# Climate Change Adaptation Options Assessment

Developing flexible adaptation pathways for the Peron-Naturaliste Coastal Region of Western Australia

Prepared for the Peron-Naturaliste Partnership

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ACIL Tasman
Economics Policy Strategy

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## ACIL Tasman Pty Ltd

ABN 68 102 652 148
Internet www.aciltasman.com.au

### Melbourne (Head Office)
Level 4, 114 William Street
Melbourne VIC 3000

Telephone (+61 3) 9604 4400
Facsimile (+61 3) 9604 4455
Email melbourne@aciltasman.com.au

### Brisbane
Level 15, 127 Creek Street
Brisbane QLD 4000
GPO Box 32
Brisbane QLD 4001

Telephone (+61 7) 3009 8700
Facsimile (+61 7) 3009 8799
Email brisbane@aciltasman.com.au

### Canberra
Level 2, 33 Ainslie Place
Canberra City ACT 2600
GPO Box 1322
Canberra ACT 2601

Telephone (+61 2) 6103 8200
Facsimile (+61 2) 6103 8233
Email canberra@aciltasman.com.au

### Perth
Centa Building C2, 118 Railway Street
West Perth WA 6005

Telephone (+61 8) 9449 9600
Facsimile (+61 8) 9322 3955
Email perth@aciltasman.com.au

### Sydney
Level 20, Tower 2 Darling Park
201 Sussex Street
Sydney NSW 2000
GPO Box 4670
Sydney NSW 2001

Telephone (+61 2) 9389 7842
Facsimile (+61 2) 8080 8142
Email sydney@aciltasman.com.au

## For information on this report

Please contact:

Nick Wills-Johnson
Telephone (08) 9449 9616
Mobile 0404 665 219
Email n.wills-johnson@aciltasman.com.au

## Contributing team members

David Campbell
Tess Metcalf
Simon Sagerer

John Söderbaum

Nick Wills-Johnson
Matt Eliot (Damara WA)
Glenn McCormack (Damara WA)

# Contents



## List of boxes

## List of figures



## List of tables

# Executive summary

*Provided as a separate document*

# 1 Introduction

This report details the assessment of optimal adaptation strategies to respond to climate change challenges in the Peron-Naturaliste Region; from Point Peron in the City of Rockingham to Cape Naturaliste in the City of Busselton. The report has been commissioned by the Peron-Naturaliste Partnership (PNP), which comprises representatives from the nine local governments in the region (The Cities of Rockingham, Mandurah, Bunbury and Busselton, and the Shires of Harvey, Waroona, Dardanup, Murray and Capel) as well as State Government representatives from the Departments of Water, Transport, Planning and Environment and Conservation. The project, *Developing flexible adaptation pathways for the Peron Naturaliste coastal region of Western Australi*a has been funded by the Australian Government represented by the Department of Climate Change and Energy Efficiency (DCCEE) *Coastal Adaptation Decision Pathways projects An Australian Government initiative* and is one of 13 projects which have received funding to develop leading practice approaches to better manage future climate risk to coastal assets and communities. -The aim of this project is not only to elucidate flexible adaptation options in respect of the particular case studies chosen in the analysis, but also to show how the relevant decisions were made; providing a source document for future analyses by local governments in the PNP region and beyond.

The project overall had three distinct stages:

- An initial assessment into the likely physical impacts (in terms of erosion and flooding) of climate change if no action is taken to manage these impacts.
- An assessment of the likely resourcing implications for the region as a whole in responding to climate change.
- Consideration of suitable adaptation strategies and decision-making processes around those strategies in four representative case study areas.

This report covers the second two of these three stages, with the first stage being reported separately.

Chapter Two of this report provides an overview of the techniques which can be used in the assessment of adaptation options. The aim of this chapter is to provide some background information for future assessments and explain what works well, and in what context. Chapter Three provides an overview of the regional context of the assessment, including a description of the assets potentially affected by climate change in the region and a description of those effects, summarised from the first stage of the project outlined above. Note that we consider erosion and flooding, not wider effects such as the implications for agriculture of a drying climate in the South West. Chapter

Four contains the results of the region-wide assessment, aimed at establishing the overall resourcing consequences of adapting optimally to climate change in the region as a whole. Chapter Five addresses the four chosen case study areas, describing the relevant impacts and the optimal responses, as well as outlining in detail how the analysis was undertaken. Chapter Six concludes with some useful lessons learned from the analytical process which could be applied in future, similar work.

# 2 Economic Valuation of Climate Change Adaptation Measures

In this chapter we provide an overview of economic valuation techniques that can be used to assess value in the context of the formation of climate change adaptation strategies. While this chapter is important as background for the remainder of the work, it can be skipped by those already familiar with the economics contained herein without influencing understanding of the remainder of the report.

We begin by considering the notion of value in economics; a concept which has been debated since the time of Aristotle, and one which is quite different to metrics such as units of mass or distance. In this context, we also introduce the concept of value at risk, which is crucial in making climate change adaptation problems tractable.

After outlining what value means in an economic sense, we turn to how it is calculated, with a particular focus on methods which have developed to study assets that are not traded in marketplaces, such as parks and wetlands. This literature has developed significantly in recent decades, beginning in the public goods literature and finding more particular application in environmental economics.[1]

We conclude the chapter by pointing out some of the issues associated with valuation in general in an economic sense, and by outlining the approaches we have taken and providing a rationale for these choices.

Before beginning the main body of the chapter, however, it is important to consider two key issues. Firstly, the PNP Partners, like most policymakers, are not interested in economic value in its own right, but rather as a tool in an assessment process aimed at establishing whether particular adaptation measures ought to be taken. Economics is not the only way to make assessments. Conceptually, other assessment techniques could include:

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[1] A public good is something which is non-excludable and non-rivalrous at the point of consumption. National defence is an oft-quoted example; my consumption of national defence does not preclude anyone else in the country from consuming it, and government cannot prevent me from consuming national defence. Samuelson (1954) presents seminal work in the field. Very few goods are "pure" public goods and, since value and governance are inextricably linked, different perspectives on the property rights associated with assets can also illuminate the discussion on how they ought to be protected. The seminal work of Coase (1960) on property rights and the nature social cost, and the equally seminal work of Ostrom (1990) on common-pool resources is another.

- Executive decision: a mayor, premier or some other executive official simply decides that something ought to be done, and orders it so.
- Corporate decision: a group of decision makers discuss their views and come to agreement on an appropriate course of action for the wider community.
- Voting: a particular course of action is put to the affected community and they are asked to make a determination.
- Scientific/expert advice: advice from other experts who do not have skills in economic valuation but who bring other skills to bear. For example, a hydrologist might advise that a particular river must have its banks reinforced due to the danger of flooding, and this is done without assessment of the economic benefits of flood protection.

Tied into the four dot points above are two different types of information; subjective information and objective information. Subjective information is information inextricably tied to one's beliefs and biases, where there is no "right answer". One example of a decision using this information might be the decision on whether Julia Gillard or Tony Abbot ought to be Prime Minister. For this kind of decision-making, mechanisms of social choice, like an election, are ideal. The social choice literature sits outside the purview of this study, but it is worth making reference to the seminal work of Arrow (1950) who showed that, under a set of simple, plausible assumptions, there is no direct mapping from individual choice to social choice; whatever the "common good" is, it is not the sum (or any other function) of individual choices. Arrow's work touched off half a century of debate on social choice that is still ongoing.

Objective information refers to information which is free of any beliefs or biases; the physical laws which govern bridge construction, for example, are objective information.

In principle, any social decision could be made by some form of social choice mechanism such as the first three dot points above, regardless of whether it contains subjective or objective information. However, in practice, it would be very time consuming to do so; if every government decision needed to be put to a plebiscite, few decisions could be made. For this reason, decisions which could be made in the political sphere, where social choice mechanisms operate, are "out-sourced" to either a bureaucracy or to independent experts such as consultants. This outsourcing can either be total (for example, the Reserve Bank and its decisions on interest rates) or partial, such as when a minister seeks advice from her Department on environmental approvals. Where outsourcing is partial, the basic intent is that the expert (inside the bureaucracy or hired by it) provides the objective information, often to narrow the field of choice to avoid irretrievably bad decisions, and the decision-maker uses subjective information to make the final decision.

As a concept, this parcelling-out of roles in the decision-making process works very well, and indeed it forms the basis of our system of government. However, if experts are engaged to provide objective information, it rather depends upon information which is claimed as objective actually being objective.[2] If it is not, then all that happens is that the subjectivity of a political decision-maker is substituted for the subjectivity of her departmental staff, or the outside experts they hire. This does not mean that a decision is necessarily wrong, just that it is in conflict with the way in which the system is intended to work and moreover, that these inconsistencies are often not visible to the society at large in whose name decisions are being made.

The point of this rather long and theoretical discussion is to highlight a central weakness of economics, most particularly as it forms an input into policymaking; it often falls far short of the objectivity requirements outlined above. While there is a large body of theory in economics which has been used to make reasonably good predictions of economic events from time to time, this theory is not like the theories of the physical sciences (for all that economists fervently wish that it was) because it has not been, and arguably cannot be tested empirically in the same way. For example, if one wished to test the theory of gravity, one could drop different objects a million times to record the results, or map the course of billions of stars and galaxies. However, if one wanted to test whether Keynes or Friedman had the most insight into macro-economics, one could not put a society through a million different versions of the Great Depression to find out, and nor are there more than a handful of observations in history against which to test each theory.

Not only have the theories of economics not been put to the same kinds of tests as in the physical sciences, but it is arguable whether economics could, in principle, ever find the same kinds of exactitudes as physics or chemistry. This is because the particle or molecules which comprise the building blocks of the physical sciences do not possess free will, but the human agents which comprise the building blocks of an economic system do.[3] This means that any model of their behaviour can only ever be an approximation, because free will, by definition, cannot be captured in a model. The uncertainty that this causes is fundamentally different in nature from the statistical uncertainty which lies at the heart of quantum physics, and it has profound consequences for the degree to which we can "know" economics in the same way as we can "know" the physical sciences.

[2] It does not preclude the use of assumptions in an objective analysis, but it does mean that these assumptions and their consequences need to be made clear, so the subjective decision-maker can bring them into her assessment appropriately.

[3] The debates of philosophers on this point notwithstanding.

A final issue is one of complexity. The climate models which predict the climate change impacts that form the basis of this report have within them considerable complexity, and make use of powerful statistical techniques to make predictions in the face of such a complex system. Economic systems are arguably much more complex than climate systems. In the first instance, there is a great deal more that an individual human agent can do in an economic model than an air molecule can do in a climate model (and the human agent has the free will to choose), and in the second instance, every human agent is different, which makes modelling their collective activities highly complex.

The practical upshot of the discussion above is that decision-makers, particularly those with a background in engineering or science and familiar with models that produce objective, often deterministic answers, should treat economic models that purport to do the same with a considerable degree of suspicion.[4] There is, for example, no such thing as an objective benefit cost analysis, because there is always a degree of subjectivity in the analysis, even if it is not explicitly mentioned. This does not mean that all cost benefit analyses are bad, but rather that their results should not be considered in the same way as an engineer's report on the feasibility of constructing a bridge. Often the best way to proceed is for the economic analysis to go part of the way, in terms of establishing values and trade-offs, and for decision-makers to complete the work using other tools, such as the different social-choice methods outlined above. In short, do not trust professional economists like the authors of this report to make all of your decisions for you.

With the discussion above in mind, we now turn to the main body of this chapter, covering the practices of economic assessment with relevance to climate change. We begin by providing some background on the notion of value in economics, with a particular focus on value at risk, which is most crucial to our assessment. We then explore the different assessment techniques in some detail, and we close with an overview of some of the issues associated with economic assessment techniques.

## 2.1 Concepts of value

The first part of our discussion on value and its calculation is an overview of what value is and is not in the context of economic analysis. The first point, which is not always obvious, is that a dollar is not the same thing as a kilogram. A kilogram is an objective, fixed standard of measurement which is the same throughout the world (at least amongst the nations that use it) and through

[4] Arguably, the degree of suspicion should be directly proportional to the degree to which the consultant or analyst producing the results asserts their exactitude.

time. A dollar is not like this; it is a claim on the future production of the country issuing it, and it changes across time and in different jurisdictions.

Moreover, comparing measures of value is not the same as comparing measures of mass. A kilogram is always (roughly) 2.205 pounds. However, a dollar is not always 6.6 Chinese RMB, but changes on a daily basis. Moreover, the comparison changes depending upon who is doing the comparison and for what purpose. For example, consider an Australian person buying goods from a Chinese website. For her, 6.6 RMB to the dollar is the relevant rate, as she is in Australia when making the purchase. However, consider the same person contemplating how much money to bring on an upcoming trip to China. Now she needs to consider what 6.6 RMB will purchase in China, which may be more or less than what one Australian dollar will buy in Australia, because she will be consuming goods and services in China. For this purpose, she might use purchasing power parity, rather than official exchange rates.

To make matters even more difficult, if two people weigh a bag of apples and come up with different results, it can be said with confidence that at least one of them is wrong and, further, that one can establish who is wrong by testing the scales used by each. If, however, a customer and a shop-keeper value the same bag of apples at $1 and $1.50 respectively, there is no objective third-party who can use some objective approach to establish who is in error. Rather, as they have done so from time immemorial, the customer and the shopkeeper must bargain over the price until each is satisfied.[5]

Value, is thus a fundamentally different thing to other forms of measurement, like kilograms which can be tied to an objective metric (such as Planck's constant in the case of mass). Although people frequently say that the market is "wrong" because it under or over-values something, this is not logically correct and, despite the best attempts of philosophers from Aristotle onwards to try and understand the underlying "true" value of a thing,[6] there is no objective standard against which such assessments can be made.[7] Value is

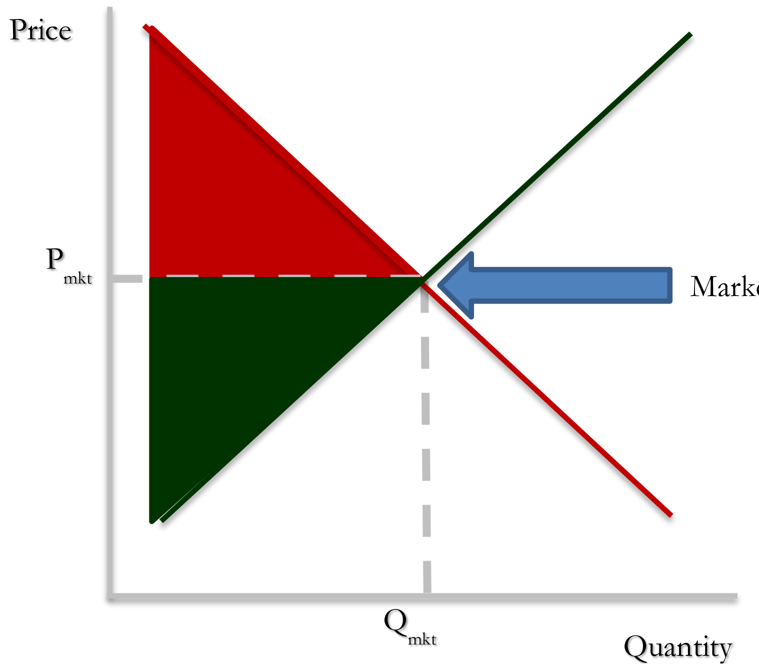
[5] Moreover, if the result of bargaining is $1.20, this need have no bearing whatsoever on the result of the bargaining which occurs with the next customer.

[6] See Schumpeter (1954) for an overview of this history, which has a lineage from Aristotle, through Roman law as codified by Justinian and the theological writings of St Thomas Aquinas and the Scholastics (who considered the issue from a moral perspective) to Adam Smith and modern economics. Interestingly, both the Romans and the Scholastics, despite their quite different viewpoints compared to modern economics, came to the conclusion that only a (well-functioning) market provided information about the "right" or "just" price.

[7] For example, Marx famously, and erroneously, argued in *Das Kapital* that all value in a thing could (or more correctly, should, in the absence of exploitation by the forces of capitalism) be accounted for by the labour embedded within it. The basic problem with that approach is that labour has human (and social) capital embedded within it, and is thus not an homogenous unit of accounting.

fundamentally a social construct. For this reason, it is erroneous to consider any kind of "kilogram-like" benchmark figure when considering notions of value. Instead, value in economics is a function of the characteristics and behaviour of market players, which gives rise to a demand and supply curve, and thence, through well-developed work on welfare economics,[8] to notions of consumer and producer surplus. These, in their simplest form, are shown in Figure 1.

Figure 1 **Measures of value**




To understand the basic notion of consumer surplus , suppose I value a particular brand of wine at $15 per bottle (my "willingness to pay", but find because of competition between Coles and Woolworths for the marginal consumer that I can buy it for $10. This means I have obtained a "net consumer surplus" of $5 on that bottle of wine, because I only needed to part with something I valued at $10 (the $10 note) to get something I valued at $15. If the total costs of the liquor store in bringing that bottle of wine to sale (including all store, staff and opportunity costs of owner's capital) were $8, then the liquor store would have earned a producer surplus of $2.

All consumers of that particular type of wine are in the same situation, and we could line them up in order of the value they place on the wine. If we added

[8] Any good micro-economics textbook provides more detail on this background. Varian (1992) is one of the more widely used.

together their net consumer surpluses (the $5 I received above), then we obtain the red triangle in Figure 1 above the market price, which shows how much more than the market price society values the particular good. By the same token, lining up all the relevant liquor stores in the same manner produces the green triangle of total producer surplus. The net consumer surplus (red triangle) is added to the market price value to produce the gross consumer surplus, which is also a measure of value.[9] Note that market price itself measures only the value of the good or service to the final, or marginal consumer, rather than societal value overall. This issue is discussed further below.

All measures of value in economics can be tied back to Figure 1 above, and the basic ideas within it. Where complexity arises is in trying to work out how someone might value something like a wetland that is not bought and sold in a marketplace. The objective part of the economics is the body of theory, as outlined in Varian (1992) and other textbooks which translates the characteristics of market players (and the construction of the market itself; Figure 1 is constructed in the context of a "perfect" market) into social welfare outcomes.[10] The subjective part is the set of assumptions around the "right" characteristics to impute to the market players in the context of the particular analysis being undertaken. In practical terms, if the analyst only provides the consumer surplus results (or worse, uses a "benchmark" figure gained from elsewhere) without highlighting the assumptions that went into it, the decision-maker using the information will not be able to ascertain what is objective and what is subjective. This is a crucial consideration for policymakers, and not one which is made often enough.

We now move to our discussion on how value is calculated. However, before doing so, we present a brief discussion in Box 1 on the difference between value per se and value at risk. Both can be calculated using the same methods, but the latter is arguably much more relevant for climate change adaptation studies.

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[9] Conceptually, one could continue down past the market price when assessing gross consumer surplus, as goods and services have value even to those who cannot consume them. I might, for example, derive a value from Swiss watches, but not enough to pay the market prices currently on offer. From the perspective of the market, my level of demand for Swiss watches is irrelevant, but from the perspective of society as a whole, my valuation can be important. For public goods, which are free at the point of consumption, the gross consumer surplus is the whole area under the demand curve.

[10] This is not strictly true. Like all disciplines, there is debate in economics around aspects of the "standard model", such as the debate on whether economic agents are truly rational. However, for the purposes of most assessments, the standard model can be taken as being objective.

Box 1 **Value at risk**

To motivate the discussion on value at risk, consider adaptation to climate change in Sydney Harbour. One way of proceeding might be to ask what Sydney Harbour is worth, and then to work out whether "saving" it is worthwhile. However, this is not a particularly useful approach. Apart from the manifest difficulties in establishing a value for Sydney Harbour, the value itself is arguably not relevant for the policy question which needs to be answered. The more relevant question to answer is "what activities might be affected in Sydney Harbour by climate change, and how are they valued?". This is the basis for the concept of the "value at risk" from climate change.

This is a much more tractable question to answer. Some aspects of Sydney Harbour will be substantially affected, such as houses close to the current watermark. Others will be affected a little, such as transport across the harbour (ferry terminals may need to be altered), and others will be affected very little (the harbour will still look much the same, and arguably still attract tourists in the same way). Breaking down the problem in this fashion, and looking at elements of what is affected arguably makes the valuation exercise much more feasible, and aids decision-makers in working out what they ought to do. In very simple terms, one needs to move from a value to an understanding of potential value lost, or value at risk. We develop a simple equation which captures this in Chapter 4, and make use of it in our region-wide assessment and the case studies

## 2.2 Economic valuation techniques

In this section, we provide an overview of different economic evaluation techniques which might be used. None of them is "perfect", and each has advantages and disadvantages based upon the context in which they are used. Some of them are relatively inexpensive, and thus are a good way of getting a rough estimate quickly, and some require considerable resources to be applied, meaning they should only be used in limited circumstances when no other method provides enough information to make the decision.

The approaches which we consider are:[11]

- Market prices
- Hedonic pricing
- Production functions
- Travel cost

[11] Note that we do not consider multi-criteria analysis. In part this is because, although it can include economic valuations, it is not an economic valuation technique. Mostly, however, we do not discuss it because it is not objective; both the choices of the criteria to include and the weights given to these criteria are subjective choices made by the analyst. Multi-criteria analysis may be an appropriate way for local government decision-makers to combine a variety of inputs and formalise their subjective choices, but it is less appropriate as an input from an independent expert in the context of the objective information we argue that expert ought to provide. For a much more detailed treatment and critique of multi-criteria analysis and its use in infrastructure assessment, see BITRE (1999).

- Contingent valuation and choice
- Replacement cost
- Benefit transfer

The first three of the approaches are tied to market prices in some way; directly in the first and indirectly in the second two. Travel cost and contingent valuation and choice are tied more directly to the estimation of consumer surplus. Replacement cost is not an economic valuation techniques at all, as it is not part of the basic framework outlined in Figure 1, but it is often used, and hence deserves explanation. Benefit transfer simply means using findings from elsewhere, and can thus be a combination of any of the other valuation methods.

In each of the cases below we provide a brief, non-technical introduction to the approach and its advantages and disadvantages. We do not provide a detailed history, or a detailed treatment of the underlying economics. We also do not provide an extensive literature review. Instead, we direct the interested reader to relevant chapters from the *Handbook of Environmental Economics* which, for most of the valuation techniques below, provides the history, the underlying economic detail and the gateway to the much more extensive literature.

### Market prices

In Figure 1, the market price is the intersection between the demand and supply curves. That is, it is the point at which the consumer willing to pay the lowest price that a producer is willing to supply at meets that supplier. In a perfectly competitive market, this becomes the price that everyone pays because of an assumption in the model that there are no restrictions on on-selling, nor constraints in production from a single producer, nor inabilities on the part of any market player to obtain information. Thus, if a producer tries to sell the product to a consumer with a high willingness to pay for more than the market price, one of the marginal consumers with a lower willingness to pay will profitably (and instantly) on-sell the product she has bought at more than she paid for it, using the proceeds to re-purchase from her supplier.

However, there is no direct link between the value society places on a good or service and its market price.[12] This is because value is a function of all of the transactions between consumers and producers (the process of "lining up" consumers described above) while the market price is formed through only one interaction. To this end, a given market price is most useful in providing empirical evidence of where the demand and supply curves ought to intersect.

[12] The link is rather indirect, though the demand curve that intersects the market price.

Since the consumer surplus is the area under the demand curve from the origin to the intersection between it and the supply curve, this is an important aspect of the calculation of value, but it is not value in its own right.

In the context of societal decisions, however, market prices can have a wider use because they show the price that society ought to pay to preserve goods or assets; if the asset can be replaced in a marketplace, then society ought not expend more resources on protecting it than would be spent on replacing it via a market purchase. From this perspective, market values can be very valuable as decision tools for policymakers.

From a more practical perspective, market values are useful because they are objective, and because data exist, meaning the analysis can be objective and relatively low-cost. The problem is that not all assets being considered will have a market price; a road, for example, is ordinarily owned by government and has never been bought or sold, and is therefore impossible to be valued by market prices. Thus, market valuations cannot be used for every asset.

Moreover, even where an asset has a market price, this might not reflect its overall value, even to the marginal consumer and producer who set its price. For example, a farm might be sold for $1 million, but contain a wetland which assists in cleaning overflow from municipal drainage before it enters the ocean. Since anyone buying the farm for farming can't use the wetland, this value is not realised in the market price; indeed, the market price of the farm might be lower because the wetland means it has less useable land. To the extent that climate change influences the wetlands, this will not be captured using market values.

### Hedonic pricing

Hedonic pricing takes as its foundation the notion that a house (usually; though it could be any traded asset) is a collection of characteristics and that the value of the house provides information about the value of each of the characteristics of that house. As amounts of each of these characteristics change, it is possible to map from the changes in characteristics, through the change in price to a change in economic welfare. Palqvist (2005) provides an extensive review of the analytical foundations of this mapping process, and overview of hedonic pricing in general. The key advantage of hedonic pricing is that it is based upon transparent market prices, and that many of the characteristics (numbers of rooms, location, block size and so on) of a house can be easily uncovered.

That said, there are three key disadvantages associated with hedonic pricing. The first of these is the basic statistical issue of comparing like with like. It is almost impossible to find even two houses that are identical except for the particular environmental characteristic which will be affected by climate change. Finding more than two is even harder. This means that all the problems which plague any statistical assessment are present in hedonic pricing. Moreover, they are complicated by the fact there is little theoretical guidance as to what ought to influence house prices, meaning that omitted variables are an important issues, and that many of the characteristics (house size and number of rooms, for example) are manifestations of the same thing, meaning multi-colinearity can be a significant issue. There are approaches to deal with these kinds of statistical issues, but their presence means that hedonic pricing should only be attempted by those with considerable statistical expertise. It should not be entered into lightly or, if consultants are being used, without a peer-review process in place.

The second issue is that environmental effects as measured by a scientist are often very different to environmental impacts as perceived by a home buyer. For example, a scientist might report that pollution has increased by a certain amount in parts per million, but it seems unlikely that there would be a direct linkage between a given level of parts per million of a pollutant and home values because home buyers do not commonly use this measure when deciding whether to buy a house.[13] They might consider whether an area is polluted or not, or even whether the air is very dirty, dirty or clean, but it seems unlikely that any home buyer would have a scale of perception as refined as a scientific instrument. Measures associated with environmental impacts are often not the same as the perception measurements consumers use. Indeed, those perception measures might not even be intrinsically observable to an outsider.

A final issue relates to the scale of the change. The economic theory which links changes in characteristics through changes in price to changes in welfare is based upon marginal analysis. It is not designed to capture the effects of very big changes, such as the complete removal of the environmental characteristic. Moreover, from a statistical perspective, unless some of the observations in the data include cases where the environmental variable has the value (all else equal) that it is hypothesised will occur as climate change happens, then the ability of the model to forecast consequences of these large changes in the variable will be impaired just from a statistical perspective, even without problems associated with the grounding of the model framework in marginal changes. Since many climate change impacts on the coast are very

[13] There might even be a perverse linkage. For example, a newspaper report that states that pollution has doubled because of an increase from five to ten parts per million of a pollutant might have more of an effect on price than one which says they have increased by ten per cent when pollution increases from 100 to 110 parts per million if the base is not stated in either case.

large, and unanticipated (in the sense that they do not appear in the historical record) this may limit the utility of hedonic pricing approaches.

### Production function approach

The production function approach (see McConnell and Bockstael, 2005, for a review of the theory and introduction to the literature) is similar, in a sense, to the hedonic pricing approach in that it seeks to link environmental inputs to a market pricing outcome. In this case, however, the link is made not through the environmental factors being characteristics of a good or service bought in the marketplace, but rather through the environment being one of the factors of production for a good or service produced in the marketplace or in the home.

The basic notion is that consumers obtain utility by consuming environmental goods directly (say, clean air), by using it in household production for consumption at home (say the soil in an urban vegetable garden) or by buying goods and services in the marketplace which have environmental inputs (say beer requiring a pure source of water). Firms, by contrast, make use of the environment as a fixed factor of production (a lake supplying a brewery, for example) and will change both production and the mix of inputs used in the production process as the quality of environmental inputs changes.

The approach does provide a conceptually neat way in which environmental impacts can have wide ramifications throughout the economy. Not only can changes influence the decisions of firms, but might also change the mix of home and market-produced goods the household consumers (say if local pollution makes the vegetable garden less tenable, meaning more purchases of vegetables from the marketplace), which in turn has implications for the amount of labour supplied, and thus further ramifications for production in the marketplace. Moreover, the linked effects can be traced even when the entity in question does not pay for the environmental goods used. For example, a brewery drawing clean water from a river might not pay for the water, but if the water is polluted, it will need to either change its production methods (say, introducing new filters) or change the amount and/or nature of what it sells (say, losing an environmental quality certification and thus the price premium which goes with it). This means that environmental goods do not need to have market prices in order for the economic effects of any environmental change (including climate change) to be calculated. For an adaptation study, conceptually, all the analyst would need to do is capture all of the household and market production processes where the environmental assets threatened by climate change are used, and establish how changes in the asset in question might lead to changes in production in all of the areas where it is used at present.

The main problem with this approach is not conceptual, but practical; capturing all of these linkages can be very difficult in practice. This has three elements. Firstly, at the level of an individual production process, whether it be in the home or in the marketplace, flexible functional forms like the translog that do not require a host of restrictions on their parameters (for example, Cobb-Douglas, which imposes constant returns to scale) require a great deal of data to establish the coefficients on each of the variables in the production function via econometric methods. It is often impossible to obtain enough data points to make these estimations.

Secondly, if the environmental effects are relatively small and localised then, provided there are enough data to estimate the relevant production functions, the impacts from environmental change might be small enough to be modelled in this way. However, as the scale of the environmental change increases, it is much more likely to change relative prices within the economic system being modelled, which makes for much more complex interactions. This is further complicated if the environmental change affects a number of like assets; all the beaches along a coastline rather than a single beach.[14] If a single beach, say, is affected by climate change, then users of that beach can substitute other nearby beaches into their production function at relatively low cost. If all beaches in the region are affected, this is not possible. The issue is particularly important when "scaling up" effects.

The final practical difficulty is that, to build a model effectively, one needs data. That is, one needs information on how production processes were changed in response to a particular change in an environmental variable. By definition, then, one cannot use the approach directly for planning for climate change impacts if the assets in question have no history of impact from which to draw data. This implies that, even if the above two issues are resolved, there would need to be some form of "benefit transfer" (see below) approach to form hypotheses about how the relevant production processes might change as assets are affected by climate change.

### Travel cost

Market prices, hedonic pricing and production function approaches are all examples of revealed preference approaches. That is, the conclusions made by an analyst are revealed from actual behaviour. In the case of the above three

[14] A computable general equilibrium model could be used to model these kinds of interactions in the wider economy from a climate-change induced "shock" to the economy (see www.garnautreview.org.au/ca25734e0016a131/WebObj/ModellingClimateChangeImpacts/$File/Modelling%20Climate%20Change%20Impacts%20-%20Frontier%20Economics.pdf) but the scale of these models is usually too coarse for the requirements of local government, and for most of the assets likely to be affected.

methods, the actual behaviour which underpins the valuation is a market purchase of something. The travel cost method is also a revealed preference approach, but the behaviour that reveals the value is not a market transaction, but a simple decision to go and visit something. The approach, and its (long) historical development is covered in detail in Phaneouf & Smith (2005) in considerable detail, and Landsell & Gangadharan (2003) provide an Australian example of the valuation of two parks in Melbourne, which we use to underpin some of our analysis.

In essence, the approach starts from the premise that one has a certain amount of leisure available, and where one decides to take that leisure tells the analyst something about the value of different leisure activities. Thus, if a consumer chooses to drive to an amusement park for leisure activities, then the value of the amusement park to the consumer (assuming it has free entry) must be at least as high as the costs of driving to the amusement park rather than enjoying an alternate leisure activity at home. The approach is conceptually very simple but as Phaneuof & Smith (2005) report, the values it derives on a like-for-like basis, compare well with more sophisticated approaches such as contingent valuation and choice (see below).

A travel cost approach is able to take non-market uses into account, as it does not require any information from market data in order to make assessments. This means it can take into account the value of non-market assets such as beaches and parks. It cannot, however, take into account intrinsic or non-use values. For example, many Australians would suggest that Uluru has a positive value for them, even if they never visit it, because of its importance as an Australian symbol. The same might be true of Kakadu or the Great Barrier Reef, and also of some key areas within the PNP region which have intrinsic value to the community.

Travel cost methods, like contingent value and choice (see below) measures consumer surplus directly, unlike the other revealed preference approaches above. It also requires surveys of consumers. However, unlike contingent valuation and choice surveys, which require respondents to answer hypothetical questions, a travel cost survey simply asks where a person has come from in order to enjoy leisure at a particular place. This means that strategic responses are less of an issue (see below), but it does mean that the analyst need to take into consideration that those who do not travel to the asset in question will logically not be represented in the survey results. Since these people would logically have a lower value for the given asset than those who travel to it (all else being equal), then this can bias results upwards. Phaneuf & Smith (2005) discuss the various methods which have been developed to take account of this bias.

A more important constraint is that, since time is the main cost associated with travelling to a particular location in most instances, the approach requires a suitable value for the cost of travel time. This is not a straightforward issue, as different people have different values for their travel time, and these values may even differ depending upon the time of the day or day of the week, with lower values on days when the person is otherwise less time-constrained, such as the weekend. Henn, Douglas & Sloan (2011) provide an indication of the scale of the issue in their survey of travel time findings just in Sydney.

For the purposes of climate change adaptation, two further issue arise. Firstly, like replacement cost measures (see below), travel cost measures indicate the minimum value people place on an asset rather than the actual value. This is because the value of the asset would need to be at least as great as the value of the time taken to travel to it, but it could be greater. The second issue is that travel time studies are good for establishing the value of an asset in totality, but not for examining how the value at risk might change if the asset is partially lost; say a park being partially flooded (unless the questions are modified in a survey to capture what people come to the park or other asset to do). This can limit the practical application of the approach in some instances.

### Contingent valuation and choice

Like travel cost methods, contingent valuation and contingent choice are particularly useful for non-market goods, and they directly estimate consumer surplus (again, like travel cost methods). However, unlike travel cost methods, they are not based upon revealed preferences, but on stated preference; what people say something is worth rather than what their actions suggest they believe it is worth.

In a simple sense, the analyst asks respondents in a survey to either respond to a hypothetical question about the value of an asset to them (contingent valuation) or asks the respondent to make a series of choices about bundles of goods to infer relative values (contingent choice). Since both methods are based upon hypotheticals, in principle, the analyst can, in principle, ask any form of question she likes. This makes the approach very flexible. It also means that both value in use and intrinsic or existence values can be captured. Indeed, it is only through stated preference approaches such as these that intrinsic values can be captured.

Contingent valuation and contingent choice methods focus on two concepts; willingness to pay to preserve a particular asset (WTP) and willingness to accept a payment to be deprived of an asset (WTA). Both can also be applied (unlike the travel cost approach) to aspects of the functionality of an asset. In principle, WTP should be the same as WTA; one should not be willing to pay more to keep an asset than one would be willing to accept to lose it. However, in reality, the two are often very different, with WTA generally being much higher than WTP. Shogren (2005) provides an overview of WTP-WTA issues, and the issue in survey design which can give rise to differences between the two values.[15]

Contingent valuation is the older of the two methodologies, and Carson & Haneman (2005) provide an overview of its development, along with that of contingent choice. They also provide an overview of the basic underlying theory, and, importantly, of the mapping from survey results to a consideration of welfare or value. In a simple sense, the value of an asset is not simply the average of the value given to it in a number of survey responses, but rather the nature of the value depends upon how the question about value was asked. Importantly, there is a different approach to be followed if the question was "do you value the asset at more than X?", compared to open-ended questions of value.

Since it asks questions about value, which respondents know they will never have to actually pay, contingent valuation methods are sensitive to strategic behaviour; people who value an asset highly are likely to give very high answers in the hope that this will bump up the average to result in the asset in question being saved. Carson & Haneman (2005) show that the appropriate solution, based on a developing literature in game theory and the notion of incentive compatibility (that is, providing an incentive to tell the truth), is to make the questions simpler, not more complex. In fact, they suggest that simple "yes-no" questions about saving a particular asset are the best form of contingent valuation studies, from the perspective of avoiding strategic behaviour. Since this is very similar to a referendum process which a local government might use in any case to make key local decisions, it may be that a local government could establish the "right" answer in terms of a decision to save or abandon a particular asset affected by climate change by holding a local vote, rather than paying a consultant to undertake a contingent valuation exercise, and still get a result which would be as accurate.

Contingent choice does not ask the direct question about value, but rather seeks to infer it by asking people to rank different bundles of goods and services, some of which contain different amounts of the relevant environmental good whose value the surveyor is interested in. Undertaken appropriately, this can avoid the strategic issues associated with contingent choice and summarised above. Additionally, so long as one of the goods in the bundles has a monetary or market-based value, it is possible to value the

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[15] There is also a literature at the juncture between economics and psychology which provides some in-principle reasons why one might expect the two to differ. It is based around the different ways in which people perceive goods they own versus goods they do not.

environmental good by considering the different rankings of bundles. However, the trade-off for both is that contingent choice surveys are much more complex and resource intensive. Moreover, their complexity requires considerable skill in survey design to ensure that the results do accurately reflect the value being sought.

As a final comment, both contingent valuation and contingent choice, because they require the use of surveys, have all of the statistical issues associated with survey use that one would expect. Most particularly, this includes ensuring that the surveys themselves are representative of the views of the population being sampled. This can be a significant difficulty, particularly as those most interested in saving the asset will have a much stronger incentive to be a part of the survey process that seeks to establish its value.

### Cost of damage avoided and replacement cost

The cost of damage avoided or the replacement cost approach asks the very simple question; "if we did nothing at all, what assets would be lost, and what would it cost to replace them?". A more sophisticated version of the same question might ask what it would cost to replace the service provided by the asset, to cover the fact that one would not necessarily replace a railway line, say, with another constructed in exactly the same fashion, if the existing line were removed due to climate change, particularly if the existing line was constructed decades ago for steam engines, and not ideally suited for the transport services it now provides.[16]

The cost of damage avoided or replacement cost approach has the advantage of simplicity; any competent engineer can usually establish the cost of a road, railway or other piece of infrastructure, and handbooks such as *Rawlinsons* provide an even easier first-pass approximation.[17] For these reasons, it is often very useful as part of a decision-relevant framework (see discussion below) which seeks to understand where resources ought to be expended on more detailed analysis and where first-pass assessments will be sufficient.

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[16] Economic regulators ask this more sophisticated question when seeking to establish the "right" price for regulated services that would otherwise earn monopoly profits. In Australia, the approach is known as the Depreciated Optimal Replacement Cost (DORC) of the relevant asset.

[17] This statement glosses over incentives. Economic regulators, for example, face considerable debate between infrastructure owners and large customers on the question of DORC, which can often devolve into debate between engineers about who has the best solution without coming to a firm or unanimous conclusion. This is because neither side has an incentive to compromise, an issue which may not be important in this context, unless the asset is privately-owned, and some compensation would be due if a decision was made not to protect it by a local government.

The approach is also useful for infrastructure assets with connections to a wide variety of places. For example, one could value a road via a production process approach. However, if it joins two towns with 50 different industries in each, then the exercise might quickly become intractable, and thus the cost of provision might be a more attractive approach just from the perspective of calculability. It is worth noting that this attractiveness also limits the approach to built assets; one could not use the approach to value a park or a beach.

There are, however, two key issues associated with the approach. Firstly, it is not a measure of value; just because a road would cost $10 million to replace does not mean that a community values it at $10 million. If the community indicates a willingness to save the road, then the best one can infer is that the community values the road at at least $10 million, as it would not logically decide to support the reconstruction of a road that was worth less than this amount. Thus, the replacement cost could be used to inform the social choice of whether to replace an asset or not, by informing decision-makers of the resource consequences of the decision (ie – how many dollars that could otherwise be used elsewhere would need to be given up). It could not, however, be used to replace that social choice mechanism.

The second issue relates to ensuring that consequences of a decision are correctly accounted for. Roads, railways and other infrastructure do not have intrinsic value in their own right, but rather derive value through what they connect. If a road connects a community to a beach (and has no other purpose) and the community makes a decision not to protect the beach from the effects of climate change, then there is no logical reason to protect the road. Conversely, if the only practical route between a town and a factory for a railway is along its current right of way, and the community decides to protect the town and the factory, then the railway would require protection as well. In practical terms, it may sometimes be necessary to consider infrastructure assets as part of other assets when undertaking assessments.

Neither of these issues above mean that the replacement cost approach cannot be used. However, both imply that it should be used with some degree of caution, and with due consideration of its limitations.

### Benefit transfer

Benefit transfer is a particular name for a practice widespread amongst academia and research; using the results of another study to inform one's own work. The basic notion is that, if people are basically the same in terms of the characteristics which drive the formation of demand and supply curves and hence value from one location to the next, and the assets themselves are basically the same (a beach in Sydney is much the same as a beach in Busselton, from the perspective of its users) then one can use the findings of one study to inform another study. There are two basic possibilities within the benefit transfer framework. The first is that the values themselves can be the same; if a beach is worth $1 a square metre in Sydney it is worth $1 per square metre in Busselton. The second is that the model of valuation is the same; a beach in Sydney derives its value from local incomes, unemployment rates and distance from the CBD, and thus the same factors ought to be at work, with the same strength of effects, in Busselton. In this second case, the value in the second location (here, Busselton) is formed by putting the relevant Busselton values for income, unemployment and distance from the city centre into the value model for Sydney to derive Busselton results.

It is worth pointing out that benefit transfer approaches could use studies which have used any of the valuation methods discussed above.

The major advantage of the benefit transfer approach is that it is cheap; a literature review of past studies is much less expensive than primary research. This means that many values are formed using a benefit transfer approach. In fact, even what is commonly regarded as the seminal paper in establishing environmental values (Constanza, et al, 1997) is itself largely an exercise in benefit transfer. The advantage of benefit transfer is also its own weakness; so many studies use values from prior studies that it can be difficult to trace back to the original study where the primary research was undertaken, and assess whether the assumptions underpinning that study are sufficiently similar to the context under review in the relevant work for which values are needed. This is rendered more complex by the fact that it is commonplace for researchers in one country to take studies undertaken in other countries, and simply change the values via exchange rates.

