DEVELOPMENT OF PRACTICAL GUIDANCE FOR COINCIDENCE OF CATCHMENT FLOODING AND OCEANIC INUNDATION

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Abstract

The interaction of catchment flooding and coastal processes is an important consideration in determining flood risk in coastal waterways. This interaction is often complex and may vary due to a number of factors.

Coastal processes can significantly impact flooding in the lower reaches of estuaries in two main ways:

- Ocean Levels: variations in ocean level, primarily due to tidal fluctuations and meteorological events, can influence the water level gradient and rate of discharge to the ocean, and / or the filling of available storage within the waterway which can affect flood levels in an estuary.
- Morphological: entrance water depth and morphology can significantly influence tidal behaviour and discharge through the estuary entrance. Sediment accumulation can constrict entrances and / or result in entrance closure by the development of entrance berms that can act as a downstream control, limiting discharge to the ocean and raising upstream flood levels.

Many of the factors that contribute to ocean water levels are independent of rainfall; however, elevated ocean levels and catchment driven flooding can originate from the same meteorological event affecting both ocean levels at the estuary entrance and rainfall within the catchment. The degree of influence of flooding from these two sources varies significantly with the relative timing of the peaks of these events and the characteristics of the catchment, coastal waterway and floodplain.

A number of key factors need to be considered when determining the overall flood risk and subsequent planning and management measures in the lower reaches of coastal waterways. These include the distance from the ocean, the site elevation, the ocean entrance condition as well as the size and shape of the catchment draining to the ocean.

This paper outlines a methodology for practical consideration of the coincidence of ocean inundation and catchment flooding recommended for use in flood studies undertaken in coastal waterways in NSW and discusses the work involved in its derivation. The information and approaches outlined in this paper are being used by OEH in developing guidance in this area to provide practical advice on the interaction of elevated ocean levels and catchment flooding for use in studies undertaken under the State Floodplain Management Program.

Introduction

Available literature and data records show that historically, significant flooding in NSW coastal catchments has occurred both from intense rainfall events over coastal river and lake catchments, and also from elevated ocean levels pushing landward through estuary entrances to inundate the lower lying foreshores and floodplain areas.

Data sets recorded for NSW estuaries over the last 30 years or so with the requisite accuracy and frequency to conduct reliable joint probability analyses, show that these catchment and oceanic flood drivers have not overlapped significantly in any large recent flood event (MHL 2013). However, several studies (including WRL 2012) have identified that the synoptic storm types critical to the generation of extreme wave and water level conditions offshore along the NSW coast are of the same synoptic type as those identified as contributing to heavy rainfall events in coastal catchments. Notably, synoptic systems such as the east coast low of the '*Pasha Bulker*' storm that generated significant flooding off the NSW central coast in 2007 and other east coast lows as well as ex-tropical cyclone systems that develop within subtropical easterly wind regimes are associated both with heavy rainfall and elevated ocean conditions. Recent work conducted as part of the review of Australian Rainfall and Runoff (Zheng *et al*., 2014) has demonstrated a statistical dependence of rainfall and storm surge for many areas of the Australian coastline, including NSW, although more work is needed before the same conclusion could be drawn for catchment runoff and storm surge.

Given the close association of both oceanic inundation and catchment flooding drivers with the same synoptic storm types, a precautionary approach is required to account for the potential joint occurrence of these drivers for flood levels in design flood analysis.

The influence of these drivers on flood risk in coastal waterways will vary with a range of factors, which include:

- The hydrodynamics of the waterway entrance and the associated degree of ocean influence within the coastal waterway.

  The propagation of ocean water levels into an estuary can be significantly altered by the complex hydrodynamics that occur in estuary entrances.

  Tidal ranges in estuaries can differ greatly and are significantly influenced by the characteristics that contribute to the shape and volume of the estuary. In particular, the length and degree of shoaling in an ocean entrance can have a significant influence on the tidal prism (volume of tidal flow exchange). The tidal range and tidal planes in an estuary are indicative of the degree that an ocean generated anomaly is likely to propagate into an estuary and are unique to each estuary.

  The entrance type varies with entrance morphology and condition. This can vary overtime due to the natural deposition (often by wave action) and scour of sediments (often due to catchment flows or freshes) in the vicinity of the entrance.

  Flood levels in the estuary are often influenced by the entrance condition, and in some cases, such as intermittently open and closed lakes and lagoons (ICOLLS), can be significantly controlled by an entrance berm.

