ADAPTATION BY DESIGN – ADAPTING NEW BUILDINGS AND FORESHORE PROTECTION WORKS TO SEA LEVEL RISE IN COASTAL ESTUARIES

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Abstract

Following a review of lake flooding to incorporate predicted sea level rise, Lake Macquarie City Council is revising its development conditions to manage the increased risk from flooding and permanent inundation around the lake foreshore. Council realised there were few precedents or examples of development conditions covering adaptable buildings and foreshore protection works in areas vulnerable to rising sea levels.

Council commissioned and reviewed two specialist studies to provide performance criteria, design principles and templates, and assessment guidelines for adaptable buildings and foreshore protection. The studies identified thresholds and triggers for the implementation of various measures.

The adaptable designs had to consider increased flood heights, increased frequency of minor flooding, permanent and tidal inundation, rising groundwater and groundwater salinity, asset life, foreshore recession, cost and practicality of implementation, and changing exposure to risk.

This paper provides a brief summary of the adaptation studies, and discusses the practical issues and difficulties in applying the findings to Council planning and development assessment. The discussion highlights the pros and cons of different approaches to dealing with uncertainty, such as spreading adaptation actions over time, or waiting for a trigger or threshold.

Issues of coordinating adaptive changes in individual developments with the adaptive changes in adjoining properties and in infrastructure remain problematic.

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Background

Lake Macquarie Local Government Area, just south of Newcastle, has more than 7,500 households around the lake foreshore that are vulnerable to flooding and sea level rise.

In 2008 Lake Macquarie City Council (LMCC) adopted a sea level rise policy, assuming a rise in ocean and lake levels of 0.91metres by 2100, and directed staff to apply these levels to planning, development assessment, and natural resource management. More recently, these levels have been 'fine tuned' by applying the 2009 NSW sea level rise benchmarks to a new lake flood and tidal inundation study (WMAwater 2012).

Approximately 100 new dwellings and commercial buildings in vulnerable areas have been assessed under the Sea Level Rise Policy since 2008. Most comply with Council's revised development conditions – mainly requiring raised floor levels – and have been approved. However, several did not or could not meet these conditions, and were approved with other adaptations such as flood barriers or adjustable floor levels.

This few years of experience raised some practical issues for Council – including how to design and construct foreshore protection works that are adaptable to rising lake levels, and how to assess development proposals for 'adaptable buildings'. Council planners have tried to develop controls that balance the need to provide certainty to developers and owners during the life of an asset, while allowing for the uncertainties – particularly in timing – involved in assessing and managing the risks from flooding and sea level rise.

Lake hazards and risks

Lake Macquarie is a tidal estuary, connected to the ocean by the Swansea Channel. The narrow channel protects the lake from ocean influences, with a tidal range in the lake of only 0.12 metres, and little or no effect from ocean waves or storm surge.

Run-off from catchments in the Watagan Mountains cause lake flooding. In the 2007 "Pasha Bulker" storm the lake rose to just over 1.0 metre AHD. The flood study indicates this was only a 1:15 year event, with the predicted 1:100 year flood rising to 1.5 metres. With projected sea level rise, the 1:100 year flood is projected to rise to 1.86 metres by 2050 and 2.32 metres by 2100.

The risk from lake floods is mainly to buildings and infrastructure. With lake flood peaks lagging about 12 hours behind rainfall peaks, and low flood velocities, there is a low risk of injury or loss of life.

Sea level rise is projected to increase lake levels and lake flood heights, as well as the frequency of flooding at a given height. So the current 1.5 metre 1:100 year flood becomes a 1:2 year event with a 0.9 metre rise in lake level (WMAwater, 2012).

Rising lake levels will progressively inundate low-lying foreshore areas, with a 0.9 metre rise permanently covering areas below 1.0 metre AHD. This will affect 1,250 hectares of land, most of it public reserve, but including about 3,300 residential lots. In sandy areas, groundwater will rise as lake and sea levels rise (WMAwater, 2012).

Inundation and rising groundwater will affect land capability, making areas unfit for current purposes such as public recreational reserves, boating facilities, or private waterfronts. It will also affect infrastructure such as sewer, roads and drainage, with about 28 km of local roads affected by a rise of 0.9 metres (NSW Department of Planning 2008), and 63 kilometres of sewer main.

The Lake Macquarie foreshore is generally quite stable, with few areas suffering active erosion. Despite this, many residents have constructed 'seawalls' on their deed-high-water-mark boundary, with or without approval from Council. In most cases, the purpose of these walls is to retain fill, to provide a flat lawn to the water's edge, rather than to protect the foreshore from recession.

The 2004 Lake Macquarie Development Control Plan discourages the construction of seawalls on the lake foreshore, requiring proof of active erosion before Council will consider a proposal. In a landmark 2004 Land and Environment Court decision, Council's refusal of an application to build a vertical seawall was upheld because the applicant could not show that the foreshore was receding (NSW Land and Environment Court, 2004). Where protection works are approved, Council guidelines encourage 'soft engineering' designs. The most commonly used treatment is a cobble beach, sometimes backed with a low rock revetment along the landward storm extent, combined with a band of salt-tolerant native plants with deep fibrous roots, such as *Lomandra longifolia*.

