Costs and coasts: an empirical assessment of physical and institutional climate adaptation pathways

Final Report

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COSTS AND COASTS

Costs and coasts: An empirical assessment of physical and institutional climate adaptation pathways

CSIRO Climate Adaptation Flagship

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Cover image: *King tide event at Shorncliffe* 2009 © Andrew Higgins

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ABSTRACT

The distribution of the potential benefits and costs of adapting to protect against storm surge inundation vary greatly both within and between coastal communities. This diversity is a result of physical factors, such as the risk of storm surge, sea level rise projections, and the topography of the landscape; as well as socioeconomic factors, such as the level of development and the capacity within the community to adapt. Because the costs and benefits of adapting to protect against inundation accrue differently across the community, different players stand to win or lose from different adaptations. Moreover, the scales at which adaptation decisions are made and funded can influence the types of adaptations being implemented. Beginning to build an understanding of these issues is vital to the design of equitable institutions to manage inundation risk by adaptation.

Using a quantitative analysis of the distribution of costs and benefits of three adaptation options (protect, accommodate and retreat) across the residential sector in six Australian coastal communities, we were able to identify a typology of Australian coastal communities based on the economy, equitability and affordability of a community adaptation (seawall) for each style of settlement. The typology provides an empirical underpinning for whether adaptation should be considered at the community level, the individual property level, or not at all, based on simple community characteristics and the distribution of risks and benefits throughout the community.

The choice about how to adapt, however, is more than one of measurement; it must be implemented via institutions that are perceived as equitable and practical by the people making the decisions. In Australia, local governments play a primary role in managing the risk of coastal inundation, and governing at this scale affects the types of adaptations chosen to manage inundation risk. We asked the local government actors responsible for adaptation decision-making in the case-study regions to appraise the relative merits of different options related to protect, accommodate and retreat adaptation strategies. In analysing their responses we found a strong preference for gradual, incremental adaptation options that can be implemented within existing development rules and council practices over options perceived as disruptive, unpopular or legally risky. While, incremental adaptation may not always provide sufficient protection against storm surge under future sea level rise scenarios it is, under present conditions, an institutionally-rational course of action.

In contrast to the Australian focus on locally managed climate adaptation, an international review showed that, globally, adaptation is more frequently coordinated and underwritten by policies, financing and responsibilities at state or national scales. The review explored the different contexts in which protect, accommodate and retreat adaptation decisions are being made. When combined with our empirical findings, our study suggests there is scope to consider new models for sharing risks and costs across scales of Australian government and industry.

EXECUTIVE SUMMARY

The distribution of coastal inundation risk varies depending on physical factors, such as the risk of storm surge, sea level rise projections, and the topography of the landscape; as well as socioeconomic factors, such as the level to which the area has been developed and the capacity within the community to adapt. Even within a community, the spatial distribution of both inundation risk and the benefits of various adaptations may be very finely structured, affecting some more than others, and raising the question of what combinations of institutions and adaptations will make for the most equitable distribution of risk within the community. Choosing between available adaptation options becomes an issue of balancing both benefit-cost economics and equitable institutions.

In any given coastal community there may be a range of adaptation options that can ameliorate some or all of the effects of future coastal inundation events by "protecting" against inundation (e.g. seawalls), redesigning infrastructure to "accommodate" inundation (e.g. raised floor heights), or "retreating" out of areas likely to be inundated. Often, a suite of adaptations may be necessary to meet all community goals and expectations. Each potential adaptation will have differing costs and side effects, and provide differing levels and qualities of protection. Moreover, those costs and benefits will vary from place to place within the community. Economic tools that can estimate specific costs and potential benefits throughout the community can help inform sensible choices about which adaptations, or suites of adaptations, are likely to yield more benefits than they cost to implement.

Even when adaptation is economically sensible to protect against the long term, uncertain risks of losses due to future inundation events, communities may not have the capacity to invest in adaptations in the short and medium term. This may be due to absolute financial constraints, but may also reflect a lack of community consensus about which adaptations to invest in, because of the expected distribution of risk within the community or differing assessments of the future risk of coastal inundation. Some adaptation options may be more acceptable to the community, because they reflect incremental changes to already familiar risk-management institutions, or because they have few side effects or costs. On the other hand, some potentially very effective adaptations may be less popular if they represent a significant change in prior behaviours and institutions. Moreover, the spatial distribution of inundation risk varies greatly at all scales, from region to region, suburb to suburb, and even property to property. The scale at which adaptation decisions find acceptance, and the scale at which they are made and funded, may directly affect the scope of adaptations able to be considered, their equitability and their effectiveness.

This report begins to address these questions by considering both the economic costs and benefits of adaptation, and the institutional factors that may enable or constrain it, across a range of case studies of Queensland coastal communities. We simulated likely storm surge events under sea level rise scenarios to estimate total costs of inundation across the case studies out to 2100, incorporating both damage to buildings and devaluation of land in the residential sector. We then simulated the implementation of adaptations, comparing the distribution of costs of implementation to the distribution of benefits in terms of avoided damages. At the same time, we interviewed a range of stakeholders within the local council governance structures managing the six case study areas. The interviews aimed to identify the biggest risks of coastal inundation, the current planning and management tools available, which of these had already been used, and how useful they were expected to be under future sea level rise scenarios. It also sought to discover how enabled or constrained local governments were by government policy at larger scales. Finally, these institutional insights were compared to the state of the art policy and governance frameworks currently in place internationally.

In each of the six case study sites, the economic costs of storm surge inundation, (including residential infrastructure damage and residential land devaluation, and the potential benefits of adaptation, in terms of avoided damage costs) were estimated for a range of adaptation options under sea level rise scenarios out to 2100. The distribution of these economic costs and benefits throughout the community were calculated, and combined with quantitative estimates of the socioeconomic capacity of each community to fund adaptations. These insights underpinned a typology of coastal settlement types based on the physical determinants of inundation risk, such as storm surge levels and site topography, combined with the distribution of risk throughout the community, and socioeconomic determinants of the capacity for adaptation, such as median household income and number of households.

The most appropriate adaptations for a given location also depend on the institutional factors at play for that context. The institutional analysis found that current governance structures in the case study areas exhibited a preference for incremental adaptation: historically tested defensive measures and extension of existing codes or practices to support accommodation of sea level rise and changing inundation regimes. It also found that current governance structures seem to be relying on an implicit ability to 'outsource' or 'scale out' capability to institutions outside local government's remit, such as the property market or insurance sector. While this is a recognised rational response from local actors operating in a multi-level governance structure, it does have implications for the types of adaptations being considered within the Australian system.

Contrasting these institutional factors to comparable jurisdictions in other places around the world, we found that the Australian experience depends much less on state-led and centralised intervention in responding to future coastal inundation risks, particularly as they manifest at the local scale. There are also signs that there is an expectation amongst local governments that market signals, responding to current risk and anticipating future risk, will provide much of the impetus for adaptation. Together, these observations suggest that large scale coordinated coastal adaptation programs are possibly underutilised in Australia, but also that the Australian context may be suitable for the development of market-based instruments that would see public as well as private benefits accrue from these processes, and that are suited under current governance arrangements to devolved, local implementation.

1. OBJECTIVES OF THE RESEARCH

Our goal was to investigate institutions for responding to changing patterns of extreme weather, specifically storm surge inundation. The impacts of extreme events will be felt differently across different locations (at state, regional and even household scales), and at different times. Conflicts between deeply held social values are often exacerbated in coastal regions where the sea meets the land, and where defenders of private property rights meet defenders of public trust and safety. Hence, while coordination, cross-scale interactions and fairness are critical in making climate adaptation happen, the magnitude of competing agendas seriously hampers progress. The lack of international agreement on mitigation reflects this, but so too does tardiness in adapting to local issues like pursuing integrated approaches to heat stress and resolving legal issues around who is responsible for the costs associated with coastal inundation and flooding (e.g. McDonald, 2007).

Such issues are complicated by the uncertainty and complexity associated with climate adaptation, because a principle of strict liability cannot be applied when causation cannot be established (Wallington and Lawrence, 2008). A critical issue for risk governance is how to allocate the costs of, and responsibilities for, adaptation when scientific knowledge of the consequences of actions is uncertain. The local nature of climate-related risk management and planning activities also means that adaptation may require a reconsideration of the institutional structures and processes that allocate risks and responsibilities between public and private partners, and between levels of government, to ensure that the ability of local actors to adapt is not constrained by regional or national processes (Adger et al., 2005; Urwin and Jordan, 2008).

The project was designed to address these issues by delivering into three broad areas, based around the production of three scientific publications, investigating: 1) the economics of climate adaptation, comparing case studies of inundation-prone coastal settlements and identifying a typology of settlements types as characterised by the distribution of costs and benefits of available adaptation options; 2) the application of an analytical framework to local institutions and policy instruments for climate adaptation; and 3) a comparison of the results from the Australian study to the international context. The following report is compiled from the outcomes of these papers.

1.1 Case studies

Climate change impacts on Queensland's coastal areas include the effects of tropical cyclones, storm surges, flooding, sea level rise, tidal inundation, and shoreline erosion (Zeppel, 2011). For this study we modelled the impact of storm surge inundation on six settlement types along the coast of Queensland, Australia. Our cases were selected within the boundaries of collaborating partners Sunshine Coast, Moreton Bay and Cairns Regional Councils (Figure 1).

The Moreton Bay and Sunshine Coast areas are located within the south east Queensland (SEQ) region and Cairns is located in Far North Queensland (FNQ). Importantly, all three local government areas share a common State policy and legislative framework that guides local land use and coastal planning efforts. The local government areas of Moreton Bay and the Sunshine Coast experience among the highest level of inundation risk to residential buildings in Australia (DCC, 2009). Some of the basic characteristics of these study areas are presented in
Table 1.

Figure 1: Location of the three local government areas within which the six specific case studies are located

Table 1: Collaborating Local Government Area characteristics

	Moreton Bay	**Sunshine Coast**	**Cairns**
Population 2010[1]	381,566	330,318	167,939
Projected population 2031[1]	533,170	508,177	241,494
Population change	151,604	177,859	73,555
Population growth %	40%	54%	44%
Median age	37	42	36
LGA size	2033.3 km^2	3120.7 km^2	4115.1 km^2
No of residential dwellings at risk of 1.1m SLR (within 110m of soft shorelines)[3]	2250	1850	480
Climate adaptation plan strategy	No	Yes	Yes
Planning scheme recognises climate change, e.g. SLR	No		Yes
Risk assessment	Scoping study 2009	Yes	Yes
Adopted SLR projection for planning purposes	0.8m by 2100	1.1m by 2100	0.8m by 2100

Source: ABS 2011 Census of Population and Housing; 1 Office of Economic and Statistical Research (OESR) 2012 medium projection; 2 Sunshine Coast Waterways and Coastal Management Strategy 2011-2021; 3 Geoscience Australia 2011

The economic analysis used detailed data from six communities/settlements within these local government areas. The location and scope of case studies were chosen in conjunction with partner councils. Release of location specific results are left to the discretion of the partner councils, but we provide summary data (Table 2) and a broad conceptualisation of each case study to help interpret the results contained in the report.

Case study 1 is a relatively flat coastal suburb, with minimum property heights ranging from just over 1 m up to 4 m above the Australian Height Datum (AHD) and exposed directly to bay-front waters. A significant fraction of properties there would be at risk of an ARI 100 year event today, and more are likely to be exposed in future as sea levels rise. Case study 2 is an exposed hamlet, but has no properties below 3.5 metres AHD, meaning that the risk of damage due to storm surge is very low. Case study 3 is a slightly protected coastal hamlet, with a flat area containing approximately 20% of the residential properties up to 2 m above AHD, with the rest positioned on upward slopes in roughly equal proportions up to 10 m above AHD away from the waterfront. Case study 4 is an exceptionally flat coastal central business district with almost all properties lower than 3.5 m AHD. A large proportion of properties would be at risk of an ARI 100 year event today, and practically all will be at risk by 2100 without adaptation measures as sea levels rise. On the other hand, the developed nature of the site, the strong funding base and the proactive local government suggest that continued adaptation is likely to mitigate future damages in this area. Case study 5 is a coastal hamlet directly exposed to the ocean, with significant topography up to 40 m AHD and most properties set on upward slopes near the water. As a result, only a small proportion of properties are at risk of an ARI 100 year event today, and although rising sea levels are likely to affect those properties already at risk in the future, many others are set high enough that they will remain unaffected. Case study 6 is a coastal canal estate protected from direct exposure to the ocean by a dune system, but exposed to tidal surge via short distances along canals to the ocean. Very few properties are at risk of an ARI 100 year event today, but the site is very flat and as ocean levels rise a small but increasing proportion of properties may face risk of inundation during major events.

Table 2: Settlement case-study statistics

Settlement	**1**	**2**	**3**	**4**	**5**	**6**
Category	Coastal Suburb	Coastal Hamlet	Coastal Hamlet	Coastal CBD	Coastal Suburb	Canal Estate
Number of residential properties modelled	560	312	122	575 residential, 1346 commercial	489	2620
Median property value	$181,000	$241,000	$169,000	$215,000	$267,000	$290,000
Median infrastructure value	$89,000	$125,000	$88,000	$114,000	$136,000	$141,000
Sub-region Population[1]	3,900	1,800	500	9,900	3,000	4,700
Median annual household income[1]	$44,000	$35,000	$38,000	$52,000	$67,000	$52,000

Source: CSIRO analysis of composite datasets, [1] ABS 2011 Census of Population and Housing;

2. GLOBAL LESSONS FOR ADAPTING OUR COASTAL COMMUNITIES TO PROTECT AGAINST STORM SURGE INUNDATIONS[1]

2.1 Introduction

This chapter reviews both the international and national literatures to better understand the different adaptation options and contexts in which decisions are being made to manage inundation risk as a result of sea level rise and coastal storm surge events. We adopt the commonly used adaptation categorisation of “protect, accommodate and retreat”, which was first introduced by the IPCC in 1990 (Table 3). This review informed discussions with councils, including discussions related to what adaptation options were most usefully considered by subsequent economic modelling.

