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Flood Risk Management Guide

Incorporating sea level rise benchmarks in flood risk assessments

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Abbreviations

AEP	Annual exceedance probability
AHD	Australian Height Datum
ARI	Average recurrence interval
DECC	Department of Environment, Climate Change NSW
DECCW	Department of Environment, Climate Change and Water NSW
ICOLL	intermittently closed and open lakes and lagoon

1 Introduction

The NSW Sea Level Rise Policy Statement (NSW Government 2009) was prepared to support consistent adaptation to projected sea level rise impacts. The policy statement includes sea level rise planning benchmarks for use in assessing potential impacts of sea level rise in coastal areas, including in flood risk and coastal hazard assessment.

The benchmarks are a projected rise in sea level, relative to the 1990 mean sea level, of 0.4 metres by 2050 and 0.9 metres by 2100. The sea level rise planning benchmarks will be periodically reviewed if new information indicates change is required.

This guide has been prepared to assist local councils, the development industry and consultants to incorporate the sea level rise planning benchmarks in floodplain risk management planning and flood risk assessments for new development. The information in this guide updates the sea level rise information in the *NSW Floodplain Development Manual* (NSW Government 2005) and should be read in conjunction with the Manual.

This guide also updates the sea level rise section of the *Floodplain Risk Management Guideline: Practical Consideration of Climate Change* (DECC 2007). The 2007 guideline provides additional information relating to the management of the impacts of climate change on existing developed areas and on potential changes to flood-producing rainfall events caused by climate change.

The *NSW Coastal Planning Guideline – Adapting to Sea Level Rise* (Department of Planning 2010) provides detail about the consideration of this information in land-use planning and development assessment.

2 The impacts of sea level rise in areas vulnerable to flooding and tidal inundation

Sea level can have a significant impact upon the tidal range and flood levels in tidal waterways (Figure 2.1).

This influence usually diminishes with increasing distance upstream from the entrance of the waterway. Flood levels can be affected even in areas that are mostly separated from the ocean by outlet berms, such as intermittently closed and open lakes and lagoons (ICOLLs).

The Appendix to this guide provides advice and information on the setting and modelling of ocean boundary conditions for hydraulic flood modelling in tidal waterways.

Figure 2.1. Inundation during high tide at Carrington, near Newcastle (14 December 2008).

The degree of the impact of sea level rise will vary significantly with location and vulnerability to the impacts of sea level rise and may lead to:

- an increase in normal tidal depth and an increase in areas affected by inundation due to normal tidal fluctuations
- an increase in the frequency and duration of inundation in areas already affected by tides
- tidal influences occurring at higher elevations in tidal waterways and associated geomorphic and environmental impacts
- an increase in the duration, frequency and magnitude of coastal flooding and the levels reached by flood waters during these events
- a reduction in the capacity of drainage systems that discharge into tidal waters; this may lead to an increase in localised stormwater flooding and more water flowing overland rather than through drainage systems.

3 Where is sea level rise likely to impact on flood levels?

This guide applies to areas where the sea level rise planning benchmarks are likely to have an impact on predicted flood levels. This includes areas in the vicinity of tidal waterways, including ICOLLs. In particular, this is likely to apply if the land is:

- likely to be inundated if water levels are 1 metre above the upper limit of the current tidal range, which is usually defined by annual exceedance from local tidal records
- likely to be inundated if water levels are 1 metre above the current flood planning level in tidally affected waters
- within 1.5 metres of the maximum historic height of the entrance berm or the upper limit for management intervention identified in entrance management plans for any ocean entrance to the waterway which controls flooding (this commonly applies to ICOLLs)
- below 4 metres Australian Height Datum (AHD).

Major infrastructure crossings (road and rail bridges) often have a significant impact on flood levels and may represent the upper limit of the area that will be influenced by changes in sea level due to flooding. This needs to be assessed on a case by case basis because it depends upon the configuration and size of the structure relative to the crossing's waterway area.

The effects of sea level rise are influenced by the configuration and behaviour of a creek or river's entrance and will usually diminish with distance upstream of the entrance (Figure 3.1).

Figure 3.1. Bellingen River flooding at Mylestom (2009).

