An ocean of inundation – managing coastal floodplain inundation risks

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Abstract

Within a coastal floodplain affected predominantly by oceanic inundation due to coastal storm surge into an estuary, the mitigation of flood risk is a complex task, and the projected additional risks associated with sea level rise in coastal floodplain locations presents further management challenges.

In December 2009, Gosford City Council resolved to adopt a sea level rise planning level which was consistent with the NSW State Government's *Sea Level Rise Policy Statement* (DECCW, 2009). Council also determined it had a duty of care to advise existing and future property owners by encoding properties with a message under Section 149(5) of the NSW *Environmental Planning & Assessment Act* 1979.

The *Brisbane Water Foreshore Floodplain Risk Management Study* is currently in preparation by Cardno in partnership with Gosford City Council. As part of the study, the management techniques described in the *Floodplain Development Manual* (NSW Government, 2005) were combined with the sea level rise benchmarks set out by the NSW Government (DECCW, 2009) (a sea level rise of 0.9m by 2100). When completed, the management study will provide an approach to addressing infrequent ocean water levels (primarily as a result of storm surge) both for the existing scenario (no sea level rise) and the future scenario (0.9m sea level rise).

The foreshores of the Brisbane Water estuary vary in nature, however many areas are low-lying (below 4mAHD) and incorporate considerable urban development (primarily residential). A number of challenges are present for the floodplain, including the relative importance of the existing flood risk (no sea level rise) compared to the future flood risk (with sea level rise), and the distinction between infrequent high water level events associated with less frequent *coastal inundation* (oceanic flooding), compared to the more frequent *tidal inundation* that is projected to occur in the future (with sea level rise).

In consultation with the community and through careful consideration of the flooding processes and issues, a relative balance between addressing the existing flood risk and ensuring a level of preparedness for sea level rise can be achieved. It is important to note that this paper presents preliminary information only, and the *Brisbane Water Foreshore Floodplain Risk Management Study* document is not yet completed, nor has it been released into the public domain as yet.

This paper provides an overview of the learnings from a large-scale floodplain risk management study, with a community of over 6000 people affected and where regional development pressures are substantial (Cardno, *in preparation*).

Introduction

When considering flooding, the type of waterway and floodplain affected form the basis for the type of flooding issues experienced. In coastal locations, the flooding issues and management challenges presented differ from those experienced in non-coastal catchment locations. This variance is due not only to differences in flooding processes but also due to the added impacts of projected sea level rise in coastal locations.

The Brisbane Water estuary is a wave dominated barrier estuary and tidal tributary of the Lower Hawkesbury River system that is affected by coastal inundation (due to storm surge and ocean wave action that penetrates through the entrance). The estuary is located approximately 50km north of Sydney within the City of Gosford Local Government Area. Figure 1 provides a locality plan and visual representation of the study area. The estuary has a number of tributary creeks, which are the subject of separate but related floodplain management assessments.

Coastal inundation as result of elevated ocean and estuarine water levels is caused by events such as significant coastal waves and surges associated with large ocean storms. Coastal inundation is the major type of inundation affecting the foreshores of Brisbane Water (Cardno, 2009). Catchment flooding, where intense rainfall causes rising water levels, is dominant only in individual sub-catchments and tributaries of the main estuary.

In addition to the aforementioned flooding types (coastal inundation and catchment flooding) another inundation type that is likely to occur with projected sea level rise is that of frequent tidal inundation. As sea levels rise, so too will the upper limit of the tidal range, and as such, regular inundation during high tides and “king tides” is likely to impact on foreshore areas in the future.

In 2009, the NSW government released the *NSW State Policy on Sea Level Rise* (DECCW, 2009). This policy sets out sea level rise (SLR) benchmarks of 0.4m by 2050 and 0.9m by 2100, and acknowledges that projected increased sea levels are likely to have significant medium to long-term social, economic and environmental impacts. The compatibility of flood risk management techniques with such policies is integral in ensuring the consistent management and future planning of these areas.

This paper considers the complex nature of flooding of the Brisbane Water estuary foreshores and identifies a possible approach to the management of existing flood risk in addition to the management of, and adaptation to, projected sea level rise as a result of climate change. This approach could be adapted for other similar floodplains both in Australia and internationally.

Figure 1: Locality plan and study area

Historical events and existing and future flood risks

Cardno (2009) found that coastal inundation (oceanic flooding) is dominant for the majority of the Brisbane Water foreshore areas, i.e. severe ocean storms cause the highest water levels rather than catchment floods of the same average recurrence interval (ARI). The exception was found to be within Fagans Bay (just south of West Gosford, see Figure 1), which is dominated by catchment flooding in lower probability events. This is due to large catchment flows from Narara Creek and the local hydraulic control (the Main North railway bridge) which reduces the rate of discharge of catchment flows into the estuary.

Major historical flood events for the Brisbane Water foreshore include the severe ocean storm of 1974 and a more recent but less severe event in 2007 (when the Pasha Bulka ran aground off the coast of Newcastle). Past flooding of the Brisbane Water foreshore has caused property damage, impeded emergency access and inconvenienced residents.

