the costs of adaptation options and the need to avoid costs associated with the above risks (e.g. financial penalties).

For community groups, volunteers and recreational users of the creek, attitudes to risk are less clear. In addition to the corporate risk of stakeholders, the social and political context of the Berry Creek case study was also discussed in the workshops. In particular, the presence and community involvement in the ongoing rehabilitation and bush care of the reserve was highlighted. North Sydney Council highlighted the investment and ongoing involvement they have had in the reserve and also in the wider community regarding the installation and benefits of bio-retention and other stormwater treatment devices. It was noted that any failure of the proposed bio-retention system (due to sewer overflows) would have unrecoverable impacts on North Sydney Council in terms of publicity, the future direction of Council's stormwater management campaign and the costs involved.

Within the workshops the various drivers and stakeholder risks were discussed. The following section reviews the risk drivers for the corporate stakeholders.

Sydney Water

The main drivers and risks regarding SWC relate to dry weather overflows. Sydney Water's Corporate Plan, the Sewerage Treatment System Licences, the Operating Licence and the Customer Contract include requirements to maintain and/or reduce dry weather sewage overflows.

Sydney Water's Dry Weather Overflow Management Strategy recommends preventative maintenance (such as patch repairs, junction jetting, cyclic root cut and cleaning/dredging) for inspecting and repairing a sewer 'likely to overflow to swimming sites, waterways, National Parks or urban bushlands'.

North Sydney Council

The risks to North Sydney Council generally relate to the commitments council has made in their management plans and their ongoing commitment and involvement in water quality initiatives within the government area.

North Sydney Council identifies both stormwater management and sewer overflow as key initiatives in managing water quality in Council's Water Management Plan (2010-2015)[8]. Council has already put in place various initiatives including Gross Pollutant Traps (GPTs), stormwater reuse and bio-retention systems within the greater council area and has a target of 1.5% of North Sydney's catchment area designated for bio-retention.

The Local Government Amendment (Community Land Management) Act, 1998 requires councils to prepare plans of management for all community lands. As such, North Sydney Council currently has a Plan of Management in place for Smoothey Park[9]. This Management Plan was put in place by council in 2002 and is currently being updated.

Lane Cove Council

Lane Cove Council has employed bush regenerators since the 1970s to manage remnant bushland. The current Plan of Management for Bushland in Lane Cove was adopted 5 February 2007. This document sets out bushland management policies and strategies as well as management activities for each bushland reserve. The plan covers matters such as biodiversity, cultural heritage, recreational values of bushland, weed invasion, bushfire hazard reduction and bush care volunteers.

The Local Government Amendment (Community Land Management) Act, 1998 requires councils to prepare plans of management for all community lands.

The current Plan of Management notes that the municipal boundary between Lane Cove and North Sydney runs through the middle of the Berry Creek catchment, and intersects the bushland reserves and wildlife corridor. Local councils are encouraged, and in some cases required, to work together regionally to address certain issues related to bushland. As a result, since 1990 there has been greater emphasis on regional plans and strategies to help address many issues related to bushland.

[8] North Sydney Council. Water Management Plan 2012-2015
[9] North Sydney Council, 2002. Smoothey Park Plan of Management

With regard to stormwater management, Lane Cove Council has worked with other catchment councils and committees since 1990 on a range of management plans, strategies and projects which address issues of stormwater impacts on bushland.

6.3.2 Existing assets and values

The existing assets of Berry Creek were discussed in both workshops and the presence and ownership of the relevant assets was confirmed, where possible, during a subsequent site visit with the stakeholders.

The assets considered in this case study include the following:

- Stormwater infrastructure: a storm water pipe discharges into Berry Creek at Russel Street. Information provided by North Sydney Council (WSUD Treatment for Russell Street, Wollstonecraft 2011[10]) indicates the stormwater from the upper catchment of Berry Creek is piped to a GPT before discharging to a sandstone channel (Berry Creek).
- SWC sewer infrastructure: a sewer line runs the length of Berry Creek buried beneath the creek.
- Private wastewater infrastructure: numerous connections from private households to the SWC wastewater infrastructure. North Sydney Council have undertaken a leak assessment to determine pipe leaks from private property of residents backing onto Berry Creek. This has led to a program of work to address pipe leaks. Lane Cove Council has committed to undertake a similar assessment on its side of the creek.
- Berry Creek bushlands: The bushland of Berry Creek was considered an asset in terms of ecological and community value, and is currently facing various pressures. A number of bush care groups are active in the bushlands and records of their time input plus council contracts with land management contractors, would provide a basis for estimating a value for the bushland. Additionally, Berry Creek ultimately discharges to Sydney Harbour. The ecological communities (saltmarsh and sea grass community) at the bottom of Berry Creek and in Sydney Harbour are of ecological and community value.

