Office of Environment & Heritage

Floodplain Risk Management Guide

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

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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
HHWS(SS)	High High Water Springs (Solstice Spring)
ICOLL	intermittently closed and open lakes and lagoon
ISLW	Indian Springs Low Water
OEH	Office of Environment and Heritage

Glossary

The majority of terms in the document are defined in the NSW Government's *Floodplain Development Manual*, 2005. Additional relevant terms are defined as indicated below.

Design flood	A flood being used as the basis of design for flood mitigation works.
oceanic inundation	A natural process resulting from severe storms whereby elevated ocean water levels combined with a varying combination of wave setup and wave runup along the coast can result in elevated ocean water levels in estuaries and ocean seawater overtopping frontal dune systems and coastal barriers during storms. Overtopping of frontal dunes and coastal barriers is generally rare and episodic, occurring principally around the peak of a high tide, creating a hazard mainly where frontal dunes or coastal barriers along the NSW coastline are crested below about 5 m AHD.
ocean water level boundary conditions	The ocean water level(s) used as the downstream boundary level for hydraulic modelling for a flood study in a coastal waterway.
Planning flood	A flood being used as the basis for deriving flood planning levels to manage development.
tidal waterways	The lower portions of coastal rivers, creeks, lakes, harbours, and ICOLLs affected by tidal fluctuations.

Introduction

Flooding in tidal waterways may occur independently due to oceanic inundation or catchment flooding and may also occur due to a combination of both derived from the same meteorological event.

The interaction of catchment flooding and coastal processes is an important consideration in determining overall flood risk in coastal waterways. The influence of these two factors on flooding varies with ocean level, due to both tidal fluctuations and storm impacts, the condition of the entrance interface between the coastal waterway and the ocean, distance from the ocean, and the size and shape of the waterway and catchment draining to the entrance.

The floodplain risk management process outlined in the Floodplain Development Manual (DIPNR 2005) provides the opportunity to understand the interaction of catchment flooding with oceanic inundation and examine and decide on options to manage the associated flood risks to existing and future development.

This guide provides advice on approaches that can be used to derive ocean boundary conditions and design flood levels for flood investigations in coastal waterways considering the interaction of catchment flooding and oceanic inundation for the various classes of estuary waterways found in NSW and likely corresponding ocean boundary conditions. Any decisions made on the basis of the information provided in this guide should be made and reviewed by suitably qualified industry professionals.

This guide does not by itself provide the basis for strategic land use planning, setting development controls such as flood planning levels, assessing and managing the impacts of development on flood behaviour, or addressing broader floodplain risk management issues. Advice on such issues is provided in the *Floodplain Development Manual* (DIPNR 2005) and, for the purposes of flood investigations for development assessment, should be discussed with the relevant council.

Consistency of approach with the guide

Section 3 of the guide provides advice on the type of approach that is consistent with the guide, dependent upon the purpose of the study.

Relationship to other guides

This guide updates advice previously provided in Appendix A of *Flood Risk Management Guide: Incorporating Sea Level Rise Benchmarks in Flood Risk Assessments* by the NSW Government (DECCW, 2010).

Considerations in formulating the guide

In formulating this guide, consideration has been given to:

- Waterway entrance/estuary characteristics including NSW estuary classifications and estuary hydrodynamics including tidal planes within coastal waterways.
- Deriving design flood estimates for the interaction of catchment flooding and oceanic inundation considering:
    - design ocean levels (including their variability on the NSW coastline);
    - wave set-up; historical storm events
    - the relative timing of catchment flooding and oceanic inundation events.

How to use this guide

The procedure within this guide is structured on a series of steps summarised in Table 1; separated into the three different waterway entrance types A, B and C, as discussed in Section 2. These steps relate to:

- gathering and reviewing available information (Section 1)
- determining the waterway entrance type (Section 2)
- selecting a modelling approach (Section 3)
- considering entrance morphology and management (Section 4)
- modelling the ocean water level boundary (Section 5)
- translating the ocean boundary to the study boundary or site location, in the limited cases where this may be needed (Section 6)
- considering relative timing of catchment flooding and oceanic inundation (Section 7)
- determining design flood level (Section 8)
- sensitivity testing (Section 9)
- advice for incorporating changes into sea level in assessments (Section 10)

This guide does not provide advice on developing sea level rise projections.

The guide is supported by:

- Appendix A Dynamic Ocean Boundaries for South of Crowdy Head.
- Appendix B Dynamic Ocean Boundaries at and North of Crowdy Head.
- Appendix C Indicative Spring and Neap Tide Cycle (incorporates HHWS(SS) & ISLW)
- Blank word file template for documenting methodology and assumptions.
- Example case studies of the derivation of downstream ocean boundary conditions in accordance with the Floodplain Risk Management Guide: Modelling the Interaction of Catchment Flooding and Oceanic Inundation in Coastal Waterways.
- An excel spreadsheet which has the hourly water levels used to derive the graphs provided in Appendices A to C for use in modelling.

Support to local government for strategic studies

The Floodplain Management Program provides local councils with the opportunity to competitively apply for financial assistance to undertake or update flood investigations under the floodplain risk management process outlined in the NSW Floodplain Development Manual (DIPNR 2005). Program details can be found on the Office of Environment and Heritage website at Coastal, estuary and floodplain management grants. Technical assistance on flood risk management to support local government undertaking studies funded under the program is available through the NSW Office of Environment and Heritage.

Summary Table – Coincidence of Catchment Flooding and Oceanic Inundation in Coastal Waterways

Table 1a Typical Ocean Boundary Conditions and Modelling Considerations for Waterway Entrance Type A

Waterway Entrance Type **(Section 2)**	**Selected modelling approach (Section 3)**	**Methodology**					
		Entrance Condition and Management **(Section 4)**	**Modelling the Ocean Water Level Boundary** **(Section 5)**	**Translating the Ocean Boundary to Study Boundary or Site** **(Section 6)**	**Relative timing of catchment flooding and oceanic inundation** **(Section 7)**	**Determining design flood levels** **(Section 8)**	**Sensitivity Testing** **(Section 9)**
A Generally Group 1 Oceanic Embayments & Group 2 Tide Dominated Estuaries * Estuaries of NSW: Physical characteristics, tidal surveys and hydrographic surveys	**Simplistic approach**	Not applicable	Steady state ocean boundary based on level obtained from Figure 5.1 for Waterway Entrance Type A (adjusting for whether site is north or south of Crowdy Head see Figure 5.2)	Adjust ocean boundary utilising information from a previous study or available HHWS(SS) analysis	Peak catchment flood level with static ocean boundary	Only 1% and extreme	Nil
	General approach	Not applicable	• Dynamic ocean boundary for Waterway Entrance Type A for each ocean scenario (adjusting for whether site is north or south of Crowdy Head see Figure 5.2) • Dynamic Indicative Spring & Neap Tide Cycles incorporating ISLW & HHWS(SS) adjusted for north or south of Crowdy Head	Adjust ocean boundary utilising information from a previous study or available HHWS(SS) information	Peak catchment coincident with ocean boundary	Refer Table 8.1	• 6-24hr Time of Concentration vary coincident peak +/-3hrs • >24hr Time of Concentration vary coincident peak +/-6hrs
	Detailed approach	Not applicable	• Dynamic ocean boundary for Waterway Entrance Type A for each ocean scenario (adjusting for whether site is north or south of Crowdy Head see Figure 5.2) • Dynamic Indicative Spring & Neap Tide Cycles incorporating ISLW & HHWS(SS) adjusted for north or south of Crowdy Head	Adjust ocean boundary utilising information from a previous study or available HHWS(SS) analysis	Peak catchment coincident with ocean boundary	Refer Table 8.1	• 6-24hr Time of Concentration vary coincident peak +/-3hrs • >24hr Time of Concentration vary coincident peak +/-6hrs

* Waterway Entrance Types A, B & C are covered in Section 1 of this document

Table 1b Typical Ocean Boundary Conditions and Modelling Considerations for Waterway Entrance Type B

Waterway Entrance Type **(Section 2)**	**Selected modelling approach (Section 3)**	**Methodology** **Entrance Condition & Management** **(Section 4)**	**Modelling the Ocean Water Level Boundary** **(Section 5)**	**Translating the Ocean Boundary to Study Boundary or Site** **(Section 6)**	**Relative timing of catchment flooding and oceanic inundation** **(Section 7)**	**Determining design flood levels** **(Section 8)**	**Sensitivity Testing** **(Section 9)**
B Generally Group 3 wave dominated Estuaries* Estuaries of NSW: Physical characteristics, tidal surveys and hydrographic surveys	**Simplistic approach**	• Identify peak shoaled entrance condition from previous estuary/coastal study or historical analysis • Consider current entrance geometry (confirmed by survey)	Steady state ocean boundary based on level obtained from Figure 5.1 for Waterway Entrance Type B (adjusting for whether site is north or south of Crowdy Head, see Figure 5.2)	Adjust ocean boundary utilising information from a previous study or available HHWS(SS) analysis	Peak catchment flood level with static ocean boundary	Only 1% and extreme	Increase ocean boundary condition by 0.3m
	General approach	• Identify peak shoaled entrance condition from previous estuary/coastal study or historical analysis • Consider current entrance geometry (confirmed by survey) • Consider dynamic morphology of entrance	• Dynamic ocean boundary for Waterway Entrance Type B for each ocean scenario (adjusting for whether site is north or south of Crowdy Head, see Figure 5.2) • Dynamic Indicative Spring & Neap Tide Cycles incorporating ISLW & HHWS(SS) adjusted for north or south of Crowdy Head	Adjust ocean boundary utilising information from a previous study or available HHWS(SS) analysis	Peak Catchment coincident with ocean boundary	Refer Table 8.1	• 0.3m increase in ocean level • 6-24hr Time of Concentration vary coincident peak +_3hrs • >24hr Time of Concentration vary coincident peak +/-6hrs
	Detailed approach	• Identify peak shoaled entrance condition from previous estuary/ coastal study or historical analysis • Consider current entrance geometry (confirmed by survey) • Consider dynamic morphology of entrance	• Use dynamic ocean boundary for Waterway Entrance Type B for each ocean scenario (adjusting for whether site is north or south of Crowdy Head, see Figure 5.2) • Conduct 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 Indicative Spring & Neap Tide Cycles incorporating ISLW & HHWS(SS) adjusted for north or south of Crowdy Head	Adjust ocean boundary utilising information from a previous study or available HHWS(SS) analysis	Peak Catchment coincident with ocean boundary	Refer Table 8.1	• 0.3m increase in ocean level • 6-24hr Time of Concentration vary coincident peak +_3hrs • >24hr Time of Concentration vary coincident peak +/-6hrs

