# Risk Mitigating methods – protecting community, protecting commerce. The importance of structural risk mitigating measures for coastal cities.

Sarah Sinclair and Chris Carboon, Sinclair Knight Merz.

**Abstract**

46 tropical cyclones have hit Australia since 1967 causing damage estimated at AS$ 8.8bn[1]. The perception of coastal risk in Australia appears to be relatively low, although there is growing awareness of the link between development and 'disasters' as the assets at risk increase[2].

This paper looks at emergency management issues related to increased development and the importance of protecting people and assets. Although the means of protection are generally different for both, a developed area is likely to need a combination of emergency responses and structural protection.

The paper identifies various types of structural solutions against coastal hazards and examines positive and negative aspects of each. General issues relating to coastal structures are also discussed.

The implications of climate change on coastal hazards in Australia are summarised. The paper then examines government guidance on climate change in relation to coastal structures in Australia.

The paper concludes by examining risk management options available, including lessons learned from past floods. The paper finds that structural solutions are an integral part of risk management for developed areas, along with planning, predicting and warning of events.

**Introduction**

Coastal risk is not a new phenomenon in Australia. Cyclone Tracy in 1974 (which killed 65 people and caused $4.2 Billion of damage[1]) is probably the most severe coastal storm in most people's memories – however there have been quite a few less severe ones since then. Emergency Management Australia documented major natural disasters since 1990[2] including a storm in May 1996 which affected Southern Queensland and Northern NSW, killing 4 people, and causing landslides and erosion along the coast as well as flooding. Cyclone Justin affected the Queensland area and killed 7 (5 on a boat which sank)– huge waves also caused house undermining and damage to roads and bridges.

The West coast is also at risk – the coastal stretch from Exmouth to Broome has the highest incidence of tropical cyclones anywhere in Australia (including 4 in 2006), although recent damage appears to be mainly associated with heavy rains.[3] Wind storms in 1994 also created severe erosion in the Perth Area [4].

The Australian coastline is at risk of cyclones in many areas, as well as other types of coastal storm. This is an important issue, as Queensland Government Environmental Agency[5] notes that the greatest potential for loss of life related to a cyclone is from an associated storm tide. This paper examines storm tide risks and responses, and how climate change will affect these.

**Impact of Development in Emergency Management**

Coastal development is a significant part of Australian life. CSIRO assessed in 2002 that over 80% of Australia's population lives within 50km of the coast – the majority in coastal towns and cities along the east, south east and south west coasts.[6] Between 1991 and 1996, one quarter of Australia's total increase in population was concentrated within 3km of the coastline, mainly in the NSW and Queensland coasts and the southwest of WA.

EMA recently identified the growing awareness of links between development and 'disasters'[2]. Without climate change, the probability of a storm occurring doesn't increase with development. However, as development increases, the consequences associated with the storm increase. Queensland's Environmental Protection Agency recently defined storm tide inundation as being 'a natural disaster when severe disruption occurs to a community, requiring assistance from various levels of government'[7]. The fact that much of the coastal development is in large towns and cities makes a compelling case for emergency management planning to be in place, because of the potential consequences of a major storm event.

The scale of risk depends very much on the topography – water depth and water speed can be critical to the likelihood of loss of life. Flood defence funding prioritisation in the UK suggests that floods which reach the level of the sleeping quarters of a property put lives far more at risk[8].

The impacts of flooding have been documented globally[9] . They include:

- Loss of life
- Injury or health impacts
- Land drainage effects – secondary flooding
- Contamination of potable water supplies
- Overflowing of wastewater systems
- Loss of power supply
- Loss or damage to infrastructure including transport routes
- Floodwater damage to property (physical structures and contents)

In terms of flood hazard management, protecting people is generally a priority. A report to US Congress following Katrina [10] questioned whether loss of life and economic and social disruption should figure more prominently in decision-making relating to structural defence provision – currently this tends to be related to physical damage to property only, based on the assumption that people will be evacuated. BTE[1] estimated the cost of a human life to be AU$1.3M in 1998 prices, which could have a considerable impact on justifying structural defences.