The purpose of these designs is to retain the natural functions of foreshores as much as possible: allowing seagrass wrack to wash out and dry on land; providing habitat; absorbing wave energy; and maximising public foreshore access.

Foreshore recession and foreshore protection with sea level rise

The stability of the lake foreshore will change as sea and lake levels rise. Low-lying foreshores will be progressively inundated and, like sandy ocean shorelines, they will erode to re-establish an equilibrium profile. An investigation by Cardno (2010) found estuarine foreshores do not follow the Bruun rule as the lower energies do not allow the erosion and re-deposition of sediment as readily as on the open coast. They estimated the combined effects of inundation and subsequent erosion in wave-dominated coastal estuaries would result in recession in the order of 5 to 20 times the rise in water level – that is, recession of up to 20 metres for each 1 metre rise in lake levels. Council developed the on-line "eShorance" tool to assess these effects. (Cardno 2010; LMCC 2012).

Not unreasonably, public land managers and private landholders are asking how they can protect against this predicted recession. Council is about to begin a community collaboration with vulnerable communities to assess strategic planning issues in which the community and Council need to consider: where, when and how is it best to accommodate, protect, or retreat? It is likely that protection will be the 'default' position of many landholders, and that it will be among the options included in local area adaptation plans. Accordingly, Council engaged Clouston Associates to work with Council to develop a suite of designs for foreshore protection works that would retain Council's current 'soft engineering' designs, provide protection from recession for foreshore dwellings, and that could be adapted to deal with the predicted effects of sea level rise up to 2100.

The Clouston (2012) designs followed six principles:

1. Conserve and rehabilitate foreshore biodiversity and natural processes
2. Protect the foreshore from recession
3. Conserve and enhance public access
4. Conserve scenic values
5. Ensure treatments are sustainable and flexible over time
6. Ensure treatments do not adversely affect neighbours

Additionally, Council nominated the prime purpose of the protection works was to protect structures, particularly dwellings, rather than protect land. It was interesting that this caused some initial difficulty with the consultants, simply because of the strong cultural assumption that the purpose of protection works is to allow everything to remain as it is, and where it is. Typically, sea walls are built at the property boundary, rather than where it is functionally necessary to protect the built asset(s) at risk. This shift in emphasis has not yet been validated by discussion with the Lake Macquarie community.

Clouston's designs (e.g. Figure 1) offer a suite of foreshore treatments suitable for different functions and situations, from simple vegetated berms that slow foreshore erosion in low-risk areas, to seawalls and rock revetments to protect against immediate risk to buildings.

Each treatment is designed for a projected sea level rise of only 0.2 metres. On current predictions, this would provide protection for about 20-30 years. Given the relatively low cost of construction, this was thought to be an appropriate time frame. It allows the asset to earn its keep, while providing time to plan for further protection work, if required.

To achieve protection for a greater rise over a longer period, 0.9 metres to 2100, for example, the treatments can be repeated and rolled landward or, if this option is not available due to the proximity of the dwelling to the shoreline, the height of the protection can be progressively increased. In many circumstances, a combination of the various treatments and successive re-locations will be used as the hazard and risks increase. The choice of materials and construction styles allows for relatively easy relocation or for the treatments to be left in situ as they are gradually inundated by the rising lake waters.

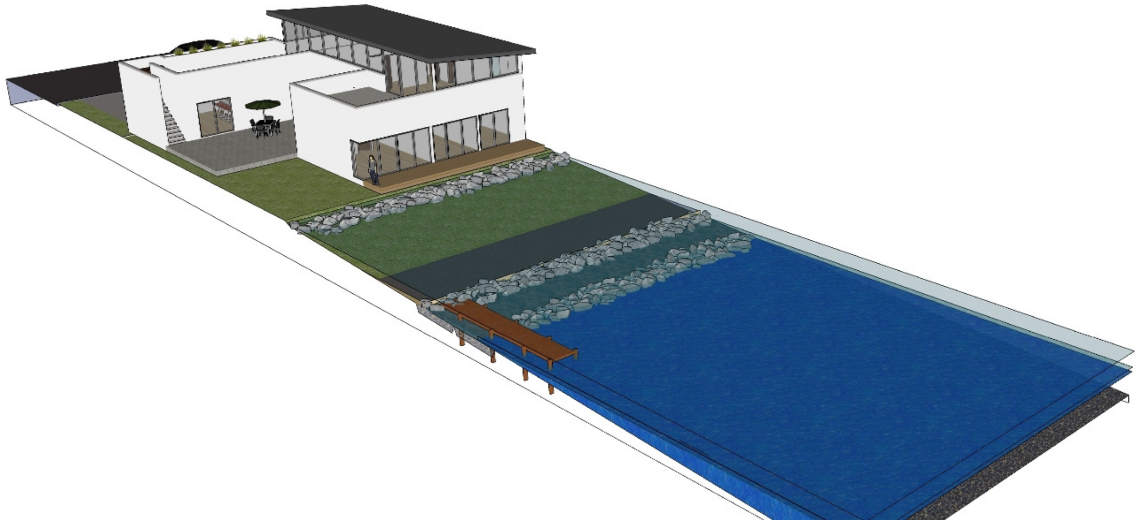

FIGURE1: Foreshore protection using sloping rock revetment showing staged retreat as foreshore recedes, with protection for the maximum expected hazard close to the protected asset (Clouston 2012)