The major problem with benefit transfer approaches is that they are almost always wrong. Colombo, Calatrava-Renquena & Hanley (2007) and Morrison, Bennett, Blamey & Louviere (2002), test the benefit transfer approach by comparing values for their study locations formed from a benefit transfer approach (both in terms of values and in terms of adopting the models) with values formed through primary research. In almost all instances they find that the benefit transfer values are very different from the values suggested by primary research. Such work is very rarely done (Colombo et al, 2007, provide a brief introduction to the literature), but these papers, and the literature they cite suggest that errors from using benefit transfer may be significant, because the basic characteristics of the economic agents and the assets being studied do in fact differ widely from one context to the next.

Another key issue associated with benefit transfer is one of scale; the value derived for the loss of one beach in one study cannot be used to establish the value for the loss of all beaches in a study area. That is because, in the original study from which the value was drawn, consumers (presumably) would have had access to substitute beaches, so losing one would not be a particular hardship. However, if all beaches along a coastline are to be lost, the total loss may be much greater than the sum of the loss of individual beaches while substitutes remain. Costanza et al (1997) were criticised for making precisely this error.

With this in mind, we suggest that benefit transfer approaches can play a role, but only one with limited scope. This is in the context of the "decision-relevant framework" which we discuss in more detail in our conclusions to this section below.

### Conclusions

The most important conclusion which should be drawn from the discussion above is that none of the methods are perfect; each has flaws. Market prices would be the ideal method if markets were "perfect", with perfect information (for all players), rational players and no externalities. They would also be ideal if all of the relevant assets were in fact traded in markets, and thus had market prices. However, they are not.

Market prices are objective, but do not reflect societal value, in part because they are a reflection of marginal, not average values and in part because markets themselves are rarely perfect. In the case of ecosystem goods and services, the market is quite clearly imperfect, and there is no market value to speak of. However, in other cases, the imperfection is less clear. For example, house prices relate to the services which a given piece of real estate can provide its future owners, and these are constricted by planning and zoning regulations. Since planning and zoning regulations ultimately reflect the wishes of the community who votes for the local government which imposes them, to the extent that a democratic process and a market reflect societal values equally accurately, one might expect a similar long-run equilibrium between planning regulations and market outcomes. However, the impact of a particular set of regulations at a particular point in time is unclear, in terms of market imperfections.

Although the aim of using the approaches outlined above is to provide objective advice to decision-makers, all of the other methods outlined above involve some degree of subjectivity. Production function approaches require the analyst to make assumptions about functional form (or requires large amounts of data) for the production function, and contingent valuation and choice approaches require assumptions about utility functions. The former also requires assumptions about how the price of inputs should be characterised, and the latter can be significantly influenced by the way in which questions in the surveys are framed, most particularly if respondents behave strategically.

Travel cost approaches are influenced by the value which is placed upon the time of travellers, most particularly when average values are used, which is a usual approach to support equity concerns. At best they provide a lower bound to the value of the resource being assessed. Replacement cost and damage avoidance approaches similarly provide lower bounds, but both are additionally bedevilled by subjectivity around whether society would make the choice to replace a given asset or avoid a given damage.

Finally, benefit transfer approaches are only ever as good as the original analysis undertaken. Moreover, they rely upon an assumption that the context of the original analysis and the context of the adaptation assessment being assessed are sufficiently similar to allow benefit transfer to be used in the first instance.

The practical response of many analysts is to use several methods, and if each provides similar results then this is usually taken to be an indication of accuracy, or at least adequacy. This is true, however, only when any bias in the assessment methodologies does not influence results in different methodologies in the same fashion. It is not clear whether this is always the case, and even if it is, multiple methodologies would greatly increase the cost of any assessment using these approaches.

We therefore take a more practical approach, by considering the key question of whether all of these imperfections actually matter. We would argue that; if estimation of value is paramount, then they are very important, if estimation of value at risk is important, then the imperfections in value estimation are less so, and that they need not be important at all in the context of decisions that actually need to be made by policymakers. This provides the basis for our "decision-relevant framework", summarised in Box 2.

Box 2 **Decision relevant framework**

A decision relevant framework is not a form of economic analysis per se, but rather a way of using economic valuation approaches in a way that supports good decisions *and* efficient use of resources in the analysis that supports a decision.

Consider, for example, that benefit transfer approaches provide a rough estimate for the various activities on a beach of $20 million, and it cost $2 million to build a groyne which will save the beach. Even if the benefit transfer approach is highly inaccurate, this is still enough information for decision-makers to decide whether or not to save the beach, because it is very unlikely that the benefit transfer approach would be out by more than 90 per cent of the estimated value.

Likewise, if the replacement cost method suggests that it would cost $1 million to rebuild a road elsewhere and the cost of raising the road to protect it from periodic flooding was $50 million, then again, decision-makers have enough information to make the necessary decisions, and it is not worthwhile devoting significant resources to estimating the value of the road more precisely.

This is what we term *decision relevant* information. That is, even though the benefit transfer and replacement cost approaches might be highly inaccurate, they are accurate enough to make a decision. Using a decision relevant approach such as this is important because there are usually hundreds or even thousands of assets to be considered in an assessment of climate change adaptation; in the PNP area, for example, there are four cities, each with dozens of parks, community facilities and other assets. If we endeavoured to value each of these exactly, the assessment process would be highly time-consuming. Within a decision relevant framework, however, a first pass assessment using a benefit transfer approach, for example, weeds out all of the cases like the beach and road outlined above, leaving assets for which the difference between value at risk and the cost of saving are small, based on the rough process of value at risk assessment. These assets can then be subject to more detailed analysis, say via a contingent valuation exercise, to establish how the community values what might be lost in more detail.[18] The result is a much less costly process of assessment, with no diminution in the ability of decision makers to make sound decisions.

## 2.3 Issues with economic valuation

Underpinning all of the economic valuation methods outlined above are several issues which cut across methodology. We outline some of these issues

[18] Note that we do not do any more detailed analysis here. The basic issue is one of timing; understanding which assets have values close to their cost of saving requires most of the work undertaken as part of this report to be done, and there was simply insufficient time, as part of this project, to then go and undertake (say) contingent valuation surveys of the assets whose value at risk was close to their cost of protection. However, in practice, we note that the number of assets which fall into this category is in fact very small. It is unclear whether this would be a general finding outside the South West of WA, but if it is, then it suggests that the amount of work needed to reach a decision-relevant stage may be substantially less than a full valuation, and that detailed knowledge of the valuation methods outlined in this chapter may not be required by local governments.

below, and note that the reason for doing so is that there is currently no "correct" answer in terms of how to treat the relevant issues within economic theory or practice. Every assessment needs to make assumptions on these issues, even if a particular report does not explicitly outline these assumptions. It is important to understand these issues as it provides further information about the limits of economic analysis in assessment processes, and helps to guard against impressions of false precision inherent when numerical results are presented.

### Risk types

Donald Rumsfeld, amongst his other accomplishments, is responsible for a succinct description of types of uncertainty and their influence on decision-making. He divided knowledge about the future into three types:

- Known knowns.
- Known unknowns.
- Unknown unknowns.

Known knowns are things about which it is possible to be certain in future. Strictly speaking, they do not exist, as there is always uncertainty about the future, but for a practical perspective, there are many things about the future that one can accept as known; the sun will come up tomorrow, physical forces will act in the same way they have in the past and so on. There are also things which one can treat as known for the purposes of a particular analysis; when assessing the future consequences of a given government policy action, one generally assumes it will occur as and when government says it will, even though there may be considerable uncertainty about what the government may actually do.[19]

From a decision-making perspective, known knowns are very simple; they enter the decision framework as simple numbers or events, with no probability distributions or other summaries of uncertainty around them.

Known unknowns are those events where the analyst does not know exactly when and how an event might occur, but does understand the bounds of uncertainty around it. That is, the distribution of likely outcomes is known. Statistical forecasts fall into this category; based upon past relationships uncovered through an adroit econometric/statistical model, the analyst develops an understanding of the relationship between variables, and uses this relationship to forecast for the variable of interest. Such forecasts provide a central estimate, with a confidence interval around them, which states (within

[19] If government has several options, one might use scenario analysis, which takes each action as a known known within the context of a particular scenario.

the context of the model) the likelihood that the true future observation will lie between the relevant upper and lower bounds. In this instance, the analyst does not know what the actual future state/value of a given variable will be, but the variable can still be incorporated into a decision-making framework by using the information in the distribution around its prediction. A real options framework does this, which is why it is well-suited to situations where uncertainty is important, like assessments of adaptation to climate change.

Known unknowns are often poorly understood, because those without training in statistics can find probabilistic statements difficult to interpret. One example is the P50 and P90 estimate of costs commonly used by engineers. Both are based upon a model of total project costs which takes into account uncertainty about the likely costs of inputs into a project. A P50 estimate means that 50 per cent of the forecasts of project cost from the model lie below the quoted number. A P90 estimate indicates that 90 per cent of forecasts lie below the quoted number. In essence, it is just a different way of expressing a confidence interval. In such a framework, where the forecast project cost follows a distribution based upon uncertainty in the project inputs, the median point in the distribution will lie below the 90$^{th}$ per centile. Engineers commonly establish a P50 estimate first, when there is more uncertainty about inputs, and move to a P90 estimate later. If nothing in the underlying model changes, the P90 estimate will always be above the P50 estimate, and it will usually be larger unless the mean values and/or the distributions around each of the input variables changes significantly. Despite this, major projects are often reported as having “cost blowouts” in the press when all that has happened is that the basis of the forecast (P50 to P90) has changed.

Unknown unknowns are the things about which we know nothing; not the event itself nor its consequences. For example, while NASA might be able to track certain meteorites and develop a model (containing known unknowns) to describe whether a particular meteorite will hit the earth, since it does not know the flight paths of all meteorites in the sky, the event of a meteor strike in general is an unknown unknown. The key difference between a known unknown and an unknown unknown is that the former can be formally incorporated into a decision-making framework, the latter cannot. The best that can be done is to use scenario analysis. In the context of a meteorite strike, the analyst could establish the consequences of a meteorite strike and compare these to mitigation strategies to prevent such a strike (investing in tracking technology and the ability to launch missiles or “tractor satellites” to use gravity to tow the meteor out of harms way, for example), the analyst cannot say in an objective and quantifiable sense whether it is worthwhile investing in the relevant mitigation strategy because she cannot objectively establish the likelihood of a strike.

The distinction between known unknowns and unknown unknowns is important for climate change adaptation studies. Only a few decades ago, climate change was itself an unknown unknown. Models have subsequently been developed which endeavour to gather sufficient information to be able to class it as a known unknown. The perceived success of these models in doing so underpins the current global debate about climate change in general and adaptation strategies more particularly.[20] Even those who consider that the burden of proof at the global level has turned climate change from an unknown unknown to a known unknown, often suggest that more localised models are not as accurate. This does not mean that local communities can do nothing to either mitigate against or adapt to climate change, but it does mean that formal, objective valuation models may be less useful in circumstances where local models of climate change are poor or non-existent.

### Attitudes towards risk

Any formal, objective modelling of the behaviour of human agents into the future need to make some form of assumption about attitudes towards risk preferences amongst the human agents in the model. Broadly speaking, there are three types of risk preference:

- Risk adversity: the agent actively seeks to avoid risk. In a formal sense, the agent would not make a bet which returned a payment of $100 with a probability of less than or equal to 0.5 against a certain payment of $50.
- Risk neutrality: the agent is neither averse to or attracted to risk. In a formal sense, she will be indifferent between a bet which returns $100 with a probability of 0.5 and a certain payment of $50.
- Risk loving: the agent is attracted to risk; he will accept a bet which returns $100 with a probability of less than 0.5 over a certain payment of $50.

Attitudes towards risk are of key importance in climate change adaptation, because people react to climate information when making their own decisions about the future. Therefore, the model needs to take into account risk attitudes in some way. Failure to do so can result in gross over-estimates of the resources required to address climate change, because it can assume that people will do much less than they actually will without government intervention. In our approach, we assume risk neutrality.

[20] An argument such as this underpins arguments such as those made by Nordhaus (2007) who suggests that, when knowledge is limited, a better strategy may well be to invest in understanding the problem better (moving from an unknown known to a known unknown, and then narrowing the confidence intervals) than in attempting address the problem directly through a costly diversion of resources to mitigation and adaptation strategies.

## Rationality and motives for making decisions

Most standard economic models are based upon a basic framework which assumes that people are rational and act in their self-interest. This is not as narrow as the straw-man in arguments about economic rationalism often pretend, and can accommodate a broad range of empirically-observed phenomena such as altruism.

However, it is not clear that people always act in a rational fashion, or even understand what their self-interest is under certain circumstances (particularly where financial information is involved).[21] One salient finding from experimental economics is that people tend to value loss of things they currently possess more highly than not being able to obtain things which ostensibly have the same value (a factor underpinning the WTP/WTA debate). From the perspective of climate-change impacts, this may mean that people value the homes they currently live in more highly than the market as a whole (which, by definition, does not possess them in the sense of living in the on a day-to-day basis), and this may influence policy prescriptions and the amount of resources government needs to allow to address climate change impacts.

From the perspective of this study, the most basic concern is that, if we do not apply an assumption that people are rational and act in their own self-interest, there is very little we can replace the assumption with, as it is very hard to quantify the effects of a certain "degree" of irrationality. Moreover, assuming complete irrationality on the part of the community is worthless for policymakers, because it robs models of any ability to predict how the community might react; by definition, an irrational agent will act at random and will not be influenced by policy moves in the model. From this perspective, it is worthwhile asking what would be gained in the model, or in the economic assessment, from assumptions of irrationality, even to a degree.

We would consider it more appropriate to treat irrationality outside the model, rather than endeavour to incorporate it within a model. For example, there may be political, social or cultural reasons for protecting an asset that a "rational" economic analysis suggests ought to be abandoned. As noted at the outset to this chapter, these may be perfectly appropriate within a wider context of societal decision-making. However, rather than endeavour to bring such "irrationalities" into our modelling framework, we consider it more appropriate to provide a set of "rational" results from an economic model which can then be used by policymakers and the community as one tool for

[21] The field of bounded rationality in economics, as well as the growing literature at the interfaces between economics, neuroscience and psychology, seek to address issues such as these.

making relevant decisions. In other words, it is up to these decision makers to determine how to make use of "irrational" information.

### Discounting of future benefits

A key issue with assessing climate change and adaptation to it is what value to place upon future consumption; what discount rate to use. This is not an issue which has been resolved in economics, and the common use of "benchmarks" by government agencies in Australia (such as the four, seven and ten per cent figures used by Infrastructure Australia) have no robust backing at all; they are merely convenient assumptions.

The debate on discount rates is summarised in Appendix B.[22] In essence, there are two approaches, each with a different philosophical basis. The first, the social opportunity cost of capital argument, suggests that discount rates should reflect what the capital employed could otherwise earn in the market. The second, the social rate of time preference, suggests that discount rates should reflect the degree to which people prefer consumption now to consumption in the future. Some argue that the "right" approach should be based upon whether the relevant public investment has a consumption or an investment focus; something which is not always easy to ascertain, in part because both can be the focus of a particular public investment.

Within each of these philosophical camps, there is considerable debate. In the social opportunity cost of capital camp there is a debate about whether the market risk premium is a benefit (and thus should be included in the discount rates) or a cost associated with risks in market investments. Amongst supporters of the social rate of time preference is a much more nuanced debate about inter and intra-generational equity; very low discount rates can imply that we as a society place more importance on the welfare of future generations than we do on members of society in the current generation.[23] The issue is clouded by empirical observations that suggest that people exhibit very high discount rates in their own consumption (they want that flat screen television today, and will pay a lot for a hire purchase agreement to get it) but very low or

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[22] BITRE (1999) and the Productivity Commission (2010) provide additional references, and each focuses on a different aspect of discounting; whether to include a premium for risk or whether to use the risk free rate, a debate which can be traced back to seminal work by Arrow & Lind (1970). The two bodies have opposing viewpoints, with the former favouring the risk free rate and the latter favouring a market risk premium. However, there is a reconciliation of sorts in that the definitions of risk are slightly different, with Harrison (2010) specifically referring to risk as the covariance between returns in the investment and consumption.

[23] In extremis, a discount rate of zero implies that we would be prepared to sacrifice the entire wealth of the world today to make those a thousand generations hence a little better off, which is clearly illogical.

even negative discount rates for the consumption of their children, whom they choose to leave bequests.

Adoption of a social rate of time preference approach generally (though not necessarily) leads to a lower discount rate being used, and climate change assessments tend to make use of very low discount rates because of the very long-lived nature of climate change and its impacts. However, it would be wrong to conclude that discount rates ought to be low because we are examining climate change, and even less accurate to suggest that there is a "correct" discount rate. We have used a discount rate of three per cent, which is roughly the real growth of Australian GDP over the past few decades, as well as being the current forecast of future growth in the 2012-13 budget. In effect, we are assuming (with a marginal elasticity of utility of income of one – see Appendix B) that the "pure" rate of time preference is zero, and discounting at the rate at which future generations will become wealthier (and hence more able to pay costs) compared to the present. We would stress, however, that our discount rate is an assumption, and is not objective, in the context of the discussion above.

### Who pays?

The discussion above on discount rates leads into a broader consideration of a fundamental question; "who pays the costs of adaptation?". Our assessment looks at the societal costs and societal benefits, but is silent on the issue of who ought to pay. We do this for a very good reason; the question of who pays the costs of protection is essentially a question of wealth distribution within each of the local areas (and the State as a whole), and the "right" distribution of wealth is a normative or subjective issue, not an objective one.[24] Based on our discussion above, it is not appropriate for us to provide a "right answer" if our advice is to remain objective. Instead, the right answer is something which ought to be determined by decision-makers in each jurisdiction (at the State or Local Government level; though it seems unlikely that a single solution for the State as a whole could adequately reflect the disparate views in different communities around the State), to reflect the will of the relevant community.

Although not able to offer a "right answer", economics does offer some guidance. As a basic principle, those who obtain the benefits ought to pay the

[24] Rawls (1971 – see also Sen, 2009) and Nozick (1974) provide two opposing philosophical viewpoints on distributive issues. Empirical evidence on whether equality is "good" (in the economic sense of supporting growth) dates back to the seminal work by Kuznets (1955) which showed an inverted U-shaped relationship whereby the poorest and the richest are less equal than countries of middling wealth. Subsequent empirical work has produced mixed results (see Acemoglu & Robinson, 2002 or UNRISD, 2010 for reviews of this literature) with no definitive answer on what level of inequality a country ought to aim for.

relevant costs. This is not a normative statement, but is rather based upon the consequences of ignoring this basic maxim. Economics is based around the notions of marginal cost and marginal benefit. In this instance, part of the marginal cost of a home near the beach is the cost of any protection needed to prevent that house being lost to erosion or flooding. In some cases, the marginal benefits of living near the beach compared to the next best location for that homeowner will be less than the marginal costs of the protection needed for the house next to the beach. In a (perfect) free market, where the homeowner faces all of the costs of her decisions to locate near the beach, such houses would not be built.[25] If government does not require the homeowner to face these marginal costs by spreading the costs of protection across the whole community, then the allocation of housing resources in the community will be inefficient; too many houses will be located near the beach and too few inland.[26] Thus, where the relevant land use endangered by climate change results wholly in private benefits, that land-owner ought to pay for the costs of protection, rather than the community as a whole doing so.

This is particularly important in the case of new developments which have yet to be approved. It might be argued (though not from an economic perspective) that existing homeowners near the beach bought their homes before anything was known about climate change and its impacts, and thus it would be "unfair" to force them to be one-hundred per cent liable for the new costs associated with climate change protection.[27] However, this argument is false for new developments approved after the information in this report has been made public. In fact, the efficient use of land resources for residential properties requires that government mandate that all new developments pay the full costs of development, including any measures to protect the development from climate change. If they currently lack the power to do so,

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[25] One of the assumptions underpinning the economic construct of a perfect free market is perfect information. One role of government could therefore be as a provider of information about climate change to support rational responses to it within the marketplace.

[26] Since those living right on the beach tend to be richer than those living inland, an effect of levying the entire community for protective measures to protect private homes near the beach would be to transfer resources from the relatively poor to the relatively wealthy within the community. There is nothing in principle that is "wrong" with this from a narrow economic sense, but it may not be perceived as being particularly fair by the relevant local community. Certainly, any debate around protective strategies ought to be fully informed of this consequence of a decision to protect private land with public funds.

[27] The allegory is when a government changes the zoning of an area to allow a factory nearby, and local residents argue for compensation because a government decision has altered the value of their land compared to the value it had absent of government action. Here, however, government has not acted to cause climate change, which is rather a consequence of the actions of all in society. For this reason, it does not necessarily follow that government ought to compensate (or build protection) simply because the information available about risks, and thus land values, near the beach has changed.

then government ought to act to ensure that power is available. This is not a question of equity, but of the efficient allocation of resources.

The situation becomes more complex where the relevant land near the beach is not held in private hands. Consider first the case of a local park or beach that is used solely by the local community. In this instance the same argument about marginal costs and benefits suggests that the local community should pay for the protection. A difficulty arises, however, in that individuals can free-ride on the contributions of others; since parks are public goods, a person in the community can still use the protected park if others pay for that protection, which limits the incentives to contribute to protection. This suggests some a need for action to prevent free riding.

However, it ought to be noted that this is not necessarily an argument for government to decide on protection and then simply levy a tax to support it; Ostrom's (1990) seminal contribution to economics lies in the governance of common pool resources (like aquifers, irrigation channels, fisheries and public parks used by the community), and she provides conclusive evidence from thousands of years of human history that a "tragedy of the commons" (the consequence of free riding as discussed above) is not a necessary outcome in public resources subject to free riding. Although the issue of how the community ought to pay for the protection of community assets affected by climate change is intrinsically a subjective social-choice issue (as opposed to an objective issue that could be determined by "experts"), the next stages of the PNP's work in regards to this project could benefit from the contributions of Ostrom and the common pool resource literature to assist in developing local community frameworks to determine how to protect key community assets.[28]

The situation becomes more complex if the land near the beach, say, has a mixture of public and private uses, and a given protective measure would serve both purposes. In principle, there ought to be some apportionment of costs, based upon some simple measure of the area protected or its value. However, this may be difficult to achieve in practice, particularly if some land uses lie behind others, and would be affected much later by climate change. The owners of this land may argue that they ought not to pay for protection earlier than it is needed to protect their properties, or they may argue that the rates of protection ought to be lower to reflect the fact that the benefits will only be felt further in the future. It appears likely that a social choice mechanism (like a local vote) would be a more suitable approach than attempting to develop an objective assessment of the "right" cost-sharing mechanism.

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[28] Apart from Ostrom's book, thousands of case studies on successful common pool resource governance are available at http://dlc.dlib.indiana.edu/dlc/.

In this context, government will also need to be wary of strategic behaviour by developers of new residential land. If a policy is developed that specifies sharing mechanism for private and public lands affected by climate change where these are protected by a single measure, then there is an incentive for developers of new land to design their developments to limit the private cost and maximise the public cost of protection. Since there is a requirement to devote a certain percentage of any new residential development to parkland (usually ten per cent), a developer could reduce her own costs and increase the cost borne by the community by putting the parkland "in harm's way".[29] Since this new parkland is only being developed because the area is being developed for residential use, this would result in an inefficient allocation of resources, and thus any policies around sharing of costs would need to differentiate between existing and new developments.

The situation is clouded still further where the asset in question is either used or valuable to people outside the local area. There are, for example, several national parks within the region, as well as thrombolites that are currently the subject of a petition for world-heritage listing.[30] In this instance, the "community" is much larger than the local base of rate-payers or even the State as a whole, and it is much more difficult to implement common pool resource solutions such as those Ostrom (1990) suggests. There is also an issue of fairness; if part of the value of an area attaches to the local community and part to a State, national or (in the case of world heritage sites) international community, the a requirement that local people in the region pay for the protection costs themselves represents a transfer from the region to the wider State, national or international community. In some cases, this may not be an issue, if the cost of protection is low and the local community firstly has benefits above this low cost and secondly is willing to make the subsidy. However, if either of these things are not true, then a case could be made for partial State or Federal Government funding. The exact proportions, however, would be subject to the same caveats as for local community cost sharing above, and would likely be determined through negotiation between the State and local governments.

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[29] In so doing, she would sacrifice the greater returns that could be earned by putting residential properties nearer the beach, so there will likely be a trade-off, rather than all parkland being located near the beach.

[30] See www.thepetitionsite.com/1/-help-list-lake-clifton-as-a-world-heritage-site/. Note that the thrombolites are already in the Ramsar-listed Peel-Yalgorup System which is protected under the Commonwealth Environmental Protection and Biodiversity Conservation Act of 1999, meaning that the "community" associated with this area is already larger than the local region.

# 3 The PNP Context

In this chapter, we provide an overall assessment of the context of the analysis undertaken in the subsequent chapters. This chapter contains no economics. Instead, it contains two sections which describe the study area and which describe the impacts; summarising the results from Phase One

## 3.1 Description of the study area

The study area includes nine Local Government areas; from the City of Rockingham in the North to the City of Busselton in the South. Figure 2 shows the study areas, between the two dashed orange lines. The letters in Figure 2 show the "sediment cells" in the region; areas which delineate different levels of internal cohesiveness when it comes to the movement of sediment along the coast.

Figure 2 **Peron Naturalist Partnership study region**


*Source:* Google Earth

The modelling of the physical impacts of climate change (discussed in Section 3.2) produces "hazard lines" which highlight which tracts of land are in danger of erosion and flooding in a particular year. It is these hazard lines which form the core contribution from Phase One to the remainder of the project, because they show which assets are in scope.

## Asset register development and results

In order to assess the value at risk of assets affected by climate change, to underpin suitable adaptation options, we divided the assets into 15 different categories, reflective of the types of assets and the types of information available within the databases used. Broadly speaking, there are two groups of assets; those delineated by length (roads, railways and power and water infrastructure) and those delineated by area, residential, commercial and other forms of land use.

The asset register for the region wide analysis of the Peron Naturalist Coastal Region in Western Australia was prepared in conjunction with the Department and Planning. The Department of Planning kindly overlayed their data files on numerous areas, such as utilities and land use, over the erosion progress lines defined by Damara. We would like to take this opportunity to thank staff within the Climate Change and Coastal Planning, and Mapping and Geospatial Data teams at the Department for the considerable assistance they provided in developing the asset register.

### Roads

Roads were measured using the Department of Planning data file "Road Centrelines", that measures the centreline length of roads. The final data was filtered to remove proposed road segments, mall roads and not applicable classifications, and then filtered again to remove unsealed roads. This resulted in the measurement of minor and major sealed roads and sealed laneways and mall roads. These roads were then divided into one lane, or two or more lanes. Table 1 shows the length of roads at risk of erosion over the years. In total there is approximately 183 kilometers at risk, and the majority of this occurs in the later years of 2070 and 2100.

Table 1 **Length of roads at risk (meters)**

| | 2030 | 2040 | 2050 | 2070 | 2100 | **Total** |
|---|---|---|---|---|---|---|
| One lane | 4,343 | 2,298 | 4,045 | 13,277 | 18,171 | **42,134** |
| Two or more lanes | 20,795 | 7,272 | 14,006 | 37,808 | 60,645 | **140,526** |
| **Total** | **25,138** | **9,570** | **18,051** | **51,085** | **78,816** | **182,660** |

*Data source: (Department of Planning, 2011)*

### Railways

Railway infrastructure length was measured using the Department of Planning data file "Railway Lines". The only operational railway line that fell within the area under analysis was the Picton Junction- Casuarina Point via Harbour Junction. In total, there are 977 meters of railway, with more than half of that being at risk in the year 2030 (see Table 2).

Table 2 **The length of railway at risk (meters)**

| | 2030 | 2040 | 2050 | 2070 | 2100 | Total |
|---|---|---|---|---|---|---|
| Freight railway | 537 | 108 | 104 | 138 | 90 | **977** |

*Data source: (Department of Planning, 2012)*

### Water

Water infrastructure refers to water mains operated by WaterCorp, AQWEST and the Busselton Water Board, and covered in three different data files (one for each company) in the Department of Planning's database. The assessment only covers operational pipes.

Overall there is approximately 159 kilometres of water main that will be at risk. The majority of this will become at risk at the years of 2070 and 2100 (see Table 3).

Table 3 **Length of water mains at risk (meters)**

| | 2030 | 2040 | 2050 | 2070 | 2100 | Total |
|---|---|---|---|---|---|---|
| Water Corporation | 9,510 | 2,326 | 8,470 | 23,975 | 41,761 | **86,042** |
| Aqwest (Bunbury Water Board) | 980 | 567 | 922 | 3,706 | 3,693 | **9,868** |
| Busselton Water Board | 4,451 | 3,632 | 6,908 | 24,665 | 23,585 | **63,241** |
| **Total** | **14,941** | **6,525** | **16,300** | **52,346** | **69,039** | **159,151** |

*Data source: (Department of Planning, 2011)*

### Sewerage

Sewerage infrastructure was measured using the Department of Planning data files "Water Corporation pressure main" and "Water Corporation gravity pipes". The final data for the regional area under analysis was filtered to remove any dead, not in use or proposed lines. In total there are approximately 113 kilometers of sewer mains at risk of erosion, 45 per cent of the mains become at risk in 2100 (see Table 4).

Table 4 **Length of sewerage lines at risk (meters)**

| | 2030 | 2040 | 2050 | 2070 | 2100 | Total |
|---|---|---|---|---|---|---|
| Pressure mains | 5,120 | 1,916 | 3,133 | 12,606 | 10,176 | **32,951** |
| Gravity mains | 9,942 | 2,983 | 5,865 | 20,263 | 41,054 | **80,107** |
| **Total** | **15,062** | **4,899** | **8,998** | **32,869** | **51,230** | **113,058** |

*Data source: (Department of Planning, 2011)*

### Electricity

Electricity was broken down into low and high voltage lines for both underground and overhead. The Department of Planning data files used for measuring electricity lines was "Western Power Underground Distribution lines" and "Western Power Overhead Distribution lines". There is 226,000 meters of electricity line at risk in total (see Table 5). Over 45 per cent of this occurs in 2100.[31]

Table 5 **Length of electricity lines at risk (meters)**

| | 2030 | 2040 | 2050 | 2070 | 2100 | Total |
|---|---|---|---|---|---|---|
| Underground low voltage | 6,111 | 2,663 | 6,280 | 23,902 | 41,077 | **80,033** |
| Underground high voltage | 2,569 | 1,537 | 3,175 | 8,209 | 11,564 | **27,054** |
| Overhead low voltage | 9,928 | 3,910 | 9,455 | 24,414 | 35,632 | **83,339** |
| Overhead high voltage | 3,692 | 625 | 1,946 | 13,196 | 16,108 | **35,567** |
| **Total** | **22,300** | **8,735** | **20,856** | **69,721** | **104,381** | **225,993** |

*Data source: (Department of Planning, 2011)*

### Gas

Gas mains were measured using the Department of Planning data file "Gas Distribution Facilities" and "Gas Network Pipelines". The data was filtered to exclude abandoned line, proposed common trenching, proposed main, duct, sleeve and offline service line. In total there was approximately 95km of gas main measured, comprising of 33km of high pressure line and 62km of medium pressure line. Roughly half of this total only becomes at risk in 2100.

Table 6 **Length of gas main at risk (meters)**

| | 2030 | 2040 | 2050 | 2070 | 2100 | Total |
|---|---|---|---|---|---|---|
| High pressure | 2,707 | 2,229 | 3,253 | 10,153 | 15,032 | **33,374** |
| Medium pressure | 8,449 | 1,591 | 4,207 | 13,826 | 33,444 | **61,517** |
| **Total** | **11,156** | **3,820** | **7,460** | **23,979** | **48,476** | **94,891** |

*Data source: (Department of Plannning, 2006)*

[31] Note that we do not account for telecommunications infrastructure in the analysis, as there are no data in the relevant databases which allow such infrastructure to be identified.

### Community infrastructure

Community infrastructure refers to a wide range of public purpose assets such as schools, hospitals, car parks, churches, service stations, nursing homes, fire stations, local government facilities, waste disposal, museums, child care and caravan parks. They are considered together for two reasons. Firstly, the relevant databases are not always specific about what land with the relevant zoning (see below) is actually used for, which makes it difficult to value of a case-by-case basis. Secondly, most of the community purpose assets are not traded in any markets, and thus present challenges in terms of valuation. However, valuing the assets at the alternate use of the relevant land allows for a reasonably consistent, and simple valuing methodology. This is discussed further in Chapter 4.

Community infrastructure was taken from the Department of Planning data file "LPS land use". The data contained in this file is from the Local Planning Schemes, defining land use according to region scheme reserves, local scheme reserves and zones. To measure the area of land containing "infrastructure" this class of the asset register measured categories described as community purpose(s), public purpose, public utilities, special purpose and special use across the seven cities and shires involved ( Rockingham, Mandurah, Bunbury, Busselton, Capel, Harvey and Waroona).

The area of community infrastructure at risk is shown in Table 7. In total there is approximately 935,000 m$^2$ (93.5 ha) at risk, with most becoming at risk in 2030 of after 2070. Nearly 80 per cent of the total is found in the City of Busselton, consistent with the large area of the town that the erosion process lines suggests will be at risk. Approximately 15 per cent of the total area is in Bunbury and the remainder is made up of relatively small areas from Mandurah, Rockingham, Harvey and Capel.

Table 7 **Area of community infrastructure at risk (meters squared)**

| | 2030 | 2040 | 2050 | 2070 | 2100 | **Total** |
|---|---|---|---|---|---|---|
| Community infrastructure | 217,507 | 59,377 | 99,948 | 277,047 | 281,039 | **934,918** |

*Data source: (Department of Planning, 2011)*

### Residential land

Information on residential land was taken from the Department of Planning data file "LPS land use". The data contained in this file are from the Local Planning Schemes, defining land use according to region scheme reserves, local scheme reserves and zones. To measure the area of land zoned for residential purpose this part of the asset register measured categories described as residential, special residential and canal. Rural residential land has been left as an asset class in its own right.

The total area of residential land at risk over the study period is approximately 5,773,000 $m^2$, or 577.2 ha (see Table 8). There are significant amounts of land that become at risk between 2070 and 2100. Approximately 88 per cent of this total is from the Cities of Busselton (269.2 ha), Mandurah (106.9 ha) and Rockingham (133.4 ha). The City of Bunbury has 2.9 ha of affected residential land in total. The Shire of Harvey has 17.7 ha, and the Shire of Capel 46.9 ha. The area in these Shires is on the whole reflective of the Myalup, Binninyup and Peppermint Grove settlements along the coast.

Table 8 **Area of residential land at risk (meters squared)**

| | 2030 | 2040 | 2050 | 2070 | 2100 | **Total** |
|---|---|---|---|---|---|---|
| Residential land | 374,500 | 296,431 | 640,564 | 1,660,396 | 2,800,913 | **5,772,804** |

*Data source: (Department of Planning, 2011)*

### Commercial land

Information on commercial land was taken from the Department of Planning data file "LPS land use". The data contained in this file is from the Local Planning Schemes, defining land use according to region scheme reserves, local scheme reserves and zones. To measure the area of land zoned as commercial purpose this part of the asset register measured categories described as business, city centre, commercial, tourist and shop.

The total area of commercial land at risk is approximately 715,000 $m^2$, or 71.4 ha (see Table 9). The majority of this land becomes at risk between 2070 and 2100. Around 94 per cent of this is in the City of Busselton.

Table 9 **Area of commercial land at risk (meters squared)**

| | 2030 | 2040 | 2050 | 2070 | 2100 | **Total** |
|---|---|---|---|---|---|---|
| Commercial land | 70,060 | 48,792 | 89,401 | 220,390 | 285,876 | **714,519** |

*Data source: (Department of Planning, 2011)*

### Development land

Development land refers to land that has been zoned for residential or commercial use, but which does not yet (necessarily) have the houses, shops and other built infrastructure on it.[32]

[32] In some instances, development may have begun to occur already, is a database has not been updated recently.

Development land was taken from the Department of Planning data file "LPS land use". The data contained in this file are from the Local Planning Schemes. To measure the area of land zoned for development purpose this part of the asset register measured categories described as development, precinct development, urban development and Mandurah Ocean Marina Development.

As shown in Table 10, the total area of development land that is at risk under this analysis is approximately 806,000 m$^2$, or 80.6 ha. Almost 60 per cent of this area at risk occurs in 2100. This development land is in the Cities of Rockingham and Mandurah and the Shire of Capel. Mandurah has 60.1 ha at risk, of which 26.8 ha can be deemed commercial land (the Mandurah Ocean Marina Development). The other areas of development land are in the Shire of Capel, 8.9 ha, and the remaining is 11.5 ha is in Rockingham.

Table 10 **Area of development land at risk (meters squared)**

| | 2030 | 2040 | 2050 | 2070 | 2100 | **Total** |
|---|---|---|---|---|---|---|
| Development land | 133,706 | 18,489 | 39,190 | 133,243 | 481,625 | **806,253** |

*Data source: (Department of Planning, 2011)*

### Rural residential land

Information on rural residential land was taken from the Department of Planning data file "LPS land use". The data contained in this file is from the Local Planning Schemes, defining land use according to region scheme reserves, local scheme reserves and zones. To measure the area of land zoned for rural residential purpose this asset classing measured the category described as rural residential.

The total rural residential area at risk is approximately 169,000 m$^2$, or 16.8 ha (see Table 11). All of this land area is in the City of Busselton, and almost all of it is only at risk after 2070.

Table 11 **Area of rural residential land at risk (meters squared)**

| | 2030 | 2040 | 2050 | 2070 | 2100 | **Total** |
|---|---|---|---|---|---|---|
| Rural residential | 911 | 442 | 1,558 | 33,729 | 131,951 | **168,591** |

*Data source: (Department of Planning, 2011)*

### Rural and agricultural land

Information on rural and agricultural land was taken from the Department of Planning data file "LPS land use". The data contained in this file is from the Local Planning Schemes, defining land use according to region scheme reserves, local scheme reserves and zones. To measure the area of land zoned for rural purpose this asset classing measured the categories described as rural, rural coastal-3A, agriculture and general farming.

There is a slight difference in nomenclature between the City of Busselton and other local government areas, with the City using the term "agricultural land" to refer to a land use that would be termed "rural" in other local government areas and is, for the purposes of this study at least, identical. In total, there is 958 hectares of this land at risk. The Shire of Harvey has 437.4 ha at risk overall, and the Shire of Capel 310.3 ha at risk. Waroona and Mandurah have 52.1 and 14.4 ha at risk, respectively and the City of Busselton has approximately 143.5 ha at risk. Around three-quarters of the land is only at risk after 2070.

Table 12 **Area of rural land at risk (meters squared)**

| | 2030 | 2040 | 2050 | 2070 | 2100 | Total |
|---|---|---|---|---|---|---|
| Rural and agricultural land | 895,574 | 312,203 | 749,096 | 2,757,983 | 4,864,091 | **9,579,947** |

*Data source*: *(Department of Planning, 2011)*

### Parks, recreational and conservation areas

An area measurement of parks, recreational and conservation areas was taken from the Department of Planning data file "LPS land use". To measure the parks, recreational and conservation areas in the region wide analysis it was necessary to take into account the Local Planning Schemes as well as the Region Planning Schemes. To ensure that there was no double counting the Region Schemes file was overlayed on the Local Planning Schemes file and any cross over was removed.

It is important to note that this asset class covers a broad range of parks, recreational areas, national parks, conservation areas and reserves. It can encompass local playground parks, grassed areas, foreshore areas and larger tracts of land that can be considered national parks, nature reserves or conservation areas. This is a product of the planning schemes classification that varies across the Cities and Shires. Due to this broad classing we endeavoured to create a divide between those larger areas that are considered national parks and conservation areas and those smaller areas such as playgrounds and foreshore area. To achieve this the data was split into areas that were greater than three hectares in size and those less than three hectares. This produced a rough guide of the different areas under consideration and allowed for a different value to be assigned to each.

Firstly, an area measurement of local parks, recreational and conservation areas was taken from the Department of Planning data file "LPS land use". The data contained in this file is from the Local Planning Schemes, defining land use according to region scheme reserves, local scheme reserves and zones. To measure the area of land reserved this asset classing measured the categories described as local recreation, parks and recreation, public open space, recreation, district recreation, conservation and conservation and foreshore. This data was then filtered to separate the smaller areas of land (< 3 ha) from the larger (> 3 ha).

Secondly, an area measurement of regional parks, recreational and conservation areas was taken from the Department of Planning data file "Region Schemes LPS Union". The data contained in this file was all reserves within the three Region Schemes marked as Parks and Recreation and Regional Open Space. The Metropolitan Region Scheme (MRS) included Rockingham, the Peel Region Scheme (PRS) Mandurah and Waroona and the Greater Bunbury Region Scheme (GBRS) included Harvey, Bunbury and Capel. It was assumed that all of the land at risk in the Region Schemes files was from areas greater than three hectares.

Of the approximate 34,098,000 $m^2$ (or 3410 ha) of land that is at risk, close to 30 per cent was contained in the LPS and the remainder was from the Region Schemes. Table 13 shows the breakdown of this separation over the years being analysed. The majority of land, 3,361 ha was greater than three hectares in size, leaving approximately 48.5 hectares regarded as playgrounds, foreshore, grassed areas etc.

Table 13 **Area of parks, recreational and conservation areas at risk (meters squared)**

| | 2030 | 2040 | 2050 | 2070 | 2100 | **Total** |
|---|---|---|---|---|---|---|
| Parks, recreational and conservation areas (< 3 ha) | 107,179 | 4,860 | 29,791 | 191,112 | 152,410 | **485,352** |
| Parks, recreational and conservation areas (> 3 ha) | 18,907,499 | 1,927,789 | 2,611,692 | 4,487,637 | 5,678,527 | **33,613,144** |
| **Total** | **19,014,678** | **1,932,649** | **2,641,483** | **4,678,749** | **5,830,937** | **34,098,496** |

*Data source: (Department of Planning, 2011)*

### Beaches

The identification and length of beaches was taken from Short (2006), and a broad classification made of the types of beaches according to the definition of coast as set out in the State Coastal Planning Policy (Western Australian Planning Commission, 2012). The entire length of coast from Point Peron to Cape Naturaliste is 212 km, and the coast has been classified as either urban, natural or remote, defined as follows:

- urban coast- where the adjacent uses are predominately residential and commercial and there is a high demand for recreational activity

- natural coast- with less intensive hinterland uses and concentrations of tourism and associated recreational and cultural activities
- remote coast- with limited opportunity for low key tourism and associated recreational and cultural activities

The identified lengths of urban, natural and remote coast are shown in Table 14,

Table 15 and Table 16, respectively. There is 105 kilometres of urban coast, 19.2 kilometres of natural coast and 87.9 kilometres of remote coast.