  The condition of the waterway entrance can be influenced by human interventions such as modifications to entrances and management activities around the entrance. These include the development and implementation of entrance management plans aimed at maintaining water quality within set parameters or reducing the potential influence of flooding on development in the vicinity of the waterway.

- The variability of ocean influences along the NSW coastline and at a specific entrance.

  Still water levels and tidal levels vary, with northern NSW around 0.1m higher than southern NSW.

  The influence of wave set-up on entrances varies with the specifics of the entrance. Where estuary entrances are shallow, the impact of coincident ocean waves may increase wave set-up to elevations that are potentially significant to design and planning.

- The timing and duration of elevated ocean water levels and catchment floods is important when assessing design flood levels in estuaries. The duration of elevated ocean level adopted for design can influence peak estuary levels where the estuary volume is large.

- The distance upstream from the ocean is to a particular location of interest for an investigation. In general, as this distance increases the influence of the ocean on flood risk will decrease.

Development of Guidance

The floodplain risk management process outlined in the *Floodplain Development Manual* (FDM 2005) and the financial and technical assistance from the State Floodplain Management Program and OEH respectively provides an opportunity for local councils to understand the interaction of catchment flooding with oceanic inundation as well as examine and decide upon options to manage the associated flood risks to existing and future development.

The FDM 2005 provides the basis for setting flood planning levels, assessing and managing the impacts of development on flood behaviour and addressing broader floodplain risk management issues. It does not however, provide detailed advice on developing an understanding of the interaction of oceanic inundation and catchment flooding. Advice is provided in Appendix A of *Flood Risk Management Guide: Incorporating Sea Level Rise Benchmarks in Flood Risk Assessments* by the NSW Government (DECCW, 2010). However, this advice was limited due to the information available.

OEH identified the need for improved and more specific advice in this area and sought funding partners to support the development of guidance. Funds from the Commonwealth and State funded Natural Disaster Resilience Grants Scheme (NDRGS) have been allocated to this work. The NDRGS is managed by the Ministry of Police and Emergency Services with Commonwealth financial support being provided through the Attorney General's Department of the Australian Government.

The funding has been used to inform the development of guidance specifically aimed at providing a practical, robust and cost effective way of deriving ocean water level boundary conditions for use in flood investigations and advice on how to use this information in deriving design flood levels. The project involved work by Manly Hydraulics Laboratory and the University of New South Wales Water Research Laboratory, for OEH as discussed below:

- Manly Hydraulics Laboratory (MHL 2012a, Report No MHL2135) examined what could be learnt by examining the available data from NSW coastal and water level gauges. This formed Stage 1 of this project.

  This involved a broad analysis to identify waterways with different entrance types to investigate further based upon available data and occurrence of catchment flood events. The project was limited by the length of available data and the lack of significant events within this period. Observations and conclusions derived from this study are based on data sets characterised by the few large floods captured in the record and therefore should not be considered as definitive, rather this can be used primarily to inform further research. A summary of the relevant general findings of this report are as follows:

  - There is some evident level of coincidence between catchment flooding and ocean anomalies (exceeding the 1 year ARI). Some level of coincidence between the timing of catchment floods and ocean anomalies is also evident.
  - The analysed coastal lakes and lagoons generally show the highest level of coincidence between flooding and large ocean anomalies, and the strongest coincidence between the timing of floods and ocean anomalies. Catchments of coastal lakes and lagoons are often predominantly in the coastal area and therefore more likely to be influenced by the same type of synoptic event that influences ocean anomalies.
  - The analysed river systems show a lower level of coincidence between flooding and large ocean anomalies, and a lower coincidence between the timing of floods and ocean anomalies. Catchments from coastal rivers are generally relatively large and extend away from the coast. Therefore, even where the same synoptic type of event may result in ocean anomalies the effects of these on the lower coastal waterway may have dissipated before significant catchment flooding reaches these areas.
  - The analysed coastal creek and tributary creeks within lakes showed a lower level of coincidence between flooding and large ocean anomalies, and a lower coincidence between the timing of floods and ocean anomalies. Significant flooding within these systems often occurs due to short duration storms, which often do not result in ocean anomalies.
  - Based on the limited flood data and number of systems analysed, and considering the variation of other important characteristics between analysed systems, it is difficult to draw conclusions on the role of geographic location in observed levels of coincidence.
  - Furthermore, relative quantification of coincidence levels and comparisons between estuaries is complicated by the variation in water level records available for each estuary in terms of the differing length of record, number of floods on record and significance of the recorded flood magnitudes.

- University of New South Wales Water Research Laboratory (WRL 2013, WRL Technical report 2013/16) examined the findings of stage 1, reviewed the availability of additional historical data, undertook an international literature review, and examined the differences in NSW estuary classification to provide recommendations on improving guidance. This formed stage 2 of the project.