These designs are suitable for the low-energy foreshore typically found in sheltered coastal estuaries such as Lake Macquarie. Open ocean shorelines, and shorelines that experience oceanic tidal ranges, would need different designs. The treatments are to control long-term recession, and they do not provide protection against extreme events such as flooding or storm waves.

Clouston and Council identified several difficulties in implementing their proposed designs. As mentioned above, there is an unresolved question over community acceptability of the concept of managing a retreating shoreline.

There is also an issue with the coordination of such works. The protection works will be ineffective if, along a given shoreline, they are disjointed or incomplete. Given that works are likely to occur on each property at different times (when the site is redeveloped, for example) public authorities such as Council will have to devise a framework to ensure the cumulative effect is to produce a continuous and integrated foreshore treatment (Figure 2). Council will also address this issue as part of the development of local area adaptation plans.

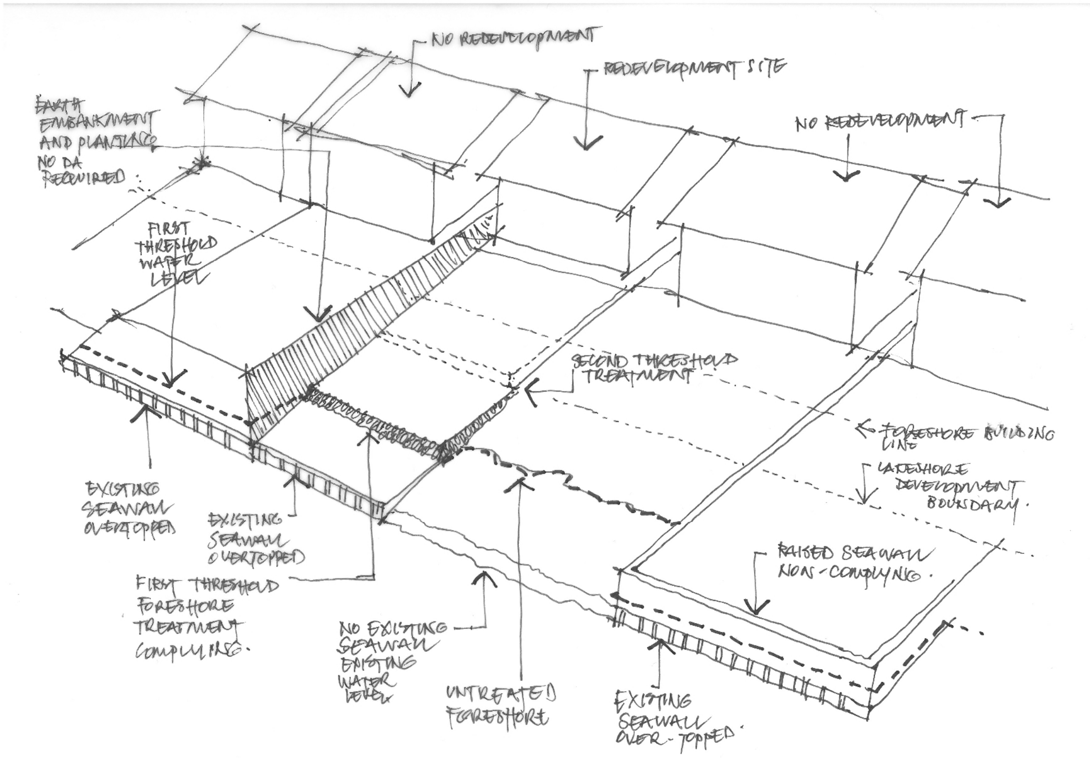

FIGURE 2: Schematic representation of possible foreshore protection works – existing and future – highlighting the issue of coordination between individual properties (Clouston 2012)

A common difficulty in the application of adaptable designs is to determine suitable thresholds or triggers, at which point the next stage of the adaptation begins. These issues are discussed later in this paper. An advantage of the relatively small scale, and progressive staging of the Clouston approach is that the trigger can be simply left up to functionality – when the treatments are no longer providing the protection required, they need to be up-graded or replaced.

Adaptable buildings

An adaptable building is one which can be easily re-configured to respond to a change in hazard, if and when required. It allows the building to function safely over a range of scenarios, and the investment in additional risk mitigation can be timed to coincide with the increase in hazard, which may occur faster or slower than predicted. It may also allow construction in areas of high risk, where other buildings would fail or become dysfunctional.