However, even with defences in place, people will need to be evacuated from areas at imminent risk of a coastal storm – mainly for personal safety from the direct consequences, but also because of secondary impacts the storm may have such as sewerage overflows, power loss etc. Evacuation plans will need to be drawn up which ensure that critical services act on appropriate triggers. Any evacuation plan will rely on storm warning which can sufficiently identify areas at risk, scale of risk and time to impacts. Therefore, development will indirectly lead to the need for improved forecasting, monitoring and planning.

As well as the immediate emergency response plan, lessons learned from Katrina and other floods indicate that recovery plans are an important part of pre-event planning.[11]

Emergency response planning focuses on separating people and risk. It does not move any of the property or assets out of the floodplain. The cost of replacing or repairing these assets is generally used as the justification for installing structural defences to separate the property from the flood risk, as noted above.

The scale of loss arising from coastal flooding can be surprisingly high. The 1996 Queensland flood listed above caused insurance losses of US $ 22M, estimated total losses were US $ 160M. Cyclone Justin caused losses estimated at US$133M (all at 1998 rates). Structural methods can be used to reduce or mitigate the damage, and also to make sure that people get back to their property more quickly, and are therefore an important part of managing risks in developed areas.

**Structural Protection**

To illustrate the types of protection available, the elements requiring protection must be identified.

Storms, such as cyclones, bring strong winds together with falling atmospheric pressure. The low pressure allows the sea to 'rise' locally, and the strong winds push it inshore, creating a storm surge which effectively raises the sea level for a number of hours. Strong winds will also create larger waves, which may travel closer to shore because of the increased sea depth.

When the storm surge hits the coast, both the sea level and the waves can cause flooding. Surges will also be pushed up estuaries. If rain accompanies the storm, the raised sea or estuary water levels will affect drainage of any stormwater, potentially causing further flooding. The effects of a storm will, in part, depend on the area where the storm occurs – the shape of the seabed will determine how large inshore waves can get; the shape of the estuary will determine whether a surge is magnified as it moves up the estuary.

In addition, coastlines can be vulnerable to erosion, both in storms and on a day-to-day basis. The types of structural measures below can be used for flood defence and erosion protection, in appropriate circumstances.

*Hard Defences*
Traditionally, the response to elevated sea levels has been a sea wall. These are hard defences, often vertical although they may have a curved wall at the top to reflect waves back to sea. They are designed to resist wave attack, and to provide a specific height to withstand a specific level of surge. Generally, the structure is fairly simple – they can be simple to design, the materials to build them are readily available and they tend to be relatively cost-predictable. Vertical walls don't take up much room, so they can be easily built in urban areas with a beach frontage, although they may detract from the visual amenity.

The down side of placing sea walls directly at the coast is that they are subject to daily attack from the sea, which reduces their effectiveness over time. Seawalls directly on the coast also have unfortunate consequences –they are often installed in areas where there is erosion, and whilst they stop erosion of the upper beach, they cannot stop erosion of the foreshore, so the beach will steepen. As seawalls are hard structures, they reflect wave energy, which can lead to erosion of the beach, and erosion of the structure's foundations. They also affect the natural coastal processes, which may have consequences elsewhere. Reeve et al[12] state that "the evidence of beach steepening and foreshore lowering in areas where there are seawalls in the UK is irrefutable."

In rural areas, particularly those with clay soils, earth embankments are used instead of concrete or timber sea walls – also known as dykes or levees. In many places, earth embankments in the intertidal area have been a traditional way to reclaim land, particularly in estuaries, and the structures are usually built at the edge of the intertidal area. Material is sourced from the area landward of the bank. They are simple to design in most cases, and provide a set level of defence against surge tides. They require a certain level of skill to build, as the material has to be placed and compacted well.

Because embankments are generally sited at the edge of the intertidal area, erosion from wave attack can be an issue. Sea facing embankments are often protected at the front face with rock, concrete blocks or even tarmac. In areas where the coastline is eroding (particularly reclaimed areas) the banks may need more substantial protection. If possible, it is better to move the seawalls closer to the property they are to protect, and away from the direct action of the sea. The Netherlands has secondary flood banks inland which are smaller as they don't have to resist coastal wave attack– it can also be far cheaper to build a defence around a small town than along a long stretch of coastline.

Embankments are costly to maintain, because they have to be maintained very regularly to remain effective. They are particularly subject to pest attack – eg rabbit holes, and they settle over time, so they have to be raised at regular intervals.