Additionally, it should be noted that at the area where the stormwater pipe enters the creek at Russel Street, there are several other infrastructure assets, including telecommunications and gas. Any proposed works in this area would need to take into account these other assets.

The existing condition, level of service and value of these assets is currently unknown and will require confirmation once source and extent of faecal coliform contamination is confirmed.

6.3.3 Ownership and investment model

The ownership of the assets associated with this case study was established in the stakeholder workshops and confirmed through information provided by the

[10] Equatica, 2011. WSUD Treatment for Russell Street, Wollstonecraft (Draft).

relevant stakeholders. The section below discusses the ownership and investment model for each stakeholder in relation to the relevant assets.

Stormwater infrastructure

This includes pipes owned by North Sydney Council and Lane Cove Council and a GPT owned by North Sydney Council.

Currently, North Sydney Council's drainage maintenance works are funded by the Infrastructure Levy, which has been in place for five years. However, it is due to expire in June this year. Additionally, Gore Cove Reserve (including Smoothey Park/Berry Creek) is listed by council as an Environmental Improvement and/or Protection initiative under North Sydney Council's Environmental Levy[11].

Lane Cove Council has been successful with an application to IPART for a permanent Special Rate Variation (Infrastructure Levy) to help fund the gap in infrastructure funding for roads, footpaths, stormwater and facilities (community buildings)[12].

The Infrastructure Levy will commence 1 July 2011. The additional funds collected via this levy will fund $10m of the $22.9m identified funding gap over the first 10 years[13]. It will be utilised in conjunction with existing reserves and budgets and S94 Development Contributions to meet the infrastructure challenge.

The levy must be utilised specifically for infrastructure renewal projects. It will replace the current 'Stormwater Management Charge' of $25 per property; hence the levy represents an additional cost to ratepayers of approximately 6%.

Lane Cove Council currently maintains a total of 93km of pipes. Recently a comprehensive audit of drainage infrastructure has resulted in the electronic mapping of drainage systems and the identification of over 2000 additional hidden pits, which now total 4247. Each length of pipe was assessed for its condition and capacity, and where pipes were in poor condition CCTV was used to examine the situation more fully.

Current annual spend on stormwater is $390,000 with the required spend estimated at $1,200,000.

SWC wastewater infrastructure

The ownership relationship between private customers and SWC is complex. For the SWC owned infrastructure, SWC has in place decision framework/management strategy[14] for the evaluation of maintenance and renewal of sewer mains that block causing dry weather overflows. Information from SWC indicates that the cost of managing dry weather overflows is $30m per year for operational expenditure (including $15m per year for breakdown maintenance) and $20m per year for capital expenditure.

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[11] North Sydney Council Environmental Levy Matrix 2010-2015 http://www.northsydney.nsw.gov.au/www/html/2145-environmental-levy.asp

[12] Independent Pricing and Regulatory Tribunal (IPART), Determination of Lane Cove Council's application for a Special Variation, June 2011

[13] Independent Pricing and Regulatory Tribunal (IPART), Section 508 (2) Special Variation Application Form – Part B, Lane Cove Council, March 2011

[14] Sydney Water, 2011. Decision Framework Dry Weather Overflow Management.

Private wastewater infrastructure

Private connections are owned by individual property owners. Sydney Water's Customer Services Policy on Sewer Choke Claims set out the responsibilities of private owners in relation to SWC.

Customers connect their private sewer pipes to the SWC sewerage system through a small connection point ('junction'). Customers are responsible for maintaining their private sewer pipes up to the junction where SWC's responsibility commences. SWC owns the junction but not the first joint where the property service connects to the junction.

Berry Creek bushlands

The bushlands are owned by Lane Cove Council and North Sydney Council. North Sydney Council have developed a Plan of Management for Smoothey Park (including Berry Creek bushland). However, the plan is in need of updating and does not include specific water management provisions. It is listed by Council as an Environmental Improvement and/or Protection initiative under North Sydney Council's Environmental Levy.