In practice, however, the benefits are less clear-cut. There are already dwellings that are highly adaptable to the risks of flood and permanent inundation, for example, in The Netherlands and elsewhere there are neighbourhoods of buildings on floating foundations (World Architecture News 2007). But the real limits to functionality are more generally related to access, provision and maintenance of infrastructure, cost of construction and maintenance, and use of the land. In a modern urban neighbourhood, a home has not really been fully adapted if it has no sewer, or the backyard is regularly inundated, or the garbage service has no access.

Special construction requirements already apply to buildings at risk of flooding and tidal inundation: raised floor levels, foundations designed to resist wave erosion or rising groundwater, or use of flood resistant building materials. However, these are designed to deal with a fixed level of hazard. If the hazard increases, the risk increases, unless the buildings can be adapted to reduce their exposure to the hazard.

Lake Macquarie, along with many other NSW Coastal Councils, is using these well-established risk reduction measures as the basis for its management of the risk from rising sea and flood levels. By basing floor heights, for example, on predicted increases in the flood hazard during the life of the asset it is possible to build-in a permanent adaptation to sea level rise. These built-in measures are referred to as "static adaptations" in this paper, to distinguish them from the more flexible measures such as adjustable floor heights and relocatable structures - "dynamic adaptations".

For the first period of the asset life these static adaptations provide a much greater safety margin from flooding than is normally required – there is a built-in redundancy. Later, if the asset continues in use beyond its nominal asset life, and sea levels rise as predicted, the asset will be at greater risk than the normal flood planning threshold.

In Lake Macquarie, the flood planning level for new single dwellings in areas affected by sea level rise and lake flooding is 2.36 metres AHD. This is based on a nominal asset life to 2050 and a sea level rise of 0.4 metres. If built today, this flood planning level is equivalent to the 1:500 year flood level plus 0.5 metres freeboard – well above the normal flood risk threshold. In 2050 it is equivalent to the 1:100 year flood level plus freeboard – the 'standard' flood threshold in many jurisdictions (DIPNR 2005). In 2100, if the dwelling is maintained, the flood planning level of 2.36 metres AHD is equivalent to the 1:15 year flood level plus freeboard – well below the accepted threshold.

The cost of these static adaptations, if installed at the time of construction, is relatively low. Slab-on-ground project homes are the market norm, and there is a cost – estimated about 5% - 10% of construction cost – in moving to a pier-on-joist construction (Greg Field 2012 – pers com.). However, once this transition has been made, the additional required floor height has little effect on construction cost. This means the benefit ratio of static adaptation, even if sea levels rise more slowly than predicted, is quite high. One incidence of over-floor flooding may cost $20,000 to $60,000 per household, depending on the depth of inundation (WMAwater, 2012).

Because of the relatively low cost, and the convenience of making these static adaptations at the time of construction, this is a 'no regrets' option. In practice, there has been good acceptance in Lake Macquarie. However, specific developments and sites cannot always meet these conditions, so further adaptation measures are needed to allow future risk to be managed sufficiently for the development to proceed.

Lake Macquarie case studies

Swansea commercial centre

The commercial area of Swansea is on the low sand barrier that separates Lake Macquarie from the Pacific Ocean. It is mostly below 2.0 metres AHD, and is subject to flooding from the lake and tidal inundation from ocean king tides and storm surge. When two local businesses, a garage and supermarket, wanted to re-build, Council applied new floor height requirements that included an allowance of 0.40 metres for sea level rise during the nominal asset life of the buildings (to 2050). The developers objected, pointing out that to build to this height they would have difficulty connecting to existing infrastructure. Footpaths and roadways were more than a metre lower, and it was difficult to connect disability ramps and driveways, and provide the street-level shop fronts favoured by Council's urban designers.

A compromise was negotiated, involving several elements:

- Floor heights would be raised as much as practical, but would be below the new flood planning levels
- It was acknowledged that the commercial asset life of the tilt-slab supermarket, as judged by industry norms, was closer to 30 years than 50 years
- Internal fit-outs would place electrical installations above flood planning levels, use flood resistant building materials, and install adjustable shelving
- Buildings would be designed with only two unsealed entrances/exits, which would be fitted with flood barriers
- A flood emergency plan would be developed and implemented on each site

Council considered that these adaptations reduced the risk from flooding and sea level rise sufficiently, over the likely useful life of the building, to approve the developments.

Lake Macquarie Yacht Club

Lake Macquarie Yacht Club at Belmont lodged an application for a new clubhouse and marina extension as a Part 3A major project through the NSW Department of Planning. Council made a submission asking that the new clubhouse, which is built over the lake, should achieve a floor height of 2.27 metres AHD to allow for future sea level rise and flooding. The Club argued it would be very expensive and inconvenient to connect the raised club to the surrounding boating infrastructure – dry-storage, the marina, and service areas – as these have to be close to water level and at-grade. The Club proposed to raise the boating infrastructure at some future date, as required, and adapt the club facilities at the same time. The new clubhouse was designed with higher than usual window openings, door openings, and ceilings (Figure 3), to allow them to remain functional if and when the floor is raised. This adaptable design was accepted by the NSW Department of Planning, and included as a condition of the development consent.