Table 1c Typical Ocean Boundary Conditions and Modelling Considerations for Waterway Entrance Type C

Waterway Entrance Type (Section 2)	Selected modelling approach (Section 3)	Methodology: Entrance Condition & Management (Section 4)	Modelling the Ocean Water Level Boundary (Section 5)	Translating the Ocean Boundary to Study Boundary or Site (Section 6)	Relative timing of catchment flooding and oceanic inundation (Section 7)	Determining design flood levels (Section 8)	Sensitivity Testing (Section 9)
C Generally Group 4 ICOLLS * Estuaries of NSW: Physical characteristics , tidal surveys and hydrographic surveys	**Simplistic approach**	• Identify peak shoaled entrance condition from previous estuary/coastal study or historical analysis • Consider current entrance geometry (confirmed by survey) • Consider whether there is a trigger level for mechanical intervention under entrance management policy	• Steady state ocean boundary for Waterway Entrance Type C based on level obtained from Figure 5.1 (adjusting for whether site is north or south of Crowdy Head, see Figure 5.2) • Consideration of maximum height of berm and /or recorded water levels in the estuary	N/A	Peak catchment flood level with static ocean boundary	Only 1% and extreme	0.3m increase in both ocean water level boundary condition and berm level
	General approach	• Identify peak shoaled entrance condition from previous estuary/coastal study or historical analysis • Consider current entrance geometry (confirmed by survey) • Consider whether there is a trigger level for mechanical intervention under entrance management policy • Consider dynamic morphology of entrance	• Dynamic ocean boundary for Waterway Entrance Type C for each ocean scenario (adjusting for whether site is north or south of Crowdy Head see Figure 5.2) • Dynamic Indicative Spring & Neap Tide Cycles incorporating ISLW and HHWS(SS) adjusted for north or south of Crowdy Head • Consideration of maximum height of berm and /or recorded water levels in the estuary	N/A	Peak Catchment coincident with ocean boundary	Refer Table 8.1	• 0.3 increase in berm & ocean level • 6-24hr Time of Concentration vary coincident peak +_3hrs • >24hr+ Time of Concentration vary coincident peak +_6hrs
	Detailed approach	• Identify peak shoaled entrance condition from previous estuary/coastal study or historical analysis • Consider current entrance geometry (confirmed by survey) • Consider whether there is a trigger level for mechanical intervention under entrance management policy • Consider dynamic morphology of entrance	• Use dynamic ocean boundary for Waterway Entrance Type C for each ocean scenario (adjusting for whether site is north or south of Crowdy Head, see Figure 5.2) • Conduct 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 Indicative Spring & Neap Tide Cycles incorporating ISLW & HHWS(SS) adjusted for north or south of Crowdy Head • Consideration of maximum height of berm and /or recorded water levels in the estuary	N/A	Peak Catchment coincident with ocean boundary	Refer Table 8.1	• 0.3 increase in berm & ocean level • 6-24hr Time of Concentration vary coincident peak +_3hrs • >24hr+ Time of Concentration vary coincident peak +_6hrs

1. Gathering and reviewing background information

The initial step in any investigations into flood behaviour in tidal waterways should start with determining the available background information that can inform the investigations, and the associated model development, calibration and validation. This may include:

- Historical information on flood levels, storm events, catchment flooding, oceanic inundation, tidal inundation and entrance conditions as this will influence modelling of flood behaviour.
- Available studies i.e., flood studies relevant to the current investigations.These may already have considered ocean boundary conditions.
- The way in which ocean boundary conditions were derived and used in existing studies should be assessed for fitness for the intended purpose of current work in consideration of this guide and available historical information (including any significant flood events since completion of existing studies).
- Available information on waterway structures that may influence flood behaviour.
- Historical information on peak shoaled and open conditions of any entrance berms or shoaled waterways.
- Available survey of the waterway and entrance.
- Any management strategy for an entrance berm.
- For site specific assessments, flood related development controls requirements of the relevant council or consent authority.

The remainder of this guide assumes available background information has been collected and is used to inform the process.

2. Determining the waterway entrance type

In simple terms, the degree of influence that coastal processes have on flooding within a waterway depends on the connectivity of the waterway to the ocean. This in turn depends on the type of estuary linked to the coastal waterway, the morphology and training of the waterway entrance and any management intervention.

The Estuaries of NSW website 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).
- **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 guide 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 2.1. These waterway entrance types form the basis of identifying the potential influence of ocean inundation on catchment flooding at a given estuary.

Note that there are some estuaries that have not been classified under the work of Roy et al (2001). If this is the case, the category selected from this guide will need to be justified. 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).

Table 2.1 – Simplified Waterway Entrance Types

Type A	Type B	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 entrance types 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

3. Selecting a modelling approach

Having selected the waterway entrance type appropriate to the location, the next step is to select the modelling approach used for determining an ocean water level boundary condition.

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.

The guide outlines three modelling approaches: a simplistic approach, a general approach and a detailed approach. 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. This degree of conservatism is in lieu of a more sophisticated analysis outlined in the detailed approach.

To be consistent with the guide, studies undertaken for a local council or with state government funding under the State Floodplain Management Program should follow either the general or detailed approaches unless agreed to in writing by: the relevant council and; where the council project has state government financial assistance, through the Office of Environment and Heritage. Use of the simplistic approach in these cases without this agreement is not consistent with this guide.

The simplistic approach is generally only considered suitable for analysis of small scale site specific developments where a cost effective but conservative approach is warranted.

Simplistic approach. This approach generally aims to derive design flood levels as the basis for determining planning controls, such as the flood planning level 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 provide the basis 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 an entrance waterway type may be considered conservative, given the minimum analysis and considerations nominated in this guide 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.

Having selected a modelling approach appropriate to the situation, the relevant section of Table 1 (a, b or c for waterway entrance types A, B and C respectively) and Sections 4 to 10 provide advice on the methodology for deriving critical components in determining ocean boundary conditions and design flood levels based on the chosen modelling approach.

4. Consideration of entrance morphology and management

This section applies to Waterway Entrance Types B and C (It is not applicable to Type A Entrances). 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 a steady (fixed) or unsteady (dynamic) state. The methodology selected needs to be fit for purpose given the specific entrance conditions and advice below.

4.1 Steady state (fixed) entrance condition

In the simplistic approach steady state entrance conditions are used. These may also be applicable for the general and detailed approaches where there is a stable entrance channel. Where adopted, a steady state entrance condition needs to be conservative and account for potential variations in 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 (generally 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 in the waterway having significant impact on the surrounding community.

4.2 Unsteady state (dynamic) entrance conditions.

In the general and detailed approaches, unsteady state entrance conditions are used to represent changes to the downstream flood control mechanism over time during an event. This approach is less conservative than using steady state entrance conditions.

Initial entrance geometry conditions would be based upon the steady state entrance condition approach (Section 4.1). 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 in the model to match available calibration data.
- Peak shoaled (governing peak flood levels) and peak scoured (governing peak flow velocity and ocean inflow) states over time.
- The limits of the potential dynamics such as vertical and lateral limits of 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 of the entrance 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 model runs may be required to develop upper boundary or envelope curves for flood levels and flow velocities.

5. Modelling the ocean water level boundary

This section provides more detailed advice on how to derive the ocean water level boundary condition relevant to the location.

5.1 Methodology based on modelling approach

The methodology used to determine ocean boundary conditions for the simplistic, general and detailed approaches (as outlined in Section 3) are provided below. Section 3 discusses consistency of approach with the guide for particular types of studies.

Simplistic approach. This 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 using a combination of Figure 5.1 for the appropriate waterway entrance type and entrance conditions and Figure 5.2 for its location on the NSW coast. Table 5.2 provides a summary of peak design ocean water levels for different waterway types and locations.

General approach. This approach assumes the default unsteady state (dynamic) open-ocean water level boundary conditions (Figures A1 to B6 and C1 to C2) in modelling, depending on the ocean boundary condition determined using Figures 5.1 and 5.2. Note: when using dynamic ocean boundary conditions it is important to ensure the model has stabilised and is performing well with general tides prior to adding a tidal anomaly.

Detailed approach. This 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 the entrance classification requires it. 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 where relevant) and their potential coincidence with catchment flooding. This approach needs to derive both peak levels and dynamic ocean boundary conditions as discussed in Section 5.2 and should use a dynamic boundary condition based upon the May 1974 storm as recorded at the Fort Denison Gauge in Sydney Harbour 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 runoff flows may be completed to support detailed floodplain risk management and planning.