Table 14 **Length of urban coast (km)**

| Beach name | Number ID | Length | Beach name | Number ID | Length | Beach name | Number ID | Length |
|---|---|---|---|---|---|---|---|---|
| Castle Bay (Little Meelup) | 740 | 0.4 | McKenna Point (W) | 762 | 0.07 | Leighton Park | 787 | 2 |
| Castle Point | 741 | 0.1 | Harbour Beach | 763 | 0.6 | Blue Bay (S) | 788 | 0.8 |
| Castle Point (S) | 742 | 0.06 | Harbour Groyne | 764 | 0.05 | Blue Bay (S) | 789 | 0.8 |
| Curtis Bay | 743 | 0.06 | Point McLeod (W) | 765 | 0.2 | Halls Head Beach | 790 | 0.8 |
| Point Dalling | 744 | 0.15 | Point McLeod (E) | 766 | 0.25 | Mandurah | 791 | 0.8 |
| Point Daking | 745 | 0.25 | Koombana Beach | 767 | 0.8 | Silver Sands | 792 | 1.6 |
| Dunn Bay | 746 | 0.7 | Point Hamilla | 768 | 0.3 | San Remo | 793A | 4 |
| Dunsborough | 747 | 7.5 | The Cut | 769 | 1.5 | Mandora | 793B | 2 |
| Toby Inlet | 748 | 5.3 | Tims Thicket | 773 | 2.3 | Singleton | 793C | 2.5 |
| Busselton Beach | 749 | 15.3 | Melros | 774 | 1.3 | Golden Bay | 793D | 2.5 |
| Port Geographe (1) | 750 | 0.08 | Florida Bay | 775 | 0.5 | Secret Harbour | 793E | 5.7 |
| Port Geographe (2) | 751 | 0.06 | Florida (N) | 776 | 0.8 | Becher Point | 794 | 0.25 |
| Port Geographe (3) | 752 | 0.25 | Pyramids | 777 | 1.4 | Kennedy Bay | 795 | 1.3 |
| Port Geographe (4) | 753 | 0.25 | Northport (1) | 778 | 0.1 | Warnbro Beach | 796 | 8.3 |
| Wonnerup Beach | 754 | 1.8 | Northport (2) | 779 | 0.5 | Safety Bay | 797 | 2.1 |
| Bunbury Beach | 757 | 11.5 | Avalon | 780 | 1.2 | Shoalwater | 798 | 1.5 |
| Hungry Hollow Beach | | 0.5 | Falcon | 781 | 1.3 | Peron | 799 | 2.5 |
| Ocean/ Back Beach | | 0.5 | Falcon Bay (1) | 782 | 0.5 | White Rock | 800 | 0.7 |
| Lighthouse Beach (Symmonds St Beach) | 758 | 0.7 | Falcon Bay (2) | 783 | 0.5 | Point Peron (S3) | 801 | 0.06 |
| Point Casuarina | 759 | 0.9 | Falcon (N1) | 784 | 1.3 | Point Peron (S2) | 802 | 0.03 |
| Point Casuarina (N) | 760 | 0.05 | Falcon (N2) | 785 | 1 | Point Peron (S1) | 803 | 0.04 |
| McKenna Point | 761 | 0.3 | Polleys Hole | 786 | 1.2 | Point Peron | 804 | 0.3 |

*Data source:* (Short, 2006)

Table 15 **Length of natural coast (km)**

| Beach name | Number identification | Length |
|---|---|---|
| Bunker Bay | 733 | 2.3 |
| Eagle Bay (N) | 736 | 0.75 |
| Eagle Bay | 737 | 1.5 |
| Eagle Bay (N) | 738 | 0.25 |
| Forrest-Peppermint Grove Beach | 755 | 14 |
| Meelup Beach | 739 | 0.4 |
| **Total** | | **19.2** |

*Data source: (Short, 2006)*

Table 16 **Length of remote coast (km)**

| Beach name | Number identification | Length |
|---|---|---|
| Cape Naturaliste (E) | 731 | 0.4 |
| Shelly Beach | 732 | 0.07 |
| Rocky Point (1) | 734 | 0.15 |
| Rocky Point (2) | 735 | 0.05 |
| Stirling Beach | 756 | 10.9 |
| Binningup Beach | 770 | 22 |
| Myalup Beach | 771A | 22.5 |
| Preston Beach | 771B | 9 |
| Yalgorup NP | 771C | 7 |
| Cape Bouvard | 771D | 15 |
| Tims Thicket (S) | 772 | 0.8 |
| **Total** | | **87.9** |

*Data source: (Short, 2006)*

### Summary

The total area of land at risk of erosion under a 2100 medium scenario is approximately 5,205 ha. This figure is an approximate area, perfect accuracy is not possible given a number of factors including rounding aspects, the scale and scope of the area under analysis, and variances that may occur with the way data files have been overlayed and defined. The summary asset register is displayed in Table 17, along with measurements of other assets such as roads and water mains and beaches. Collectively this register represents the main assets that are at risk of erosion in the region. Of note are the significantly large areas of residential and rural land and areas of park, recreational and conservation.

Overall, the timing of the impact is correlated with the land use. A significant portion of parkland/reserve is foreshore reserve, and this is at risk early in the timeframe as it is closest to the ocean. Residential land (and the infrastructure that serves it) site behind the foreshore reserve, and is thus impacted next, with other land uses such as agricultural land generally being further from the coast, and thus affected last.

Note that our focus in the discussion above is on land at risk of erosion. This is because, in the region-wide analysis, this is the most crucial impact, with flooding only affecting a relatively small area of land. This is discussed in more detail as a separate section in Section 4.3.

Table 17 **Asset register**

| Asset classing | | 2100 medium erosion risk scenario |
|---|---|---|
| Roads | one lane | 42 km |
| | two or more lanes | 140 km |
| Railways (freight) | | 0.98 km |
| Water | mains | 159 km |
| Sewerage | pressure main | 33 km |
| | gravity pipes | 80 km |
| Electricity | underground | 107 km |
| | overhead | 119 km |
| Gas pipelines | | 94 km |
| Commercial land | | 71 ha |
| Residential land | | 575 ha |
| Rural Residential land | | 17 ha |
| Rural and agricultural land | | 958 ha |
| Development land | | 81 ha |
| Community infrastructure | | 93 ha |
| Parks, recreational and conservation areas | | 3410 ha |
| Beaches | urban coast | 105 km |
| | natural and remote | 107 km |

## 3.2 Description of the impacts

The Phase One Report; Coastal Hazard Mapping for Economic Analysis of Climate Change Adaptation in the Peron-Naturaliste Region (Damara, 2012) contains considerable detail on the modelling undertaken to derive the hazard lines.

# 4 Region-Wide Analysis

In this section, we provide an overview of the region-wide analysis and its results. The purpose of the region-wide analysis is to develop a broad understanding of the likely overall resource costs associated with adapting to climate change within the region, if changes are optimal in the sense that adaptation options are not more costly than the assets they preserve. It is not the intent of this chapter to highlight strategy; this will be the role of the case studies in the following chapter.

The process of analysis in this section is as follows. Firstly, we evaluate the value at risk if nothing is done by government to adapt to climate change. This is done for each of the assets discussed in the previous section. We then assess the costs of undertaking different interventions for each of the asset classes. In the regional analysis, only limited temporal or spatial information are used, which is why it is more suited for assessing overall resource cost than developing strategy. The interventions we consider are a generic engineering option, a generic planning option and a generic market intervention option. Finally, we compare the costs of these options with the value at risk for each asset class, and form conclusions as to whether a decision based on the economic analysis in this chapter would result in protection of the asset in question via an engineering, planning or market intervention approach, or whether a retreat option (that is, realising the value at risk) would be more appropriate This includes a brief sensitivity analysis to test the robustness of these conclusions as underlying assumptions change.

The structure of this chapter follows that of the analysis. The first section provides an overview of how value at risk is calculated; the methods used. The second section shows how the costs of each intervention method have been calculated, and shows what these costs are. The third shows the results of the analysis, including sensitivity analysis.

## 4.1 Calculating value at risk

In this section, we outline how value at risk is calculated. The description is relatively detailed because the same basic approach is used in the case studies, and it thus might be used at a later stage by local government officials seeking to undertake their own analyses. For this reason, it is appropriate that the methodology is described in some detail.

Our estimation of value at risk starts with an asset value. This is either a market value or a quasi-market value formed (in this instance) through a benefit transfer or replacement cost approach.[33] We then use the value at risk estimation tool to move from an assessment of asset value to an assessment of value at risk, by first converting asset values to an annualised stream of benefits and then assessing how that stream is affected by climate change.

We now turn to a description of the value at risk estimation tool, and then outline how asset values (which feed into this tool) are assessed.

### The value at risk estimation tool

As noted above, in order to assess value at risk, we start with an asset value, which is then converted into an annualised value. The annualised value is then altered to take into account the influence of climate change and converted back into a new asset value. The difference between the two is the value at risk.[34]

To explore this further, consider a house worth $500,000 in the open market. What does that $500,000 actually mean? It means that the person who buys the house considers that they will obtain sufficient "utility" from living in the house and realise a sufficient resale value to warrant parting with $500,000 to buy it. Moreover, the resale price is, in economic terms, an assessment on the part of a buyer of the likely utility and future resale value that a future buyer might receive, and so on through time. In other words, a market price for a house (or indeed any other asset) can be considered as the net present value of a stream of future benefits from its use. The same is true of a quasi-market price, and the general framework also admits non-use values, because "utility" can be gained simply from knowing something is there.

In practice, the utility gained from the house may go up and down from year to year. However, to simplify the mathematics which underlie our assessment process, instead of using the utility stream from the house itself, we use the utility stream from a notional equivalent asset that is constant, but delivers the same present value of utility as the house. In other words, we ask the question of what asset yielding a constant stream of benefits would we need to compensate a home-owner (or other asset owner, including a community that notionally owns a parks) in order to leave them indifferent to surrendering

[33] Time and resource constraints prevent us, in this report, from using contingent valuation or other similarly resource intensive approaches to value assets. As noted previously, under our decision relevant approach, we highlight where we consider our estimates of value require further assessment in order that policymakers can make robust decisions. In practice, such examples are rare in our report.

[34] This is why errors in the estimation of value need not be important for the estimation of value at risk, because they are usually repeated in the original and subsequent asset valuation steps (ie – before and after climate change is taken into account), meaning that the difference between the two is independent of (common) errors in the formulation of each.

their house.[35] This simplification, common in economics, allows us to make use of a simple piece of mathematics associated with the net present value (NPV) equation. Note that the standard formula for net present value is:[36]

$$NPV = \sum_{t=1}^{n} \left(\frac{1}{1+r}\right)^{t} V \qquad (1)$$

If V is constant through time, this can be re-arranged as follows:

$$V = \frac{NPV}{\sum_{t=1}^{n}\left(\frac{1}{1+r}\right)^{t}} \quad if \quad t < \infty$$
$$V = rNPV \quad if \quad t = \infty \qquad (2)$$

The NPV is the value of the equivalent asset; effectively the market value of the house, and $r$ is the discount rate to allow comparison of current with future enjoyment of utility. The result which we use is the $V$ on the left had side above, and we then consider how $V$ might change in a general sense due to climate change. We consider three possibilities, which cover the scope of what could occur in a general sense:

- The land upon which the asset sits could be eroded away at some point in time in the future. This would mean that an annual utility of $V$ would be enjoyed up to that point in time, and an annual utility of zero would be enjoyed thereafter. Plugged back into an NPV formula, this would mean that $t$ no longer goes to infinity, and thus that NPV would be smaller than before, and the difference would be the value at risk.
- The land upon which the asset sits could experience an increase in flooding risk. This would mean that the annual utility of $V$ would change; now the asset owner would need to devote resources to either insuring against flood risk via an insurance premium that pays out in the event of a flood occurring, or building some kind of defence to prevent flooding from affecting her enjoyment of the asset. In both cases, this means that the new $V$ is smaller for each year after the increase in flood risk, and thus that the sum of these through time in an NPV formula will be smaller

[35] This framework opens the possibility of including non-market values, such as sentimentality associated with a house; provided a dollar figure can be attached to it.

[36] Note that $t$ refers to time periods, which range from 1 to n, ∞ stands for infinity, < denotes "less than", and Σ denotes the sum over the range in sub and superscript.

compared to the original NPV. The difference between the two is the value at risk.

- The land upon which the asset sits could experience an increase in flood risk for a time, and eventually be eroded away. This would result in both a diminution of *V* and in the summation being to $t<\infty$.

We summarise these three effects in Equation 3 below, in three different square bracketed terms. Note that it can be applied to a single asset experiencing just one of the three effects outlined above, or to *m*, *p* and *q* different assets experiencing any of the three effects. Note also that it is independent of the source of asset valuation, meaning it can be applied to any asset, however, it is valued.

$$VAR = \sum_{i=1}^{m}\left[NPV_i - \sum_{t=1}^{n}\left(\frac{1}{1+r}\right)^t rNPV_i\right] + \sum_{f=1}^{p}\left[NPV_f - \sum_{t=1}^{\infty}\left(\frac{1}{1+r}\right)^t \left(rNPV_{fi} - \Delta_t I_t\right)\right] + \sum_{fi=1}^{q}\left[NPV_{fi} - \sum_{t=1}^{n}\left(\frac{1}{1+r}\right)^t \left(rNPV_{fi} - \Delta_t I_t\right)\right] \quad (3)$$

In respect to Equation 3, note that it includes:

- A summation across *m* different properties which are eroded away at some point in time. This means that the owners of each are able to enjoy the full annual benefits of their property for a number of years (*n* years), and then for each year after erosion the value goes to zero. Thus, the impact on the current NPV of the equivalent asset is to subtract the (discounted) years for which the value goes to zero.
- A summation across *p* properties which suffer an increase in flooding risk. What this means is that the annualised value (*rNPV*) that previously existed is reduced in each year by a factor of $\Delta I$; the increase in "insurance premiums" necessary to cover the loss due to climate change. Note that this has a subscript *t* to denote that this value might change year by year, as flooding risk changes over time. Note that, when flooding risk increases to the point that the land is economically unusable (say, for example, if insurance premia were more than the land is worth) then we treat this land as being eroded, even if it physically still exists.
- A summation over q properties which are afflicted both by a flooding risk and an inundation risk, so that their "insurance premia" increase for a time, reducing their annual enjoyment of the property, and then after a certain point in time, they are no longer able to enjoy the property as it is under water; after year *n*.

Using Equation 3 allows us to estimate how much value has been lost in respect of each asset, over the course of its lifespan. It is also possible to incorporate other sensitivities, such as sensitivity to risk. In this project, we assume risk-neutrality, which we interpret as being strict belief in the climate modelling work; if Damara's model says that land will be eroded in 2050, then this is reflected exactly in the valuation of the property.

Two issues require further consideration. Firstly, discount rates. The debate on what the "correct" discount rate is in studies of climate change impacts is far from settled; the "benchmark" figures used by different Australian government bodies (usually four, seven and ten per cent) are certainly not "correct" in that there is solid economic theory or empirical findings that back them up, but they are rather convenient benchmarks useful if many different projects are being assessed.

We have included a brief account of the debate on discount rates in Chapter 2, with more detail as an appendix for the interested reader. We use a discount rate of three per cent in our work.

Secondly, in terms of the relationship between flooding risk and insurance premia, there is very little in the literature or insurer practise upon which to base our findings. In essence, climate change and the consequences of flooding is a new issue for the insurance industry as well, and they are still in the process of establishing how increases in flooding risk might translate into higher insurance premia. Detail of the Australian and global experience in this regard are provided in Appendix A.

For the purposes of this paper, we take the recent data summarised in Appendix A, which suggests that a house with a flood risk of greater than one in 111 would attract a premium of $77 per annum, and one of between 100 and 67 would attract a premium of $507, and assume that the former is applicable to properties in the one in 500 region and the latter to the properties in the one in 100 region. A more detailed treatment of insurance premia and risk is provided in the case studies.

We now turn to a discussion of how assets are valued; the first stage in establishing value at risk.

### Valuing assets

As noted above, Equation 3 is used in both the region-wide and case study analyses, where it is applied to asset values. In the region wide analysis, the assets valued are those shown in Table 17 in Chapter 3, and their values are shown in Table 18 below.

Table 18 **Region wide asset values summary**

| Asset classing | | Cost | | Unit |
|---|---|---|---|---|
| Roads | one lane | $ | 275 | metre |
| | two or more lanes | $ | 360 | metre |
| Railways (freight) | | $ | 2,325,000 | kilometre |
| Water | mains | $ | 450 | metre |
| Sewerage | pressure main | $ | 200 | metre |
| | gravity pipes | $ | 190 | metre |
| Electricity low voltage | underground | $ | 150 | metre |
| | overhead | $ | 45 | metre |
| Electricity high voltage | underground | $ | 300 | metre |
| | overhead | $ | 55 | metre |
| Gas pipelines | | $ | 90 | metre |
| Commercial land | | $ | 1,000 | square metre |
| Residential land | | $ | 600 | square metre |
| Rural Residential land | | $ | 24 | square metre |
| Rural land | | $ | 1.70 | square metre |
| Development land | commercial | $ | 1,000 | square metre |
| | residential | $ | 600 | square metre |
| Agricultural land | | $ | 2.00 | square metre |
| Community infrastructure | | $ | 1,000 | square metre |
| Parks, recreational and conservation areas | (>3ha) | $ | 6 | square metre |
| | (< 3ha) | $ | 60 | square metre |
| Beaches | urban coast | $ | 9,000,000 | square kilometre |
| | natural and remote | $ | 3,000,000 | square kilometre |

Where possible, we have used market-based valuations, because of the objectivity of the available data. However, this is not possible for all assets under consideration. We discuss the derivation of each asset value below.

### Roads

Roads do not have a market value per se because they are not traded assets, at least in WA where they remain in public hands. Conceptually, one could value them via a production function approach, but it is difficult to ascertain how a road features in the production of a good or service when it is a means of transport (often among many) rather than a key input into the process per se. There is the additional issue of the number of different production processes a road serving a medium-sized town (say) feeds into. For these reasons, we have chosen to use an asset replacement approach to value these assets. In most cases, the roads in question would indeed be replaced or protected in the event of a risk from climate change, because they connect settlements which are (usually) themselves worth protecting. This means that one weakness of the asset replacement approach (that it would be replaced) is avoided. The other weakness, that it represents a lower bound, is potentially an issue where roads are deemed not worthy of protection, which does not, in general, occur.[37]

The value used for roads came from Rawlinsons (2012, p681). The asset register was able to divide the classing of roads into one lane and two or more lanes and so there is a value for both. Rawlinsons report a mid-figure of $275 per meter for an eight meter wide suburban road with in situ concrete curbs built in Perth, this was used for the single lane roads. For the two or more lane roads a mid-figure of $360 per meter was used, describing a two lane country highway with shoulders.

### Railways

Railways are subject to the same considerations as roads, and for this reason we also make use of a replacement cost approach in estimating their value. The value used for railways was $2,325,000 per kilometre. This value was taken from WestNet Rail's Floor and Ceiling Costs Review (ERA, 2007).

### Water, sewerage, electricity, gas

Utilities, including water, sewerage, electricity and gas, were estimated via personal communication with two civil engineering companies and from there an appropriate value for replacement cost was determined:[38]

- for water mains were estimated at $450 per m.
- for sewer mains, pressure pipes were estimated at $200 per m and gravity pipes at $190 per m
- for underground electricity, low voltage lines were estimated at $150 per m and high voltage lines at $300 per m
- for overhead electricity, low voltage lines were estimated at $45 per m and high voltage lines at $55 per m
- for gas mains were estimated at $90 per m.

It must be kept in mind that these values are broad estimates representing the south-west region.

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[37] At the region-wide level. In case studies, a given road connecting only a small settlement or even single house would be treated differently, as the assumption that it would be replaced if the small settlement goes is probably not true. This level of detail is not relevant for the region-wide analysis.

[38] Due to inconsistencies in data, stormwater drainage assets were not included in this study. This is one are of potential future investigation in future work.

### Community infrastructure

Conceptually, commercial infrastructure could be valued by replacement cost methods. However, its broad scope within the dataset obtained from the Department of Planning makes it difficult to establish what the "average" cost of replacement might be. We therefore adopt the assumption that the community infrastructure is on land that might otherwise be used for commercial purposes (which is generally true, as it is largely in urban centres) and thus that the community must value it as least as highly as commercial properties in order to have made the relevant land use switch in each instance.

Community infrastructure covers a broad range of differing assets. For example, hospitals, car parks, schools, churches, service stations, nursing homes, fire stations, drainage, local government, waste disposal, museums, child care and caravan parks. The value of community infrastructure was equated to the value of commercial land, \$1,000 per $m^2$, as it was proposed that these areas can be considered 'public' commercial situations.

### Residential land

Residential land is one type of asset for which market price data are readily available, and we therefore make use of such data. The same is true of commercial, development, rural residential and rural and agricultural land.

The areas of residential land at risk are concentrated in the Cities of Busselton, Mandurah and Rockingham. A visual appraisal of these areas highlighted the suburbs most at risk, including Shoalwater, Safety Bay, Waikiki, Warnbro, San Remo, Silver Sands, Mandurah, Geographe, Busselton, West Busselton, Broadwater, Abbey and Dunsborough. Utilising REIWA data on the median and upper quartile sale prices of houses in these suburbs a regional value of \$480,000 was approximated for residential land (REIWA, 2011). From this a value of \$600 per $m^2$ was obtained, through the assumption of 800 square meter lots (perscomm. Cities of Busselton, Rockingham and Mandurah).

### Commercial land

Most of the commercial land at risk in the region wide case study is in the City of Busselton, and so the value established here is representative of this area. Through communication with the City of Busselton a value of \$1,000 per $m^2$ was placed on commercial land.

### Development land

Land zoned for development purposes has been split into two sub categories for the purpose of valuing. A value for commercial development land and another for residential development land. These are assumed to be the same as for commercial and residential land (\$1,000 and \$600 per $m^2$, respectively) due to the fact that they will one day have commercial or residential property on them, if not already.

### Rural residential land

Rural residential land is all in the City of Busselton. Through communication with the City of Busselton a value of \$24 per $m^2$ was established. This figure represented a fair/ average quality block of rural residential land in Busselton.

### Rural and agricultural land

As noted in Chapter 3, there is a slight difference in nomenclature between the City of Busselton and the remaining shires in terms of what might broadly be called farming land. Rural land (as it is called in the relevant Shires) is mainly located in the Shire of Harvey, and smaller areas in the City of Mandurah and Shire of Capel. An internet search of rural properties in these areas, particularly around Myalup and Binningyup, revealed a market price of approximately \$7,000 per acre, or the equivalent of \$1.70 per $m^2$.

Agricultural land, as it is called in the City of Busselton, is slightly more valuable, due to its location near Busselton; discussions with the City reveals that farmland in this region sells for around \$2 per $m^2$. We have therefore used this figure for this land.

### Parks, recreational and conservation areas

Parks, recreation and conservation areas present a particular challenge for valuation because they are not generally bought and sold in any marketplace and, unlike built infrastructure such as roads, do not generally have a robust replacement cost. Moreover, they not only attract a value in use, but also an intrinsic or existence value and, further are valuable in their ecosystem services to humans or to other creatures. For this reason, the debate still rages about how they ought to be valued (see, for example, Barbier, 2011 and Liu et al 2010 for two recent reviews),[39] and although there appears to be some form of consensus in the literature about the framework within which they ought to be valued (the basic services provided by ecosystems and their linkages for valuation purposes), there is much less progress on how the various elements of the framework ought to be assessed empirically. There is certainly no robust "benchmark" figure which suggests that a square metre of parkland ought to be valued at \$x.

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[39] For a much more comprehensive treatment, see Committee on Assessing and Valuing the Services of Aquatic and Related Terrestrial Ecosystems, National Research Council (2004)

We make use of two approaches to value parks and recreational and conservation areas. Firstly, from the literature, we make use of a study by Lansdell & Gangadharan (2003) of a regional park in Melbourne, Victoria. This was for Maroondah Park, approximately 60 kilometres from Melbourne itself. This park is a part of Maroondah Reservoir, comprising of 40 hectares of area open to the public for recreational purposes. This study placed a value of \$2.5 million on the park for its recreational value. This is equivalent to \$6.25 per $m^2$. We use this figure for parks, nature reserves and recreation areas which, like the Maroondah Reserve, are outside major townsites.

It is worth noting that this figure is three times the market value of surrounding farmland, and that a direct conversion of the annualised values of Costanza et al (1997; perhaps the most widely-cited paper in the field of ecosystem valuation) using a discount rate of three per cent results in \$0.70 per $m^2$ for grasslands, \$1.00 per $m^2$ for forests and \$50 per $m^2$ for wetlands; where these figures are expressed in 1994 US\$. We suspect on the basis of this evidence that \$6.25 is too high,[40] but for the purposes of a decision-relevant analysis, prefer to err on the side of conservatism.

Within each of the townsites, we make use of the Department of Planning's Policy No DC 2.3 (see www.planning.wa.gov.au/publications/804.asp) which governs land to be set aside in new residential developments for parks. The policy has operated for several decades, and might reasonably be considered as representative of the community's value of parkland in residential areas compared to the residential land itself. The policy requires (in most cases) that ten per cent of land in a new development be set aside, free of charge, for parklands and recreational areas. We thus conclude that the community's value of parklands and recreational areas within a residential setting is ten per cent of the value of the surrounding residential land. Since the surrounding residential land is worth \$600 per $m^2$, this equates to \$60 per $m^2$.[41]

Within the land zoned for parks, recreational areas and conservation areas, roughly 336 hectares is outside townsites and 48 hectares is within them. We acknowledge that this approach will not be suitable for all assets within this category. Some specific assets of significant importance to either the local or

[40] For example, if the average value of the land is \$6.25 per square metre in conservation and \$2 in farming, we would expect to see an expansion of reserves and a contraction of farmland until, at the margins, each was equal.

[41] As one of the PNP Senior Officers pointed out in the context of the draft report, residential values are for properties, rather than land per se, and include the value of the house and associated services. Parks, on the other hand, do not commonly include such built infrastructure (though some do include playgrounds and other amenities), and thus it may be more appropriate to use only the en-globo value of residential land, which would reduce the value of parklands and reserves in townsites significantly. Note that doing so would make only small changes to our conclusions.

wider community are likely to be much more valuable.[42] However, as a region-wide average, we consider the values above are likely to be sufficient to provide an overall indication of values at risk suitable to understanding the resource costs of optimal adaptation measures in the region as a whole.

### Beaches

Beaches, like parks, recreational and conservation areas, are not bought and sold, and thus do not have a market value.[43] For this reason, we make use of benefit transfer approaches.

Beaches in the asset register were divided up into urban beaches and natural and remote beaches. Thus, there is a different value for each. The value established for urban beaches was $9 million per km$^2$. This value was taken from a study by Blackwell (2007), who used the work of Carlsen (1997) to derive this value. The value established for natural and remote beaches, $3 million per km$^2$, was taken from the same study by Blackwell but using the work of Pitt (1992) who valued 'non-urban' beaches. For the purposes of our analysis, we have assumed beaches are 40 metres wide (based on an analysis of beaches in the region using Google Earth) in order to turn the lineal figures in Table 14 to Table 16 into areas.

In the case of beaches, there are also good reasons to treat the valuation with caution, particularly since many of the urban beaches in the studies which are used to derive values are in areas of much higher urban density than occurs in the South West; though not necessarily higher surrounding real estate values or personal wealth. Moreover, for non-urban beaches, except where these have specific value to particular groups of users that would be lost (a good surfing break, for example), one could argue whether the beach is indeed being lost by climate change, as opposed to simply being moved "inland" as the shoreline is eroded. For these reasons, there may be a case for considering our estimates of value as being too high.

## 4.2 Calculating the cost of each option

For the region-wide analysis, we considered three different options for each asset; a generic engineering, planning and market response.[44] It is important to specify what each means in more detail; most particularly because planners

[42] An issue we canvassed with the PNP members.

[43] In general; some private property rights in some areas, extend to the waterline.

[44] Originally, we also considered a mandatory insurance option, but removed it after discussions with planning professionals which indicated that these requirements are often difficult to enforce, and do not always remove liability from local government in the even of a flood or erosion event.

typically make use of all three options when undertaking their planning work, and some confusion may arise from our nomenclature.

Engineering options involve physical building. This might be a sea-wall, a raised road or a drainage culvert. For the region-wide analysis, a defensive measure such as a seawall would cost roughly $2,500 per lineal metre on average. The case studies in Chapter 5 use cost figures tailored to the specific characteristics of each local area.

Planning options we (rather narrowly) define as options which involve changes to legislation, regulation or planning schemes. That is, it encompasses all of the things a Local Government (or State Government) might do to compel something through their legislative powers. One example might be the imposition or lifting of zoning controls, another might be the establishment of larger set-backs.

There are two important aspects of planning options as we have defined them. The first is that their direct costs are small relative to their indirect costs. It costs relatively little to alter a regional plan to include greater set-backs, but the indirect costs in terms of foregone land uses during times preceding the actual flooding or inundation might be very large. The second is that planning options as we have defined them are rather limited in their application; as has been known since the time of King Canute, one cannot legislate to hold back the sea, however attractive the fiction might be to legislators.[45]

The final option is market intervention which, in this case, means a Local (or State) Government entering the market and buying up affected properties, and then taking them out of their current economic use in order to remove the risk of climate change influencing the particular plot of land. This also has limited application; government cannot intervene, for example, to buy crown land or a public road, as it owns these assets already. In many cases, infrastructure is owned by corporatised government entities; WaterCorp for many water assets, Western Power for the power assets. For this reason, we assume that market intervention is not an option for these assets.

In many cases, the difference between a planning options (as we have described it above) and a market intervention option will just be who bears the indirect costs; with a planning option, the existing land-holders bear the cost of no longer being able to use the land in the manner in which they have become accustomed, while in the market intervention option, the relevant government authority bears the cost through having to purchase the land. In some instances, however, the two may differ. These distinctions will become more

[45] For a more recent example, see http://news.sciencemag.org/scienceinsider/2012/06/legislating-sea-level-rise.html

important in local areas, where it might be optimal for a Local Government authority to buy up a strategic plot of land and give itself the option of later building a sea wall across that plot of land (say if it contains a valley through which sea-water might otherwise pour during a flood), rather than trying to impose more general planning restrictions over a wider area.

In the context of the region-wide analysis, almost all of the impact at the region-wide level is erosion, we do not calculate the cost of planning or market intervention options, as these are infeasible as ways of dealing with erosion of land. If a Local Government rezones land or puts conditions on its development, it cannot prevent the land from being eroded.[46] Likewise, a Local Government might buy land that is threatened, but this merely moves the costs from the private to the public sector without removing them. We note that the situation is different for flooding risk, which we treat separately in Section 4.3.

One final aspect of the analysis relates to the size and shape of the packages of land being assessed. Our analysis is not spatial for the region-wide assessment and thus we do not identify where the hectares of affected land are.[47] This means that we do not establish what their shape is or how the land slopes and thus, it is difficult to be precise about how long a sea wall might need to be to protect a certain number of hectares of residential land, nor how wide a buffer might need to be to protect a certain number of hectares of agricultural land.

For this reason, we need to make some assumptions. In the case of erosion, the average width of the erosion zone is 200 metres. We therefore assume that every asset considered has an erosion zone that is 200 metres wide. Since we know the overall area of each of these assets that are affected (those which are land use types), then making an assumption about width tells us the length of the seaward-side of each area to be protected, and thus the length of any protection mechanism.[48]

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[46] However, it can prevent developers from changing existing land uses, and then creating fresh value at risk by, say, building a residential sub-division is an erosion-prone are and not protecting it. This is discussed in more detail in Section 2.3. As a related point, a Local Government could require all residents to protect their land from erosion, either individually or collectively, but this would have the same effect, from the perspective of cost, as the engineering option we have outlined above.

[47] Note that this is not true for the case studies, which are explicitly spatial and thus do not suffer from these issues.

[48] Note that this approach implicitly assumes that the assets are all strung along the cost next to each other. This is true in many cases, but not in all; in some cases, one asset is behind another, and could thus be protected by the same sea-wall. For this reason, our assessment of costs, to the extent that it errs, does so on the side of caution.

Box 3 **Planning and market responses to climate change**

The issue of erosion and planning responses throws the issue of planning in response to climate change into sharp relief, and forces questions of where planning intervention can be effectively used. As noted in the main text, it may have limited relevance in the case of erosion, at least in respect of existing assets. However, it is worth asking how planning interacts with an increase in flooding risk as well.

A zoning change on an area where flood risk is likely to increase, or a requirement to undertake measures like increasing floor heights can reduce the consequences of flooding in these areas. However, why is planning needed to make these changes? In a perfectly informed marketplace, a householder (say), receiving the same information available to the planner, provided she has the same risk preference, would either sell her property or take preventative measures, and would arguably not need a planner to tell her to do so.

In principle, there are four reasons why an asset owner or a planner might differ in their responses. Firstly, the planner might have better information, better ability to process information or a different risk preference to the asset owner. Secondly, imperfections in other marketplaces, such as insurance, might mean that the asset owner does not face the full consequences of her actions until a flood hits. Thirdly, imperfections in institutional frameworks might mean the asset owner can sue the local council, even though she was made fully aware of the consequences of not preparing for floods. Finally, externalities may exist which make individual responses inefficient; say a collection of seas-walls rather than a single wall along a section of coast.

The first reason is not a valid reason why a planner's decision should prevail. Although in practice, government planners may devote more effort to informing themselves about climate change and its consequences, "government knows best" is a poor principle upon which to found policy in a democracy. Moreover, if society is more risk loving than planners, then this is a signal that the planners are not reflecting public wishes, not that public wishes are incorrect.

The remaining reasons are valid. If insurance markets, judicial institutions or property rights are imperfect in their treatment of climate change risks, it may be more effective, at least in the short term, to use planning instruments to overcome these shortcomings. However, over the longer term, it is arguably better to understand the root causes of the relevant imperfections and ascertain how they might be addressed. This may result in a reduction in the need to use planning as an instrument to address climate change.

For assets such as roads, railways, water and sewer lines and energy and telecommunications infrastructure, their width is not a pressing issue, and we just examine the cost per unit length of protecting these assets. However, since these assets largely exist in order to serve other land uses, we take the sum of the infrastructure assets in each time period, and apportion it across the community infrastructure, residential land, commercial land, development land and rural residential land on a hectare basis, rather than considering these infrastructure assets in isolation.

## 4.3 Results of analysis

We now turn to the results of our analysis. On the basis of the information provided by the Phase One report (and subject to its caveats about that information) the conclusions are relatively clear; rural, agricultural, conservation and park land ought not be protected from erosion via a seawall, but every other type of land ought to be protected. Moreover, even though climate change impacts are unlikely to become pressing for 20 years, the benefit cost ratio of protecting land by building defences now would be roughly ten to one. This, moreover, is likely to be an understatement, as the lack of a spatial component to the analysis means we consider each asset type individually, rather than incorporating cases where, say, a seawall that protects a residential area from erosion would also protect the farmland behind it.

A related issue is that the analysis does not consider the consequences of a decision to protect a certain piece of land on surrounding land, where these consequences are negative. For example, a seawall along a stretch of coast would likely result in greater erosion in the unprotected areas either side of the seawall. A region-wide plan for addressing climate change impacts would need to take this into account in a way which is not possible as part of this single, first-step study. We discuss a way forward in this respect in Section 5.6.

The conclusions for agricultural and rural land are likely to be troubling for many stakeholders, although, as noted above, protecting residential areas will mean protecting the agricultural land inland from these areas in some cases. We emphasise that our findings are based on our economic analysis alone, and as we suggest at the outset of this report, economic analysis should only form one input into making decisions about land in a community. In making such decisions, what is key is understanding the resource costs of a particular decision. In the case of agricultural and rural land, the erosion zone is around 200 metres wide along most of the coastline. This means a hectare of land has a sea-frontage of roughly 50 metres, and at $2,500 per lineal metre, means that protecting a hectare of this land would cost roughly $125,000. A community wishing to protect this land from erosion would need to consider these costs when weighing up any non-economic benefits (not captured in our model) from doing so. In the event that a local community decides it wishes to spend $125,000 per hectare to prevent some agricultural land from being lost, it ought to do so.

Table 19 **Value at risk**

| | 2030 | | 2040 | | 2050 | | 2070 | | 2100 | | Total | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Area (ha) | VAR ($'000) | Area (ha) | VAR ($'000) | Area (ha) | VAR ($'000) | Area (ha) | VAR ($'000) | Area (ha) | VAR ($'000) | Area (ha) | VAR ($'000) |
| Community infrastructure | 21.8 | $117,924 | 5.9 | $23,876 | 10.0 | $29,823 | 27.7 | $45,435 | 28.1 | $18,517 | 93.5 | $235,575 |
| Residential land | 37.4 | $122,830 | 29.6 | $72,056 | 64.0 | $115,505 | 165.7 | $164,274 | 278.2 | $110,682 | 575.0 | $585,347 |
| Commercial land | 7.0 | $37,984 | 4.9 | $19,620 | 8.9 | $26,676 | 22.0 | $36,143 | 28.6 | $18,835 | 71.5 | $139,258 |
| Development land | 13.4 | $66,697 | 1.8 | $6,129 | 3.9 | $9,117 | 13.3 | $16,026 | 48.2 | $21,535 | 80.6 | $119,504 |
| Rural residential land | 0.1 | $18 | 0.0 | $6 | 0.2 | $16 | 3.4 | $193 | 13.2 | $289 | 16.9 | $523 |
| Rural and agricultural land | 89.6 | $7,301 | 31.3 | $1,702 | 74.9 | $2,914 | 275.8 | $5,844 | 486.4 | $3,595 | 958.0 | $21,356 |
| Parks, recreational & conservation areas and beaches | 1,901.5 | $62,615 | 193.3 | $4,712 | 264.1 | $5,150 | 467.9 | $6,226 | 583.1 | $2,820 | 3,409.8 | $81,523 |

Table 20 **Costs and protection decisions**

| | 2030 VAR ($'000) | Save? | 2040 VAR ($'000) | Save? | 2050 VAR ($'000) | Save? | 2070 VAR ($'000) | Save? | 2100 VAR ($'000) | Save? |
|---|---|---|---|---|---|---|---|---|---|---|
| Community infrastructure | $2,719 | Yes | $742 | Yes | $1,249 | Yes | $3,463 | Yes | $3,513 | Yes |
| Residential land | $4,678 | Yes | $3,704 | Yes | $8,004 | Yes | $20,714 | Yes | $34,778 | Yes |
| Commercial land | $876 | Yes | $610 | Yes | $1,118 | Yes | $2,755 | Yes | $3,573 | Yes |
| Development land | $1,671 | Yes | $231 | Yes | $490 | Yes | $1,666 | Yes | $6,020 | Yes |
| Rural residential land | $11 | Yes | $6 | No | $19 | No | $422 | No | $1,649 | No |
| Rural and agricultural land | $11,195 | No | $3,915 | No | $9,364 | No | $34,475 | No | $60,801 | No |
| Parks, recreational and conservation areas | $237,683 | No | $24,158 | No | $33,019 | No | $58,484 | No | $72,887 | No |

### Residential land at risk of flooding

As noted previously, there are roughly 800 hectares of residential land which will experience an increase in flooding risk from one in 500 to one in 100 in 2070, and we address responses to this increase in flood risk in this section. Conceptually, there are three things that government could do in relation to this land:

- It could protect it via a flood protection wall; an engineering solution.
- It could purchase the land, or re-zone it, which would have the same effect except for who bears the costs.
- It could require all new homes to be raised on a higher pad to avoid flooding risk.

In terms of the engineering solution, the series of walls needed to protect the areas subject to an increased flooding risk (in Mandurah, Eaton-Australian, Busselton and Bunbury) would need to be roughly 100km long in total. At $2,500 per lineal metre, this implies a total cost of approximately $250 million.[49]

In the case of a zoning change or a market purchase, the relevant cost would be the difference between the value at risk and the difference between the land in its current use and in its next best use, which we assume to be agriculture. The reason for this is simple. If nothing is done, the people living in the area suffer a loss of amenity through higher insurance premia. If the land is rezoned, or bought and re-sold to a more suitable use, then the value from the land is reduced once it is re-zoned.

The value at risk is slightly less than $25 million in present value terms (because it occurs so far into the future). By contrast, converting the land to agricultural land (in 2070) would result in a reduction in the lifetime value of the land of $827 million in present value terms. Thus, the net cost to society of the re-zoning would be in the order of $800 million in current dollars.

The final solution is to make a requirement that each new house is built on a higher pad. The required height to avoid flooding is 450mm, which engineering advice from Damara suggests would add roughly $12,000 to the cost of each new house built. AECOM (2010) suggests an approach of assuming that houses are raised as they are renewed, and that houses last an

[49] Another way of developing the wall could be to incorporate it into road structures (depending upon road positioning), which would also mean transport links would not be severed in the event of a flood.

average of 40 years, meaning 2.5 per cent of houses are renewed each year.[50] In order to ensure that all of the houses are raised by 2070, this would necessitate commencing in 2030, and if each residential lot is 800 square metres, this means there are slightly more than 10,000 houses overall, resulting in an annual cost of just over a million dollars. If this cost begins to be incurred in 2030, and is incurred every year until 2070, then the total cost in present value terms is $39 million.

By this measure, a planning response requiring a raise in the pad upon which new houses are built is clearly the most appropriate response in terms of flooding risk. Additionally, the $39 million cost would need to be paid by householders directly as they construct their new homes, while there may be demands from the (affected) community for government to pay for floodwalls. Although it is still society that pays, tying payments directly to the affected homes means that homeowners in flood-affected areas pay the full costs of their decision to live in these areas, which promotes efficient allocation of land resources.