The trigger to raise the floor was set as "a lake flood that reaches or exceeds 1.2metres AHD", the floor level of the old clubhouse, and equivalent to a predicted 1:20 year lake flood. (See further discussion on triggers and thresholds below).

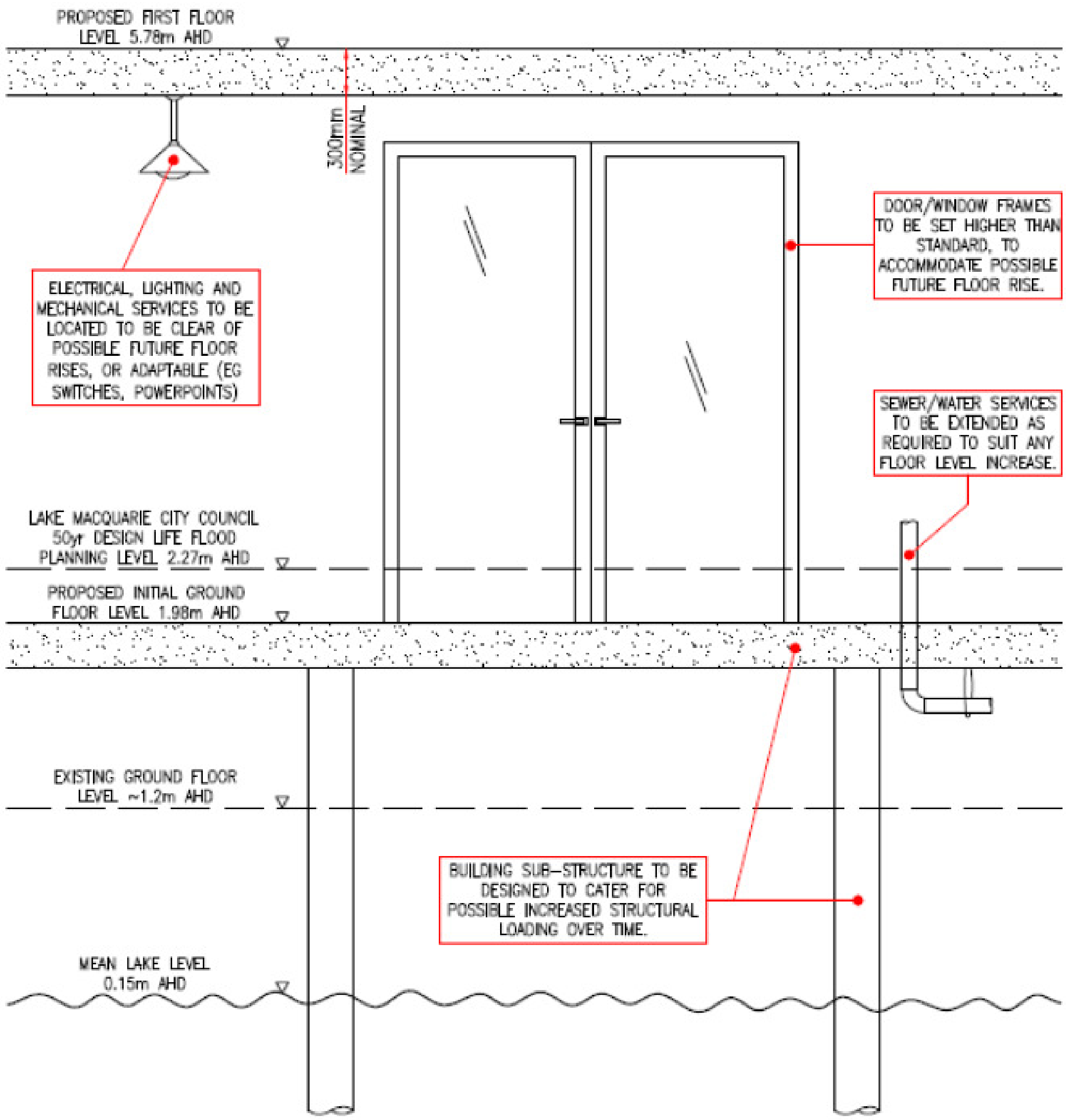

FIGURE 3: Proposal for adjustable floors in the Lake Macquarie Yacht Club (Northrop 2010)

Marks Point medium density development

Like many coastal councils, Lake Macquarie has discovered that several residential areas that were earmarked last decade for increases in residential density are in areas vulnerable to risks from sea level rise and increased flooding. Marks Point is typical. Older style bungalows on large blocks have been gradually redeveloped as medium density town houses and villa units. However, much of the area zoned for increased development is subject to flooding, and the risk will increase with sea level rise. As well, some very low-lying areas are projected to be permanently inundated, with an associated rise in groundwater levels. This may make some land and infrastructure unusable - inundating drainage systems and immersing sewers and road-base in rising groundwater.