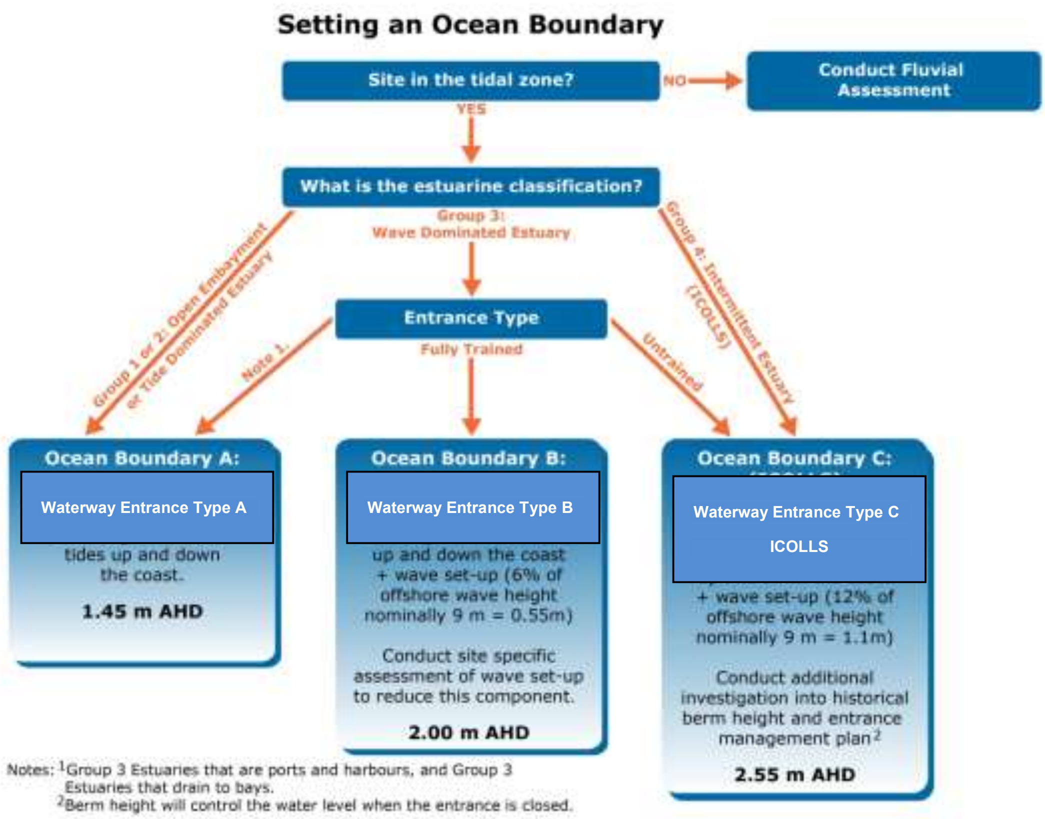

Figure 5.1: Setting a Peak Ocean Boundary for Different Waterway Entrance Types for the simplistic and general approach (Ref: Derived from WRL 2013)

Notes:

- In determining whether the site is within the tidal zone, MHL (2006) defines the upstream tidal limits in estuaries (the point that tides do not pass) and the upstream limit of mangroves for the main arm and tributaries of estuaries. It can be found at Survey of Tidal Limits and Mangrove Limits in NSW estuaries 1996 to 2005
- The above boundary conditions are shown for the New South Wales Coast south of Crowdy Head (see Figure 5.2). North of Crowdy Head peak design ocean levels require an additional 0.1m to account for tidal variability along the coast (see Table 5.2). Waterway entrance types are described in Table 2.1 of this guide.
- Group 3 estuaries which have trained entrances and are maintained as navigable ports (e.g. Newcastle Harbour) will have little ocean tide attenuation and negligible wave set-up. These port and harbour estuaries should use ***Waterway Entrance Type A***.
- Group 3 estuaries which drain to bays including the Brisbane Water, Tilligerry Creek and Cullendulla Creek should adopt ***Waterway Entrance Type A***.
- Group 3 estuaries with fully (both sides of entrance) trained entrances which are not maintained as navigable ports will have little ocean tide attenuation but some potential for wave setup and should use ***Waterway Entrance Type* B;**
- Group 3 estuaries with untrained entrances are likely to have very shallow flow depths across the entrance or may fully close from time to time. These estuaries should adopt ***Waterway Entrance Type C*** by default.
- ***Waterway Entrance Type C*** applies for coastal lakes where flow out of or into the lake will be controlled by the beach berm characteristics (height, width and breadth). In this case, the design flood assessment should take into account the berm history and the berm management strategy where these are available. The peak ocean level suggested for coastal lakes is provided as a downstream boundary for lake models.

Figure 5.2: Location of Ocean Wave Buoys and Ocean Tide Gauges relative to Crowdy Head

5.2 Design ocean water levels

A flood study generally requires design ocean still water levels over the range of probabilities. Peak elevated ocean levels for Fort Denison gauge in Sydney Harbour as presented in Table 5.1 are suggested for design purposes (rounded up to nearest 0.05 metre) in lieu of a similar analysis for a more local ocean tide gauge with length of record that is fit for purpose.

Table 5.1 Design Still Water Levels for Fort Denison

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

Tidal water levels increase from south to north along the NSW coastline (MHL, 2011). Table 5.2 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 5.2.

Table 5.2 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

To assist with dynamic numerical modelling, ocean water levels and time series for boundary conditions are provided (Figures A1 to B6).These have been based on a time series of the May 1974 storm as recorded at the Fort Denison gauge in Sydney Harbour, factored slightly to meet the peak of the design still water level shown in Figure 5.3 and 5.4 for the relevant AEP event. This event time series is considered an appropriate basis for modelling as it is representative of an historical storm of similar peak magnitude and duration to test the impact of oceanic inundation on both storage volume and flood levels within the waterway.

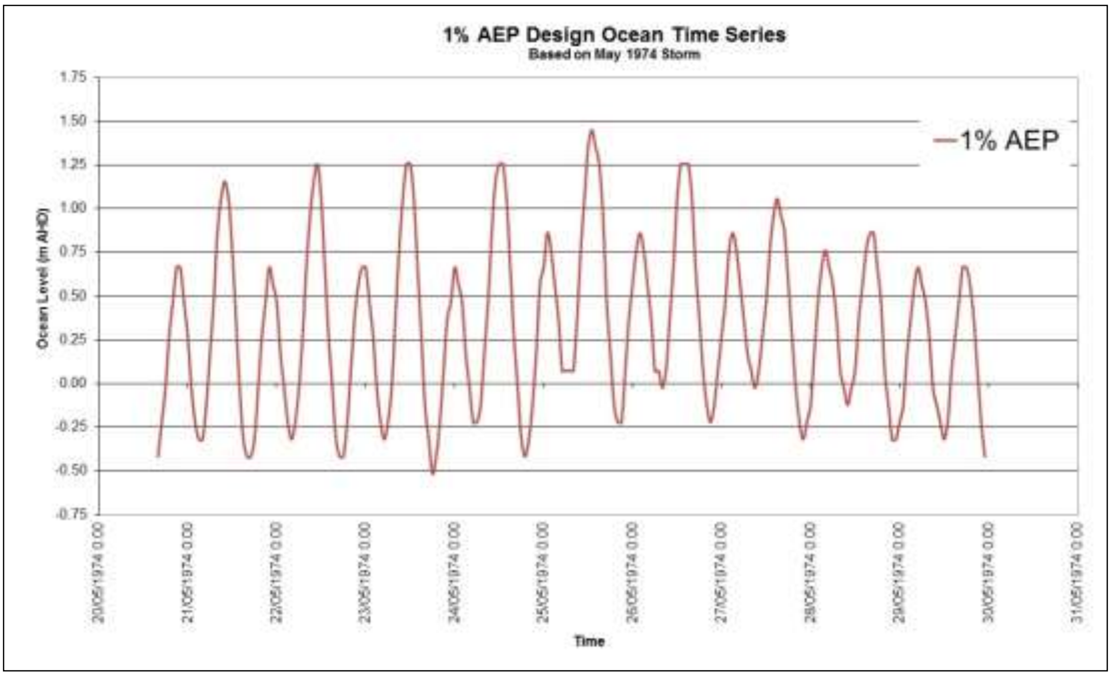

Figure 5.3: Waterway Entrance Type A - 1% AEP Ocean Boundary Time Series Based on Fort Denison May 1974 (South of Crowdy Head)

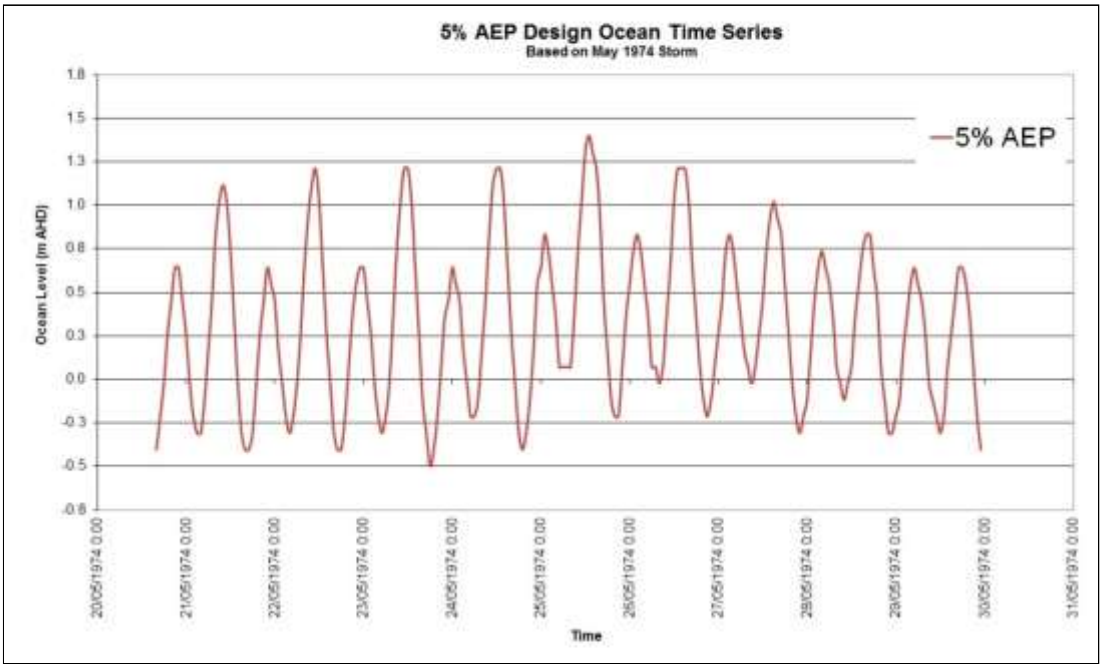

Figure 5.4: Waterway Entrance Type A - 5% AEP Ocean Boundary Time Series Based on Fort Denison May 1974 (South of Crowdy Head)

5.3 Initial water level in estuaries

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 water levels in the waterway which can be informed by either:

- tidal plane information (based upon HHWS(SS) water levels available for most NSW estuaries in the report '*OEH NSW Tidal Planes Analysis, 1990-2010 Harmonic Analysis*', (MHL, 2012)
- modelling penetration of HHWS(SS) into the waterway

For Group 4 Estuaries (ICOLLs) initial water levels are often independent of ocean levels. They can be determined based upon the following approaches:

- Considering estuary 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.
- The maximum historic height of the berm, noting that this approach is likely to be conservative.