Under existing conditions, numerous properties are at risk of coastal inundation, with approximately 1900 properties at risk in the existing 100 year ARI event, and 3000 properties at risk in the probable maximum flood (PMF) event. In some locations, existing high tides can cause inundation of the foreshores, especially "king" tides with joint occurrence of storm conditions.

Table 1 shows the number of properties of various types affected at various design ARIs under existing conditions.

Table 1: Number of properties affected by over-ground flooding - existing conditions (Cardno, in preparation)

Flood Event	Residential	Commercial	Industrial	Total
2 Year ARI	455	23	1	**479**
5 Year ARI	846	55	1	**902**
20 Year ARI	1341	87	2	**1430**
100 Year ARI	1792	114	4	**1910**
200 Year ARI	1965	122	5	**2092**
500 Year ARI	2334	141	7	**2482**
PMF	2765	160	9	**2934**

A greater number of properties are expected to be affected by coastal floodplain inundation under projected sea level rise conditions, with an additional 2000 properties (a total of nearly 5000 properties, see Table 2) affected under future conditions in the PMF event. Table 2 shows the number of properties of various types affected at various design ARIs under future conditions.

In addition, the population of the Brisbane Water foreshore is expanding, within continued growth anticipated (DoP, 2008). The social impacts of flooding may increase in the future due to projected population growth in addition to projected sea level rise unless appropriate management techniques are applied.

Table 2: Number of properties affected by over-ground flooding - future conditions (0.9 m SLR) (Cardno, in preparation)

Flood Event	Residential	Commercial	Industrial	Total
2 Year ARI	3394	188	9	**3591**
5 Year ARI	3625	197	13	**3835**
20 Year ARI	3863	205	14	**4082**
100 Year ARI	4109	215	19	**4343**
200 Year ARI	4239	218	21	**4478**
500 Year ARI	4379	221	27	**4627**
PMF	4619	246	32	**4897**

Figure 2 shows the extent of inundation for the existing 100 year ARI event and several events with sea level rise.

In addition to privately-owned dwellings and commercial and industrial properties, numerous private and public assets are affected by coastal inundation. Similarly, these impacts are likely to increase with sea level rise. Council has sought to consult with private asset managers (such as electricity, gas and telecommunications managers) during the course of the preparation of the Floodplain Risk Management Study with very limited responses, suggesting that asset managers may not be fully aware of the risks or do not wish to engage on the matter at this time. Future consultation with asset managers will be necessary to ascertain impacts on and management strategies for assets such as electricity, gas and telecommunications services, to ensure continuity of service for existing flood risks, or reconsideration of the location of assets that are potentially permanently inundated under sea level rise.