  The report consolidated all relevant available information on flooding in NSW estuaries and made pragmatic recommendations for the combination of ocean driven and catchment driven flooding mechanisms for design purposes. Key findings of this report are as follows:

- The search of recent and available local and international literature on the joint occurrence of ocean and catchment flood drivers revealed that, while there has been some progress made on statistical techniques for joint occurrence, the application of these techniques to suitable recent NSW data sets showed little basis for changing the combinations of catchment flood and ocean water level for design applications from previous advice.
- Tidal records for Fort Denison (which exist from 1870 to the present) were analysed over the 140 year record. This record includes large ocean anomaly events such as the May 1974 and April 1990 storm events. This data provides a sound basis for estimating design elevated ocean levels.
- Entrances can be classified based upon available information and this can be used to assess the likely influence of an estuary entrance on the propagation of design ocean levels inland to inform coincidence of coast and catchment flooding for flood studies in NSW.
- The potential for wave set-up to be an issue at an estuary entrance can be assessed and can be used in setting appropriate ocean boundary water levels for flood studies in NSW.
- The timing and duration of elevated ocean water levels and catchment floods is important when assessing design flood levels in estuaries. While no clear statistical analysis of elevated ocean water level duration is available, the use of the ocean water level time series based on the record May 1974 storm at Fort Denison, factored to meet design peak ocean levels was recommended.

The advice provided by this work is being used by OEH to develop guidance which once finalised and released, will replace Appendix A of *Flood Risk Management Guide: Incorporating Sea Level Rise Benchmarks in Flood Risk Assessments* by the NSW Government (DECCW, 2010).

The intention is to develop separate guidance to replace the main body of the original DECCW 2010 guideline on incorporating sea level rise into flood risk assessments as part of the current coastal reforms. This is beyond the scope of this paper.

Since the completion of the MHL and WRL work, a paper presented by Zheng et al (2014) examined the coincidence of ocean anomalies and rainfall events. Whilst the OEH work focuses on the coincidence of ocean anomalies and flooding, the work by Zheng is considered in approaches in this paper.

Development of guidance on Modelling the Interaction of Catchment Flooding and Oceanic Inundation in Coastal Waterways

The intent of the guidance is to provide advice on understanding flood behaviour in coastal waterways considering the interaction of catchment flooding and oceanic inundation for the various classes of coastal waterways found in NSW and likely corresponding ocean boundary conditions. It aims to provide essential information on the interaction of catchment flooding and oceanic inundation to enable effective consideration in decision making. This paper discusses the key steps (as shown in Table 1) to be followed when developing the required flood information.

Table 1 Typical Ocean Boundary Conditions and Modelling Considerations

		Methodology			
Waterway Entrance Type	**Selected Modelling Approach**	**Entrance Condition & Management**	**Modelling the Ocean Water Level Boundary**	**Relative timing of catchment flooding and oceanic inundation**	**Determining design flood levels**
A Table 2	**Simplistic**	Not Applicable	Steady state ocean water level boundary (Table 4)	Peak catchment flood level with static ocean boundary	Only 1% and extreme
	General	Not Applicable	• Dynamic ocean water level boundary (Table 4) • Dynamic neap tide and HHWS	Peak Catchment coincident with ocean boundary	See Table 5
	Detailed	Not Applicable			
B Table 2	**Simplistic**	• Identify peak shoaled entrance condition from previous estuary / coastal study or historical analysis • Consider current entrance geometry (confirm by survey)	Steady state ocean boundary level (Table 4)	Peak catchment flood level with static ocean boundary	Only 1% and extreme
	General	• Identify peak shoaled entrance condition from previous estuary / coastal study or historical analysis • Consider current entrance geometry (confirm by survey) • Consider dynamic morphology of entrance	• Dynamic ocean water level boundary (Table 4) • Dynamic neap tide and HHWS	Peak catchment flooding coincident with ocean boundary	See Table 5
	Detailed		• Dynamic ocean water level boundary (Table 4) • Local site specific analysis of wave setup at entrance to estuary for each ocean scenario conducted by suitably qualified coastal engineer • Apply wave setup to dynamic still ocean water level • Dynamic neap tide and HHWS		
C Table 2	**Simplistic**	• Identify peak shoaled entrance condition from previous estuary / coastal study or historical analysis • Consider current entrance geometry (confirm by survey) • Consider whether there is a trigger level for mechanical intervention under entrance management policy	Static, steady state ocean boundary (Table 4)	Peak catchment flood level with static ocean boundary	Only 1% and extreme
	General	• Identify peak shoaled entrance condition from previous estuary / coastal study or historical analysis • Consider current entrance geometry (confirm by survey) • Consider whether there is a trigger level for mechanical intervention under entrance management policy • Consider dynamic morphology of entrance	• Dynamic ocean water level boundary (Table 4) • Dynamic neap tide and HHWS	Peak catchment flooding coincident with ocean boundary	See Table 5
	Detailed	• Identify peak shoaled entrance condition from previous estuary / coastal study or historical analysis • Consider current entrance geometry (confirm by survey) • Consider whether there is a trigger level for mechanical intervention under entrance management policy • Consider dynamic morphology of entrance	• Dynamic ocean water level boundary (Table 4) • Local site specific analysis of wave setup at entrance to estuary for each ocean scenario conducted by suitably qualified coastal engineer • Apply wave setup to dynamic still ocean water level • Dynamic neap tide and HHWS		