Table 3: “Protect, accommodate and retreat” categorisation of climate adaptation responses

	Protect Continue the use of vulnerable areas by using defensive measures	**Accommodate** Continue living in vulnerable areas by adjusting living and working habits	**Retreat** Withdrawal from vulnerable areas
Hard	Dikes, seawalls, groynes, breakwaters, storm tide barriers	Building on pilings, adapting drainage, emergency flood shelters	Relocate or abandon threatened assets
Soft	Beach nourishment, dune restoration, living shorelines	New building codes, public disclosure, early warning and evacuation systems, risk-based hazard insurance	Land use restrictions, setbacks, rolling easements

2.2 Defend/Protect

Coastal defence measures involve the use of both hard and soft approaches to protect vulnerable coastal areas from inundation and sea level rise. Areas where ongoing coastal protection is a long-term option include highly developed urban areas with a long history of protection, and areas where there is a need to preserve irreplaceable cultural, indigenous and heritage values.

2.2.1 Hard defences

Hard defences, such as seawalls, dikes, levees and groynes, are common strategies for managing coastal flooding and erosion (Klein, 2011). Many European countries, such as Germany, the United Kingdom and the Netherlands, have a long history of using hard coastal defence structures. For example, northern Germany’s first dike rings

[1] Edited from draft paper: BP Harman, S Heyenga, CS Fletcher, BM Taylor, Global lessons for adapting our coastal communities to protect against storm surge inundation (provisional details only)

were erected about 1,000 years ago to protect farmland from flooding by saltwater and by the 14th century the entire German North Sea coast was protected by a continuous dike line (Hofstede, 2008). As a result, the German coast is entirely protected from coastal flooding by hard defences, while in England and Denmark large parts are protected. In the Netherlands, dike rings are used to protect most low-lying parts of the country from coastal flooding. The national government has responsibility for the main dikes and embankments along the coastline.

Several countries are currently in the process of upgrading/reinforcing their existing levees and dikes to account for sea level rise induced by climate change. For example, the Dutch Government is investigating the option of reinforcing existing dikes to create so-called unbreachable Delta Dikes, especially in areas with the highest concentration of population and fixed assets (Ligtvoet et al., 2012). These dikes are typically engineered to a standard such that the probability of failure is virtually zero (Deltacommissie, 2008). The wide dike area can then also be used as a space for agriculture and recreation. Pilot projects are currently being undertaken that even situate entire residential areas on top of Delta Dikes (European Environment Agency, 2009). A similar approach is taken in Japan, which is investing heavily in the concept of super levees. A super levee is a river embankment with a broad width, which makes it more resistant to overflow, seepage and earthquakes. They also provide usable land and space for urban developments on top of the levee (Van der Most, 2009). In Germany, the Master Plan for Coastal Protection (2007) has raised safety standards of dikes by an average of 25cm to protect against the risk of flooding. In Singapore, nearly 80 percent of the coastline is protected from coastal inundation by seawalls and revetments. These existing structures are currently being strengthened and reinforced to combat the long-term impacts of rising sea levels.

Another adaptation technology gaining increasing popularity is the construction of storm-tide barriers. These large-scale coastal defence projects typically involve movable or fixed barriers or gates which are closed when an extreme water level is forecast in order to prevent flooding. They are usually located at narrow tidal inlets to reduce the length of the structure (Linham and Nicholls, 2010). In Singapore, the construction of the Marina Barrage was completed in 2008 protecting low-lying areas of the city centre from coastal flooding (MEWR, 2008). Similarly, the Thames Barrier is a tidal barrier to protect London from tidal surges entering from the North Sea (The Royal Commission on Environmental Pollution, 2010).

In Australia, seawalls are the most common strategy for shoreline protection in many highly urbanised coastal communities susceptible to storm-tide inundation (DCC, 2009). For example, in South Australia, approximately 14km of the metropolitan coastline is protected by seawalls (DEH, 2005; DEWNR, 2010). In Manly, a suburb in the North of Sydney, a 2.5km long seawall was constructed in stages between 1887 and 1999 using a number of different design standards (Oertel undated).

The use of sub-merged structures (also known as artificial reefs) using geotextile materials for multi-purpose benefit are a relatively new coastal management concept in comparison to the more traditional hard engineered responses to manage coastal erosion and storm surge (Edwards and Smith, 2005). There are obvious amenity benefits and thus are generally well received by the community. In this instance, coastal managers are able to satisfy both community aspirations and coastal protection imperatives. One of the most successful multi-purpose reefs in Australia is located on the Gold Coast, Queensland. Built in 1999/2000, the Narrowneck reef has been successful in achieving both beach protection and improved the surfing conditions (Jackson et al., 2007). It was estimated that for every dollar spent on beach enhancement, a return of between $60-80 could be expected via tourism using the reef

(Raybould and Mules 1998). Other benefits include: enhanced fishing, diving, snorkeling and spearfishing (Jackson et al., 2004).

Despite the potential benefits associated with the construction of hard coastal defence structures, there are a number of concerns (Rupp-Armstrong and Nicholls, 2007), including: asset deterioration and failure (DEH, 2005), construction and maintenance costs (Sovacool, 2011), equity responsibility concerns, and changes in erosion and sediment patterns (McLaughlin, 2010; Tomlinson and Helman, 2006). The New Zealand's Coastal Policy Statement discourages the use of hard protection structures and instead promotes the use of alternative natural defences, including wetlands, coastal vegetation, dunes and barrier islands (DEC, 2010). The United Kingdom's strategy for flood and coastal erosion risk, Making Space for Water, also outlines a deliberate shift away from the use of hard defences, which were becoming more expensive to maintain, to a more holistic, risk-driven strategy. It proposes a wide portfolio of responses to manage coastal flooding, including wetland creation, river corridor widening and managed realignment (DEFRA, 2005). Even in the Netherlands, a new acceptance of coastal dynamics and natural processes is slowly entering Dutch coastal adaptation policy and law (Verschuuren and McDonald, 2012).

In comparison to the international context, there has been no consistent and strategic approach to the location and construction of seawalls in Australia. Construction occurs at the local scale and is funded by local governments and private actors depending on the nature of the asset being protected. A lack of coordination and consistent planning and policy has led to a number of illegally placed seawalls. In some instances, landholders have been asked to remove the illegally placed seawalls at the owners' expense (Horton and Cameron, 2012). In many cases, the ad hoc construction of seawalls, and failure to augment with other strategies such as sand nourishment, has led to downstream impacts (Tomlinson and Helman, 2006). The consequences of poorly executed seawalls have resulted in some councils taking a more consistent and coordinated approach.

For example, the Gold Coast City Council sets out clear direction for the materials used in construction and strategic placement of the A-Line seawall along with appropriate coastal setbacks and rules. However, given the high capital costs associated with hard defence measures, the spatial vulnerability of the urban fabric, and the extensive coastline in Australia, large scale operation of hard coastal defence measures are unlikely to occur along all parts of the coastline susceptible to erosion and inundation. Instead, hard coastal defence efforts will continue to be ad hoc and dominate in areas where there is significant infrastructure and investment already developed (e.g. Gold Coast City). More broadly, there are concerns that hard defence measures may facilitate development in vulnerable areas, thereby creating a false sense of security and increasing risks from catastrophic failures (Grannis, 2011). Finally, hard defence measures create the potential of lock-in, reducing future adaptation options (Klein, 2011).

2.2.2 Soft defences

Soft coastal defence measures, such as beach nourishment and sand dune restoration, adapt to and supplement natural processes. Beach nourishment, in particular, has seen a rapid growth in interest and application over the past few decades (Linham and Nicholls, 2010; Rupp-Armstrong and Nicholls, 2007). Beach nourishment presents a flexible no-regrets approach to deal with climate adaptation as it is reversible and it can also easily be modified to the actual rate of sea level rise (Hofstede, 2011). It often complements hard protection measures, such as seawalls.

The natural appearance of beach nourishment projects also means these schemes are aesthetically pleasing, promoting recreation and tourism (Linham and Nicholls, 2010).

Beach nourishment has a long history of application in many developed countries, such as Germany, the Netherlands and the United States. It has also found application in developing nations, including Brazil, South Korea and Malaysia. In Germany, for instance, since 1963 almost 40 million m^3 of sand has been nourished on the beaches of Sylt, a German island in the North Sea (Hofstede, 2008). According to the National Water Plan 2009-2015, beach nourishment is also a major focus of the Dutch government to protect its communities from coastal flooding on the North Sea and on Wadden Sea Islands. Over the next few decades, beach nourishment is planned to be intensified so that the Dutch coast grows around 1km in a seaward direction in order to create a new land buffer (Deltacommissie, 2008).

An innovative experimental sand nourishing project is also proposed. It involves the dredging and positioning of a super dune of sand in the sea in such a way and in a location that enables hydrological forces to spread the sand to where it is needed. If the experiment is successful, it will replace traditional sand nourishment projects (Verschuuren and McDonald, 2012). Beach nourishment is also one of the preferred methods of erosion and inundation control along coastal parts of the United States (Trembanis et al., 1999). The great majority of the Atlantic and Gulf Coast states have beach nourishment policies in place. Many of these receive federal or state funding for beach nourishment activities, either as an ongoing program or provided on a case-by-case basis (Higgins, 2008). The United States Army Corps of Engineers has responsibility for federal beach nourishment projects and primarily manages beach restoration activities to mitigate future hurricane and storm surge damage.

Almost half of Australia’s coastline comprises sandy beaches (Cooke et al., 2012). The use of beach nourishment and sand dune restoration programs to manage erosion is also widely practised (Cooke et al., 2012). Soft coastal defence measures are seen as viable options to manage destructive coastal processes particularly where amenity and costs are concerned. However, the effectiveness of beach nourishment programs is expected to decrease over time as beaches become more unstable (DCC, 2009, p. 152). Beach nourishment and sand dune restoration are common strategies employed by many local authorities throughout Australia in areas dependent on beach use for tourism (e.g. Gold Coast and Sunshine Coast, Queensland). For example, the Maroochy Beach on the Sunshine Coast attracts almost three million person-visits per year, which contributes approximately $88 million of economic benefit to the region (SCRC, 2012).

There are also a number of sand bypass projects in Australia where sand is utilised for nourishment purposes. For example, Bandy Creek Harbour (WA), Noosa (Qld), Tweed River Entrance (Qld), and Port of Portland (Vic) are all sand bypass projects (Cooke et al., 2012). Since becoming operational the Tweed River Entrance Sand Bypass Project has pumped over 5 million m^3 of sand (AECOM Australia Pty. Ltd., 2010). A recent study investigating beach nourishment practices in Australia revealed a total of 130 beaches are currently managed by artificial nourishment, replenishment or beach scraping programs (Cooke et al., 2012).

Despite its numerous benefits, beach nourishment also has some limitations. Periodic re-nourishments are needed to maintain a scheme’s effectiveness, which requires ongoing and regular monitoring, maintenance and engineering. In the United States, debates have emerged about the appropriate federal role in beach nourishment activities and who should pay for the high costs (Trembanis et al., 1999). Some opponents argue that federal funding spent on nourishment projects is wasted and has also led to the accelerated development of vulnerable coastal areas, thereby putting even more people and properties at risk (Jones and Mangun, 2001; Pilkey and Young, 2005). In addition, protection benefits are seen to be temporary and poorly documented, while the primary beneficiaries often are private property owners and recreational interests (Carter, 2012).

The most important determinant of nourishment costs is the transport distance for the beach material. In addition, finding ongoing sources of sand can be difficult. Beach nourishment requires a suitable source of sediment to be identified in close enough proximity to the nourishment site. The increasing popularity of beach nourishment worldwide may cause sediment availability constraints (Linham and Nicholls, 2010). For example, a limited availability of contractors, coupled with an increase in demand for nourishment projects, has already caused cost increases for nourishment projects in the Netherlands (Hillen et al., 2010). This upward trend in costs is likely to be observed elsewhere.

2.2.3 Living shorelines

In recent years, a third defence approach to protect vulnerable coastal areas from inundation and sea level rise has slowly been gaining traction. The use of “living shorelines” is described as ‘a suite of bank stabilisation and habitat restoration techniques to reinforce the shoreline, minimise coastal erosion, and maintain coastal processes while protecting, restoring, enhancing and creating natural habitat’ (Latta and Boyer, 2012). They are considered to be less intrusive and more sustainable than hard defences. The use of living shorelines is being encouraged in several parts of the United States. One example is the GreenShores project in Florida, which created more than 30 acres of oyster reefs, salt marsh and seagrass habitat along two miles of urban waterfront.

Studies suggest that the construction and maintenance of living shorelines is more economical than hard defences and also requires less maintenance over time (Pace, 2010). Furthermore, living shorelines improve water quality, sequester carbon, and provide space for recreation and for critical habitat for fish and wildlife. However, they are not suited for high-energy areas like open beaches, where beach nourishment remains a better means for addressing erosion and coastal flooding (Pace, 2010). Another disadvantage is that living shorelines may require more space than hard defences such as levees, and also involve more time to become established. The concept of living shorelines is well embedded in the Australian context, however implementation and practice is not well advanced. The location and existence of hard coastal defence measures along with major infrastructure investment in highly urbanised coastal environments are key barriers which prevent both the construction and migration of natural defence measures (e.g. wetlands) (Abel et al., 2011; Burley et al., 2012). Consequently, the use of hard structures (e.g. seawalls) and sand nourishment continue to dominate coastal management practices in Australia.

2.3 Accommodate

Accommodation measures seek to allow the continued or extended use of at-risk areas by reducing the sensitivity and/or exposure to sea level rise (Alexander et al., 2011; DCC, 2009). A range of measures are utilised to allow the continued use of at-risk areas, including changes to building codes and urban design standards, elevated floor requirements, increased setback requirements, hazard insurance, improved drainage and the preparation of emergency evacuation plans. Accommodation measures are often cost effective in a transitional strategy and are particularly suitable for areas with modest to higher value assets where exposure to climate change risk is low to medium.

2.3.1 Building codes and urban design standards

Building codes and design standards play an important role in making development safer from predicted climate impacts. They can address a number of issues, including building elevation, foundation design, moisture-entrapment, and damage from debris (Nichols and Bruch, 2008). The Finnish City of Helsinki on the Baltic Sea began to initiate changes to design standards addressing coastal flooding and sea level rise in the late 1980s. For instance, the City Planning Department held its first seminar on the issue in 1989, which resulted in the decision to raise floor levels in the inner city suburb of Ruoholahti from 1 metre to 3 metres above mean sea level (Lehtonen and Luoma, 2006; Peltonen et al., 2005). Similarly, the City of Espoo's building code prescribes that the lowest construction level is set at three metres above sea level for coastal developments (Hilpert et al., 2007).