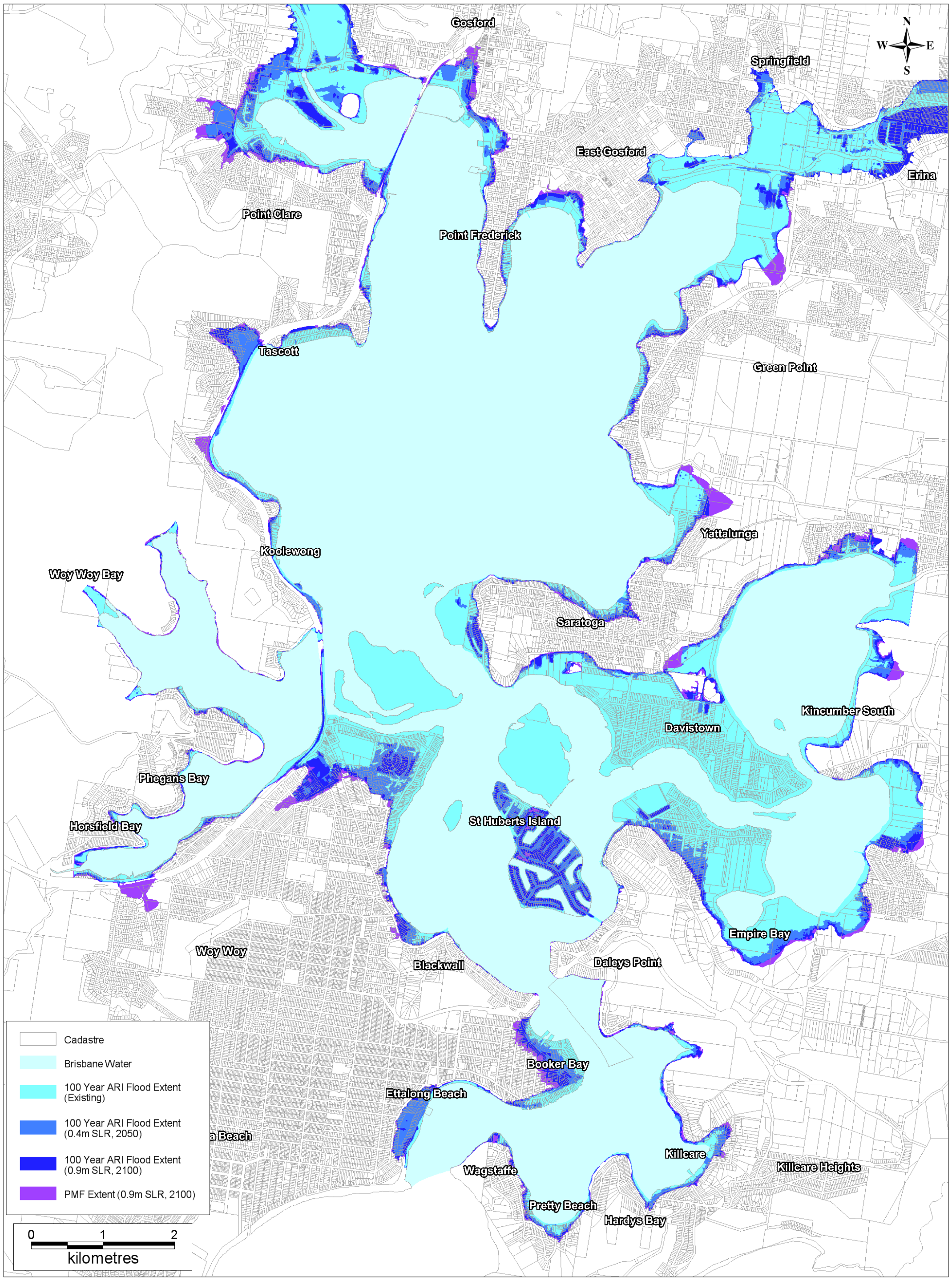

Figure 2: Extent of flood inundation – 100 year ARI event and PMF event

Management issues and flood risk

Based on the findings of the *Brisbane Water Foreshore Flood Study* (Cardno, 2009) and the flood risks identified above and associated economic consequences, complex flooding issues affecting the Brisbane Water foreshores were recognised. In floodplain risk management generally, the three types of risk (existing, future and continuing risk) are considered. In the case of Brisbane Water (and likely for any coastal location), additional flood risks were identified within the future risk category, due to potential impact of sea level rise. The key flooding processes that were identified as causing flood risk management issues in the floodplain are:

- Existing <u>coastal flood</u> inundation risk (infrequent likelihood, high water levels occurring under existing conditions, moderate consequences)
- Future <u>coastal flood</u> inundation risk (infrequent likelihood, high water levels occurring under future, sea level rise conditions, high consequences); and
- Future <u>tidal</u> inundation risk (more frequent likelihood, but with lower water levels than for coastal flood inundation occurring under future, sea level rise conditions, moderate consequences).

During the process of identifying flooding issues in Brisbane Water, it became apparent that the above flood processes were intertwined and somewhat difficult to separate out for the purposes of identifying and implementing appropriately prioritised flood risk management techniques. For example, options that provide protection against existing coastal inundation risk (no sea level rise) may also inherently provide protection against future tidal inundation risk (with sea level rise). This is simply because the water levels for future everyday tidal inundation may be lower than for existing infrequent flood events.

It was concluded that the existing flood risk to the area (i.e. 100 year ARI, no SLR) remains the primary concern, and that sea level rise, although still a very important issue, is not immediately endangering life or property and therefore has a lower priority in terms of risk management.

All properties including reserves that are subject to future tidal inundation will be considered in a separate *Climate Change Adaptation Plan*. Mitigation measures identified in the forthcoming *Floodplain Risk Management Plan* will need to complement adaption measures recognised in these plans and the *Coastal Zone Management Plan for the Brisbane Water Estuary*. The relationship between the *Floodplain Risk Management Plan* and the *Climate Change Adaptation Plan* is discussed further below.

Damages analysis

The flood damage assessment for Brisbane Water was undertaken for the existing case, the 0.9m sea level rise scenario (2100) and later for a number of flood risk management options that could be hydraulically modelled. The assessment was based on standard damage curves by the Office of Environment and Heritage (OEH),however, limitations were found in trying to assess the value of economic damages for the future scenario (with sea level rise) and subsequently compare the results to the assessment of existing case damages (no sea level rise). This is explained below.

The results of the damage assessment showed that the damages for the sea level rise scenario were highly influenced by the damages incurred in a 2 year ARI event (50% AEP). This influence was considered to be disproportionate because by 2100, most of those low lying properties being inundated would be inhabitable in their existing condition due to frequent inundation from increased tidal levels. In reality, these highly affected properties would have either undergone retreat or protection by 2100. Therefore, in 2100, the 2 year ARI damages would be likely to be much lower than the assessment result.

Despite this limitation, the 2100 economic damage calculations were still considered useful in identifying the scale of modification or retreat that would need to occur over the next 90 years to protect against these impacts.

Management options

Flood risk management measures provide an opportunity to reduce potential flood damage and personal danger, however with climate change included as driver within the document it was necessary to breakdown management options into two discrete themes, namely:

- Coastal inundation; and
- Tidal inundation.