The ownership and the relationship of the assets in and around Berry Creek is complex. Further clarification of asset ownership and interaction is required as part of the problem definition. However, as the assets are closely linked any adaptation solution is likely to result in multiple beneficiaries. Therefore, joint funding arrangements are possible.

6.3.4 Current risk

Information from North Sydney Council confirms that the ecology of Berry Creek is already under pressure from a number of sources. Water quality monitoring data confirms increases in faecal coliform during wet weather events and exceedance of guideline levels for the annual mean for faecal coliform in eight of the last ten years. However, the source of faecal coliform is not known.

Additionally, the link between faecal coliform contamination and the impact on the Berry Creek bushland has not clearly been established. To understand this link, site specific studies will need to be undertaken.

6.3.5 Risk with climate change

It is expected that under the agreed climate scenario, rainfall intensity will increase and will be accompanied by potential periods of drought, exacerbating the current water quality issues in Berry Creek. While the source of faecal coliform is unknown, it is likely that increased rainfall intensity, accompanied by prolonged drought periods will lead to increases in observed levels of faecal coliforms.

Depending on the source of the contaminants the climate change scenarios will have varying impacts on Berry Creek, refer to Table 27 for further explanation. For example, if the source of contamination originates upstream and is transported through urban runoff, increased rainfall under climate change will dilute the contaminants, whilst prolonged drought will contribute to a build up of higher concentrations. Conversely to this, if the source of contaminants is related to sewer or private sewer connection overflows, increased rainfall is likely to result in increased incidences of sewer surcharge and overflow. In addition, prolonged periods of drought are likely to lead to increased root penetration of sewer lines, leading to cracking and leakage into the creek.

The quantification of damages and cost associated with the existing problem has not been undertaken for this case study. More information regarding the source of faecal coliforms and impacts to the Berry Creek biodiversity is needed to undertake this.

6.4 Adaptation options

Through two workshops, a number of potential adaptation options were identified to respond to the risk of wastewater overflow resulting from increased rainfall intensity. These included:

a. Address problem in existing SWC sewer line through relining. This would first entail an assessment of the condition of the asset through CCTV inspection.

b. Replace sewer line (long term).

c. Move to a decentralised system (long term).

d. Require private owners to fix defective sewer lines/connections through appropriate enforcement provisions.

e. Improve quality of workmanship of the sewer line installation and connections.

f. Incorporate measures in DCPs/LEPs which minimise impact on sewer infrastructure (e.g. guidance on appropriate tree planting).

g. Raise awareness of the relationship between tree planting/management and impact on sewer lines, incorporating role of bush care groups.

Adaptation options (a) to (c) refer to hard engineering solutions that will have a cost implication. Some indicative cost rates for pipe maintenance, relining and replacement have been provided by SWC. However, following further discussions with SWC, North Sydney Council and Lane Cove Council, it was agreed that further data was required to determine the source of faecal coliforms. It was also agreed that proceeding with adaptation options (particularly options (a) to (c)) in advance of further data gathering ran the risk of maladaptation.

Adaptation options (d) to (g) are primarily focussed on providing information or undertaking further assessment work, and would represent low cost, 'no regret' adaptation measures compared to (a) to (c). As such they should be progressed in parallel with the water quality monitoring program:

Private sewer connections

North Sydney Council have already undertaken a leak assessment of private pipe connections on the North Sydney Council side of the creek. Based on this assessment a program of works has been put in place to address leaks. Lane Cove Council has also committed to repeating a similar program for the Lane Cove Council side of the creek.

Planning

North Sydney Council indicated the need to include sewer best practice in the DCP. It was acknowledged that further information regarding triggers and penalties on this matter is needed. Additionally, North Sydney Council have included a 'tick box'/sign off process with the Development Application process, to ensure that matters such as sewer capacity and tree plantings are considered.

Awareness

SWC has produced an information brochure on tree planting in proximity to sewer lines. This includes a list of typical species which should be avoided in close proximity to sewer lines.

6.4.1 Barriers and adaptive capacity building options

In parallel with identifying adaptation options, the case study workshops identified barriers to the implementation of these options. These are described in Table 29.