Gathering and Reviewing Available Information

The initial step in any investigations into flood behaviour in tidal waterways should start by determining the available information. This may include: historical information and available studies on flooding, oceanic inundation and entrance condition, available survey information on the waterway and entrance and any waterway structures likely to impact upon flood behaviour, advice on any management strategy such as that for an entrance berm.

Waterway Entrance Type

The 'Estuaries of NSW' website (http://www.environment.nsw.gov.au/estuaries/list.htm) lists all NSW Estuaries and gives them a classification based on the work of Roy *et al.* (2001). The five groups are:

- *Group 1 Oceanic Embayments* - marine waters with little influence of freshwater inflow, e.g. Botany Bay, Jervis Bay;
- *Group 2 Tide Dominated Estuaries* - large, deep entrances with tidal ranges similar to the open ocean, also known as 'drowned river valleys', e.g. Port Stephens, the Hawkesbury River;
- *Group 3 Wave Dominated Estuaries* - entrances that are constricted by wave-deposited beach sand and flood-tidal deltas, but are permanently open, e.g. Tweed River, Lake Illawarra. Within this group there is significant variation based upon whether the waterway discharges into a bay, port or harbour, whether the entrance is trained (and the degree of training and stability), the relative size of the entrance and potential for the entrance to shoal.
- *Group 4 Intermittently Closed Estuaries* - also known as intermittently closed and open lakes and lagoons, ICOLLs. These are coastal water bodies that become isolated from the sea for extended periods, e.g. Dee Why Lagoon, Lake Conjola; and
- *Group 5 Freshwater Bodies* coastal water bodies that rarely, if ever, are brackish but have occasional connection to the ocean, e.g. Cudgen Lake, Myall Lakes. These are outside the scope of this approach and the lakes should be examined as part of specific investigations for these locations.

The influence of the ocean characteristics on water levels within estuaries can be simplified from the *Roy et al* (2001) classification in determining the waterway entrance type as described in Table 2.

These waterway entrance types form the basis of identifying the potential influence of ocean levels at a given estuary on flood characteristics.

Table 2 – Simplified Waterway Entrance Types

Waterway Entrance Type A	Waterway Entrance Type B	Waterway Entrance Type C
all ***Group 1*** open oceanic embayment all ***Group 2*** tide dominated estuaries ***Group 3*** estuaries: • draining directly to the ocean which have trained entrances and are maintained as navigable ports (e.g. Newcastle Harbour), excludes entrances maintained for small boat craft. • with trained entrances which drain to bays including the Brisbane Water, Tilligerry Creek and Cullendulla Creek. These entrances result in little ocean tide attenuation and negligible wave set-up. These entrances result in little ocean tide attenuation and negligible wave set-up.	***Group 3*** estuaries with fully (both sides of entrance) trained entrances which are not maintained as navigable ports. These entrances result in little ocean tide attenuation but have some potential for wave setup	***Group 4*** Intermittently Closed Estuaries or ICOLLS ***Group 3*** estuaries with untrained or partially trained entrances which are likely to have very shallow flow depths across the entrance or may fully close from time to time. In these cases discharge to the ocean will be controlled by outlet berm characteristics (height, width and breadth). Design flood assessment for this classification needs to take into account the berm history and any entrance berm management strategy. The ocean boundary condition determined for the entrance type and approach (see Section 5) should be used as a downstream boundary for modelling, which should start at an appropriate location downstream of the controlling berm

Note: there are some estuaries that have not been classified under the work of *Roy et al* (2001). In this case, a conservative approach should be taken to deciding upon a waterway entrance type (i.e. use a type with a higher tailwater level condition) where insufficient information or evidence exists to justify a less conservative type (i.e. with lower tailwater condition).