6. Translating the ocean water level boundary within the estuary

This step is only suitable for Entrance Types A and B. It is not applicable for waterways with Entrance Type C (Generally ICOLLs), due to the significant, often controlling influence of entrance berms on flood levels within an ICOLL.

The ocean boundary condition and hydrographs derived by the methods described in Section 5 are valid at the interface between the entrance and the ocean. However, in circumstances where extending the model to the location is not warranted, a decision may be made to translate the boundary condition to the site in question (for a site specific assessment) or the downstream study boundary for the flood investigation (where upstream of the ocean interface). This translation needs to take into account the entrance and broader estuary hydrodynamics.

For waterway entrance types A and B translation of the ocean boundary condition inland to a site or downstream study boundary can be achieved by the following methods:

- Adjusting the derived ocean boundary condition considering the flood gradient of a relevant design event where a flood study exists for the waterway.
- Adjusting the derived ocean boundary condition considering the change in tidal influence relative to the ocean interface. The degree of tidal influence for a particular location within a specified NSW estuary, excluding non-tidal anomalies, can also be estimated using either:
- Tidal plane information (based upon HHWS(SS) available for most NSW estuaries in the report '*OEH NSW Tidal Planes Analysis, 1990-2010 Harmonic Analysis*', (MHL, 2012).
    - Modelling the penetration of HHWS(SS) into the waterway.

A more reliable method is by use of a numerical modelling approach. Where a calibrated numerical model is available, the dynamic boundary condition can be applied to the model ocean boundary and the model analysis used to determine peak levels at a site or boundary.

7. Relative timing of catchment flooding and oceanic inundation

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

For the **Simplistic approach,** use a 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 approach** use variable water level ocean boundary condition, such as Figures 5.3 and 5.4 (for one per cent and five per cent AEP for Waterway Entrance Type A) 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. Dynamic modelling takes the variable volume effects of the estuary into account and may be important for waterways that respond dynamically (pump up) in response 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.

8. Determination of design flood levels

Catchment flooding and oceanic inundation can occur due to the same storm cell and therefore design flood levels in a lower coastal waterway will be influenced by a combination of these sources. Whilst the degree of coincidence of the storm related factors varies significantly between storm events the approaches below provide reasonable estimates considering the information on coincidence in 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. Advice on deriving design flood levels and other information to consider in managing flood risk using the selected approach is given below.

The **simplistic approach** is limited in application (generally only to site specific developments e.g. individual houses where no relevant flood information is available from council) and therefore generally only requires derivation of:

- a design flood (typically one per cent AEP event) for setting site specific development conditions. This should use the higher of the one per cent AEP ocean level (derived in earlier steps) and the one per cent AEP flood level at the site derived from the one per cent AEP flood flow at the site.
- an indicative level for an extreme event to assess the need for any additional development conditions relating to emergency management issues.

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 8.1.

Deriving design or planning flood levels 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 one per cent AEP event, may involve the testing of the following scenarios:

- Design one per cent AEP oceanic inundation with five per cent AEP catchment flooding with coincident peaks, to test peak levels.
- Design five per cent AEP oceanic inundation with one per cent AEP catchment flooding with coincident peaks; to test peak levels.
- Coincidence of ISLW in indicative spring and neap tide cycle (Appendix C) with one per cent AEP catchment flooding to test peak velocities.

Table 8.1: 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(SS)	Dynamic hydrograph can be taken from Appendix C with peak flood to coincide with HHWS(SS) highest peak for highest water levels Peak HHWS(SS) 1.25m AHD
20%	20% AEP	HHWS(SS)	
10%	10% AEP	HHWS(SS)	
5%	5% AEP	HHWS(SS)	
2%	2% AEP	5% AEP	Dynamic ocean water level boundary hydrograph Appendices A or B for relevant waterway type
1% Envelope level	5% AEP	1% AEP	Envelope provides 1% AEP design flood estimate Dynamic ocean water level boundary hydrograph Appendices A or B for relevant waterway type
1% Envelope level	1% AEP	5% AEP	
1% Envelope velocity	1% AEP	ISLW	Dynamic hydrograph can be taken from Appendix C with peak flood to coincide with ISLW lowest trough for peak velocities in entrance. Fixed ISLW approx. -0.95m AHD
0.5%	0.5% AEP	1% AEP	Dynamic ocean water level boundary hydrograph Appendices A or B for relevant waterway type
0.2%	0.2% AEP	1% AEP	
PMF	PMF	1% AEP	
1% Catchment	1%	HHWS(SS)	Suggested envelopes for analysis of catchment flooding only
PMF Catchment	PMF	HHWS(SS)	

Note: *Individual projects are likely to specify the use of only a select number of AEPs outlined in the table.*

9. Sensitivity testing

Testing and reporting on the sensitivity of results to key parameters reflects good practice in flood investigations. This sensitivity is generally undertaken for a key flood event, typically the one per cent AEP flood event. For ocean boundary conditions sensitivity testing would relate to ocean boundary condition, entrance condition, and relative timing of catchment flooding and oceanic inundation.

Sensitivity to design ocean boundary condition

Sensitivity to ocean boundary condition can be tested by increasing the ocean boundary condition and initial water levels in the waterway by 0.3 metres to provide an allowance (or increased allowance) for wave setup.

Sensitivity to initial outlet berm height in Type C entrances

Sensitivity to initial berm height can be tested by an increase in initial berm height by 0.3 metres. If the estuary water body demonstrates significant sensitivity to this level change then further, more detailed examination of the downstream water level may be warranted.

Sensitivity to entrance efficiency for waterways with limited tidal range

Large coastal lakes, where the tidal range and exchange are significantly dampened (+/- 0.1m to 0.3m) compared to ocean tidal ranges (+/- 0.7m) can be particularly sensitive to changes in the efficiency of the entrance. This could be the case in Type B waterway entrances. If undertaking detailed analysis of the entrance additional modelling may be warranted to test sensitivity to improved efficiency (e.g. increase in waterway area within the tidal range of the entrance channel) by 10 per cent, considering any physical limits, e.g. bedrock) and associated loss of available storage volume within the estuaries to absorb flood impacts.

Sensitivity to catchment timing

The assumption made in this guide in aligning the peak of the catchment flood hydrograph to the peak of the ocean flood hydrograph should be tested where the estuary has a reasonable volume and the time of concentration of the catchment flooding is greater than 6 hours as described below:

<u>If catchment time of concentration is moderate: 6–24 hours:</u>

Variable anomaly e.g. Figure 5.3 (for 1% AEP for Waterway Entrance Type A) or Figure 5.4 (for 5% AEP for Waterway Entrance Type A) but with the peak of the catchment flow offset by +/-3 hours of the peak of the ocean boundary level time series at the location of interest to test sensitivity.

<u>If catchment time of concentration is long: 24 hours or longer:</u>

Variable anomaly e.g. Figure 5.3 (for 1% AEP for Waterway Entrance Type A) or Figure 5.4 (for 5% AEP for Waterway Entrance Type A) but with the peak of the catchment flow offset by +/-6 hours of the peak of the ocean boundary level time series at the location of interest to test sensitivity.

10. Testing the implications of sea level rise

Testing the implications for sea level rise on flooding can best be undertaken by examining a specific design event, such as the one per cent AEP flood which is typically used for defining the flood planning level with an appropriate freeboard.

Sea level rise will impact upon both oceanic inundation levels and the configuration of entrances and their dynamics, which will have implications for flood behaviour. Assuming that the nature of the estuary remains the same, the implications of these changes will vary depending upon the estuary group and specifics of the location. It is recommended that the following changes to conditions be tested.

For estuaries with Entrance Waterway Type A the assessment of the impact of change can be assessed by directly adding the sea level rise projection to:

- ocean water level boundary conditions
- initial water level conditions in the tidal waterway.

For estuaries with Entrance Waterway Type B the assessment of the impact of change can be assessed by directly adding the sea level rise projection to:

- ocean water level boundary conditions
- starting conditions for entrance configuration
- initial water level conditions in the tidal waterway.

For estuaries with Entrance Waterway Type C (ICOLLS) the assessment of the impact of change can be assessed by directly adding the sea level rise projection to:

- ocean water level boundary conditions

- starting conditions for entrance configuration
- initial water level conditions in the waterway.

11. Documenting methodologies and assumptions

The recommended minimum information required to document the derivation of an ocean boundary condition is outlined the Template for documenting methods and assumptions when deriving ocean boundary conditions using the Floodplain Risk Management Guide that can be completed and incorporated into report.

12. References

Department of Environment Climate Change and Water (DECCW) NSW. (2010). *Flood Risk Management Guide: Incorporating sea level rise benchmarks in flood risk assessments*. Prepared by the Department of Environment, Climate Change and Water NSW: Sydney.

Manly Hydraulics Laboratory (MHL). (2011). *NSW Ocean Water Levels*. Report No. MHL1881.

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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.

Roy, P. S., Williams, R. J., Jones, A. R., Yassini, I., Gibbs, P. J., Coates, B., West, R. J., Scanes, P. R., Hudson, J. P. and Nichol, S. (2001). "Structure and Function of South-east Australian Estuaries". *Estuarine, Coastal and Shelf Science,* 53 (3), pp.351-384.

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Smith, G. P., Davey, E. K., Cox, R. J. and Peirson W. L. (2013) *Coincidence of Catchment and Ocean Flooding, Stage2 - Recommendations and Guidance.* UNSW Water Research Laboratory, Manly Vale. WRL Technical Report 2013/16.

Toniato, A., McLuckie, D., Smith, G. P. Development of Practical Guidance for Coincidence of Catchment Flooding and Oceanic Inundation. Paper for the 54th Annual Floodplain Management Association Conference, Deniliquin NSW, May 23-25 2014.