As a final point, it is worth noting that a protective wall offers different protection than raising pads. Raising pads provide "islands" of safety within a subdivision or suburb, but mean that all of the infrastructure in and out of the suburb becomes submerged in the case of a flood. Thus, if an "island" becomes untenable and can no longer save the residents, it may be difficult for them to be evacuated, depending upon the type of flood. Furthermore, it means that roads and other infrastructure may need to be replaced after floods if protection occurs at the house level. By contrast, a protective wall suffers none of these "island" problems, but it does face the possibility of much more widespread damage if a particular flood does breach the wall and the water cannot easily escape from behind the wall, which acts as a dam. Therefore, the balance of risks are different, and more information than just the comparison between costs and benefits may be needed to make assessments on a case-by-case basis.

### Sensitivity analysis

Our analysis above is based upon some simplifying assumptions in regards to the shapes of the areas being protected. Therefore, our first sensitivity analysis considers the implications of different shapes; more specifically, an assumption that the erosion areas are thinner (while keeping the overall area affected constant), and therefore the walls longer. This can also be used as a proxy for the walls being more expensive to build. The effect of increasing the length of

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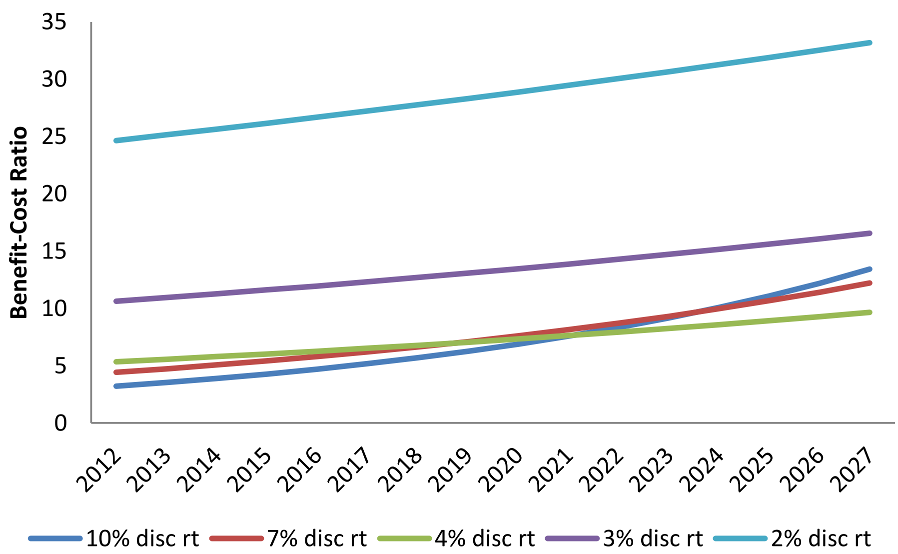
[50] Providing flood resilience for existing houses would incur a roughly comparable cost.

the wall is a direct linear effect on cost; doubling the length of the walls doubles the cost, and roughly halves the benefit cost ratio.

The second sensitivity analysis examines the consequences of delaying the construction of defences until erosion pressures begin to become pressing; around 2030. Since costs are discounted as well as benefits, this has the effect of increasing the benefit cost ratio from around ten to around 16 if construction starts in 2027 (roughly three years before erosion begins to become a significant issue).[51] Again, the impacts are approximately linear.

A final sensitivity analysis involves different discount rates. We consider rates of two per cent, and the "standard" figures of four, seven and ten per cent used by Infrastructure Australia (with the caveat from Section 2.3 that "standard" does not mean "robust"). In this instance, the changes are not linear, as shown in Figure 3.

Figure 3 **Different discount rates sensitivity analysis**




The reason why some of the benefit cost curves now cross is that, at higher discount rates, fewer assets are worth preserving today. This is especially the case for assets that are not affected until the end of the period; unsurprisingly, it becomes less and less worthwhile to take action now to protect assets that will not be affected for 70 years if the value of the benefits of protection falls due to higher discount rates.

[51] We do not include a reduction in maintenance costs associated with delaying construction, which would increase the benefit cost ratio still further, most particularly because maintenance expenditure begins immediately.

By the time discount rates are ten per cent, the cost of protection has reduced by 90 per cent because it is only worthwhile undertaking protection measures today for assets affected in 2030 and 2040, not those in 2050, 2070 or 2100. It is worth noting that, even with a discount rate of ten per cent, it is still worth protecting residential land, commercial land, development land and community infrastructure in 2030 (each is only line-ball by 2040), and that putting in place such protection yields a benefit cost ratio in excess of three. Put another way, with a rolling 20-year time horizon in planning, even if the discount rate was ten per cent, the decision would still be to protect the same types of assets as in Table 19 and Table 20, except that there would be no reason to do so more than 20 years before the erosion event occurs.

Benefit cost ratios could be increased still further by considering the nature, rather than just the timing, of the planning process. For example, a one-hundred year time horizon could be used for considering future land uses and a need to reserve particular strategic land that is currently unused. The same time horizon could be used for considering more detailed data collection to support future decision. That is, Phase One of the project could be run periodically, based on updated data, with the same 100-year time horizon, to highlight needs for more information in future as well as keeping track of predictions and their accuracy. A 20-year time horizon could be used to begin more detailed thinking about what kinds of measures to adopt (essentially repeating the work in this report in a more systematic manner) and to begin the process of examining environmental, heritage and other issues associated with protection that can be time consuming, but not overly costly. A ten-year time horizon could be used for work with the community on what ought to be done and how the community will fund and govern the process. A five year time horizon could be used to plan for and commit funds, and then the actual application of those funds would be based on the construction schedule of the relevant protection mechanism (if the protection mechanism was indeed physical). Staging the thinking process about climate change adaptation in a manner such as this is likely to reduce the overall costs relative to benefits substantially, as well as leading to much better decisions than are likely to occur from a knee-jerk reaction to a perceived crisis made in an environment of limited information about the extent of that crisis. The next stage of the process of climate change strategy formulation within the PNP community that begins once this report is complete and has been endorsed by the PNP partners can begin the process of thinking about different time horizons and ongoing processes, such as those outlined above.

# 5 Case Study Analysis

In this chapter, we provide an overview of the four case studies which comprise our analysis. These are:

- Mandurah (at the estuary mouth).
- Busselton-Marybrook.
- Peppermint Grove Beach.
- Eaton/Collie River.

The case studies were chosen by the PNP members, and we are grateful to them for their assistance. The process followed was dictated by the fact that Phase One of the overall project was not available at the commencement of our project, and indeed only became available after we had done much of our initial work. The case studies were chosen as the project progressed, rather than at its outset.

At the first workshop with PNP members, on March 2nd at the City of Rockingham, a set of eight potential case studies were chosen by ourselves and the PNP members present. The basis of choosing each was to provide a range of environments to subject to the detailed case-study analysis. At that stage, it was unclear precisely where the hazard lines, which determine flooding and inundation risk, would run. For this reason, it was unclear whether there would be a suitable number of each of the assets in each of the case study areas, and hence there was another round of consideration.

The hazard lines which were to have been the key output from Phase One of the study were made available mid-April.[52] We thus sent a letter out to all of the PNP members on April 19th with maps attached showing the eight case studies and the hazard lines superimposed. PNP members were given two weeks to choose their preferred options. They then met, and chose the four case studies, refining their choices through subsequent communication.

The result of this process is the four case studies listed above, which are subject to more detailed analysis in this chapter.

It is important to note that our purpose in this chapter is subtly different from the preceding chapter. Rather than endeavouring to ascertain a broad overview of the likely resource costs throughout the region to allow for suitable adaptation to climate change events, our focus is strategic; what strategies ought to be employed as a micro level to adapt to climate change by individual local governments. This results in a number of key differences from

[52] The final Phase One report, which underpins all of our work, was delivered in August.

Chapter 4, which we summarise before coming to the main body of this chapter which assesses each of the case studies in turn.

## 5.1 Differences from Chapter Four

In this section, we provide an overview of the differences in the analysis between this chapter and the preceding one. Many of the elements are the same; we still make use of the decision-relevant analytical framework, we still make use of the same value framework as shown in Table 18 (albeit with market values and some non-market values tailored to local circumstances), we still make use of Equation 3 as the basic tool of analysis and we still follow the approach of developing an understanding of the value at risk and how this changes with different options. Given our focus, however, we make a number of departures from the previous chapter, which are summarised below.

### Introduction of specificity for assets

Each of the case studies has a small geographic area providing a much more micro-focus for our analysis in this chapter. A corollary of the micro focus is that we are now specific about assets; we identify streets and properties, as well as individual beaches and other non-market assets. We then aggregate upwards to include all of the assets that face the same risks of erosion and flooding at the same time. There are two reasons for doing this. Firstly, it saves time in modelling to treat similarly affected assets together.

Secondly, and more importantly, treating each house (say) individually causes a number of problems. Consider Figure 4 below.

Figure 4 **Illustration of the house-by-house problem**


*Source:* Google Earth

If the analysis is done on a house-by-house basis (which is possible within the mathematical context of the model) and the model suggest that the house with the light-brown roof (nearest the beach) is worth protecting with a sea-wall but the house with the light-blue roof (next to it) is not, what is the appropriate policy option to implement? The problem is worse with the second row of houses. If the first row is protected, then this automatically protects the second row and hence the decision about the second row is not independent of the first; this means they would need to be considered together, meaning at least that one would need to consider rows of houses perpendicular to the coast.

For this reason, we aggregate to the point where a single adaptation option can protect all of the relevant assets. Thus, for example, where a collection of houses are all influenced by the same level of erosion risk and would all be optimally protected by a single coastal structure, we treat them as one composite asset. This means that our assets are actually collections, and may include some residential, some commercial and some parkland.

The aggregation process raises an issue because erosion generally happens from the current shoreline backwards, which means that the amount of our composite asset which is at risk increases over time. However, the values of the property, particularly residential property, are not uniform, but generally increase the closer one is to the beach. This means that the rate of value erosion is not the same as the rate of physical erosion.

We address this issue by multiplying the physical erosion series by a multiplier (essentially one for every per cent, or fraction of a per cent, of physical erosion) to "front-load" the value erosion and take account of the fact that land nearer the ocean is more valuable. There is a foreshore park of roughly 50 metres width along most of the case study shorelines before one comes to the first row of houses, and a survey of real estate agents in each of the study areas indicates that the first row of houses attracts a premium of roughly 25 per cent above the houses further back.[53] By setting the value of the first metre at the value of parks (ten per cent of the value of residential) and then increasing the multiplier to reach 125 per cent of the average value 50 metres back, before decreasing such that the value erosion of the last metre equals the physical erosion of the last metre, we front load value such that the first ten per cent of physical erosion accounts for ten per cent of the value eroded, whereas the first 25 per cent of physical erosion accounts for 37 per cent of value erosion, after which point in time the two series slowly converge again. This effectively captures the higher value of the first few rows of houses.

[53] A more detailed hedonic pricing examination of the premium associated with beachside location would have been preferable, but we were limited by constraints of time.

### Introduction of time

Another key difference between the analysis in this chapter and the previous chapter is a much more nuanced treatment of time, and of the sequence of events. In the previous chapter, we used a number of different timeframes to consider where hazard lines would be in different years, and thus to establish from when, in general terms, value would actually be put at risk.

In this chapter, we are much more detailed; mapping out a detailed timeframe of events for each asset considered. This includes both the impacts and the adaptation measures. In terms of impacts, we map out when particular levels of risk will be reached for each asset (in the event of nothing being done to adapt to risk) and what the probable events might be in each year under this "do nothing" scenario. This allows us to track, for example, how a flooding risk increases gradually year-on-year until the relevant asset becomes economically unusable.

For adaptation measures, the introduction of time means we can optimise the timing of the intervention, based upon when it will deliver the maximum benefits. This avoids building protection too early or too late. Since our assessment of optimality also incorporates the uncertainty in the climate modelling, we make use of a real options framework as our assessment tool (see below).

### Introduction of more detailed options

In the previous chapter, we used generic options that made no allowances for specific local conditions. In this chapter, our adaptation options are tailored to each of the case study areas and each of the assets within them. The options were developed with the PNP Partners through a process of "brain-storming" with representatives from the local governments concerned. This had two stages. In the first stage, we contacted representatives individually, to ask for their ideas as to interventions. Each of these people we contacted had the Google-Earth image for the case study area in their jurisdiction, and were thus able to identify exactly where we were referring to.

We collected together these individual responses, and met as a group with the PNP Partners. At this meeting, all of the interested parties were able to examine options feasible elsewhere, and to then re-think what might be possible in their jurisdictions.[54] We then gathered together the options generated at that meeting, combined them with information on the aggregated assets for each case study are and produced a set of feasible options for each of

[54] We would again like to thank the members of the PNP Partnership for being generous with both their ideas and time in developing these options with their local knowledge.

the case study areas that was then circulated among the PNP Partners for final consideration, before being used in the analysis. The final feasible set for each case study area is presented in each of the case study summaries below. Note that each of the options has a capital and an operating cost explicitly identified.

The assessment approach first looks at each feasible option to ascertain when (and if) it is likely to be optimal to apply it given the context of climate change in the relevant area. We then join feasible options together into pathways (including consideration of the "third row of houses" effect alluded to above) such that protection is assured throughout the 100 year period. Finally, we compare the values of these pathways, to ascertain which is best in the context of each sub-area under analysis.

### Use of a real options framework

One way in which to assess the net benefits of different proposals for options and pathways, is to establish the net present value of the stream of net benefits, incorporating investment at some point in time (usually the immediate future). However, this approach has two main problems:

- Unless the timing of the investment is optimised outside of the valuation framework (say, for example, with reference to a climate model that shows when land will be inundated) then the question being asked is "should we build the relevant infrastructure at time x?", when in fact the more relevant question to ask is "when, if ever, should we build infrastructure x?". The basic issue is that the NPV approach only provides limited information in terms of understanding whether an investment is a good idea.
- In most cases, the future is not deterministic, but is rather clouded with uncertainty, and an NPV result only provides an indication of the net benefits of a single future outcome, with no indication of how likely that outcome is.

Both of these issues make a standard NPV approach very poor for developing strategies for climate change adaptation. However, it is still widely used, and in many cases, more effort is expended on the second order issue of how to value assets than the more fundamental issue of how to use that information to sensibly inform strategy.

We have not done so here, and indeed, our assessments of what the values ought to be have only formed a relatively small part of our considerations, resulting in values which we would agree, in many cases, are imperfect. Instead, we have focussed much more on the issue of how to move away from a simplistic NPV framework, and use the information about value (more specifically, about value at risk) in a suitable fashion for the formulation of strategy. This has lead us to the use of real options in our assessments of optimal strategies for each of the case studies.

Real options were developed out of the literature on financial options. Financial options are contracts which give the holder the right, but not the obligation, to buy or sell a stock at a particular time for a particular price (the strike price). Whilst options have existed for a long time, at least since Ancient Greece, an appropriate means of valuing them was only developed in 1973, in pioneering work by Black & Scholes (1973) and Merton (1973). The Black-Scholes Model is now a mainstay of financial markets.

A financial option is a special case of contingent claims analysis, and thus the approach developed by Merton Black and Scholes has wide application in any endeavour involving uncertain futures (see Dixit & Pindyck, 1994, for an expansion on this notion). Of particular interest is its use in valuing investment prospects. Meyers (1977) realised that an allegory to financial market options existed in the investment planning undertaken by firms or government. In assessing its future growth, a firm need not invest at a certain time, but can choose the optimal time to invest. A government seeking to invest to address a particular issue, be it climate change or traffic congestion, can often do the same, tailoring the investment timeframe to maximise the beneficial impacts of investment. Just as a financial (call) option is the right but not the obligation to buy a stock, firms or governments making investment decisions have the right, but not the obligation to make the relevant investments. This right has a value. Lander and Pinches (1998) summarise approaches undertaken in almost 200 papers written in the two decades between Meyers' original work and their own review, and Merton (2001) explores the breadth of applications of real options valuation (ROV) since his own seminal contribution.

Real options has two key advantages over NPV analysis in the context of our study. Firstly, it does not posit specific investment times, but rather seeks the optimal time to invest in a way that maximises societal value. Secondly, it incorporates uncertainty, making it the foundation of the strategic decision, rather than ignoring it, or relegating it to sensitivity analysis.

A key difficulty in undertaking real options analysis is that the "standard" solution approaches involving continuous time (see Black-Scholes, 1973) or its discrete-time equivalents (see, for example, Cox, Ross & Rubenstein, 1979) is that only one or two sources of uncertainty can be incorporated before the solution becomes intractable. This is not necessarily an issue in valuing financial options, where uncertainty can often be modelled as a single random walk, but it is often an issue in valuing real options, where uncertainty can come from many sources.

However, a paper by Longstaff & Schwarz (2001) presents a way around this issue, by adroitly separating the sources of uncertainty and the decision-making of the option-owner. This allows for multiple sources of uncertainty to be incorporated, meaning that the technique has been widely used in infrastructure assessments.[55] It does so by firstly using the sources of uncertainty to generate a wide range of "pathways" that map out potential ways in which the variable of interest could evolve over time. It then back-solves from the last period to the first to establish in each period whether, along that pathway, the relevant holder of the real option would choose to invest (and thus realise the net present value of the stream of future net benefits) or wait until the next period. Crucially, at each stage in the back-solving process, the decision-maker does not compare the actual future returns predicted by that pathway, but an expectation of future benefits generated by a cross-sectional regression that takes into consideration information from all pathways. For this reason, the approach is often called "Monte Carlo Least Squares". In this manner, the approach makes use of the fact that a regression will "span" the "space" of interest (here the space of possible decisions which can be made). The comparison of current (ie – in the relevant period of the back-solving process) and *expected* future returns generates an optimal "stopping point" along each pathway, and the relevant value of that each pathway is turned into a present value and the average across pathways taken to obtain the option value. The pattern of stopping points provides information about when the option to invest ought to be exercised.

Although real options is now widely used in the private sector for valuing assets such as mining leases, and it is beginning to be used overseas for assessments of infrastructure, it has yet to be widely used in assessment of climate change adaptation strategies (see Dobes, 2008), particularly in Australia. In fact, we have come across only a single study which uses a real options approach to examine optimal responses to increased flooding risk at the Narrabeen Lagoon in NSW, prepared by AECOM for the Department of Climate Change (AECOM, 2010).

In this report, AECOM make use of 11 different climate change models to generate the required uncertainty to support a real options analysis. They then used a Monte-Carlo approach to examine the distribution of net present values of different responses to the flooding risk, for the predicted flood levels from each of the different models, where the intervention was undertaken at different points in time. The resulting analysis was then compared against a benchmark of no adaptation, and provided both an optimal timing for

[55] The *Journal of Infrastructure Systems* has published a number of case studies where the approach has been used. Most relate to road projects, where the source of uncertainty is traffic demand. To the best of our knowledge, this study represents the first use of the technique in the context of climate change adaptation

intervention and a value of that optimally-timed intervention.[56] The shape of the distributions also provide an indication of the "confidence", in a statistical sense, that can be attached to each of the results.

The resulting analysis is much more robust than a standard NPV approach, and provides a rich set of information with which to guide strategy. However, we believe it can be improved upon by making use of Longstaff & Schwarz's (2001) framework which not only allows more uncertainty to be brought into the model but also more correctly represents the actual decision-making process. The process followed by AECOM (2010) with its Monte-Carlo sampling implies that the decision-maker has no idea which pathway the future will travel down right now (which is correct) but that, once a particular pathway is chosen, will know exactly how that pathway will evolve. We would argue that the latter part does not reflect reality; in reality, there is uncertainty now, and in the future, when the decision-maker does not know with certainty which pathway she is on. The approach of Longstaff & Schwarz (2001) handles this rather neatly by making use of regression analysis to develop expectations, which implies that the person, at each point in time in the future, can observe what has happened to that point and, by understanding the range of future possibilities (the "shape" of the "decision space"; as opposed to specific points within it), make an educated guess as to where things will be next period but will not be certain.

For these reasons, we follow Longstaff & Schwarz (2001), which differs from AECOM's approach somewhat in aspects of the technical approach to developing the option value and optimal investment timeframe. However, we note that there are many similarities, in broader terms, between our two approaches.

### Our real options approach

With the discussion above in mind, we now turn to a more detailed explanation of how we actually undertake the relevant calculations which ascertain the real options valuations, and optimal timing.

The first step in the process is to divide the case study areas into assets (aggregated as appropriate; see discussion above) and derive an annualised value for these assets using the VAR approach (see Equation 3) which incorporates the effect on the value of an asset from being subject to erosion and flood risk. In this instance, because of the way we have constructed our

56 AECOM then used a further Monte-Carlo process to combine the different options at different points in time to develop optimal options pathways. We discuss this further below, as we take a different approach.

composite asset, rather than erosion being a "yes/no" issue, we allow for a percentage of erosion each year.

The second step is to generate the "pathways" for each of the sets of assets in terms of how their value at risk might evolve from different climate change impacts. This means bringing the uncertainty associated with the climate modelling into the forefront of the economic modelling and, for each asset, under each pathway, re-establishing the value at risk for that asset as different flooding and erosion effects occur. The basic form of the "pathway generation model comes from the work undertaken by Damara in Phase One of the project, and it consists of a model that predicts sea-level, storm surges erosion effects and flood risks from the same base components as used in Phase One, and converts the results into a percentage of land eroded each year and a different flood risk. Variation in the base variables that drive the model in Phase One provides the different pathways.

Down each pathway, at each point in time, we compare a protected with an unprotected scenario. That is, in 2050, say, if the relevant protection measure is put in place, flood risk and erosion remain constant (during the design life of the protective structure) thereafter, but if they do not, they increase in each subsequent year. We take the NPV of the protected and the unprotected case, to provide us with an NPV difference. These NPV differences then form the basic inputs into the real options model. We do this a thousand times, generating a hundred thousand different observations for NPV difference.

The real options model examines a known quantity in each year, along each pathway with an expectation of the relevant value in the following year. Here the relevant value is the NPV difference; if the NPV difference in a given year is greater than its expectation in the following year, then this is the trigger for investment. The expectation is formed by regressing the NPV difference in a given year down a given pathway against the next-period NPV difference minus the cost of each option.[57] That is, the decision-maker bases her expectation on all of the possible next-period values of the decision variable, rather than treating it as deterministic down a pathway. The model back-solves and returns the earliest point at which the current NPV difference minus the cost of the relevant option is greater than the expected next period NPV difference minus the cost of the given option. It does this for each pathway (of 1000) and the resulting distribution provides an indication of the optimal result and the certainty around this result. Note that the model shows both the value of the option (the NPV difference minus the cost of the option) and the optimal timing of the option.

[57] "Profit" next period is a function of "revenue" this period, in an investment sense.

Box 4 **Model simplifications**

The approach described above is not our ideal form of the model. Instead, a number of simplifications have been made to accommodate the tight timeframe for developing this component of the project; eight weeks were originally planned for this part of the work, and this was compressed into two weeks. These simplifications are as follows:

- For each protection scenario, we have only one unprotected scenario. Originally, the model paired 50 different unprotect scenarios with every protect scenarios, and we thus had, for each pathway, 100 protect scenarios and 5000 unprotect scenarios. This allowed us to capture much more forward-looking variation at each point in time. However, running the model down one pathway was taking more than an hour, despite all attempts at speeding the model runs, and it was infeasible to use this form of the model. Instead, we substitute variation in the pathways in total for variation after each point in time down each pathway.
- Random flooding risk was monotonic in the original model, but this proved very time consuming in model runs, and thus the random element was made truly random, rather than monotonic to speed the model. Note that the trend is still monotonic, so the effect of this change is small.
- When forming expectations, the model uses all of the pathways in a given year. This means that, if erosion in a given year down a given pathway is at 20 per cent, we may be using pathways in the expectation formation where it is 80 per cent in the same year as part of the expectation formulation. If the erosion pathway is not linear (that is, if the proportional movement from 80 per cent is different from the proportional movement from 20 per cent) this could cause problems. However, in most cases, the pathways are reasonably close in terms of erosion in each year (no differences as dramatic as 80 per cent and 20 per cent) and the deviations from linearity are not too great.

We do not consider that the simplifications above would have made major differences to the decisions which the model derives, though they may change the values of the optimal choices. From the perspective of showing how the model works, and can assist in making decisions, the simplifications are not material. However, we would suggest that it would be wise to devote some time to refining the model (time which could not be included in the current project because of the contraction from eight to two weeks for this stage) and re-running it before making any final decisions about investment. We note, however, that there is a need to re-run the model in any case, to consider effects outside the case study areas, as discussed in Section 5.6.

Note that we assess each option individually, rather than in concert at this stage. Note also that the technical term for what we are doing here is an "American Option" which in the world of finances is a right but not an obligation to buy or sell a stock at any point in time up to a given point. This is distinct to a European Option, which is the right to buy or sell an asset at a particular point in time. Our model operates in both "modes"; an American option mode is used to choose the optimal timing of each option on an individual basis and a European option mode is used to assess collections of options in "pathways" which provide cohesive coverage.

To form the pathways, one can follow a model-based combinatorial approach or a more manual approach. AECOM (2010) does the former, choosing combinations of options (each exercised at different times) via a Monte Carlo process which allows them to include large numbers of combinations to compare outcomes. We opt for a simpler approach, for two reasons. The first is that it is not clear to us whether the additional complexity of another Monte Carlo process is necessary given the results from individual optimisation. The second is that it is not clear how AECOM (2010) have accounted for the fact that taking one option first can change the benefit stream associated with taking the second option later. For example, if the individual optimisation results suggest a planning solution in year 10 and an engineering solution in year 25, but implementing the planning solution in year 10 meant that the engineering solution didn't need to be implemented (or was not optimal) until year 30, it is not clear (to us at least) how the AECOM (2010) approach is picking this up. It should be noted, however, that there is nothing preventing future analysts from grafting our approach up to the point of choosing optimal timing of individual options onto the AECOM (2010) approach of combining groups of options if this was desired.

Instead of a model-based combinatorial approach, we collect options together manually, on the basis of what can be feasibly grouped with what (that is, options that are complementary to each other through time, rather than being substitutes that provide the same services at the same times), considering their individually optimal timeframes and how they would influence future flows of benefits in the manner suggested above for the planning option at year 10. This is a manual process, which we repeat for the different groupings of assets in the different case studies to create a series of options pathways. Each pathway may have different options within it, or different timing for the same options. Each will, however, be "logical" in the sense that we would not advocate a pathway where a very expensive option with a long lifespan, such as a seawall, was undertaken before a much less expensive option such as establishing a zoning restriction or set-back.[58]

Having collected options together into pathways, we run the model in "European Option Mode". That is, over the same set of pathways as were used to develop the optimal timing of the individual options, we examine the sets of options in each option pathway. The difference in this case is that there is no need for a backward-solving algorithm, because the decision-maker is not making a decision about when to exercise an option; this has been defined in the manual process described in the previous paragraph. Instead, the model provides an optimal timing (as part of a distribution across pathways) and a

[58] It is worth noting that, in practice, very few pathways were formed as part of this project. For most assets in most case studies, there was only one viable option or, where there were two, they were substitutes rather than being complementary. This may not always be the case in future applications of the model, however, and the discussion above is intended to support future applications of the model.

value for each pathway, and these values (and their distributions, which indicate levels of confidence) can be compared with each other to ascertain which of the pathways is best suited to the asset in question.

## 5.2 Case Study One: Mandurah Estuary Mouth

This case study area runs from Madora Bay in the north, along the coast and across the estuary mouth to Halls Head, and down the entrance of the estuary to Erskine on the west side of the entrance and Coodanup Reserve on the east side. It takes in beachside properties along the coast, the Mandurah Ocean Marina, part of the CBD and city foreshore, canal estates at Halls Head and Dudley Park as well as residential, parkland and commercial areas.

The case study area has been divided into 12 sub-areas for the purposes of analysis. The division has been made in such a fashion that all of the properties within a given sub-area is affected in the same way by climate change events, and thus requires the same adaptation strategy. The sub-areas are summarised in Table 21.

# Table 21 Summary of asset values in Mandurah

| Asset classing | | 1 Northern beaches | | | 2 Seashells | | | 3 CBD | | | 4 Mandurah Ocean Marina | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | area (m2) | unit value of asset | value of sub-area | area (m2) | unit value of asset | value of sub-area | area (m2) | unit value of asset | value of sub-area | area (m2) | unit value of asset | value of sub-area |
| Roads (m) | one lane | 973.8 | $ 275 | $ 267,797 | 838.0 | $ 275 | $ 230,452 | 171.7 | $ 275 | $ 47,214 | 228.2 | $ 275 | $ 62,748 |
| | two or more lanes | 19715.2 | $ 360 | $ 7,097,477 | 2264.4 | $ 360 | $ 815,196 | 3431.7 | $ 360 | $ 1,235,398 | 1344.8 | $ 360 | $ 484,134 |
| Water (m) | retic | 22436.3 | $ 428 | $ 9,591,521 | 2655.2 | $ 428 | $ 1,135,089 | 3607.6 | $ 428 | $ 1,542,255 | 1127.0 | $ 428 | $ 481,776 |
| Sewerage | pressure main | 3647.5 | $ 200 | $ 729,505 | 610.6 | $ 200 | $ 122,130 | 622.3 | $ 200 | $ 124,470 | 17.2 | $ 200 | $ 3,446 |
| | gravity pipes | 10485.0 | $ 190 | $ 1,992,143 | 1886.4 | $ 190 | $ 358,415 | 4656.9 | $ 190 | $ 884,812 | 1095.6 | $ 190 | $ 208,156 |
| Electricity low voltage (m) | underground | 17068.2 | $ 150 | $ 2,560,224 | 1653.4 | $ 150 | $ 248,013 | 1723.3 | $ 150 | $ 258,489 | 2374.1 | $ 150 | $ 356,108 |
| | overhead | 10447.3 | $ 45 | $ 470,131 | 966.3 | $ 45 | $ 43,482 | 2267.6 | $ 45 | $ 102,042 | 0.0 | $ 45 | $ - |
| Electricity high voltage (m) | underground | 2232.7 | $ 300 | $ 669,824 | 2239.0 | $ 300 | $ 671,694 | 1450.4 | $ 300 | $ 435,130 | 968.8 | $ 300 | $ 290,633 |
| | overhead | 2337.4 | $ 55 | $ 128,559 | 671.8 | $ 55 | $ 36,947 | 873.5 | $ 55 | $ 48,044 | 0.0 | $ 55 | $ - |
| Gas pipelines (m) | | 42072.6 | $ 90 | $ 3,786,531 | 5335.6 | $ 90 | $ 480,200 | 7244.0 | $ 90 | $ 651,957 | 1872.1 | $ 90 | $ 168,487 |
| Commercial land (ha) | | 0.3 | $ 22,045,900 | $ 7,255,387 | 10.8 | $ 22,045,900 | $ 238,074,481 | 13.4 | $ 22,045,900 | $ 294,415,621 | 25.8 | $ 22,045,900 | $ 568,722,536 |
| Residential land (ha) | | 90.6 | $ 6,875,000 | $ 622,698,715 | 6.5 | $ 5,437,500 | $ 35,268,807 | 7.8 | $ 3,600,000 | $ 28,064,630 | 0.0 | $ 3,600,000 | $ - |
| Development land (ha) | | 17.7 | $ 6,875,000 | $ 121,618,666 | 0.0 | $ 5,437,500 | $ - | 3.0 | $ 3,600,000 | $ 10,869,832 | 0.0 | $ 3,600,000 | $ - |
| Agricultural land (ha) | | 0.4 | $ 369,500 | $ 150,359 | 0.4 | $ 369,500 | $ 158,507 | 0.8 | $ 369,500 | $ 308,330 | 0.0 | $ 369,500 | $ 3,012 |
| Community infrastructure (ha) | | 1.5 | $ 13,493,300 | $ 19,613,588 | 0.0 | $ 13,493,300 | $ - | 0.0 | $ 13,493,300 | $ - | 0.0 | $ 13,493,300 | $ - |
| Parks, recreational and conservation areas (ha) | | 67.6 | $ 687,500 | $ 46,452,200 | 4.0 | $ 543,750 | $ 2,193,271 | 1.5 | $ 360,000 | $ 525,606 | 0.0 | $ 360,000 | $ - |
| Beaches (m) | | 6519.0 | $ 900 | $ 5,867,100 | 1023.0 | $ 900 | $ 920,700 | 0.0 | $ 900 | $ - | 0.0 | $ 900 | $ - |
| **Total** | | **178** | | **$ 850,949,724** | **22** | | **$ 280,757,383** | **26** | | **$ 339,513,830** | **26** | | **$ 570,781,035** |

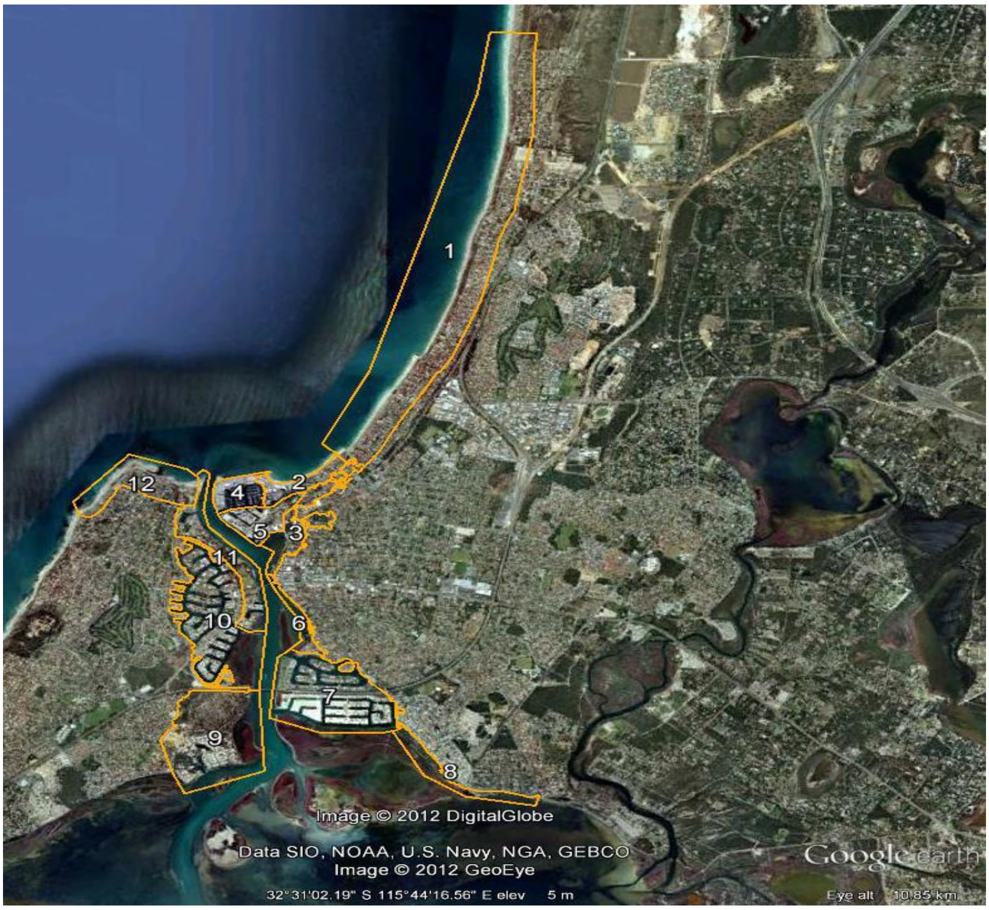
| Asset classing | | 5 Peninsula | | | 6 Walk to Soldiers Cove | | | 7 SE canal estate | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | area (m2) | unit value of asset | value of sub-area | area (m2) | unit value of asset | value of sub-area | area (m2) | unit value of asset | value of sub-area |
| Roads (m) | one lane | 2173.6 | $ 275 | $ 597,732 | 11.0 | $ 275 | $ 3,028 | 2553.7 | $ 275 | $ 702,263 |
| | two or more lanes | 2084.5 | $ 360 | $ 750,417 | 1003.2 | $ 360 | $ 361,148 | 6009.7 | $ 360 | $ 2,163,477 |
| Water (m) | retic | 4103.0 | $ 428 | $ 1,754,013 | 969.8 | $ 428 | $ 414,585 | 6652.9 | $ 428 | $ 2,844,117 |
| Sewerage | pressure main | 567.0 | $ 200 | $ 113,400 | 270.1 | $ 200 | $ 54,030 | 3668.1 | $ 200 | $ 733,617 |
| | gravity pipes | 3071.6 | $ 190 | $ 583,605 | 1538.7 | $ 190 | $ 292,360 | 6255.3 | $ 190 | $ 1,188,516 |
| Electricity low voltage (m) | underground | 7978.0 | $ 150 | $ 1,196,696 | 836.0 | $ 150 | $ 125,399 | 10414.9 | $ 150 | $ 1,562,233 |
| | overhead | 0.0 | $ 45 | $ - | 361.4 | $ 45 | $ 16,261 | 0.0 | $ 45 | $ - |
| Electricity high voltage (m) | underground | 4186.0 | $ 300 | $ 1,255,795 | 104.4 | $ 300 | $ 31,312 | 7243.7 | $ 300 | $ 2,173,117 |
| | overhead | 0.0 | $ 55 | $ - | 251.9 | $ 55 | $ 13,854 | 0.0 | $ 55 | $ - |
| Gas pipelines (m) | | 5951.1 | $ 90 | $ 535,602 | 1975.2 | $ 90 | $ 177,772 | 15037.6 | $ 90 | $ 1,353,388 |
| Commercial land (ha) | | 23.5 | $ 22,045,900 | $ 517,565,691 | 0.0 | $ 22,045,900 | $ - | 0.0 | $ 22,045,900 | $ - |
| Residential land (ha) | | 0.0 | $ 3,600,000 | $ 175,548 | 2.9 | $ 3,600,000 | $ 10,396,163 | 78.9 | $ 5,062,500 | $ 399,376,768 |
| Development land (ha) | | 4.0 | $ 3,600,000 | $ 14,344,446 | 0.2 | $ 3,600,000 | $ 666,189 | 0.0 | $ 5,062,500 | $ - |
| Agricultural land (ha) | | 0.0 | $ 369,500 | $ 17,881 | 0.3 | $ 369,500 | $ 104,606 | 0.8 | $ 369,500 | $ 284,523 |
| Community infrastructure (ha) | | 0.0 | $ 13,493,300 | $ - | 0.0 | $ 13,493,300 | $ - | 0.0 | $ 13,493,300 | $ - |
| Parks, recreational and conservation areas (ha) | | 0.2 | $ 360,000 | $ 69,292 | 4.3 | $ 360,000 | $ 1,531,483 | 18.2 | $ 506,250 | $ 9,213,939 |
| Beaches (m) | | 0.0 | $ 900 | $ - | 0.0 | $ 900 | $ - | 0.0 | $ 900 | $ - |
| **Total** | | **28** | | **$ 538,960,116** | **8** | | **$ 14,188,190** | **98** | | **$ 421,595,959** |

| Asset classing | | 8 Creery Wetland Foreshore | | | 9 SW canal estates | | | 10 Port Mandurah | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | area (m2) | unit value of asset | value of sub-area | area (m2) | unit value of asset | value of sub-area | area (m2) | unit value of asset | value of sub-area |
| Roads (m) | one lane | 480.6 | $ 275 | $ 132,174 | 2227.5 | $ 275 | $ 612,569 | 4440.3 | $ 275 | $ 1,221,076 |
| | two or more lanes | 30.4 | $ 360 | $ 10,947 | 3917.9 | $ 360 | $ 1,410,450 | 6138.7 | $ 360 | $ 2,209,936 |
| Water (m) | retic | 31.8 | $ 428 | $ 13,581 | 5565.2 | $ 428 | $ 2,379,141 | 11345.2 | $ 428 | $ 4,850,066 |
| Sewerage | pressure main | 47.2 | $ 200 | $ 9,434 | 534.8 | $ 200 | $ 106,966 | 8386.2 | $ 200 | $ 1,677,245 |
| | gravity pipes | 142.1 | $ 190 | $ 27,000 | 6466.6 | $ 190 | $ 1,228,648 | 4361.8 | $ 190 | $ 828,743 |
| Electricity low voltage (m) | underground | 329.2 | $ 150 | $ 49,385 | 9175.2 | $ 150 | $ 1,376,279 | 13667.4 | $ 150 | $ 2,050,114 |
| | overhead | 21.2 | $ 45 | $ 955 | 0.0 | $ 45 | $ - | 40.8 | $ 45 | $ 1,835 |
| Electricity high voltage (m) | underground | 20.9 | $ 300 | $ 6,269 | 2499.6 | $ 300 | $ 749,879 | 6677.0 | $ 300 | $ 2,003,090 |
| | overhead | 0.0 | $ 55 | $ - | 0.0 | $ 55 | $ - | 36.4 | $ 55 | $ 2,000 |
| Gas pipelines (m) | | 56.2 | $ 90 | $ 5,054 | 5168.2 | $ 90 | $ 465,138 | 22348.6 | $ 90 | $ 2,011,372 |
| Commercial land (ha) | | 0.0 | $ 22,045,900 | $ - | 5.3 | $ 22,045,900 | $ 117,181,212 | 2.1 | $ 22,045,900 | $ 45,953,800 |
| Residential land (ha) | | 3.1 | $ 3,375,000 | $ 10,554,967 | 29.9 | $ 5,531,250 | $ 165,272,741 | 55.6 | $ 5,125,000 | $ 284,864,856 |
| Development land (ha) | | 0.0 | $ 3,375,000 | $ - | 29.8 | $ 5,531,250 | $ 164,721,217 | 0.0 | $ 5,125,000 | $ - |
| Agricultural land (ha) | | 0.0 | $ 369,500 | $ - | 0.1 | $ 369,500 | $ 35,714 | 0.1 | $ 369,500 | $ 53,254 |
| Community infrastructure (ha) | | 0.0 | $ 13,493,300 | $ - | 0.0 | $ 13,493,300 | $ - | 0.0 | $ 13,493,300 | $ - |
| Parks, recreational and conservation areas (ha) | | 20.7 | $ 337,500 | $ 6,974,190 | 29.4 | $ 553,125 | $ 16,238,530 | 12.5 | $ 512,500 | $ 6,387,568 |
| Beaches (m) | | 0.0 | $ 900 | $ - | 0.0 | $ 900 | $ - | 0.0 | $ 900 | $ - |
| **Total** | | **24** | | **$ 17,783,957** | **94** | | **$ 471,778,485** | **70** | | **$ 354,114,954** |

| Asset classing | | 11 Western Foreshore | | | 12 Halls Head | | | Total | |
|---|---|---|---|---|---|---|---|---|---|
| | | area (m2) | unit value of asset | value of sub-area | area (m2) | unit value of asset | value of sub-area | area (m2) | value of case study area |
| Roads (m) | one lane | 1829.4 | $ 275 | $ 503,089 | 182.0 | $ 275 | $ 50,056 | 16109.8 | $ 4,430,198 |
| | two or more lanes | 2180.7 | $ 360 | $ 785,046 | 3803.0 | $ 360 | $ 1,369,074 | 51924.2 | $ 18,692,699 |
| Water (m) | retic | 4242.9 | $ 428 | $ 1,813,846 | 3463.2 | $ 428 | $ 1,480,527 | 66200.0 | $ 28,300,517 |
| Sewerage | pressure main | 2404.2 | $ 200 | $ 480,839 | 560.3 | $ 200 | $ 112,056 | 21335.7 | $ 4,267,137 |
| | gravity pipes | 1277.6 | $ 190 | $ 242,745 | 3640.3 | $ 190 | $ 691,656 | 44877.9 | $ 8,526,798 |
| Electricity low voltage (m) | underground | 3561.1 | $ 150 | $ 534,166 | 1034.9 | $ 150 | $ 155,233 | 69815.6 | $ 10,472,340 |
| | overhead | 912.0 | $ 45 | $ 41,040 | 2894.8 | $ 45 | $ 130,267 | 17911.4 | $ 806,013 |
| Electricity high voltage (m) | underground | 564.2 | $ 300 | $ 169,274 | 38.9 | $ 300 | $ 11,669 | 28225.6 | $ 8,467,685 |
| | overhead | 262.1 | $ 55 | $ 14,417 | 190.2 | $ 55 | $ 10,458 | 4623.2 | $ 254,279 |
| Gas pipelines (m) | | 5468.2 | $ 90 | $ 492,138 | 6221.4 | $ 90 | $ 559,929 | 118750.8 | $ 10,687,569 |
| Commercial land (ha) | | 0.0 | $ 22,045,900 | $ - | 0.0 | $ 22,045,900 | $ - | 81.2 | $ 1,789,168,727 |
| Residential land (ha) | | 10.8 | $ 5,125,000 | $ 55,472,399 | 13.8 | $ 5,125,000 | $ 70,850,727 | 299.9 | $ 1,682,996,321 |
| Development land (ha) | | 0.0 | $ 5,125,000 | $ - | 0.0 | $ 5,125,000 | $ - | 54.7 | $ 312,220,349 |
| Agricultural land (ha) | | 0.5 | $ 369,500 | $ 197,867 | 3.1 | $ 369,500 | $ 1,152,818 | 6.7 | $ 2,466,871 |
| Community infrastructure (ha) | | 0.0 | $ 13,493,300 | $ - | 0.5 | $ 13,493,300 | $ 6,609,673 | 1.9 | $ 26,223,261 |
| Parks, recreational and conservation areas (ha) | | 20.7 | $ 512,500 | $ 10,587,315 | 14.6 | $ 512,500 | $ 7,465,717 | 193.4 | $ 107,639,112 |
| Beaches (m) | | 0.0 | $ 900 | $ - | 2231.0 | $ 900 | $ 2,007,900 | 9773.0 | $ 8,795,700 |
| **Total** | | **32** | | **$ 71,334,182** | **32** | | **$ 92,657,760** | **638** | **$ 4,024,415,575** |

Figure 5 provides an overview of the case study area and the 12 sub-areas.