Selection of Modelling Approach

Elevated water levels at the ocean boundary can vary significantly with the waterway entrance type and the specifics of the location and can be costly to derive. The decision on the approach used for their selection needs to weigh up the degree of investigation required against the potential implications in determining an approach that is fit for purpose.

Three modelling approaches: a simplistic approach, a general approach and a detailed approach that can be used by suitably qualified professional to derive or review ocean water level boundary conditions for flood investigations for coastal waterways. 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 analysis outlined in the detailed approach.

Simplistic Approach. This is considered suitable for analysis of small scale site specific developments where a cost effective but conservative approach is warranted. This approach generally aims to derive design flood levels as the basis for determining planning controls, typically the 1% AEP flood for example, for an individual house where no flood information is available from council. This approach may also require determination of peak velocities. The conservatism of this approach may warrant the additional cost of undertaking one of the less conservative approaches outlined below.

General Approach. This requires a more detailed and rigorous modelling approach. It should be used where information is required to inform the development of a floodplain risk management plan, or strategic land use planning, or for larger scale developments. This approach will generally involve modelling to derive design flood levels and flow velocities across a range of flood events.

Detailed Approach. This approach may to be undertaken where the general approach for a type of an entrance waterway type may be considered conservative given the minimum analysis and considerations nominated in this guidance and the specific characteristics of the waterway entrance. This approach will involve detailed modelling to derive design flood levels and flow velocities across a range of flood events.

The selection of approach should be consistent with the type of study being undertaken and exposure of the community to flood risk. For strategic studies undertaken for local government or with state government funding either the general or detailed approaches (outlined below) should be used unless agreed to in writing by the local council and the funding provider, if state government. Use of the simplistic approach in these cases would not be considered fit for purpose.

Consideration of Waterway Entrance Morphology and Management

This section only applies to Waterway Entrance Types B and C (not applicable to Type A). It takes into account entrance boundary geometry and, in the case of entrance shoaling and scouring, the dynamics and physical limits of these mechanisms. These should be represented in the model as either a steady (fixed) or unsteady (dynamic) state. The methodology selected needs to be fit for purpose given the specific entrance conditions and advice below.

Steady State (Fixed) Entrance Conditions are used in the simplistic approach and may also be used in the general and detailed approaches only where the entrance channel is stable. Where adopted, the steady state entrance condition needs to be conservative and account for potential variations in entrance conditions over time.

For untrained entrances, peak shoaled (highest level of the entrance berm that is the interface with the ocean and with the waterway potentially closed) and scoured states (open state for the entrance berm interface with the ocean) need to be determined to inform peak water level and flow velocity calculations. 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.

Where entrances are managed, typically in the case of ICOLLs, intervention under an entrance management policy is generally proposed to assist berm opening before a flood occurs or before the berm can contribute to any elevated water level having significant impact on the surrounding community.

Unsteady State (Dynamic) Entrance Conditions are used in the general or detailed approaches to represent changes to the downstream flood control mechanism over time during an event and is a less conservative approach. Initial entrance geometry conditions would be based upon the steady state entrance condition approach outlined above and an understanding of the entrance dynamics and physical limits which can be derived from:

- A particular historical event - this may require alteration to the entrance configuration within realistic limits in the model to match available calibration data;
- Peak shoaled (governing peak flood levels) and peak scoured (governing peak velocity and ocean inflow) states over time; and
- 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.

For Group 4 Estuaries (ICOLLs), a more sophisticated approach to simulate the 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 or envelope curves for flood levels and flow velocities.

Modelling the Ocean Water Level Boundary

Design ocean still water levels over the range of probabilities generally required for a flood study are available for the Fort Denison gauge in Sydney Harbour. Peak elevated ocean levels as presented in Table 3 are suggested for design purposes (rounded up to nearest 0.05 m) in lieu of a similar analysis for a more local ocean tide gauge with length of record that is fit for purpose. Tidal water levels increase from south to north along the NSW coastline (MHL, 2011). Table 4 provides a summary of peak ocean water levels for design taking into account this tidal variability based on the location of the site relative to Crowdy Head shown in Figure 1.

Advice on how to derive the ocean water level boundary condition for the different approaches is provided below.

The Simplistic Approach uses 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 peak design ocean water level for the appropriate waterway entrance type and entrance conditions and its location on the NSW coast from Table 4.