Appendix A: Ocean Water Level Boundaries South of Crowdy Head

See the Hourly Water Levels for Figures in Appendices A to C in the Floodplain Risk Management Guide: Modelling the Interaction of Catchment Flooding and Oceanic Inundation in Coastal Waterways

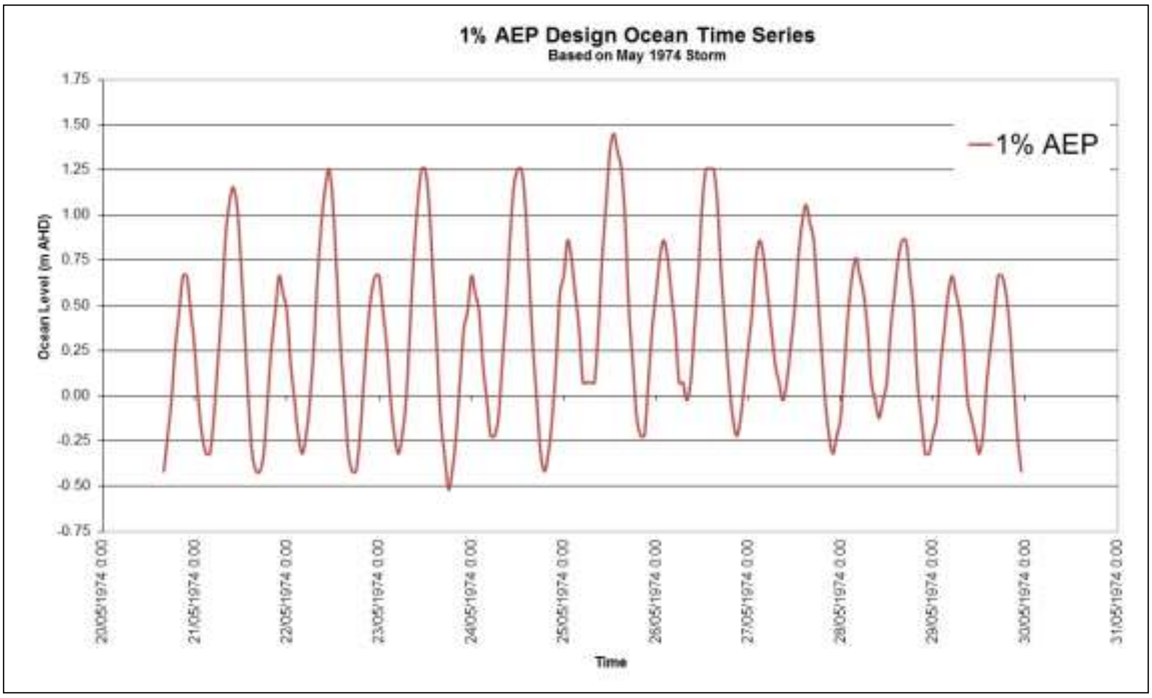

Figure A.1: Waterway Entrance Type A - 1% AEP Ocean Boundary Time Series Based on Fort Denison May 1974 (South of Crowdy Head)

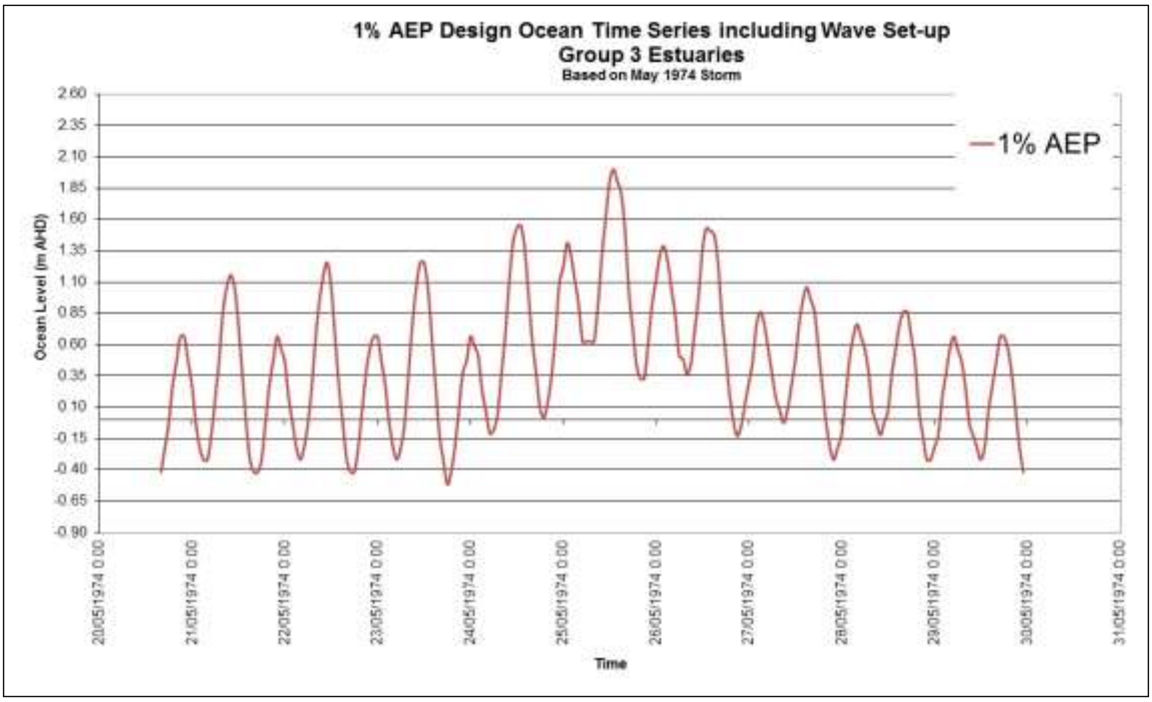

Figure A.2 Waterway Entrance Type B - Group 3 Estuary Time Series for a Fully Trained Entrance – 1% AEP Ocean Boundary Time Series Fort Denison May 1974 with 0.55m wave set up (South of Crowdy Head)

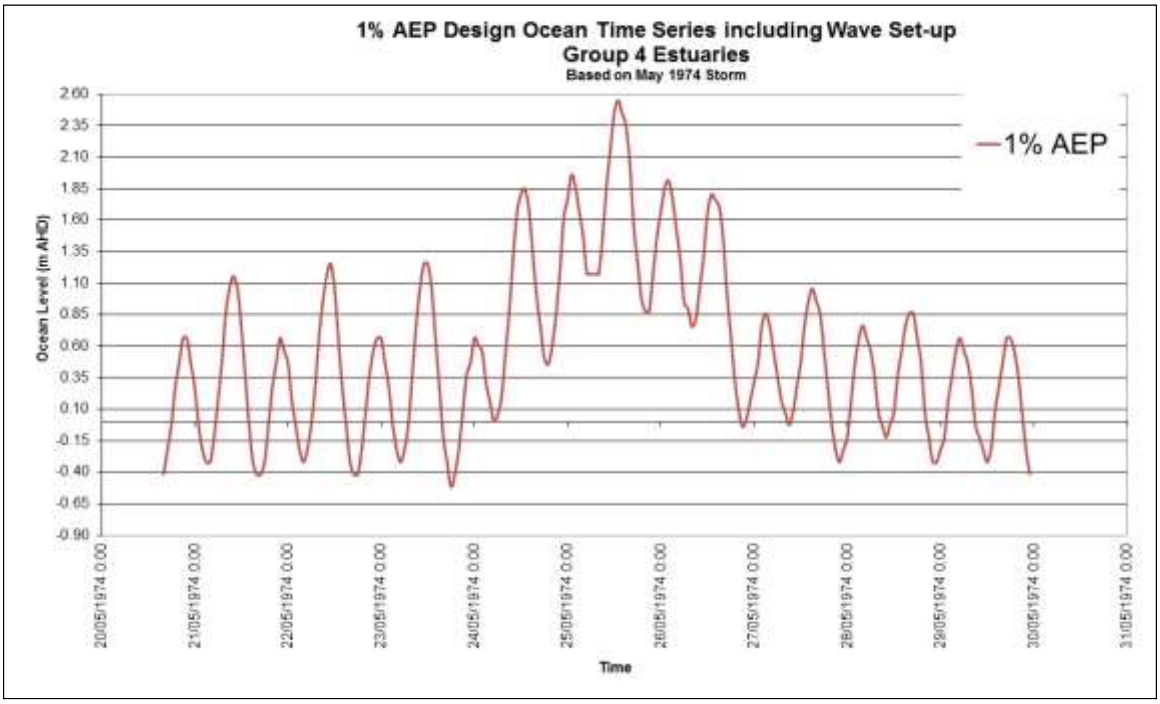

Figure A.3 Waterway Entrance Type C - Group 4 Estuary Time Series for an Untrained Entrance or ICOLL– 1% AEP Ocean Boundary Time Series Fort Denison May 1974 with 1.1m wave setup (South of Crowdy Head)

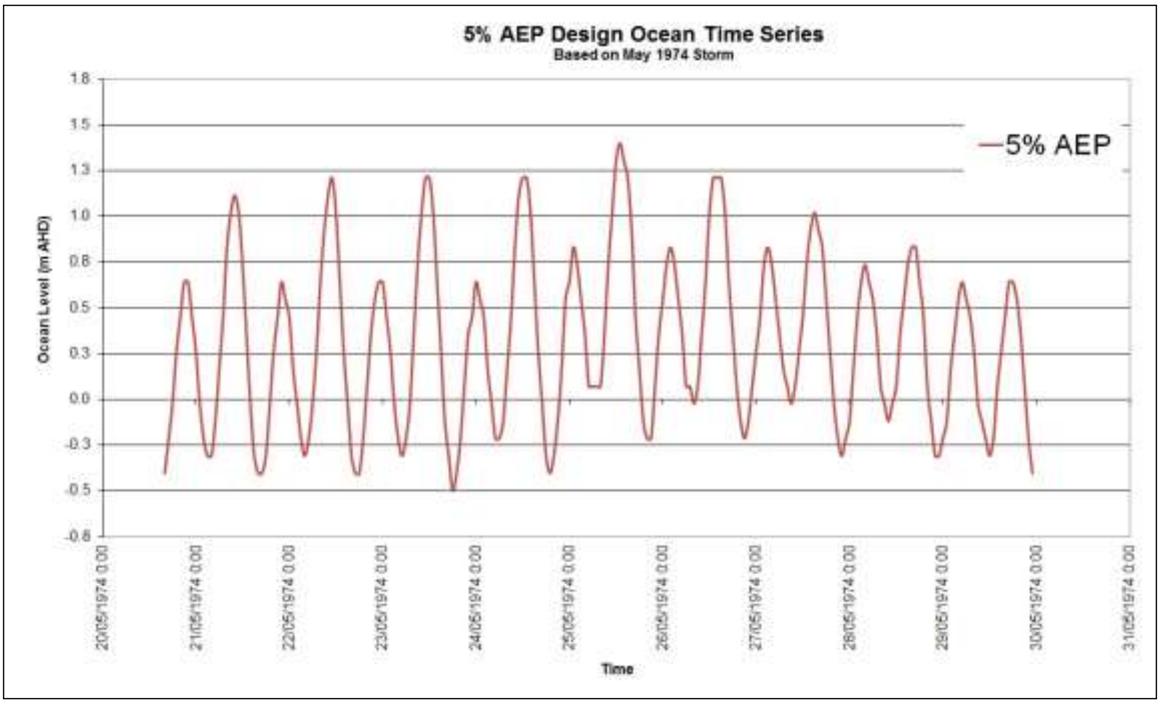

Figure A.4 Waterway Entrance Type A - 5% AEP Ocean Boundary Time Series Based on Fort Denison May 1974 (South of Crowdy Head)