In the Netherlands, the City of Rotterdam is emerging as a frontrunner in the field of climate adaptation through its innovative Rotterdam Climate Initiative and the Rotterdam Climate Proof Programme. Rotterdam lies approximately two metres below mean sea level, making the city highly vulnerable to coastal inundation. The Rotterdam Climate Proof Programme is forecast to make Rotterdam climate resilient by 2025. Rotterdam seeks to realise the development of a climate-proof city, partially to be achieved through floating construction. For instance, Rotterdam has plans to build floating urban districts, such as Stadshavens, over an area of 1600 hectares outside the levee system. By 2040, approximately 1200 floating homes will be built in Stadshavens. The first pilot project of a floating pavilion was realised in 2011.

In Germany, the City of Hamburg is currently developing a new city quarter, the Hafen City, in the old port area along the Elbe River, one of the largest inner-city rebuilding projects in Europe. It has incorporated a range of innovative design standards to make the Hafen City more resilient to flooding from storm surges. Examples include floating parks, floating buildings, waterproof parking garages, retrofitting old buildings with waterproof windows and doors on lower levels, and a network of emergency pedestrian walkways 20 feet above the street. In addition, all newly built houses have been raised through the construction of artificial bases to eight metres above sea level (Junghans, 2012).

In New Zealand, the Christchurch City Plan was updated in 2011 to account for climate change induced sea level rise and flooding. It now contains provisions that control development in areas vulnerable to flooding, including raised floor levels and set-backs from waterways.

In Australia, 'buildings are designed and constructed in accordance with the Building Code of Australia (BCA) to withstand climate related hazards such as cyclones and extreme winds, intense rain, bushfires and to some extent flood' (ABCB, 2010, p. 2). While the standards for construction of buildings are constantly reviewed based on their performance post major hazard events and via on-going research and design, the current BCA is likely to be deficient if the climate changes in accordance with the high emissions scenario proposed by the IPCC (ABCB, 2010).

2.3.2 Public disclosure

Home buyers are a key group who will need to be aware of potential coastal inundation threats. Providing this information is believed to be most effective at the time of purchase. In the United States, disclosure statutes require the seller to identify whether the property has been affected by floods or is located in a flood zone or on a floodplain (Ruppert, 2010). For example, in California property owners are required to disclose if they are selling residential property that is located in a flood hazard area (Grannis, 2011). A disclosure requirement has the advantage of being focused on an individual property. The disclosure can take several forms, including generic notification that the property is in a zone vulnerable to sea level rise or a more specific notification that the particular property has experienced flooding or storm damage in the past.

2.4 Retreat

The retreat approach refers to the planned or managed withdrawal from hazard-prone areas of the coast. This may involve relocating or abandoning assets in high risk areas, preventing development in coastal areas, and allowing development to take place on the condition that it will be abandoned if necessary. Retreat is considered to be a feasible adaptation option in several countries, especially in the United States and northern Europe (Rupp-Armstrong and Nicholls, 2007). Planned or managed retreat involves the implementation of thresholds or triggers (e.g. seas encroach within pre-determined distance of infrastructure) which activate the policy.

2.4.1 Managed retreat

Managed retreat involves a decision to withdraw, relocate or abandon assets that are at high risk of being affected by climate change hazards in the coastal zone (Alexander et al., 2011). Managed retreat is a coastal management approach that acknowledges coastal processes and long-term recession as a dominant factor in planning for the use of coastal areas. On an eroding coastline, this requires the retreat of development and infrastructure as the erosion escarpment moves inland. Managed retreat allows the temporary use and occupation of coastal lands until the erosion escarpment encroaches within a specified distance from a development, which will be required to be relocated. Managed retreat is a precautionary approach to managing coastal development, comprising actions aimed at maintaining a buffer along the coastline. This is designed to accommodate natural coastal processes, and reduces the level of risk associated with storm inundation (Helman et al., 2010).

Managed retreat offers several socioeconomic and ecological benefits. Investing in managed retreat today will save communities from future costs of flood protection. The ongoing maintenance costs are significantly lower than for protection measures. In addition, managed retreat protects existing habitats and creates new intertidal habitats, which are a natural form of flood protection (DCC, 2009). It thereby also enhances opportunities for amenity and recreation. For these reasons managed retreat policies are increasingly being considered as an alternative to the use of hard structures (DEFRA, 2005; Luisetti et al., 2011).

The New Zealand Coastal Management Statement encourages the consideration of managed retreat in areas of high coastal hazard risk. This includes the relocation or removal of existing structures and their abandonment in extreme circumstances (DEC, 2010). Waitakere City Council in Auckland successfully implemented a voluntary managed retreat project. It was able to purchase and relocate approximately 80 houses from areas facing increasing risk from coastal flooding.

The United Kingdom has also experienced a growing trend towards using managed retreat to protect from coastal flooding. However, the term “managed retreat” has been abolished due to its negative connotations and is now called “managed realignment” (Rupp-Armstrong and Nicholls, 2007). Managed realignment in the UK includes the deliberate breaching of existing sea defences with the land behind then consequently flooded. This results in the creation or restoration of salt marshes, which are considered to be more sustainable flood defences in helping to dissipate wave energy. Managed realignment is usually cheaper than holding the line of coastal defences in the long term. An example of a successful managed realignment project in the United Kingdom is the Hesketh Out Marsh in Lancashire, which utilised voluntary agreements with landholders to abandon their land.

In Australia, managed retreat techniques have been implemented along sections of the Australian coastline (e.g. Marion Bay, SA., Lakes Entrance, VIC and Byron Bay, NSW) (Niven and Bardsley, 2013). Byron Shire, in northern New South Wales, was one of the first councils to initiate and implement a policy response of 'planned retreat' (Bryon Shire Council, undated). This policy has existed since 1988 when it was developed in response to concerns over coastal erosion following a series of storm events. The policy 'enables the temporary occupation of lands subject to coastline hazards, until such time that the risk to the development from coastal processes is unacceptable thus requiring the relocation or removal of development from that property' (Byron Shire Council, 2009, p. 4).

The coastal zone is highly dynamic and there have been several storms and cyclonic events over the past century which have damaged or destroyed public and private assets. A severe storm event in May 2009 led to significant erosion of beach environments in Byron Shire which subsequently triggered the retreat policy (Leitch and Robinson, 2012). Landowners were prevented from doing any restorative work by Byron Shire Council. However, the policy was recently contested in the NSW Land and Environment Court which overruled the Council's policy and acknowledged that the Council was liable for maintaining coastal defence works as part of their development consent to offset the effects of coastal erosion (Sydney Morning Herald, 2010).

One of the most recent examples where local government considered planned retreat as an option was seen in the case of the Port Macquarie Hastings Council (PMHC) in New South Wales. The Council engaged a private consultant (SMEC) to investigate potential adaptation options for managing coastal erosion. Planned retreat was identified as one of the options available to manage risk through acquisition and voluntary purchase of affected properties (SMEC, 2012). The possibility of implementing planned retreat generated significant community concern and angst. The plan was released for public exhibition and comment for a period of ten weeks. The PMHC received approximately 4600 submissions and the overwhelming response from the community was in support of constructing a revetment wall and beach nourishment to manage erosion (PMHC, 2012).

2.4.2 Rolling easements

A rolling easement is a land use planning tool that allows development to occur, but only with the explicit condition that the property will not be protected from rising sea levels (Titus, 1998; Watson et al., 2001). This approach allows wetlands and beaches to migrate inland as the sea rises at the expense of existing structures, thereby preserving natural shoreline processes (Higgins, 2008; McLaughlin, 2010). Rolling easements are mostly used in the United States. For example, Maine, Rhode Island, California, North and South Carolina and Texas have implemented versions of rolling easements. The South Carolina Beach Front Management Act (1988) determines a setback line for ocean-front property. Lots which are seaward of the setback line can be developed but no hard structures can be used to protect the property. If the lot is inundated during a storm tide, rebuilding is no longer allowed. Rolling easements have a number of benefits over other regulatory approaches, such as setbacks. First, this option requires neither a specific estimate of future sea level rise nor large public land purchases. The concept of rolling easements is well embedded in the Australian literature but to date there is little evidence of the policy being implemented in a direct attempt to manage coastal processes under changing climatic conditions (Abel et al., 2011; Alexander et al., 2011).

Complex institutional and governance arrangements in Australia prevent widespread adoption and implementation of planned retreat and rolling easements policies (Verschuuren and McDonald, 2012). In Queensland, one of the fundamental challenges to effective climate adaptation relates to issues regarding potential economic losses and compensation claims as a result of changes to local government plans in light of predicted climate change impacts. The potential for compensation claims against local government from changes to planning schemes or planning scheme policies that reduce the value of land may result in a reluctance to implement adaptation strategies (Low Choy et al., 2012).

2.4.3 Setbacks

Setbacks are restrictions on how far from the water construction is permitted (Nichols and Bruch, 2008). Setbacks thereby provide a buffer between a hazard area and coastal development. They are similar to rolling easements in that they also seek to protect shoreline dynamics. Setback policies are widely used in many countries, including the United States, Canada, Denmark, Germany, Norway, Finland and Sweden.

In the United States, setback regulation has been used for more than three decades to protect communities and development from coastal erosion and flooding. For example, Florida began incorporating setbacks into its shoreline management plan in 1970, with an initial 50-foot setback for construction along sandy beaches (Pace, 2010). In parts of Rhode Island, residential development must be set back at least thirty times the average annual erosion rate (Higgins, 2008). Setbacks provide a highly effective method of minimising property damage due to coastal flooding by removing structures from the hazard zone. They are a low-cost alternative to hard coastal structures, such as seawalls or dikes, and also help to preserve natural shoreline dynamics.

Over time, rising sea levels will reduce the size of the buffer between structures and the sea. As a result, setbacks will need to be periodically reviewed to ensure that buffer zones continue to provide sufficient protection. Florida and South Carolina in the United States reassess their setback distances every 10 years.

In Australia, most state governments have implemented setback criteria for beachfront development, although these vary between states due to local circumstances (Tomlinson and Helman, 2006). For example, setbacks in South Australia are based on a 100-year erosion trend and storm surge flood level with a projected sea level rise (Resource Assessment Commission, 1993). The Western Australian Government prohibits development within 100 metres from the horizontal setback datum (HSD) with additional setbacks for erosion areas based on the 100-year erosion trend (Western Australian Planning Commission, 2003). On the Gold Coast, Queensland, the foreshore seawall line or A-line sets a minimum setback requirement for ocean-front properties at a distance of no less than 8.1 metres from the A-line wall (GCCC, 2012).

2.5 Regulatory instruments

Most coastal adaptation law around the world is still fairly recent. Many countries are utilising regulatory instruments to prohibit urban development in flood-prone areas. In some cases, such as Germany and Finland, these regulations take into consideration the latest scientific knowledge concerning climate change impacts such as expected rises in sea levels (Hilpert et al., 2007). In Germany, the *Flood Control Act* (2005) prohibits the development of new human settlements in flood plains. The basis for designating flood plains is the 100-year flood. In the Netherlands, the Delta Programme is an annual plan with a six-year planning horizon detailing all measures necessary to combat flooding as a consequence of climate change. In addition, the National Spatial Plan is a regulatory instrument that is used to avoid unwanted land-use developments taking place. For example, it prevents new building activities in specific areas along the coast. It also identifies emergency water storage areas to be preserved from development along the coastline (Verschuuren and McDonald, 2012).

In Sweden, the *Planning and Building Act* (2011) includes a number of climate change requirements. Planning authorities are required to take into account the effects of climate change in all of their decision-making, from strategic planning decisions through to development control and the issuing of building permits (Diş et al., 2011).

The United Kingdom adopted the *Flood and Water Management Act* in 2010, an integrated piece of water legislation with a focus on coastal adaptation. The measures that can be taken to reduce coastal flood risk are very comprehensive and include hard defences, the removal of buildings and the restoration of natural processes. While implementation is occurring at the local level, the UK's Environment Agency must develop and maintain a national flood and coastal erosion risk management strategy. The Environment Agency is also responsible for funding flood and coastal risk management (Verschuuren and McDonald, 2012).

The impacts of coastal inundation as a result of climate change induced sea level rise and storm surge have been well debated over the past five years (Verschuuren and McDonald, 2012). On-ground implementation of coastal adaptation in Australia is managed at the scale of local government. Local governments are critical players in coastal adaptation through their mandated role in statutory land use planning and development assessment. However, given the complexity of legislation, government and private sector interests in coastal resources, the planning and management of Australia's coastline transcends the local scale to incorporate state, national and even international interests and obligations (Kay and Alder, 2005). All Australian states have planning laws that relate to coastal hazards with many of the states amending these to include measures that relate specifically to hazards exacerbated by climate change and sea level rise (Verschuuren and McDonald, 2012).

For example, in Queensland coastal planning and management is largely guided by the provisions contained within the *Sustainable Planning Act 2009* (SPA) and the *Coastal Protection and Management Act 1995 (CPMA).* Consideration of climate change impacts on coastal management and development during the plan making and development assessment stages has been mandated under the SPA 2009 (s5(1)(a)(c)) and CPMA 1995 (s21(2)(b)). Furthermore, the *Coastal Protection and Management Act 1995* (s110) provides that a land surrender condition may be imposed on a development situated within an erosion prone area (DERM, 2012). Land is surrendered to the State to ensure that land remains undeveloped to allow natural processes to occur as a condition of allowing bonus development rights on the remaining unaffected land outside the erosion prone area (DERM, 2012).

Until recently, most Australian states had either developed or adopted sea level rise planning benchmarks to guide land use planning and development assessment activities (see

In addition to regulatory controls, state governments can also provide targeted financial support to local governments for coastal protection and management (e.g. the NSW government grants scheme) (DEH, 2013). While these schemes exist, this report does not provide a detailed assessment of the feasibility or effectiveness of these programs in supporting local adaptation needs.

Table 4). However, both NSW and Qld have since revoked their respective sea level rise planning benchmarks following state government elections.

In addition to regulatory controls, state governments can also provide targeted financial support to local governments for coastal protection and management (e.g. the NSW government grants scheme) (DEH, 2013). While these schemes exist, this report does not provide a detailed assessment of the feasibility or effectiveness of these programs in supporting local adaptation needs.