The General Approach assumes the default unsteady state (dynamic) open-ocean water level boundary conditions (example in Figure 2) in modelling, depending on the ocean boundary condition in Table 4. To assist modelling the dynamic ocean water level boundary conditions for different entrance types and a range of scenarios will be made available on the web.

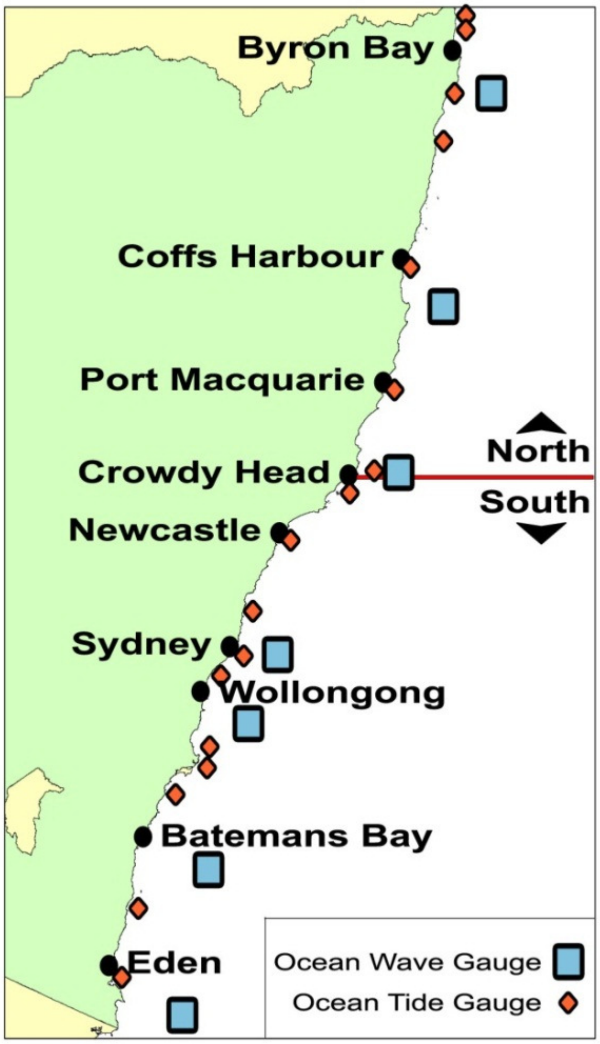
Table 3 Design Still Water Levels for Fort Denison

Annual Exceedance Probability (AEP)	Design Still Ocean Water Level (m AHD)
1%	1.45
2%	1.40
10%	1.35
1 exceedance per year	1.25

Table 4 Summary of Peak Design levels for Various Categories and Locations

Classification	Peak Design Ocean Water Level (m AHD)			
	South of Crowdy Head		North of Crowdy Head	
	1% AEP	5% AEP	1% AEP	5% AEP
Waterway Entrance Type A	1.45	1.40	1.55	1.50
Waterway Entrance Type B	2.00	1.90	2.10	2.00
Waterway Entrance Type C	2.55	2.35	2.65	2.45

Figure 1: Location of Ocean Wave Buoys and Ocean Tide Gauges relative to Crowdy Head



The Detailed Approach provides information that is more directly relevant to a particular entrance and the associated conditions. Analysis should include validation of the design open ocean water level at the specific entrance and a detailed examination of site specific wave set-up where necessary. It should be undertaken 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) and their potential coincidence with catchment flooding.

Peak and dynamic ocean water level boundary conditions need to be derived. The dynamic boundary condition for Fort Denison based upon the 1974 storm (example in Figure 2) should be used unless a more conservative local storm, in height and duration, is available and documented. Where suitable data time series are available for a specific catchment, a detailed joint probability analysis of elevated ocean levels and catchment flows may be completed to support detailed floodplain management and planning.

For dynamic modelling, initial water levels in the waterway also need to be established. In open waterways (Groups 1 to 3) these should be developed considering mean water levels in the waterway, which can be informed by either: modelling tidal penetration into the waterway; or the tidal plane information (based upon mean water levels available for most NSW estuaries in (MHL 2012a).