*Soft Defences*

In terms of 'soft' defences, more natural forms of defence include the beaches themselves. Beaches absorb wave energy rather than reflect it, - under wave attack, the material in the beach is redistributed to form a storm profile which is based on the direction and size of the waves, so the beach actually responds to the specific event. The volume of material on the beach can be increased and held in place to defend against larger storms. Beach management has traditionally been used on the East Coast of Australia, to respond to erosion issues. Beaches work very effectively as storm protection, although they need a lot of maintenance, especially if there is a trend of sediment movement along the coastline. For example, the Netherlands until very recently had a policy of holding its existing coastline in place, and protecting against the trend of erosion by continually re-supplying the beaches with material[13]. This uses 6 million cubic metres of sand every year – maintenance of the coastline costs €43M/yr.

Sand Dunes are a type of beach used extensively as hurricane and coastal flood protection[14], to provide a buffer against sea erosion, wave overtopping and tidal inundation during storm events and provide a source of sand to replenish the beach during periods of erosion[15]. The dunes are an accumulation of wind-blown sand, often vegetated. They have particular advantages in that the dunes act as a store of beach material for extreme events, and also act as a barrier to high water levels. However, the dunes are particularly sensitive to environmental damage.

Beaches and dunes are complex to design, and tend to require modelling. They can be built or supplemented from existing. Sand supply can be problematic, as particle size needs to be matched. Placing material by sea requires specialist equipment and is very weather-dependent.

Mangroves or saltmarsh can be used seaward of beaches or embankments to absorb part of the energy of a storm before it reaches the defence[16]. However these tend to be lost very quickly in storm conditions, and are more effective in protecting areas against day-to-day wave and tide energy.

*Combined Defences*
As noted above, beaches can be difficult to maintain if there are sediment movement trends along the coastline. In areas where there is a lot of beach movement along the coast, groynes are used to hold the beach in place until it is needed. In the past, groynes tended to be timber – a Victorian legacy, and a traditional image of a UK seaside town. More recently, rock groynes have gained in popularity, not least because they also absorb wave energy, and so are much more effective in retaining beaches, particularly if the outer ends are extended to act as mini-headlands. Both timber and rock groynes need a healthy beach already in place to be an effective supplement to coastal defences.

Groyne fields have a major impact on sediment processes, and down-drift effects need to be considered very carefully. The design of groyne fields is specialist – it is prudent to undertake modelling to get the spacing correct, as there can be erosion issues mid-bay if the groynes are too far apart. The design can be very site-specific, so if wave directions change with climate change, the effectiveness of the groyne field could be reduced. There is a visual and amenity impact of groynes, as they separate beaches into compartments. Rock groynes can be difficult to access over safely. However, rock groynes in particular are very effective against erosion.

Material supply for timber groynes can be difficult if sourcing sustainably, as they need to be made from borer-resistant hardwoods. Material for rock groynes is easier, although to work effectively the rocks have to be shaped well, and placed well – the effectiveness of rock structures relies in part on the spaces between the rocks, so they can be difficult to build.

Another use of rock is for offshore reefs or islands. These protect the beach from a distance. Offshore reefs reduce the wave energy in the whole nearshore area, although the spaces between the reefs can let some waves through. These reefs can be above normal sea level, or partly or fully submerged depending on the tidal range and effects they are intended to mitigate.

Elmer UK – source www.environment-agency.gov.uk

The difficulties with building rock structures also apply offshore. However, visual impact is reduced and beaches are left open. These can have a profound effect on sediment supplies downdrift of the area protected. The rocks can provide a good habitat, although the reefs can impact on sea-users.

*Estuaries*

Within estuaries, surge protection can be through sea wall or embankment structures – if there is significant development upstream protection can be offered by means of a surge barrier. The Thames Barrier in London is an iconic example of this – more recent examples tend to be side closing rather than rising gates for ease of maintenance. Barriers can take the form of gates that close only when a surge is forecast, leaving the estuary to flow naturally for the rest of the time, or they can be barrages which control the water level upstream and provide additional amenity, with locks to the open sea. Barriers and barrages are expensive. Barrages have some impacts on the natural environment, and don't work well with commercial shipping. Barriers can be managed to work with shipping and have far fewer environmental impacts. Both are visually obtrusive.