Table 4: State government sea level rise planning benchmarks

Jurisdiction	**2050 (on 1990 levels)**	**2100 (on 1990 levels)**	**Key reference**
Queensland		0.8m	Queensland Coastal Plan 2010 (since revoked)
New South Wales	0.4m	0.9m	NSW SLR Policy Statement 2009 (since revoked)
Victoria		0.8m	Victorian Coastal Strategy 2008
Tasmania	0.2m (on 2010 levels)	0.8m (on 2010 levels)	Tasmania Government 2012
Western Australia		0.9m (by 2110)	State Coastal Planning Policy 2003
South Australia	0.3m	1.0m	Coastal Protection Board Policy Document 2012
Northern Territory	Nil	Nil	NT Climate Change Policy 2009

3. TOWARDS A TYPOLOGY OF ADAPTATION SCENARIOS TO PROTECT COASTAL SETTLEMENTS AGAINST STORM SURGE INUNDATION: ECONOMIC, EQUITABLE AND AFFORDABLE ADAPTATION[2]

3.1 Introduction

Having reviewed the types of adaptations being deployed internationally, we then collaborated with local councils to analyse how a representative subset of adaptation options faired economically. We performed a property-level analysis of six suburb-sized case studies distributed along the coast of Queensland, Australia (see Table 2). We assessed the potential economic costs of storm surge inundation events in the residential sector both now, and in the future, under sea level rise projections, and the potential avoided costs following adaptation to protect against inundation. We also estimated the distribution of risk in each community, and compared the potential costs of adaptation with the capacity of the community to pay for their implementation. We used these insights to define typologies of coastal communities based on their exposure to total inundation risk, the distribution of that risk within the community, and their capacity to adapt.

We calculated the distribution of the expected costs of storm surge inundation and the potential benefits, in terms of avoided costs, of various adaptation options across six settlement case studies, and compared them to various quantitative socioeconomic factors describing each community (Table 2). The case studies covered a range of settlement types, from the central business district of a coastal city to small coastal hamlets, and a range of inundation risks, from highly exposed low-lying coastal strips to sheltered hamlets and canal estates.

Damage costs included potential damage due to residential infrastructure, calculated using damage curves, and devaluation of residential property, based on hedonic analysis. Three modellable adaptation options of most interest to councils were considered, a “protect” strategy (construction of a seawall along the length of the case-study waterfront), an “accommodate” strategy (raised floor heights of buildings within the case-study area), and a “retreat” strategy (purchase of at-risk properties). The distribution of economic costs and benefits throughout the community were also calculated. The economic benefit of the various adaptation options were compared to socioeconomic factors across case study types to identify rules of thumb for optimal adaptations in different coastal settlements.

3.2 Methods

3.2.1 Calculating the costs of inundation

The costs of inundation were calculated by estimating the depth of inundation on each property, and within each building, for an annual maximum storm surge event drawn from the observed extreme value distribution at each site; with an offset to account for expected sea level rise in future years. Inundation depths were converted to a dollar value of damage to infrastructure using published damage curves (Middelmann-Fernandes, 2010). In addition, the devaluation of residential property due to increasing

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[2] Edited from draft paper: CS Fletcher, AN Rambaldi, F Lipkin, RRJ McAllister, Towards a typology of adaptation scenarios to protect coastal settlements against storm surge inundation: economic, equitable and affordable adaptation (provisional details only)

inundation risk was estimated based on hedonic analysis of the value of inundation security in the Australian residential property marketplace (Rambaldi et al., 2012). High resolution data about case-study terrain, the position and location of buildings, and factors contributing to the value of residential buildings were estimated using analysis in a Geographical Information System (ESRI Inc., 2010). A high resolution DEM was created from high resolution (2m) LiDAR data (DERM, 2010). Minimum and maximum property heights above the Australian Height Datum (AHD) were calculated by intersecting council cadastral data with this high resolution DEM. Building footprints were extracted using learning algorithms analysing return data from both the ground and first return signals of the LiDAR dataset and multichannel aerial imagery on the colour profile of building roofs. This process automatically generated building footprint polygons, which were manually checked and cleaned against aerial imagery, and building minimum floor heights (AHD), and maximum height of the built structure were extracted by intersection with the high resolution DEM. Some councils provided manually collected floor height data, which were used where possible, otherwise floor height was estimated as ground level plus freeboard of 300mm (DCCEE, 2011).

Probabilistic distributions of storm surge events were described by the generalised extreme-value distribution, fit to observed council inundation data from each case study (Gumbel, 1958). Each year of each model run, the maximum height of an extreme storm surge event was drawn from the distribution, with an offset added equal to the projected sea level rise expected at that point in the future. We used the global averaged SRES A1B sea level rise scenario (Hunter, 2010) with corrections for regional departures (CSIRO, 2011) (we use the A1B scenario because it is the only one for which regional corrections were available at the time of analysis). We used the 95th percentile estimates of sea level rise of approximately 0.2m by 2030 and 0.5m by 2070 (Wang et al., 2010). These estimates may be conservative, because they do not account for all factors which contribute to sea level rise, such as accelerated melting of the Greenland ice sheets. With a changing climate other inundation-related events, such as coastal erosion and inland flooding, are likely to occur both in isolation and in conjunction with changing storm surge regimes; however we do not consider these more complicated events here. Although some reports have identified the possibility of coincident storm surge coupled and changed storm intensity and wind speed as major risks for low lying developed urban areas (DCCEE, 2011), estimates of these affects are much less certain than sea level rise, and along Australia's east coast best estimates suggest that the joint probability of storm surge and rainfall driven flooding is unlikely to change (Abbs and McInnes, 2011).

The inundation depth was converted to an inundation region using a static "bath tub" approach, filling the terrain hydrologically connected to the ocean at the specified level. The inundation depth within each property and building was calculated, and the economic costs of inundation damage to residential infrastructure was estimated using stage damage curves to reflect a percentage or dollar damage as a function of the depth of inundation on each property (Middelmann-Fernandes, 2010). In addition to infrastructure damage to residential housing stock, we assessed the loss of value to the land on which residential houses were built. This potential loss represents a vital component of the impacts of sea level rise on individual households, because land values appreciate over time (Rambaldi et al., 2011), and because the land on which the family home rests represents the largest single asset of most Australians (Wilkins et al., 2009). Rambaldi *et. al.* (2012) calculated the historical devaluation of residential land in Australia due to inundation risk as 1.28% + 5.45% per metre of inundation during an 100-year Average Recurrence Interval (ARI 100 year) event. This value quantifies the devaluation of residential property due to inundation risk, relative to the value of an identical but fully protected property. Thus, it provides an estimate of the potential property-value benefit of adapting to protect against inundation, a major part of how individuals will be affected by adaptation which is likely to strongly influence the motivations of communities to support and/or undertake action. On the other hand, public assets will also be at risk of inundation during storm surge events, and these will contribute to broader impacts felt both individually and across the community as a whole. A full benefit-cost analysis would need to take into account all of these factors, and because public assets are “community owned”, and damage to them must be repaired from the public purse, therefore incorporating these effects may more evenly spread the risks and benefits of inundation and adaptation throughout the community.

The model was run a thousand times for each case study, drawing peak annual storm surge events under sea level rise scenarios between 2010 and 2100, and calculating the depth of inundation on each property and building and the associated damages, which were corrected to net present value (2010 dollars) and accumulated. In most years of each model run storm surges were too low to cause significant damage, as observed in the real world, but over each ninety-year run damages from the few uncommon extreme events accumulated. Statistical estimates of the likely costs of inundation, incorporating the fundamentally variable nature of weather into the future, were calculated across the thousand of model runs from each case study. This approach provides a significantly more advanced picture of the likely accumulated costs of inundation compared to the more traditional estimate of the costs due a single specified event (usually an ARI 100 year event) at a specified point in the future (usually 2030, 2050 or 2100).

3.2.2 Calculating the benefits of adaptation

We estimated the potential avoided costs due to adaptation by implementing three types of adaptation within the model, and rerunning it to compare with the unadapted case. These options were: 1) a “protect” option, seawalls, which were assumed to prevent all damage for inundation levels below their height, and proportional protection for inundation levels above it; 2) an “accommodate” option, changed building codes specifying the minimum floor height of buildings, which prevented building damage if inundation did not reach the floorboards, and reduced it for inundation that exceeded the floorboard level, but did nothing to protect land values; and 3) a “retreat” option, in which the houses most at risk of inundation were purchased by council and rezoned non-residential, avoiding any future costs due to inundation. These options can be understood within the context of the categories of adaptation used in our literature review (Table 3).The extent of each adaptation was specified in terms of protecting properties likely to be exposed to an ARI 100-year event in 2050, implemented today.

Approximate costs of adaptations were estimated from council data or the literature. The cost of implementing seawalls varies greatly depending on location, access, foundation materials, length and height. A recent report in the study region identified four different seawall projects, with budgeted costs ranging from $1,250/m to $4,200 /m, similar to estimates from the literature (Walsh et al., 2004; Yohe et al., 1996). We assumed build costs of $2,500/m for a worst-case scenario of a seawall constructed across the entire vulnerable coastline of each case-study region, capable of withstanding an ARI 100 year event in 2050. Council reports from elsewhere in Australia budget costs for raising houses at approximately $40,000 per residence (Webb McKeown and Associates Pty. Ltd., 2001), although the costs of raising masonry buildings on in-ground foundations are recognised to be higher. Buildings were raised to avoid inundation during an ARI 100 year event in 2050. Residential lots that would be inundated in an ARI 100 year event in 2050 were purchased today as part of retreat operations at their market value within the model.

The per-household cost of each type of adaptation was estimated assuming that all property owners contributed equally to funding the adaptation, a reasonable assumption for adaptations implemented by local councils. In Australia, a potential model for funding such a mechanism exists in a current special charge (~$1000/year) levied on canal estate residents for long-term maintenance costs of canals, in addition to normal council rates. Looking at households in case study 6 (a canal estate, Table 2), this charge represents ~1.92% of the annual median income of an estate household. We estimate, then, the ability of a community to fund adaptations as 1.92% of the median annual income in the community, indexed to the discount rate, with a planning and funding horizon of forty years out to 2050. If the ability of the community to fund a community-level adaptation, in this case a seawall, exceeded its cost, we said that the adaptation was “affordable”.

The mean household benefit/cost ratio was calculated for each scenario, averaged across the entire case-study community. This mean benefit:cost ratio is the same as the total benefit:cost ratio of the case study, the metric most commonly used in these sorts of analyses (Wang et al., 2010). If the case study was expected to see a net benefit due to avoided damage costs by 2100 following implementation of the community-level seawall adaptation, we said that the adaptation was “economic”.

In addition, the 25%, 50% (median) and 75% benefit quartiles were calculated to capture the distribution of benefits within the community. The median emphasises rare large values less than the mean, so if only a few properties benefit from an adaptation the median benefit may be low even when the mean benefit is high. The point at which the median benefit exceeds the mean costs of adaptation represents the point at which most properties in the case study realise a net benefit, assuming that all property owners contributed equally to funding the adaptation. When most of the people in the community achieved a net benefit, we said that the adaptation was “equitable”.

3.3 Results

3.3.1 The costs of inundation

Table 5 shows a summary of the predicted costs of inundation due to an ARI 100 year event today, and over typical planning horizons in 2030 and 2050, under sea level rise scenarios consistent with A1B scenarios with local corrections. It shows absolute costs, proportional or per-property costs, and median costs.

All three costs vary dramatically from case study to case study, due to case study size, the proportion of residential properties that are at risk, and the interaction between the topography of the land and sea level rise. Absolute damages are highest for heavily developed areas (case studies 1, 4 and 6, Table 5). Mean damages are highest where a significant portion of the community is at risk (case studies 1, 4 and 5, Table 5). Median damages depend critically on the risk profile for the specific location, but they are always much lower than mean damages, indicating that many households face little risk of inundation. Case study 2 is naturally protected from storm surge events, and the predicted risk across the community is extremely small, even out to 2050.

Table 5: Risk of inundation for each case study

Case study	# modelled	Year	# inundated	% inundated	Total loss ($m)	Mean loss ($k)	Median loss ($k)
1	560	2010	212	38	7	12	0
		2030	237	42	12	21	0
		2050	250	45	25	44	10
2	312	2010	1	0	0	0	0
		2030	1	0	0	0	0
		2050	1	0	0	0	0
3	122	2010	24	20	1	4	0
		2030	27	22	1	7	0
		2050	31	25	2	14	0
4	575	2010	192	33	5	8	0
		2030	213	37	8	14	2
		2050	290	50	15	26	11
5	489	2010	10	2	2	4	0
		2030	20	4	3	6	0
		2050	25	5	5	10	0
6	2620	2010	117	4	4	2	0
		2030	118	5	7	3	0
		2050	121	5	13	5	0

Figure 2 extends the insights provided in Table 5 out to 2100, in terms of the proportion of properties within each case study at risk of inundation during an ARI 100 year event. Note that case study 2 is not expected to face significant risk even from an ARI 100 year event including sea level rise effects by 2100; in some others only a small proportion of properties are ever at-risk, and in others cohorts of properties are expected to face increased risk as sea levels rise. Understanding this distribution of exposure within the community is vital for designing equitable adaptations and institutions to manage risk.

Because case study 2 faces no appreciable risk, we expect no significant economic benefit in terms of avoided damages to accrue from adaptation. In the following tables of results we omit it to avoid unnecessary reporting of null results, but we return to it again when we examine different categories of community adaptations in the Discussion.