Additional complexity is added when considering the effects of catchment flooding (overland flow). While a management solution may be appropriate for both coastal and tidal inundation, it may also increase the impacts of catchment-generated events. For example, a levee that provides protection from coastal inundation may not allow overland flows to be transmitted back to the estuary during a catchment flood event and may therefore worsen flooding overall. This is particularly relevant when both coastal inundation and catchment flood events occur simultaneously.

Following a multi-criteria matrix assessment, recommendations emerged based on a quadruple bottom line approach. The following section outlines the process developed within the study.

Coastal inundation risk management options

In consultation with government agencies and the Floodplain Risk Management Committee, along with community participation (through a survey of flooding issues), the process of identifying risk management options to address existing, future and continuing (residual) flood risk in the floodplain was undertaken:

- Existing risk – options to manage existing risk represent mostly flood modification (structural) options (e.g. levees) and some property modification options (e.g. voluntary house purchase). Once implemented, these options generally become effective immediately, however they are also likely to take a longer time to implement (especially when feasibility assessments are required).
- Future risk – options to manage the future risk of flooding (especially due to increased risk as a result of sea level rise) represent mostly property modification (PM) measures (e.g. updates to planning and development controls). Although property modification measures are generally able to be implemented in the short term, once implemented, these measures do not generally become effective immediately, but rather will become more and more effective over the medium to long term, such as when land use changes take place.
- Continuing (residual) risk – options to manage the residual risk of flooding represent mostly emergency response modification measures. These options are generally able to be implemented immediately and, once implemented, generally become effective immediately.

On this basis, a series of management options covering flood modification, property modification and emergency response were identified for the floodplain. Examples of coastal inundation risk management options included:

- Implementation of voluntary house purchase for identified properties;
- Implementation of voluntary house raising for identified dwellings;

- Investigation into a land swap program for properties that meet specified criteria with Council-owned land in non flood-prone areas (for example the approach adopted in Grantham in Queensland);
- Providing balanced and socially sensitive education to advise the local community about the risk and effects of inundation, placing an emphasis on specific groups or locations at risk;
- A review of planning instruments and development controls to ensure consistency with coastal inundation;
- A review of the *Gosford City Flood Plan* (Gosford LEMC, 2009) to incorporate coastal inundation;
- A review of flood warning systems;
- A review of evacuation centre locations and the nature of facilities available;
- Development of an alternative road route plan for use during evacuation.

Through careful consideration and use of decision making tools such as a multi-criteria matrix, each of the management options was prioritised on the basis of risk reduction. To further delineate the priority of each management strategy, options were also identified as having an implementation timeline of one of the following:

- Immediate – option can be implemented in the short term. Feasibility of the option is generally high and additional investigations or further development of the management strategy would be minimal.
- Staged – option can be undertaken in the short to medium term. However, additional investigations, feasibility studies or further development of the management strategy are likely to be required and a staged implementation approach is therefore more suitable. Where appropriate, interim policy and planning measures could be employed in the intervening time.
- Trigger – option should be undertaken over the long term. Further investigations are required to determine an appropriate trigger for implementation.

For options classified as “staged” or “trigger”, interim policy and planning measures (e.g. time-consent development and moratoriums on affected properties) could be employed. Gosford City Council is currently undertaking a pilot project that will provide further data to assist with the development of policy surrounding risk management triggers. Similarly for options classified as “staged” or “trigger”, implementation could be undertaken to address existing risk in the first instance, but over the medium to long term (as more information and/or trigger levels become available) could be modified to incorporate sea level rise. This concept particularly relates to large structural options. For example, a levee could be built in the short term to withstand the existing flood risk (no sea level rise), and once an appropriate trigger or trigger level had occurred, the levee could be raised to incorporate sea level rise (the levee footing and other elements would need to be designed appropriately at the outset in order for future levee-raising to succeed).

Sea level rise risk management options

Several options were identified that primarily address sea level rise processes but do not have great benefits for the management of flood risk in the existing scenario. These options generally scored lower in the multi-criteria matrix and most are unlikely to be recommended for implementation under the flood risk management process. However, since these issues have been identified, an approach to address these issues was sought. Rather than addressing sea level rise issues within the flood risk management process, to which they are somewhat removed, it was resolved to address issues primarily relating to sea level rise in a separate document. Although not yet produced, the document would aim to establish appropriate adaptation responses to climate change in accordance with Council and State Government policy. The *Climate Change Adaptation Plan* would assist in the investigation of appropriate sea level rise “trigger levels” and other trigger events that may be utilised to initiate a particular response or management option that relies on a particular trigger for implementation.