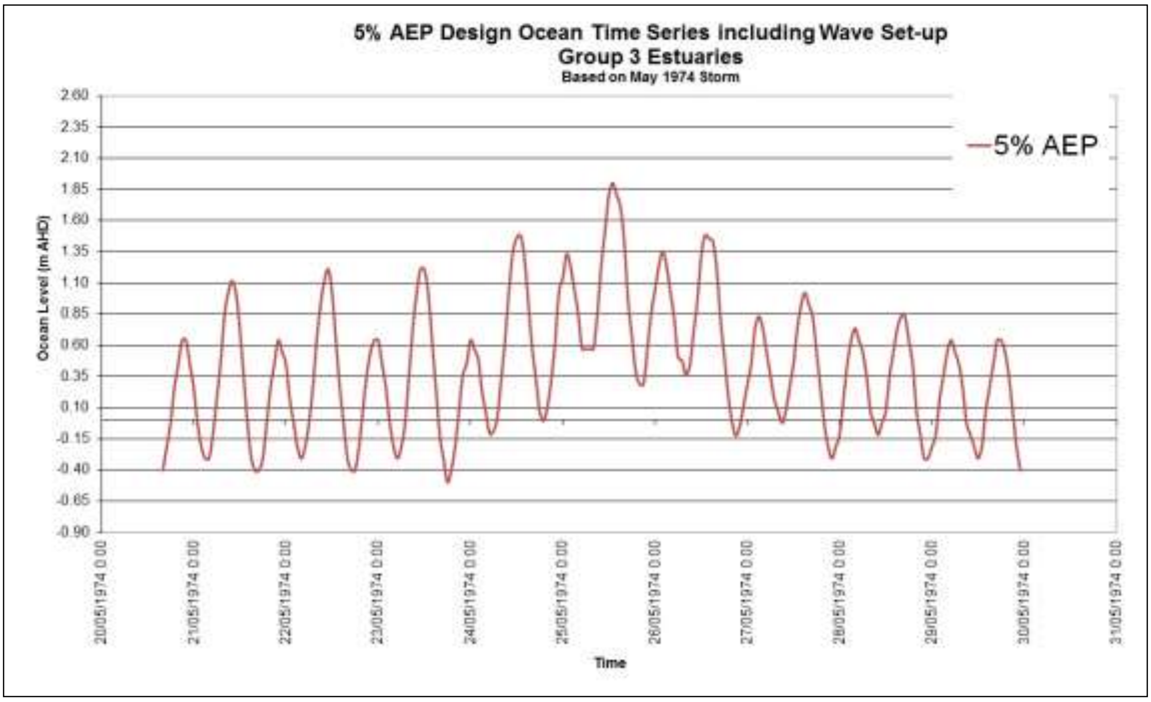

Figure A.5 Waterway Entrance Type B - Group 3 Estuary Time Series for a Fully Trained Entrance – 5% AEP Ocean Boundary Time Series Fort Denison May 1974 with 0.5m Wave Setup (South of Crowdy Head)

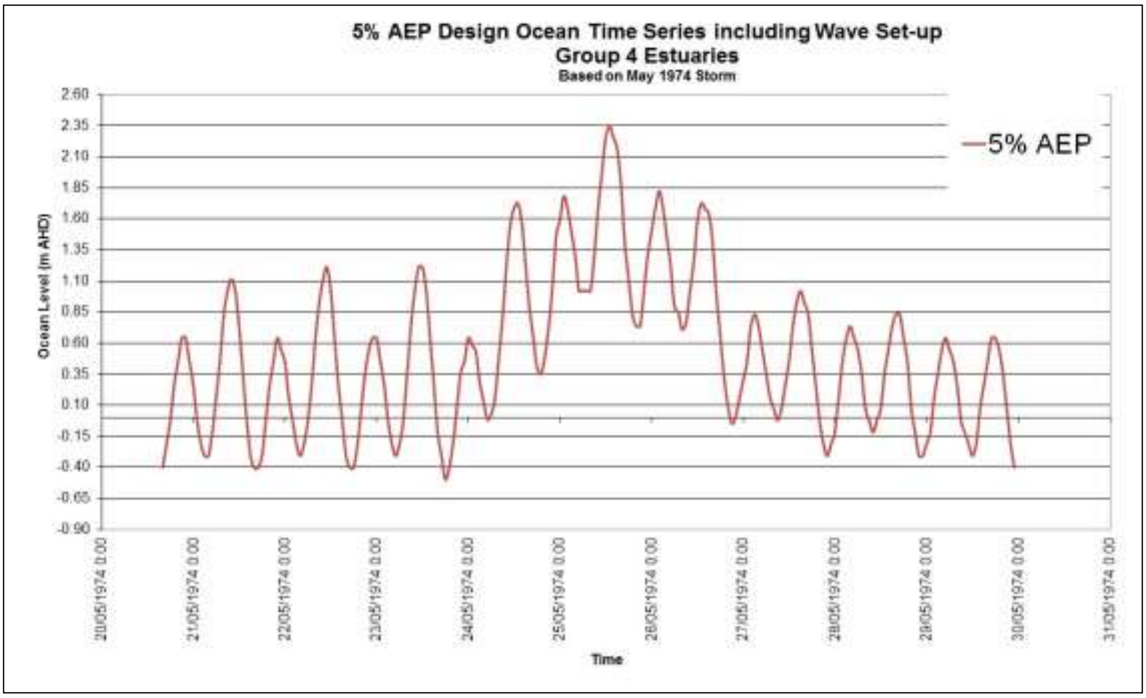

Figure A.6 Waterway Entrance Type C - Group 4 Estuary Time Series for an Untrained Entrance or ICOLL – 5% AEP Ocean Boundary Time Series Fort Denison May 1974 with 0.95m wave setup (South of Crowdy Head)

Appendix B: Ocean Water Level Boundaries North of Crowdy Head

See the Hourly Water Levels for Figures in Appendices A to C in the Floodplain Risk Management Guide: Modelling the Interaction of Catchment Flooding and Oceanic Inundation in Coastal Waterways

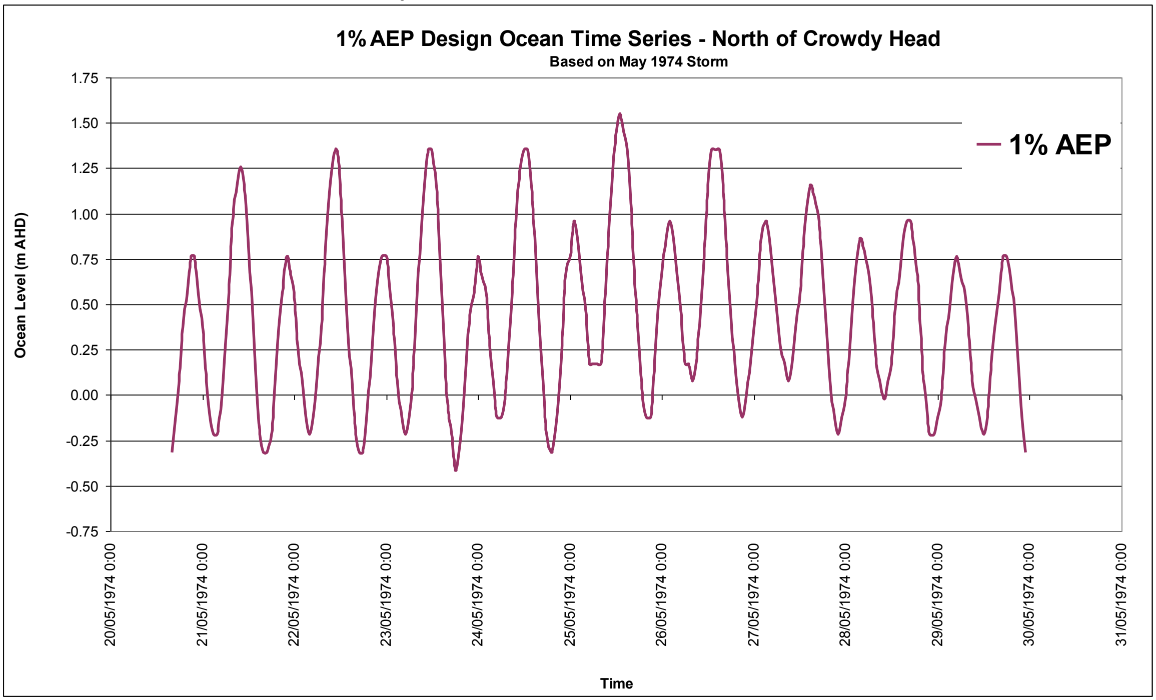

Figure B.1: Waterway Entrance Type A - 1% AEP Ocean Boundary Time Series Based on Fort Denison May 1974 (North of Crowdy Head)