Figure 5 **Mandurah case study areas**




### Climate change impacts in the Mandurah case study

By far the most pervasive impact from climate change in Mandurah, as for the remainder of the coast, is coastal erosion. By 2100, if nothing is done, the coastline in Mandurah could retreat by as much as 200 metres; effectively removing all land up to two streets back from the current beach. The effects would be felt largely in residential areas, though the Mandurah Ocean Marina would also be threatened.

There is also a risk of flooding which could, if left unaddressed, influence the CBD and tourist developments in the estuary, as well as most of the foreshore parks in the case study area. Canal developments in Halls Head and at Dudley Park are also threatened, and have the added complication that the private property line extends to the waterline, meaning that collective action on the part of private residential land-owners may be necessary. Other residential areas are less affected by flooding, with the exception of low-lying land in Sub Area 2, to the north and south of the City of Mandurah offices.

There is also a danger that climate change may shift the boating channel which runs through the centre of the mouth of the estuary, and this may have an additional effect on wetlands at Erskine and to the south of Dudley Park.

### Description of options

In this section, we describe the options which might be applied in each one of the sub areas in the Mandurah case study area. These are summarised in Table 22.

Table 22 **Mandurah option costs**

| | Option | Capital Cost | Operating Cost (% capital cost) |
|---|---|---|---|
| Sub-Area 1 - Northern beaches | 1) Large enclosing groynes - Small groynes (phase 1) | $10,000,000 | 1% |
| | 1) Large enclosing groynes - Intermediary "T" groynes (phase 2) | $10,800,000 | 1% |
| | 1) Large enclosing groynes - Offshore reef with 90 % gap (phase 3) | $8,300,000 | 1% |
| | 1) Large enclosing groynes - Offshore reef with 75% gap (phase 4) | $12,100,000 | 1% |
| | 1) Large enclosing groynes - Offshore reef with 60% gap (phase 5) | $12,100,000 | 1% |
| | 1) Large enclosing groynes - Offshore reef with 50% gap (phase 6- extend BWs landward) | $17,500,000 | 1% |
| | **1) Total cost (staged)** | **$71,000,000** | |
| | **1) Total cost (not staged)** | **$66,100,000** | |
| | 2) Seawall - Small seawall (phase 1) | $4,600,000 | 1% |
| | 2) Seawall - extension downwards of small seawall (phase 2) | $2,200,000 | 1% |
| | 2) Seawall - Large seawall (phase 3) | $16,100,000 | 1% |
| | **2) Total costs- (staged)** | **$22,900,000** | |
| | **2) Total costs- (not staged)** | **$21,600,000** | 1% |
| Sub Area 2 - Seashells | 1) Increase seawall to medium (phase 1) | $1,100,000 | 1% |
| | 1) Increase seawall to large (phase 2) | $510,000 | 1% |
| | **1) Total costs (staged)** | **$1,610,000** | |
| | **1) Total costs (not staged)** | **$1,500,000** | |
| Sub area 3 - CBD | 1) Use roads as part of drainage system (Ormbsby Tce) | $200,000 | 1% |
| | 2) Build flood levee (Ormsby Tce, Beam Rd & Mandurah Tce). Change structural requirements on houses to make flood-proof | $916,000 | 0% |
| | 3) Build flood levee (Ormsby Tce, Beam Rd & Mandurah Tce). Change house foundations to make flood-proof (west of Ornsby Tce Levee & west of Man Tce Levee). | $756,000 | 0% |
| | 4) Seawall for coastal flooding (Mandurah CBD only) | $470,000 | 2% |
| | 5) Change structural requirements on houses to make flood-proof (west of Ornsby Tce Levee, between Ornsby Tce of Beams Rd Levees, east of Beams Rd Levee, west of Man Tce Levee, east of Man Tce Levee -Hackett, Cooper St, east of Man Tce Levee - Peel St) | $8,940,000 | 0% |
| | 6) Change house foundations to make flood-proof (west of Ornsby Tce Levee, between Ornsby Tce of Beams Rd Levees, east of Beams Rd Levee, west of Man Tce Levee, east of Man Tce Levee -Hackett, Cooper St, east of Man Tce Levee - Peel St) | $6,730,000 | 0% |
| | 7) Improve drainage system to deal with flooding (Seashells - Beams, Shannon, Stewart, Ormsby, CBD - Hackett, Cooper, Mandurah, Peel, Rockford) | $1,230,000 | 1% |
| Sub area 4 - MOM | 1) Raise and strengthen sea walls | $1,140,000 | 1% |
| Sub area 5 - Peninsula | 1) Raise walk area | $110,000 | 0% |
| | 2) Flood wall (raise existing walls) | $1,640,000 | 2% |
| | 3) Flood gates at estuary mouth. Flood gates at Old Mandurah Bridge (would also serve 6,7,10 & 11). | $154,100,000 | 1% |
| Sub area 6 - Walk to Soldiers Cove | 1) Build a second wall - land-side of path, raise boardwalk and wall | $1,870,000 | 1.2%* |
| | 2) Build a second wall - sea-side of path. Raise boardwalk and wall | $1,670,000 | 2% |
| | 3) Flood gates at estuary mouth. Flood gates at Old Mandurah Bridge (would also serve 6,7,10 & 11). | $154,490,000 | 1% |

| | | | |
|---|---|---|---|
| Sub area 7 - SE canal estate | 1) Flood gates at estuary mouth. Flood gates at Old Mandurah Bridge (would also serve 6,7,10 & 11) | $154,100,000 | 1% |
| | 2) Flood gates at estuary mouth and Dawesville Channel (would also serve 6,7,10 & 11) | $132,600,000 | 1% |
| | 3) Sea wall prior to building houses. Fill low land | $1,740,000 | 1.2%* |
| Sub area 8 - Creery Wetland Foreshore | 1) Strengthen embankment. Add wall. | $610,000 | 1.8%* |
| Sub area 9 - SW canal estates | 1) Flood gates at estuary mouth and Dawesville Channel (would also serve 6,7,10 & 11) | $132,600,000 | 1% |
| | 2) Flood gates at Old Mandurah Bridge and Dawesville Channel (would also serve 6,7,10 & 11) | $193,500,000 | 1% |
| | 3) Sea wall prior to building houses / sea wall to prevent channel movement | $1,100,000 | 1% |
| Sub area 10 - Port Mandurah | 1) Flood gates at Old Mandurah Bridge and Dawesville Channel (would also serve 6,7,10 & 11) | $154,100,000 | 1% |
| | 2) Flood gates at estuary mouth and Dawesville Channel (would also serve 6,7,10 & 11) | $132,600,000 | 1% |
| | 3) flood gates at entrance to residential canal area | $43,000,000 | 1% |
| Sub area 11 - Western Foreshore | 1) Raise houses on foundations (progressive - at the end of each houses design life) | $2,600,000 | 0% |
| | 2) Require zoning changes for new houses to flood-proof | $6,600,000 | 0% |
| | 3) Crest wall | $1,600,000 | 1% |
| | 4) flood gates at estuary mouth and Old Mandurah Bridge (would also serve 6,7,10 & 11) | $154,100,000 | 1% |
| Sub area 12 - Halls Head | 1) Large enclosing groynes - Small groynes (phase 1) | $1,600,000 | 1% |
| | 1) Large enclosing groynes - Small groynes (phase 2) | $1,300,000 | 1% |
| | 1) Large enclosing groynes - Intermediary "T" groynes (phase 3) | $2,400,000 | 1% |
| | 1) Large enclosing groynes - Offshore reef with 50% gap (phase 4) | $7,900,000 | 1% |
| | **1) Total cost (staged)** | **$13,200,000** | |
| | **1) Total costs (not staged)** | **$11,300,000** | 1% |
| | 2) Seawall - Small seawall (phase 1) | $1,100,000 | 1% |
| | 2) Seawall - Extension downwards of small seawall (phase 2) | $550,000 | 1% |
| | 2) Seawall – Large seawall (phase 3) | $2,800,000 | 1% |
| | **2) Total costs- (staged)** | **$4,450,000** | |
| | **2) Total costs- (not staged)** | **$4,100,000** | 1% |

*Note: entries marked with a * are those where the individual elements have different operating costs and a weighted average of the different elements is shown*

*Data source:* Damara WA

In the coastal areas threatened with erosion, there are no "planning" options, in the sense that we define them in Chapter 4. This is because erosion has essentially two responses; either do something physical to prevent the erosion, or do nothing and lose the land (a retreat option).

The engineering options for coastal areas all involve protection of some form or another. There are three broad types of protection; seawalls, groynes and offshore reefs (though not all are applicable in each case), and several levels of protection in each case. The basic intuition is that one could begin relatively small, but the relevant infrastructure would become inadequate at some point in time, at which point it would be upgraded. Alternatively, one could start at a large scale, which offers more permanent protection.

Sub Areas 1,2, 4 and 12 would all require some form of engineering protection against erosion. The full range of options could be employed in Sub Area 1. However, Sub Areas 2 and 4 already have sea walls (in Sub Area 4, the outer wall of the marina) meaning the focus would be on strengthening rather than new construction, and in Sub Area 12, the need to trap sediment for redistribution means that offshore reefs are not appropriate.

Sub Area 2 is subject to flooding as well as erosion. In particular, there is a long thin finger of low-lying land behind the (now built-over) dune system which is at risk. This could be protected by a levee or, since it is some time before the flood risk is realised, by planning requirements that require all new buildings to be flood-proofed. If we assume (see AECOM, 2010) an average building life of 40 years, then implementing these requirements would mean that 2.5 per cent of buildings are raised every two years on an assumption of evenly distributed ages of buildings.

Within the CBD in Sub Area 3, there is less scope for a planning solution requiring flood proofing because of the heterogeneous uses of land within the precinct, which makes it more difficult to implement such a planning response compared to the predominantly residential Sub Area 2. Its longer sea-frontage makes a levee more expensive, and has visual amenity issues in what is primarily foreshore park. However, a seawall for coastal flooding as part of a promenade may prove a suitable alternative. Note in Sub Area 3 that the low cost of using roads as part of the drainage system is based on a marginal cost assumption; that is, that the relevant engineering work needed to do this would be undertaken at the time when the roads were due for an upgrade or maintenance in any case.

Sub Area 5 presents particular problems because commercial development is very close to the water's edge. This means that anything larger than a relatively small flood wall would be untenable, and this may be insufficient to protect the developments in the event of a large flood. This means that the option as presented is not "optimal" in the sense that it will not offer full protection for this asset. In the longer term, it may be appropriate to change the requirements for new commercial buildings in the area to require them to build flood-protection into the building design, and to negotiate with existing commercial developments to retro-fit the same (where possible) in a cost-effective manner. A final option for this sub area, which would also influence flood risk in Sub Areas 6,7,8,9,10 and 11 as well could be to put flood gates at the estuary mouth and at the old and new Mandurah Bridges. A gate at the old bridge would protect Sub Area 5 and part of Sub Area 11, while one at the new bridge would protect all sub areas except 8 and 9 and part of 7; to protect these using flood gates would require a flood gate at the Dawesville Cut or a narrowing of the channel, both of which are very expensive options but one with impacts throughout the estuary.

Sub Areas 6 and 8 are similar in that they have foreshore reserves with existing, albeit low walls that could be strengthened. Sub Area 11 is also mostly parkland. However, it also contains houses in its northern extremity.

Sub Areas 7, 9 and 10 present similar problems in that they are canal estates. In Sub Area 9, we understand that there are existing plans to fill the areas where flooding is a risk. However, it may also require a seawall to prevent movement of the channel. Sub Area 10 has the advantage that, although it is a canal estate, there are only two entrances to the estuary, and it may thus be possible to install flood gates across the entrances and protect the development. The same is true of the northern part of Sub Area 7, but not of the southern part, which looks over wetlands. For all three canal estates, an issue exists in that private land extends to the waterline, meaning that solutions within each estate would need to be carried out by landowners, rather than government.

### Options and optimal timing results

Table 23 provides an overview of the options that are viable in Mandurah in an economic sense. By viable, we mean that the options are chosen in at least some of the scenarios by the real options algorithm, at some year during the 100-year timeframe under analysis. Table 23 shows the capital cost of each option, its operating cost, the optimal year for implementing the option and the net benefit (the reduction in value at risk it provides minus the cost of the option) in produces. The final column shows the percentage of scenarios in which the option is viable (as defined above). It is worth noting that the optimal year and net benefit results for each option are based on the viable realisations of that option. Thus, in some instances, where an option is only viable in a small number of scenarios, these results can be skewed. This is discussed further below.

Table 23 **Mandurah viable options summary**

| | Option | Capital Cost | OPEX | Optimal Year | Net benefit | % let expire scenarios |
|---|---|---|---|---|---|---|
| Sub-Area 1 - Northern beaches | 1 | $10,000,000 | $100,000 | 12 | $35,755,000 | 25.70% |
| | 2 | $10,800,000 | $108,000 | 30 | $13,599,000 | 16.00% |
| | 3 | $8,300,000 | $83,000 | 38 | $10,552,000 | 6.00% |
| | 4 | $12,100,000 | $121,000 | 57 | $1,674,000 | 80.00% |
| | 5 | $12,100,000 | $121,000 | 57 | $1,674,000 | 80.00% |
| | 7 | $66,100,000 | $708,000 | 8 | $28,511,000 | 55.00% |
| | 8 | $4,600,000 | $46,000 | 23 | $4,979,000 | 92.20% |
| | 9 | $2,200,000 | $22,000 | 12 | $34,310,000 | 28.30% |
| | 10 | $16,100,000 | $161,000 | 26 | $19,850,000 | 6.40% |
| | 11 | $21,600,000 | $229,000 | 11 | $50,898,000 | 4.00% |
| Sub Area 2 - Seashells | 1 | $1,100,000 | $11,000 | 8 | $11,855,000 | 38.00% |
| | 2 | $510,000 | $5,100 | 23 | $10,863,000 | 0.00% |
| | 3 | $1,500,000 | $16,100 | 7 | $27,132,000 | 2.30% |
| Sub area 3 - CBD | 1 | $200,000 | $2,000 | 49.5 | $1,127,000 | 0.00% |
| | 2 | $916,000 | $- | 68 | $437,000 | 0.00% |
| | 3 | $756,000 | $- | 68 | $459,000 | 0.00% |
| | 4 | $470,000 | $9,400 | 67 | $496,000 | 0.00% |
| | 7 | $1,230,000 | $12,300 | 53 | $893,000 | 0.00% |
| Sub area 4 - MOM | 1 | $1,140,000 | $14,500 | 3.5 | $61,247,000 | 5.80% |
| Sub area 5 - Peninsula | 1 | $110,000 | $- | | | |
| | 2 | $1,670,000 | $28,400 | 67 | $319,000 | 0.00% |
| Sub area 7 - SE canal estate | 3 | $1,740,000 | $28,000 | 65 | $534,000 | 0.00% |
| Sub area 8 - Creery Wetland Foreshore | 1 | $610,000 | $10,900 | 57 | $102,000 | 0.00% |
| Sub area 9 - SW canal estates | 3 | $1,100,000 | $11,000 | 41 | $1,331,000 | 0.00% |
| Sub area 11 - Western Foreshore | 1 | $2,600,000 | $- | 59 | $439,000 | 0.00% |
| | 3 | $1,600,000 | $16,000 | 56.5 | $617,000 | 0.00% |
| Sub area 12 - Halls Head | 1 | $1,600,000 | $16,000 | 8 | $1,291,000 | 85.70% |
| | 2 | $1,300,000 | $13,000 | 20.5 | $881,000 | 79.70% |
| | 3 | $2,400,000 | $24,000 | 18.5 | $1,285,000 | 62.30% |
| | 4 | $7,900,000 | $79,000 | 14 | $1,226,000 | 96.10% |
| | 5 | $11,300,000 | $122,000 | 2.5 | $1,353,000 | 95.60% |
| | 6 | $1,100,000 | $11,000 | 10.5 | $753,000 | 93.50% |
| | 7 | $550,000 | $5,500 | 12 | $3,331,000 | 34.20% |
| | 8 | $2,800,000 | $28,000 | 25.5 | $1,713,000 | 20.40% |
| | 9 | $4,100,000 | $44,500 | 5 | $5,615,000 | 12.50% |

Mandurah is the most complex of the case studies, and we divide the discussion in three; an overview of the coastal sub-areas (1,2,4 and 12), an overview of the inland or estuarine sub areas and a discussion of the impacts of sand replenishment on the coast as an option.

### Coastal areas

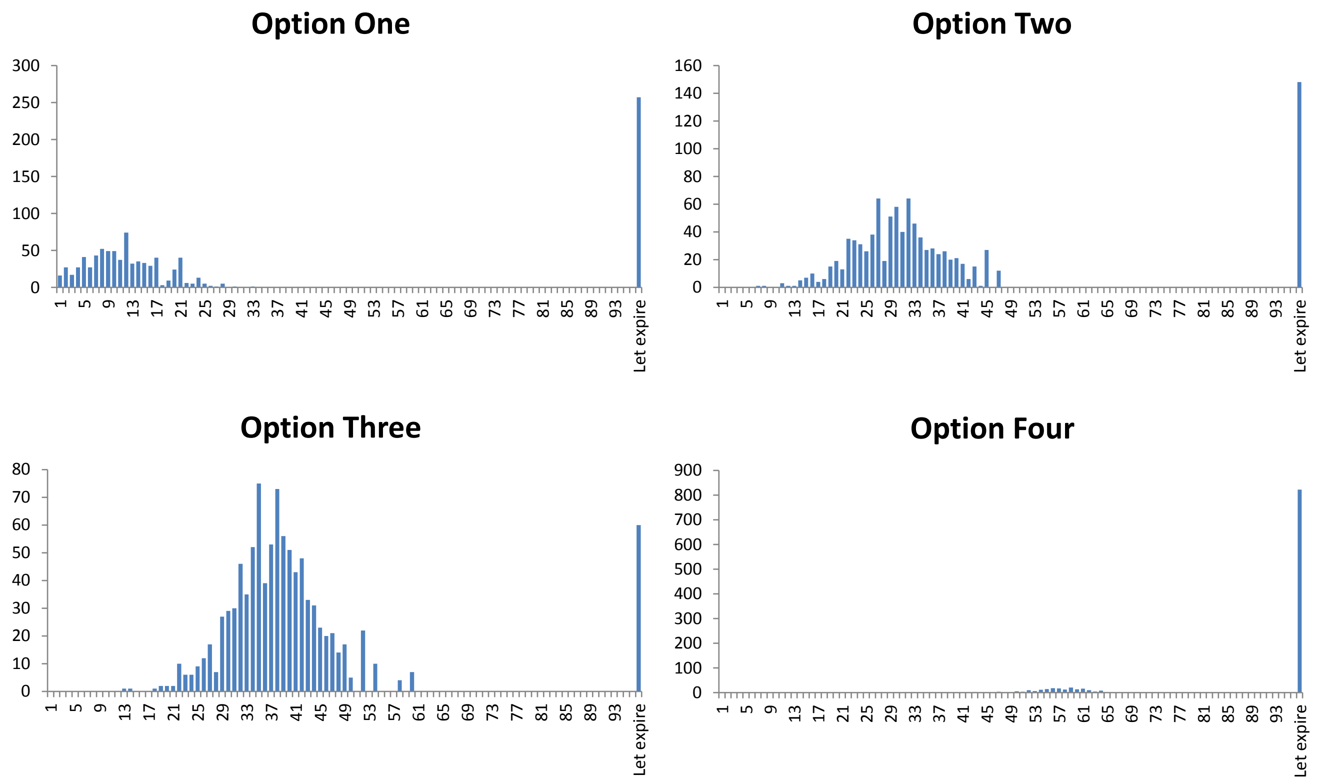
Within the coastal areas, Sub Areas 1 and 12 have the option of using groynes or seawalls, while Sub Areas 2 and 4, which already have some existing seawall structures, only have the option of extending their seawalls.

Groynes, in Sub Areas 1 and 12, are roughly three times the cost of seawalls. In the case of Sub Area 12, the value of the asset being saved means that the more expensive groynes are not the preferred option (note the large "let expire" percentages), and the relevant choice is between staging the seawall, or building it all at once. Note that staging is more valuable; roughly $59 million in sum across the three stages compared with $51 million for constructing the walls all at once.

In Sub Area 1, the more valuable asset means that groynes are feasible. However, only the first three stages of the groynes are viable, with the fourth stage expiring in 80 per cent of scenarios. This is shown clearly in Figure 6, which charts the distribution of optimal times (across scenarios) for the first four stages.[59] Note how the distribution becomes more spread out, as well as smaller, as the investment cost increases.

[59] For reasons of space restrictions, the axes are unlabelled in Figure 6. However, each picture is a histogram showing the number of scenarios (the vertical axis) where the given option is optimal in the corresponding year, shown on the horizontal axis.

Figure 6 **Mandurah northern beaches sub area groynes options – histograms of optimal timing**



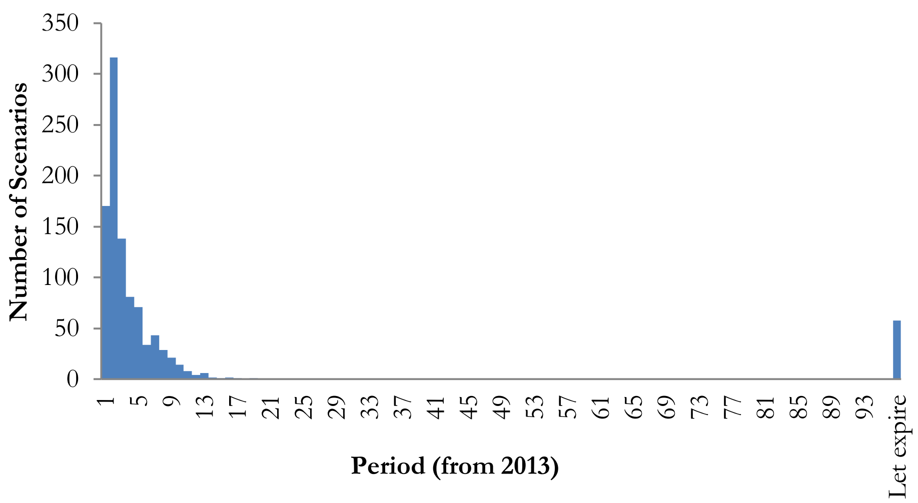

The basic issue is the extent of erosion risk. The first three stages of the groynes provide protection up to an erosion level of 50 per cent, the number of scenarios (and extent of exceedance) which exceed this amount is insufficient to warrant the additional expenditure. The same effect is not seen in seawalls, as the first two stages only provide protection up to 17 per cent erosion, meaning the third stage is viable.

In comparing the first three stages of the groyne options with the seawall option (also in three stages), the groyne option provides a slightly higher net benefit, meaning society would be slightly better off by adopting this option. However, the cost of the option is much higher, and for this reason, it is likely that seawalls would be a preferable option to groynes, if cost and risk are the only considerations.

Sub Area 12 and Sub Area 2 both highlight a similar issue in their first stage; their first stages are only viable in a small number of scenarios. This is because the seawalls in their first stages only provide protection up to seven per cent erosion, and with the rise in sea levels in the scenarios, this proves to be too little, resulting in the first stage soon needing to be replaced by a second stage. This means that the value at risk savings are generally too small to make the first stage viable in its own right (in each Sub Area) and suggests it may be wiser to move straight to the second stage in each instance.

Sub Area 4 highlights a different aspect of the model. There is only one option, and it is optimal to undertake it very early, in only four years. Moreover, as shown in Figure 7, this finding is consistent across most scenarios; the distribution around the mean is very tight.[60]

Figure 7 **Mandurah Ocean Marina optimal protection times**




The model works by backwards solving down each scenario to ascertain whether the net benefit (value at risk saved minus cost of the intervention) of investing in protection now is greater than it is in the next period. There are typically many times in each scenario where this is true. We have used the first instance as the basis of our analysis. We do this because we consider it suits the kinds of decisions which are made by local governments; they do not want to waste money by investing too early, but they are not profit maximisers, and are likely to prefer the prudence of the earliest viable intervention to waiting until the net benefit is at its maximum.[61] Moreover, the net benefit is a societal one, rather than being a cash return to the relevant local government.

The result of our choice above, in the model, is that it favours early intervention. When the value of the asset is very high, and the cost of the

[60] Note that this occurs in many of the case study areas. To avoid repetition, we have not repeated the distribution figures for all options in all sub areas.

[61] There is nothing intrinsic in the model which makes it choose the first viable timeframe, and in a different context (a private investor who might make profits from the investment, for example, the maximum, rather than the earliest, net benefit would be preferable.

intervention is very low (as is the case in Sub Area 4), the net result is an optimal investment time which appears very early in the context of the engineering information about coastal erosion presented in the Phase One report. One way of considering strategy based upon this is that it represents the earliest viable time to intervene, not the last possible moment in which one ought to do so.

In each of the coastal areas, the intervention times are several years hence, during which time erosive pressures are likely to occur. However, except in the case of Sub Area 12, existing structures are in place. In Sub Area 12, around five per cent of the sub area would be lost to erosion by the time it becomes optimal to construct the sea wall. This equates to around 15 metres of beach (no houses would be affected), which could either be sacrificed or maintained through sand replenishment (see discussion on sand replenishment as an option below).

### Estuarine areas

Moving now to the inland (or rather estuarine) regions, we begin with Sub Area 3 in the CBD. Here the model suggests starting with Option One in 50 years, and moving to either of Options Two, Three or Four in around 65 years. Each of these subsequent options has the same profit (slightly less than $500,000) and thus, since they are direct substitutes for each other, it appears wise to use the lowest-cost option, Option Four.

Some care needs to be used when interpreting the model results for Sub Area 3. The first option lasts 50 years, and needs to be implemented in 50 years, while the latter three last for 30 years, and need to be implemented in slightly under 70 years. This suggests that the chosen end point of the engineering analysis (the NPV calculations go out 500 years, but there is no change in erosion or flooding after year 100) may be influencing results. Changing the approach to allow erosion and flooding after 2110 may result in a later intervention.

For Sub Areas 4 and 5, there is only a single optimal choice. In Sub Area 4, there is only one choice, and in Sub Area 5, although the first two options are viable, the first lasts for 100 years and costs only $110,000, while the second lasts for only 30 years and lasts for only 30 years. In the case of Sub Area 5, however, it should be noted that none of the solutions "solve" the problem completely in the sense that the location of the commercial properties in the sub area preclude the construction of defensive measures that will be fully effective. In the longer term, a solution will have to be reached with property owners and lease-holders in this sub area to re-design their properties to account for flood protection measures.

Sub Areas 6 and 10 both have no action as the modelling result; none of the options that are feasible from an engineering sense are feasible from an economic sense. Sub Area 10 is perhaps of the greatest interest in this respect, as it is a canal estate, dominated by private property, and thus it would seem a simple matter if the residents of that region value their properties more highly than we have done in our assessment to collectively implement the proposed measures. However, we note that the extent of flooding predicted by the models in this area is not sufficient to result in the potential loss of houses. Rather, it is sufficient to result in the loss of gardens, jetties and structures at the waterline. The residents in question may decide to wear this loss, rather than paying to protect the whole area via the flood-gates or other measures suggested above.

Sub Areas 7and 9 are similar in that each has one very low cost option and two very high cost options; the gating of either the Dawesville Cut, the Old Mandurah Bridge or the estuary mouth. The result is a clear preference for the much cheaper option (see Box 5 for more detail). In the case of Sub Area 7, the model suggest implementation in 65 years and for Sub Area 9 it suggests action in 41 years. However, in both cases, the relevant measures need to be taken before the houses are built, after which time they become impossible. It seems unlikely, given growth in the area, that developers will wait this long before building in these areas, regardless of our model results, and this may mean that the City of Mandurah needs to consider requiring the relevant action to be taken by the developer prior to any more development occurring.

Sub Area 8 has a single option, which the model suggests ought to be implemented in 57 years.

Finally, Sub Area 11 has three low cost options and one very costly one (flood gates). Of the three less costly ones, a crest wall would be insufficient to meet the rising risks, and would fail too quickly to deliver value at risk savings. The two options involving raising the houses as they are renewed would both be optimal at around the same time (56 and 58 years from now respectively), and both would have roughly the same profit ($400 and $600,000 respectively). This suggests that the less expensive option, Option 1, would be the better choice. As a final point, it is worth noting that the low costs are achieved by fixing each house as it reaches the end of its operational life and is renewed. In the model, the options are shown as being optimal in 56 and 58 years. However, in reality, since an average house lasts around 40 years, the City would need to change its building requirements is around 15 years to ensure that the option is complete by the time it is needed.

Box 5 **Flood gates**

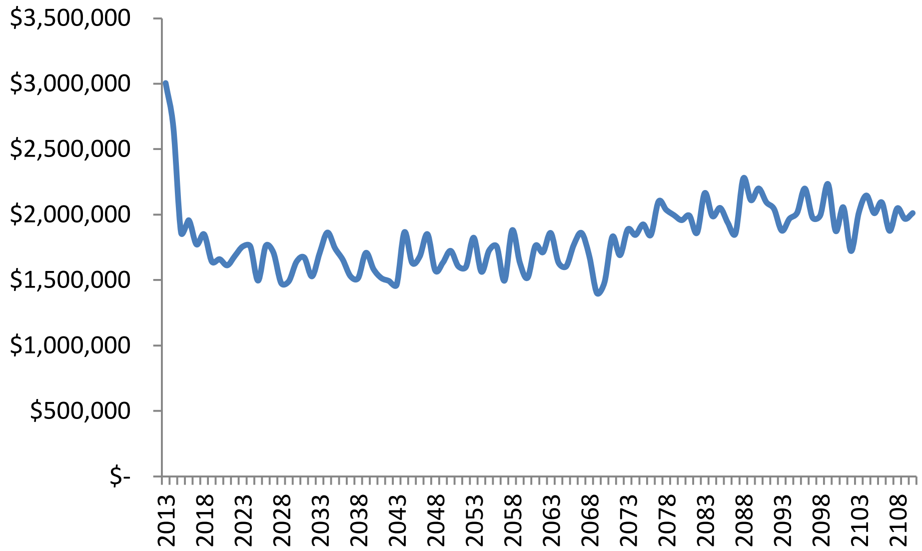
There are several "large-scale" options involving flood gates at the estuary mouth, the Old Mandurah Bridge and the Dawesville Cut (which could also be narrowed). In the modelling, we assessed each of these against each of the individual sub-areas, and it was never optimal to implement any of them to save a single sub-area. However, each of these options would save several sub-areas in conjunction. We did not model these large-scale options against several sub-areas in conjunction. The reason for doing this is that the flood gates and channel narrowing are more than twice as expensive as *all* of the other options which could be used to protect the relevant regions put together (and two-thirds of that cost is flood gates in Sub Area 10, which are not optimal either). Since each sub area has an optimal solution which is much less expensive than the large, region-wide structures, there is little benefit in employing them at this stage. They would rather become viable for a two-metre, rather than a one-metre sea level rise. The caveat, however, is that our conclusion is based upon the value of the assets in the case study area alone, and such structures would act to protect the whole estuary. A wider scale of analysis may conclude that they are viable.

### Sand replenishment as an option

For each of the coastal areas subject to erosion where seawalls are used, the land will be protected, but not the beach. We therefore examine the option of sand replenishment. The cost of sand replenishment is roughly $2.6 million for every one per cent of erosion; the more the erosive pressure, the more sand would need to be replenished in order to keep the beach (and the land behind it) in place.

We consider the case of Sub Area 1, as it is the area which is the most valuable. However, the findings are generalizable to other assets. The cost of sand replenishment is $2.637 million per percentage point of erosion (more correctly, erosive pressure, through sea-level rise) in Sub Area 1. As sea levels rise, more and more sand will need to be put onto the beach in order to protect it. In reality, some sand will be eroded from year to year, in between replenishment episodes, increasing the amount that would need to be put onto a beach. However, if we adopt a more conservative approach, and assume that new sand is needed only for incremental erosive pressure, the annual cost of replenishment is as shown in Figure 8 for Sub Area 1.

Figure 8 **Annual cost of sand replenishment – Sub Area 1**




On average, the figure is between $1.5 and $2 million per annum, which equates to around $51 million in net present value terms over the hundred-year time horizon. This makes it much more expensive than any of the other options, even before we consider whether sufficient sand would in fact be available, and thus it would not be an optimal solution compared to the other measures suggested above.

Another consideration with sand replenishment is that the seawall (or groynes) could be used to protect the land, and sand replenishment could be used to provide a beach for the community; absent of sand replenishment, beaches would vanish, particularly if a seawall was used. In this instance, the value of the beach would need to warrant the replenishment expenditure.

In Sub Area 1, the beach alone is worth $6 million, or $180,000 per annum, and thus the cost of replenishment would be around ten times the economic value of the beach by the time the seawall was put in place. This means that the community would need to consider how its valuation of the beach differs for our own, and whether it is willing to fund its continuation under a scenario involving these kinds of costs.

## Formulation of options pathways

In most of the sub areas, there is only one option that is viable or, if there are two, they are substitutes rather than complements. The exceptions are Sub Areas 1 and 12, where the different options are staged.

For these options, we look at the first stage, considering when it is optimal. Then, in looking at the second stage, we assume stage one is in place, offering a level of protection for a period of time, until the erosive pressures are too great (or design life is exceeded, which does not happen in practice), and then the optimal time to put the second stage in place is then the first time after the "failure point" that the net benefit is positive.

This optimal second stage can result in some erosion in the interim, depending upon the optimal timing of the second stage. However, in this case, the model results indicate a gap of only a year in each case, which effectively means no erosion.

Note that the approach above is subtly different from the description in Section 5.1, in that we have effectively used an American option approach twice, rather than the European option approach noted above. We did this because the relevant pressure for the second stage was not the design life of the structure, but the degree of erosive pressure it can withstand, and this is different in every scenario.

## 5.3 Case Study Two: Siesta Park-Marybrook

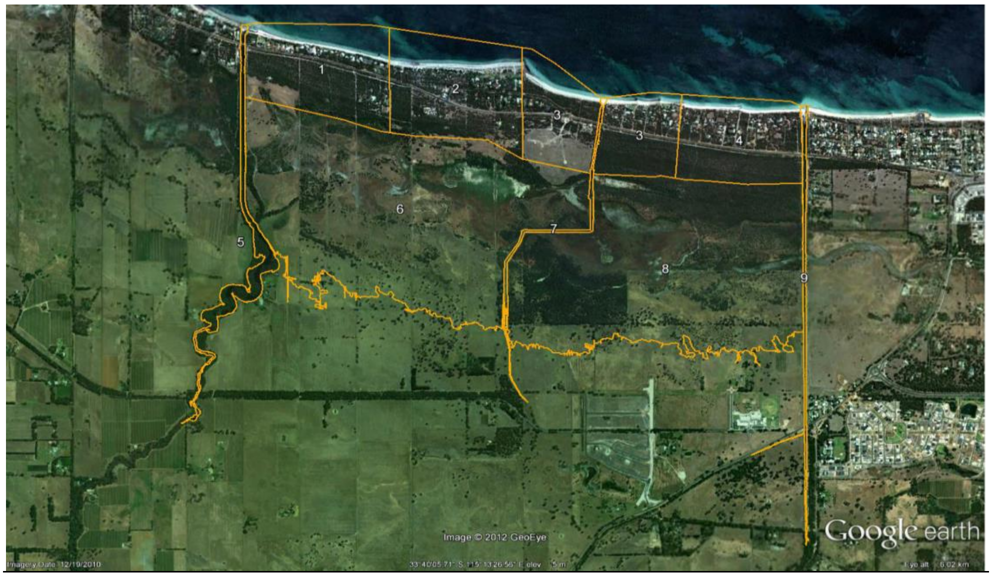
This case study runs from the Lennox Drain to the Buayanup Drain (from Forth St to Mitchell St) along Caves Road, and extends inland almost two kilometres, covering farmland that would be affected by flooding. The land uses are residential along the coast, and farming land inland from the coast. The residential land uses are the least dense amongst the case study areas. However, some of the residential land, particularly in Siesta Park, is very valuable; to the point that some land-owners have already begun to install their own seawalls to protect their property. The sub-areas are described in Table 24, and shown in Figure 9.