4 Projected changes to flood planning areas

Flood behaviour may have been identified in a flood study prepared as part of the floodplain risk management planning process described in the *NSW Floodplain Development Manual* (NSW Government 2005), or carried out on behalf of a developer for new urban development proposals. This may have involved the prediction of flood levels and mapping of flood extents, which usually correspond to the current 1% annual exceedance probability (AEP) or 1-in-100-year average recurrence interval flood. Additional mapping may have been prepared to define the flood planning area, which represents the extent of the residential flood planning level or the limit of the design flood (typically the 1% AEP event) plus an appropriate freeboard, such as 0.5 metres. Mapping may also identify areas affected by the probable maximum flood.

Sea level rise will increase flood levels and the areal extent of floodwaters over coastal floodplains. This effect usually diminishes with distance upstream from the coast and results in changes in the extent of flood planning areas, as illustrated in Figure 4.1. These changes cover the area between the current flood planning area, derived from a flood assessment excluding consideration of sea level rise, and the projected flood planning area for the relevant planning horizon.

Modelling of the projected flood planning area should be undertaken using the 2050 and 2100 sea level rise planning benchmarks and should be based upon the predicted extent of the 1% AEP flood level, incorporating the relevant sea level rise planning benchmark plus an appropriate freeboard (as used in the derivation of the flood planning level, such as 0.5 metres).

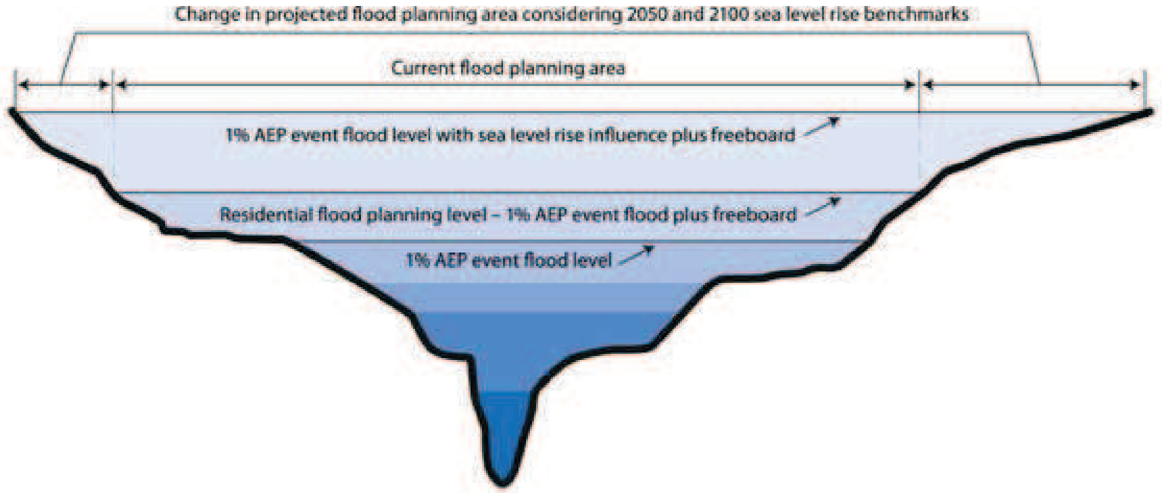

Figure 4.1. Flood levels, flood planning areas and the influence of the sea level rise benchmarks (cross-section view).

The typical 0.5 metre freeboard outlined in the *NSW Floodplain Development Manual* (NSW Government 2005) for general residential development provides a factor of safety to ensure that the risk exposure selected is accommodated. This freeboard includes a component related to climate change impacts on flood levels in coastal and non-coastal areas and a wide variation in sensitivity of estimated flood levels to flood flow. The freeboard provides a relatively small allowance to accommodate some of the projected increases in rainfall intensity from flood-producing storm events associated with climate change, which have currently not been accurately quantified. The manual's small allowance for climate change in the 0.5 metre freeboard figure should be considered to address only some of the uncertainty associated with estimating climate change impacts. Freeboard should not be used to allow for sea level rise impacts, instead these should be quantified and applied separately as shown in Figure 4.1.

The estimation of flood planning areas will usually involve extension of an existing floodplain risk management study and plan for a tidal waterway. This involves changing model parameters in consideration of the sea level rise planning benchmarks. These include increasing the ocean boundary conditions, whether static or dynamic and increasing initial water levels in tidal reaches by the sea level rise planning benchmark.