*Design Issues in Resistance and Resilience*

The above list of defence types is a very basic outline of structural defence methods on a large scale. Another key element in risk management is improving flood resistance and resilience of assets at risk including infrastructure. Flood proofing of buildings can be undertaken, either temporarily or permanently, although the building must be capable of withstanding water loads imposed. In addition, buildings can be designed to remove assets from the flood plain, or even to allow flow paths to continue under habitable accommodation, for example by designating ground floor as car parking only. There are also temporary or demountable defences, which can be used to protect critical assets. These are less effective than permanent structures, but are less costly and easy to mobilise if sufficient warning is given. They have no long term visual impacts.

Issues such as wind resistance, to reduce risks associated with higher wind speed, can also be designed into structures in the hazard zone.

Temporary defence structure. Source: www.environment-agency.gov.uk

Measures to manage secondary flooding can also be utilised to improve resilience. To minimise upstream flood effects, large (dams) or small scale (rain tanks) storage can be used to hold rainfall at least until the risk of tidal flooding has receded. Storage in river floodplains (washlands) can also be utilised and managed.

**Structural Protection Issues**

Each description of structural defence types includes negative impacts of each type of defence. There are some difficult issues to address with any structural defences, the main one being climate change, and along the same theme how each type of defence reacts to over-design events. The most critical decision to be made in terms of flood defence however is how much the community or nation is willing to pay for defence.

*Cost of Structural Defences*
Cost affects the standard of defence provided. It can affect the type of defence chosen, the level of maintenance and monitoring undertaken, the materials used, and the physical dimensions and scale of storm that the defence will withstand. As noted previously, defences are best used to protect assets rather than people. Generally decisions are made on the cost of defence versus the level of protection provided and the consequent reduction in flood damage costs associated with the defence. Unless defences are funded entirely through national taxation and evaluated in terms of risks

and benefits to the nation as a whole, these decisions fall all too often on a community and its willingness and ability to pay.

*Effect of above-design storms*
All coastal defences are designed to withstand a particular scale or frequency storm event. A factor of safety will have been added. However, it is inevitable that at some stage in the future a storm event will occur that is larger than the event which the defence has been designed for. If this has not been considered at design stage, there is a far higher risk that the defence will fail catastrophically, rather than staying in place, and providing a residual positive effect.

The type of failure depends on the type of structure. Seawalls and levees can fail structurally, or if overtopped material washes away from the rear of the defence and it moves or overturns. Embankments sometimes fail on the seaward face when the tide recedes, this is not helpful if the surge lasts for more than one tide. Beaches move with the storms – a storm crest forms but if there is insufficient material that crest fails as it tries to move landward and mobilise more beach. Groynes tend to suffer structural failure, and become ineffective which may result in the protective beach being lost – however this generally occurs as the storm tide recedes.

Lessons learned in previous floods show that breaches in flood defences are very difficult to repair at the time of flood. In the cases of large scale flooding, it can be months before defences are replaced.[17] Post-failure characteristics of defences must form part of the risk analysis in planning for structural defences.

**Impact of Climate Change**

The impact of climate change on the coast is multiple, and is presented elsewhere in far more detail. Current data is included here for completeness – the inference to be drawn is that over-design events are likely to become more frequent as the climate changes[18]:

| | |
|---|---|
| Mean sea level | ▪ 0.5m rise by 2100 (central estimate) |
| Ocean currents and temperature | ▪ No quantitative or qualitative models are available for coastal regions of the continent |
| Wind climate | ▪ Trade winds may weaken<br>▪ Westerly wind stream may move further south<br>▪ Cyclone intensity may increase 10% to 20%<br>▪ Regions affected by tropical cyclones not expected to change significantly |
| Wave climate | ▪ Regional climates will alter with wind patterns<br>▪ Seasonal directions could change if latitudinal position of major weather systems change<br>▪ Site specific effects resulting from increased water depth |
| Rainfall / runoff | ▪ Possible increase in frequency of high-intensity rainfall events |
| Air temperature | ▪ Possible increase in frequency of extreme high-temperatures<br>▪ Reduced frequency of very low temperatures. |

There is some debate on whether extreme tide levels will increase more, or stay the same quantum above mean sea level. [19] Currently, storms are scaled by the statistical probability of them occurring – this can be reported as a percentage eg a 1% probability storm is one that has a 1 in 100 year probability of occurring – what we used to call a 100 year storm. The Tyndall centre assessed that a storm with 2% probability now, will have 33% probability in 2080[20]. Whilst this refers to the UK, and therefore incorporates a local problem of isostatic tilt, it still implies that a (non-cyclone) storm with a perceived ferocity of a 50 year storm will occur a lot more frequently in 2080.