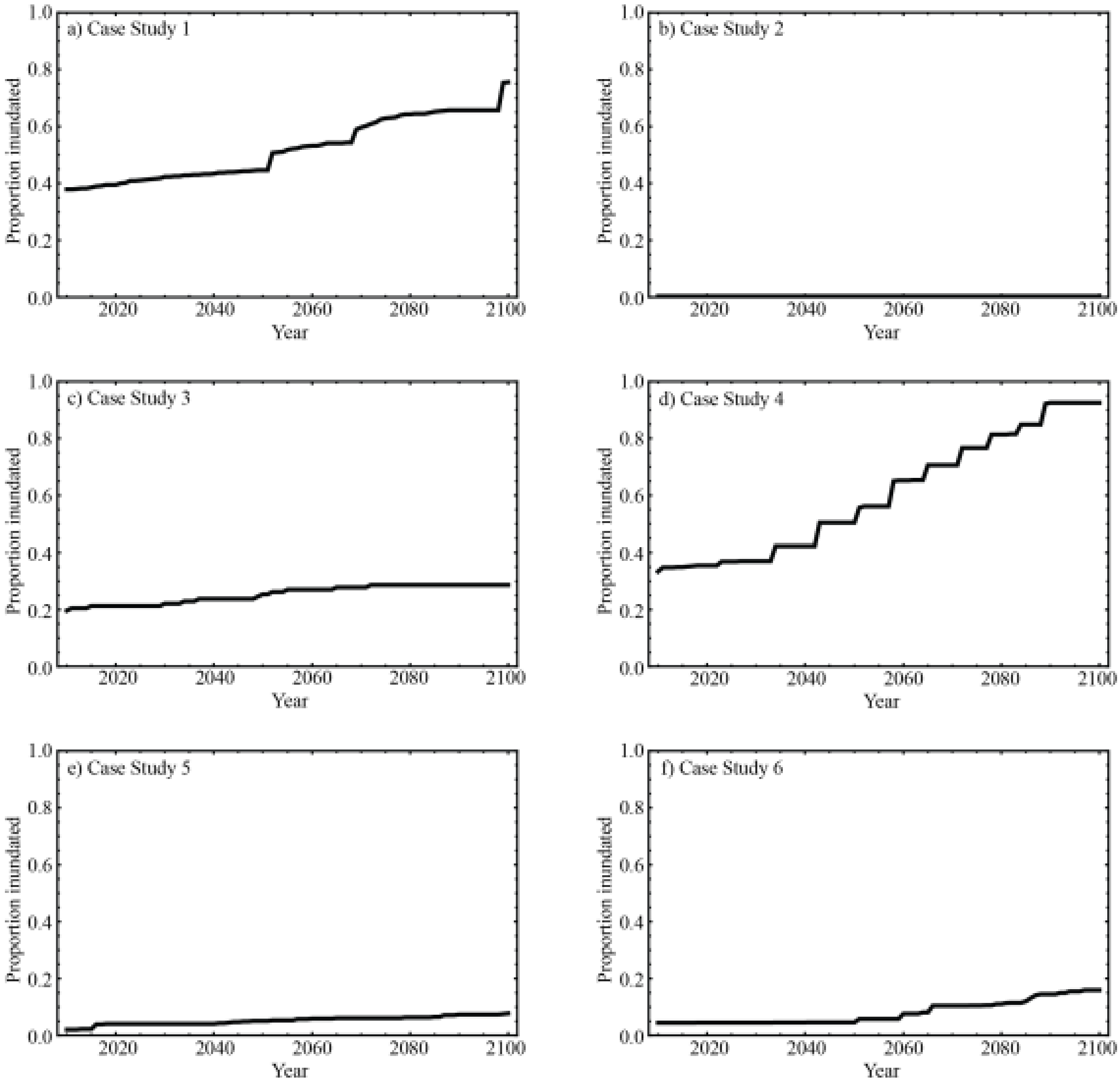

Figure 2: The proportion of properties in each case study expected to be at risk of inundation from an ARI 100 year event under sea level rise out to 2100

3.3.2 The costs of adaptation

Table 6 shows the estimated costs of each type of adaptation within each case-study site estimated as the average cost per household, or in the case of the coastal CBD, per household and commercial property. It also shows the median annual household income, and the median adaptation budget per property, assuming a contribution of 1.92% median annual income per year, indexed to the discount rate out to 2050, a forty-year funding horizon. It shows the ratio of the cost of each adaptation to the adaptation budget, and notes whether the estimated adaptation budget is sufficient to fund a community adaptation, in this case, a seawall. In all cases, seawalls and increasing floor heights are significantly more affordable to implement than retreat.

The per household cost of implementing a community level adaptation such as a sea wall is determined by the length of sea wall to be constructed, the number of properties contributing, and the median household income in the community. Small communities, such as case study 3, incur high per property costs and low affordability due to the low number of households contributing, exacerbated in this case by low median household income. Larger communities, especially those with a compact exposure to the ocean, such as case studies 4 and 5, can realise much lower and more affordable per property costs. However, large communities with complex and extended exposure to storm surge events, such as case study 6, may face significant per property adaptation costs despite large numbers of relatively high incomes households being available to contribute to adaptation.

Table 6: The costs of adaptation for each case study

Case study	Adaptation	Adaptation cost ($k/property)	Median annual household income ($k)	Adaptation budget ($k/property)	Adaptation budget: cost	Affordable? (Seawall)
1	Seawall	37	44	34	0.92	No
	Floor height	14			2.47	
	Retreat	170			0.20	
3	Seawall	34	38	30	0.87	No
	Floor height	7			4.08	
	Retreat	59			0.50	
4	Seawall	6	52	40	6.65	Yes
	Floor height	2			25.98	
	Retreat	83			0.48	
5	Seawall	9	67	52	5.46	Yes
	Floor height	1			40.12	
	Retreat	56			0.92	
6	Seawall	26	52	40	1.52	Yes
	Floor height	6			6.61	
	Retreat	209			0.19	

3.3.3 The benefits of adaptation

Table 7 shows the mean expected benefits per property in each case study, when all benefits are accumulated to 2100. Comparing these benefits to the mean adaptation cost per property, we can calculate the estimated benefit:cost ratio of the adaptation across the community.

Case studies 1, 3 and 4, in which a significant proportion (>25%) of properties are expected to be at risk of an ARI 100 year event by 2100 exhibit benefit:cost ratios greater than unity for all types of adaptation, even retreat. Raising floor heights is the cheapest adaptation to implement in each case study, and can lead to high benefit:cost ratios (case settlements 1, 3 and 4), but if the bulk of expected damages due to future inundation events lies in land devaluation, benefit:cost can fall below unity (case studies 5 and 6). Interestingly, for all examples other than case study 2 (not shown), building a community adaptation such as a seawall is expected to yield net benefits by 2100, even if only a small proportion of the community is at risk of an ARI 100 year event by 2100 (case studies 5 and 6). That is, looking at these case studies as a whole, as is the norm in most benefit:cost analyses, we might conclude that there is a strong economic justification for implementing a community adaptation like a seawall.

Table 7: Benefit of adaptation for each case study

Case study	Adaptation	Adaptation cost ($k/property)	Mean benefit ($k)	Mean benefit: cost	Economic? (Seawall)
1	Seawall	37	1155	31.15	Yes
	Floor height	14	736	53.15	
	Retreat	170	1104	6.47	
3	Seawall	34	382	11.22	Yes
	Floor height	7	259	35.61	
	Retreat	59	378	6.43	
4	Seawall	6	155	25.73	Yes
	Floor height	2	3	1.85	
	Retreat	83	148	1.78	
5	Seawall	9	39	4.09	Yes
	Floor height	1	1	0.65	
	Retreat	56	39	0.71	
6	Seawall	26	27	1.03	Yes
	Floor height	6	4	0.58	
	Retreat	209	28	0.13	

However, the benefits of implementing an adaptation are not spread uniformly across the community. Table 8 shows the maximum benefit received by the 25% of households receiving the smallest benefits (Q25), the median benefit received in the community (Q50), and the minimum benefit received by the 25% of households receiving the greatest benefit (Q75), along with the benefit:cost ratios for each of these households. Asking whether most people in each community will achieve net benefits by contributing to a community adaptation such as a seawall (Table 8: Equitable?), we see that in many cases the answer is no, even though a case-study level analysis suggested that the adaptation was economically justified (Table 7: Economic?)

The fact that the median benefit:cost ratio of adaptation (Table 8) is always lower than the corresponding mean benefit:cost ratio (Table 7) indicates that in all case studies a few properties receive a disproportionate benefit from the construction of a sea wall. In case studies 3, 5 and 6 this effect is very pronounced: the median benefit: cost ratio is ~0.00 and more than 50% of properties receive no benefit whatsoever from their contribution to the community sea wall. In case studies 5 and 6 not even 25% of properties receive benefit:cost ratio greater than unity from the adaption, implying a very small number of properties in these locations are receiving a very large benefit from adaptation, while the bulk receive little to no benefit. Case study 3 represents an interesting intermediate case; 25% of the community do realise a benefit:cost ratio greater than unity from a sea wall adaptation, but beyond this "at risk" proportion, very few others benefit.

Table 8: Distribution of benefits of adaptation for each case study

Case study	Adaptation	Adaptation cost ($k/ property)	Benefit ($k)			Benefit: cost			Equitable? (Seawall)
			Q25	Q50 (Median)	Q75	Q25	Q50 (Median)	Q75	
1	Seawall	37	88	281	733	2.38	7.59	19.77	Yes
	Floor height	14	0	4	210	0.02	0.27	15.17	
	Retreat	170	56	241	663	0.33	1.42	3.89	
3	Seawall	34	0	0	160	0	0	4.69	No
	Floor height	7	0	0	3	0	0	0.35	
	Retreat	59	0	0	164	0	0	2.78	
4	Seawall	6	55	95	146	9.1	15.8	24.36	Yes
	Floor height	2	0	1	2	0.15	0.44	1.55	
	Retreat	83	55	95	146	0.66	1.13	1.76	
5	Seawall	9	0	0	3	0	0	0.29	No
	Floor height	1	0	0	0	0	0	0	
	Retreat	56	0	0	1	0	0	0.02	
6	Seawall	26	0	0	0	0	0	0	No
	Floor height	6	0	0	0	0	0	0	
	Retreat	209	0	0	0	0	0	0	

3.4 Discussion

Around the world, studies have calculated how much to spend on adaptations at specific case study locations now to avoid future damages using a benefit-cost analysis (Genovese et al., 2011; Hall et al., 2003; Hall et al., 2005; Kazama et al., 2010; McLeod et al., 2010; Snoussi et al., 2009; Sterr, 2008; Wang et al., 2010; Yohe et al., 1996). Some others have considered the social factors that can foster or impede adaptation in coastal communities (Abel et al., 2011). However, very few have tried to assess how these costs and benefits might be distributed throughout at-risk communities, and even fewer have generalised their results across a range of case studies, as we do here.

Starting to develop such insights is important, however, because of the increasingly widespread nature of the problem faced by coastal communities around the world (McGranahan et al., 2007). Studying specific adaptations in specific locations is vital, but the scale of the problem demands also a broader perspective, to help prioritise areas for action and draw out useful comparison across similar physical or social systems in different locations.

What general insights can be drawn from these observations? Firstly, the benefit of adapting to protect against inundation is a strong function of the risk of inundation for a specific coastal community. If the community is naturally protected from storm surge (e.g. case study 2, Table 5, Figure 2), it is unlikely that significant benefits may be realised from further adaptation. On the other hand, many coastal communities will be at risk of coastal inundation, and a simple benefit:cost analysis may indicate that some adaptation options are likely to avoid more damages than they cost to implement under future sea level rise scenarios (case studies 1, 3, 4, 5, and 6, Table 7 (mean benefit:cost)).

However, the *distribution* of risk within these communities is also important (Table 8 (median benefit:cost)). In cases where only a small proportion of the properties are expected to experience risk from coastal inundation, even under sea level rise scenarios, most properties may not experience a net benefit from contributing to a community adaptation, such as a seawall, for a long time to come, even if a traditional cost-benefit analysis might suggest that the community, on average, would receive a net benefit from adaptation.

Even if such analysis recommends a community invest in adaptation to protect over the long term, not all communities will have the financial capacity to fund community-level adaptations, such as seawalls, in the short or medium term. The per-property costs of implementing such a community-level adaptation are reduced as the density of development increases. Additionally, the expected benefits of implementing adaptations increase as more properties are protected. This suggests that while some at-risk communities will have the capacity to implement community level adaptations to protect themselves from storm surge under sea level rise scenarios, some others, especially small, low-density communities, may not. Such situations will demand alternative adaptation options, such as individual adaptations (e.g. raising floor heights) funded by each property owner, or alternative funding from scales of governance beyond the local community.

Based on these insights, Table 9 presents a typology of coastal settlements, defined by their exposure to risk and the distribution of risk in the community, the potential benefits of adaptation, and the potential capacity for adaptation in the community. The typology is determined by the suitability of a community-scale adaptation, in this case a seawall, to protect a community against future storm surge events, around criteria of overall economic effectiveness, equitability, and affordability. Table 9 integrates the results from Table 6, Table 7 and Table 8 to provide a simple example of a framework to decide which type of adaptation each community should investigate further to maximize the economy, equity and affordability of adaptation to protect against storm surge.

Table 9: A typology of settlement types

<table>
<tr><th>Economic</th><th>Equitable</th><th>Affordable</th><th>Case study</th><th>Action</th></tr>
<tr><td>No</td><td>-</td><td>-</td><td>2</td><td>Do nothing</td></tr>
<tr><td rowspan="2">Yes</td><td rowspan="2">No</td><td>No</td><td>3</td><td>Retreat / household adaptation, e.g. raised floor heights</td></tr>
<tr><td>Yes</td><td>5, 6</td><td>Household adaptation, e.g. raised floor heights</td></tr>
<tr><td rowspan="2">Yes</td><td rowspan="2">Yes</td><td>No</td><td>1</td><td>Funding from larger scale government for community engineering, e.g. seawall</td></tr>
<tr><td>Yes</td><td>4</td><td>Local council to fund community engineering, e.g. seawall</td></tr>
</table>

Case study 2 is an example of a coastal community that is unlikely to face significant risk from storm surge, even under sea level rise scenarios out to 2100, due simply to the topography of the case study site; unless there are other reasons for protecting the coast, such as erosion of tourist beaches (Raybould and Lazarow, 2009), no adaptation may be necessary. Where there is an economic argument for adaptation at the case study level, the distribution of risk throughout the community should be assessed: if only a small proportion of properties are at-risk, such as case studies 3, 5 and 6, a community-level adaptation is unlikely to be equitable, and focused property-level adaptations may make sense; if a large proportion of the community faces risk of inundation, as in case studies 1 and 4, a community level adaptation may be more efficient. Once there is a clear justification for adaptation, and a decision about the broad type of adaptation (funded at the community level, or funded by individual at-risk properties), an assessment of affordability may constrain which adaptation options are realistic within the community (e.g. case study 4), and which ones may require support from larger scales of governance (e.g. case study 1).

Community-level seawall adaptations like those considered here can provide a good mix of total benefit and benefit:cost ratio (Table 7), but require coordination and funding from the entire community, highlighting issues of equity and affordability. In contrast, raised floor heights often provide lower total benefit, even when their benefit:cost ratios are high, and can be coordinated by individual at-risk properties. In the case studies considered, retreat never provides benefit:cost ratios comparable with building a seawall. In cases where a community-level sea-wall adaptation is not recommended due to issues of equity, adaptations coordinated and funded at the level of affected households may be appropriate (as noted in Table 9 “Action”).