Specific local requirements may apply to these flood studies, including:

- key parameters to be used in the study (such as downstream boundary conditions and initial water levels) that may be influenced by sea level rise
- the use of appropriate flood models used in previous studies
- the availability of improved land surface elevation data, such as detailed ground or aerial laser survey
- the availability of new flood information
- allowances for the potential impact of climate change on flood producing rainfall events or antecedent catchment conditions.

Figure 4.2. Flooding in Coffs Harbour (2009).

Flood levels in tidal waterways are influenced by a combination of catchment and coastal flooding which can result from the same storm cell. The degree of influence of coastal flooding varies significantly with the type of ocean–waterway interface, the distance from the ocean boundary, the catchment, the floodplain and the location (Figures 4.3 and 4.4).

Therefore, flood studies need to account for the coincidence of catchment and coastal flooding and their varying influence with location in the tidal waterway in deriving flood levels and associated flood planning levels. This requires appropriate assumptions on downstream boundary conditions and initial water levels and examination of a number of combined catchment and coastal flooding scenarios. The Appendix to this guide provides advice on this assessment for a variety of classes of entrances and conditions. It is likely to be updated once the current update of *Australian Rainfall and Runoff* (Engineers Australia 1999) is completed.

Where flood modelling has been undertaken, it can be updated to include the sea level rise planning benchmarks or a conservative assumption can be made about sea level rise impacts. Where the site is below 4 metres AHD, an appropriate conservative assumption to estimate the 1% AEP flood level considering sea level rise is to add the sea level rise planning benchmarks to the 1% AEP flood level relevant to the site. Site-specific modelling should be undertaken to refine this approach where warranted, for example, where additional development controls would be applied as a result, and/or where the area was to be shown in a local environmental plan.

In such cases, the additional extent of flooding, beyond the current flood planning area, can then be determined based on the flood level (derived by incorporation of the sea level rise planning benchmarks) and freeboard.

In addition to the 1% AEP flood, the probable maximum flood should be modelled, including the effects of sea level rise, for emergency response planning purposes, and consideration in strategic planning for critical infrastructure, such as emergency care hospitals, and vulnerable developments, such as residential aged care facilities.

Figure 4.3. Flooding from the Richmond River at Coraki (January 2008).

5 References

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NSW Government (2005) *Floodplain development manual: the management of flood liable land*, published by the Department of Infrastructure, Planning and Natural Resources, Sydney.

NSW Government (2009) *NSW Sea level rise policy statement*, published by the Department of Environment, Climate Change and Water, Sydney.

6 Glossary

The majority of terms in the document are defined in the NSW Government's Floodplain Development Manual. Additional relevant terms are defined as indicated below.

ocean boundary conditions	The ocean water level(s) used as the downstream boundary level for hydraulic modelling for a flood study.
tidal waterways	The lower portions of coastal rivers, creeks, lakes, harbours, and ICOLLs affected by tidal fluctuations.

7 Appendix – Modelling the interaction of catchment and coastal flooding for different classes of tidal waterway

7.1 Introduction

Flooding in tidal waterways may occur due to a combination of ocean and catchment flooding derived from the same storm cell. The influence of flooding from these two sources on overall flood risk in these waterways varies significantly with location, distance from the ocean and with the level of ocean influence affected by the ocean entrance conditions.

This appendix provides interim advice on undertaking flood risk assessments in tidal waterways considering the coincidence of catchment and coastal flooding for the varied classes of waterways and likely ocean boundary conditions. This advice will be reviewed when *Australian Rainfall and Runoff* (Engineers Australia 1999) is updated to provide advice on the coincidence of catchment and ocean flooding or when other improved information is available.

The sophistication of approach in selecting downstream water-level boundary conditions and the entrance morphology modelling approach should be consistent with the exposure of the community to flood risk. This appendix provides advice on a range of approaches of different levels of sophistication, with more simplistic approaches incorporating a degree of conservatism in lieu of a more detailed and costly site-specific analysis. The appendix is structured on a series of decision points relating to entrance classification (section 7.2), entrance modelling approaches and assumptions (sections 7.3 and 7.4) and key information (sections 7.5–7.7) to be determined to allow for the assessment outlined in this guideline.

7.2 Entrance classifications for catchment and coastal flood coincidence

The influence of the ocean on flooding as well as the required modelling approach varies depending on entrance type for the tidal waterway, which can be classified as follows:

Class 1 – catchments that drain to a coastal lake (e.g. Lake Illawarra, Tuggerah Lakes)
Class 2 – catchments that drain directly to the ocean via trained or otherwise stable entrances (e.g. Port Jackson, Hunter River estuary)
Class 3 – catchments that drain directly to the ocean via shoaled entrances (e.g. Manning River, Shoalhaven River)
Class 4 – catchments with normally closed or partially blocked entrances (e.g. Lake Cathie).