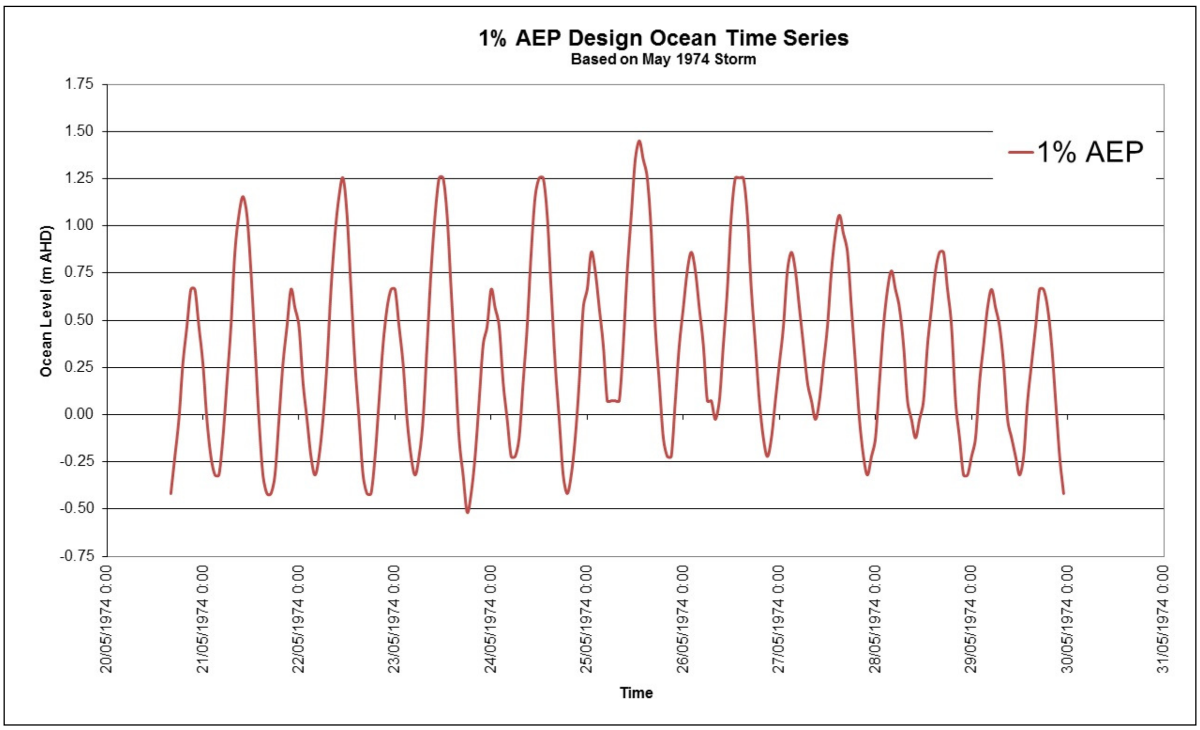
For Group 4 Estuaries (ICOLLs) initial water levels are often independent of ocean levels. They can be determined based upon the following approaches: considering entrance management strategies, which often include a maximum water level in the ICOLL as a trigger for management response, such as berm opening; recorded water levels in the estuary where sufficient record exists; or the maximum historic height of the berm, noting that this approach is likely to be conservative.

Considering the Relative Timing of Catchment Flooding and Oceanic Inundation

The methodology used for design runs depends on the approach selected.

For the Simplistic Approach, constant peak ocean influenced water level (assumes estuary volume is filled by the peak of oceanic inundation and therefore likely to be conservative in all but small volume estuaries).

For the General and Detailed Approaches use variable water level ocean boundary condition, such as Figure 2 in dynamic modelling. Dynamic modelling needs to consider the relative timing of catchment flooding and oceanic inundation as, in some circumstances, this can significantly influence peak flood levels in the waterway. The dynamic modelling approach takes the variable volume effects of the estuary into account and may be important for waterways that respond dynamically (pump up) due to tidal anomalies. Whilst there may be a disparity in timing between the peak of catchment flooding and oceanic inundation, for simplicity of modelling the recommendation is to adjust the alignment of the peak of the catchment flood hydrograph and the peak of the ocean boundary condition hydrograph to coincide at the key location of interest (e.g. township) in the waterway or an appropriate point in the catchment to balance several key points of interest.



Note: This event time series is considered an appropriate basis for modelling as it is representative of an historical storm of appropriate peak magnitude and duration to test the impact of oceanic inundation on storage volumes and flood levels

Figure 2: Example Dynamic Ocean Water Level Boundary: Waterway Entrance Type A

Determining Design Flood Levels

Catchment flooding and oceanic inundation can occur due to the same storm cell and therefore flood levels in lower estuaries will occur due to a combination of the influence of oceanic inundation with catchment flooding. Whilst the degree of coincidence of the storm related factors varies significantly between storm events the methods outlined below based upon the selected approach are considered reasonable given the available information on coincidence in records and the relatively short length of available records. If oceanic inundation or catchment flooding were examined on their own the flood levels derived are unlikely to be fit for purpose for making informed floodplain risk management decisions in the lower portions of coastal waterways.