Table 29 Barriers and adaptation options

Adaptation Options	Barriers
Better understanding the nature of the problem through cross agency water quality monitoring program	Cost to agencies involved Expertise required to design and implement a monitoring program Implications of conclusions of monitoring data
Address problem in existing SWC sewer line through relining	Cost to SWC and competing priorities Understanding how the adaptation option aligns with existing SWC priorities and targets Understanding link between wastewater flow and water quality/biodiversity outcome (cause and effect), i.e. will the adaptation option address the problem Ability to value the biodiversity outcome as a driver for the adaptation option Public perception of and/or awareness of the problem, and therefore need to act
Replace sewer line (long term)	Cost to SWC and competing priorities Understanding how the adaptation option aligns with existing SWC priorities and targets Understanding link between wastewater flow and water quality/biodiversity outcome (cause and effect), i.e. will the adaptation option address the problem. Ability to value the biodiversity outcome as a driver for the adaptation option Public perception of and/or awareness of the problem, and therefore need to act
Move to a decentralised system (long term)	Cost to SWC and competing priorities Understanding how the adaptation option aligns with existing SWC priorities and targets Understanding link between wastewater flow and water quality/biodiversity outcome (cause and effect), i.e. will the adaptation option address the problem. Ability to value the biodiversity outcome as a driver for the adaptation option

Adaptation Options	Barriers
	Public perception of and/or awareness of the problem, and therefore need to act
Require private owners to fix defective sewer lines/connections through appropriate enforcement provisions	Cost to private owners Clear responsibility for cost sharing (private owners, council, SWC) Regulatory – strength of enforcement provisions Ability to encourage better workmanship and role of Fair Trading
Improve quality of workmanship of the sewer line installation and connections	Ability to encourage better workmanship and role of Fair Trading Role of Building Professionals Board
Incorporate measures in DCPs/LEPs which minimise impact on sewer infrastructure (e.g. guidance on appropriate tree planting)	Ability to incorporate into a DCP/LEP (institutional/political barrier) (discussed need to identify a good practice example of where this has been incorporated into a DCP)
Raise awareness of the relationship between tree planting/management and impact on sewer lines, incorporating role of bush care groups	Identifying responsibility for awareness program, and related cost Public perception of and/or awareness of the problem, and therefore need to act

An overarching barrier to adaptation is the lack of data to accurately define the scope of the problem, in particular the source of water quality issues. An expanded water quality monitoring program is required, building on the work of North Sydney Council, but allowing a better understanding of the source of water quality issues. The cost and expertise required to design and implement such a program presents a barrier to its implementation. However, the Berry Creek site visit identified some simple ways in which agencies could work together to improve monitoring and provides a basis for discussions on an expanded monitoring program. This included utilising agency water quality expertise to design a more advanced water quality monitoring program.

Not only would this generate better data, it would build relationships between agencies with interest in and responsibilities for managing Berry Creek. It would also develop knowledge within those agencies around core issues of water quality monitoring and climate adaptation, in the process building the adaptive capacity of those involved.

6.4.2 Economic appraisal

An economic appraisal of adaptation options has not been undertaken as it has not been possible to identify specific adaptation options in advance of further assessment being undertaken to determine the source of faecal coliforms.

Consideration has been given to methodologies to value the creek from an environmental and community perspective. Benefit-cost assessment has not typically assessed the benefit of abstract concepts such as environmental and community value because of the absence of market or price information to assign a value.

However, a number of methodologies exist which allow a value to be placed on these concepts using market values. Given the availability of information on volunteer time input to the management of the Berry Creek bushland and the financial value of contracts between councils and land management contractors, it is possible to estimate the annual value of the creek based on the cost of the costs of volunteer hours. This reflects the value that the community and the councils place on the creek.

It is well recognised that volunteer work contributes significantly to our economy's GDP. Methods to place an economic value of volunteering have been derived in terms of the process value and output value. Where process value refers to the value derived from the individual in undertaking the work, and the output value referring to the value of the goods or services produced by the work. While the value of the process is difficult to quantify, the value of the output can be measured in terms of the opportunity cost of time. A 2011 publication commissioned by the Government of South Australia indicated a value of $27.45 per hour was considered an appropriate national value for volunteer work[15].