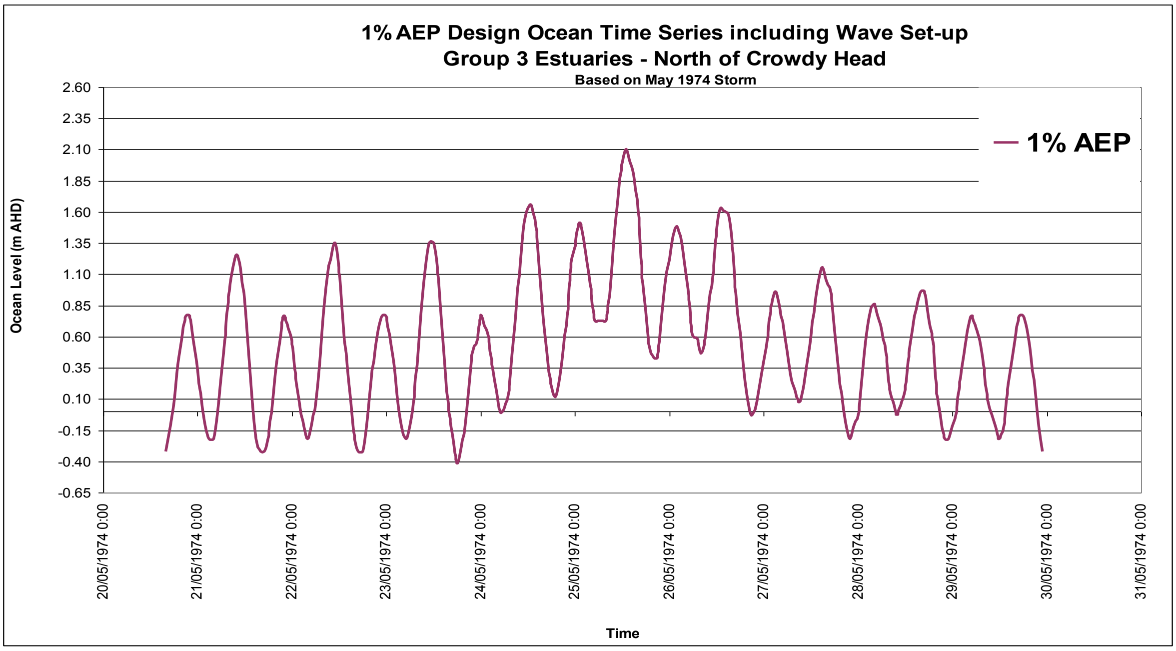

Figure B.2 Waterway Entrance Type B - Group 3 Estuary Time Series for a Fully Trained Entrance – 1% AEP Ocean Boundary Time Series Fort Denison May 1974 with 0.55m wave set up (North of Crowdy Head)

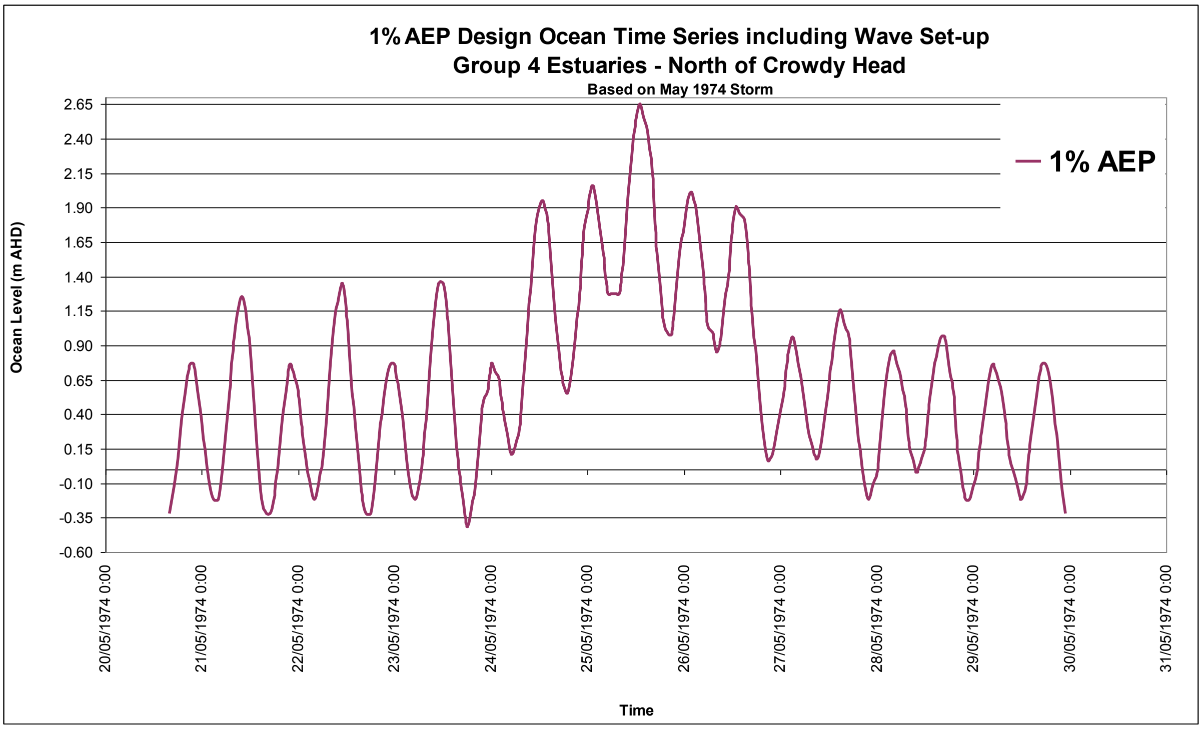

Figure B.3 Waterway Entrance Type C - Group 4 Estuary Time Series for an Untrained Entrance or ICOLL – 1% AEP Ocean Boundary Time Series Fort Denison May 1974 with 1.1m wave set up (North of Crowdy Head)

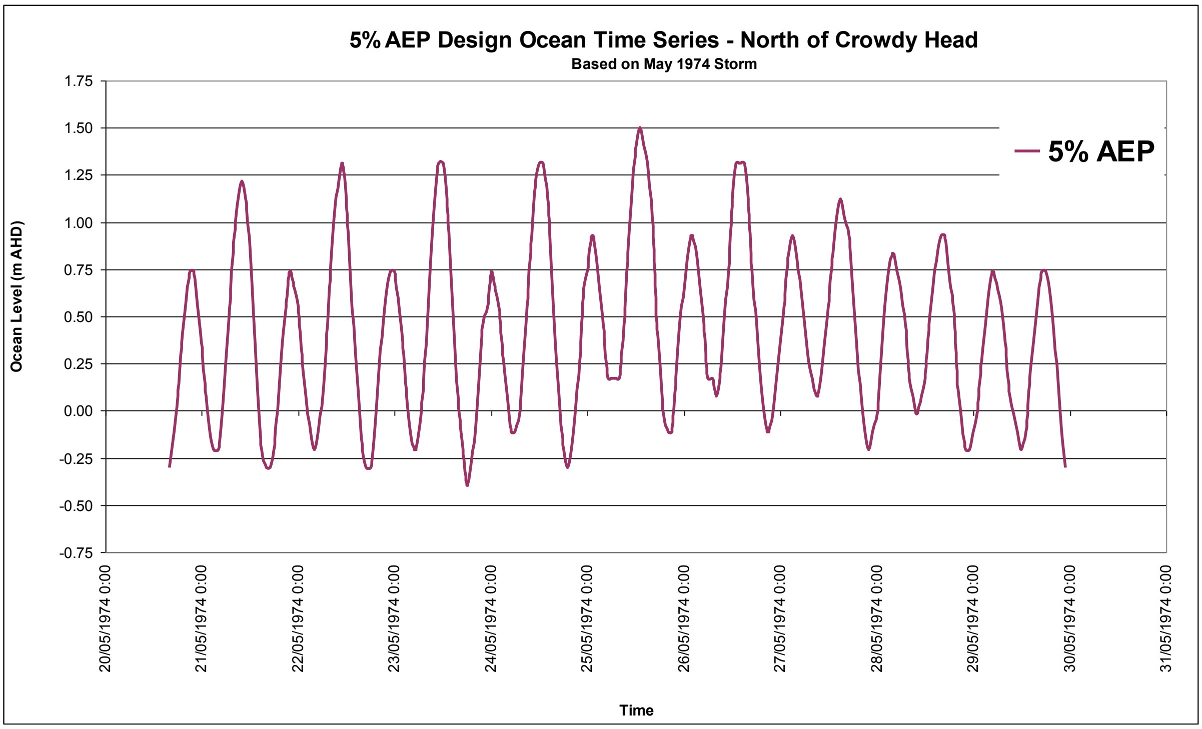

Figure B.4 Waterway Entrance Type A – 5% AEP Ocean Boundary Time Series Based on Fort Denison May 1974 (North of Crowdy Head)