For each entrance type, assessing the risk of flooding and determining flood planning areas requires a decision on the appropriate modelling approach for the ocean boundary conditions, including entrance configuration (section 7.3) and the selection of an appropriate ocean entrance boundary water-level condition (section 7.4).

Table 7.1 provides guidance for the determination of:

- the extent of existing tidal inundation (section 7.5)
- modelled envelope scenarios to determine flood planning levels and areas and flood hazard (section 7.6)
- the influence of sea level rise in tidal inundation extent and flood planning areas (section 7.7).

Table 7.1. Summary of typical ocean boundary conditions and modelling issues.

Class of entrance	Modelling approaches (section 7.3)	Considering entrance morphology (section 7.3)	Elevated water levels at the ocean boundary (section 7.4)	Modelling scenarios to determine a flood envelope (section 7.6)	Influence of sea level rise planning benchmarks (section 7.7)
Class 1 **Coastal lakes**	Use of steady and unsteady models may be suitable. Considerations other than entrance conditions will determine form of modelling.	Should be considered part of lake flood study. If the lake is modelled as part of this study refer to classes 2–4.	May be obtained from lake flood studies, otherwise the lake should be modelled as part of this study. In the latter case, refer to classes 2–4.	Determine peak flood levels using the 1% AEP catchment flood with adopted downstream boundary condition.	Should be assessed as changed ocean water level boundary and initial water level conditions as part of flood study for lake.
Class 2 **Trained or deep stable entrances**	Use of steady and unsteady models may be suitable. Considerations other than entrance conditions will determine form of modelling.	Not applicable.	Use Figure 7.1 (particularly conservative for these entrances) or undertake site-specific analysis.	Develop an upper envelope of effects from scenarios.	Should be assessed as changed ocean water level boundary conditions and initial water level in the waterway.
Class 3 **Shoaled entrances**	Use unsteady models.	See section 7.3.	Use Figure 7.1 or undertake site-specific analysis.	Develop an upper envelope of effects from scenarios.	Should be considered as changed shoaled, initial water level and changed ocean water level boundary conditions for the waterway.
Class 4 **Closed entrances**	Use unsteady models.	See section 7.3.	Use Figure 7.1 or undertake site-specific analysis.	Develop an upper envelope of effects from scenarios.	Should be considered as changed entrance conditions and initial water level conditions for the waterway.

7.3 Entrance morphology

Modelling of ocean-related boundary conditions needs to take into account entrance boundary geometry, and, in the case of entrance shoaling and scouring, dynamics and physical limits. Modelling would usually be conducted using one of the following approaches.

- A simple approach based upon a steady- or fixed-entrance condition. The entrance condition adopted needs to be conservative and account for potential variations. For unmanaged entrances, peak shoaled and scoured states need to be determined. This involves consideration of the current entrance geometry (confirmed by survey) and historic entrance configurations based upon the interpretation of historical aerial photos and other relevant information.

For managed entrances, the trigger level for management intervention under the entrance management policy will govern catchment flood levels. The policy's trigger level should have regard to prevailing entrance conditions (that is, degree of choking/shoaling). Modelling of the post-intervention geometry (that is, fully scoured opening) should also be carried out to estimate maximum flow velocities.

- A more sophisticated unsteady or dynamic modelling approach. The initial entrance geometry conditions would be based upon the steady state approach above. An understanding of the entrance dynamics and physical limits can be derived from:
  – A particular historical event, this may require alteration to the entrance configuration within realistic limits to match available calibration data
  – Peak shoaled and peak scoured states over time, peak shoaled condition will govern catchment flood levels whereas peak scoured condition will govern discharge velocities and the ingress of coastal flows
  – The limits of the potential dynamics, these include limits to vertical and lateral scour, including any headlands, rock shelfs or reefs known to exist in the locality. This is essential to appropriate modelling of the area rather than the use of arbitrary limits.
  For ICOLLs, a more sophisticated approach to breakout involves detailed modelling via a built-in dynamic scour model or by interfacing with a breach model to examine scouring. The dynamics of the situation may be complex; i.e. different conditions may dominate flooding at different times during an event and different starting conditions can govern peak flood levels and catchment flow velocities. Therefore, a number of runs may be required to develop upper boundary curves for flood levels and flow velocities.