Although the distribution of the risks of coastal inundation and the potential benefits of adapting to protect against inundation vary greatly both within and between coastal communities, by focussing on the underlying drivers that make adaptation likely or desirable, it is possible to identify a simplified typology of coastal communities that may benefit from different types of adaptation. General insights from this typology could be taken into account by planners now, even though the full analysis as presented requires several sources of specialist data that may limit its direct application to real world adaptation decisions being made today.

However, the approach presented here will become no more difficult than a typical benefit-cost analysis as: 1) local councils continue to generate more detailed descriptors of coastal inundation risk and update their cadastral datasets with building footprints automatically generated from high resolution LiDAR and aerial imagery; and 2) more results on Australian land devaluation due to inundation risk are published and combined to create generalised response curves similar to "stage damage" curves for infrastructure damage. In addition, we hope to extend this work to test how well simple rules of thumb could capture some of the insights from our detailed analysis, based only on readily available data, such as the total number of lots within a community and the proportion of those lots at risk of inundation during an ARI 100 year event as sea levels rise.

4. ASSESSING LOCAL ADAPTATION RESPONSES TO COASTAL INUNDATION RISK: THREE LOCAL GOVERNMENT CASES FROM EASTERN AUSTRALIA [3]

4.1 Introduction

This chapter draws on observations from interviews with local government actors from three local government areas in coastal Queensland, Australia (Figure 1). Discussions with local governments were focussed around adaptation responses to inundation at the six specific settlements used above (see Section 2). However it is important to note that in the interviews the adaptation options discussed were not limited to those included in the economic analysis. Instead the economic analysis and the interview data presented below combine to provide a perspective on local adaptation responses.
In our interviews, local government actors (including strategic planners, emergency management officers, engineers and social planners) appraised the relative merits of different options related to "protect", "accommodate" and "retreat" strategies. These appraisals were then considered in light of several criteria of effectiveness, efficiency, flexibility, equity and acceptability. Further, the analysis considered the influence of the local institutional context in which those options are likely to be implemented.

The timing of this work is significant when contrasted to earlier studies. During the last decade there has been a gradual but perceptible shift in debates about adaptation strategies from the realm of the science-policy arena to the practitioner domain. This has been most notable in the Australian context by the identification of sea level rise benchmarks to inform planning as part of legislation and guidance from state level jurisdictions to local governments (Gurran et al., 2011). In this sense, the focus has now shifted from essentially a hypothetical framing of possible decisions to a pragmatic one of actual decisions.

In response to growing concerns around the potential impacts of climate change on coastal development and coastal processes, state governments around Australia in recent years had initiated major processes of policy reform. In Queensland, the state government adopted a sea level rise factor of 0.8 metres by 2100 based on the IPCC findings (DERM, 2012). In certain instances, given local circumstances, some local governments have taken a more risk-averse approach and adopted a higher SLR benchmark for planning purposes. For example, the Sunshine Coast Regional Council has adopted a 1.1m SLR by 2100 (see
Table 1).

As part of this planning and policy reform process, local governments were responsible for the preparation of coastal hazard adaptation strategies under the provisions of the State Planning Policy 3/11: Coastal Protection (DERM, 2012). It is important to note, however, that since the commencement of the project a recent change in government has resulted in the suspension of the state policy for coastal protection. The removal of the state policy has effectively left the responsibility for adapting to inundation as result of sea level rise and coastal storm surge to local authorities.

[3] Edited from draft paper: S Heyenga, BM Taylor, BP Harman, CS Fletcher, Assessing local adaptation responses to coastal inundation risk: three local government cases from eastern Australia (provisional details only)

4.2 Methods

The analysis presented in section 3.4 above sought to identify by quantitative means the underlying drivers that make adaptation likely or desirable and used these to identify a simplified typology of coastal communities that may benefit from different types of adaptation. The analysis presented below adopts an alternative but complementary perspective of qualitative interpretivism to understanding local actors' appraisals of different adaptation responses to coastal inundation risk. These appraisals were sought through two stages of semi-structured interviews in the regions of Moreton Bay, Cairns and Sunshine Coast. While the economic and interpretive analyses were conducted in parallel, interviews implicitly followed the same options framework of defend, accommodate and retreat as did the economic analyses. Interviewers also focused local government officers' attention on adaptation options in each of the specific case study locations or sites as assessed in the economic analysis. Lastly, as can be seen from the results below, the concepts of equity, economic efficiency and affordability (amongst others) were also recurrent themes in the qualitative analysis.

In the first stage, eighteen interviews with policy, planning and technical staff from the three local governments were conducted. These initial interviews focused on the following questions:

1. Could you describe the types of impacts on communities and infrastructure that coastal flooding (from storm surge) in your area currently generates, or is likely to generate in the future?
2. What are the current sets of planning and management tools council has at its disposal for managing coastal flood risk at present? Can you describe how these approaches have come to be used?
3. In your experience how adequate or effective are these tools in responding to existing coastal flood risks to residential areas, to public infrastructure? How adequate do you think these tools are likely to be under future flooding scenarios?
4. How acceptable, in social and political terms, are these tools to different groups (e.g. residents, councillors, planning staff, developers, others)?

Responses from these initial interviews were coded based on their association with different criteria and with different categories of adaptation response. In the second stage, in the same year, the initial interviews were followed-up with group interviews in each of the three council areas. The original 18 and six additional local officers participated in this second round. These group-based, semi-structured discussions sought to summarise and present the preliminary interview and modelling analysis to the participants and in doing so encourage more detailed reflection of their own and other participants' initial perspectives, and secondly, to provide a point of departure for talking more explicitly about the reasons and likelihood of different responses, including the institutional context in which they operate. These three group-based interviews ranged from 1-2 hours in length. Both rounds of interviews were recorded, transcribed for meaning and imported into *NVivo* qualitative analysis software for coding and analysis.

4.2.1 Analytical approach Protect, accommodate, and retreat

We use the common adaptation categorisation of protect (or defend), accommodate, and retreat as a way to organise and present the diverse options that can be used to respond to coastal inundation risk. This approach not only makes the analysis more cohesive but also improves comparison with similar types of measures applied internationally. The protect, accommodate, retreat categorisation framework was first introduced by the IPCC in 1990 (Abel et al., 2011; Dronkers et al., 1990; Few et al., 2007; Gilbert and Vellinga, 1990; Nicholls, 2011; Tol et al., 2008). Details of this framework are presented in details in Section 2.

4.3 Results

The interviews with local government officials from the three council areas identified 20 adaptation options that are presently utilised to minimise the impacts of coastal inundation or that are under consideration for future implementation. They include different types of adaptation measures, ranging from engineering solutions to the modification of building codes and the withdrawal from high risk coastal areas. Figure 3 shows the number of favourable, unfavourable and neutral comments made about each adaptation option during the interviews. The options have been grouped into the *protect*, *accommodate* and *retreat* adaptation categories.

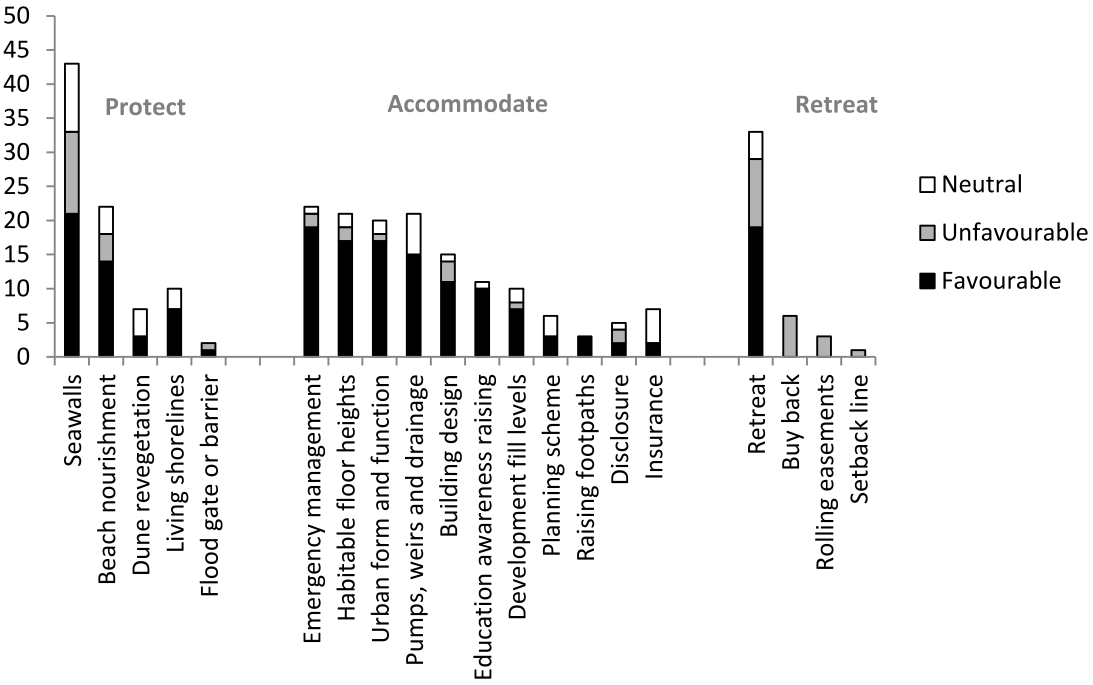

Figure 3: Number of favourable, unfavourable and neutral statements by respondents in transcripts about different adaptation options, grouped by type

4.3.1 Local appraisal of 'Protect' options

Interviewees from the three local government areas had mixed views regarding the use of hard engineering defences to protect communities and infrastructure from coastal inundation. Seawalls were the most frequently discussed adaptation option during the interviews, generally due to their historical and relatively widespread use in Australia. Indeed, seawalls have been constructed in all three local government areas as coastal defence structures. However, whilst seawalls in Cairns protect vulnerable coastal areas from inundation events such as cyclones and storm surges, the main reason for the construction of seawalls in Moreton Bay and the Sunshine Coast has been the prevention of further shoreline erosion. Overall, a greater number of interviewees indicated a favourable view of utilising seawalls as an adaptation option. The construction of seawalls has in many locations delayed the need for the renewal and maintenance of public assets, such as roads, footpaths and drainage infrastructure.

Interviewees from Cairns, in particular, stated that experiences from past storm surge events have demonstrated the effectiveness of seawalls in protecting coastal communities from flooding.

> *"We have storm surge events, cyclones and king tides, they often all kind of come together all at once. I think that the seawalls have provided a good line of defence."*

Seawalls were also perceived to be more cost efficient than other possible adaptation options, such as retreat. However, despite the generally positive views on using seawalls for coastal adaptation, a number of interviewees raised concerns about negative effects on amenity, as views and property values in coastal locations could be affected. Concerns about reduced coastal amenity in certain locations with potentially detrimental impacts on the tourism industry were also noted:

> *"This beach is one of the key tourism areas. Part of the attraction is the trees and the vegetation, and all that sort of stuff. If you start to think about putting a rock wall in that type of location, I think that there would be World War Three."*

Other concerns noted were that seawalls may put more people at risk by providing them with a false sense of security:

> *"I think, too, in some respect, seawalls give people a false sense of security. Then it just takes potentially one devastating incident, and, you know..."*

In addition, interviewees discussed the large capital expenditure required to build a seawall. Claims were made that there are hidden costs associated with the seawall construction process. For example, entire foreshore areas may have to be redeveloped and raised to protect coastal amenity values. This would require the reconstruction of existing infrastructure, such as roads and drainage. These costs have traditionally not been included when estimating the costs of building a seawall, possibly due to difficulty estimating and generalising them because of the open-ended scope of implementation (how much and how far to raise land behind the wall), and the subjective value of marginally improved views available when raising public land and assets behind the sea wall. For specific scenarios a "stated preferences" approach, where community members are asked how much they would be willing to pay for such improvements, may provide a useable valuation. Interviewees also stated that even if large amounts of funding were available, not all the coastline in their respective council areas could realistically be protected by seawalls. Instead, a certain threshold of infrastructure and properties in a specific location needs to be reached before council can economically justify the construction of a new seawall:

> *"I think that at this location perhaps there's a sufficient critical mass of property that we're defending that would warrant a great big seawall right around it."*

Lack of flexibility and the potential for lock-in were additional challenges of seawalls pointed out by participants during the interviews. To overcome this issue, seawalls in Moreton Bay are now planned and constructed for a shorter design life, but with flexible design, so that they can easily be further extended at a later date if necessary. This approach may also help council to delay and possibly even avoid some of the high investment costs:

“We are currently designing seawalls, but they are not to manage coastal inundation. They are to manage erosion. Whilst they're relatively adaptable designs that they can be amplified under a sea level rise scenario, we're not adding 0.8 metres to them now on speculation around sea level rise, because that extra cost we don’t believe it's not warranted. As long as we make sure the design is adaptable that we can spend the million dollars in 20 years' time, and then we see that as a better outcome.”

Finally, equity concerns in relation to seawalls were also raised by interviewees. For example, in one of the coastal village case study areas in Moreton Bay, individual property owners have constructed their own private seawalls in order to protect their beachfront homes from erosion and shoreline recession. This, in turn, has caused unwanted effects on erosion and sedimentation patterns, damaging nearby unprotected private properties and public reserves. At some of these sites, council officers reported that the construction of seawalls to protect the public reserves from further erosion was to be a likely consequence. A number of interviewees also reflected on the challenges of councils’ ability to fund seawall construction into the future, including whether these costs should be borne by all ratepayers or only those residents who directly benefit from the protection provided. One officer speculated that a possible course of action was the use of an annual fee paid by private property owners in the hazard area for the future construction and maintenance of seawalls, an instrument currently used to maintain infrastructure in private canal estates in that local government area:

“I can see that as being a potential model for how we would go about doing this in [location], where we say okay, you have got the enjoyment of living on the coast we might start charging people now on the basis that we’re going to build a seawall there in 50 years time.”