Although the frequency of cyclone events is not expected to increase, the intensity is. As an example of climate change impacts with Australia, CSIRO[6] suggests that the rising sea level, stronger tropical cyclones and increased intensity of storms could increase the 2050 1:100 flood level in Cairns by 0.4m.

CSIRO notes that sea level rise causes material from beaches to move to the nearshore area ie the shoreline recedes - predicted to be 4.5m to 88m by 2100[6] . There will be erosion in any areas where development is fixing the present coastline in place – beaches will reduce in size. This could put significant pressure on any existing coastal defences, or on any infrastructure close to the coastline, and it will certainly impact on amenity.

As well as cyclone intensity increasing, intensity of rainfall events will increase – there will be more rain during storms, and less the rest of the time. This will have an impact in any areas where coastal surges and rainfall correlate.

The south east of the continent will have fewer but more intense mid-latitude storms. Generally storms are predicted to increase in intensity. This could mean that areas that haven't traditionally suffered much from coastal storms will find that they become a hazard to be considered.

Any change in wind direction will change the direction that waves approach the coastline, and will start to change the shape of the coastline, and affect how current natural systems work[23]. Higher sea levels and larger waves will also affect the long term shape of the coastline.

Estuaries will get an increasing tidal prism as the water levels increases, which will move the intertidal area further upstream, and cause the mouth of the estuary to widen[23]. Increased tidal prism may also influence the way sediment crosses estuaries, and it may cause scour of structures within the intertidal area. This may impact on flood defences within the estuary, as well as infrastructure such as ports.

An understanding of the implications of climate change including the increasing likelihood of above-design events occurring is critical to designing coastal structures that work with the changing environment. Many regional councils have developed planning advice relating to climate change. There is also specific advice on engineered structures.

**Guidelines for Responding to the Effects of Climate Change in Coastal and Ocean Engineering** [18]

Guidance for coastal and ocean engineers on responding to the effects of climate change in Australia has been prepared by the National Committee on Coastal and Ocean Engineering (NCCOE) of the Institute of Engineers Australia (EA). Published in 2004, these guidelines represent an update of an earlier 1991 document and are based on the findings of IPCC 2001. Along with a concise description of the scientific basis and evidence of climate change the guidelines present a summary of the latest IPCC projections on land surface air temperature and sea level rise. The following is a summary of the guidance provided in this document.

The latest projections, known as the SRES (IPCC 2001b) scenario, are the basis of the central engineering estimate of 0.5m sea level rise by 2100. This estimate is bounded by minimum and maximum estimates of 0.1m and 0.9m, recently updated to 0.18 to 0.59m by IPCC [21]

The earlier estimates of sea level rise have been incorporated by Standards Australia as part of AS4997-2005 Guidelines for the Design of Maritime Structures[22] "*Maritime facilities should be designed to cater for increase in water level due to promulgated sea level rises caused by global warming.*" The design allowance is of course dependent on the design life of the structure with the rate of rise given as 0.1m every 25 years.

Quoting IPCC, the guidelines outline three possible response strategies:

- ***Retreat*** **–** abandonment of land and structures in highly vulnerable areas and resettlement of inhabitants;
- ***Accommodate*** **–** conservation of ecosystems, continued occupancy and use of vulnerable areas and adaptive management responses;
- ***Protect*** **–** defence of vulnerable areas, population centres, infrastructure and natural resources using both hard, "structural" options or soft solutions.

In developed areas, all three approaches may be adopted over time, but protection is likely to be required at least in the short term.

The guidelines outline an approach for conducting an Engineering Impact Assessment of maritime structures, including flood or coastal defences. The method suggests considering the likely importance of changes to key environmental variables that have been the subject of climate change scenario modelling as defined in the table above.