Examples of sea level rise risk management options included:

- A review of planning instruments and development controls to incorporate the impacts of predicted sea level rise;
- Continuation of sea level rise monitoring programs and the undertaking of periodic analyses to ascertain rates of rise in the estuary;
- Development of management strategies to adapt to the impacts of tidal inundation with sea level rise;
- A review of utilities infrastructure relative to projected sea level rise benchmarks to better understand the risks to public and private assets;
- Exploration of options for the construction of a large storm surge barrier at the entrance to the estuary or at the estuary constriction known as “The Rip”;
- Raising of railway infrastructure to accommodate sea level rise;
- Implementing managed retreat in critical areas to avoid the impacts of sea level rise.

Assessment of management options

Multi-criteria matrix

A lengthy assessment process using a multi-criteria matrix was undertaken to adequately analyse the costs and benefits of each identified management option in an economic, social, environmental and planning/governance context (also known as a quadruple bottom line assessment). This allowed the most suitable options to be ranked more highly and can subsequently be recommended for implementation in the Management Plan.

The use of criteria weightings in the multi-criteria matrix allowed management options having existing flood risk mitigation benefits to be more highly weighted than management options having sea level rise adaptation benefits. Several criteria in the multi-criteria matrix assessment were assessed for both the existing scenario and the future scenario, e.g. the criteria “reduction in risk to life (existing PMF)” and “reduction in risk to life (PMF event +0.9m SLR)” were scored separately, with the latter criteria being assigned a lower weighting. Management options benefiting both scenarios generally ranked more highly.

The integration of catchment and foreshore flood risk was also considered in the sense that an option likely to worsen catchment flooding was not considered appropriate for implementation.

Economic assessment

Using preliminary cost estimates for the implementation and maintenance costs associated with each option, an assessment of the reduction in average annual damage resulting from implementation of the proposed options was undertaken through the use of hydraulic modelling. Not all options identified could be hydraulically modelled.

In the process of assessing potential floodplain risk management options, it became apparent that assessing the potential for options to reduce flood damages would need to be based on both the existing and future (sea level rise) scenarios. Using only the existing scenario would not allow for the incorporation of projected sea level rise, whilst using only the future (sea level rise) scenario would provide a false sense of the value of an option – if the option did not provide any benefits until 0.4m of SLR has occurred then it should not have such a high priority because there is an existing flood risk that must be managed first. It therefore seemed appropriate to consider the reduction in damages in the existing scenario right through to the future (2100) scenario and it was therefore proposed that the net present value of the potential flood damages over the next 90 years would be calculated to allow for comparison of options. This methodology gave more weight to options which provided a reduction in existing average annual damage (AAD) rather than future.

Example management areas

Due to its large size, the Brisbane Water floodplain was broken down into a number of smaller "management areas". These areas were delineated to incorporate areas of similar flood impact characteristics. In addition to the previously described *coastal inundation risk management options* and *sea level rise risk management options*, a series of more site-specific management options were identified for each of the 15 management areas.

The following sections provide examples of three varying management areas, the nature of flooding within them, and some potential options for floodplain risk management.

Management area example 1 - Davistown

This management area can be affected by existing high tides, especially "king tides" with joint occurrence of storm conditions. A small seawall in place at the foreshore helps to protect against erosion and some higher water levels. However, even in higher probability ARI flood events, a large number of residential properties in Davistown are affected. Flat terrain in the area allows floodwaters to penetrate further inland. Tidal inundation with sea level rise is likely to have significant impacts on the area, particularly in the 0.9m SLR scenario. Figure 3 shows a schematised representative cross-section of the Davistown floodplain to demonstrate the issues experienced in this location. See Figure 1 for the location of Davistown in relation to the study area.

Potential management options for the Davistown management area include specific development and planning controls, road-raising, land-raising, levees and seawall maintenance.

Management area example 2 – Ettalong

This management area is not generally affected by high tides due to a small sand dune system (foredune) that extends along the foreshores. Residential properties are generally not affected in higher probability ARI flood events, however areas behind the foredune are lower-lying and may experience stormwater surcharges (upwelling) during flood events. Flood events with sea level rise would be likely to overtop the foredune. Projected tidal inundation with sea level rise would not overtop the dune but may cause stormwater surcharges. Figure 4 shows a schematised representative cross-section of the Ettalong floodplain to demonstrate the issues experienced in this location. See Figure 1 for the location of Ettalong in relation to the study area.

Potential management options for the Ettalong management area include tide flaps/gates on stormwater outlets, road-raising, land-raising and levees.

Management area example 3 – Gosford

The foreshore of this management area is predominately made up of a vertical concrete seawall. Although the seawall acts to provide some protection from higher probability ARI flood events, wave overtopping has occurred in the past during storm surge events. The seawall at its current height would serve to provide protection against regular tidal inundation with sea level rise, however flood events with sea level rise would be likely to overtop the seawall. Overall, existing flood conditions in this location are not generally as severe as in some other locations, however wave overtopping can occur. Figure 5 shows a schematised representative cross-section of the Gosford floodplain to demonstrate the issues experienced in this location. See Figure 1 for the location of Gosford in relation to the study area.