7.4 Selection of appropriate ocean water level boundary approach

Elevated water levels at the ocean boundary can vary significantly with the class of entrance and the specifics of the location and can be costly to derive. The tiered approach to the selection of a downstream ocean water level boundary condition outlined below weighs up the degree of investigation required against the potential implications.

The first two approaches comprise components related to elevated ocean water levels, tidal anomalies and wave setup and can be considered conservative in some situations, particularly where these factors are reduced or negated by entrance conditions. The degree of conservatism is in lieu of a more sophisticated and costly site-specific analysis. The three levels of the tiered approach, in order of increasing sophistication are as follows.

- A conservative assumption for the elevated water level at the ocean boundary for a catchment that drains directly to the ocean (that is, does not drain into an ICOLL or tidal waterway). This involves adopting a 1% AEP ocean level of 2.6 metres AHD.

- Using the default dynamic open-ocean water level boundary condition (Figure 7.1) in modelling. In addition, if the timeframe for flooding at the location exceeds 36 hours, the ocean boundary condition provided in Figure 7.1 needs to be extended (see Figure 7.1 note) or a detailed site-specific analysis should be undertaken.

- A detailed site-specific analysis of elevated water levels at the ocean boundary at the entrance. This analysis should include all contributions to the ocean water level at the specific entrance, for example, tides, storm surge, shelf waves, wave setup and steric effects. Further, the analysis should be done in a manner which appropriately examines the probabilities of ocean conditions at the entrance, their potential variation (in terms of absolute ocean height as well as duration of the event where relevant) and their potential coincidence with catchment flooding. This provides information that is more directly relevant to a particular entrance. It also gives a further degree of sophistication and a potentially lower, less conservative answer.