The methodology then outlines a number of secondary variables of importance to ocean and coastal engineering that may be influenced by changes in the key variables. These secondary variables include local sea level, currents, winds and waves as well as effects on structures, groundwater, flooding, beaches, foreshore stability, sediment transport, estuaries, water quality and ecological variables. Guidance is offered on the likely interactions between the key environmental variables and these secondary variables.

A combined risk and sensitivity analysis approach is then recommended based on the following process.

**Specify the Design Life or Planning Horizon**

The design life of the facility or the activity … underpins the design philosophy and may fundamentally control the selection of material, methods and expertise.

**Consider Consequences of Failure**

Direct and indirect effects on cost, safety and environment.

**Consider Design Event Encounter Probability**

Where consequence of failure is relatively high a lower probability of encounter will be necessary. Where consequence of failure is low a higher probability may be acceptable.

**Adopt Appropriate Design Philosophy**

Where consequence of failure is low adopt a *Least Regrets* approach , acknowledging that failure will probably occur and concentrating on ameliorating any failure impacts and the ability / cost to repair or replace. Where consequence of failure is relatively high the design philosophy should be one of *Robustness*, aiming to prevent failure and accepting a certain amount of reserve capacity or the ability to adapt the design throughout the design life.

**Select Appropriate Design Criteria**

Armed with the knowledge of the sensitivity of the design to the primary and secondary environmental variables, appropriate design criteria (ie. Water levels, wave heights etc.) can be determined.

**Undertake a Sensitivity Analysis**

Consider the likely median and upper estimates for the environmental variables and their impact on the design criteria. It may be necessary to consider the effects of related processes and the statistical recombination of assumptions in order to avoid unnecessary subjectivity and conservatism at this stage.

**Assess and Review Design Assumptions and Adjust Design as Necessary**

The Authors believe this to be a pragmatic approach to accommodating climate change risk into the design of defences. We believe the 'least regrets' approach is a shared responsibility between engineers and planners, to manage risk to people and property as best we can.

## Planning Approaches

The elements of 'event' planning have been highlighted earlier in this paper as part of the means of addressing risk management for existing development within the hazard zone. Emergency management and structural protection could both be seen as 'immediate' measures. However there is an opportunity afforded to planners to plan the hazard out, over a very long timescale. New Zealand's Ministry for the Environment suggests that decisions can be based on timescale[23]:

| | |
|---|---|
| 5 years | interim management measures (including structural) |
| 10 years | planning techniques – planned retreat, temporary occupation |
| 20 years | buffer mechanisms |
| 50 years | land use strategy |

In the short term, structural measures will have to be used alongside planning options to manage the risk until longer term planning measures are implemented.

Australia has developed national guidance on development in the coastal hazard zone. Each Region of Australia is developing planning guidance on mitigating flood risk and adaptation to climate change.  In Victoria, development and use of coastal Crown land is regulated and planned in accordance with the Coastal Management Act 1995, the Victorian Coastal Strategy 2002 and local government planning schemes.

In practice, the key elements for planning for coastal risk can be encapsulated into 7 principles[23], which incorporate the need for structural protection measures:
1) Know your community's coastal risks
2) Avoid new development in coastal hazard areas
3) Locate and configure new development to minimise damage
4) Design and construct new buildings to minimise damage
5) Protect existing development
6) Take special care with critical infrastructure
7) Plan for evacuation

**The Way Forward and lessons from elsewhere**

Structural solutions clearly have a place in managing coastal risk in developed areas. However, the application of structural defences will be costly and have impacts on the natural environment, so it is important to use structural defences selectively, with a balance of other risk management measures.

*Adaptation Strategy*
Our cities and infrastructure are built to accepted risk limits based on the expected return frequency of severe winds, heavy precipitation events, storm surges. If climate change increases (among other things) the energy of tropical cyclones then the return frequency of severe storms could reduce significantly with an associated increase in exposure[25]. An overall adaptation strategy is needed, incorporating emergency planning, risk management through defences and long term planning, among other things.