North Sydney Council provided the number of volunteer bush care hours and paid hours (including grants) for the Berry Creek rehabilitation. Approximately 250 hours of volunteer work is undertaken at Berry Creek every year. The output of this time is a healthy ecosystem with environmental and community value. The value of this 'output' can therefore be estimated based on this opportunity of time cost at $6,864. This is in addition to actual maintenance expenses and staff costs to maintain the creek

6.5 Flexible Adaptation Pathway

The challenges of climate adaptation for Berry Creek have been described earlier as:

- An existing water quality problem impacting on an important ecological and community asset which is likely to get worse under future climate scenarios.
- Insufficient information to identify the source of water quality issues and therefore the scope of the problem.
- Compounded by the complex governance and asset ownership issues for the Creek.
- The adaptation response needs to reflect these complex and uncertain conditions. The adaptation pathway for Berry Creek is characterised by data gathering to better understand the scope of the problem, identifying and implementing 'no regret' options drawing on the knowledge and expertise of stakeholders, and revisiting adaptation options with better data when available.

[15] Government of South Australia Office of Volunteers, The Economic Value of Volunteering in South Australia, 2011

The components of the Flexible Adaptation Pathway for Berry Creek are:

- Establish a cross-agency water quality monitoring program for Berry Creek with the aim of better understanding the scope of the problem and the source of water quality issues.
- This would enable an informed analysis of adaptation options and acts a hold point for the further development of those options.
- Broad involvement in the design and implementation of the water quality monitoring program and explanation of its results will build understanding and adaptive capacity in those involved.
- Drawing on the expertise and existing work of the stakeholders, it has been possible to identify a number of ‘no regret’ options which can be implemented in parallel with the water quality monitoring program. These involve audits of private sewer connections (already completed for NSC and planned for LCC), raising awareness of the impacts of tree planting on pipework, and consideration of how tree planting/pipework information could be reflected in local planning instruments.
- Estimating the value of Berry Creek as a means of communicating to stakeholders the imperative to act to protect it, and for inclusion in any future business case or economic appraisal associated with specific adaptation options.

6.6 Implementation

As a basis for better defining the nature of the problem and appropriate adaptation responses for Berry Creek, an expanded water quality monitoring program is required. The aim of this program would be to not only monitor water quality but to do so in a way that allowed the sources of pollution, such as faecal coliform, to be identified. The water monitoring program would be designed by North Sydney Council and Lane Cove Council with input from SWC, taking into account their expertise in water quality management. Due to the complexities of the assets in and around Berry Creek, responsibilities for implementing and managing the water monitoring program, including funding, need to be further discussed.

This initial first step would form part of a wider management plan for Berry Creek. North Sydney Council is in the process of updating its Management Plan for Smoothey Park, incorporating Berry Creek, and has identified the lack of specific water quality management measures in the previous plan as a gap to be addressed. The water quality monitoring program should be a key part of the Plan and form the basis for specific management measures.

Therefore the first adaptation option is to better understand the nature of the problem through a cross-agency water quality monitoring program.

6.7 Ongoing monitoring and evaluation

To establish the source of contamination, enable the link between sewer contamination and biodiversity impacts and to determine appropriate adaption responses for Berry Creek, a site specific water monitoring program is required. The design and responsibilities for the monitoring program are yet to be established.

Ongoing monitoring and review will require a commitment from stakeholders to assess the implications of water quality monitoring program for adaptation options. That is, once the problem is better defined through water quality monitoring, what adaptation options should be pursued.

What to monitor?

The monitoring program should be developed based on an eco-toxicological risk assessment framework. The program should consider monitoring the following:

- The potential sources of waste water
    - Urban stormwater runoff.
    - Stormwater surcharge of the sewer network
    - Private connections either side of the creek.
- The water quality of Berry Creek
- Water quality at discharge point to Sydney Harbour
- Biodiversity within Berry Creek and Sydney Harbour

Climate change projections are clearly a key area of uncertainty but other drivers which may influence adaptation and should be tracked to ensure they are incorporated into future decision-making include:

- Extent and nature of land-use proposals, including re-development but also any abandonment of re-development proposals.
- Political influences.
- Future operations/plans of interconnected water infrastructure owners such as SWC.

How often?

It is not possible at this stage to prepare a schedule for monitoring. However, consideration should be given to seasonal influences as well as how long term trends such as drought may affect results

Who?

Sydney Water, Lane Cove Council and North Sydney Council will all have some responsibility for monitoring. The details or overall responsibility is yet to be determined.

What to do with monitoring information?

The monitoring information will assist in establishing the contaminant source, how it affects the Berry Creek biodiversity and the pathways which the contamination reaches the Berry Creek biodiversity. This will allow an estimate of the likely extent and nature of harm to be established and therefore linked to climate change projections.