Table 24 **Summary of asset values in Siesta-Park-Marybrook**

| **Asset classing** | | **1** West of Siesta Park | | | **2** Siesta Park | | | **3** Locke Estate | | | **4** W. Buayanup | | | **5** Lennox Drain | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | area (m2) | unit value of asset | value of sub-area | area (m2) | unit value of asset | value of sub-area | area (m2) | unit value of asset | value of sub-area | area (m2) | unit value of asset | value of sub-area | area (m2) | unit value of asset | value of sub-area |
| Roads (m) | one lane | 0 | $ 275 | $ - | 0 | $ 275 | $ - | 0 | $ 275 | $ - | 0 | $ 275 | $ - | 0 | $ 275 | $ - |
| | two or more lanes | 1054.2 | $ 360 | $ 379,511 | 1585.6 | $ 360 | $ 570,809 | 1467.5 | $ 360 | $ 528,309 | 885.3 | $ 360 | $ 318,694 | 43.0 | $ 360 | $ 15,464 |
| Water (m) | mains | 1053.9 | $ 450 | $ 474,258 | 1579.6 | $ 450 | $ 710,829 | 1432.3 | $ 450 | $ 644,536 | 884.4 | $ 450 | $ 397,964 | 30.1 | $ 450 | $ 13,546 |
| Electricity low voltage (m) | underground | 157.3 | $ 150 | $ 23,602 | 142.6 | $ 150 | $ 21,397 | 86.1 | $ 150 | $ 12,919 | 0.0 | $ 150 | $ - | 0.0 | $ 150 | $ - |
| overhead | | 930.6 | $ 45 | $ 41,876 | 597.0 | $ 45 | $ 26,865 | 607.3 | $ 45 | $ 27,326 | 903.6 | $ 45 | $ 40,662 | 31.5 | $ 45 | $ 1,419 |
| Electricity high voltage (m) | underground | 75.7 | $ 300 | $ 22,715 | 0.0 | $ 300 | $ - | 0.0 | $ 300 | $ - | 0.0 | $ 300 | $ - | 8.0 | $ 300 | $ 2,400 |
| overhead | | 1652.6 | $ 55 | $ 90,892 | 967.1 | $ 55 | $ 53,189 | 2332.0 | $ 55 | $ 128,261 | 904.4 | $ 55 | $ 49,742 | 246.8 | $ 55 | $ 13,576 |
| Commercial land (ha) | | 0 | $ 16,672,800 | $ - | 6.5 | $ 16,672,800 | $ 108,557,142 | 0.0 | $ 16,672,800 | $ - | 0.0 | $ 16,672,800 | $ - | 0.0 | $ 16,672,800 | $ - |
| Residential land (ha) | | 8.0 | $ 13,750,000 | $ 109,659,205 | 11.9 | $ 13,750,000 | $ 163,443,906 | 2.2 | $ 5,734,375 | $ 12,395,499 | 0.0 | $ 5,734,375 | $ - | 0.0 | $ - | $ - |
| Development land (ha) | | 0 | $ - | $ - | 0.0 | $ - | $ - | 0.0 | $ - | $ - | 0.0 | $ - | $ - | 0.0 | $ - | $ - |
| Agricultural land (ha) | | 38.3 | $ 25,100 | $ 962,054 | 25.4 | $ 25,100 | $ 638,218 | 19.1 | $ 25,100 | $ 478,765 | 0.0 | $ 25,100 | $ - | 7.6 | $ 25,100 | $ 190,621 |
| Community infrastructure (ha) | | 0.4 | $ 4,395,300 | $ 1,740,176 | 0.0 | $ 4,395,300 | $ - | 13.1 | $ 5,734,375 | $ 74,873,817 | 21.8 | $ 5,734,375 | $ 125,202,335 | 8.7 | $ 5,734,375 | $ 50,155,474 |
| Parks, recreational and conservation areas (ha) | | 4.5 | $ 1,375,000 | $ 6,246,767 | 6.5 | $ 1,375,000 | $ 8,893,491 | 28.7 | $ 573,438 | $ 16,481,455 | 25.8 | $ 573,438 | $ 14,793,549 | 0.1 | $ 573,438 | $ 55,455 |
| Beaches (m) | | 1019 | $ 900 | $ 917,100 | 929 | $ 900 | $ 836,100 | 1131.0 | $ 900 | $ 1,017,900 | 843 | $ 900 | $ 758,700 | 0 | $ 900 | $ - |
| **Total** | | **51** | | **$ 120,558,157** | **50** | | **$ 283,751,946** | **63** | | **$ 106,588,787** | **48** | | **$ 141,561,646** | **16** | | **$ 50,447,956** |

| **Asset classing** | | 6 W. Wetland | | | 7 Locke Drain | | | 8 E. Wetland | | | 9 Buayanup Drain | | | Total | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | area (m2) | unit value of asset | value of sub-area | area (m2) | unit value of asset | value of sub-area | area (m2) | unit value of asset | value of sub-area | area (m2) | unit value of asset | value of sub-area | area (m2) | value of case study area |
| Roads (m) | one lane | 0 | $ 275 | $ - | 0 | $ 275 | $ - | 0 | $ 275 | $ - | 4.0 | $ 275 | $ 1,100 | 4 | $ 1,100 |
| | two or more lanes | 0 | $ 360 | $ - | 16.5 | $ 360 | $ 5,923 | 0 | $ 360 | $ - | 35.9 | $ 360 | $ 12,907 | 5088 | $ 1,831,617 |
| Water (m) | mains | 0 | $ 450 | $ - | 17.7 | $ 450 | $ 7,956 | 0 | $ 450 | $ - | 41.0 | $ 450 | $ 18,462 | 5039 | $ 2,267,551 |
| Electricity low voltage (m) | underground | 0 | $ 150 | $ - | 0.0 | $ 150 | $ - | 0 | $ 150 | $ - | 0.0 | $ 150 | $ - | 386 | $ 57,918 |
| overhead | | 0 | $ 45 | $ - | 0.0 | $ 45 | $ - | 0 | $ 45 | $ - | 27.1 | $ 45 | $ 1,220 | 3097 | $ 139,369 |
| Electricity high voltage (m) | underground | 0 | $ 300 | $ - | 4.0 | $ 300 | $ 1,200 | 0 | $ 300 | $ - | 12.0 | $ 300 | $ 3,609 | 100 | $ 29,925 |
| overhead | | 425.8 | $ 55 | $ 23,422 | 16.4 | $ 55 | $ 900 | 0 | $ 55 | $ - | 104.1 | $ 55 | $ 5,728 | 6649 | $ 365,710 |
| Commercial land (ha) | | 0.0 | $ 16,672,800 | $ - | 0.0 | $ 16,672,800 | $ - | 0 | $ 16,672,800 | $ - | 0.0 | $ 16,672,800 | $ - | 7 | $ 108,557,142 |
| Residential land (ha) | | 0.0 | $ - | $ - | 0.0 | $ - | $ - | 0 | $ - | $ - | 0.0 | $ - | $ - | 22 | $ 285,498,610 |
| Development land (ha) | | 0.0 | $ - | $ - | 0.0 | $ - | $ - | 19.0 | $ 5,734,375 | $ 109,152,059 | 0.1 | $ 5,734,375 | $ 829,293 | 19 | $ 109,981,352 |
| Agricultural land (ha) | | 253.5 | $ 25,100 | $ 6,362,561 | 4.1 | $ 25,100 | $ 103,567 | 72.9 | $ 25,100 | $ 1,829,538 | 1.6 | $ 25,100 | $ 40,070 | 423 | $ 10,605,393 |
| Community infrastructure (ha) | | 1.1 | $ 4,395,300 | $ 4,978,139 | 0.5 | $ 4,395,300 | $ 2,113,705 | 0.0 | $ 4,395,300 | $ - | 1.9 | $ 4,395,300 | $ 8,150,549 | 48 | $ 267,214,196 |
| Parks, recreational and conservation areas (ha) | | 20.4 | $ 573,438 | $ 11,717,069 | 1.0 | $ 573,438 | $ 586,036 | 142.6 | $ 573,438 | $ 81,775,423 | 0.2 | $ 573,438 | $ 139,802 | 230 | $ 140,689,048 |
| Beaches (m) | | 0 | $ 900 | $ - | 47 | $ 900 | $ 42,300 | 0 | $ 900 | $ - | 47 | $ 900 | $ 42,300 | 4016 | $ 3,614,400 |
| **Total** | | **275** | | **$ 23,081,191** | **6** | | **$ 2,861,586** | **235** | | **$ 192,757,020** | **4** | | **$ 9,245,041** | **748** | **$ 930,853,329** |

Figure 9 **Siesta Park/ Marybrook case study sub-areas**




The coastal areas are divided into four. The first two of these when moving from east to west contain the "Holy Mile"; land leased to various church bodies an community organisations, and used primarily for camping and other church group activities. This land is less valuable than the remaining two coastal areas, but this is largely a by-product of its zoning; if the leases were changed, the land would become more valuable immediately, as it was sought for re-development in the same way as other areas along the coast.[62]

The remaining two areas contain more valuable private real estate, particularly in Sub Area 1, where several householders have constructed their own seawalls (which are not always effective). Sub Area 2 also contains a groyne, which has retained sediment within this sub area, to the detriment of Sub Area 3 immediately to its east.

Inland, three of the sub areas (5, 7 and 9) are drainage culverts, which drain run-off from surrounding farmland to the sea. Sub Areas 5 and 9 (Lennox and Buayanup Drain respectively) already have levees, while Sub Area 7 (Locke Drain) does not. Sub Areas 6 and 8 are predominantly low-lying nature reserves or farmland; though there is a school and newly-created residential development just outside the south eastern corner of Sub Area 8, whose expansion would clearly need to be considered in the light of flood risk findings in this report.

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[62] This land is termed "community use in the planning schemes, and we value it according to residential, rather than commercial land in this instance, to take account of its next best alternate use.

### Climate change impacts in the Siesta Park-Marybrook case study

The danger along the coast is erosion, with the model predicting around 300 metres of land vanishing by 2100. This would result in the loss of all of the residential areas and Caves Road. However, an important caveat to the model results is that the results for Busselton may overstate the impacts (see Phase One Report for details

In the Mandurah case study area, seawater flooding had a temporary effect, for the most part, because the areas affected are predominantly residential. Thus, houses are flooded, but can be repaired and rebuilt soon after the flood has finished. Sub Areas 6 and 8 are different because they are agricultural land. If they are flooded by seawater, once the flood waters evaporate, the land is left contaminated by salt, and may be rendered unusable for a number of years. This necessitates a different treatment of the value at risk compared with Mandurah. We explore two different possibilities, either allowing some of the land to become salt-affected and protecting the rest with a levy or pumping freshwater into the low-lying areas to create freshwater lakes and prevent salt-water intrusion.

## Description of options

The options for the different areas are shown in Table 25 below.

For the coastal areas, the options are essentially the same as those for coastal areas in Mandurah, with the exception that we have considered individual sea walls for the affected properties, as many of the properties have sea-frontage, and some are already suing these seawalls on an ad-hoc basis. The difference is that there is not a need to go to the same extent in terms of scale, because the risks are slightly lower, and the number of properties affected are smaller. The only differences between the four areas are that Sub Area 2 already has a groyne, which could be extended, and that differing land values may make retreating a more palatable option in some areas than in others. Also, compared with other case studies, in this case, the affected land is almost entirely privately held (along the coast), which makes it both easier and more appropriate (in an efficient resource allocation sense) for private land-holders to pay for any protection through dedicated levies if the City of Busselton so chooses. A final issue in relation to the coast is Caves Road, which is a major access road which would most likely need to be protected to maintain the integrity of the transport system.

Table 25 **Siesta Park Marybrook options summary**

| Sub Area | Option | Capital Cost | Operating Cost (% capital cost) |
|---|---|---|---|
| Sub area 1 - West of Siesta Park | 1) individual seawalls for each property | $6,700,000 | 1.0% |
| | 2) single seawall across sub-region | $4,800,000 | 1.0% |
| | 3) single large groyne | $4,000,000 | 1.0% |
| | 4) multiple smaller groynes | $2,000,000 | 1.0% |
| Sub area 2 - Siesta Park | 1) individual seawalls for each property | $5,500,000 | 1.0% |
| | 2) single seawall across sub-region | $4,100,000 | 1.0% |
| | 3) extend existing groyne into single large groyne | $3,600,000 | 1.0% |
| | 4) multiple smaller groynes | $1,900,000 | 1.0% |
| Sub area 3 - Locke Estate | 1) individual seawalls for each property | $6,100,000 | 1.0% |
| | 2) single seawall across sub-region | $5,400,000 | 1.0% |
| | 3) single large groyne | $4,300,000 | 1.0% |
| | 4) multiple smaller groynes | $2,500,000 | 1.0% |
| Sub area 4 - W. Buayanup | 1) individual seawalls for each property | $4,900,000 | 1.0% |
| | 2) single seawall across sub-region | $3,800,000 | 1.0% |
| | 3) single large groyne | $3,400,000 | 1.0% |
| | 4) multiple smaller groynes | $1,800,000 | 1.0% |
| Sub area 5 - Lennox Drain | 1) put up gates to prevent storm surges and raise levees | $5,300,000 | 1.0% |
| Sub area 6 - W. Wetland | 1) pump fresh water in to create lakes | $14,600,000 | 1.0% |
| | 2) partition land to seal off lowest lying areas an allow them to become salty | $1,400,000 | 1.0% |
| Sub area 7 - Locke Drain | 1) put up gates to prevent storm surges | $2,000,000 | 1.0% |
| Sub area 8 - E. Wetland | 1) pump fresh water in to create lakes | $13,700,000 | 1.0% |
| | 2) partition land to seal off lowest lying areas and allow them to become salty | $1,400,000 | 1.0% |
| Sub area 9 - Buayanup Drain | 1) put up gates to prevent storm surges and raise levees | $3,000,000 | 1.0% |

*Data source:* Damara WA

Inland, the flooding problem presents a different set of options. In the first instance, Sub Areas 5, 7 and 9 would need gates at their mouths to prevent storm surges sending salt water inland. Sub Areas 5 and 9 may also need to have their levees improved to maintain their integrity.

For Sub Areas 6 and 8, there are two options. One is to compartmentalise them, sealing off part of each (the lowest part) and allowing salt water to intrude into that part as sea levels rise,[63] but protecting the other part (which is higher ground, and where the farmland is) from salt water intrusion. A second

[63] Pushing salt water inland underground.

is to pump fresh water from the drains into the low-lying parts to prevent salt-water intrusion from underground and to turn the wetlands into lakes. Each would result in some land being sacrificed in order to save another portion of land.

### Options and optimal timing results

The model results are shown in Table 26.

Table 26 **Siesta Park-Marybrook viable options summary**

| Sub area | Option | Capital cost | OPEX | Optimal Year | Net benefit | % let expire scenarios |
|---|---|---|---|---|---|---|
| Sub area 1 - West of Siesta Park | 3 | $4,000,000 | $40,000 | 4 | $5,639,000 | 13.00% |
| | 4 | $2,000,000 | $20,000 | 4 | $7,844,000 | 7.80% |
| Sub area 2 - Siesta Park | 3 | $3,600,000 | $36,000 | 15.5 | $5,940,000 | 10.50% |
| | 4 | $1,900,000 | $19,000 | 15.5 | $7,122,000 | 3.90% |
| Sub area 3 - Locke Estate | 4 | $2,500,000 | $25,000 | 37 | $652,000 | 56.40% |
| Sub area 4 - W. Buayanup | 3 | $3,400,000 | $34,000 | 4 | $5,842,000 | 13.80% |
| | 4 | $1,800,000 | $18,000 | 4 | $7,578,000 | 9.70% |
| Sub area 5 - Lennox Drain | 1 | $5,300,000 | $53,000 | 14 | $2,158,000 | 0.00% |
| Sub area 8 - E. Wetland | 1 | $13,700,000 | $137,000 | 1 | $51,967,000 | 0.00% |
| | 2 | $1,400,000 | $14,000 | 1 | $67,188,000 | 0.00% |

Like Mandurah, there is a division between the coastal areas (Sub areas 1,2,3 and 4) subject to erosion, and the inland areas subject to flooding and salt-water incursion.

For the coastal areas, Sub Area 1, 2 and 4 each have two options that are viable, and Sub Area 3 has one. The lifespan of these options is the same in each case, and within each sub area, each optimally begins at the same time. Since the choice is between one or the other, there is no scope for staging or combining the options.

In this situation, the most obvious was in which to make the choice is by which provides the greatest net benefit. In each case the difference between the better case and the less favourable case is around $2 million. In each of the sub areas, it is the fourth option that is most valuable. It is also the least costly option in each instance, making it the obvious choice.

In each of the coastal areas, it is important to consider how much erosion might occur in the interim before the optimal response is made. This is particularly the case for Sub Areas 2 and 3, where the optimal time to invest is 15 and 37 years respectively. Fortunately, in both of these areas, there is existing protection which is sufficient to withstand the erosive pressures during these timeframes; a groyne (somewhat degraded) in Sub Area 2, and a training wall in Sub Area 3. For this reason, there is no need to consider interim measures in either of these areas.

For the inland areas, the model shows only two areas where it is worthwhile making an investment in one of the protection options. These are Sub-Area 5 and Sub Area 8. In the Lennox drain (but not the other two, there is an economic case for spending $5.3 million in 14 years to raise levees and put up storm gates to prevent storm surges. This provides a net benefit, in NPV terms, of around $2 million.

The case is much stronger in Sub Area 8, where the investment is either $13.7 million or $1.4 million up front, and the benefits are $52 or $67 million (respectively).[64] In both cases, the model suggests an immediate investment. However, since the same effect is obtained from each investment, this motivates spending the smaller sum.

In the case of Sub Area 8, it is important to understand what is driving value. There are around 19 hectares of development land in the south-east corner of the area which, based on our value schema, has been valued at the same rate as residential land in Sub Areas 3 and 4 on the coast.[65] There are also 142 hectares of parkland which are valued in the model at ten per cent of residential land. In this instance, the parkland is not interwoven with residential land, but is part of a regional reserve, and we suspect that ten per cent of residential value is likely to be too high for this particular parkland. The practical upshot of this discussion is that, instead of taking Option 2 in Sub Area 8, the Local Government could simply fill the development land to an appropriate level to protect it from flooding. Since this land has the highest elevation in the Sub Area, this would not be very costly; initial discussions with Damara suggest a cost of around $500,000.[66] Although Option 2 is optimal in a modelling sense, this additional option may in fact derive more value per dollar of investment by the City of Busselton.

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64 Note that the costs of the options are the engineering costs of building the levees in the case of Option 2, and do not include the cost of land lost to productive use by salt incursion; the levee would only partially protect the land. This is because it is not clear at this stage precisely where the levee would go, and thus how much land would be sacrificed. Given the high net value of Option 2 relative to its cost, accounting for this cost would likely not change the decision, but it would reduce the value of this decision.

65 Much of the area in question is planned for a residential sub-division.

66 We understand that this may already be planned as part of the development of this area. We understand further that the development of the planned Vasse-Dunsborough road link in the future may also involve raising part of the area.

It is worth noting that, even if Option 2 is chosen for Sub Area 8, the net effect in the case study area as a whole will be to not protect the lower-lying agricultural land in the area, which could be subject to salt-incursion. From an economic perspective, the land is not sufficiently value in its use as agricultural land to warrant the rather costly protection measures that would be required. This is an issue which would need to be considered by the City of Busselton in more detail, as to whether there are sufficient non-economic reasons to warrant spending the funds necessary to save the relevant farmland. This investigation ought to also consider in more detail how much farmland would need to be sacrificed, which has not been possible in this study.

### Formulation of options pathways

Each sub area has a single option which is viable or, where there are two viable options, they are substitutes rather than complements. For this reason, it is not necessary to consider pathways comprising combinations of options.

## 5.4 Case Study Three: Peppermint Grove Beach

The third case study is the settlement of Peppermint Grove Beach. The case study area runs from the area of agricultural land (Stirling Estate) just to the north of the settlement, down to Higgins Cut at the southern end of the settlement, and inland to approximately Ludlow Road North, taking in the low-lying land immediately behind the dunes upon which the settlement is built. The case study area has been divided into seven sub sections which are summarised in Table 27 and shown in Figure 10.

## Table 27 Summary of asset values in Peppermint Grove Beach

| Asset classing | | 1 Northern wetlands | | | 2 Levee system | | | 3 Southern wetlands | | | 4 Higgins Cut | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | area (m2) | unit value of asset | value of sub-area | area (m2) | unit value of asset | value of sub-area | area (m2) | unit value of asset | value of sub-area | area (m2) | unit value of asset | value of sub-area |
| Roads (m) | one lane | 0 | $ 275 | $ - | 0 | $ 275 | $ - | 4267.2 | $ 275 | $ 1,173,480 | 0 | $ 275 | $ - |
| | two or more lanes | 522.6 | $ 360 | $ 188,136 | 271.4 | $ 360 | $ 97,704 | 1415.9 | $ 360 | $ 509,724 | 160.3 | $ 360 | $ 57,708 |
| Water (m) | retic | 0 | $ 428 | $ - | 0 | $ 428 | $ - | 145.6 | $ 428 | $ 62,244 | 0 | $ 428 | $ - |
| Electricity low voltage (m) | underground | 0 | $ 150 | $ - | 0 | $ 150 | $ - | 115.6 | $ 150 | $ 17,340 | 0 | $ 150 | $ - |
| overhead | | 0 | $ 45 | $ - | 0 | $ 45 | $ - | 72.1 | $ 45 | $ 3,245 | 0 | $ 45 | $ - |
| Electricity high voltage (m) | underground | 0 | $ 300 | $ - | 0 | $ 300 | $ - | 1004.1 | $ 300 | $ 301,230 | 0 | $ 300 | $ - |
| overhead | | 552.6 | $ 55 | $ 30,393 | 163.2 | $ 55 | $ 8,976 | 2484.5 | $ 55 | $ 136,648 | 162.9 | $ 55 | $ 8,960 |
| Residential land (ha) | | 0 | $ - | $ - | 0 | $ - | $ - | 2.6 | $ 6,250,000 | $ 16,250,000 | 3.6 | $ 6,250,000 | $ 22,500,000 |
| Rural land (ha) | | 95.7 | $ 33,500 | $ 3,205,950 | 11.7 | $ 33,500 | $ 391,950 | 395 | $ 33,500 | $ 13,232,500 | 17.8 | $ 33,500 | $ 596,300 |
| Agricultural land (ha) | | 4.8 | $ 33,500 | $ 159,982 | 3.3 | $ 33,500 | $ 110,640 | 0 | $ 33,500 | $ - | 0 | $ 33,500 | $ - |
| Community infrastructure (ha) | | 0 | $ - | $ - | 0 | $ 6,250,000 | $ - | 11.7 | $ 6,250,000 | $ 6,766,875 | 0 | $ 6,250,000 | $ - |
| Parks, recreational and conservation areas (ha) | | 45.5 | $ 625,000 | $ 28,437,500 | 21.2 | $ 625,000 | $ 13,250,000 | 67.82773 | $ 625,000 | $ 42,392,333 | 11.6 | $ 625,000 | $ 7,250,000 |
| Beaches (m) | | 780 | $ 900 | $ 702,000 | 353 | $ 900 | $ 317,700 | 0 | $ 900 | $ - | 212 | $ 900 | $ 190,800 |
| **Total** | | **146** | | **$ 32,723,961** | **36** | | **$ 14,176,970** | **477** | | **$ 80,845,618** | **33** | | **$ 30,603,768** |

| Asset classing | | 5 North Pepp Grove | | | 6 Central Pepp Grove | | | 7 South Pepp Grove | | | Total | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | area (m2) | unit value of asset | value of sub-area | area (m2) | unit value of asset | value of sub-area | area (m2) | unit value of asset | value of sub-area | area (m2) | value of case study area |
| Roads (m) | one lane | 2713.7 | $ 275 | $ 746,268 | 2981.1 | $ 275 | $ 819,803 | 1760.6 | $ 275 | $ 484,165 | 11723 | $ 3,223,715 |
| | two or more lanes | 0 | $ 360 | $ - | 0 | $ 360 | $ - | 0 | $ 360 | $ - | 2370 | $ 853,272 |
| Water (m) | retic | 2994.3 | $ 428 | $ 1,280,063 | 3564.3 | $ 428 | $ 1,523,738 | 1988.2 | $ 428 | $ 849,956 | 8692 | $ 3,716,001 |
| Electricity low voltage (m) | underground | 3190.1 | $ 150 | $ 478,515 | 1966.2 | $ 150 | $ 294,930 | 2294.6 | $ 150 | $ 344,190 | 7567 | $ 1,134,975 |
| overhead | | 993.2 | $ 45 | $ 44,694 | 2043.3 | $ 45 | $ 91,949 | 446.9 | $ 45 | $ 20,111 | 3556 | $ 159,998 |
| Electricity high voltage (m) | underground | 821 | $ 300 | $ 246,300 | 667.5 | $ 300 | $ 200,250 | 404.6 | $ 300 | $ 121,380 | 2897 | $ 869,160 |
| overhead | | 509.1 | $ 55 | $ 28,001 | 1496 | $ 55 | $ 82,280 | 189.1 | $ 55 | $ 10,401 | 5557 | $ 305,657 |
| Residential land (ha) | | 23.6 | $ 6,250,000 | $ 147,500,000 | 19.1 | $ 6,250,000 | $ 119,375,000 | 10.3 | $ 6,250,000 | $ 64,375,000 | 59 | $ 370,000,000 |
| Rural land (ha) | | 10.1 | $ 33,500 | $ 338,350 | 0 | $ 33,500 | $ - | 23.3 | $ 33,500 | $ 780,550 | 554 | $ 18,545,600 |
| Agricultural land (ha) | | 5.4 | $ 33,500 | $ 181,992 | 5.2 | $ 33,500 | $ 174,047 | 6.57 | $ 33,500 | $ 220,059 | 25 | $ 846,720 |
| Community infrastructure (ha) | | 0 | $ 6,250,000 | $ - | 0.6 | $ 6,250,000 | $ 3,750,000 | 0.1 | $ 6,250,000 | $ 625,000 | 12 | $ 11,141,875 |
| Parks, recreational and conservation areas (ha) | | 17.3 | $ 625,000 | $ 10,812,500 | 3.5 | $ 625,000 | $ 2,187,500 | 31.3 | $ 625,000 | $ 19,562,500 | 198 | $ 123,892,333 |
| Beaches (m) | | 1151 | $ 900 | $ 1,035,900 | 899 | $ 900 | $ 809,100 | 1484 | $ 900 | $ 1,335,600 | 4879 | $ 4,391,100 |
| **Total** | | **56** | | **$ 162,692,582** | **28** | | **$ 129,308,596** | **72** | | **$ 88,728,911** | **849** | **$ 539,080,405** |

Figure 10 **Peppermint Grove beach case study areas**


Sub Areas 1 and 3 takes in two low-lying agricultural and wetland areas to the north of the settlement and between it and the Ludlow Tuart Forest. Sub Area 2 takes in land immediately adjacent to the Capel River that flows into the ocean immediately to the north of the settlement, and Sub Area 4 takes in Higgins Cut south of the settlement which is a potential pathway for salt water to flow from the ocean to the low-lying land behind the dunes system. The settlement itself is divided into three sub areas; 5, 6 and 7. Almost all of this land is residential or rural, with a small amount of community infrastructure which further inspection shows is a disused caravan park site. This is currently on the market for $1.6 million, but the real estate agent selling the property notes that it was valued at twice this value a few years ago by a valuer.[67] We have used the figure of $3.2 million rather than multiplying the area by a per square metre figure for commercial land (as we have done elsewhere) because the sale value is a more realistic indication than a proxy.

### Climate change impacts in the Peppermint Grove case study

For the settlement itself, erosion is the key risk, with up to 300 metres of land being at risk of erosion by 2100. This would result in the entire settlement disappearing without intervention.

[67] See www.summitbunbury.com.au/pol/property/search.asp?f_propertyID=1896631&xsl=4863&f_st=1&f_ct=12&f_ps=2

Behind the settlement, the main risk is of flooding, which could come through Higgins Cut in the south, or through underground salt water intrusion as sea levels rise; the land is only one or two metres above current sea levels. The access road for the settlement also transverses this land.

## Description of options

The options for the different areas are shown in Table 28 below.

Table 28 **Peppermint Grove options summary**

| | Option | Capital Cost | Operating Cost (% capital cost) |
|---|---|---|---|
| Sub area 1 - Northern wetlands | 1) Encourage dune growth to protect coast (dune fencing to pinch point north of study area). Maintain dune buffer by building groynes (to pinch point north of study area). Pump water to turn freshwater system into a lake. | $22,630,000 | 1.7%* |
| Sub area 2 - Levee system | 1) Levee and weir controls (upgrade) | $3,100,000 | 5% |
| Sub area 3 - Southern wetlands | 1) Encourage dune growth in southern part to protect coast (dune fencing to pinch point south of study area). Maintain dune buffer by building groynes (to pinch point south of study area). Raise access road to town. Pump water to turn freshwater system into a lake. | $22,485,000 | 1.7%* |
| | 2) Encourage dune growth in southern part to protect coast (dune fencing). Maintain dune buffer by building groynes (to pinch point south of study area). Raise access road to town. Subdivide into cells to prevent salt-water flow | $10,285,000 | 1.0%* |
| Sub area 4 - Higgins Cut | 1) Fill the channel to the beach | $780,000 | 0% |
| Sub area 5 - North Pepp Grove | 1) build groynes and manage dunes | $2,032,760 | 1% |
| Sub area 6 - Central Pepp Grove | 1) build groynes and manage dunes | $1,649,432 | 1% |
| Sub area 7 - South Pepp Grove | 1) build groynes and manage dunes | $1,649,432 | 1% |

*Note:* entries marked with a * are those where the individual elements have different operating costs and a weighted average of the different elements is shown

*Data source:* Damara WA

The two areas of agricultural and wetlands (Sub Areas 1 and 3) have similar issues and solutions as the similar lands in the Busselton-Marybrook case study above. That is, they can be divided into cells, with some cells sacrificed to salt intrusion, or they can have fresh water pumped into them (from the Capel River) to create a freshwater lake system that prevents salt water intrusion.[68]

[68] Note that the cost of raising the access road to town is a marginal cost. That is, it is the additional cost of raising the road when it is next due for upgrading or replacement as part of its asset management programme.

For this to be successful would require levees and weir controls on the Capel River in Sub Area 2, and would also require Higgins Cut in Sub Area 4 to be filled in. If this is not filled in, then there will be a risk of salt water flooding of Sub Area 3, regardless of whether a freshwater lake system is created or not. The culvert could be filled in through man-made engineering, or it could be closed by encouraging a dune to form in the area by building a small groyne. The former is a short-term and the latter a longer-term option.

The three sub areas within the settlement could be protected by installing groynes at the appropriate time to hold sand on the beach and prevent erosion. This would involve beginning in Sub Area 5 in the north of the settlement, and moving progressively south with new groynes. The dune area would also require active management by both the Council and by local residents, to prevent blowouts threatening the viability of the dune systems. Part of this management would also include relocation of beach-side carparks as the beach and dune systems change; up to a dozen times during the course of the current century.

### Options and optimal timing results

The viable options for Peppermint Grove Beach are shown in Table 29.

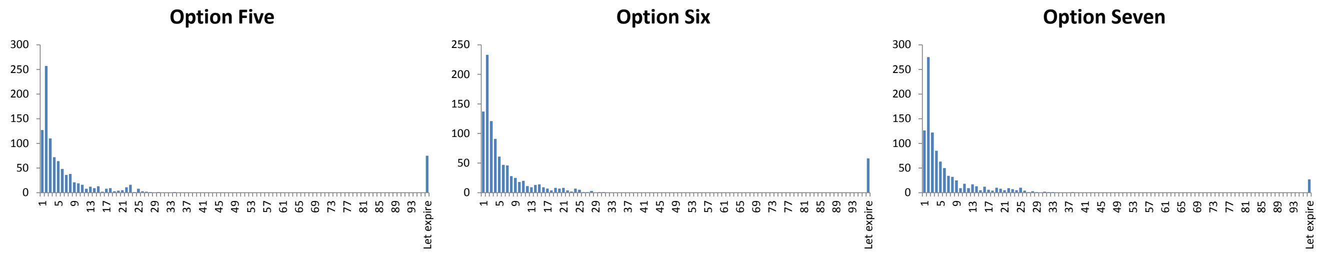
Table 29 **Peppermint Grove Beach viable options summary**

| Sub area | Option | Capital cost | OPEX | Optimal Year | Net benefit | % let expire scenarios |
|---|---|---|---|---|---|---|
| Sub area 3 - Southern wetlands | 2 | $10,285,000 | $100,000 | 2 | $5,240,000 | 1.70% |
| Sub area 4 - Higgins Cut | 1 | $780,000 | $- | 1 | $4,046,000 | 0.00% |
| Sub area 5 - North Pepp Grove | 1 | $2,032,760 | $20,328 | 5.5 | $17,474,000 | 7.50% |
| Sub area 6 - Central Pepp Grove | 1 | $1,649,432 | $16,494 | 5.5 | $14,030,000 | 5.80% |
| Sub area 7 - South Pepp Grove | 1 | $1,649,432 | $16,494 | 5.5 | $10,451,000 | 2.70% |

As with the previous two case studies, there is a division between coastal assets affected by erosion, and inland assets affected by flooding.

In the case of coastal assets, the solution is the same in each of the three Sub Area 5,6 and 7; build the groynes in the middle of the fifth year. The net benefit from doing so is $17, $14 and $10 million respectively. Moreover, the distribution around this mean is very tight, suggesting a good degree of confidence around these findings. This is shown in Figure 11.

Figure 11 **Optimal timing distribution for Options 5, 6 and 7 – Peppermint Grove Beach**




There is no existing protection at Peppermint Grove, and by the fifth year of our time period, 3.5 per cent of each of these coastal assets will have been eroded. Based on the model results, the community has two choices; either let the erosion happen or begin building the groynes earlier in a staged process. Within the sub areas in question, the erosion zone is roughly 375 metres wide, meaning that 3.5 per cent of it is roughly 13 metres wide. The beach itself, looking from Google Earth, is 65 metres wide.[69] Thus, one option could be to simply allow some of the beach to disappear; no residential properties would be in danger.

The other option is to stage the groynes, building one third of the total in Sub Area 5, and one half in Sub Areas 6 and 7. This would incur a cost of $680,000 for Sub Area5, and $820,000 in Sub Areas 6 and 7. The optimal time to do so would not change much from the full option, meaning it would not save much erosion. However, it would mean that the second stage could be delayed for 30 years, rather than being done immediately. Thus, costs would be saved.

[69] There is no way of knowing whether the Google Earth image was taken at high or low tide.

Box 6 **The decision tool and counter-intuitive results**

When the model results were presented at the draft report stage, it was noted by PNP Senior Officers that the rapid timeframe for construction at Peppermint Grove Beach did not match local understanding of the nature of the erosion threat in the region. We therefore examined some different assumptions in the model to ascertain what might have caused these counter-intuitive results.

The real options model works by comparing (in each scenario, and for each option) a current year outcome with the expectation of an outcome in the following year, choosing a current year for action if it produces a better outcome than is expected in the following period. This bilateral comparison is done in each period, and thus there may be several years in a given scenario where acting in a current year is better than waiting. In the context of a profit-maximising private-sector operator, the time at which the difference between the current year outcome and waiting is greatest is the logical "best" timing for that scenario, if there are several years where current action is preferred over waiting. However, government is not (necessarily) a profit-maximiser, and is likely to choose to err on the side of caution. Thus, in all of the modelling in this report, we chose the first time that a current period was better than an expectation of the future as being the best time to act. In this way, government does not waste resources by acting too early, but nor does it run the risk of leaving action too late. The practical upshot of doing so, however, is that the timing for action is biased towards the present.

For this reason, we re-ran the Peppermint Grove Beach case study, redefining "best" to mean the time when the difference between a current period and an expectation of the future is maximised (a "profit-maximising" case) and the last time in the 100-year timeframe when acting in a current period is better than waiting (a "last-minute" scenario). In areas subjecting to flooding, such as Sub-Area 3, this resulted in a significant change in timing; from the second to the 20$^{th}$ year in the case of Sub Area 3. However, for those areas subject to erosion, changes were minor; from five to nine years in each of Sub Areas 5, 6 and 7.

Two conclusions might be drawn from this. The first is that the case for immediate action is very strong, as all three definitions of "best" give broadly similar results. The second is that the underlying data which are used in the erosion models from the Phase One report are problematic. We consider the latter to be more likely; in the case of Peppermint Grove Beach, there are no data on precisely where rock lies along the coast, and the model in the Phase One report has thus assumed no rock. This has the effect of greatly amplifying the amount of erosion. For this reason, we would suggest that, in the case of Peppermint Grove Beach, the first action should be to collect more of the basic data needed for the engineering models, rather than commencing construction of groynes. Time limitations restricted a similar exercise for other case study areas, but we suspect the data availability issue may be more pervasive (see Phase One report for details).

In the case of inland assets, there is no economic justification for protecting the northern wetlands or the levee, as the cost of doing so is larger than the reduction in value at risk.[70] This is not the case for the southern wetlands, or

[70] In this context, it is worth noting that the levee is capable of handling a 50-year flood risk event, but there are insufficient benefits in upgrading it to handle a 100-year flooding event.

Higgins Cut. In the former case, this is because the southern wetlands have an option which does not require pumping water to maintain a freshwater lake (not available north of the levee) which halves the protection cost. It should be noted that it would be necessary to install protection at Higgins Cut if the southern wetlands were worth protecting, because failure to do so would allow salt water incursion through the cut in times of storm. The model suggests that both the southern wetlands and Higgins Cut ought to have protecting applied in the next couple of years, and that doing so would have a net benefit of between $4 and $5 million. In both cases, the distribution around the mean optimal year was very tight, suggesting confidence in these results.

Note that, as in Siesta Park-Marybrook, the protection in the southern wetlands involves the sacrifice of some land and, since the exact position of the relevant protection measures has not been identified at this stage, we have not included the cost (or value lost) of this land being affected by salt-incursion. In this instance, since the net benefits are much lower than was the case in Siesta Park-Marybrook, this may change the protection decision once the location of the relevant protection measures are finalised. Note also that the no-protect decision for the northern wetlands would involve the sacrifice of agricultural land whose value does not warrant protection in an economic sense. In this instance, if the community believed the land was worth protecting, it would need to consider much larger protection costs than in Siesta Park-Marybrook.

### Formulation of options pathways

Aside from the potential to stage the construction of groynes to avoid an initial loss of 3.5 per cent of the land to erosion, there are no pathways for options in the case study area; each sub area has a single option which is viable.

## 5.5 Case Study Four: Eaton-Collie River

This case study are covers Eaton, Pelican Point and the southern extremity of Australind, up to the intersection between Elizabeth St and the Old Coast Road. It follows the Collie River around the first major bend from the river mouth and ends roughly at the highway to the East. The case study area includes the Leschenault Peninsula, and includes three Local Government areas; the City of Bunbury and the Shires of Harvey and Dardenup. The case study area has been divided into nine sub sections which are described in Table 30 and shown in Figure 12.