Council staff determined that new medium-density developments in this area were not desirable if Council could not confidently guarantee the continued provision of infrastructure. As these larger developments involved greater investment than a single dwelling, and the strata-title made changes and redevelopment more difficult, the developments were assumed to have a nominal asset life to 2100. This required allowing for 0.9 metres of sea level rise, with a minimum floor level of 2.82 metres AHD. In an area where much of the land is at or below 1.0 metre AHD this presented some practical difficulties for design and construction, especially for medium density developments which seek to limit the space allocated to driveways, access, and infrastructure.

When Council staff recommended refusal for two applications on land below 1.0 metre AHD on the basis that it could be inundated during the life of the asset (i.e. by 2100), that the required floor levels couldn't be achieved, and that infrastructure provision couldn't be guaranteed, the matters were referred to Council. In both cases Council approved the developments, with a reduced floor level based on the 2050 asset life ascribed to single dwellings, but with conditions that made them more adaptable. These included building on pier-and-joists; building units in blocks of only two, to allow them to be raised in future; asking that units be subdivided into Torrens title to allow easier re-development; and using flood-resistant building materials. The provision of infrastructure was not specifically addressed, with an unspoken assumption that the large number of units already approved in the neighbourhood would require continued provision of infrastructure, at least for the asset life to 2050 now ascribed to the proposed new developments.

Council is developing 'Area Adaptation Plans' in a collaborative partnership with affected communities, beginning next year at Marks Point. These strategic plans will develop options to manage the risk from rising sea and lake levels, and increased flooding, to land use, infrastructure, and natural resources to at least 2100. They will seek to answer those big questions: retreat, adapt, or protect? This will guide Council's future decisions on proposals that increase development intensity in vulnerable areas, and on the continued provision of infrastructure to new developments and re-developments.

Assessing adaptable building designs

One of the issues highlighted by these case studies was that Council did not have, and could not find, any guidelines to assess proposals for adaptable building designs. For example, constructing on pier and joists was accepted as an 'adaptable design' as the building could be raised or moved if required, but no other assessment was done to see if this was really the case. Choice of cladding, structural integrity, connection of services, cost of relocation versus depreciated value of asset, access to the site, effect of future additions or renovations: all these could be relevant to the ability to raise or move the building, but they weren't systematically considered or assessed.

Accordingly, Council commissioned Edge Environment to prepare some performance criteria and assessment guidelines for residential buildings in areas affected by sea level rise and flooding.

Assessment and performance guidelines

At the time of writing, the project had only just begun. Some of the issues to be addressed by the consultant were set out in the project brief:

- Define what is an adaptable building and identify the criteria for adaptability across a range of residential building types.
- Develop acceptable performance criteria for Adaptable Buildings appropriate for areas identified as low and high hazard flood areas in the Lake Waterway Flood Study. Whilst performance criteria may be specified for each hazard area, the focus will be on high hazard flood areas.
- Facilitate innovative development.
- Risk reduction measures should not rely on filling or protection works, but should allow for possible future implementation of such strategies.
- Address appropriate building heights and other controls, consistent with draft Lake Macquarie Local Environmental Plan 2012 and draft DCP 2012 provisions. Note, adaptable building design proposals will need to consider the impact on adjoining properties to inform any merit assessment as part of the Development Application process.
- Address foundation stability associated with high levels of groundwater and/or receding shorelines.
- Identify constraints associated with the acceptable performance criteria for Adaptable Buildings.
- Address issues associated with access to the site and buildings, and the future connection to services such as sewer, water and electricity (adaptation plans for the provision of services are being done separately).
- Have regard to different asset values and varying asset life spans for residential building types, particularly medium and high density development.
- Incorporate review mechanisms to ensure that the acceptable performance criteria for Adaptable Buildings is based on the best available information at any given time.
- Comply with current NSW Planning Legislation.
- The acceptable performance criteria of the Guidelines are to incorporated into the draft DCP 2012.

Issues with triggers and thresholds

Dynamic adaptations, unlike static adaptations, are commonly linked to some sort of trigger or threshold, at which point the adaptive action is implemented. As briefly described in the following examples, experience shows that triggers and thresholds provide a useful conceptual and practical tool for strategic planning, but are less useful as tools to assess and manage the risk for individual developments, particularly in existing settlements.

One of the arguments for adaptive design is that it is flexible in the face of the uncertainty of climate change hazards. The adaptation can be implemented at the optimum time, rather than pre-fitted or retro-fitted. This offers economic advantages, as well as allowing use of existing assets without modification, until change becomes necessary.

However, triggers and thresholds can also be a convenient excuse to delay action now, in the belief that the predicted hazard may never materialise, or will not materialise until much later than predicted. If there is a significant lag between the projected hazard and the actual event, then this could have a significant benefit in convenience and cost. But if the projection, for sea level rise for example, is about right, or is an under-estimate, delays may cause greater disruption and expense.