Soft coastal defence measures, such as beach nourishment, dune revegetation and living shorelines, were also quite frequently discussed during the interviews. Beach nourishment, in particular, was widely reported as a desirable response. All three councils already have over two decades of experience with beach nourishment projects in some locations. Beach nourishment was also considered favourable because of its perceived flexibility in timing, location, method, community acceptance (and even demand) and also for the ancillary benefits of improved aesthetics, access to beaches for recreation and promoting local tourism. Reported drawbacks of this strategy being experienced in their areas, however, included the lack of long term available sources of sand, the costs of offshore dredging for this supply, and the repetitive nature of the process, which ultimately leads to high costs in the long term:

“We lose about 25,000 cubic metres of sand off our beaches each year. So, in terms of sea level rise combined with a net loss of sand, the idea of renourishment is certainly worth considering or exploring further. It just comes down to how much the ratepayer is willing to spend on it…or [suitability] as a long term viable option.”

Living shorelines were considered a possible alternative adaptation option to hard coastal defence structures. Interviewees from Moreton Bay Regional Council, in particular, emphasised the multiple benefits of using coastal ecosystems to protect communities from storm surge inundation events, whilst also providing space for critical fish and wildlife habitat. Indeed, MBRC is proposing a feasibility study on rehabilitating the riparian zone along the foreshore rather than building a seawall. Under this proposal the density of the mangrove ecosystems is to be enhanced so as to reduce the active wave zone along the coastline, thereby reducing the risk to the local community from storm-tide inundation:

> *"We know where our precious ecosystems are and we do need to allocate land behind them for their adaptation...We understand that the mangroves are providing a natural coastal buffer to then protect residents....We have started to think about making room for migrating mangroves. It's definitely something that we're watching really closely but we haven't really put anything permanent into planning about it yet."*[4]

4.3.2 Local appraisals of 'Accommodate' options

Overall, options within the accommodate category were the most numerous and received far less unfavourable statements than protect or retreat options. Emergency management was the most frequently discussed adaptation option falling into the accommodate category. Most comments related to the importance of improving evacuation planning efforts during a disaster event. This is not really surprising since lack of road access and isolation were the most significant perceived existing impacts of climate change in the case-study sites.

Overall, interviewees indicated that their council areas have invested significant money and effort into evacuation planning in the past two years, a change driven by the January 2011 flood event in South East Queensland and cyclone Yasi in North Queensland in February 2011. To improve road access during a flood event, councils have commenced projects that will upgrade those evacuation routes that are prone to flooding. One interviewee, however, raised concerns about an overreliance on evacuation strategies during disaster situations:

> *"I'm concerned about how heavily evacuation is relied upon in disaster situations. I think that a lot more of our planning probably needs to be oriented around keeping people safe in their homes and off the roads. I think you need to be able to survive in situ."*

What is generally evident within the interviews is how disaster planning and recovery serves as an indirect way for councils to start thinking about increased frequencies and intensities of events associated with climate change and their responsibility in managing for those events. Often this means local governments improving their information base on these risks, including refining broad scale mapping produced by higher levels of government:

> *"Storm tide has become much more of an elevated issue, I'd say, in the last decade. I mean, it's always been an issue, but it's now become much more to the forefront with the natural disasters that we've had over the last five years. It's now*

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[4] Since the interviews were undertaken, Moreton Bay Regional Council released its *Draft Strategic Framework* as the first of three documents that constitute its revised planning scheme. This strategic policy-level document contains provisions to protect land that may potentially cater for the landward retreat of coastal habitats and species at risk from predicted sea level rise through appropriate land-use allocation.

> *much more an imperative to actually have a map so people know. The state government generally just produces their base layer mapping, if you like. Then they [say]: 'local government, you check it, you do more work on it'. It really is a fallback position, and the mapping is quite rudimentary."*

In more intensively developed commercial and residential areas with significant infrastructure investment such as central business districts there were examples discussed of councils investing significantly in engineering responses such as drainage and under-street pumps and raising of footpath heights:

> *"…this council's spent several million over the past few years dealing with existing drainage impacts with tail water levels and obviously ensuring that they can continue with climate change impacts as well."*

Importantly, as indicated above, these investments are essentially about resolving existing and longstanding problems of flooding and therefore providing immediate benefits to the community.

Raising habitable floor heights was another focus of discussion. In all three local government areas new developments are required to be built above the 100-year ARI flood event. In addition, some local authorities may choose to implement a safety freeboard, varying in size from 0.3 to 0.8 metres, to determine minimum floor heights of residential developments in flood prone locations. A persistent theme in the discussions however was that current emphasis on raising floor heights in the case-study locations were to address risks with riverine flooding and "nothing [to do] with coastal process at the moment". Council officers also commented on the socially acceptable 'limits' to raising floor heights based on community standards of street amenity and character in many locations.

Several interviews canvassed the use of different building designs and materials including elevating electrical and air-conditioning wiring and equipment to higher locations within a building, and constructing transportable homes:

> *"I am thinking about different types of building structures that are separating the value of the building from the land so that the building may be able to be removed and placed in another location...Transportable homes could be quite attractive if not even better and possibly less expensive than a slab on ground home."*

Council officers described, however, how the degree of flexibility in this regard is constrained by the minimum building design standards set at the national scale. It was therefore difficult for local governments to politically justify setting more stringent requirements in their local areas in relation to flood resilient building designs.

It was also acknowledged that improvements in design are more easily achieved in new developments over changes to existing buildings, where costs of modification were believed to be high and impractical, and also the responsibility of the private homeowner rather than that of council:

> *"We can really only plan for our future developments, as opposed to the existing ones ... There are tools available for people to assess their house and consider replacing certain materials now. But that's a private matter as opposed to a council matter."*

One anticipatory approach to adaptation that is supportive of accommodation by limiting the extent of future retreat is to limit intensification of urban development, via land-use planning controls, in identified future hazard areas. This involves changes to the planning scheme and zoning rules, aimed to avoid inappropriate development in high-risk coastal areas. In some cases this also requires promoting infill and redevelopment in existing or alternative urban areas which are not vulnerable:

> *"From a planning point of view, any development that does occur will be contained within the urban limits that area already set, but it won't be expanding out...We won't be expecting them to be developed any further, other than in-fill."*

Regarding new urban development, each of the three local governments are directing growth away from high risk coastal areas towards inland locations[5]. However, interviewees also indicated that some development is continuing to occur in vulnerable locations, mainly due to previous granting of development approvals[6]:

> *"With development commitments, council aren't in a position to refuse development applications within existing urban areas or existing zone areas. They can refuse, but obviously it's a compensation risk, and council primarily can't afford that risk."*

One interviewee described the difficulty in implementing policies such as this even where a precedent existed for removing development rights due to other risks such as hillslope erosion:

> *"As you'd appreciate with planning schemes, sometimes land has been zoned for a long, long time. To actually take those zoning rights away is a very slow and, oftentimes, expensive compensation process. Progressively, we have made particularly with hill slope land over the last few years winding back those inappropriate zonings. With the new planning scheme, we're going to continue to do that step by step, incrementally."*

Just prior to the second round of interviews Moreton Bay Regional Council released its draft Strategic Framework in September 2012, which provides a vision and strategy for

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[5] In Cairns, for example, new development will be directed towards Mt Peter, which is a Greenfield area located inland on the southern end of Cairns. Similar approaches of extending regional centres in lower risk inland locations are taken in Moreton Bay and the Sunshine Coast. All three council areas are currently in the process of developing their new local planning schemes, which are due to commence in 2014. Interviewees indicated that the new planning schemes will give greater recognition to climate adaptation in the coastal zone. In Moreton Bay, for example, development will be avoided in areas with high exposure to storm-tide inundation to reduce the risks from coastal hazards. Overall, the new planning schemes will impose stricter controls on land use and development in flood-prone areas. Changes in zoning will be undertaken to reduce development in high-risk areas.

[6] Under Queensland State Government planning law the condition of 'injurious affection' exists which in effect makes governments, including local governments, subject to compensation claims if changes to planning rules or development permissions reduce the development rights previously granted to a private property holder.

the region's growth and development to 2031. It plays an important role in guiding the creation of the region's new planning scheme. According to this framework some locations have been assessed as at significant risk to future coastal inundation and as such considered unsuitable for future infrastructure or residential development:

> *"The coastal villages are exposed to existing and future coastal hazard events including storm tide and erosion events which are projected to increase in the future and permanent inundation due to sea level rise, therefore limited development and limited investment in infrastructure is anticipated in these areas."*

4.3.3 Local appraisal of 'Retreat' options

When contemplating a decision about retreat there was an overwhelming sense that the implementation of such a program was well beyond the financial capacity of individual councils to fund:

> *"I think it's going to come down to the cost. So, if we retreated, where do we retreat to? What's the cost of doing it?"*

In many cases, it was argued, the community would not be willing to retreat from coastal areas even those clearly at risk from flooding. Communities were willing to 'trade-off', at least at this point in time, that risk for the benefits of a high amenity coastal location.

> *"It's probably unrealistic to expect existing communities that are now coastal based to disappear, so I don't think there'll be a retreat strategy unless it is a very small community, and there is really a huge benefit in doing so because they're established, they're there."*

In addition to the direct costs of retreat and the community sentiment that would oppose such a move, the familiar issue of likely legal and compensatory consequences, under existing Queensland planning law, of such a strategy were widely raised:

> *"Obviously if there were changes from a legal perspective around compensation rulings that could potentially make things easier for council...I think council often feels a bit stuck because there are not many options available within the Queensland planning context."*

The cumulative effect of these extant economic, public opinion and legal constraints created a situation where, according to one interviewee:

> *"It's just not politically palatable for council to take up a planned retreat option."*

However, interviewees from all three council areas indicated that retreat, in general terms, may be a necessary and likely option in the future. The implementation of this option would, however, depend on the actual eventuation of future severe weather and storm surge events and the adequacy and reliability of available information and risk mapping. Even under these new circumstances retreat would only be considered 'practical' in high-risk locations with very small populations and no significant infrastructure:

> *"They have identified quite a few of those northern and southern areas that could be retreated, but then go into the practicality of doing that. The ones that end up being practical end up being the ones with very small populations."*

While there was some willingness to consider the efficacy of future retreat strategies there appeared to be limited support for different types of specific retreat options, such as council-funded buy back schemes, setback lines or rolling easements. For instance, buy back was seen to be too expensive and beyond the capacity of local councils to implement. Local officers went further saying they considered it outside of local government's responsibility:

> *"We don't think that buy back is a local government job."*

Indeed the prospect of implementing a buy-back scheme highlighted the close proximity between the actions of local governments and the actual mandate elected councillors believe they have to implement those actions:

> *"My view that the councillors won't go into that space [of a buy back program] is because they believe that the community doesn't want them to go into that space, so when it comes back into your own personal backyard there's not a willingness to do that."*

More 'palatable' options suggested included different forms of "modified" retreat options, including taking away the right of land owners to further develop/redevelop once a certain sea level rise trigger is met.

Above, we have presented local government officers' appraisal of a diverse range of potential adaptation responses to coastal inundation risk. In describing what they consider as the relative merits or flaws of these different options it is possible to gain valuable insights. These insights are developed further below and focus on: i) the relative influence of different 'criteria' in local appraisals; ii) how the institutional setting in which local governments operate conditions those appraisals; and iii) what the practical implications are for implementation of local coastal adaptation strategies.

4.4 Discussion

Local government officers' appraisals show some distinct relationships between particular broad strategies of adaptation (protect, accommodate, retreat) and the emphasis they place on different criteria of effectiveness, cost-efficiency, flexibility, equity and acceptability. At a broad level, options related to accommodation were considered favourably relative to protect, and certainly, retreat strategies. This was closely related to the idea that practices of accommodation usually involved smaller, more incremental changes to existing practices or rules. Conversely, some of these options do not require radical change such as the relocation of communities or major publicly-funded capital investments (with the exception of projects such as under-street pumps and drainage).

For these reasons options in the accommodate category are perceived to be relatively more acceptable in political terms (within the community) and timeframes for implementation more flexible. In addition, as the costs of raising habitable floor heights, for instance, are borne by the property owner or developer, such a response is perceived as more cost-efficient than permanent defences. In comparison, if we consider retreat as a broad strategy, council officers place different emphasis on the same criteria.

There are also some interesting distinctions between how a general strategy of retreat is appraised when compared with more specific actions to achieve that strategy. Many officers conceive that implementing a retreat strategy for some smaller high-risk settlements in their local government area in the medium term to long term future is highly likely. There is, however, less support for short term to medium term implementation of specific instruments associated with retreat such as buyback or rolling easements. Few, if any, of these options are perceived to be currently politically acceptable, cost-efficient (in most cases), or necessarily effective in the case-study areas due to patterns and scale of development[7]. However there are obvious shifts towards reducing future development intensification and extent in small, isolated coastal settlements considered at risk through cost-effective planning controls providing the implications of compensation resulting from down-zoning of privately owned land in these areas is seen as 'manageable'.

Options associated with protect and accommodate (of one kind or another) are described by council officers as the most likely course of action in the shorter term to medium term, even though technical and financial constraints are acknowledged. The conditionality with which retreat is spoken about is pronounced. These conditions are often framed by local officers as different kinds of thresholds. These thresholds were described in physical terms, for example the maximum number of dwellings for which retreat would be practically feasible. Clear sociopolitical thresholds were also articulated.

There was a common position for instance that action on implementing retreat would largely be taken on the basis of a community 'push' as residents near or pass what they themselves consider to be acceptable levels of risk and demand government intervention. Indeed, our observations point to different options having quite distinctive thresholds. Intensification of defensive structures primarily views economic or cost-effectiveness thresholds, whereas retreat is predicated more on political or social thresholds conditioned by local perceptions of acceptable risk by residents in vulnerable locations.

So, how might we understand these sorts of observations in relation to the institutional setting in which options are assessed or implemented? At an organisational level there is a distinct preference for the historically tested defensive measures and extension of existing codes or practices to support accommodation. This is incremental change that is within the parameters of existing locally administered regulatory instruments or standards, and therefore does not need to countenance a 'new' policy position or instruments.

Responses that are able to be designed and implemented within the often fragmented internal responsibilities of local government organisations such as the planning, development assessment, infrastructure services and economic development branches are more likely to remain institutionally viable. In these fragmented systems incrementalism is the strategy employed. The above observations speak to Primmer's (2011) description of institutional change in local governance where social demand is a

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[7] One interviewee suggested for instance that the use of rolling easements in highly developed areas of the coastal zone would be relatively ineffective due to the small property sizes, and density of these properties in these locations.

major driver of that change. It is these thresholds that must be met in order to overcome the existing inertia or structural constraints of embedded rules and practices around local planning and coastal management. It is at the ‘critical moment’ described by Buitelaar et al. (2007), when these thresholds are reached, that the potential for institutional change is presented, but not guaranteed. Further, the tendency to build on existing norms and practices described in local officers’ appraisals may be particularly beneficial in local government areas that are familiar in dealing with other natural hazards.