Potential management options for the Gosford management area include road-raising, land-raising (particularly for the area that is planned to be revitalised under the *Gosford City Masterplan* [GCC, 2010]), wave run-up dissipation devices, levees, seawall maintenance and the relocation of Gosford Primary School.

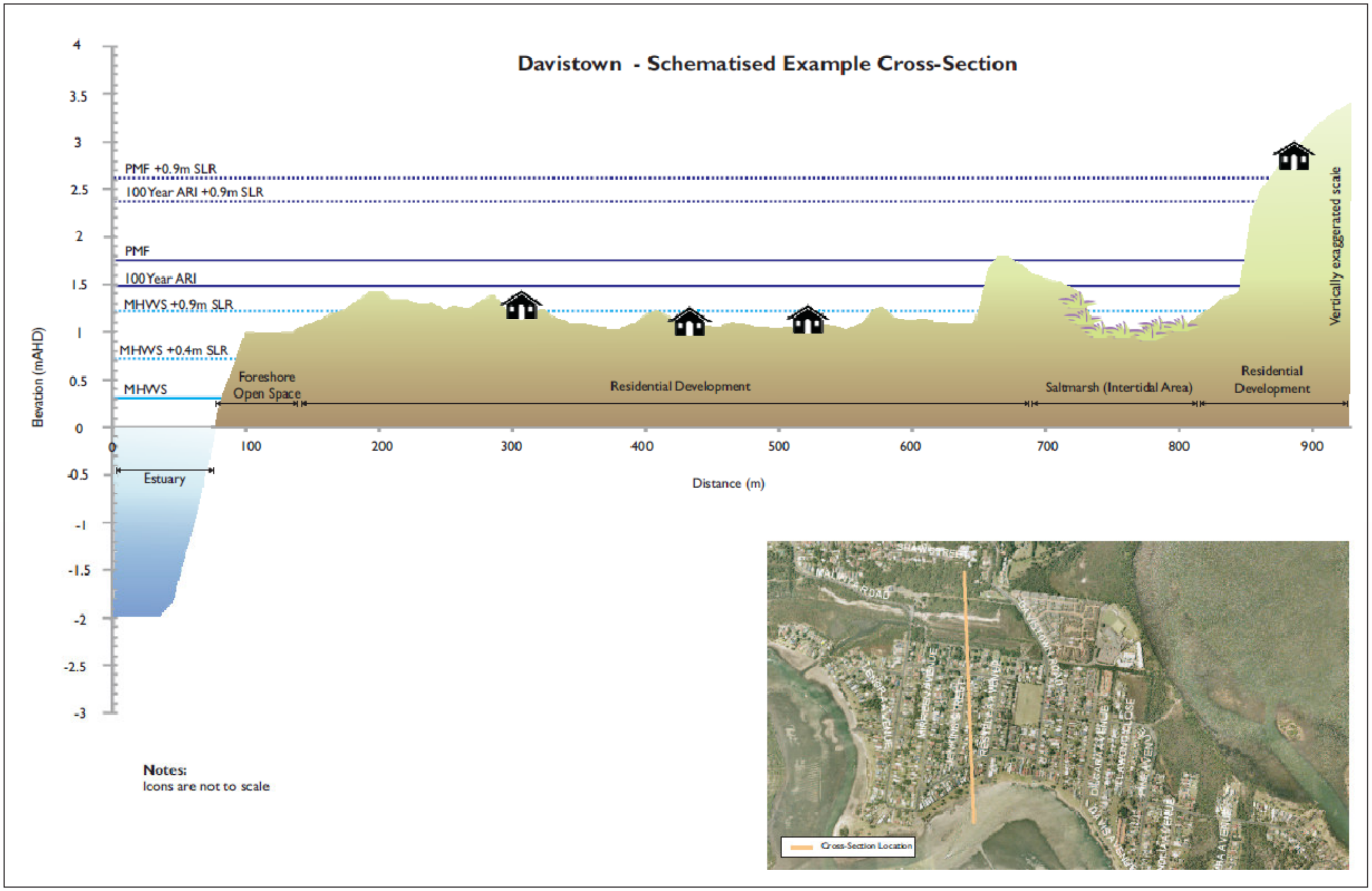

Figure 3: Schematised cross-section, Davistown

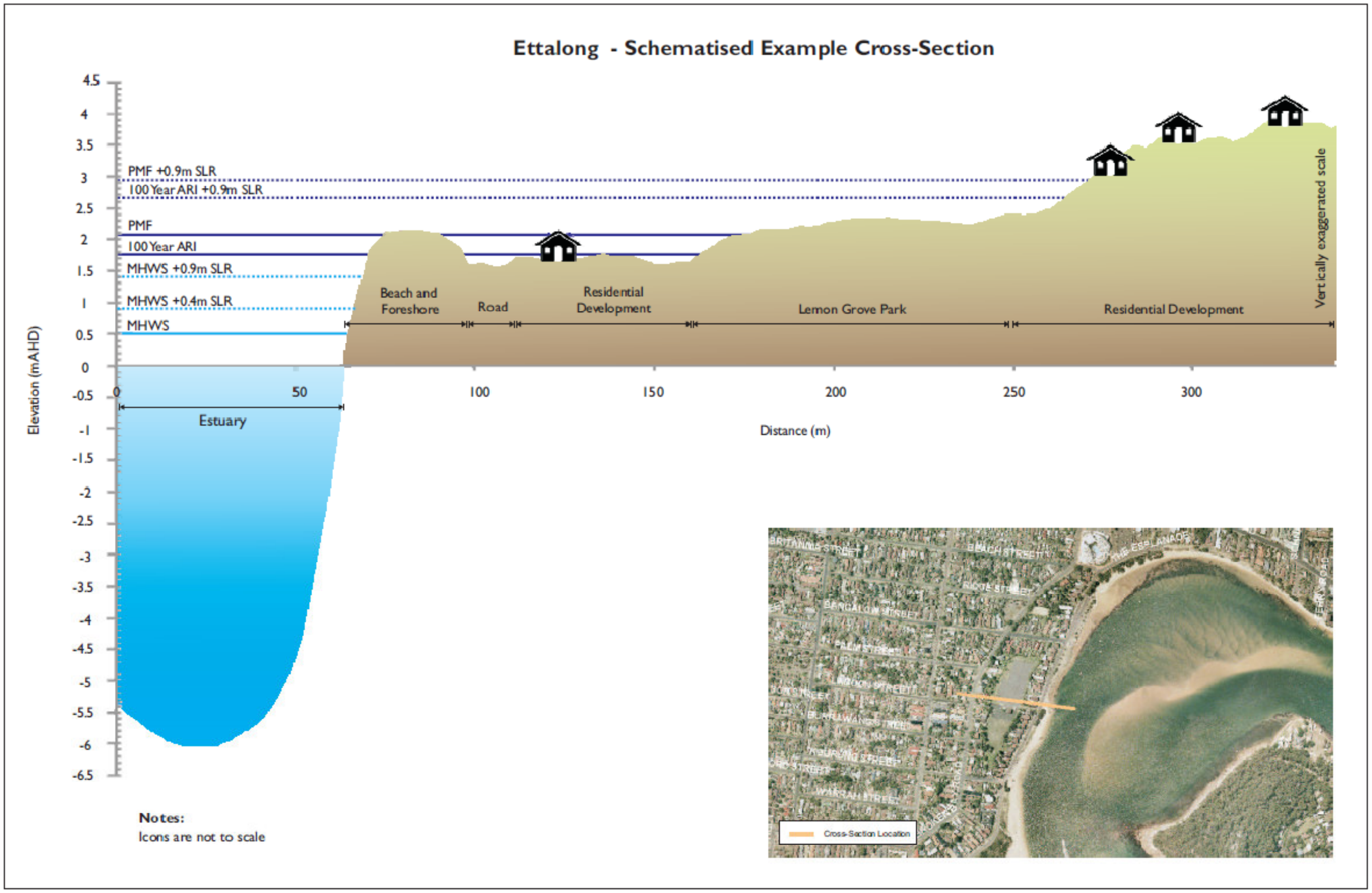

Figure 4: Schematised cross-section, Ettalong

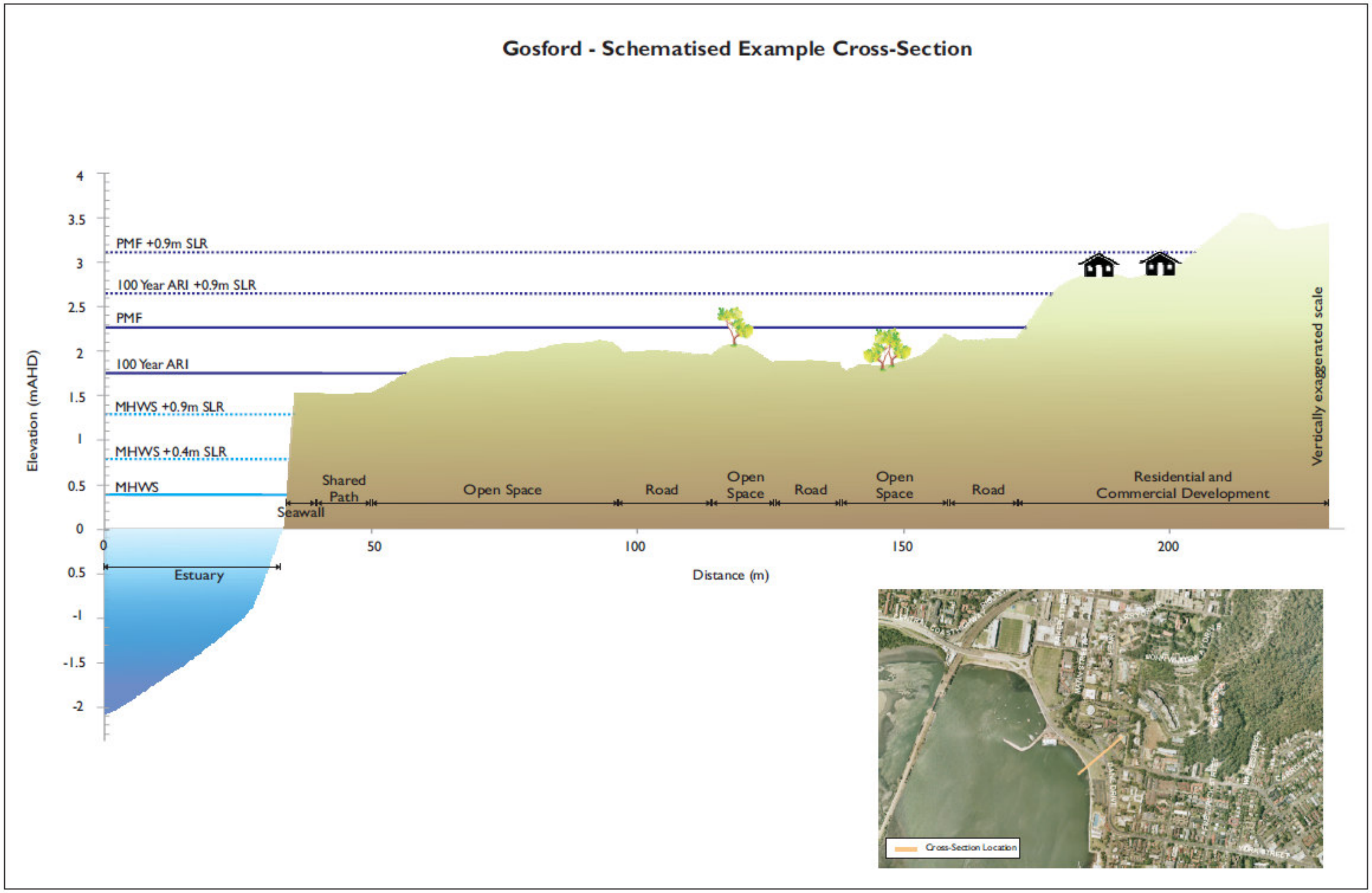

Figure 5: Schematised cross-section, Gosford

Highly ranked management options

Although the options assessment for the Brisbane Water floodplain has not yet been finalised, there are some key aspects of note. For the existing scenario, the implementation of management options that provide a large reduction in economic damages is generally not achievable within given social, environmental, feasibility and other constraints. In the assessment completed to date, those options which cause a reduction in risk to life generally ranked more highly, usually due to lower economic and environmental costs, in addition to reductions in risk. Generally, options that ranked more highly relate to emergency management and property modification.

For future flood risks, including those relating to sea level rise, highly ranking management options often related to planning measures and development controls that are likely to become effective over the long term. Structural management options did not generally rank very high in the options assessment, due primarily to economic, environmental or feasibility issues.