The tendency to delay is exacerbated by the influence of future discounting - people are more likely to take immediate benefits than wait for future benefits, even when they are greater (Productivity Commission 2012)

For example, when Council surveyed members of its Community Advisory Group about risk reduction measures for waterfront properties, the only proposal that received no support was to position new buildings away from the foreshore recession hazard. In discussion it was clear that, although this was the only cost-neutral proposal on offer, the benefit of living right on the water's edge was considered more valuable than an unrealised future safety benefit.

Response times

Existing settlements change due to the cumulative effect of individual re-developments. If the total housing stock is conceived as a single asset, to change the total asset to achieve a new safety threshold takes time – that is, the 'response time' (Figure 4) is very slow. The current rate of re-development of lakeside properties in Lake Macquarie is approximately 20-30 per year. By 2050 only 1200 of the 6,000 residential buildings identified as being in the 1:100 year flood envelope will have the increased floor levels and other adaptations designed to prepare them for the increased flood hazard. At this rate of re-development, to bring all 6000 buildings up to the 2050 floor height threshold, beginning now, would take until 2210.

The response time is thus the determinant for these types of cumulative changes across a population or stock of assets, which is typical of established cities and towns on the NSW coast. The response time could be reduced by driving a faster rate of re-development, mandating house raising or other modifications within a fixed time period, for instance. However, the experience with voluntary house raising schemes in high hazard flood zones in NSW shows that, even with a financial incentive for owners, up-take is slow and limited by the construction style of housing stock (Duncan McCluckie pers. comm. 2012).

To be effective the response time needs to allow a realistic interval between achieving the desired risk threshold, and setting an appropriate trigger for action (Figure 4). New buildings designed to be adaptable, to be easily raised to remain above predicted 1:100 year floods, for example, have a much reduced response time. For existing settlements, the problem of cumulative up-dating of the existing stock remains, but this approach might work for new settlements.

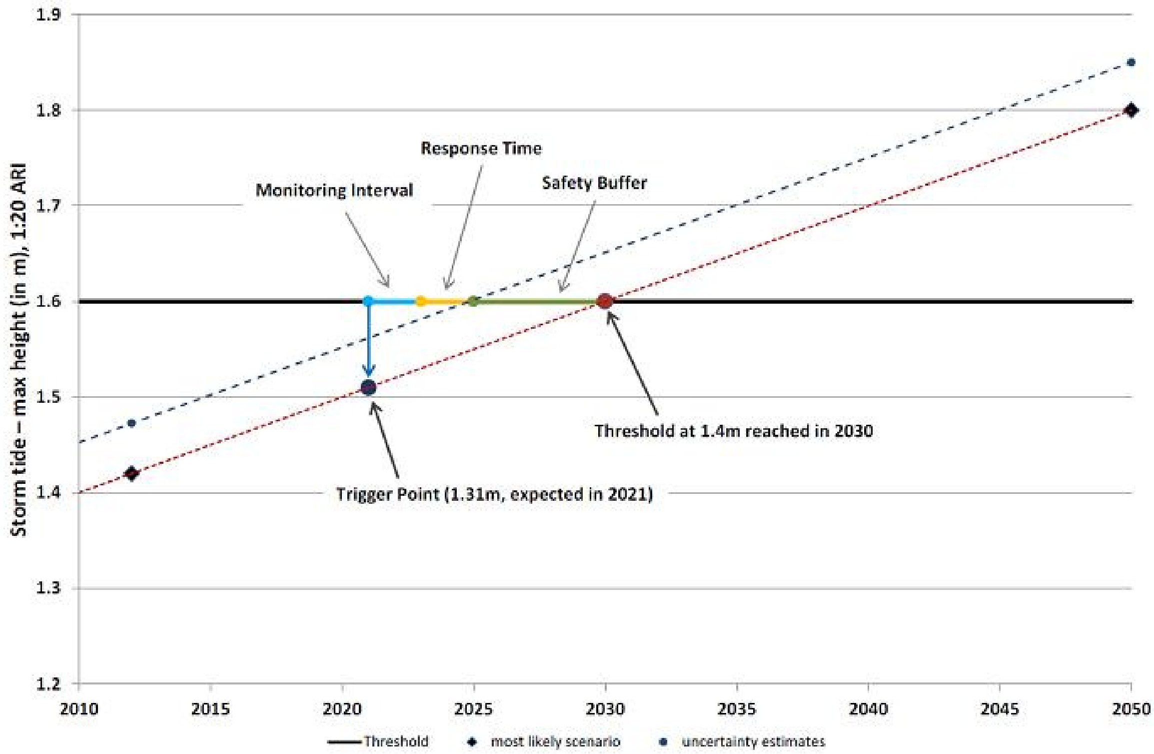

FIGURE 4: Example of the selection and timing for a trigger point for action to meet a risk threshold. Applying the same criteria to the stock of residential dwellings affected by sea level rise in lake Macquarie, the response time would be 200 years, assuming no intervention in the existing market (Marsden Jacobs, 2010)