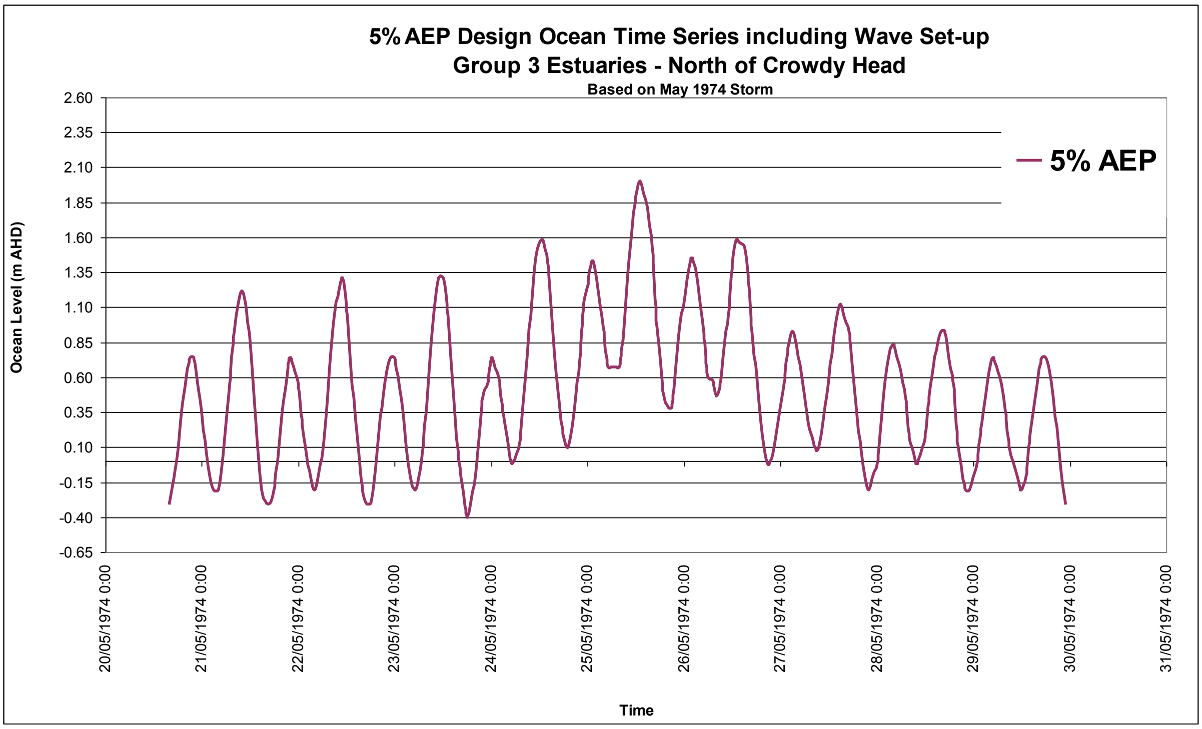

Figure B.5 Waterway Entrance Type B - Group 3 Estuary Time Series for a Fully Trained Entrance – 5% AEP Ocean Boundary Time Series Fort Denison May 1974 with 0.5m wave set up (North of Crowdy Head)

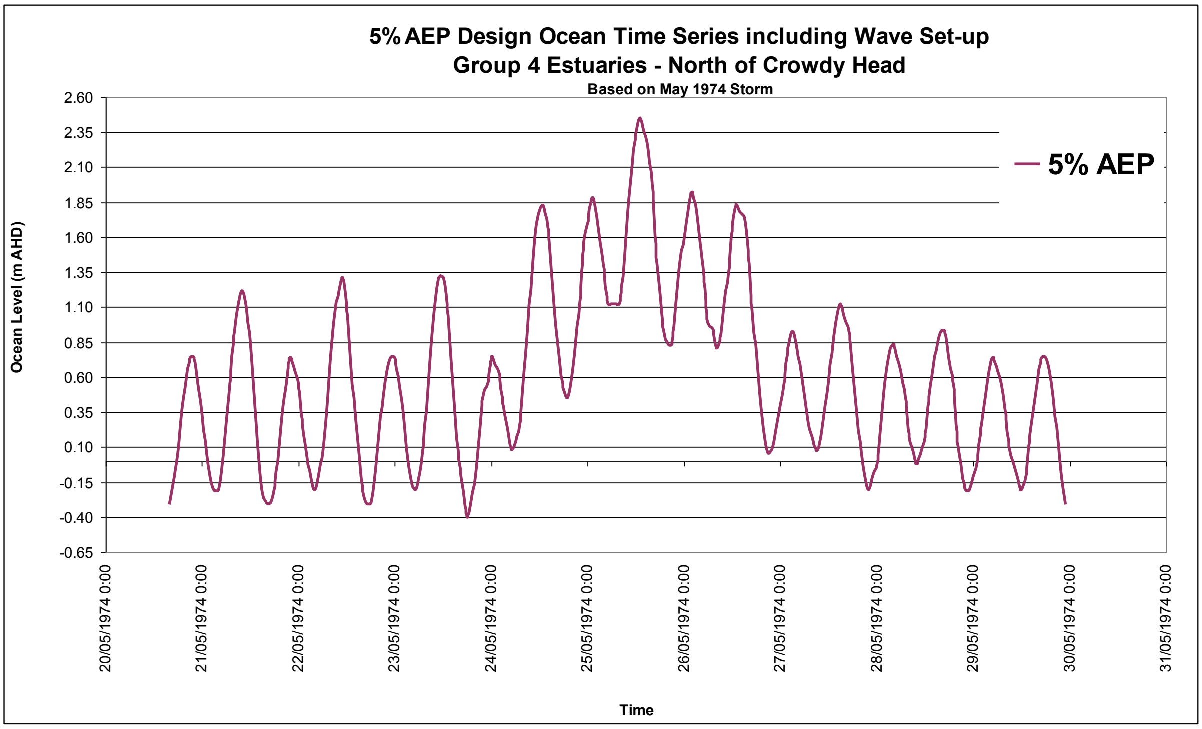

Figure B.6 Waterway Entrance Type C - Group 4 Estuary Time Series for an Untrained Entrance or ICOLL – 5% AEP Ocean Boundary Time Series Fort Denison May 1974 with 0.95m wave set up (North of Crowdy Head)

Appendix C: Indicative Spring and Neap Tide Cycle incorporating HHWS(SS) and ISLW

See the Hourly Water Levels for Figures in Appendices A to C in the Floodplain Risk Management Guide: Modelling the Interaction of Catchment Flooding and Oceanic Inundation in Coastal Waterways

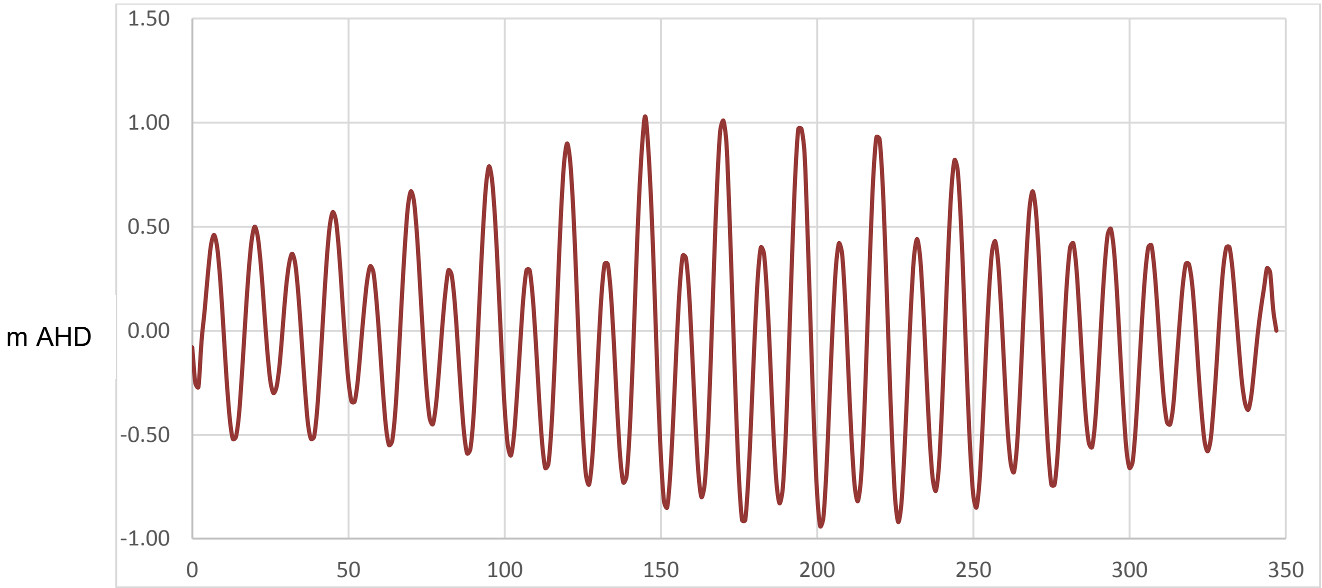

Figure C.1: Indicative Spring & Neap Tide Cycle incorporating HHWS(SS) & ISLW for South of Crowdy Head

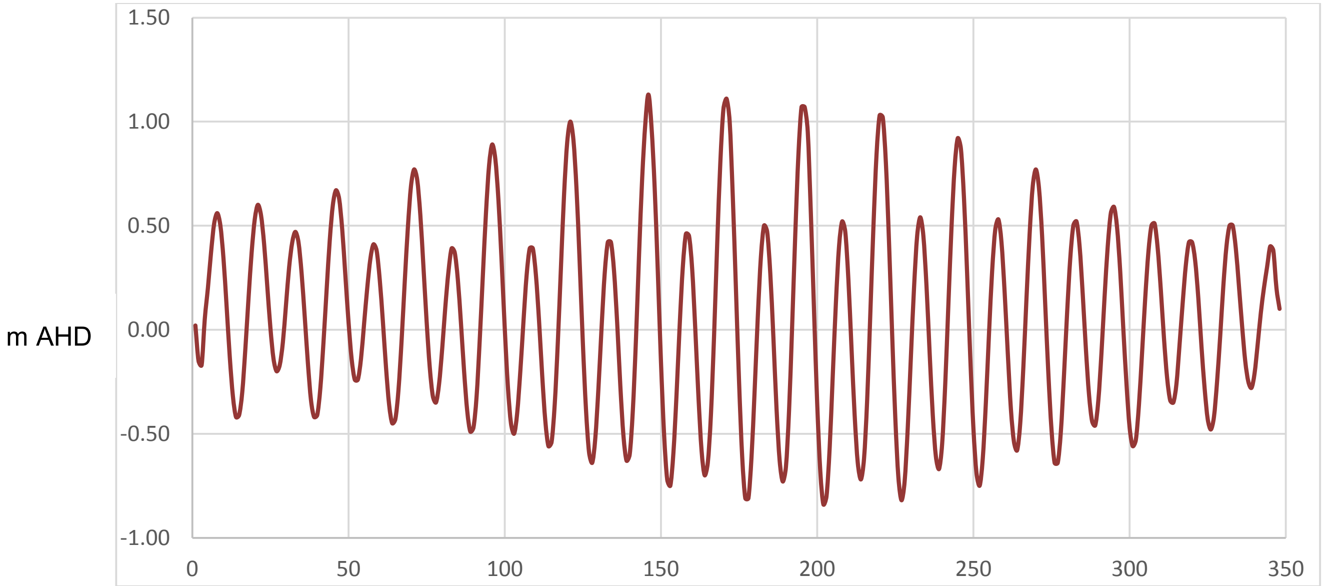

Figure C.2: Indicative Spring and Neap Tide Cycle incorporating HHWS(SS) and ISLW for North of Crowdy Head