Although not finalised, recommended options for the Brisbane Water floodplain are most likely to be those options that initiate a reduction in *existing* flood risk, i.e. those options relating solely to sea level rise are unlikely to be recommended. However, in several cases, options that address existing risk also assist in reducing risks associated with sea level rise and so both aspects would therefore be addressed. As previously described, those options relating to sea level rise that are not recommended at this stage would be incorporated into the *Climate Change Adaptation Plan* and implemented where appropriate. These options could then be reviewed at a later stage in the planning process as additional information and sea level rise projections become available.

Conclusion

This paper sets out an approach to floodplain risk management that addresses both existing flood risk and secondarily the risks associated with projected sea level rise. This approach may be used as a basis for future studies and plans that have a requirement for addressing both the impacts of coastal inundation and future projected impacts of sea level rise. The identification of such management techniques covers responsibilities under the Floodplain Risk Management process, whilst the incorporation of a separate plan for climate change adaptation covers the issues surrounding sea level rise projections and in particular the more frequent, tidal-based inundation that is projected to take place in the future but that is not considered a “flood” event.

This paper presents preliminary information only, and the *Brisbane Water Foreshore Floodplain Risk Management Study* is not yet completed, nor has it been released into the public domain. Community engagement is an important aspect of the study and Council will need to consider the most appropriate manner in which to disseminate the results of the study once it has progressed further.

When completed (anticipated late 2012) the *Brisbane Water Foreshore Floodplain Risk Management Plan* will provide another incremental step in the challenge to adapt or manage existing or future flood risks.

Acknowledgements

The Brisbane Water Floodplain Risk Management Study and Plan project was funded under the NSW Floodplain Management Program jointly by the NSW Office of Environment and Heritage and Gosford City Council. In addition to the funding partners, numerous agency and community stakeholders have contributed to the study, including the State Emergency Service, the Department of Planning and Infrastructure, the Department of Primary Industries (NSW

Fisheries and Lands) and the Hunter Catchment Management Authority. The authors would also like to acknowledge the important contribution of the Floodplain Management Committee, who have met regularly to discuss the range of complex issues and contributed positively to the preparation of the Study.

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