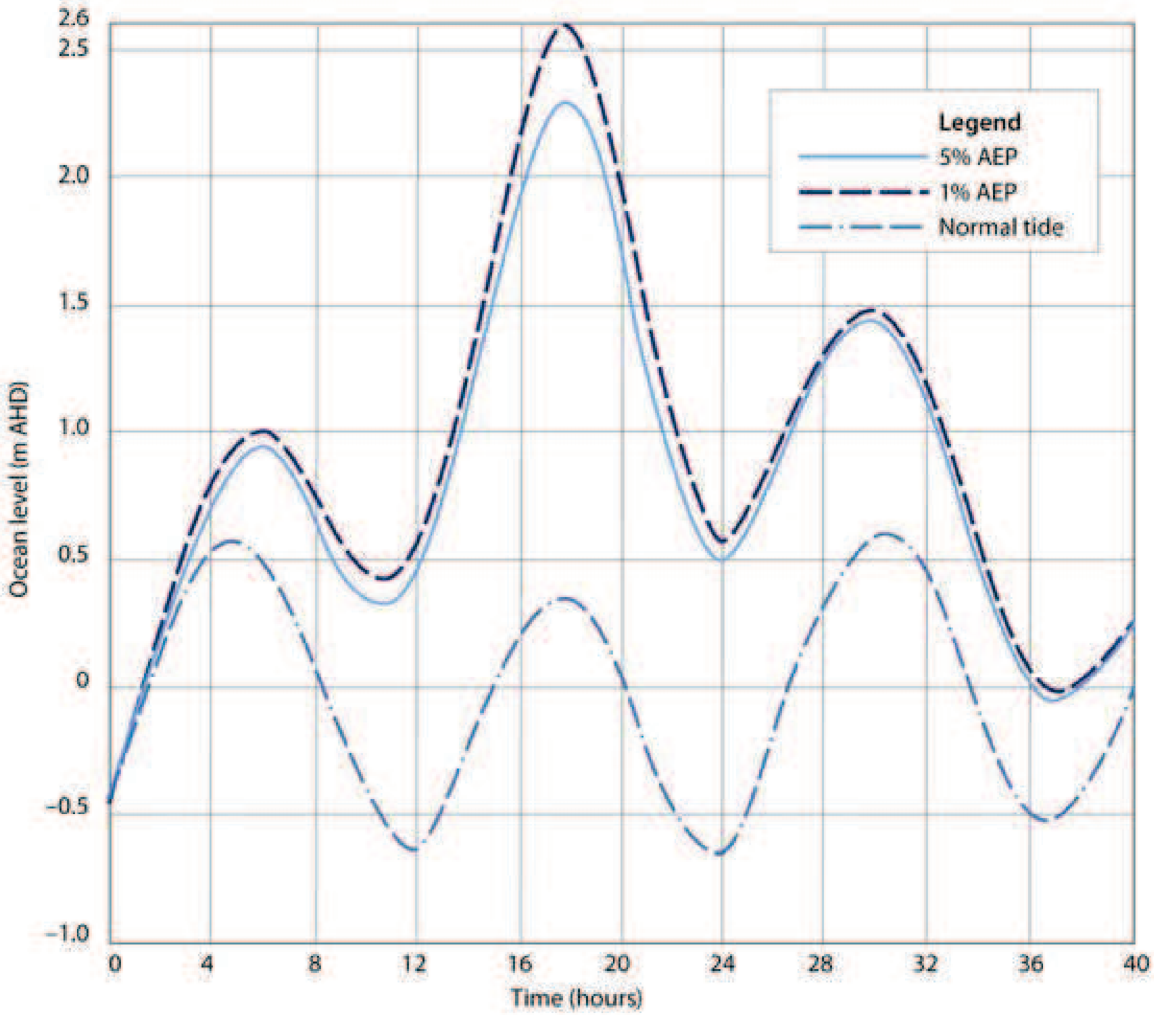

Figure 7.1. Default open-ocean elevated water level boundary condition.

Note: Where the length of flooding at a location exceeds 36 hours, a longer duration anomaly needs to be included. The duration of Figure 7.1 can be extended by 48 hours either side by adding an assumed anomaly of 0.4 metres on top of the normal tide cycle for the 1% and 5% AEP events for this assessment.

7.5 Extent of existing tidal inundation

Current tidal limits and extents resulting from normal ocean processes provide an understanding of current tidal penetration into tidal waterways. Normal ocean processes can be based upon different records for the different entrance morphologies as follows.

- open entrances – annual exceedance from local tide records
- unmanaged closed entrances – the berm height determined from historical records
- managed closed entrances – the trigger level for management intervention under the entrance management policy will govern catchment flood levels.

7.6 Envelope scenarios for determining flood planning levels and areas

Determining flood planning areas in tidal waterways requires consideration of the interaction of catchment and coastal flooding and requires the selection of peak flood levels and flow velocities from an envelope of scenarios such as:

- estimated 1% AEP ocean flooding with 5% AEP catchment flooding with coincident peaks
- estimated 5% AEP ocean flooding with 1% AEP catchment flooding with coincident peaks
- neap tide cycle with 1% AEP catchment flooding with coincident peaks.

These scenarios assume that initial water levels within a tidal waterway are based upon the peak tidal water level in the waterway (section 7.5) or the height of any controlling entrance outlet. They provide an envelope of peak levels and velocities that can be used to estimate the 1% AEP flood effects in the tidal waterway.

7.7 Influence of sea level rise on tidal extents and flood planning levels and areas

Any rise in sea level will result in a direct change to tidal levels and directly impact upon:

- ocean water level boundary conditions
- ocean entrance configurations including geomorphology
- initial water level conditions in the tidal waterway.

This will result in increased extents of tidal inundation and changes to flood levels in tidal waterways.

To assess the impacts of sea level rise, the benchmarks outlined in the *NSW Government Sea Level Rise Policy Statement* (NSW Government 2009) need to be added directly to:

- the ocean water level boundary conditions
- the starting conditions and dynamics for entrance configurations
- initial water level conditions in the tidal waterway.

The extent of tidal inundation (section 7.5) as well as flood planning levels and areas determined using the envelope approach (section 7.6) need to be determined for 2050 and 2100 considering sea level rise planning benchmarks.

7.8 Conclusion

The above guidance is intended to provide a structured approach to ensure adequate consideration of the interaction between catchment and coastal flooding for different classes of tidal waterways. The decision points in each section should be followed sequentially. This will ensure that, where a conservative approach is required and site-specific modelling is limited, an assumption can be made on a uniform basis. Conversely, where information is available to undertake a more sophisticated modelling approach, guidance is provided on consideration of site-specific characteristics. The most appropriate conditions for determining the interactions between catchment and coastal flooding should be based on expert knowledge and acknowledging that the class of waterway fundamentally affects the type of interactions expected.