Changes in existing settlements do not just depend on maintaining safe, liveable buildings. The settlements cannot function without working infrastructure – roads, drains, sewers, electricity lines, and parks. Urban infrastructure is part of a complex and inter-connected system. It is not possible to raise a large section of road, for example, without realigning the drainage system from the adjoining properties, their driveway access, footpaths, culverts and bridges, connecting roads and more. Like the example of residential housing stock, this lends itself to a program based on making adaptations – static or dynamic – at the time of maintenance or renewal, rather than in response to a biophysical trigger such as mean lake level or flood frequency.

Thresholds, triggers, and risk

The Lake Macquarie example, of the increased risk to dwellings from rising flood levels, is based on risk thresholds. The 1:100 year flood threshold, for example, is widely adopted in NSW as the level of acceptable risk for over-floor inundation of homes. These risk thresholds are based on very complex assumptions about social and economic acceptability, and different thresholds are used in other circumstances and jurisdictions. Drainage infrastructure, for example, is usually built to accommodate a 1:20 year flood threshold.

What may seem like very black-and-white thresholds or triggers – such as when sea levels increase by 0.4 metres, for example - are actually a proxy measure for a risk threshold. In some circumstances, such as a tidal gate built to deal with water up to a certain level, this threshold is relatively clear-cut. But for a decision about flood risk, for example, it is simply a point on a continuum of risk. On one side of the point there is a 1:101 year risk of over-floor flooding, and on the other side of the point there is a 1:99 year risk of over-floor flooding. Looked at in this way the threshold doesn't seem so clear-cut, especially if it is used to mandate disruptive and expensive change such as house raising, retreat, or re-building.

Practical issues in choosing triggers and thresholds

There is the problem of fixing suitable (measurable, acceptable, meaningful, and enforceable) physical triggers. For sea level rise some of the triggers that have been proposed are:

- Time limited consents (e.g. Wyong Shire Council). This trigger provides development consent for a limited time, based on the estimated time the asset will comply with risk thresholds. Of all the uncertainties associated with sea level rise and flooding, timing is the most uncertain, so its choice as a trigger seems unusual, and a very conservative response time may be required to allow for this uncertainty. The advantage is it gives certainty for the development within the allotted time, and allows future reassessment when the uncertainties are less. However, unless the building has in-built adaptive capacity, it begs the question, what to do when the risk is too great at the time of reassessment – abandon, or rebuild? Both options are expensive, and the uncertainty and possible loss of the asset affects the residents, owners, and lending institutions, among others.
- Erosion scarps for coastal erosion (e.g. Byron Bay Shire). This physical trigger, the proximity of the erosion scarp to a building, is based on predicted 1:100 year storm cut or something similar, and triggers the planned retreat of buildings. This relies on having buildings that are designed to be relocated quickly and cheaply. Experience of coastal planned retreat shows it has been difficult to enforce, with examples showing widespread resistance and non-compliance from owners.
- Flood event (e.g. Lake Macquarie Yacht Club). This trigger is based on the probability of a certain extreme event, in this case a 1:20 year flood. However, this could occur during construction, it may not occur for another 50 years. Although the chances of it occurring will increase as sea levels rise, it is still a chance event. If a larger event occurs it may result in over-floor flooding. The trigger could prove to be the threshold you are trying to avoid.

Conclusion

In effect, for most local government development decisions and infrastructure renewal, the adaptation decision will be made at the time of construction or renovation, with static adaptations to sea level rise built in at that time to manage the risk over the expected life of the asset. It is the strategic decisions – will re-development be allowed at all, or what type and scale of protections and adaptations are required – that will be based around threshold and triggers.

Adaptable buildings should be considered within a hierarchy of risk mitigation measures:

- Avoid the risk by planning to avoid new developments in high risk locations
- If redeveloping in existing settlements, ensure the redevelopment is situated on the lowest risk area of the available land through foreshore setbacks, for example
- Assess strategic planning issues such as long-term land capability and infrastructure provision, and the triggers that will prompt decisions for retreat or protection
- For new developments, include cheap and no-regrets risk-reduction measures (static adaptations) such as raised floor heights and flood-resistant building materials at the time of construction
- Use dynamic adaptation measures, tied to triggers and thresholds, if the risk from the increased hazard cannot be mitigated sufficiently using the measures above
- Use dynamic adaptation measures, in combination with static adaptations and the planning measures outlined above, to further reduce risk and increase the building's resilience to change and uncertainty

Perhaps the only truly adaptable building in areas affected by sea level rise is one that cuts its ties with all the fixed, complex, inter-connected land-based systems of urban settlement – the self- sustaining, energy generating, floating house of science fiction and final year architecture students. But they aren't yet permissible under the NSW Government's LEP template or the Lake Macquarie Development Control Plan.

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