## Table 30 Summary of asset values in Eaton-Australind

| Asset classing | | 1 Leschenault Peninsula | | | 2 Pelican Point | | | 3 Sth Pelican Point | | | 4 Sporting Precinct | | | 5 Bridge & Commercial | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | area (m2) | unit value of asset | value of sub-area | area (m2) | unit value of asset | value of sub-area | area (m2) | unit value of asset | value of sub-area | area (m2) | unit value of asset | value of sub-area | area (m2) | unit value of asset | value of sub-area |
| Roads (m) | one lane | 0 | $ 275 | $ - | 2426.6 | $ 275 | $ 667,317 | 2991.5 | $ 275 | $ 822,655 | 747.59 | $ 275 | $ 205,588 | 505.5 | $ 275 | $ 139,007 |
| | two or more lanes | 1783.9 | $ 360 | $ 642,204 | 993.5 | $ 360 | $ 357,650 | 2393.5 | $ 360 | $ 861,647 | 2176.28 | $ 360 | $ 783,461 | 2670.6 | $ 360 | $ 961,403 |
| Railways (m) | | 417.1 | $ 2,325 | $ 969,758 | 0.0 | $ 2,325 | $ - | 0.0 | $ 2,325 | $ - | 0.00 | $ 2,325 | $ - | 0.0 | $ 2,325 | $ - |
| Water (m) | retic | 0 | $ 428 | $ - | 2883.8 | $ 428 | $ 1,232,827 | 4424.1 | $ 428 | $ 1,891,304 | 2676.27 | $ 428 | $ 1,144,104 | 1894.0 | $ 428 | $ 809,671 |
| Sewerage | pressure main | 0 | $ 200 | $ - | 0.0 | $ 200 | $ - | 202.3 | $ 200 | $ 40,459 | 530.92 | $ 200 | $ 106,183 | 0.0 | $ 200 | $ - |
| | gravity pipes | 0 | $ 190 | $ - | 3265.3 | $ 190 | $ 620,398 | 4522.4 | $ 190 | $ 859,258 | 2183.73 | $ 190 | $ 414,908 | 913.0 | $ 190 | $ 173,463 |
| Electricity low voltage (m) | underground | 1.1 | $ 150 | $ 165 | 5247.3 | $ 150 | $ 787,100 | 6801.8 | $ 150 | $ 1,020,269 | 1159.21 | $ 150 | $ 173,881 | 1325.7 | $ 150 | $ 198,856 |
| | overhead | 107.5 | $ 45 | $ 4,838 | 0.0 | $ 45 | $ - | 0.0 | $ 45 | $ - | 1999.80 | $ 45 | $ 89,991 | 2072.6 | $ 45 | $ 93,268 |
| Electricity high voltage (m) | underground | 788 | $ 300 | $ 236,400 | 1404.7 | $ 300 | $ 421,424 | 635.8 | $ 300 | $ 190,750 | 150.86 | $ 300 | $ 45,257 | 124.6 | $ 300 | $ 37,373 |
| | overhead | 714.2 | $ 55 | $ 39,281 | 143.0 | $ 55 | $ 7,867 | 989.2 | $ 55 | $ 54,408 | 1005.25 | $ 55 | $ 55,289 | 2054.4 | $ 55 | $ 112,994 |
| Gas pipelines (m) | | 0 | $ 90 | $ - | 6172.2 | $ 90 | $ 555,495 | 10593.8 | $ 90 | $ 953,445 | 4314.69 | $ 90 | $ 388,323 | 4892.2 | $ 90 | $ 440,300 |
| Commercial land (ha) | | 0 | $ 7,049,300 | $ - | 0.0 | $ 7,049,300 | $ - | 0.0 | $ 7,049,300 | $ - | 0.00 | $ 7,049,300 | $ - | 15.1 | $ 7,049,300 | $ 106,535,618 |
| Residential land (ha) | | 0 | $ - | $ - | 12.1 | $ 6,203,125 | $ 74,866,492 | 15.9 | $ 6,203,125 | $ 98,324,365 | 0.00 | $ 4,462,500 | $ - | 2.3 | $ - | $ - |
| Agricultural land (ha) | | 124.84592 | $ 17,200 | $ 2,147,350 | 0.0 | $ 17,200 | $ - | 0.5 | $ 17,200 | $ 7,958 | 1.48 | $ 17,200 | $ 25,440 | 4.2 | $ 17,200 | $ 71,404 |
| Community infrastructure (ha) | | 0 | $ 7,049,300 | $ - | 1.2 | $ 7,049,300 | $ 8,576,469 | 1.9 | $ 7,049,300 | $ 13,051,262 | 0.00 | $ 7,049,300 | $ - | 14.4 | $ 7,049,300 | $ 101,475,613 |
| Parks, recreational and conservation areas (ha) | | 176.22147 | $ 620,313 | $ 109,312,378 | 12.4 | $ 620,313 | $ 7,672,186 | 29.3 | $ 620,313 | $ 18,190,447 | 13.83 | $ 446,250 | $ 6,173,334 | 45.6 | $ 446,250 | $ 20,349,006 |
| Beaches (m) | | 3426 | $ 900 | $ 3,083,400 | 0.0 | $ 900 | $ - | 0.0 | $ 900 | $ - | 0.00 | $ 900 | $ - | 0.0 | $ 900 | $ - |
| Total | | **301** | | **$ 116,435,773** | **26** | | **$ 95,765,224** | **47** | | **$ 136,268,229** | **15** | | **$ 9,605,760** | **82** | | **$ 231,397,976** |

| Asset classing | | 6 Sth Australind Commercial | | | 7 North Eaton/ South Australind | | | 8 Eaton | | | 9 Proposed Development N | | | Total | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | area (m2) | unit value of asset | value of sub-area | area (m2) | unit value of asset | value of sub-area | area (m2) | unit value of asset | value of sub-area | area (m2) | unit value of asset | value of sub-area | area (m2) | value of case study area |
| Roads (m) | one lane | 361.1 | $ 275 | $ 99,307 | 157.8 | $ 275.00 | $ 43,387.37 | 2,158.4 | $ 275 | $ 593,568 | 17.8 | $ 275 | $ 4,908 | 9,366 | $ 2,575,737 |
| | two or more lanes | 2,195.3 | $ 360 | $ 790,296 | 7,684.9 | $ 360 | $ 2,766,559.44 | 4,546.0 | $ 360 | $ 1,636,575 | 0.0 | $ 360 | $ - | 24,444 | $ 8,799,795 |
| Railways (m) | | 0.0 | $ 2,325 | $ - | 0.0 | $ 2,325 | $ - | 0.0 | $ 2,325 | $ - | 0.0 | $ 2,325 | $ - | 417 | $ 969,758 |
| Water (m) | retic | 2,431.0 | $ 428 | $ 1,039,244 | 11,930.0 | $ 428 | $ 5,100,089.87 | 8,374.1 | $ 428 | $ 3,579,937 | 472.8 | $ 428 | $ 202,114 | 35,086 | $ 14,999,291 |
| Sewerage | pressure main | 921.8 | $ 200 | $ 184,370 | 600.3 | $ 200 | $ 120,069.52 | 1,478.3 | $ 200 | $ 295,660 | 0.0 | $ 200 | $ - | 3,734 | $ 746,742 |
| | gravity pipes | 1,644.1 | $ 190 | $ 312,386 | 12,975.5 | $ 190 | $ 2,465,340.87 | 7,490.8 | $ 190 | $ 1,423,250 | 6.5 | $ 190 | $ 1,232 | 33,001 | $ 6,270,235 |
| Electricity low voltage (m) | underground | 307.9 | $ 150 | $ 46,179 | 489.6 | $ 150 | $ 73,434.79 | 5,511.3 | $ 150 | $ 826,690 | 0.0 | $ 150 | $ - | 20,844 | $ 3,126,576 |
| | overhead | 1,636.7 | $ 45 | $ 73,651 | 7,438.4 | $ 45 | $ 334,727.22 | 3,202.1 | $ 45 | $ 144,094 | 0.0 | $ 45 | $ - | 16,457 | $ 740,569 |
| Electricity high voltage (m) | underground | 202.8 | $ 300 | $ 60,827 | 39.6 | $ 300 | $ 11,865.86 | 2,132.6 | $ 300 | $ 639,787 | 200.3 | $ 300 | $ 60,095 | 5,679 | $ 1,703,779 |
| | overhead | 1,505.5 | $ 55 | $ 82,803 | 2,642.3 | $ 55 | $ 145,327.44 | 208.4 | $ 55 | $ 11,462 | 780.5 | $ 55 | $ 42,927 | 10,043 | $ 552,358 |
| Gas pipelines (m) | | 5,647.8 | $ 90 | $ 508,304 | 18,843.9 | $ 90 | $ 1,695,951.97 | 13,752.9 | $ 90 | $ 1,237,764 | 0.0 | $ 90 | $ - | 64,218 | $ 5,779,583 |
| Commercial land (ha) | | 0.2 | $ 2,769,700 | $ 568,048 | 0.1 | $ 7,049,300 | $ 959,356.62 | 0.0 | $ 7,049,300 | $ - | 0.0 | $ 7,049,300 | $ - | 15 | $ 108,063,022 |
| Residential land (ha) | | 7.2 | $ - | $ - | 43.5 | $ - | $ - | 0.0 | $ 4,462,500 | $ - | 0.0 | $ - | $ - | 81 | $ 173,190,858 |
| Agricultural land (ha) | | 1.6 | $ 17,200 | $ 27,404 | 0.2 | $ 17,200 | $ 3,096.59 | 0.4 | $ 17,200 | $ 6,337 | 0.0 | $ 17,200 | $ 62 | 133 | $ 2,289,052 |
| Community infrastructure (ha) | | 0.0 | $ 2,769,700 | $ - | 5.7 | $ 7,049,300 | $ 40,151,387.00 | 0.0 | $ 7,049,300 | $ - | 0.0 | $ 7,049,300 | $ - | 23 | $ 163,254,731 |
| Parks, recreational and conservation areas (ha) | | 10.9 | $ 446,250 | $ 4,871,227 | 15.1 | $ 446,250 | $ 6,733,979.72 | 20.3 | $ 446,250 | $ 9,061,797 | 84.5 | $ 446,250 | $ 37,698,227 | 408 | $ 220,062,582 |
| Beaches (m) | | 0.0 | $ 900 | $ - | 0.0 | $ 900 | $ - | 0.0 | $ 900 | $ - | 0.0 | $ 900 | $ - | 3,426 | $ 3,083,400 |
| Total | | **20** | | **$ 8,664,046** | **65** | | **$ 60,604,574.28** | **21** | | **$ 19,456,920** | **84** | | **$ 38,009,565** | **661** | **$ 716,208,067** |

Figure 12 **Eaton-Australind case study sub-areas**


Sub Area 1 covers the Leschenault Peninsula itself. Sub Area 2 covers the residential area on Pelican Point, while Sub Area 3 covers the Sanctuary Golf Course and residential areas between it and the estuary. Sub Are 4 covers Eaton Sports Ground. Sub Areas 5 and 6 cover the area on the estuary north of the Collie River up to the southern extremity of Australind. Sub Areas 7 and 8 cover residential areas east of the Clifton Community Reserve on the north shore of the river and Lions Park on the southern shore. Sub Area 9 covers the riverside land, presently unsettled but slated for development, up to the first major bend in the Collie River.

### Climate change impacts in the Eaton-Collie River case study

The aspect of this case study area which differs from the remainder is the nature of erosion. According to the climate modelling, the Leschenault Peninsula will be eroded right at the very end of the case study period, in 2100. Thus, for the entirety of the case study period, it will offer protection to the estuary and associated settlements, meaning that all suffer an increase in flood risk, but no increase in erosion risk. The adaptation options developed below have been developed with this in mind, and should be considered as such. If the peninsula begins to erode faster than the model predicts, then there may be a need to consider measures to alleviate erosion on the peninsula which we do not consider here. However, it will likely be many decades before such considerations are needed.

Within the estuary, the main impact is from increased flooding risk. This is important because many developments, particularly the canal estates in Sub

Area 2 are low-lying and already subject to flood risk. Moreover, new development is proposed in several areas within the case study area. The need to consider action is thus somewhat more urgent than is the case in other case study areas.

### Description of options

The options for the different areas are shown in Table 31 below.

Table 31 **Summary of options in Eaton-Australind**

| Sub Area | Option | Capital Cost | Operating Cost (% capital cost) |
|---|---|---|---|
| Sub area 2 - Pelican Point | 1) Crest wall. Rock Revetment surrounding Pelican Point. Large seawall around exposed section of Pelican Point | $7,700,000 | 1.23%* |
| | 2) Minimum fill for existing and new houses to raise them (progressive - at the end of each houses life span). Rock Revetment surrounding Pelican Point. Large seawall around exposed section of Pelican Point | $12,900,000 | 0.48%* |
| | 3) Fully fill existing and new houses (progressive - at the end of each houses life span). Rock Revetment surrounding Pelican Point. Large seawall around exposed section of Pelican Point | $12,200,000 | 1.0% |
| | 4) Require all new houses to have flood-proofing through raising or other measures. Rock Revetment surrounding Pelican Point. Large seawall around exposed section of Pelican Point | $17,600,000 | 0.37%* |
| Sub area 3 - Sth Pelican Point | 1) Surrounding crest wall. Rock Revetment surrounding Pelican Point. Large seawall around exposed section of Pelican Point | $4,500,000 | 1.22%* |
| | 2) minimum fill for existing and new houses to raise them (progressive - at the end of each houses lifespan). Rock Revetment surrounding Pelican Point. Large seawall around exposed section of Pelican Point | $8,200,000 | 0.43%* |
| | 3) Fully fill existing and new houses (progressive - at the end of each houses lifespan). Rock Revetment surrounding Pelican Point. Large seawall around exposed section of Pelican Point | $7,200,000 | 1.0% |
| | 4) Require all new houses to have flood-proofing through raising or other measures. Rock Revetment surrounding Pelican Point. Large seawall around exposed section of Pelican Point | $12,600,000 | 0.28%* |
| Sub area 4 - Sporting Precinct | 1) zone to require future buildings to be flood-proof (assumed potential for 22 lots @ $40,000 per lot) | $880,000 | 0.0% |
| | 2) fill oval to raise its level | $900,000 | 0.0% |
| | 3) protect oval with a levee | $240,000 | 0.0% |
| Sub area 5 - Bridge & Commercial | 1) Raise the road and bridge and use road embankment as a levee. Armour the coastal strip (revetment). Large seawall along coastal strip. | $5,310,000 | 1.0% |
| | 2) Preclude development on the coastal side of the road | $54,000,000 | |
| Sub area 6 - Sth Australind Commercial | 1) Basic foreshore control with low level walling (rock revetment). raise and fill all the land (progressive - at the end of each houses lifespan). Large seawall along coastal strip. | $9,100,000 | 1.0% |
| | 2) Basic foreshore control with low level walling (rock revetment). Protect waterside houses with a wall. raise the road and use road embankment as a levee). Large seawall along coastal strip. | $8,700,000 | 1.05%* |
| Sub area 7 - North Eaton/ South Australind | 1) Bank protection and watching brief. Rock revetment along bank. Manipulate and deepen channels. Modify bridge. | $9,00,000 | 2.18%* |
| | 2) Bank protection and watching brief. Rock revetment along bank. Create an upstream detention basin. | $200,800,000 | 0.51%* |
| Sub area 8- Eaton | 1) Bank protection and watching brief. Rock revetment along bank. Manipulate and deepen channels. Modify bridge. | $9,130,000 | 2.19%* |
| | 2) Bank protection and watching brief. Rock revetment along bank. Create an upstream detention basin. | $201,530,000 | 0.51%* |
| Sub area 9 - Proposed Development N | 1) Fill the areas planned for development prior to development. Create an upstream detention basin. | $199,010,000 | 0.5%* |
| | 2) Build levees to protect planned development areas. Create an upstream detention basin. | $198,920,000 | 0.5%* |

*Note:* entries marked with a * are those where the individual elements have different operating costs and a weighted average of the different elements is shown

*Data source:* Damara WA

As noted above, for the peninsula (Sub Area 1), the fact that erosion is not a key issue until the end of the period means that a watching brief is the most appropriate option at this stage.[71] However, there may be relatively low cost things which the Local Government(s) could do in the interim to reduce erosion. Firstly, they could encourage less erosion by dune fencing.[72] Secondly, when Bunbury Harbour is dredged, rather than dumping the sand out to sea, it could be dumped on the seaward side of the Peninsula, which would actually be less costly than dumping at sea. This would require assessment of what contaminants, if any, are in the sand being dredged from the harbour.

Sub Area 2 is particularly endangered by sea level rise, which would see flood risk increase substantially, and may render the land uneconomical. Since the land is already low-lying, a response is required sooner, rather than later, and there is insufficient time to use a zoning requirement that all new houses be flood-proofed by raising their foundations with fill or by some other measure. This means that a cresting wall is required; either with a requirement to fill new blocks before building houses or without. Sub Area 3 is in a similar situation, but is slightly less low-lying, and has substantially more houses already developed.

The main asset in Sub Area 4 is the Eaton Sports Ground, where plans exist for new spectator facilities. These plans may require re-consideration, particularly in respect to drainage. The oval itself is in danger of flooding and is indeed designed to be a floodway.

In Sub Area 5, the main asset is the road and bridge, which can't be functionally isolated. This suggests a strategy of raising both to provide a flood levee, or to armour the coast. The latter would be needed if development plans in the Clifton Community Reserve go ahead, as this area would not be protected by a levee at the roadway. A raised road/levee could also be used in Sub Area 6, but this would not protect the scattering of houses on the water-side of the Old Coast Road in the north of the sub area. These would need to be raised (which is difficult for existing houses), or protected with a small floodwall.

Sub Areas 7 and 8 already have some level of flood control which means that bank protection and a watching brief may be sufficient. Beyond that, there may be scope to manipulate the channel in the Collie River to deepen it, or to

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[71] Some land will be lost, but not enough to prevent the peninsula from performing its role of protecting the residential and other land in the estuary region. It is, in effect, a "natural" sea wall.

[72] This would cost roughly $10,000 per annum.

create an upstream detention basin in land that is currently not developed. This detention basin would also protect Sub Area 9. Since it is yet to be developed, it can be raised, or flood levees can be built into the design of any proposed subdivision.

### Options and optimal timing results

Table 32 provides a summary of the viable options at Eaton-Australind.

Table 32 **Eaton-Australind viable options summary**

| | Option | Capital cost | OPEX | Optimal Year | Net benefit | % let expire scenarios |
|---|---|---|---|---|---|---|
| Sub area 3 - Sth Pelican Point | 1 | $4,500,000 | $55,000 | 66 | $70,000 | 0.00% |
| Sub area 4 - Sporting Precinct | 1 | $880,000 | $- | 1 | $2,221,000 | 0.00% |
| | 2 | $900,000 | $- | 1 | $5,258,000 | 0.00% |
| | 3 | $240,000 | $- | 1 | $4,415,000 | 0.00% |
| Sub area 5 - Bridge & Commercial | 1 | $5,310,000 | $18,100 | 9 | $918,000 | 0.00% |

Eaton-Australind presents the most challenging findings from the perspectives of the Local Governments involved because there are very few instances where the model suggests protection is worthwhile.

With this case study, so long at the Leschenault Peninsula remains in place, erosion is not an issue, and the main issue is flooding. In this context, there are only a small number of options for which an economic justification can be found. In Sub Area 3, it is worthwhile undertaking Option One, but only in 65 years, and even then for a very modest $70,000 net benefit. In Sub Area 5, it is worthwhile taking Option One in nine years, as it again has a very modest cost of $5.3 million.[73] Finally, Sub Area 4 is worth protecting immediately, as each of the protective measures have a small cost. However, we note that the oval is used as part of flood mitigation strategies in the area, which would need to be considered as part of any overall strategy.

For the remaining areas, there is no economic justification for protection, as the assets are too low in value compared to the high costs of protection; in some cases, the protection costs are higher than the gross value of the assets

[73] It is worth noting that a second option for Sub Area 5, precluding development on the coastal side of the road, would have no engineering cost, but would have an opportunity cost, in terms of lost land value from a change in zoning of $53 million. Moreover, not allowing development directly on the coast would not protect the $231 million of existing assets in the area, but would rather place an additional $53 million at risk. Any decision on re-zoning of this land would need to include a requirement for the developers to protect the land being re-developed from the impacts of climate-change induced flooding.

themselves. However, this does not mean that all of the region will be immediately subject to very high flood risk. In Sub Areas 6,7 and 8, much of the residential land is sufficiently elevated from sea level that it would not be affected by flooding, which would instead impact largely on the parks which are by the shoreline. This means that the actual impacts of non-protection are likely to be less than might be apparent from a cursory examination of the model results.

This is not true in Sub Area 2 or in Sub Area 9. Sub Area 9 is not yet developed, meaning its land value is relatively low. However, the costs of protection are very high; around $200 million. This means that any plans for future development would need to ensure that the developer pays this protection cost up-front to ensure that the allocation of land uses is not economically inefficient. This may preclude the growth of Eaton into Sub Area 9.

Sub Area 2 is perhaps the most problematic, as it is already settled, but the analysis suggests there is insufficient economic justification to protect it. However, much of the value of Sub Area 2 is due to residential land or the services to it (power, water, roads etc).[74] Moreover, although was, as outside observers, cannot perceive sufficient economic value to protect the area, those who live there may have different views. In this instance, since most of the asset is private land or services to it, there is a prima facie case for residents to face the full costs of their decision to live in this flood-risk area.

### Formulation of options pathways

Since there is very little protection that is economically justified, and only one option apiece for the Sub Areas where some action is warranted, there are no pathways per se.

## 5.6 Lessons learned from case studies

This study in unique in the sense that it is the first time that many of the aspects involved in undertaking it have been combined. As such, it involved significant learning curves for both the consulting team and the PNP members. In this section we provide a brief overview of some lessons learned from the case studies, which might go on to inform future assessments.

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[74] About half of the actual area is zoned residential, with the remainder being parkland. Depending on the value of this parkland to ratepayers outside the Sub Area, there may be scope for partial payment for protection by residents within the Sub Area, and partial payment from the community as a whole. This would be a key issue for the local community in this region to decide.

## Underlying coastal data

As noted in reference to the Peppermint Grove Beach case study area, we have some concerns in regards to the underlying data which are available for the engineering assessment undertaken as part of Phase One. The shortcomings of the available data have been summarised as part of the Phase One Report, but the key point to make here is that all future decisions about adaptation ought to be made with the state of the currently available data in mind. This is particularly important in the context of the model results outlined in this chapter; we would consider that the current state of information about the coast is not sufficient to allow for immediate action, as per the model results. It would rather be more appropriate for resources to be put to better data collection, followed by a re-assessment of optimal strategies using the same modelling process as is outlined in this chapter. The most resource intensive part of strategy formulation from the perspective of the economic modelling lies in the construction of the model framework. As this has now been done, the marginal costs of re-running the model using new data (or, indeed, for new case study areas) are relatively low.

## Consideration of areas outside the case study areas

In this report, we do not include consideration of impacts outside the case study areas. This is because treating these impacts properly would require an iterative process that is both outside the scope of this study, and not suitable from a methodological perspective for an initial study such as this which includes only our assessments, and not direct input from the local community. However, we can suggest a way forward.

Once this project is complete (subject to the data issues outlined above), and the findings of our report have been turned, through community consultation and discussion (taking in non-economic factors as necessary) into proposed actions in each of the case study areas, this provides a baseline for the next stage; to consider areas either side of the current case study areas.

In our study, we have begun with an assumption of no existing protection in place. For the next round of studies, even if no protection has actually been built, the starting assumption is that the protection mechanisms developed as part of this project (once endorsed by each local community) ought to form a baseline for the next study. This would then mean, in a practical sense, that there would be more erosion in the areas either side of the current case study areas, and the optimal response to that greater erosion (and flooding) should be developed through a process like that followed in this paper. To the extent that the optimal responses for the areas either side of the current case study areas impose an impact on the case study areas themselves, then consideration should be made to changing current conclusions about optimal responses in the case study areas. There would then be a logical iteration of considering these impacts on the new areas and so on. The whole process would then be validated through a community process as we suggest for our study, and there would be a new baseline for the next assessment, further up and down the coastline.

In each instance, the movements away from the current case study areas would continue until the optimal response was not to impose any protection, but rather to allow the (greater, due to prior protection elsewhere) erosion forecast. This then forms a natural "break-point" along the coast because allowing erosion, by definition, halts the process of influence up and down the coast. It would then be a case of choosing a new collection of case studies (probably settled areas not included at present) and beginning the same iterative process again.

The whole process appears time-consuming. However, the next stages of any such process would be much less resource intensive than this first stage, because all of the basic elements are in place, and the models have been developed. Moreover, it is important to work carefully through these iterative processes to ensure that optimal solutions are reached. Finally, there is still a great deal of uncertainty associated with future climate change impacts in the region and a series of future studies, as information is updated (more studies with the same information are less useful) is likely to lead to lower costs in the long-run than poorly-timed investment.

### Asset specification

In principle, assets can be specified at any level, from an individual house upwards. However, as noted in Section 5.1, this presents logical flaws and modelling difficulties when the relevant units are too fine-grained. In our study, we have matched assets to protection measures, but it may not always be appropriate to match in exactly this fashion. What is required is not a mechanistic application of exactly what we have done in this report, but rather careful consideration of the specific circumstances of the next assessment, in terms of different asset aggregation methods. Moreover, we would suggest that it is unlikely that our aggregation choice is perfect, given that this is an initial study; we would rather expect approaches to improve over time as more consideration is given to these matters.

### Continuation of protection mechanisms

In each instance, the protection mechanisms suggested are sufficient to handle the predicted erosion or flood risk which warrants their consideration. However, they are not infinitely lived; some will last to the end of the 100-year timeframe, and some will need to be replaced 30 or 40 years after first being constructed, because this is the asset life for these assets.

We have not included the replacement cost of the assets as they reach the end of their operational life in our models. The reason for doing so is that most assets that have a lifespan which ends prior to 2100 only end their lives a few years before this date, and the summary of the net benefits of the next asset is somewhat unrealistic because the erosion series only goes as far as 2100.

Extending the model out to infinity would change both the cost and the net benefit, but it would not change the decision of when the first time to invest is, nor, since each asset lasts until its design life ends, would it change the timing of subsequent replacements of each asset. The value of the change in benefit is impossible to forecast with any accuracy, but since benefits are expressed in net present value terms, is likely to be small. As a rough rule of thumb, the present cost of each subsequent protection measure replacement is roughly a third of the previous replacement, if the protection measures last 40 years (and the discount rate is three per cent), which would mean that the present value of the costs involved for keeping each protection measure in place forever would be 50 per cent above the cost of establishing it in the first instance.

### Mechanistic use of models

One way of moving from options to option pathways is to use a model to test all possible combinations. However, as we note with our "third row of houses" problem noted above, this is unlikely to be optimal, and it is far more likely that human intervention and consideration are required. The same is true of the assessment of the options themselves. The first set of results that came out of our modelling are not the same as the final set, and there were various issues which needed to be considered to question what the results were actually saying and why. Part of this was because the model was in the development stage. However, any model is only as good as what goes into it, and it is usually the case that model results need to be interpreted carefully, rather than blindly accepted. This requires a degree of familiarity with the way in which the model(s) work, and not treatment of them as a black box.

### Institutional knowledge

As noted above, this project involved a great deal of new learning for all concerned. Moreover, the process has only just begun; turning the findings of this report into realistic actions for each local community will present its own set of fresh challenges. Through this process, a considerable deal of institutional knowledge has been developed. The tasks at hand are not simple, and the existing knowledge base within the State and Local Governments is not ideally suited to doing this kind of work; even down to very simple issues like being able to produce maps of assets across local government boundaries. This means that, if all that happens out of this process is that a report sits on a shelf, the next group of councils (and the PNP partners themselves at the next stage of the process; we have not "solved" climate change adaptation for the region by any means) will face exactly the same learning curve. We therefore consider it crucial that resources be put to maintaining the PNP structure and institutional knowledge, as well as sharing that knowledge with other local government bodies elsewhere in the State. In this manner, vital information will not be lost, and the project will have a much greater lasting value to the community.

# 6 Conclusions and Steps Forward

This project has examined the issue of how to formulate options and make decisions in regards to adaptation to climate change. In this respect, the report has two key roles; firstly to develop and implement approaches to assist in strategic decisions pertaining to climate change adaptation, and secondly to provide a reference or guidebook for future assessment. For this reason, it includes extensive discussion of economic technique, and underlying economic ideas, to assist decision-makers less familiar with economics.

The report comprises three main parts:

- A background discussion around the key economic concepts of value and methods of valuation.
- A region-wide assessment intended to provide an overall appreciation of the resource cost of climate change adaptation in the South West of WA.
- A detailed account of four case study investigations of adaptation strategy in four case study areas in the South West of WA.

The first element focuses on ideas and techniques. Since adaptation responses often involve assets that are not traded in marketplaces, such as parks and reserves, and since the valuation of these assets presents unique decision-makers, much of the focus of the discussion is on the valuation of non-market assets. In many cases, such assets are valued according to "benchmark" values, drawn from other studies and/or used by many decision-makers without any real consideration about where these numbers come from and whether they are in fact applicable. This kind of "paint-by-numbers" approach to economics is not only damaging in that it can lead to poor, poorly-informed decisions, but also because it invests economics with a great deal more objectivity and "science" than it actually possesses, and pushes other decision-making techniques, that are often more effective, to the background. For this reason, we devote extensive space to critiquing economic valuation and valuation techniques, putting economic methodologies in what we consider to be a more appropriate context in decision-making. As economists, we consider that, if this section of the report does little more than cast doubt on "paint-by numbers" economic assessment and contributes to decision-makers considering a wider range of inputs to decisions than consultants' benefit-cost analyses, it will have been successful.

The section on ideas and techniques also introduces two concepts that we have found useful in our consideration of adaptation strategies. The first is the notion of "value at risk". Consider the case of Sydney Harbour, affected by climate change. One approach to designing strategies could be to begin with an investigation of what the harbour is worth, and whether it is worth saving.

However, this is not only very difficult, but, worse, it is pointless for decision-makers. Instead, one needs to look at what might happen in Sydney Harbour if sea levels rose; some housing would be affected, along with some transport links, but many of the aspects of the harbour which gives it value (like its views) would be largely unaffected. A value at risk approach looks at what climate change might do to an asset, and the costs of society from these impacts. It not only has a spatial element (the various parts of Sydney Harbour above) but also a temporal element; a house that is not affected by erosion for 50 years still has value by virtue of being habitable for several decades before it must be abandoned, for example. In general, value at risk is much simpler to establish than value (we present some simple mathematical equations) and also provides a much more robust basis for decision-making.

The second notion we term "decision-relevant analysis". As noted above, benchmark values usually make for very poor economics, but, used within the correct context, they can still support robust decision-making. For example, consider a local government officer who needs to make a decision about protecting a beach from erosion. Surveying the local community is expensive, but accessing work undertaken in Melbourne suggests that the beach might be worth $1 million, based on the value of roughly comparable beaches in Melbourne. This estimate might have an error band around it which renders it useless as a valuation tool (or even an estimate of value at risk), but if the only way to protect the beach is to spend $50 million on off-shore reefs, then even this highly imperfect estimate of value (at risk) might be good enough to make a decision not to save the beach; it is "decision-relevant" information. The same would be true if the numbers were reversed.

The decision-relevant approach is useful because it allows local government officers to make use of scarce resources more efficiently. For example, an initial assessment, based on imperfect benchmarks could be used to make decisions on all the "obvious" cases; say those where the ratio between value at risk and costs of protection was either greater than five to one or less than one to five. Our experience in this project suggests that many if not most assets fall into this category. For these assets, the benchmark is decision-relevant. For those that remain (between one to five and five to one), the officer can then consider more detailed assessments, which take into consideration local factors. For those where the benefits and costs are very closely aligned, the local government in question could devote yet more resources to detailed discussions with the community; at each level, the decision-relevant information changes. The benefit of this approach is in the resources that are saved; rather than doing detailed work on all assets in the community (or the ones that people say are most important), the local government in question can focus its resources on the ones where it is hardest for an outside observer using generalist information to come to the "correct" decision.

The second part of the project involves developing an understanding of the overall resource cost of adaption within the region as a whole. This does not mean the cost of "saving" every inch of coastline, but rather the cost, in general terms, of protecting those assets where the value at risk exceeds the cost of protection, and engaging in a strategic retreat elsewhere. The aim of the report is not to design strategy, which we consider ought to be developed at a more micro level, but is rather to highlight likely resource cost.

Since the work is being undertaken at a regional level, it involves a number of key abstractions and simplifications from what would be expected in a more detailed, micro-level assessment. The first such simplification is on the assets themselves. These are classed into several classes (houses, roads, parks etc; based on the classification in databases held by the Department of Planning) and then a single, representative value is applied to all assets in a given class. The second key simplification is that the location of the assets is not considered; we consider residential properties in general, rather than where they are located. This means that we assess the merit of protecting each asset class in its own right, without considering whether a protection mechanism along the shoreline would protect different types of assets behind it, including those which would not merit protection in their own right. Finally, the investigation examines assets at four snapshots in time, rather than as a continuous series over time.

At the regional level, erosion is a far more pervasive issue than flooding; while around 800 hectares of residential land would be subject to an increase in flooding risk (from one in 500 to one in 100), a strip roughly 200 metres wide is at risk from erosion along the whole extent of the coastline. The value at risk of the affected assets along this section of coastline is approximately $1.2 billion. Of these, a little more than $1.1 billion of assets are worth saving, as a cost of around $120 million, giving a benefit cost ratio of approximately nine to one.

A corollary of this finding is that around $80 million in assets are not worth saving. However, in land area terms, this equates to around 80 per cent of the affected region. The basic finding of the model is that the highly-valued settlements along the coast ought to be saved, delivering a benefit cost ratio of nine to one, while the much lower-values agricultural land and nature reserves, delivering a benefit cost ratio of only 15 per cent, ought not to be protected. In practice, where this farmland and/or nature reserve sits behind more valuable settled areas, the protection afforded to the settled areas will also affect the less valuable land (though not from incursion of salt-water flooding). However, in many instances, local farming communities will need to consider the value of protection very carefully, given its costs.

Flooding is, as noted above, less of an issue at a regional level than erosion. The 800 affected hectares of residential (primarily) land would be optimally protected by requiring all new homes in the affected areas to be built on pads 450mm thick, at a cost (marginal, at time of building, of $12,000 per house). The timeframe of the increase in risk is such that, were this requirement to be imposed now, few existing houses would still be standing when the flood risk changes. The cost, in net present value terms, of this requirement would be $39 million.

The third part of the report is the four case studies, assessed at a much more detailed level intended to inform strategy for the relevant local governments. Here again, there is a strong emphasis on the "how to" side, and a detailed description of methodology. Unlike the region-wide analysis, the case studies have a temporal (that is, effects occur on an annual basis) and a spatial element; we differentiate between locations, and consider assets together than would be protected together.

There are four case study areas; in Mandurah, Eaton-Australind, Peppermint Grove Beach and Siesta Park-Marybrook. The areas, and the different feasible adaptation measures, were chosen in conjunction with the PNP Partners, whose assistance in this regard is greatly appreciated. In most instances, with the exception of Eaton-Australind, there were viable options that represented significant net benefits from protection.

The results of the assessment are perhaps less important than the means by which the assessment was undertaken. A common way of assessing infrastructure investments, whether they be as part of climate change adaptation measures or not is to use benefit cost analysis. However, benefit cost analysis is rarely suitable in this context. In the first instance, the timing of the investment has to be found by some other means; a benefit cost assessment will not indicate the optimal timing of investment. Secondly, a benefit cost assessment cannot suitably address uncertainty, which means the results of such an analysis are not robust to changes in circumstance.

For this reason, we made use of real options analysis, in particular an approach developed by Longstaff & Schwarz (2001), which is able to encapsulate numerous sources of uncertainty in a mathematically tractable fashion. Real options analysis has its origins in the study of financial options, and is a special case of contingent claims analysis. It takes into consideration the fact that a decision-maker does not need to act today, but instead can wait before investing. This ability to wait has a value to the decision-maker in the case of irreversible investments. It also brings uncertainty about future outcomes into the centre of the analysis, delivering answers that show the optimal time to implement a response that is the most robust over the range of feasible situations likely to be faced.

Our approach works in practice by taking the models used to generate climate change outcomes in the Phase One report, and using them to derive several thousand future scenarios which could be faced by each of the assets in each of the case study areas. The model then chooses the best time to invest in each one of these scenarios through a process of backwards induction, and the optimal response in an overall sense is then the average (the approach also shows the distribution around the average, allowing for statistical inference to be applied) of the optimal responses over all of the scenarios chosen. The approach shows both the value of this optimal response, and when it ought to be applied. It can also be used to bring together several options in a "pathway" which represents the best combinations of these individual options.

Real options is widely used by decision-makers in the private sector, particularly mining companies seeking to value leases which confer the right, but not the obligation, to mine for minerals. However, there has been only very limited application of the approach in climate change assessment, despite its utility in handling issues of timing and uncertainty which are so germane to the field. To our knowledge, this paper represents the first application of the particular methodology of Longstaff & Schwarz (2001). However, we hope that the exposition of our approach in the report does not mean it is the last.

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# Appendix A Cost of Insurance and Climate Change

Managing society's exposure to events associated with climate change is essentially an exercise in risk management. This can involve physical measures (such as building flood protection infrastructure), regulatory measures (such as land planning and building codes), emergency response measures and financial instruments (such as creating a contingency fund or insuring against risk of extreme events). This section examines how the latter can help society manage the risks associated with climate change and how the insurance industry responds to changes in the risk exposure to extreme events.

## A.1 Community response to changes in insurance

The insurance industry can exert a strong influence on private firms and citizens to take actions or adopt measures to manage future risk exposure. For example, as insurance premiums on coastal properties at risk of flooding due to sea level rise increase this will have an influence on decisions on where to build or even whether to build at all.

Indeed, houses in an area with high probability of damage due to weather events should sell for less than comparable houses in an area with a lower risk of damage. Researchers in the US have examined property values after and before extreme weather events to judge people's perceptions of risk on property values. One such study (Halstrom & Smith, 2005) examined property values before and after hurricane Andrew in Lee County, Florida. They found that property values in special flood hazard areas of Lee County declined by 19 per cent after hurricane Andrew.

The findings agreed with those of a similar study that examined housing values in a flood plain in North Carolina (Bin & Polasky, 2004). It found that prices declined significantly after hurricane Floyd, compared to houses not seen as at risk. For the average house, the decline in price exceeded the present value of premiums for flood insurance, suggesting that the latter could be regarded as a lower bound to the value of avoiding floods.

Insurance can of course also have the perverse incentive of encouraging more risky behaviour. A more common example is sometimes referred to as the safe development paradox. This occurs when perceived increases in safety (for example, due to the construction of sea walls) induces more building than might otherwise be the case (such as in areas considered safe due to the protection provided by a sea wall), leading to increased losses if a major storm surge overwhelms the sea wall (Karl, et al, 2008).

## A.2 Insurance industry response to climate change

The insurance industry has for some time been at the forefront of private sector firms expressing concerns regarding the impacts of climate change. This is not surprising given that insurance claims for damage from extreme weather events have a direct impact on insurance companies' bottom lines. Indeed, as the world's largest industry the implications of rising disaster losses on insurers are as important as defining the industry's role in furthering understanding of the problem and advancing loss prevention solutions.[75]

To date, efforts to quantify trends in losses caused by climate change impacts have tended to be based on insured loss data or on total loss (insured plus non-insured losses) estimates developed by insurers. However, the details of the insured losses are seen as commercially sensitive and therefore only aggregated information tends to be available. The relationship between insured losses and total losses will vary as a function of the nature of the extreme event, building codes, the cost of insurance, insurance take up rates, and other factors (Mills, 2005).[76]

However, it is clear that the trend in insured losses is upwards. As one researcher noted (ibid):

> "weather-related [insured] losses in recent years have been trending upward much faster than population, inflation, or insurance penetration, and faster than non-weather-related events"

As losses have mounted the insurance has responded by increasing the premium paid by businesses and individuals. There has also been pressure on governments to step in as the 'insurer of last resort' when the private sector is either unwilling to provide an insurance product or the cost of that product is too high. Where this occurs, the individual losses for victims of major events can decrease as society as a whole absorbs a portion of their losses either through disaster relief and or government insurance schemes.

Government insurance schemes transfer the risk from the private sector to the public sector. This can expose governments to considerable costs. For example, Hurricane Katrina exhausted the federally backed US National Flood Insurance Program, which had to borrow $20.8 billion from the Government to fund the Katrina residential flood claims (Hunter, 2006). However,

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75 The insurance industry would be the third largest country if its $3.2 trillion in yearly revenues were compared with national gross domestic products (GDPs).

76 The US National Hurricane Center generally assumes that total losses are twice insured loss estimates. However, this relationship will not necessarily be true in other countries or for other loss causing events.

governments that are trying to balance their budgets find that paying large numbers of claims make doing so much more difficult and, not surprisingly, they will seek to limit their risk exposure in different ways. This normally results in more of the cost of any losses being shifted back to the individuals and businesses affected by climate change.

For example, it is very difficult to insure against the risk of residential flooding in the United States, this has given rise to a National Flood Insurance Program (NFIP), with more than 4.2 million policies in force, representing nearly $560 billion in coverage. However, the NFIP limits payouts to no more than $250,000 per loss per household and $500,000 for small businesses(Mills, Roth & Lecomte, 2006).

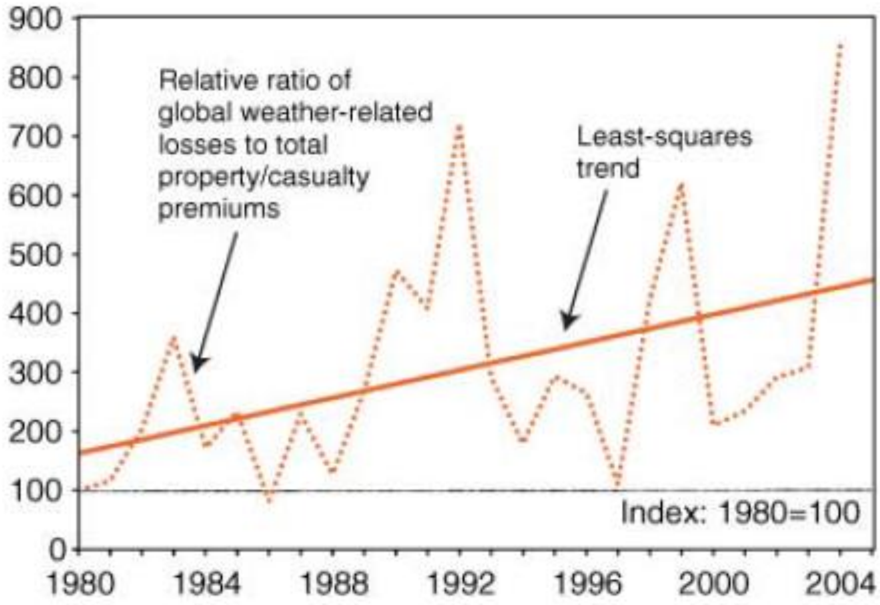
The NFIP is discussed further in section A.3.

### Insurance premiums

Insurance firms set premiums according to their analysis of risk being insured against. Premiums generally lag behind actual losses. This is perhaps most pronounced in the case of life insurance, where premiums may be fixed over long periods. The lag is however less in the case of other forms of insurance (for example, property insurance).

The impacts of the growth in insured losses include an elevated need for assistance from outside impacted areas and a shrinking gap between insurance premiums and losses. Insurance companies have essentially two means of responding to increasing losses. They either withdraw from the market or increase the premiums they charge.

Figure A1 **Ratio of global weather-related property losses to total property/casualty premiums**

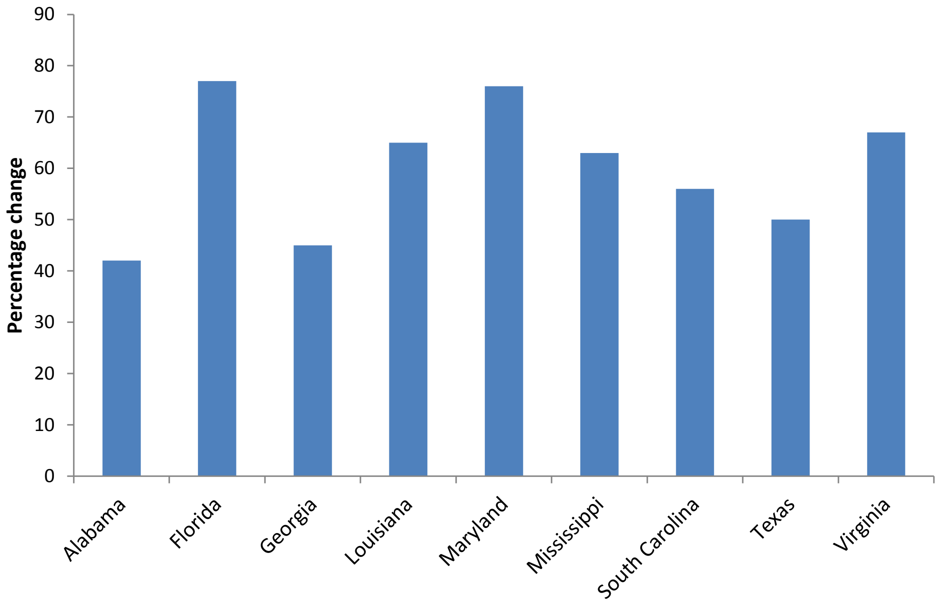



*Source:* Mills(2005) reporting natural hazard statistics and losses from Munich Re, NatCatSERVICE; and premiums from Swiss Re, Sigma

In the US, nobody collects standardised data on insurance price changes, researchers have therefore relied on news reports and other secondary sources for information on changes to insurance premiums

For example, Florida-based firms providing home insurance were awarded 15-20 per cent premium increases to recover losses (of around $30 billion) due to hurricanes in 2004 (Mills, Roth & Lecomte, 2006), further increases were expected to be awarded in response to the losses (more than twice those in 2004) arising from hurricane Katrina in 2005. Another study examined changes in US home insurance premiums over the period 2001-2006. The results of that study are shown in Figure A2. As can be seen Florida topped the rises among the States shown with a 77% increase in premiums over the period.

Figure A2 **Percentage change in US home insurance premiums between 2001 and 2006**




*Note:* Premiums for Miami Beach increased by 500%
*Data source:* Mills et al (2006)

Home insurance also has become harder to obtain in the US. A study by the Independent Insurance Agents & Brokers of America found that nearly 3.0 million U.S. households lost their homeowners coverage between 2003 and mid-2007, although half of these persons were able to obtain replacement coverage.

One firm, Allstate, reported that climate change has prompted it to cancel or not renew policies in many Gulf Coast states, with recent hurricanes wiping out all of the profits it had garnered in 75 years of selling homeowners insurance. The company has cut the number of home insurance policies it offers in Florida from 1.2 million to 400,000 with an ultimate target of having no more than 100,000 policies in that region (Mills et al 2006).

Such withdrawals of insurance cover has also occurred in Australia. In May 2012 Queensland's biggest insurer, Suncorp, announced it would no longer offer new policies in two regional towns (Roma and Emerald) until flood mitigation works were carried out (see Box 1). The company spokesman stated that:

> We are sending a very strong message here today to those communities. We're trying to encourage local governments, the State Government, to start taking some action - I think the time for talking is over.[77]

[77] ABC online news report, *Suncorp won't offer new policies in flood-prone towns,* 7 May 2012.