The general principles are the same throughout the developed world:
- Plan to protect the people
- Provide structures to protect key assets
- Make sure you protect the weakest link

Developing an adaptation strategy to respond to climate change will increase the resilience of human and natural systems in climate conditions where this is likely to be feasible and cost effective and takes account of the social dimensions of distributing losses. However, the regional government approach rather than a centralised approach may lead to inconsistencies in risk management across Australia, or a focus on perceived local issues and priorities[25]. US Congress reviewed the role of national vs regional government decisions after Katrina, and questioned whether regional policies resulted in an acceptable level of aggregate risk to the nation[10] – this question also needs to be asked in an Australian context.

*Uncertainty*
The AGO[25] notes that uncertainty is a key obstacle to climate change planning, including (inter alia) uncertainty regarding future climate outcomes globally and regionally and limited knowledge of the detailed interaction and inter-dependencies of climate affected systems. Whilst State Goverments are investing in better understanding the hazards,[24] recent experience in the UK suggests that detailed flood warnings are needed to successfully implement evacuations of risk areas at times of hazard.[9] Uncertainty about effects can also lead to uncertainty about cost, or unnecessary expenditure on structural solutions.

*Cost*
Cost is a major factor in responding to climate change using structural means, particularly given the uncertainty in future design needs. Engineering solutions include designing structures that can be adapted later for the changing climate – this involves some investment now, but gives flexibility later.

Because of the cost of flood defence structures, government[25] is looking at ways for government to work with business to protect assets – this can offer opportunities to provide structures that are multi-functional, and bring benefits to the community. The Australian Greenhouse Office[25] notes that some sectors, like insurance and re-insurance, are already including climate risk in their decision making, and suggests that Government will have to consider the issues around the distribution of losses in the community arising from the possibility of either a withdrawal of companies from covering some risks, a huge increase in costs or the failure of one or more of the major companies.

*Making Space for Water*
The net effect of climate change is going to be to increase the hazard at the coast. Any defences will need to be increasingly robust. The implication is that coastal defences will cost more to build in order to provide the standard of defence required, and that they will need maintenance more frequently. In Europe, the growing awareness of climate change issues has led to a complete rethink in policy, which is moving away from defending the entire coastline towards more focused areas.

Making Space for Water [26] accepts that generally, floodplains should be used as nature intends them to be, and that they can be managed to assist in removing the risk from developed areas. The Netherlands has progressed this policy[13], removing or setting back defences and deliberately deepening floodplains to store more water. Much of the proposed estuary management in the UK relies on allowing surges to be stored in floodplains at the mouth of the estuary, rather than flooding communities upstream. Structural defences remain in use, to protect critical infrastructure. If this policy can work in such limited land masses, there is enormous scope for success in larger countries!

*Starting a dialogue with communities*
The introspection associated with the current focus on climate change offers communities the opportunity to develop policies that will help manage the risk in the long term by planning out of the flood plain, or planning in flood resilience[27]. This is

also the opportunity to start a dialogue with affected communities, and to start developing flood hazard awareness in people.

The Victorian Coastal Council notes that a critical factor to the success of any coastal strategies is that commitment and integration of all stakeholders is required[28].

*Conclusion*

Developed coastal areas are at risk from coastal hazards, particularly those relating to coastal surges. Impacts can be flooding, with wide ranging consequences, or rapid coastal erosion during storms. Climate change will exacerbate the effects of storms on the coast, in terms of flooding, as storms are likely to become more intense. Sea level rise will also cause erosion in non-storm conditions.

As development already exists in at-risk areas, emergency planning and structural protection will be needed to protect people and assets in those areas. Structural methods can be used to reduce or mitigate the damage, and also to make sure that people get back to their property more quickly. There is a specific need for improved forecasting and warning to improve emergency management.

The cost of structural defences is high. Unless funded entirely through national taxation and evaluated for the nation as a whole, decisions on structural protection expenditure fall all too often on a community and its willingness and ability to pay – the scale of potential impacts in some areas may indicate a need for national government involvement, in addition to the regional focus.

The final word on the importance of structural measures in flood defence must go to the researchers from the Gulf Institute[11]. In analysing lessons learned from Katrina and 3 other floods in other continents the researchers drew the following conclusions (among others):

“Even when local systems are overwhelmed, well coordinated regional efforts guided by effective communication and situational awareness can mitigate the suffering.”

and

“Structural solutions are necessary but not sufficient”

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[3] Government of Western Australia (2006) – Fire & Emergency Services Authotity of Western Australia Annual Report 2005 – 2006.
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