For example, Cairns Regional Council and their community’s cultures are familiar with managing risk and the public debates surrounding these types of policies. This situation where local institutions are effectively ‘primed’ for these changes (cited in Burch Jr and DeLuca, 1984; Field and Burch, 1988, p. 111) presents opportunities to transfer or modify existing practices or ‘thinking’ from dealing with existing hazards to emerging or predicted future hazards with limited social disruption.

The second key insight from the analysis is the often implicit institutional strategy of ‘outsourcing’ that local governments presently rely on to manage limitations in their own toolkit. Such shortcomings include the equitable allocation of costs and benefits of managing storm surge events. This is particularly evident in historical and ongoing regulation of seawall construction on private properties. Here, existing local regulatory or financial means are inadequate to manage the temporally and spatially heterogeneous consequences of these ad hoc developments, either between neighbours or between public and private values on the foreshore. In these kinds of instances the institutional means is, in effect, transferred to other institutions outside of local government’s remit, such as the property market or insurance sector. The assumptions here are that “leaving it up to the market” means that “we [local government] might not have to get involved.”

Where internal rules and practices are ill-equipped to address, for instance, the spatial and temporal dimensions of risk sharing, this ‘outsourcing’ or ‘scaling out’ of institutional capability is a rational and arguably inevitable response by local actors. This response is also recognised as a characteristic function of multi-level environmental governance (Reed and Bruyneel, 2010) and has also been observed in studies of local governments in other Australian jurisdictions (see Section 4).

Overall, we find that under existing institutional conditions it is unlikely that individual local governments will make significant shifts towards disruptive, unpopular or legally risky adaptations to manage coastal inundation risk. This suggests, at least in the foreseeable future, that gradual, incremental adaptations are likely with any major change to this pattern only likely following episodes of community-led demand.

5. DISCUSSION[8]

We conclude by reflecting on how the Australian experience compares to the broader international context for adaptation to protect against coastal erosion and inundation. This reflection is structured around themes of: scale and effectiveness; suitability and acceptability; and roles and responsibilities.

5.1 Scale and effectiveness

The scale of the problem and the scale of response to the problem of coastal inundation differ between international and domestic settings. Australia has one of the lowest population densities in the developed world (ABS, 2012). In Europe, the area to be protected from inundation is much smaller and much more densely populated. The level of state and national government involvement in adaptation planning in the international context is perhaps not surprising given the scale of the problem, spatial distribution of risk and relative concentration of response required to manage inundation risk. Australia, on the other hand, has a much longer coastline and is sparsely populated (Williams and Thompson, 2007) with 84 percent of the population concentrated within 50 kilometres of the coastline (ABS, 2003). Many coastal settlements are at risk of future inundation as a result of rising seas (DCC, 2009).

However, Australia does not face some of the major risks faced in Europe, where significant cities have developed below sea level (e.g. Rotterdam), or in the path of expected sea level rise (e.g. Venice). Instead, Australia faces a large number of smaller at-risk communities spread along a very large coastline. To some degree, the types of adaptations that have been implemented, and are currently being considered for implementation, are bound by the scale at which adaptation options are governed. Because of its emphasis on local government, many of Australia's adaptations are local in scale. The large-spatial distribution of inundation risk in Australia and diverse coastal settlement types can imply poor economies of scale, small-scale adaptations managed at the local scale and a diversity of responses. Consequently, options that are cost-effective in Europe might not be cost-effective in Australia, where there is greater reliance on identifying and tailoring locally-specific responses.

These insights correlate strongly with the results of our economic analysis. There is great variability in who stands to win and who stands to lose from adaptation responses even at very local scales. Although community-level adaptation options, such as seawalls, have the potential to yield a good mix of total benefits and benefit:cost ratios (Table 7), they require coordination and funding from the entire community, highlighting issues of equity and affordability. Going beyond traditional whole-of-case-study-scale benefit:cost analyses, to investigate the distribution of costs and benefits within the community, will be vital for ensuring the most efficient adaptation options can be equitable and affordable as well as economic. Ignoring these issues risks either inequitable subsidisation of small numbers of at-risk properties by the rest of the community, or inefficient and potentially ineffective adaptations by individual households when a community-scale adaptation would provide a more efficient or effective solution. Worse, the perception that the impacts of inundation and benefits of adaptation are leading to inequitable outcomes has the potential to impede any action on adaptation. Only by understanding these issues can we begin to address them.

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[8] Edited from draft paper: BP Harman, S Heyenga, CS Fletcher, BM Taylor, Global lessons for adapting our coastal communities to protect against storm surge inundation (provisional details only)

5.2 Suitability and acceptability

The suitability and acceptability of different adaptations is an important component of implementation given that engineered responses to coastal inundation are embedded within socio-political contexts. Both Australian and international examples show an emphasis on hard coastal defence structures to manage inundation risk in densely populated areas. This is, in large part, a strong reflection of the significant investment in coastal assets and infrastructure and the institutional limitations and political risk associated with measures that impact adversely on well entrenched private property rights. Our interview data showed a distinct preference for the historically tested defensive measures and extension of existing codes or practices which seek to accommodate climate change. The strategy of beach nourishment to complement hard coastal defence structures is also widely preferred in high amenity environments dependent on tourism. The acceptability of these adaptations is bound by the socio-political conditions in which they are embedded.

Many European countries have relied on coastal defences for hundreds or even thousands of years. While construction and maintenance costs are a major consideration of implementing hard coastal defence measures, the approaches are often favoured because they do not require major institutional change or impact on private property rights. Conversely, planned retreat has proven to be extremely controversial in the Australian context given that it requires major institutional change and impacts on private property rights and values. While there are significant long-term social, economic and environmental benefits to implementing planned retreat, our economic analysis shows that the short term costs are high. Notwithstanding, the success of strategies such as planned retreat for managing inundation risk and erosion, 'depends on the social acceptability of options for adaptation; the institutional constraints on adaptation; and the place of adaptation in the wider landscape of economic development and social evolution' (Niven and Bardsley, 2013).

Coastal retreat may be more politically acceptable in lower density coastal environments. In Australia, beach nourishment programs and hard coastal defence structures are the dominant strategies employed for managing coastal erosion and inundation. However, the suitability of beach nourishment programs in high energy beach environments is likely to decrease over time as beach systems become more volatile under changing climatic conditions.

5.3 Roles and responsibility

Adaptation in cities and coastal settlements are presently dominated by regulatory planning controls and engineering structures. Indeed the 'normal' culture (of historical responses and investment) revolves around large-scale engineering works for protective or defensive barriers to coastal flooding risks with, in many nations, decades if not centuries of cultural and institutional investment. Likewise in Australia, much of the implementation of coastal adaptation is done at the local scale; however, one of the fundamental differences between Australia and the international context relates to the degree of centralisation of financial and regulatory control. For many countries the responsibility to fund major protection works is carried by state and national governments. In the Netherlands, for example, the national government has a legislative responsibility to act and ensure that its communities and settlements are protected from coastal flooding. In Australia, coastal adaptation practices and funding are predominately the responsibility of the local authorities, with the exception of some major infrastructure projects which cross jurisdictions.

Our economic analysis highlights the fact that some Australian coastal communities will struggle to fund their own community adaptation measures, even if they may be economically justifiable and provide broad, equitable benefit to the community. Our institutional analysis shows that in many instances, the cost of construction and maintenance of hard coastal defence measures has been a major issue for many landholders which has often prevented their widespread use. The uncoordinated construction of seawalls in Australia has also disproportionally spread inundation risk. In these situations, providing mechanisms for coordination and funding from larger scales of governance may achieve better long-term outcomes for both the communities at risk and the Australian population at large.

Our institutional analysis showed that attempts to implement policies of planned retreat in Australia have been met with great resistance and generated tensions between local authorities and private landholders, highlighting the ongoing debate and confusion over roles and responsibilities, private property rights and development expectations within vulnerable coastal areas. International experience with coastal retreat policies is more advanced than in Australia, although there have been some concerns in the UK surrounding the negative connotation associated with current terminology.

Adaptation efforts in Australia have been constrained by inconsistency between institutional-cultural-political norms and the need for greater government intervention to manage the risks to public safety, property, ecosystems and infrastructure. The fact that many of the decisions about adaptation are heavily localised (devolved) in Australia also creates conflict with development and other interests that have material stakes in development outcomes at the local scale. That is, councils are faced with the short-term interests of local stakeholders and investors while attempting to implement far-sighted, public-good change in these contexts, sometimes without the support of larger scales of governance.

In contrast, international efforts suggest a high level of state and national involvement in local adaptation planning with significant support and investment, particularly in coastal defence. These observations raise some important points in the light of current Australian practices, including: (i) the level of centralisation-decentralisation of adaptation planning, funding and implementation, (ii) the relative stability or otherwise of the policy frameworks that structure local action, and (iii) the degree of vertical integration between local, provincial and central tiers of government to provide coherence and appropriate levels of subsidiarity.

5.4 Insights

Our analysis suggests four key findings that may help inform further policy development:

1. Australia has a unique distribution of risk due to its long coastline and relatively low population densities. This presents conditions which emphasise the importance of locally managed adaptation responses and, because of this, the importance of local governments. This has led to well developed institutions for making decisions about adaptations at these local scales, but it has also tended to constrain the choice of adaptations to those which can be implemented, funded and managed at the local scale.

2. Local governments are increasingly relying on gradual ‘outsourcing’ of some facets of the community adaptation process to other organisations such as the property market and the insurance sector. This is a rational and potentially effective approach, but leaves important aspects of the management response outside of local governments’ control. This can limit their ability to implement longer-term plans, and consequently expose them and their communities to significant risks. A more strategic,

formally brokered partnership with external service providers may allow a more considered and efficient response to balancing risk between the public and private sectors.

3. There will be cases where particular adaptation options (e.g. sea walls) are equitable and economically feasible, but not affordable from the perspective of local funding. Addressing this affordability constraint means identifying suitable cost-sharing models between local and higher levels of government. Implicit in this is the need for state and national governments to set and maintain clear policies and regulations that support the necessary actions of local governments to respond to these pressures. This would provide the structures through which physical, legal and financial risk is shared amongst different tiers of government.

4. In the absence of mechanisms where by local governments can share risk, it is unlikely that individual local governments will make significant shifts towards disruptive, unpopular or legally risky adaptations to manage coastal inundation risk. This suggests that local government responses are likely to be gradual and incremental, despite the fact that in some cases incremental adaptation may be suboptimal or inequitable, and actually increase risk over the long term. Translating lessons from Europe and the USA may provide important insights into how to most effectively combine state and national sponsorship with local implementation of coastal adaptation.

5.5 Conclusions

This project has made significant progress towards a more detailed quantitative and qualitative understanding of the distribution of risks, benefits and adaptive capacity across Australia's coastal communities. Previous work has generally focused on either broad, quantitative case-study-wide benefit:cost analyses (Wang et al., 2010) or qualitative descriptions of the factors than enable and constrain community adaptation to protect against climate change (Abel et al., 2011), such as changing coastal inundation regimes under sea level rise scenarios. Here, we extend both of these approaches to provide a much more detailed quantitative description of the distribution of costs and benefits due to adaptation throughout our coastal communities, as well as an assessment of progress and constraints towards adaptation operating within those same communities, and a comparison to the current state-of-play internationally. We find that, as useful as those broader studies have been, there are vitally important insights from the distribution of risk at finer scales that are likely to impact our coastal communities' ability to adapt effectively to protect against storm surge.

Although both the risk of inundation and the capacity of communities and governments to adapt to protect against inundation vary strongly from place to place, there are some similarities to be drawn across the range of examples available around the world. Australian governments, when compared to international cases, appear less likely to rely on state-led and centralised intervention in responding to future coastal inundation risks, particularly as they manifest at the local scale. Although Australia has a long history of managing coastal inundation risk at the scale of local government, and although that scale generally matches the spatial scale of inundation risk well, some Australian coastal communities will struggle to fund their own community adaptation measures, even if they are economically justifiable and provide broad, equitable benefit to the community. In these situations, providing mechanisms for coordinating funding across scales of government may achieve better long-term outcomes for both the communities at-risk and the Australian community at large.

6. GAPS AND FUTURE RESEARCH DIRECTIONS

The quantitative modelling framework used in this project defines a simple typology of coastal communities, based on their exposure to inundation risk, the total benefit (economy) and distribution of benefits (equity) expected from adaptation, and the community's financial capacity to adapt (affordability). The framework is designed to allow relative comparison between different communities, to understand the underlying drivers that enable and constrain adaptation, and to recommend broad adaptation options for different classes of coastal communities based on these characteristics. However, there is ample scope for further research to refine these quantitative measures, particularly the measures of "equity" and "affordability", for different communities. An important part of this process may be implementing damages to broader asset classes within the model: for instance, everybody in the community may benefit from the protection of the natural amenity of tourist beaches, even if their residential property is not directly at risk of inundation. Incorporating more asset classes into the modelling framework would provide a greater analysis of the distribution of risks across different parts of communities.

As these measures of equity and affordability are refined, there is scope to design institutions that respond with adaptations directly linked to any new measures. For instance, adaptation funding measures that levy variable charges across case studies based on household risk could be supported. Such a funding measure, while achieving the same mean benefit:cost ratio for a given adaptation, could significantly increase the median benefit:cost ratio, improving the equitability of funding adaptations. The modelling framework should allow the design of "optimal" adaptations, or mixtures of adaptations, for any given definition of equity and affordability. This, and continued efforts to understand how institutions manage issues of risk, distributional changes and equity, are major areas of interest for further work.

Finally, with the data now at hand from our analyses, there is significant scope to further combine insights from the three approaches to begin to more deeply address issues of, for instance, how the abstract insights from the quantitative studies could be successfully implemented in practice, with the support of local governments and communities. There is scope to draw further lessons from the international context into the Australian arena, and assess to what degree they apply to Australia's unique conditions. Some of the qualitative insights of the institutional analysis, especially issues around gradual incremental policy change, may benefit from further quantitative analysis within the modelling framework.

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