The Simplistic Approach is limited in application and therefore generally only requires derivation of a planning or design flood (typically 1% AEP event) for setting site specific development conditions and an indicative level for an extreme event to assess the need for any additional development conditions relating to emergency management issues. This should use the 1% AEP ocean boundary water level (derived in earlier steps) and the 1% AEP flood flow to derive an appropriate 1% AEP flood level at the site.

The General and Detailed Approaches would be expected to involve more rigorous analysis of flooding to inform strategic studies and associated risk based decision making. Strategic studies conducted to determine flood risk on a catchment or locality wide basis generally involve analysis of a range of design events, as outlined in Table 5. Deriving the design or planning flood (flood being used as the basis of flood mitigation works or for deriving flood planning levels to managing development) in coastal waterways uses an approach involving the use of a series of catchment flood and oceanic inundation scenarios to produce an envelope of peak flood levels and velocities as these vary with location. Deriving the peak flood levels and velocities for a 1% AEP event, may involve the testing of the following scenarios:

- Peak 1% AEP flood levels based upon the envelope of peaks from the following:
  - Design 1% AEP oceanic inundation with 5% AEP catchment flooding with coincident peaks
  - Design 5% AEP oceanic inundation with 1% AEP catchment flooding with coincident peaks
- Peak 1% AEP flood velocities – based upon the coincidence of low tide in neap tide cycle with 1% AEP catchment flooding.

Where the peak flood levels derived in the coastal waterway using this approach are particularly sensitive to the joint occurrence of catchment flooding and oceanic inundation then the approach outlined in Zheng et al 2014 could also be considered where this is fit for purpose. This would need to be supported by appropriate justification and agreement should be sought to its use.

In addition, as flood insurance does not cover coastal inundation; it may be prudent for the study to undertake several additional model runs dealing purely with catchment flooding, which are more fit for purpose for the assessment of insurance risk, as suggested in Table 5.

Table 5: Combinations of Catchment Flooding and Oceanic Inundation Scenarios

Design AEP for peak levels / velocities	Catchment Flood Scenario	Ocean Water Level Boundary Scenario	Comment/ Reference
50% AEP	50% AEP	HHWS	HHWS dynamic hydrograph to be given Peak flood coincidence with highest peak of HHWS for highest levels Peak HHWS 1.13m AHD
20%	20% AEP	HHWS	
10%	10% AEP	HHWS	
5%	5% AEP	HHWS	
2%	2% AEP	5% AEP	Dynamic ocean water level boundary hydrograph for relevant waterway type
1% Envelope level	5% AEP	1% AEP	Envelope provides 1% AEP design flood estimate Dynamic ocean water level boundary hydrograph for relevant waterway type with peak flood and peak ocean water level boundary levels coinciding
1% Envelope level	1% AEP	5% AEP	
1% Envelope velocity	1% AEP	Neap	Dynamic ocean water level boundary hydrograph with peak flood to coincide with lowest neap suggested for peak velocities Fixed Neap -0.95m AHD
0.5%	0.5% AEP	1% AEP	Dynamic ocean water level boundary hydrograph for relevant waterway type
0.2%	0.2% AEP	1% AEP	
PMF	PMF	1% AEP	
Catchment Flood only	1% AEP	HHWS	These runs may provide information for flood insurance as it does not cover ocean inundation
	PMF	HHWS	

Note: Individual projects are likely to specify the use of only a select number of AEPs outlined in the table.
HHWS is High High Water Springs (Summer solstice)

Overall

OEH is developing updated guidance on the interaction of elevated ocean levels and catchment flooding for use in studies undertaken under the State Floodplain Management Program.

The intent is to support guidance with supplementary data on the OEH website providing the dynamic ocean boundary scenarios outlined in Figure 5 for different types of waterways and considering location in NSW and a number of examples.

This paper outlines the methodology for practical consideration of the coincidence of ocean inundation and catchment flooding. These approaches are recommended for use in flood studies undertaken in coastal waterways in NSW. This paper also discusses the work that was undertaken to inform this methodology.

This paper gives advice on a range of the key issues. However, guidance is also expected to provide advice on:

- Translating the ocean water level boundary condition to a point within the waterway
- Sensitivity testing
- Considering sea level rise in ocean water level boundary conditions.
- Documenting methodologies and assumptions with reports on studies undertaken under the State Floodplain Management Program expected to provide a clear statement of the assumptions made in deriving ocean boundary conditions based upon a template to be provided on the web.

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