More difficult to detect than formal withdrawals from the market or large price spikes are the other changes to insurance coverage, such as increases in excess payments, reduced limits on claims, and exclusions that restrict insurance cover in some way. The losses due to hurricane Katrina in 2005 are expected to strengthen the industry trend in the US towards specifying percentage deductibles for nominated events instead of fixed-value ones. For example in the US, 'wind deductibles' of 2 per cent already exist in some markets. This would correspond to a $10,000 deductible for a $500,000 loss (compared to the $500 to $1000 fixed-level deductibles otherwise typical of home insurance policies).

## A.3 The government as an insurance provider

As private sector insurers withdraw from the market, the pressure on the public sector to step in will increase, effectively to be an insurance provider of last resort. For example, the US National Flood Insurance Program (NFIP) provides insurance against the risk of residential flooding in the United States. In 2010 the NFIP had over 5.6 million policies in force, representing nearly $1245 billion in coverage.

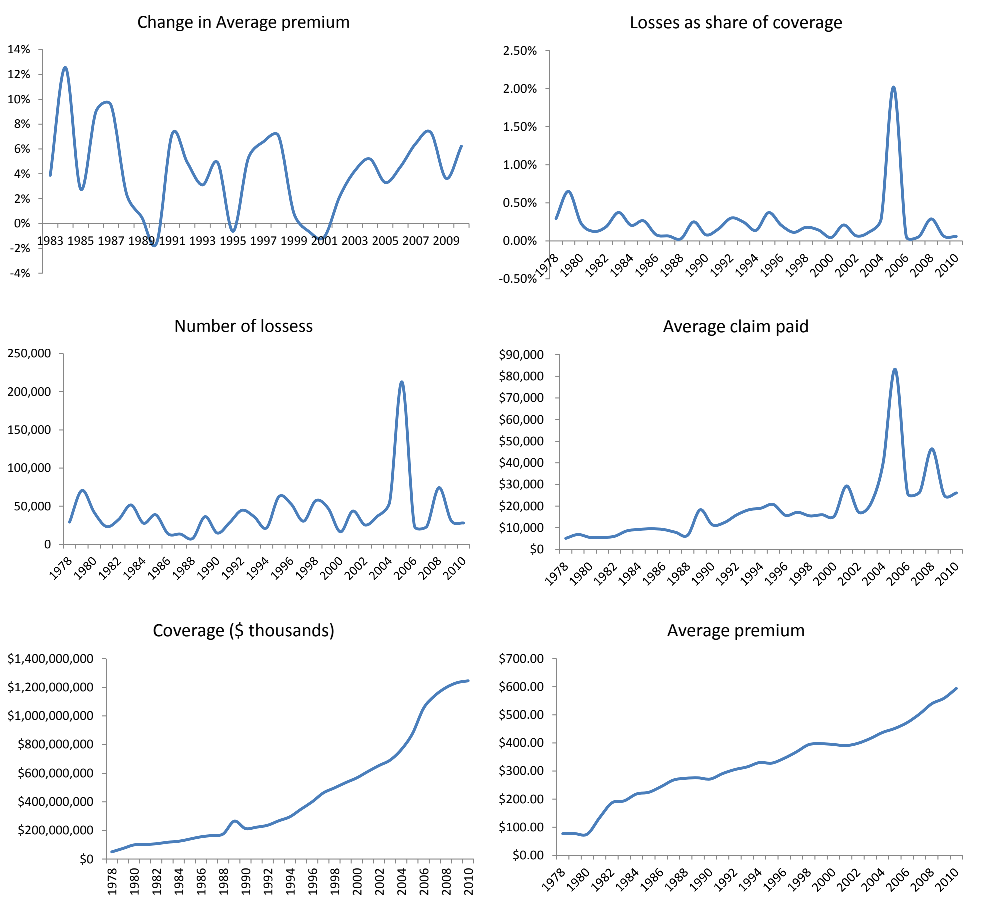
Participation in the NFIP is based on an agreement between local communities and the US Federal Government. Under that agreement, if a community adopts and enforces a floodplain management ordinance to reduce future flood risks to new construction in Special Flood Hazard Areas (SFHAs), the US Government will make flood insurance available within the community to provide financial protection against flood losses. The NFIP limits its payouts to no more than $250,000 per loss per household and $500,000 for small businesses.

Communities that achieve higher than the minimum standard of safety and protection for their citizens may receive a discount on their flood insurance premiums. The Community Rating System (CRS) recognizes the efforts communities make to:

- reduce flood damage to insurable property
- strengthen and support the insurance aspects of the NFIP
- encourage a comprehensive approach to floodplain management.

Communities that join the CRS receive a rating based on a point system that reflects the level of safety provided through the floodplain management activities they have put in place. CRS communities are assigned a CRS Class, from 9 to 1. The discount policyholders in Special Flood Hazard Areas are eligible to receive on their annual flood insurance premiums ranges from 5% for a CRS Class 9 community, up to 45% for a Class 1 community.

Figure A3 **Some NFIP statistics**




*Data source:* http://www.fema.gov/business/nfip/statistics/statscal.shtm

The Insurance Council of Australia (ICA) has argued that US Government policy has meant that the NFIP's premiums are well below those that the private market could offer for flood insurance (up to one-third the true risk cost in higher risk areas). ICA claims that the NFIP's rating methodology and restrictions in law limit NFIP's ability to adjust existing rates and to offer risk-based pricing. According to ICA, the results of this are demonstrated by the findings of a March 2011 report by the US Government Accountability Office which concluded that the NFIP owed the US Treasury US$17.8 billion.

## A.4 Insurance industry response to recent riverine flooding

Premiums for flood insurance are directly correlated to the expected frequency of flooding (or the 'average return interval'). The Insurance Council of Australia (ICA) in its July 2011 submission to the National Disaster Insurance

Review provided the information shown in Table A1 on how insurance premiums vary according to average return interval of flooding events.

Table A1 **ICA estimates of flood insurance premiums by flood risk**

| Risk band | Frequency of flooding (Average return interval) | Number of properties [a] | Probability of flooding per year (%) | Average claim size ($) | Flood risk premium ($) | Annual cost of flood ($ million) |
|---|---|---|---|---|---|---|
| **No flood risk** | Nil | 6,174,912 | 0 | 0 | 0 | 0 |
| **Low** | Greater than 111 | 276,277 | 0.19 | 40,242 | 77 | 21 |
| **Medium** | 111-105 | 3,509 | 0.93 | 40,849 | 378 | 1 |
| | 105-100 | 3,081 | 0.96 | 40,895 | 399 | 1 |
| | 100-67 | 25,292 | 1.25 | 40,544 | 507 | 13 |
| | 67-50 | 18,483 | 1.75 | 41,475 | 726 | 13 |
| **Total medium** | | **50,366** | | **40,926** | | **29** |
| **High** | 50-40 | 14,092 | 2.25 | 42,333 | 952 | 13 |
| | 40-33 | 12,149 | 2.75 | 43,269 | 1,190 | 14 |
| | 33-29 | 8,160 | 3.25 | 43,557 | 1,416 | 12 |
| | 29-25 | 9,373 | 3.75 | 43,979 | 1,649 | 15 |
| | 25-22 | 8,073 | 4.25 | 45,220 | 1,922 | 16 |
| | 22-20 | 6,019 | 4.75 | 45,832 | 2,177 | 13 |
| **Total High** | | **57,867** | | **43,736** | | **84** |
| **Extreme** | 20-18 | 6,654 | 5.25 | 46,458 | 2,439 | 16 |
| | 18-17 | 3,610 | 5.75 | 46,514 | 2,675 | 10 |
| | 17-15 | 7,905 | 6.25 | 47,554 | 2,972 | 23 |
| | Less than 15 | 39,410 | >6.5 | 58,880 | 6,777 | 267 |
| **Total Extreme** | | **57,578** | | **55,114** | | **316** |

[a] The property numbers quoted in the table are based on 2006 estimates and they are believed to be conservative.

*Notes:* These premium estimates are based on the risk rated price only and do not include other costs that would be added to a retail premium such as taxes or brokerage fees. For example, Suncorp stated that taxes, duties and levies made up 44% of the cost of home/building policies in NSW in 2011.[78]

*Data source*: Insurance Council of Australia response to the 2011 Natural Disaster Insurance Review, July 2011.

An examination of the data in Table A1shows that the:

$$\textit{Flood risk premium} = (\textit{probability of flooding}) \times (\textit{average claim size})/100$$

Separate discussions with Suncorp revealed that they applied the same approach when setting flood risk premiums (see Box 1).

78 Suncorp's submission to the 2011 Natural Disaster Insurance Review, July 2011

Box A1 **Suncorp's response to recent flooding events in Queensland**

Following two major flood events in Queensland in the space of two years, the insurance firm Suncorp announced that it while it would continue to provide coverage to existing policy holders, it would no longer offer any new home insurance policies to residents in the towns of Roma and Emerald, unless and until flood mitigation measures (such as building levees) are implemented.

Suncorp notes that there had been some 25 flood events affecting the two towns in the last 20 years. Five of those floods had involved water over 14 meters in depth and three of those had been classified as 'high floods'. Two of the latter occurred in the last two years. During that time Suncorp has reportedly taken $4 million in premiums from the towns' residents. However, it has paid out $150 million in claims over the same period.

Suncorp advises that existing premium holders will be allowed to renew their policies. However, policy holders' premiums will increase to reflect the expected 'average return rate' of flood events. For example, if there was an average of one 'high flood' in a region every 20 years then the flood risk premium for a house in that region that was worth around $200,000 would be of the order of $10,000 a year. When insurance costs for other risks, various State levies and GST are included the total premium payable could be close to $15,000 a year. This is approximately an eight fold increase on the average home insurance premium in the towns prior to the floods. [79]

Suncorp is confident that there is strong community and political support for addressing the flood risk in Roma and Emerald and that if such measures were implemented it would enable the company to reduce the premiums for home insurance. For example, the levee in Goondiwindi in south-west Queensland saved the community from January's floods and enabled Suncorp to keep average insurance premiums down by 33%.

Source: Suncorp submission to National Disaster Insurance Review in July 2011 and personal communication with Suncorp, 24 May 2012.

## A.5 Implications for insurance in the PNP region

The National Disaster Insurance Review identified a range of natural disasters that are currently not universally covered by insurance policies. One of those is 'actions of the sea'.

For example, insurance is not available for inundation associated with tidal events such as king tides. These are regarded as 'expected' or predictable events since they occur at time intervals that can be precisely predicted,. However, an event may be covered if it is the result of another event that is covered by insurance. For example, if a home is inundated by a storm surge that was caused by a cyclone.[80] Such an event is regarded as an 'unexpected' or unpredictable event

[79] The increase in Suncorp flood premiums will be phased in over a period of two to three years.

[80] Final report of the Natural Disaster Insurance Review - Inquiry into flood insurance and related matters, September 2011

The insurance industry has not yet begun to consider in any detail the insurance implications of issues such as more frequent inundation events associated with sea level rise. It is highly likely however, that when it does so their approach will evolve in much the same way as it has for riverine flooding, namely that when claims for events such as storm surges begin to increase in frequency premiums will rise to match the increased risk.

As inundation events increase in frequency, it is likely that pressure will grow for high level inudation maps to be prepared. Such maps are seen as essential by the industry to enable them to determine the risks and the market for insurance against inundation.[81]

At some point the average return interval will become so short (and claims so frequent) that the premium that needs to be charged by the insurance firm is no longer realistic for most householders. At that point it is probable that property will effectively become uninsurable in the absence of other mitigation measures such as sea walls or similar.

Pressure will also mount on regions at risk of inundation to develop and implement flood mitigation plans. Those plans will vary from region to region, but will include the kinds of measures that are discussed elsewhere in this report.

It is also likely that governments will be asked to step in and provide insurance of last resort. Overseas experience has shown that any steps by governments to assist in this area are likely to be accompanied by a requirement to implement flood mitigation plans.

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[81] Personal communication with Insurance Council of Australia, May 2012.

# Appendix B Discounting for Multi-Generational Projects

This briefing note provides an overview of potential options for discounting the flows of costs and benefits of major infrastructure projects. The key point to note up front is that there remains considerable debate, even at the philosophical level, about the concept of discounting; there is no generally agreed "best practice" rate. Broadly speaking, there are two approaches which can be used:

- **The social opportunity cost of funds (SOC):** Due to Hirschleifer (1965) Baumol (1968) and Harberger (1972). Essentially, government should not tax society and spend the proceed of taxation on investments if there exist private sector inestments which can earn a better rate of return.
- **The social rate of time preference (STP):** Due to Ramsey (1928), Koopmans (1960, 1965) and Cass (1965), also used (controversially) by Stern et al (2006). This measures the degree to which society prefers to consume goods and services today, as opposed to tomorrow, and is grounded the theory of inter-temporal utility.

There are valid reasons supporting either of these two approaches,[82] We briefly discuss the debate associated with each approach in the following two sections. The debate on discount rates has been extensive, and the reader is directed to the bibliography for further information.

## B.1 Social opportunity cost discounting

SOC tends to be widely used in North America. The US Office of Budget Management uses a discount rate of 2.5 to 3 per cent (based on the cost of government funds) for assessing the cost effectiveness of potential interventions and 7 per cent (based on the marginal return to US equity investment) for cost-benefit analysis, while the European Commission recommends using SOC only when a financial return is the main intent of government (Lopez, 2008).

Canada uses a "weighted SOC", which reflects different sources of funding; taxation (which affects consumption), bonds (which might crowd out private investment) and foreign borrowings. Boardman, Moore & Vining (2010) provide a detailed account, and critique, of the Canadian approach. BTRE (2005) suggests that, in principle, all of these sources of funding should result

[82] Lind (1982, 1990) presents two summaries of the debate from a time when it generated a lot of academic literature, and Feldstein (1964) presents an early account highlighting the differences between SOC and STP, Spackman (2004) presents a more recent historical overview of the development of both concepts.

in the same discount rate, but taxation and other influences drive a wedge between them. BTRE also points out a more practical issue; it is almost impossible to understand what proportion of funding for a particular project has come from which source.

Whether a single or a weighted SOC is used, there are several issues which militate against simply using stock market returns. Firstly, if funds are crowded out by public investment, this affects marginal, not average projects, so the relevant discount rate would be lower than market returns. Secondly, market indices exhibit a "survivorship bias" by not taking into account firms that leave the index through bankruptcy.[83] In the long run, it would be mathematically impossible for the market to grow more rapidly than the economy itself. Thirdly, and more fundamentally, as Spackman (2004) points out, the "equity premium" which stocks possess exists because said stocks are risky, and thus represents a cost, not a benefit of market operations.[84]

The notion that one should not include risk in analysing the societal benefits of public investment dates back to a seminal paper by Arrow and Lind (1970), who note that in perfectly functioning markets, all risks can be diversified away, and thus there would be no need for a premium. However, they go on to note that, while markets are clearly not perfect in this respect, the tax and spend powers of government mean that it can spread risk among everyone in a country (resulting in almost no first-order individual welfare impacts) and thus should not consider risk when assessing public investments; subject to some key caveats discussed below. Debate on this perspective has raged in the literature ever since; see Van Ewijk & Tang (2003), Bazelon & Smetters (1999), Spackman (2004) or Watson (1992) for accounts of this debate.[85]

BTRE (2005) takes a more practical perspective, noting that systemic risk (that which cannot be diversified away by government – or anyone else – holding a balanced portfolio) may be an issue in principle, but in reality, the size of this risk is very small; smaller in fact than the error around most cost-benefit analysis estimates, and thus that it can be ignored in most cases.[86]

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[83] Market rates of return are also very sensitive to the period over which returns are being analysed.

[84] The "equity premium" is also larger than economic theory predicts; see Grant & Quiggin (2003) for an account of this "puzzle", which has long been recognised in the literature.

[85] One key concern is that if the public sector uses a low discount rate and the private sector a higher discount rate, then the benefits from public sector investment will seem artificially larger than those from the private sector, resulting in more resources being diverted (by government) into its own spending.

[86] BTRE (2005) point out, however, that project specific risks cannot be ignored, but show why they should not be addressed through discount rates. Instead, BTRE (2005) suggest that they should be addressed using state-contingent analysis. Bazelon & Smetters (1999)

Arrow & Lind's (1970) model is based on two key assumptions; that the size of the investment project is small relative to the economy as a whole and that the returns on the investment project are uncorrelated with the economic growth (there is no systemic risk). BTRE (2005) point out that if the former is true but the latter is not, the problem caused is probably very small. However, when both assumptions fail, then there is a case for adding a risk premium to the risk-free rate.

## B.2 Social rate of time preference discounting

The STP is firmly grounded in utility theory, which perhaps explains its greater popularity in Europe (see Lopez, 2008) where utility theory has always played a larger role in academic economic debate (Spackman, 2004). The UK has recently changed the basis of its calculation of discount rates from a SOC to an STP approach (see Nash, 2010) and has (in common with many other jurisdictions – see Boardman et al, 2010) reduced its discount rate considerably.[87]

The STP was used most famously in recent times to form the discount rate in the *Stern Review on the Economics of Climate Change* (Stern et al, 2006), which touched off a flurry of debate not for the use of the STP per se, but for the values chosen for some of its parameters. Nordhaus (2007), Weitzman (2007) and Dasgupta (2007) are three of the most-cited critiques of Stern, and Dasgupta (with Mäler & Barrett, 2000, and individually, 2005, 2007 and 2008, and vimeo.com/22748647 and vimeo.com/22709345 for a less technical presentation which covers the essential ideas of the case which he makes) has written extensively on the fundamental conceptual basis of discounting via an STP. Boardman et al (2010), Lopez (2008), Evans & Sezer (2004) and Evans (2005) provide an overview of the empirical literature which shows how people actually calculate the STP, as well as the debate about whether such calculations are meaningful.

The STP is based upon a model of inter-temporal utility first proposed (in a mathematical sense; the literature extends back into the 19th Century) by Ramsey (1928) which shows how society ought to trade off consumption today for consumption tomorrow, given the fact that economic growth and technical progress means there will be more to consume tomorrow than there is today, and that a dollar's worth of consumption to a rich person is worth less than a

also advocate the use of real options analysis to account for these risks, but there is limited use of this approach amongst Australian policymakers.

[87] The STP often gives a lower discount rate when used in practice than the SOC, but this is not a necessary outcome, and can often occur because the risk-free rate is not used in the SOC formulation.

dollar's worth of consumption to a poor person. Feldstein (1965) provides a nice algebraic treatment of the relevant arguments, which result in the following functional form for the STP:

$$STP_t = \delta + \varepsilon g(C_t) \tag{1}$$

Where $STP_t$ is the STP at time $t$, $\delta$ is the "pure" rate of time preference, $\varepsilon$ is the elasticity of marginal utility of income and $g(C_t)$ is the growth of per-capita consumption at any point in time; sometimes taken to be constant.[88]

The growth rate of consumption is relatively uncontroversial, and it is generally estimated by considering long-run growth of per capita GDP. However, $\varepsilon$ and $\delta$ are much more controversial, particularly $\delta$, where the debate extends to key philosophical and ethical questions rather than just measurement issues (see Arrow, et al, 2006 and Dasgupta, 2005).

One school of thought in regards to $\delta$ suggests that it should be zero, as there is no ethical basis to favour the current generation over the future. However, this is just one ethical perspective. Other authors have argued on both technical and philosophical grounds for positive discount rates (see Lopez, 2008 for a review of both these perspectives). Nordhaus (2007) points out that other ethical perspectives provide a rationale for favouring the current generation; for example, a Rawlsian (1971) perspective that favours the utility of the poorest over that of the richest would, in a world of positive economic growth, mean that it is ethical to favour the poor present over the richer future. The ethical perspective of $\delta$=0 also faces a practical problem; if humanity lives for a long time, it is worthwhile for the current generation to sacrifice all income above subsistence levels in order to provide an infinitesimally small increase in the standard of living of every generation that lives 10,000 years hence and this, moreover, is always true (Arrow, 1995).

One might seek to avoid the ethical debate by examining how, in practice, people reveal their rate of time preference; if indeed it is legitimate to move from how people actually behave to what a social planner seeking to maximise social welfare over time ought to do.[89] However, here too, there are problems;

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[88] It is worth noting that the "correct" use of this STP requires that capital be valued at its shadow cost where capital markets are imperfect (see Dasgupta, 2008) or where resources are constrained (see BTRE, 2005), though as Watson (1992) notes, this is rarely done in practice.

[89] Others (see, for example, Evans & Sezer, 2004) use the death rate, on the basis of an argument which Dasgupta (vimeo.com/22748647) suggests was originally made by John

people exhibit time inconsistency in their discounting (see Shane, Lowenstein and O'Donoghue, 2002 for a review of the literature in economics and Heal, 1997, 1998 for the perspective from cognitive psychology). By way of a simple example which is relevant for long-lived projects, lay-by, "interest free" and other schemes which allow people to obtain durable consumption goods sooner (and often at high cost) are popular, which suggests a very high rate of time preference on an intra-generational scale, but at the same time people invest in their children's education and leave inheritances, which suggests a low or even negative rate of time preference on an inter-generational scale. Dasgupta (vimeo.com/22748647) provides a good account of this phenomenon, and Dasgupta & Maskin (2005, see also Hunter, 2003) propose hyperbolic discount rates to account for this, while Heal (1997, 1998) proposes logarithmically declining discount rates, Weitzman (2001) proposes a gamma function and Sumaila & Walters (2005) propose a function which combines inter and intra-generational discount rates. Policymakers, too have begun to respond; in the UK, lower discount rates are used for project benefits that occur beyond a certain cut-off date (Nash, 2010).

The estimation of $\varepsilon$ is less fraught with philosophical debate, but it also raises problems, as it is difficult to understand what society's preference is for equality in income. There are numerous proxy measures (see Boardman et al 2010 or Lopez, 2008 for a discussion), but one of the more commonly used is the tax system (see, for example, Evans & Sezer, 2004 and Evans, 2005), which is a tool used by government to reflect a more "ideal" distribution of wealth within a country. Based on measures such as this, Lopez (2008) suggests that the literature has moved from a range of $1< \varepsilon<10$ in Stern (1977) to $1.3< \varepsilon<1.7$ in Evans & Sezer (2004). However, the structure of a tax system is the end result of an historical process of negotiation between parties with differing levels of political power at different points in time, and it is unclear how much of its structure truly reflects desire, and how much reflects historical baggage.

Thus, establishing the STP from first principles is relatively difficult. The growth rate of consumption is relatively uncontroversial, and if one is prepared to accept that the tax system reflects society's desire for the distribution of wealth amongst its people, then the estimation of $\varepsilon$ is relatively straightforward. However, $\delta$ remains problematic, and it may be the case that this is a subjective variable that objective methodologies such as those used by economists are

Harsanyi that a reason for consuming now rather than later might be the knowledge that we might not be around in future to consume. However, as Dasgupta points out, for a social discount rate, it is the potential for societal collapse, not individual death rates that are important, and there is not likely to be any correlation between the two. Nordhaus (2007) attempts to back-solve for $\delta$ by setting STP=SOC, but this requires him to make assumptions about $\varepsilon$, which is also controversial. This means it is difficult to use STP as a means of checking the value of SOC.

unable to suitably quantify. Dasgupta (2008), however, offers one small ray of hope by pointing out that one can interpret $\delta$ as a measure of the preference for the distribution of consumption and $\varepsilon$ as a measure of the preference for the distribution of income across people (regardless of when they live). If this is true, then the two are linked; it would be illogical (as Dasgupta, 2008, points out Stern et al, 2006 have done in their choices of $\varepsilon$ and $\delta$) for society to prefer equality across time but be unconcerned about equality amongst people. This suggests that a low value for $\delta$ should necessarily imply a high value for $\varepsilon$, which may go some way towards understanding whether the values chosen for these variables in the construction of an STP are "reasonable".

# Appendix C Confidence in Cost Estimates

A key component of the real options modelling framework is the costs of the various options for adaptation. Since the cost estimates have been sourced from a wide variety of sources, it is appropriate to include a brief overview of the confidence in each of these cost estimates. This is provided, in tabular form, overleaf.

Table C1 **Mandurah Case Study cost estimates confidence summary**

| Sub Area | Option | Confidence | Notes |
|---|---|---|---|
| Sub-Area 1 - Northern beaches | 1) Large enclosing groynes - Small groynes (phase 1) | Good | Design and rock rates based on recent Project - factored for increase height for SLR |
| | 1) Large enclosing groynes - Intermediary "T" groynes (phase 2) | Good | Design and rock rates based on recent Project - factored for increase height for SLR and depth required |
| | 1) Large enclosing groynes - Offshore reef with 90 % gap (phase 3) | Good | |
| | 1) Large enclosing groynes - Offshore reef with 75% gap (phase 4) | Good | |
| | 1) Large enclosing groynes - Offshore reef with 60% gap (phase 5) | Good | |
| | 1) Large enclosing groynes - Offshore reef with 50% gap (phase 6- extend BWs landward) | Good | |
| | 2) Seawall - Small seawall (phase 1) | Good | typical design (-1 to 4.5m AHD) and rock rates based on recent Project |
| | 2) Seawall - extension downwards of small seawall (phase 2) | Good | extend extra 1m depth with toe rocks...rock rates based on recent project |
| | 2) Seawall - Large seawall (phase 3) | Good | typical design (-2 to 4.5m AHD with toe rocks) and rock rates based on recent Project |
| Sub Area 2 - Seashells | 1) Increase seawall to medium (phase 1) | Good | See Sub Area 1 Option 2 |
| | 1) Increase seawall to large (phase 2) | Good | |
| Sub area 3 - CBD | 1) Use roads as part of drainage system (Ormbsby Tce) | Poor | Rawlinsons (2007), rough design, fill rate $25/m3 - highly dependent on availability |
| | 2) Build flood levee (Ormsby Tce, Beam Rd & Mandurah Tce). Change structural requirements on houses to make flood-proof | Poor | Rawlinsons (2007), rough design, fill rate $25/m3 - highly dependent on availability. Loose rates per undeveloped/developed lots (~10% of house cost), and large building (3*10%) |
| | 3) Build flood levee (Ormsby Tce, Beam Rd & Mandurah Tce). Change house foundations to make flood-proof (west of Ornsby Tce Levee & west of Man Tce Levee). | Poor to moderate | Rawlinsons (2007), rough design, fill rate $25/m3 - highly dependent on availability. Fill rate $40/m3 - highly dependent on availability. |
| | 4) Seawall for coastal flooding (Mandurah CBD only) | Moderate | Typical vertical wall costs, further investigation into best means of adaption (impact on CBD etc) |
| | 5) Change structural requirements on houses to make flood-proof (west of Ornsby Tce Levee, between Ornsby Tce of Beams Rd Levees, east of Beams Rd Levee, west of Man Tce Levee, east of Man Tce Levee - Hackett, Cooper St, east of Man Tce Levee - Peel St) | Poor | Loose rates per undeveloped/developed lots (~10% of house cost), and large building (3*10%) |
| | 6) Change house foundations to make flood-proof (west of Ornsby Tce Levee, between Ornsby Tce of Beams Rd Levees, east of Beams Rd Levee, west of Man Tce Levee, east of Man Tce Levee -Hackett, Cooper St, east of Man Tce Levee - Peel St) | Moderate | Fill rate $40/m3 - highly dependent on availability |
| | 7) Improve drainage system to deal with flooding (Seashells - Beams, Shannon, Stewart, Ormsby, CBD - Hackett, Cooper, Mandurah, Peel, Rockford) | Poor to moderate | May require a large pump station (with drainage network based on Rawlinsons (2007). |
| Sub area 4 - MOM | 1) Raise and strengthen sea walls | Moderate | Using typical costs, further investigation into best means of adapting existing structures |
| Sub area 5 - | 1) Raise walk area | Poor | Rawlinsons (2007), rough design, fill rate $25/m3 - highly dependent on availability |

| | | | |
|---|---|---|---|
| Peninsula | 2) Flood wall (raise existing walls) | Moderate | Using typical costs, further investigation into best means of adapting existing structures required |
| | 3) Flood gates at estuary mouth. Flood gates at Old Mandurah Bridge (would also serve 6,7,10 & 11). | Poor | Very loose costs based on recent SMALL scale flood gate project |
| Sub area 6 - Walk to Soldiers Cove | 1) Build a second wall - land-side of path, raise boardwalk and wall | Moderate to good | Typical vertical wall costs, 7 block high with footomg. loose rates for boardwalk components and installation (includes new rock revetment) |
| | 2) Build a second wall - sea-side of path. Raise boardwalk and wall | Moderate to good | Typical vertical wall costs. loose rates for boardwalk components and installation (includes new rock revetment) |
| | 3) Flood gates at estuary mouth. Flood gates at Old Mandurah Bridge (would also serve 6,7,10 & 11). | Poor | See Sub Area 5 Option 3 |
| Sub area 7 - SE canal estate | 1) Flood gates at estuary mouth. Flood gates at Old Mandurah Bridge (would also serve 6,7,10 & 11) | Poor | See Sub Area 5 Option 3 |
| | 2) Flood gates at estuary mouth and Dawesville Channel (would also serve 6,7,10 & 11) | Poor | See Sub Area 5 Option 3 |
| | 3) Sea wall prior to building houses. Fill low land | Moderate | Typical vertical wall costs, rock revetment in crease at entrance. with fill rate of ($20/m3) - highly variable |
| Sub area 8 - Creery Wetland Foreshore | 1) Strengthen embankment. Add wall. | Good | Costs obtained for panels and pins and using assumed labour rates for installation. Typical vertical wall costs |
| Sub area 9 - SW canal estates | 1) Flood gates at estuary mouth and Dawesville Channel (would also serve 6,7,10 & 11) | Poor | See Sub Area 5 Option 3 |
| | 2) Flood gates at Old Mandurah Bridge and Dawesville Channel (would also serve 6,7,10 & 11) | Poor | See Sub Area 5 Option 3 |
| | 3) Sea wall prior to building houses / sea wall to prevent channel movement | Good | Typical rock revetment design and rock rates |
| Sub area 10 - Port Mandurah | 1) Flood gates at Old Mandurah Bridge and Dawesville Channel (would also serve 6,7,10 & 11) | Poor | See Sub Area 5 Option 3 |
| | 2) Flood gates at estuary mouth and Dawesville Channel (would also serve 6,7,10 & 11) | Poor | See Sub Area 5 Option 3 |
| | 3) flood gates at entrance to residential canal area | Poor | See Sub Area 5 Option 3 |
| Sub area 11 - Western Foreshore | 1) Raise houses on foundations (progressive - at the end of each houses design life) | Moderate | Fill rate $40/m3 - highly dependent on availability, with limestone retaining wall around |
| | 2) Require zoning changes for new houses to flood-proof | Poor | Loose rates per undeveloped (~10% of house cost), developed (~20% of house cost) |
| | 3) Crest wall | Good | Typical vertical wall costs |
| | 4) flood gates at estuary mouth and Old Mandurah Bridge (would also serve 6,7,10 & 11) | Poor | See Sub Area 5 Option 3 |
| Sub area 12 - Halls Head | 1) Large enclosing groynes - Small groynes (phase 1) | Good | design and rock rates based on recent Project - factored for increase height for SLR |
| | 1) Large enclosing groynes - Small groynes (phase 2) | Good | design and rock rates based on recent Project - factored for increase height for SLR and depth required |
| | 1) Large enclosing groynes - Intermediary "T" groynes (phase 3) | Good | |
| | 1) Large enclosing groynes - Offshore reef with 50% gap (phase 4) | | |
| | 2) Seawall - Small seawall (phase 1) | Good | See Sub Area 1 Option 2 |
| | 2) Seawall - Extension downwards of small seawall (phase 2) | Good | |
| | 2) Seawall – Large seawall (phase 3) | Good | |

Table C2 **Siesta Park-Marybrook Case Study cost estimates confidence summary**

| Sub Area | Option | Confidence | Notes |
|---|---|---|---|
| Sub area 1 - West of Siesta Park | 1) individual seawalls for each property | Good | Based on costs for construction of Dunsborough foreshore |
| | 2) single seawall across sub-region | Good | |
| | 3) single large groyne | Good | 150m groyne based n the length of Siesta Park, requires significant nourishment to saturate |
| | 4) multiple smaller groynes | Good | 3 groynes with nourishment (spacing betweeng 280m (2deg rule) and 430m (San Remo effective length *10) |
| Sub area 2 - Siesta Park | 1) individual seawalls for each property | Good | See Sub Area 1 |
| | 2) single seawall across sub-region | Good | |
| | 3) extend existing groyne into single large groyne | Good | |
| | 4) multiple smaller groynes | Good | |
| Sub area 3 - Locke Estate | 1) individual seawalls for each property | Good | |
| | 2) single seawall across sub-region | Good | |
| | 3) single large groyne | Good | |
| | 4) multiple smaller groynes | Good | |
| Sub area 4 - W. Buayanup | 1) individual seawalls for each property | Good | |
| | 2) single seawall across sub-region | Good | |
| | 3) single large groyne | Good | |
| | 4) multiple smaller groynes | Good | |
| Sub area 5 - Lennox Drain | 1) put up gates to prevent storm surges and raise levees | Moderate | Based on flood gates built at Wonnerup in 2004 and Levees based on Vasse Diversion drain with only the cost of increasing the levees by 1m estimated (note this is likely to be overstated. |
| Sub area 6 - W. Wetland | 1) pump fresh water in to create lakes | Poor | Very rough concept design and costs |
| | 2) partition land to seal off lowest lying areas an allow them to become salty | Moderate | Based on Levee costs for Diversion drain for one 800m partition |
| Sub area 7 - Locke Drain | 1) put up gates to prevent storm surges | Moderate | Based on 45-50m wide flood gates built at Wonnerup in 2004 - applying these costs to a 17m wide flood gate is rough |
| Sub area 8 - E. Wetland | 1) pump fresh water in to create lakes | Poor | See Sub Area 6 |
| | 2) partition land to seal off lowest lying areas and allow them to become salty | Moderate | |
| Sub area 9 - Buayanup Drain | 1) put up gates to prevent storm surges and raise levees | Moderate | See Sub Area 7 |

Table C3 **Peppermint Grove Beach Case Study cost estimates confidence summary**

| Sub Area | Option | Confidence | Notes |
|---|---|---|---|
| Sub area 1 - Northern wetlands | 1) Encourage dune growth to protect coast (dune fencing to pinch point north of study area). Maintain dune buffer by building groynes (to pinch point north of study area). Pump water to turn freshwater system into a lake. | Moderate to good, poor for freshwater system | Seasonal dune fencing to pinch point. 9*50m dunes. Freshwater system based on rough concept design |
| Sub area 2 - Levee system | 1) Levee and weir controls (upgrade) | Moderate | Levee based on Vasse Diversion drain with only the cost of increasing the levees by 1m estimated (note this is likely to be overstated. Weir is based on upgrading the Sabina Diversion Weir |
| Sub area 3 - Southern wetlands | 1) Encourage dune growth in southern part to protect coast (dune fencing to pinch point south of study area). Maintain dune buffer by building groynes (to pinch point south of study area). Raise access road to town. Pump water to turn freshwater system into a lake. | See Sub Area 1 | See Sub Area 1. Road costs based on Rawlinsons |
| | 2) Encourage dune growth in southern part to protect coast (dune fencing). Maintain dune buffer by building groynes (to pinch point south of study area). Raise access road to town. Subdivide into cells to prevent salt-water flow | Good to moderate. | Seasonal dune fencing to pinch point. 9*50m dunes. Road costs based on Rawlinsons. Levee based on Levee costs for Diversion drain for 2 900m |
| Sub area 4 - Higgins Cut | 1) Fill the channel to the beach | Good | Fill rate of $25/m3 to an average depth of 4m - includes reveg of dune |
| Sub area 5 - North Pepp Grove | 1) build groynes and manage dunes | Good | Northern 1000m - 3 Groynes + nourishment + reveg (groynes are depth controlled = 50m length, spacing min 430m) |
| Sub area 6 - Central Pepp Grove | 1) build groynes and manage dunes | Good | Central 1000m - 2 Groynes + nourishment + reveg (groynes are depth controlled = 50m length, spacing min 430m) |
| Sub area 7 - South Pepp Grove | 1) build groynes and manage dunes | Good | Northern 1000m - 2 Groynes + nourishment + reveg (groynes are depth controlled = 50m length, spacing min 430m) |

Table C4 **Eaton Australind Case Study cost estimates confidence summary**

| Sub Area | Option | Confidence | Notes |
|---|---|---|---|
| Sub area 2 - Pelican Point | 1) Crest wall. Rock Revetment surrounding Pelican Point. Large seawall around exposed section of Pelican Point | Good | Using typical costs for limestone walling. using typical design ands costs for rock revetment (0-3.5m AHD). Using typical design ands costs for seawall (-2-4.5m AHD with toe rocks) |
| | 2) Minimum fill for existing and new houses to raise them (progressive - at the end of each houses life span). Rock Revetment surrounding Pelican Point. Large seawall around exposed section of Pelican Point | Moderate to good | Fill rate $40/m3 - highly dependent on availability. using typical design ands costs for rock revetment (0-3.5m AHD). using typical design ands costs for seawall (-2-4.5m AHD with toe rocks) |
| | 3) Fully fill existing and new houses (progressive - at the end of each houses life span). Rock Revetment surrounding Pelican Point. Large seawall around exposed section of Pelican Point | Moderate to good | Fill rate $35/m3 - availability, wall surrounding entire residential area, 1% maintenance accounts for walling to be replaced every 30yrs). using typical design ands costs for rock revetment (0-3.5m AHD). using typical design ands costs for seawall (-2-4.5m AHD with toe rocks) |
| | 4) Require all new houses to have flood-proofing through raising or other measures. Rock Revetment surrounding Pelican Point. Large seawall around exposed section of Pelican Point | Flood-proofing poor, remainder good | Loose rates per undeveloped (~10% of house cost), developed (~20% of house cost). using typical design ands costs for rock revetment (0-3.5m AHD). using typical design ands costs for seawall (-2-4.5m AHD with toe rocks) |
| Sub area 3 - Sth Pelican Point | 1) Surrounding crest wall. Rock Revetment surrounding Pelican Point. Large seawall around exposed section of Pelican Point | See Sub Area 2 Option 1. | |
| | 2) minimum fill for existing and new houses to raise them (progressive - at the end of each houses lifespan). Rock Revetment surrounding Pelican Point. Large seawall around exposed section of Pelican Point | See Sub Area 2 Option 2. | |
| | 3) Fully fill existing and new houses (progressive - at the end of each houses lifespan). Rock Revetment surrounding Pelican Point. Large seawall around exposed section of Pelican Point | See Sub Area 2 Option 3. | |
| | 4) Require all new houses to have flood-proofing through raising or other measures. Rock Revetment surrounding Pelican Point. Large seawall around exposed section of Pelican Point | See Sub Area 2 Option 4. | |
| Sub area 4 - Sporting Precinct | 1) zone to require future buildings to be flood-proof (assumed potential for 22 lots @ $40,000 per lot) | Poor | Assumed potential for 22 lots @ $40,000 per lot) + 7 on Ennis st |
| | 2) fill oval to raise its level | Moderate | Fill rate $20/m3 - highly dependent on availability |
| | 3) protect oval with a levee | Moderate | Fill rate $25/m3 - highly dependent on availability |
| Sub area 5 - Bridge & Commercial | 1) Raise the road and bridge and use road embankment as a levee. Armour the coastal strip (revetment). Large seawall along coastal strip. | Good | Rawlinsons (2007), rough design, fill rate $25/m3 - highly dependent on availability. Using typical costs for rock revetments. |
| | 2) Preclude development on the coastal side of the road | Good | |
| Sub area 6 - Sth Australind | 1) Basic foreshore control with low level walling (rock revetment). raise and fill all the land (progressive - at the end of each houses lifespan). Large seawall along coastal strip. | Moderate to good | Using typical costs for rock revetment. Fill rate $35/m3 - availability, wall surrounding entire residential area, 1% maintenance accounts for walling to be replaced every 30yrs). |

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| Commercial | 2) Basic foreshore control with low level walling (rock revetment). Protect waterside houses with a wall. raise the road and use road embankment as a levee). Large seawall along coastal strip. | Good | Using typical costs for rock revetment. 1.75m high wall with a footing - 8 blocks high. Road based on Rawlinsons, rough design, fill rate $25/m3 - highly dependent on availability, typical cost for a limestone wall. |
| Sub area 7 - North Eaton/ South Australind | 1) Bank protection and watching brief. Rock revetment along bank. Manipulate and deepen channels. Modify bridge. | Good, but bridge modification poor | Costs obtained for panels and pins and using assumed labour rates for installation. Using typical costs for rock revetment (4m high). Based on dredging rate of $12/m3 (variable) + 80,000 prelim. Bridge based on USA bridge rates with a factor of 1.4 (Australian rates). |
| | 2) Bank protection and watching brief. Rock revetment along bank. Create an upstream detention basin. | Good, but detention basin poor | Costs obtained for panels and pins and using assumed labour rates for installation. Using typical costs for rock revetment (4m high). Detention basin based on total $/catchment area for 3 recent projects (water corp) along the Vasse/Sabina with basins. |
| Sub area 8- Eaton | 1) Bank protection and watching brief. Rock revetment along bank. Manipulate and deepen channels. Modify bridge. | See Sub Area 7 Option 1 | |
| | 2) Bank protection and watching brief. Rock revetment along bank. Create an upstream detention basin. | See Sub Area 7 Option 2 | |
| Sub area 9 - Proposed Development N | 1) Fill the areas planned for development prior to development. Create an upstream detention basin. | Poor | Fill rate $30/m3 - highly dependent on availability, development area assumed from TPS 3 Dardanup. Based on total $/catchment area for 3 recent projects (water corp) along the Vasse/Sabina with basins. |
| | 2) Build levees to protect planned development areas. Create an upstream detention basin. | Poor | Fill rate $300/m3 (based on levee)- h, development area assumed from TPS 3 Dardanup. Based on total $/catchment area for 3 recent projects (water corp) along the Vasse/Sabina with basins. |